King County Department of Natural Resources and Parks

Solid Waste Division

CEDAR HILLS REGIONAL LANDFILL
ENVIRONMENTAL CONTROL SYSTEMS MODIFICATIONS PROJECT
CONTRACT NO. E00286E12

EAST PERCHED ZONES
REMEDIAL INVESTIGATION AND FEASIBILITY STUDY

Prepared by
Aspect Consulting, LLC

King County
Department of
Natural Resources and Parks
Solid Waste Division

Waste **Prevention** · *Resource* **Recovery** · *Waste* **Disposal**

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December 2016
AGENCY DRAFT

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EXECUTIVE SUMMARY

This Remedial Investigation and Feasibility Study (RI/FS) report has been prepared for the Cedar Hills Regional Landfill (CHRLF) East Perched Zones (EPZ area), which are located on the east side of the Main Hill Area of the CHRLF, in unincorporated King County near Maple Valley, Washington. As a result of the findings from previous hydrogeologic investigations and on-going groundwater quality assessment monitoring completed in the EPZ area, the Washington State Department of Ecology (Ecology) on behalf of the Seattle King County Department of Public Health (SKCDPH) requested that King County Solid Waste Division (KCSWD) engage in corrective action under the Model Toxics Control Act (MTCA) for perched saturated zones beneath the EPZ area at the CHRLF.

The purpose of the RI/FS is to identify the extent of environmental impacts in the EPZ area, evaluate the potential risks posed to human and ecological receptors, and establish cleanup levels (CULs) for media-specific select constituents. Based on the established CULs, four remedial alternatives were evaluated in the FS to mitigate the impacted areas, and one preferred remedial alternative has been proposed for implementation. The RI/FS is focused on the perched saturated zone of the EPZ. Other areas of the CHRLF where environmental monitoring data exist are not included within the scope of this RI/FS. This RI/FS was conducted in accordance with MTCA, as established in Chapter 173-340 Washington Administrative Code (WAC).

The CHRLF includes the eastern portion of the Main Hill Area and the adjacent EPZ area. The EPZ area is bounded by groundwater monitoring well MW-87 to the northwest, Stream 3 to the north, the CHRLF east property buffer boundary to the east, gas probe GP-2 to the south, and the Main Hill edge of refuse to the west.

Sections 1.0 through 8.0 of this document present the RI findings for the EPZ area. Sections 9.0 through 11.0 present the FS alternatives evaluated for remedial action, and the document concludes with Section 12.0, which identifies the preferred remedial alternative and required long-term compliance monitoring requirements. An overview of the RI/FS findings are discussed below.

EPZ Conceptual Site Model

Operations at the Main Hill started in 1961, it began receiving refuse in 1965, and continued to operate through the mid-1980s. Refuse was placed in the Main Hill prior to enactment of regulations requiring bottom-lining systems. The Main Hill contains 18.3 million cubic yards of refuse. A temporary cover was installed in the 1980s and a permanent geomembrane cover system was installed by 1991. Other landfill environmental control systems phased in at the Main Hill include landfill gas (LFG) extraction, stormwater management, leachate collection, and a groundwater extraction system.

Hydrogeology

The EPZ is comprised of two localized areas of perched groundwater: the east shallow perched zone (ESPZ) and the northeast shallow perched zone (NESPZ). Both perched groundwater zones are saturated areas of shallow groundwater of limited lateral and vertical extent, east of the landfill's unlined Main Hill.

- The ESPZ consists of seasonally saturated, low-permeability glacial till and glacio-lacustrine silt units along the east central side of the Main Hill, west of the Passage Point facility, and around the wetland areas in that vicinity. Recharge to the ESPZ occurs via infiltration of direct precipitation, infrequent and incidental spillage from overfilling of dust-control tanker trucks and seepage from adjacent wetlands. Horizontal groundwater movement in the ESPZ is very slow (on the order of 1 to 2 feet/year) due to the low-permeability properties of the glacial till and glacio-lacustrine units. Several seasonally dry groundwater extraction wells bordering the western side of the ESPZ indicate that saturated horizontal flow is limited. The travel time for fluids to reach the Regional Aquifer is estimated at 159 years due to the thick unsaturated zone (approximately 280 feet) and the relatively slow nature of unsaturated groundwater migration. This lengthy travel time through the unsaturated zone is favorable for buffering and attenuation of any vertically migrating impacted groundwater.
- The NESPZ occurs in the vicinity of Stream 3. Perched groundwater in this zone occurs within stratified drift unit, where downward infiltration is reduced by less permeable siltier interbeds within the stratified drift. There appears to be little hydraulic connection between the ESPZ and the NESPZ. The NESPZ is north of the ESPZ and these areas are separated by a seasonally unsaturated zone. Some limited horizontal connection between the zones could occur at relatively shallow depths within more permeable layers of the glacial till; however, no impacted groundwater has been observed in the NESPZ.

Extent of Impact

The following presents the conclusions of the RI. Based on these conclusions, the MTCA site boundary can be defined for use in the FS.

- There is no impacted groundwater in the NESPZ or surface water in Stream 3.
- LFG is the primary source of shallow EPZ groundwater and soil gas impacts.
- Impacted groundwater is predominantly limited to the shallow, low permeable, glacial till/glacio-lacustrine units within the ESPZ. Migration of groundwater in the ESPZ is very limited, but has displayed predominantly vertical, downward migration toward the thick unsaturated zone above the Regional Aquifer. The 280-foot-thick unsaturated zone above the Regional Aquifer and the very low unsaturated hydraulic conductivity acts as a buffer zone between the limited impacted ESPZ groundwater and the Regional and provides for attenuation of any vertically migrating impacted groundwater. Groundwater within the Regional Aquifer is monitored by several monitoring wells downgradient of the ESPZ.

- The constituents detected in groundwater in the EPZ area at concentrations exceeding CULs carried forward into the FS as constituents of concern (COCs) are: metals (arsenic, iron, and manganese) and volatile organic compounds (VOCs; vinyl chloride). Iron and manganese exceedances are the result of redox conditions in groundwater, and appear to follow a similar attenuation pattern as arsenic. However, iron and manganese are not of primary concern for the EPZ area as their respective CULs are very high because these constituents present low toxicity to humans. Furthermore, it is understood that the control of LFG will limit vinyl chloride impacts to groundwater as well as improve arsenic, iron, and manganese concentrations.
- Naphthalene was detected in soil gas exceeding screening levels. A second sample event was added to the RI program to verify these initial soil gas exceedances. There were no soil gas constituent exceedances in the second sample round.
- Methane was also detected in EPZ area gas probes and LFG extraction wells at concentrations greater than the lower explosive limit. LFG) from the unlined Main Hill area of the CHRLF is the suspected primary source of groundwater quality and soil gas impacts in the EPZ area. Infrastructure refinements (including LFG probe installation) and flow optimization to the Main Hill LFG collection system will be considered to manage fugitive LFG in the EPZ area.
- It is likely that there may be localized, low-level leachate affects in the vicinity of EW-6 and EW-7 that are causing some of the leachate parameters to be elevated, but not enough of a leachate influence to have a marked effect.

Exposure Pathways and Receptors

The EPZ area contains landfill facility buildings, landfill infrastructure, Passage Point residential buildings, asphalt roads, and utilities. Potential exposure pathways for VOCs in groundwater include direct contact, ingestion, and transport to air and surface water. The following exposure pathways and human receptors were identified as potentially active:

- Groundwater: direct contact by above- and below-ground workers and inhalation by below-ground workers. Groundwater ingestion by residents is a potentially active pathway that is currently mitigated by a moratorium on drinking water wells within 1,000 feet of the landfill.
- Landfill Gas: LFG-to-groundwater pathway (see groundwater pathways and receptors above) and VOC inhalation by indoor residents. Inhalation by future above-ground indoor workers and outdoor below-ground workers are currently mitigated by existing landfill health and safety protocols.
- Leachate: discharge to groundwater (see groundwater pathways and receptors above). Direct contact to leachate by above-ground indoor workers and below-ground outdoor workers are currently mitigated by existing landfill health and safety protocols.

The only ecological exposure pathway evaluated for the RI was surface water as soil contamination is not a media of concern for the EPZ. However, through the evaluation of RI data it was determined that no impacts to surface water quality is present and thus there are no complete ecological exposure pathways or threatened ecological receptors.

MTCA Requirements for Landfills

Under MTCA, closed landfills are considered to be sites that use “containment of hazardous substances” as the preferred remedy. To meet the requirements of MTCA, the selected remedy must be protective of human health and the environment under specified exposure conditions. 173-340-360(2)(a) WAC specifies four threshold criteria that all cleanup actions must satisfy. The threshold criteria are:

1) Protect human health and the environment.
2) Comply with cleanup standards (173-340-700 through 173-340-760 WAC).
3) Comply with applicable local, state, and federal laws (173-340-710 WAC).
4) Provide for compliance monitoring (173-340-410 WAC and 173-340-720 through 173-340-760 WAC).

In addition, 173-340-360(2)(b) WAC specifies three other criteria that alternatives must achieve:

5) Use permanent solutions to the maximum extent practicable.
6) Provide for a reasonable restoration time frame.
7) Consider public concerns (173-340-600 WAC).

Preferred Remedial Alternative

The FS establishes the remedial action goals and describes how the landfill containment requirements will be met in accordance with the MTCA regulatory requirements. The FS relied on a large volume of experience with the successful closure and/or cleanup of solid waste landfills. The FS evaluated four remedial alternatives and selected one preferred alternative for implementation of a cleanup action. The preferred alternative for the EPZ area consists of the following elements:

- Institutional Controls;
- LFG Probe Installation and Monitoring;
- Decommissioning of Groundwater Extraction Wells;
- Monitored Natural Attenuation (MNA) of Groundwater;
- Optimization of the LFG Operations on portions of the CHRLF Main Hill including:
  - Changing operating conditions from relaxed/moderate to aggressive/very aggressive as defined in the SWANA Landfill Gas Operations and Maintenance Manual of Practice, and
  - The addition of select flow control devices on collection laterals tied into the East and Central Header series.

Contingency actions are also presented that will be implemented, if necessary, in a phased manner. The selected cleanup action will be presented in the Draft Cleanup Action Plan (CAP), which will describe the preferred cleanup action and specify cleanup standards and compliance monitoring requirements. Following public review of the CAP, the remedy will be implemented in phases, including (as applicable) predesign investigation, remedy design, permitting, construction, development and filing of institutional controls, and long-term compliance monitoring.

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ACRONYMS AND ABBREVIATIONS

AECOM	AECOM Technical Services Inc.
amsl	above mean sea level
ARARs	Applicable or relevant and appropriate requirements
Aspect	Aspect Consulting, LLC
BEW	Bio Energy Washington
bgs	below ground surface
BHC	BHC Consultants, LLC
CAP	Cleanup Action Plan
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
CHRLF	Cedar Hills Regional Landfill
cis-1,2-DCE	cis-1,2-dichloroethene
cm/sec	centimeters per second
COC	constituent of concern
COPC	constituent of potential concern
CSM	Conceptual Site Model
CUL	Cleanup Level
DCA	disproportionate cost analysis
DCE	dicholorethene
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
EPZ	East Perched Zones
ESPZ	East Shallow Perched Zone
FS	feasibility study
HEC	Herrera Environmental Consultants, Inc.
KCEL	King County Environmental Laboratory
KCSWD	King County Solid Waste Division
LEL	lower explosive limit
LFG	landfill gas
MCL	Maximum Contaminant Level
MDLs	method detection limits
MFS	Minimum Functional Standards for Solid Waste Handling
mg/L	milligrams per liter
MNA	monitored natural attenuation
MSWH	municipal solid waste handling

MSW	municipal solid waste
MTCA	Washington State Model Toxics Control Act
NESPZ	Northeast Shallow Perched Zone
O&M	operation and maintenance
PCE	tetrachloroethene (also known as tetrachloroethylene and perchloroethylene)
PDB	passive diffusion bag
POC	point of compliance
PRB	permeable reactive barrier
QA	quality assurance
QA/QC	quality assurance and quality control
QC	quality control
RAOs	remedial action objectives
RCRA	Resource Conservation and Recovery Act
RCW	Revised Code of Washington
RI	remedial investigation
RPP	rigid porous polyethylene
SAP	sampling and analysis plan
SEE	Sweet-Edwards/EMCON
SEPA	State Environmental Policy Act
SKCDPH	Seattle-King County Department of Public Health
SL	screening level
SSPZ	Seasonally Saturated Perched Zone
SSWA	South Solid Waste Area
SVOC	semivolatile organic compound
TCE	trichloroethene
TDS	total dissolved solids
USGS	U.S. Geological Survey
VC	vinyl chloride
VI	vapor intrusion
VOC	volatile organic compound
WAC	Washington Administrative Code
µg/L	micrograms per liter
µg/m^3	micrograms per cubic meter

1.0 INTRODUCTION

This Remedial Investigation (RI) and Feasibility Study (FS) Report (RI/FS Report) has been prepared to document the results of the focused RI/FS at the Cedar Hills Regional Landfill (CHRLF), located in unincorporated King County, Washington (Figure 1.1). In response to compliance requirements in its 2004 Municipal Solid Waste Handling (MSWH) permit, King County Solid Waste Division (KCSWD) initiated two projects to investigate environmental control systems in the pre-1986 unlined areas of CHRLF. The report from one of those projects, *Cedar Hills Regional Landfill Site-Wide Groundwater Wells and Hydrogeologic Report* (CH2M HILL/UES, 2004a), examined hydrogeology to resolve questions regarding the perched groundwater in the East Perched Zones (EPZ) and the South Solid Waste Area (SSWA) perched zone. The report also refined the conceptual site model (CSM) for the Regional Aquifer. Groundwater monitoring data from the EPZ area indicated that concentrations of certain parameters do not meet 173-351 Washington Administrative Code (WAC) regulatory criteria. These impacts to groundwater quality are suspected to be due to interactions with landfill gas (LFG). When exceedances of the regulatory criteria in the EPZ shallow groundwater were confirmed during retesting, the nature of the monitoring program at the landfill was required under state regulations (WAC) to shift from a detection monitoring program to an assessment monitoring program. Assessment monitoring is required whenever a statistically significant increase over background has been detected for any of the parameters listed in 173-351-990 WAC Appendix I.

An addendum to the hydrogeologic report (Aspect, 2013a) was developed to satisfy conditions of the 2009-2019 MSWH permit, which required an update to the site-wide hydrogeologic report (CH2M HILL/UES, 2004a), including a more detailed investigation of the EPZ area.

The combined findings of the site-wide hydrogeologic report, the hydrogeologic report addendum, and the assessment monitoring led the Washington State Department of Ecology (Ecology) on behalf of the Seattle King County Department of Public Health (SKCDPH) to request that KCSWD engage in corrective action under the Model Toxics Control Act (MTCA) for perched saturated zones beneath the EPZ area at the CHRLF (KCSWD, 2013).

This document presents the results of the RI/FS for the EPZ project area (EPZ area) at the CHRLF. The subject of this investigation is restricted to the perched saturated zone of the EPZ. At the outset of the investigation, as indicated in KCSWD's letter of intent to Ecology dated September 12, 2013 (KCSWD, 2013), the only constituent of concern (COC) planned for evaluation under MTCA was vinyl chloride (VC). Other areas of the CHRLF where environmental monitoring data exist are not included within the scope of this RI/FS.

1.1 Study Area Description

The CHRLF is located at 16645 - 228th Avenue SE in unincorporated King County near Maple Valley, Washington (Figure 1.1). The landfill occupies 920 acres, approximately half of which is buffer (described further in Section 2). One of the largest municipal solid waste landfills in the Pacific Northwest, CHRLF serves King County, exclusive of the Cities of Seattle and Milton. Figure 1.2 depicts an aerial view of CHRLF property features, with existing landfill areas delineated. The CHRLF includes the eastern portion of the Main Hill landfill unit and the adjacent EPZ area that is the focus of this RI/FS Report. The EPZ area is bounded by groundwater monitoring well MW-87 to the northwest, Stream 3 to the north, the CHRLF east property buffer boundary to the east, the Passage Point transitional housing facility to the south, and the Main Hill edge of refuse to the west. Figure 1.3 depicts the EPZ area current features and RI monitoring locations.

“Site,” as defined by MTCA in 173-340-200 WAC, is any area where a hazardous substance has been deposited or otherwise comes to be located. The boundaries of the MTCA Site, which cannot be fully delineated until COCs, cleanup levels (CULs), and the spatial extent of contamination have been defined, are noted in Section 8 of this RI/FS Report.

1.2 Remedial Investigation/Feasibility Study Objective

The objective of this RI/FS is to collect, evaluate, and document data by which to characterize the environmental conditions associated with the EPZ area and to enable selection of a cleanup action in compliance with MTCA regulations (173-340-350 through 173-340-390 WAC). Specifically, the RI/FS objectives include:

- Characterize the nature and extent of impacted media (i.e., groundwater, surface water, and soil gas) in the EPZ area and define the “Site” in accordance with MTCA.
- Identify the potential for LFG migration and the need for further LFG controls.
- Identify the potential for leachate migration and the need for further leachate controls.
- Identify CULs for affected media that are not contained within the landfill refuse footprint.
- Identify remedial action objectives (RAOs) appropriate for municipal solid waste landfills, including identification of landfill-related applicable or relevant and appropriate requirements (ARARs).
- Develop and evaluate cleanup action alternatives that protect human health and the environment.
- Identify the preferred alternative.

This RI/FS Report presents the information collected and the evaluations performed to achieve these objectives.

1.3 Report Organization

The RI/FS Report is organized as follows:

- Section 2.0 (Background) presents project background, including a summary of CHRLF history and a description of previous environmental investigations related to the EPZ area.

- Section 3.0 (Summary of Completed Investigations) summarizes investigations conducted at the EPZ area; describes the RI activities, including groundwater, surface water, leachate, and soil gas investigations; and describes the groundwater sampling technology investigation (passive sampling technique pilot program).
- Section 4.0 (EPZ Area Setting) describes the environmental and land-use setting for the EPZ area, including its physical features, geology, and hydrogeology.
- Section 5.0 (Environmental Regulations and Development of CULs) identifies environmental regulations for the purposes of comparing chemical concentrations and identifying potential exposure pathways.
- Section 6.0 (Interim Actions) summarizes the interim remedial measures conducted at the EPZ area to date.
- Section 7.0 (Nature and Extent of Contamination) presents the results of the investigations, which delineate the nature and extent of contamination for each medium. The beginning of this section screens the RI data using CULs presented in Section 5 to develop a list of COCs for further evaluation. Next, CULs are used to delineate the extent of contamination for each medium. This section presents the bulk of the analysis for the RI.
- Section 8.0 (Conceptual Site Model) presents the CSM, including a summary of contaminants and sources; COC fate, transport, and attenuation processes; evaluation of COC exposure pathways; and presentation of RI conclusions.
- Section 9.0 (Remedial Action Requirements) presents ARARs pertinent to remedy selection, MTCA cleanup requirements, landfill closure requirements, and presumptive remedies. Additionally, this section proposes CULs for the EPZ area, identifies RAOs, identifies potentially applicable laws, estimates the area and volumes exceeding CULs, and develops points of compliance.
- Section 10.0 (Screening of Remedial Technologies) identifies and screens technologies appropriate for the EPZ area.
- Section 11.0 (Screening of Remedial Alternatives) summarizes the remedial alternatives developed for the EPZ area, describes common elements among the alternatives, and presents the evaluation criteria for the alternatives. Next, the alternative components are evaluated with respect to applicable state and federal threshold requirements, and finally a disproportionate cost analysis is presented.

- Section 12.0 (Preferred Alternative) describes the preferred alternative. Additionally, this section presents the operations, maintenance, and monitoring required for implementation of the preferred alternative.
- Section 13.0 (References) lists the documents cited in text.
- Section 14.0 (Limitations) notes the appropriate uses of the information presented in this document.

The text is followed by tables and figures. Appendices to this report provide supporting information referenced within the text.

2.0 BACKGROUND

This section describes the CHRLF history and background with an emphasis on the Main Hill in relation to the location of the EPZ area.

2.1 Landfill History

CHRLF has been in operation since 1965. The landfill receives approximately 2,500 tons of refuse daily and more than 800,000 tons of refuse a year. Refuse disposal areas (Areas) have been added over time since CHRLF began operation. Since 1986, the Areas have been lined with a geomembrane supplemented with active landfill environmental control systems including LFG, leachate, groundwater, and stormwater collection and treatment systems. As each Area reached capacity, it was closed and covered with an engineered geomembrane cover system. In pre-1986 Areas, an active LFG collection system and an engineered cover system were installed retroactively. At current trends in incoming waste volume, CHRLF is expected to reach capacity in 2040.

CHRLF was approved for refuse disposal under a permit issued by King County Board of Commissioners in 1960. Refuse filling at CHRLF has occurred in several Areas, as delineated on Figure 1.2. These areas are referred to as the South Solid Waste Area, the Southeast Pit, the Main Hill, the Central Pit, Area 2/3, Area 4, Area 5, Area 6, and Area 7. Disposal operations continue in Area 7 to this day. Plans to start using Area 8, located near the southwest corner of the landfill, are under way. The EPZ area is located along the east side of the Main Hill (Figure 1.2).

Operations at the Main Hill started in 1961 (AMEC-Geomatrix, 2008b), with refuse received from 1965, before bottom liners were required (CH2M HILL//UES, 1999), through the mid-1980s (URS, 2008). The Main Hill contains 18.3 million cubic yards of refuse. A temporary cover was installed in the 1980s, and a permanent geomembrane cover system was installed by 1991 (URS, 2008). Other environmental controls phased in at the Main Hill include systems for LFG extraction, stormwater management, leachate collection, and groundwater extraction.

2.2 Existing Infrastructure

The existing infrastructure at the CHRLF includes landfill support facilities on the south side of the property, such as the main office building, a fueling station, portable buildings, the Bio Energy Washington (BEW) plant, which generates pipeline-quality gas from LFG, two leachate lagoons, and several stormwater lagoons. The landfill is developed with groundwater monitoring and extraction wells, LFG extraction wells and gas probes, and subsurface utilities (including stormwater, sewer, water, and leachate collection lines), all of which support the monitoring and resource protection infrastructure.

Table 2.1 presents a summary of the explorations conducted in the EPZ. Boring logs for monitoring wells, gas probes, and gas extraction wells completed in the EPZ area are presented in Appendix A. Figures depicting the layout of the subsurface utilities are presented in Appendix B. These infrastructure elements are discussed further in the following subsections.

2.2.1 Groundwater Monitoring and Extraction Wells

Twelve monitoring wells and six piezometers have been completed in the shallow perched water-bearing zones of the EPZ and 15 monitoring wells have been completed in the Regional Aquifer, as shown on Figure 1.3. In addition, 29 groundwater extraction wells have been installed within the shallow perched groundwater outside of the landfill footprint east of the Main Hill. Well construction logs are presented in Appendix A. The following subsections describe these two distinct well networks.

2.2.1.1 Groundwater Monitoring Wells

The existing groundwater monitoring well and piezometer network was installed across the EPZ area during several Main Hill investigation phases, as summarized in Table 2.1 and depicted on Figure 1.3. Construction details are provided in Table 2.2. Initially installed for routine monitoring purposes (i.e., to characterize groundwater conditions) and for targeted hydrogeologic investigations, the network has also been used periodically to collect water level and groundwater quality data.

Groundwater quality is sampled quarterly in four monitoring wells (MW-30A, MW-47, MW-62, and EB-6D) to meet the landfill's permit requirement for detection monitoring. In addition to the routine groundwater monitoring of selected wells, other wells have historically been sampled as part of specific investigations in the EPZ area.

2.2.1.2 Groundwater Extraction Wells

A groundwater extraction system was recommended as part of a study of the MW-30A and MW-47 area (SEE, 1991b). In 1993, 29 groundwater extraction wells (EW-1 through EW-29) were installed along the east side of the Main Hill to intercept impacted shallow perched groundwater along the northeast shallow perched zone (NESPZ) and east shallow perched zone (ESPZ) portions of the EPZ area. The locations of the extraction wells and zones are shown on Figure 1.3. Construction details are provided in Table 2.2. Groundwater extraction wells EW-1 through EW-11 are considered part of the seasonally saturated perched zone (SSPZ) between the NESPZ and ESPZ, and extraction wells EW-12 through EW-29 are considered part of the ESPZ. The extraction system was shut down on July 27, 2010; poor well performance due to extensive biofouling limited the recovery of groundwater and contaminant mass. Performance of the extraction wells is further discussed in Section 6.1.

2.2.2 Stream 3 Staff Gages

Two staff gages and corresponding shallow piezometers (SG-4 and SG-5) are located along Stream 3. Stream 3 flows to the southeast, from SG-4 to SG-5. These devices provide stage (water surface elevation) measurements and allow for measurement of subsurface water during low-flow periods (CH2M HILL/UES, 2004b).

2.2.3 Landfill Gas Monitoring and Collection Infrastructure

Landfill gas is monitored throughout the Main Hill area. Infrastructure for collection of LFG and leachate is in place.

2.2.3.1 Landfill Gas Monitoring

LFG is monitored throughout the EPZ area. There are 81 gas probe completions at 41 locations in the EPZ area, as summarized in Table 2.3 and shown in Figure 1.3. Typical gas probe completions consist of multiple probes completed at various depths to monitor LFG in both shallow and deep soil horizons. The LFG monitoring network consists of compliance probes along the property boundary as well as probes installed in native soils near the Main Hill edge of refuse. Within the EPZ area, the compliance probes near the property boundary include GP-15 through GP-20 and GP-ATC-6 through GP-ATC-8. As required by LFG operation procedures, the perimeter probes are maintained and monitored monthly. Data from the perimeter probes are used to confirm that LFG is not migrating beyond the CHRLF property boundary.

The probes installed near the Main Hill refuse boundary provide additional LFG characterization data and monitor the effectiveness of KCSWD’s actions to control LFG migration into native soils. These probes include GP-1, GP-6 through GP-9, and GP-55 through GP-62. Probes GP-55 through GP-62 are shallow and deep gas probe pairs installed to investigate the LFG-to-groundwater contaminant migration pathway in the EPZ area, and to provide additional monitoring points for evaluation of LFG migration in native soils (Aspect, 2010). The term “shallow gas probe” is used to define gas probes completed with the screen interval installed in weather till/glacio-lacustrine geologic units. The term “deep gas probe” is used to define gas probes completed with the screen interval installed in stratified drift geologic units. Gas probe construction details are provided in Table 2.3, and construction logs are presented in Appendix A.

2.2.3.2 Landfill Gas Collection

LFG is collected from refuse in the Main Hill through vertical gas extraction wells, horizontal gas collectors, and vertical dual-phase (LFG and leachate) extraction wells (Figure 1.3), as shown on Figure B-3 in Appendix B. LFG extraction wells for the Main Hill connected to the East Header have an “E” prefix. LFG extraction wells and horizontal collectors for the Main Hill connected to the Central Header have a “C” or “W” prefix. Dual-phase wells, extracting both LFG and liquid for the Main Hill, have either a “GL” or “DPW” prefix. AMEC-Geomatrix (2008b) presents figures depicting the locations of the Main Hill LFG features. The collection wells typically consist of vertical perforated pipes surrounded with a gravel pack. Vacuum is applied to the wells, creating overlapping zones of influence to collect LFG generated by the refuse. LFG that collects in the leachate system is withdrawn by the LFG system through lateral connectors. The perforated LFG collectors buried in refuse are connected to a manifold through solid lateral pipes. LFG from the East Header and the southern portion of the Central Header is conveyed to a utility flare near the North Flare Station (AECOM, 2015b).

Several LFG extraction wells are also located in native soils within the EPZ area. In the ESPZ, these extraction wells include the E-29 series and gas probe GP-57 (Figure 1.3). Probe GP-57 was connected to the extraction system in December 2011.

2.2.4 Leachate Collection

Leachate conveyance facilities are present within the Main Hill and along its east perimeter. Leachate lines throughout the EPZ area are shown on Figure B-2 in Appendix B. Principal leachate lines in the project vicinity include the North Main Hill Perimeter Collector and its East Branch. Within the EPZ area, the North Perimeter Collector—East Branch extends from refuse into native soils. A shallow perimeter collector is present along the east boundary of the Main Hill, extending from south of Cleanout W northward to Cleanout N, as presented in Appendix B, Figure B-2. The East Branch is a deeper collection system roughly 20 feet deep that starts at Cleanout 13 and extends northwest to Cleanout 10. The deeper portion of the North Main Hill Perimeter Collector resumes at Cleanout 14 and extends southward to a high point at Cleanout 16. In addition to these perimeter collectors, horizontal leachate collectors and vertical leachate extraction wells are located within the Main Hill. Vertical leachate collection wells are indicated by an “SW” or “PSW” prefix. SW-3, the only vertical leachate collection well depicted on Figure B-2 in Appendix B, was the focus of a LFG recovery pilot study conducted by AMEC Geomatrix, Inc. (2008b). Other vertical leachate collection wells with SW- and PSW- prefix are depicted in AMEC Geomatrix, Inc. (2008b)

2.2.5 Other Utilities

Other subsurface utilities within the vicinity of the EPZ area include sewer and water mains, as shown on Figure B-1 in Appendix B. A former septic system drainfield was installed in the area of EW-22 and EW-24; it was associated with the Passage Point transitional housing facility currently known as “Passage Point.” The drainfield was decommissioned at some point between 1973 and 1977 (Aspect, 2011).

Water and liquefied petroleum gas lines have generally shallow burial depths (less than 5 feet below ground surface [bgs]). Gravity-flow sewer lines typically have deeper burial depths. Sanitary sewer lines extend south from the east side of the Passage Point facility (Figure B-1) and are remote from the delineated area of impacted groundwater in the EPZ area.

3.0 SUMMARY OF COMPLETED INVESTIGATIONS

3.1 Previous Investigations

Elevated readings of specific conductance, concentrations of volatile organic compounds (VOCs), and concentrations of inorganic compounds in monitoring wells MW-30, MW-30A, and MW-47 during routine landfill groundwater detection monitoring led to an investigation of the EPZ area near MW-30A and MW-47 in 1991. The investigation (SEE, 1991b) included the installation of nine monitoring wells and three soil borings, aquifer testing of MW-63, groundwater quality sampling, and water level monitoring. Post-investigation, a groundwater extraction system was recommended as a preferred remedial alternative to control the observed groundwater quality impacts. The groundwater extraction system was installed in 1993 (see Section 6.1), and was operational from October 1993 through July 2010.

In 2004, the EPZ was evaluated (CH2M HILL/UES, 2004b). As part of the investigation, performance of the groundwater extraction well system was assessed, staff gages SG-4 and SG-5 were installed, and the potential influence of engineered environmental control infrastructure systems on groundwater conditions was analyzed.

In 2007, a Phase I hydrogeologic analysis of the Main Hill perched zone evaluated the occurrence and extent of the EPZ area as well as the groundwater quality (Aspect, 2007). One borehole (EPZ-BH-1) was drilled north of Passage Point. Water level was measured in EPZ monitoring wells, 53 gas probes, and 29 groundwater extraction wells. The report noted that LFG could cause groundwater impacts and recommended further investigation of the LFG-to-groundwater contaminant transport pathway as well as the installation of additional monitoring wells.

A Phase II hydrogeologic investigation of the EPZ area, completed during 2009 and 2010 (Aspect, 2010b), addressed recommendations from the Phase I report (Aspect, 2007). The work included further investigation into the LFG-to-groundwater contaminant transport pathway, and further delineation of the EPZ extent and of groundwater flow and transport pathways. The work included a LFG survey using temporary direct-push probe explorations, installation of three new groundwater monitoring wells, installation of eight paired (shallow and deep) gas probes, VOC sampling in LFG probes, and development of infrastructure utility maps and utility cross sections.

Extensive influence testing on LFG extraction wells in the Main Hill and EPZ area was performed in 2010 (AMEC-Geomatrix/HEC, 2011) to identify areas of LFG extraction well interconnection and areas where interconnection was absent. The variable nature of connectivity between tested areas was attributed to thinning of the refuse around the Main Hill perimeter and to the addition of large amounts of fill soil placed as temporary cover during landfilling operations.

A geophysical survey was performed at several areas of CHRLF in 2012 (AMEC and BHC, 2012) using electromagnetic and mise-à-la-masse survey techniques to evaluate existing leachate and LFG systems.

The surveyed areas include the Northeast Leachate Collector in the area of Cleanouts 9 through 11 (highlighted in yellow on Figure B-2). Two anomalies were identified near the Northeast Perimeter Collector (west of Cleanout 10 and north of Cleanout 11), but were considered less likely to indicate leachate leaks than other phenomena; the recommended limited investigation of the anomalies was addressed during this RI, as discussed further in Section 6. Other investigations conducted in 2012 include a topographic survey to evaluate settlement of the Main Hill, wetland surveys, LFG well installation, and dual-phase well installation.

A data summary, analysis, and alternatives report was provided as part of the CHRLF Environmental Control Systems Modifications Project (AECOM, 2015b). The report was developed as a fast track response to observed increases in nitrogen and oxygen concentrations in the LFG supplied to the BEW facility, which converts LFG to pipeline-quality natural gas. After an analysis, summary, and discussion of 3 years of LFG performance data, the report offers recommendations and alternatives to improve design and operations of the LFG control system. The data were collected from 629 LFG collectors at CHRLF from 2011 through 2013. The primary analytical parameters were methane, oxygen, carbon dioxide, and balance gas (N2) in percent volume concentration, as well as methane production rates in tons per day. Subtitle D of the Resource Conservation and Recovery Act (RCRA), which regulates Municipal Solid Waste (MSW) landfills, requires that measures be implemented to ensure the control of LFG migration. Recommended improvements to the LFG collection system, which target safety, regulatory compliance and BEW operational constraints, focus on three objectives:

- Minimizing LFG migration;
- Minimizing air intrusion; and
- Maximizing collection of high methane concentrated LFG at each refuse area.

3.2 Remedial Investigation

This section summarizes the investigation work completed during the RI period (June 2015 through March 2016). The RI was designed to provide information sufficient to support the evaluation and selection of technically feasible remedial alternatives. It involved three phases of field investigation to address the data gaps identified during previous investigations and to refine the preliminary CSM. All work was completed in accordance with the agreement between KCSWD and Ecology as documented in the *East Perched Zones Remedial Investigation and Feasibility Study Work Plan* (Work Plan; Aspect, 2015). Components of the RI field work included water level monitoring, groundwater sampling, and soil gas sampling, the locations of which are depicted on Figures 3.1 through 3.3, respectively. The following provides a discussion of the specific RI investigation components for each medium evaluated.

3.2.1 Groundwater Monitoring

The groundwater component of the RI addressed data gaps identified in the Work Plan with 1 year of quarterly groundwater monitoring and sample events, using existing landfill infrastructure (Figure 1.3). The first quarter of groundwater sampling was conducted in two phases:

- Deployment of passive sampling equipment and comprehensive groundwater level monitoring (Figure 3.1); and
- Collection of samples (low-flow and passive samples; Figure 3.2).

The phased approach was selected to accommodate the 2-week equilibration period required by the passive sampling equipment. During the second phase (i.e., second, third, and fourth quarterly monitoring events). of groundwater levels were monitored and low-flow groundwater samples were collected.

The specific groundwater monitoring and sampling tasks included the following elements:

- Measurement of groundwater level at selected monitoring points within the EPZ area, including monitoring wells, gas probes, groundwater extraction wells, and gas extraction wells, as listed in Table 3.1.
- Collection of passive samples using passive diffusion bags (PDB) and/or rigid porous polyethylene samplers (RPP) from selected monitoring wells, extraction wells, and piezometers, as indicated in Table 3.2:
    - MW series—MW-30A, MW-47, MW-102, MW-103, and MW-104
    - EB series—EB-6D
    - EW series—EW-20 and EW-25
- Collection of low-flow groundwater samples from monitoring wells, extraction wells, and piezometers completed in perched groundwater of the EPZ area, as indicated in Table 3.2:
    - MW series—MW-30A, MW -47, MW -50, MW -62, MW -102, MW -103, and MW-104
    - EB series—EB-1, EB-2, and EB-6D
    - EW series—EW-2, EW-6 through EW-21, EW-23 through EW-27, and EW-29.

All groundwater samples were analyzed by the King County Environmental Lab (KCEL) for 173-351-990 WAC Appendix I and II parameters, in addition to select project-specific monitored natural attenuation (MNA) parameters analyzed by Microseeps. The list of specific analytes is presented in Table 3.3.

3.2.2 Surface Water Monitoring

RI work elements included surface water sampling from Stream 3:

- Measurement of the stream water level using the staff gages at SG-4 and SG-5 at the same time as the groundwater level measurements. Because the stream stage was below the level of the staff gauge during the June and September 2015 quarterly events, the water level measurements were taken with a water level meter from the piezometers installed next to the staff gage.
- Collection of surface water samples at station SW-E1 when water was present in the stream. Surface water samples were analyzed for 173-351-990 WAC Appendix I and II parameters by the KCEL. The list of specific analytes is presented in Table 3.3.

3.2.3 Landfill Gas

RI work elements related to LFG included evaluating the integrity and effectiveness of the existing LFG infrastructure, including the following elements:

- Review of conclusions regarding LFG migration provided in the Phase II hydrogeologic investigation of the EPZ area (Aspect, 2010b);
- Review of zone-of-influence testing results for the east side of the Main Hill (AMEC-Geomatrix/HEC, 2011);
- Review of conclusions and recommendations regarding LFG collection provided in the Data Summary, Analysis, and Alternatives Report (AECOM, 2015);
- Performance of a site visit in 2015 and on June 21, 2016, to observe condition, operation, and performance of LFG collectors on the east side of the Main Hill; and
- Review of the routine LFG collection system and gas probe monitoring data collected from January 2011 through November 2013, and LFG collection system monitoring data collected July 2015 through June 2016, for the LFG system on the east side of the Main Hill.

3.2.4 Soil Gas

The potential for perched groundwater to serve as a significant VOC source and to contribute to elevated soil gas levels was evaluated by directly sampling soil gas above the water table. The RI included the following tasks for locations depicted on Figure 3.3 and listed in Table 3.2:

- Collection of two soil gas samples at selected nested gas probe locations. Probes within these clusters are screened at various depths. The first sample was collected from the probe with the shallowest screen interval (in all cases the top-of-screen for these probes was 6.5 feet bgs) to evaluate near-surface conditions. The location of the deeper screen interval sample was determined by monitoring for methane using the GEM-2000 multi-gas meter. The second sample was collected from the screened interval with the highest detected methane concentration. If methane was not detected in any of the deeper probes, the deepest screen interval was sampled.

- Collection of a total of 19 soil gas samples using 6-liter Summa canisters and analysis for VOCs using U.S. Environmental Protection Agency (EPA) Method TO-15 in July 2015. In May 2016, 19 additional samples were collected: 16 samples for VOC analysis using EPA Method TO-17 and three co-located samples for VOC analysis using EPA Method TO-15. Fremont Analytical laboratory analyzed the soil gas samples collected during July 2015. Eurofins laboratory analyzed the soil gas samples collected during May 2016. The specific analytes are listed in Table 3.3.

3.2.5 Leachate

When sufficient flow was present, raw leachate samples representative of the unlined portion of the Main Hill were collected from manholes MH-17N (in the channel that conveys leachate flow from north Main Hill located in southwest corner of manhole) and FS-3 (from influent pipe). During the June and September 2015 events, insufficient flow at MH-17N, precluded leachate sample collection.

Specifically, the leachate sampling scope included the following tasks:

- Measurement of the static leachate liquid level using a water level tape at each leachate sampling point;
- Measurement of pH and specific conductance, prior to collecting a leachate sample; and
- Analysis of leachate samples for a truncated list of analytes from 173-351-990 WAC Appendix I and II parameters at the KCEL, as indicated in Table 3.3.

The leachate investigation included review of the as-builts (SEE, 1990) and evaluation reports (AMEC-Geomatrix and BHC, 2010) for the leachate collection system on the east side of the Main Hill.

3.2.6 Data Quality Assessment and Usability

As specified in the Sampling and Analysis Plan (SAP; Aspect, 2015), quality assurance and quality control (QA/QC) procedures were built into the field data collection, laboratory, and data management components of the RI. The SAP presents the details on the QA/QC process. Appendix C provides a more detailed assessment of the data quality by way of the data validation reports.

3.2.6.1 Analytical Data Assessment

The laboratory administered standard QA/QC practices including laboratory control spikes, laboratory blanks, matrix spikes, and matrix duplicates. Laboratory analytical data underwent data quality control by laboratory staff prior to finalizing the data. An independent data validation process was also conducted, externally from the laboratory, to ensure quality control of laboratory procedures. Qualifications of the data by the laboratory and by the independent data validation are incorporated into the tables summarizing the analytical results presented in this RI/FS Report.

KCSWD performed validation of the analytical data generated by KCEL for the groundwater, surface water, and leachate samples collected during the June and September 2015. Aspect performed validation of the remaining groundwater, surface water, leachate, and soil gas analytical results during the RI. Additionally, AECOM conducted a preliminary data validation of the data from the first soil gas sampling event. Data validation was conducted in accordance with the data validation guidelines detailed in the CHRLF Environmental Monitoring SAP (Aspect, 2013b). The validation process was performed to determine whether the dataset met the project-specific criteria for data quality and data use. All data were deemed acceptable by the data validator, incorporating data qualifiers as appropriate.

3.2.6.2 Field Data Assessment

Field data are considered data collected in the field that do not require laboratory analysis. Data included in this category are groundwater level data and field parameters collected during groundwater monitoring. Standard field protocols (e.g., sampling procedures and documentation, sample handling, and sample custody) are defined in the SAP included in Appendix A of the RI/FS Work Plan (Aspect, 2015). Adherence to these methods has ensured the quality of data generated. Furthermore, a Washington State-licensed hydrogeologist has reviewed field activities and generated data. Field data were judged acceptable for use in this RI.

The field QA/QC included collecting 12 duplicate samples,8 equipment blanks, 12 field blanks, and 28 trip blanks. The blanks and duplicates were submitted to the laboratory as blinds, with sample labels that were indistinguishable from the primary samples. The following were the results:

- Field duplicates were collected to evaluate field and laboratory precision and reproducibility. The field duplicate results indicated good comparability between the parent sample results and the duplicate results.
- The equipment rinsate blanks were collected to evaluate the potential of cross-contamination introduced by non-dedicated equipment. Limited VOCs were present in the rinsate blanks, including methylene chloride, acetone, chloroform, bromodichloromethane, and toluene, most of which are known laboratory contaminants. Toluene was detected in only one sample during one sampling event, indicating that decontamination procedures overall were adequate.
- Field blanks were collected to check for contamination due to the sample collection, handling, and transport, and from the sample bottles themselves. Results from the first RI sampling event indicate that deionized water was provided and that field blanks, in general, met quality control criteria. However, results from the field blanks supplied for the subsequent rounds of sampling indicate that the laboratory did not provide deionized water; the water source contained trace levels of metals and VOCs. The laboratory investigated the mistaken deionized water source and implemented corrective actions to prevent a recurrence. The mistaken water source did not affect any other blanks used by the laboratory for quality control purposes.
- The trip blanks were collected to monitor possible VOC cross-contamination during sample handling, transport, and storage. Methylene chloride and chloromethane were detected in several

of the trip blanks; however, these are common laboratory contaminants and are not indicative of handling, transport, or storage cross-contamination. The results from the trip blanks indicated no cross-contamination during the RI.

3.2.7 Deviations from RI Scope of Work

In some cases, conditions encountered during the initial field work event differed from anticipated conditions, which resulted in deviations from the scope of work developed in the Work Plan. The following is a list of the major deviations:

- Passive diffusion samples were not collected from MW-62 because there was not enough water in June 2015 to deploy the samplers.
- Passive diffusion samplers that were successfully deployed collected the groundwater sample outside of the targeted “ideal” sample-collection depth range. This occurred because friction and buoyancy caused by the number of RPP bags deployed prevented installation of the samplers to sufficient depth.
- Four gas probes (GP-ATC-2, GP-ATC-4, GP-ATC-5, and GP-ATC-7) could not be field located. According to KCSWD staff, GP-ATC-2 was never installed. Historical documentation indicates the location of GP-ATC-4 is unknown and likely was never installed. GP-ATC-5 and GP-ATC-7 were installed in 1986 to evaluate LFG migration near Passage Point (see boring and gas probe construction logs in Appendix A). Gas monitoring data are available for GP-ATC-5 only in 2010; however, it is suspected that this data was misidentified as GP-ATC-5 as there is no prior LFG data for GP-ATC-5. This probe has not been monitored since 2010 because of reported demolition during construction activities. GP-ATC-5 could not be field-verified using coordinates during the RI. The boring log for GP-ATC-7 indicates it was installed north of the Administration Building and by the Extended Care Unit, in an area now covered by dense blackberry bushes 10 feet tall. The remaining gas probes could not be located because the monuments were either destroyed or were obscured by heavy vegetation. As a result, soil gas samples were not collected in the near vicinity of the Passage Point facility.
- High groundwater levels (i.e., above the top of the screen) in three gas probes and one monitoring well (GP-17A, GP-56, GP-58, and MW-104) during the second soil gas sampling event (May 2016) precluded sample collection from those locations.
- Water level monitoring could not be conducted at all of the locations identified in the Work Plan for a variety of reasons:
    - The well could not be located; or
    - The well was inaccessible because of obstruction inside of the well, a glued-on cap, or equipment at the wellhead that prevented access to the interior of the well casing.

- Low water levels or dry conditions encountered in several of the monitoring wells precluded low-flow groundwater sample collection. Groundwater samples were not collected from MW-62, MW-102, EB-6D, EW-10, or EW-11 during the September 2015 sampling for this reason.
- Leachate was not present at MH-17N during the June and September 2015 sampling events, preventing collection of leachate samples.
- Dry conditions precluded collection of stream samples at SW-E1 during the June and September 2015.
- The North Perimeter Leachate Collector was not camera-surveyed; it had been determined that groundwater samples collected from nearby locations (i.e., MW-29, EB-1, and EB-2) were not impacted by landfill leachate, making further investigation unnecessary.
- LFG infrastructure point-of-vacuum and zone-of-influence testing was not conducted as part of this RI. Design testing has been deferred to the pilot-scale level under the preferred alternative.
- Two soil gas sampling events were conducted utilizing different analytical methods rather than just TO-15. This is discussed further in the Section 7.

Scope deviations were relatively minor. However, the absence of soil gas data from GP-ATC-5 and GP-ATC-7 represents a need for collection of baseline and performance data during the FS. The baseline data will be used to evaluate current conditions while the performance data will be used to evaluate remedy performance near Passage Point. GP-ATC-5 and GP-ATC-7 represented the soil gas sample locations closest to Passage Point and there are no other gas probes that could be sampled as replacements.

3.3 Groundwater Sampling Technology Investigation

As mentioned in Section 3.2.1, a component of the RI investigation was to evaluate several groundwater sampling technologies. The impetus for this evaluation was to determine whether alternative sample collection methods that offer advantages over traditional low-flow sample collection techniques can consistently yield similar results.

The theory behind PDB and RPP samplers is that they rely on free movement of groundwater through the sampler and passively collect the groundwater sample. VOCs and metals will diffuse across the passive sampler until the concentrations within the sampler equilibrate with concentrations in the surrounding groundwater. The advantages of passive samplers are the limited disturbance to the surrounding groundwater system, the absence of purge water for disposal after the event, time efficiency, and cost efficiency.

PDB and RPP samples were co-located at selected low-flow groundwater sampling locations during the first RI groundwater sampling event. The interpretation of the comparative results is presented in Section 7.1.1.

4.0 EAST PERCHED ZONE AREA SETTING

The physical characteristics of the CHRLF environment are described in this section. After overviews of topography, surface drainage, and climate, the text details hydrogeologic conditions at the EPZ area and notes existing uses of groundwater.

4.1 Surrounding Area Description

In addition to the landfill and its support facilities, the CHRLF property includes a LFG-to-energy facility owned and operated by BEW; Passage Point, a transitional residential community; a right-of-way for a natural gas pipeline; and numerous power transmission line rights-of-way. The surrounding area features are depicted on Figure 1.2.

4.2 Zoning and Land Use

Current and potential future land use for the property is as a sanitary landfill. The EPZ area includes the edge of the Main Hill area refuse and a section of the landfill’s 1,000-foot-wide buffer. The 1,000-foot-wide buffer zone surrounding the landfill is primarily comprised of a wooded area separating landfill activities from surrounding properties (Figure 4.1). Certain other land uses have been allowed within the buffer area. For example, Passage Point, a residential transitional housing facility, is located on the east side of the landfill area within the buffer (AECOM, 2015a). Other current uses in the buffer include leachate aeration ponds, and utility easements.

King County identifies the landfill property as a public utility. Its zoning classification is RA-10, a rural area zoned for one dwelling unit per 10 acres. The predominant zoning surrounding the CHRLF is RA-5, rural area zoned for one dwelling unit per 5 acres; the landfill is surrounded to the north, east, and west by residential properties. Figure 4.1 depicts other King County properties in the vicinity of CHRLF. Adjacent to the northeast of the landfill is the RA-5-zoned Log Cabin Reach Natural Area. Adjacent to and south of the landfill is the Queen City Farms Superfund Site, which is zoned as M, mineral property.

4.3 Topography

CHRLF is located on a northwest-trending upland near McDonald Creek to the north, Issaquah Creek to the east, Cedar Grove channel to the south, and Cedar River to the west. Topography within the EPZ area consists of a relatively flat upland surface at about elevation 640 feet above mean sea level (amsl)[1] that slopes northeastward toward an ephemeral stream referred to as Stream 3 (Figure 4.2), a tributary to Issaquah Creek. The mapped trace of Stream 3 extends from about elevation 510 to 490 feet amsl, where it exits at the CHRLF east property boundary. Surface runoff from the east side of the Main Hill Area drains to Stream 3. The Main Hill refuse mound rises to the west of the EPZ area to about elevation 780 feet amsl.

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[1] Elevations are presented relative to vertical datum NGVD 29.

4.4 Drainage, Stormwater, and Surface Water

Wetlands are present in the flat upland area and adjacent to Stream 3 (Figure 4.2). The upland wetlands consist of Wetland A and Wetland B, category III wetlands of about 2.2 acres and 1.8 acres, respectively. The wetlands receive inflows from direct precipitation and from infrequent and incidental spillage from the non-potable water tanks when the landfill's dust-control trucks are filled (AMEC-Geomatrix, 2011).

Wetlands A and B drain to an asphalt-lined ditch adjacent to the west side of the wetlands (Figure 4.2). Wetland B also drains into Wetland A via a culvert passing under the road that separates the two wetlands. Some outflow from the wetlands also occurs as a result of seepage (AMEC-Geomatrix, 2011).

4.5 Geology

Geologic conditions at the EPZ area were characterized using information gathered during previous investigations in addition to this RI.

4.5.1 Geologic Overview

Subsurface conditions in the EPZ area have been extensively studied and documented (CH2M HILL/UES, 2004b; Aspect, 2010). Subsurface geologic units identified in the EPZ area are summarized below and are presented as cross sections on Figure 4.3 through Figure 4.6. Cross-section lines and exploration locations are presented on Figure 4.2. The site-wide hydrogeologic report (CH2M HILL/UES, 2004a) divides the deposits beneath the CHRLF into seven geologic units, referred to as Units A through G, based on geologic origin and relative age. Shallow Unit C and Unit D soils are of primary interest in the EPZ area. Unit C consists of weathered glacial till/glacio-lacustrine deposits. Unit D consists of alluvial gravels referred to as stratified drift. Characteristics of the main geologic units that underlie the EPZ area are briefly described below:

- Glacial till (Unit C)—A dense mixture of gravel in a matrix of silt and sand. Weathered till, typically less than 20 feet thick, overlies the more competent unweathered till in most locations. The weathered till is less dense than the unweathered till and contains scattered roots and other organic matter. The unweathered glacial till has a maximum thickness of about 50 feet. Till underlies the upland and slope areas of the EPZ area, but has not been identified in the lower-lying area around Stream 3.
- Glacio-lacustrine deposits (Unit C)—Glacio-lacustrine deposits generally underlie glacial till in the higher-elevation upland areas of the EPZ area. These deposits have a maximum thickness of about 30 feet (Figure 4.3). They are differentiated from the till by the presence of fine-grained material.
- Stratified drift (Unit D)—The unsaturated stratified drift is present at depth throughout the EPZ area. Stratified drift includes slightly silty gravels, gravelly silty sands, and gravelly sandy silts. The stratified drift occurs beneath glacio-lacustrine deposits, directly underlies glacial till, and is also

exposed at the ground surface in the lower elevations surrounding Stream 3. The thickness of the unsaturated zone ranges from about 280 feet beneath the ESPZ to about 160 feet beneath the NESPZ as indicated by regional well boring logs.

- Lacustrine and low-energy fluvial deposits (Unit E)—Overbank sediment deposits and/or deposits representative of turbidite flows within a former lake environment. The sediments consist of fine sands and silty sands capped by laterally extensive silt beds. These sediments are unsaturated and directly overlie Unit F deposits and extend beneath most of the landfill. Beneath Passage Point, these deposits extend up to an elevation of 422 feet.
- Fluvial sands and silts with incised gravel channels (Unit F)—The top of Unit F is variable beneath the EPZ area. The Regional Aquifer occurs within the Unit F soils beneath the EPZ area.

Predominant soil types in the EPZ distinguish this area from other areas at CHRLF, and create conditions conducive for the presence of perched groundwater described in the next section.

4.6 Hydrogeology

Collectively referred to as the EPZ, the two areas of perched groundwater addressed by this RI/FS Report are depicted on Figure 1.3. Both are saturated areas of shallow groundwater of limited lateral and vertical extent east of the Main Hill:

- The East Shallow Perched Zone (ESPZ), located in the vicinity of MW-103, MW-104, and the groundwater extraction wells EW-12 through EW-29, with groundwater elevations in the range of about 639 to 600 feet amsl. Groundwater within the ESPZ occurs predominantly within glacial till/glacio-lacustrine soils.
- The Northeast Shallow Perched Zone (NESPZ), located around Stream 3 and monitoring wells MW-29, MW-62, and MW-102, with groundwater elevations in the range of 524 to 500 feet amsl. Groundwater within the NESPZ occurs predominantly in siltier portions of the stratified drift.

The perched groundwater zones have been described in previous reports (Aspect, 2010; Aspect, 2013a), but this discussion expands on those earlier findings with a more comprehensive, recent dataset.
Figure 1.3 depicts the current general interpretation of the ESPZ (in blue shading) and the NESPZ (in green shading). Between the ESPZ and the NESPZ is an area of seasonally saturated glacial till/glacio-lacustrine deposits referred to as the Seasonally Saturated Perched Zone (SSPZ) (Figure 1.3, yellow shading). The EPZ area contains all three of these hydrogeologic zones.

4.6.1 East Shallow Perched Zone

The ESPZ occurs within the very low-permeability glacio-lacustrine silts that underlie the flat upland area on the east side of the Main Hill. The low-permeability silts impede downward migration of groundwater, resulting in relatively isolated pockets of year-round saturation of the shallow glacial till/glacio-lacustrine deposits (Aspect, 2013a). Several gas probes and extraction wells completed in the stratified drift in the ESPZ indicate the presence of dry conditions beneath these silts.

Groundwater level hydrographs presented in Figures 4.10 and 4.11 illustrate the separation of perched groundwater in the glacial till/weathered till and glacio-lacustrine units in the ESPZ from groundwater in the stratified drift in the NESPZ. In Figure 4.10, hydrographs from monitoring wells screened in the stratified drift are grouped approximately 40 feet below hydrographs from monitoring wells screened above in the glacial till/glacio-lacustrine deposits.

4.6.1.1 *Hydraulic Conductivity*

Horizontal and vertical hydraulic conductivities were estimated from results of permeability tests conducted in MW-103 and MW-104 (Aspect, 2010); these wells represent groundwater in the ESPZ glacio-lacustrine deposits. The hydraulic conductivity estimates computed from rising head tests performed in monitoring wells MW-103 and MW-104 are presented in Table 4.1.

Horizontal hydraulic conductivity in the ESPZ glacio-lacustrine unit is very low—a geometric mean of 3×10^{-6} centimeters per second (cm/sec) for MW-103 and MW-104, consistent with lacustrine silts. Previous testing (HLA, 1993) of the extraction wells EW-16, EW-17, and EW-19 indicate hydraulic conductivity values of 2×10^{-6} cm/sec to 5×10^{-6} cm/sec (Table 4.1). These hydraulic conductivity estimates explain the difficulty in groundwater extraction wells EW-14, EW-20, and EW-25 at sustaining pumping rates greater than 0.3 gallons per minute (gpm) (AMEC-Geomatrix, 2008a). This pumping rate indicates that the perched zones are not suitable as a drinking water source because they do not meet potable water pump rate requirements of 0.5 gpm (173-340-720(2)(i) WAC).

The extremely low permeability of the ESPZ results in a relatively isolated and stagnant groundwater system with long residence times and slow groundwater velocities. Using the geometric mean of the available hydraulic conductivity estimates (MW-103, MW-104, EW-16, EW-17, and EW-19), the December 2015 gradients shown on Figure 4.8 in the MW-104/EB-5 area, and an effective porosity of 0.2 (representative of silt), the groundwater flow rate in the ESPZ glacio-lacustrine deposits is estimated to be on the order of 1.2 feet/year (Aspect, 2010). The vertical downward velocity within the glacio-lacustrine deposits is estimated to be similar, also at 1.2 feet/year, based on a vertical gradient as indicated by EB-5 and EB-5S in December 2015, an effective porosity of 0.2, and an assumed vertical hydraulic conductivity equal to one-tenth the horizontal hydraulic conductivity (Aspect, 2010).

4.6.1.2 *Groundwater Flow*

Groundwater moves slowly in the ESPZ because the groundwater occurs within fine-grained units. Groundwater flow is primarily downward with a limited horizontal component that has the potential to flow radially outward from the relatively flatter areas occupied by the wetlands. The horizontal component of flow is illustrated in the quarterly potentiometric surface maps presented in Figures 4.7 and 4.8. However, the horizontal component is a relatively small portion of the total groundwater flow. Essentially, the low-permeability silts store infiltrating precipitation and slowly leak it to the 280-foot-thick, fine-grained, unsaturated stratified drift that occurs beneath the ESPZ. Given the potential for vertical migration through the unsaturated stratified drift, the travel time through the unsaturated zone was modeled to evaluate how long it might take for fluid to migrate to the Regional Aquifer.

The numerical model, Variably Saturated 2-Dimensional Transport Interactive (VS2DTI) (Hsieh, Wingle, and Healy, 2000), was used to estimate vertical travel time through the unsaturated zone beneath the EPZ to the Regional Aquifer. The model simulates only advective transport, with no simulation of other processes such as diffusion, adsorption, or degradation.

The model domain was defined as a 300-foot-thick column in order to simulate vertical groundwater migration from the bottom of the glacial till/glacio-lacustrine unit (Unit C), through the unsaturated zone (Units D and E), and into the Regional Aquifer (Unit F). Parameters for the model (specific storage, porosity, and Van Genuchten parameters, see Lappala, Healy, and Weeks [1987] for definition of these parameters) were based on literature values of medium sand for the more transmissive deposits and fine sand for the less transmissive deposits. The hydraulic conductivity for more transmissive deposits was set at approximately 2.1×10^{-3} cm/sec (6 feet/day), which is among the highest hydraulic conductivity measurements made at the CHRLF (Table 4.1). The hydraulic conductivity for the less transmissive glacial till/glacio-lacustrine deposits was set to 3.5×10^{-5} cm/sec (0.1 feet/day) (see Table 4.1). The porosity values used are well within the range of porosity values measured at the CHRLF (Aspect, 2003). Anisotropy was defined as 10:1 for the entire model domain. Flow into the top of the column was defined at a steady rate of 3 inches per year, similar to deep percolation rates through glacial till found elsewhere in the Puget Sound Lowland (Bauer and Martin, 1996).

Results from the model show that under these conditions, a travel time of approximately 159 years is estimated for fluids to reach the Regional Aquifer. These findings support the assertion that the unsaturated, stratified drift provides a high degree of attenuation and buffer potential for any potential downward migrating contaminants.

The assumptions made in the model are conservative, and therefore should predict shorter travel times than more reasonable assumptions. For instance, hydraulic conductivities are among the highest values measured, where lower hydraulic conductivities would serve to increase travel times. Other types of transport processes not simulated here, such as adsorption or degradation, which would also slow travel times. A steady in-flow rate through the glacial till was used in the simulation, but a variable in-flow rate would impede fluid flow through the column and in turn slow travel times. To determine the sensitivity of the model to anisotropy, the model was reran with an anisotropy of 1:1, and the travel time to the Regional Aquifer occurred after 93 years. As the Main Hill first began operation in 1965, this model predicts, even with the conservative assumptions, fluid migration through the unsaturated zone into the Regional Aquifer to occur in 2058.

4.6.2 Northeast Shallow Perched Zone

The NESPZ lies within silty gravel and silty sand layers that hold groundwater within the stratified drift northeast of the closed Main Hill. This zone lies beyond the location where the weathered till/till pinches out between the stratified drift and land surface (Figure 4.3). Water level hydrographs for Stream 3 gage points SG-4 and SG-5, monitoring wells, and groundwater extraction wells within the EPZ area are presented in Figures 4.10 and 4.11.

4.6.2.1 *Hydraulic Conductivity*

Horizontal and vertical hydraulic conductivities were estimated from results of permeability testing conducted in MW-102, which represents groundwater in the NESPZ stratified drift deposits. The hydraulic conductivity estimates computed from rising head tests are presented in Table 4.1

The hydraulic conductivity of the stratified drift at MW-102 is estimated to be about an order of magnitude higher than that of the ESPZ glacio-lacustrine deposit, at 3×10^{-5} cm/sec (Table 4.1; Aspect, 2010). Previous investigations determined hydraulic conductivity in the stratified drift to be about 4×10^{-5} cm/sec, with a locally higher hydraulic conductivity of 6×10^{-3} cm/sec present in NESPZ monitoring well MW-63 (SEE, 1991a).

4.6.2.2 *Groundwater Flow*

Groundwater within the NESPZ moves both downward, discharging to the Regional Aquifer, and to the east-southeast, discharging to the Stream 3 near its eastern end (Aspect, 2013a). Groundwater flow towards Stream 3 moves east-northeast and generally parallels the Stream 3 gradient (Figure 4.7 and 4.8). Water levels in the stream and underlying perched zone fluctuate seasonally in a similar manner, indicating hydraulic connection between groundwater in the stratified drift and Stream 3. Seasonally, Stream 3 goes dry when the water table drops below its streambed. Dry measurements in wells are indicated by red monitoring well labels in Figure 4.7 and 4.8.

A piezometer is coupled with a staff gage at SG-4 and SG-5, allowing water levels within the hyporheic zone that underlies the stream channel to be monitored when the stream is dry. Water levels in the stream and underlying perched zone fluctuate seasonally in the same manner as monitoring wells, indicating hydraulic communication between groundwater in the stratified drift and Stream 3. The hydraulic low point and likely surface discharge point for the NESPZ occurs in Stream 3. Base flow for Stream 3 is maintained seasonally by groundwater discharge. Staff gage location SG-5 and surface water monitoring point SW-E1 are located at the downstream end of Stream 3. During periods of groundwater contribution to Stream 3, station SW-E1 provides an excellent opportunity for monitoring water quality in the NESPZ, particularly when flows are low and undiluted by surface water.

Along the upper portion of Stream 3, monitoring well MW-63 is the lowest monitored hydraulic point in the NESPZ throughout much of the year and has been dry seasonally, similar to Stream 3. The lower portion of the MW-63 screen is completed in a relatively clean sand and gravel that drains water from the overlying silty gravels, resulting in lower groundwater elevations in this area. Monitoring well hydrographs (Figures 4.10 and 4.11) show that recent water levels in MW-63 are higher than those in SG-4, consistent with a gaining condition (local groundwater discharges to the stream) in the upper portion of Stream 3. In 2006 and 2009, groundwater levels in MW-63 were lower than those in SG-4 and the upper portion of Stream 3 was in a losing condition (the stream water infiltrates into the ground and recharges groundwater). The recent gaining condition is attributed to increased precipitation since 2009. A plot of cumulative departure from the mean precipitation is presented at the bottom of the hydrographs in Figure 4.11. The rising limb of the plot, since about 2009, is indicative of wetter-than-normal conditions.

4.6.3 Seasonally Saturated Perched Zone

An area of seasonally saturated weathered till/till and glacio-lacustrine deposits surrounds the ESPZ to the north, east, and south, and separates the ESPZ and NESPZ as depicted in yellow shading on Figure 1.3. The weathered till/till of the SSPZ pinches out against the ground surface and the stratified drift along the bottom of the hill in the northeast and marks the transition from the SSPZ to the NESPZ. Most well and gas probes completed in this area are seasonally dry. Seasonally saturated monitoring points in this area include shallow monitoring points completed within shallow fill or shallow till soils, such as GP-1A, and deeper wells, such as EW-8, EW-9, and EW-10, that access shallow portions of the underlying stratified drift. Dry conditions in wells are indicated by the red monitoring well labels on Figure 4.7 and by orange elevation data in the cross sections, Figures 4.3 through 4.6. A steep slope forms the northeastern area where high runoff is expected to occur due to the low permeability of the underlying glacial till deposits (Figure 4-6).

4.6.3.1 *Groundwater Flow*

Groundwater flow within the SSPZ is primarily downward through the stratified drift. The low-permeability glacial till and areas of lower permeability within the stratified drift store infiltrating precipitation during the wet season. This stored water leaks to the underlying unsaturated stratified drift and eventually migrates to the Regional Aquifer. Groundwater levels decline under losing conditions when leakage exceeds recharge. A limited portion of groundwater flow may occur horizontally and radiate outward from the SSPZ seasonally, when perched groundwater is present. (Figure 4.8).

4.6.4 Regional Aquifer

The Regional Aquifer underlies the EPZ area at elevations ranging from about 320 feet amsl at the south end of the EPZ area to about 285 feet amsl at the north end. A thick unsaturated zone exists between the base of the EPZ and the Regional Aquifer. As indicated by regional well boring logs, the thickness of the unsaturated zone ranges from about 280 feet beneath the ESPZ to about 160 feet beneath the NESPZ. The unsaturated zone consists of stratified drift (Unit D) soils, lacustrine and low-energy fluvial deposits (Unit E), and fluvial sands and silts with incised gravel channels (Unit F). The Regional Aquifer occurs within the Unit F soils beneath the EPZ. Groundwater flow in the Regional Aquifer beneath the EPZ area is to the northwest (Aspect, 2011; Figure 4.9). Hydrographs from Regional Aquifer monitoring wells are provided in Figure 4.10, which depicts the separation of these perched groundwater zones from the Regional Aquifer. Figure 4.10 illustrates the separation and strong vertical gradients between the perched zones and the Regional Aquifer. The hydrographs indicate that a thick unsaturated zone exists in the EPZ area between the base of the shallow perched zone and the Regional Aquifer.

4.6.5 Groundwater Use

Groundwater at the CHRLF is not used as a drinking water source. Chapter 12.24 of King County Board of Health Title 12 requires a 1,000-foot setback from a landfill for public water system wells. Figure 4.12 depicts the setback distance from the landfill refuse footprint. Four non-potable groundwater wells (NPW-1 through NPW-3 and ATC-1) owned by KCSWD are located within the 1,000-foot buffer. NPW-1 through NPW-3 supply non-potable water for CHRLF maintenance activities. ATC-1 was installed as a non-potable water source for Passage Point, to replace a decommissioned well (PW-1) (CH2M HILL/UES, 2004a); however, this well is not currently operated (KCSWD, 1998). The remaining water supply wells within the vicinity of CHRLF are greater than 1,000 feet from the landfill.

5.0 ENVIRONMENTAL REGULATIONS AND DEVELOPMENT OF CLEANUP LEVELS

Many environmental laws apply to cleanup actions at the EPZ area. A number of these laws identify chemical concentrations in environmental media that are considered to be protective of human health and the environment under specified exposure conditions (i.e., CULs). This section identifies potentially applicable environmental regulations and CULs for media, potential receptors that may require protection, and potential exposure pathways for which environmental regulations may need to be protective. In Section 7, chemical concentrations detected in the EPZ area are compared to CULs to determine COCs. Proposed CULs for EPZ area COCs for use in the remedial action are presented in the FS. An evaluation of viable receptors and active exposure pathways is presented in Section 8.

5.1 Potential Applicable Regulatory Requirements

The following provides a summary of potential ARARs based on local, state and federal laws. Because implementation of the selected FS alternative would be conducted under an agreement with Ecology, permits that would otherwise be required for certain actions will not be required. However, the substantive requirements of the applicable regulations must still be met.

The primary ARARs are cleanup standards and procedures for implementation of a remedial action under the MTCA. Other potential ARARs include the following:

- Washington Chemical Contaminants and Water Quality Act and Washington Water Pollution Control Act, and the implementing regulations, Water Quality for Surface Waters (Chapter 173-201A WAC).
- Minimum Functional Standards for Solid Waste Handling (MFS; Chapter 173-304 WAC). The typical closure requirements in this set of regulations are applicable because they pertain to landfills that did not accept waste after October 9, 1991; disposal at the Main Hill ceased in the mid-1980s. The current refuse regulations, Criteria for Municipal Solid Waste Landfills (Chapter 173-351 WAC), are also applicable to the CHRLF because of the ongoing waste acceptance at the active cell Areas.
- The RCRA and Subtitle C regulations, to the extent that any hazardous wastes are discovered during the remedial action. Subtitle D of the RCRA, which regulates MSW landfills, requires that measures be implemented to ensure the control of LFG migration.
- Washington Hazardous Waste Management Act and Dangerous Waste Regulations (70.105 RCW and 173-303 WAC), to the extent that any dangerous wastes are discovered during the remedial action.
- Federal and State Clean Air Acts (42 United States Code [USC] 7401 *et seq*.; 40 Code of Federal Regulations [CFR] 50; 70.94 RCW;173-400 WAC, 173-403 WAC). Both the federal and Washington state Clean Air Acts regulate air emissions to the extent that emissions are generated during interim measures and long-term remedies implemented at the facility (i.e., LFG flares, soil vapor extraction, and vapor mitigation).

5.2 ARARs for Development of Cleanup Standards

MTCA and Water Quality Standards for Surface Waters were of primary consideration in the development of CULs (Section 9.0 [Remedial Action Requirements]). The procedures for identifying, investigating, and cleaning up MTCA sites are defined in Chapter 173-340 WAC, as are CULs for groundwater, soil, surface water, and air. MTCA procedures employ a risk-based evaluation of potential human health and environmental exposures to EPZ area COCs. To establish cleanup standards, it is necessary to determine both the CUL that will apply as well as the point of compliance (POC). For a given constituent detected in soil, groundwater, surface water, or air, CULs must be at least as stringent as established state or federal standards or other laws (i.e., ARARs) developed for human health and environmental protection. Not all constituents have state or federal standards. If a state or federal standard is available, that ARAR is evaluated to ensure that it is protective under MTCA. If the ARAR is not protective, the CUL is adjusted to a lower value to ensure its protectiveness.

The CUL for one medium must also be protective of the beneficial uses of other affected media. The procedures for developing CULs are outlined in the MTCA Cleanup Regulation Sections 173-340-720 (groundwater), -730 (surface water), -740 (soil), and -750 (air) WAC. Included in these sections are the specific rules for evaluating cross-media protectiveness.

Washington Water Pollution Control Act provides for the protection of surface water and groundwater quality. Chapter 173-201A WAC establishes water quality standards for surface waters of the state. In this RI Washington State freshwater surface water standards are potentially applicable; federal surface water criteria under the Clean Water Act and National Toxics Rule are not applicable because the surface water at CHRLF does not meet the definition of a waters of the United States (40 CFR §230.3). Regulations at 173-200 WAC protect groundwater quality; however, they also note that these cleanup standards are not applicable for remedial actions pursuant to MTCA. Therefore,173-200 WAC is not an ARAR for cleanup standards for the EPZ area.

RCRA Subtitle C and Dangerous Waste Regulations are not expected to apply unless Dangerous Wastes as defined under those regulations are discovered or generated during the remedial action. The MFS landfill closure requirements (Chapter 173-304 WAC) were considered during development and evaluation of cleanup standards. Regulations at 173-304-407 WAC identify closure and post-closure requirements for landfills. These requirements, pertaining to cleanup standards and the protection of human health and environment, include the following:

- Post-closure activities include groundwater monitoring; surface water monitoring; gas monitoring; and maintenance of the facility, facility structures, and monitoring systems for their intended use for a period of 20 years or as long as necessary for the facility to stabilize (i.e., little to no settlement, gas production, or leachate generation), and to protect human health and the environment; and until monitoring of groundwater, surface water, and gases can be safely discontinued.

The Criteria for Municipal Solid Waste Landfills (173-351 WAC) were considered during development and evaluation of cleanup standards with respect to its guidance on POC and detection monitoring analytical requirements. More specifically, 173-351 WAC requires that the POC for cleanup standards be defined as locations no more than 150 meters (492 feet) from the boundary of the waste management unit. Regarding analytical requirements, this WAC lists analytes required for detection monitoring events, but allows for modification if certain requirements, specified in 173-351-450 WAC, are met.

5.3 Potential Exposure Pathways

According to MTCA, an exposure pathway is: "…*the path a hazardous substance take or could take from a source to an exposed organism. An exposure pathway describes the mechanism by which an individual or population is exposed or has the potential to be exposed to hazardous substances at or originating from a site.*" The following are potential current and future exposure pathways for both human and ecological receptors:

- Groundwater
    - Direct human contact with impacted groundwater.
    - Ingestion of impacted groundwater.
    - Inhalation resulting from soil vapor discharge and intrusion to indoor and ambient air. Soil vapor caused by the volatilization of VOCs in shallow groundwater has the potential to migrate.
    - Groundwater discharge to surface water. See surface water exposure pathways below.
- Surface water

    Discharge of impacted groundwater to Stream 3 could affect surface water receptors.

    - Direct contact of humans in Stream 3 to impacted surface water.
    - Direct exposure of aquatic organisms in Stream 3 to impacted surface water.
    - Human consumption of aquatic organisms in Stream 3 exposed to impacted surface water.
- Landfill gas
    - Inhalation by building occupants (of current and future structures) of indoor air impacted—via vapor intrusion (VI)—by VOCs originating from fugitive LFG.
    - Direct human contact from explosions of fugitive LFG.
    - Inhalation of air impacted by fugitive LFG vapors.
- Air
    - Inhalation by building occupants (of current and future structures) of indoor air contaminated- via vapor instruction- by VOCs originating from impacted groundwater.
    - Direct exposure to air contaminated by LFG is addressed in the LFG discussion above and may occur during facility operations and maintenance activities, but these activities are performed with worker protection controls in place.
- Leachate
    - Direct contact with fugitive leachate. Direct exposure to leachate may occur during facility operations and maintenance activities, but these activities are performed with worker protection controls in place.
    - Fugitive leachate may impact groundwater and is addressed as part of the groundwater pathway.

Section 8 presents an evaluation of these potential exposure pathways in light of the RI results and presents the active and potential future active exposure pathways.

5.4 Potential Receptors

The following are potential current and future human receptors:

- **Site residential and commercial occupants**. Potential exposure of residents and commercial occupants of structures under current and potential future development scenarios.
- **Site workers.** Potential exposure of current landfill workers and future construction workers. Currently, King County maintains internal controls to ensure that workers conducting excavations at the CHRLF receive appropriate training and monitoring.
- **Recreational users**. Potential exposure of recreational users of Stream 3 and users of property adjacent to but outside of the CHRLF boundary. Recreational users on the CHRLF property are not potential receptors because property access restrictions are in effect.

Ecological receptors may also currently be exposed to affected EPZ area media. Potential ecological receptors include:

- **Aquatic species.** Potential exposure of aquatic and terrestrial ecological receptors (if any) in Stream 3.

Section 8 presents an evaluation of these potential receptors in light of the RI results and presents the active and potential future active receptors.

5.5 Development of Cleanup Levels for Detected Chemicals

This section presents the numeric criteria for groundwater, surface water, and LFG that were used to develop CULs for the EPZ area. Preliminary CULs were developed for those constituents identified in the RI/FS Work Plan (Aspect, 2014) as contaminants of potential concern (COPCs; presented in Table 5.1 of this report) because they were detected in one or more of the EPZ area media (groundwater, surface water, and soil gas) during pre-RI sample events within the last 10 years, and at concentrations exceeding preliminary screening levels developed in the RI Work Plan. Preliminary CULs take into consideration and are protective of the potential exposure pathways and receptors presented in Sections 5.3 and 5.4. Preliminary CULs are used in Section 7.0 of this report for identifying COCs, evaluating likelihood of exposure by receptors, evaluating the nature and extent of impacted media, and delineating areas requiring remedial action. The results of the preliminary CUL screening in Section 7.0 contribute to identifying the POC where those standards must be met, and preparing for development of final COC CULs for remedial alternative evaluation, discussed in Section 9.0.

CULs for each medium were selected from potentially applicable screening levels in available and pertinent chemical-specific federal and Washington State ARARs, as shown in Table 5.2 for groundwater, Table 5.3 for surface water, and Table 5.4 for soil gas. For groundwater and surface water, the numeric values carried forward as the CUL for screening the RI data (Section 7.0) are highlighted in blue. The CULs were selected in accordance with MTCA requirements to reflect potential contaminant exposure pathways, potential receptors, and applicable regulatory criteria, subject to the limitations of the currently available data and site-specific considerations.

5.5.1 Groundwater Cleanup Levels

For groundwater, CUL values were obtained from the following chemical-specific applicable regulatory criteria for Washington State:

- State primary maximum contaminant levels (MCLs; 246-290-310 WAC) that are protective of the human health ingestion pathway; and
- State MTCA groundwater cleanup Levels (173-340-740 WAC) using Method A (table values) and Method B (standard formula values) that are protective of the human health ingestion pathway.[2]

The perched zones are not used as a drinking water source at present and cannot be used as such in the future because they do not meet potable water pump rate requirements of 0.5 gpm. However, the drinking water standards are presented as potential groundwater CULs because they provide the most conservative level of protection for potential receptors. For carcinogens such as VOCs, MTCA allows for modification of the CUL to a target excess lifetime cancer risk of $1x10^{-5}$ (1 in 100,000) for constituents that also have a state or federal MCL. The calculations presented in 173-340-720 WAC were used to adjust the MTCA Method B criteria for carcinogenic COCs and the adjusted values were compared to state MCLs (246-290-310 WAC). Preliminary CULs were selected as the lower of either the modified MTCA Method B value or the state MCL (see Table 5.2).

When a natural background level was available, this value was used as the preliminary CUL instead. For example, the MTCA Method A arsenic CUL of 0.005 milligrams per liter (mg/L) is based on background concentrations for the State of Washington. When ambient groundwater quality within the Issaquah Creek Valley Groundwater Management Area (of which CHRLF is located within) was investigated by King County Water and Land Services (2005), arsenic concentrations averaged 0.003 mg/L and ranged from non-detect at 0.0005 mg/L to 0.0098 mg/L in the 15 wells sampled. Ambient arsenic concentrations exceeded the MTCA Method A CUL of 0.005 mg/L in 20 percent of the sampled wells. While less than the maximum ambient concentration, the MTCA Method A CUL of 0.005 mg/L is consistent with local background conditions and thus appropriate for use in this investigation. In addition, the MTCA Method A concentration of 0.005 mg/L is one-half of the drinking water MCL of 0.01 mg/L and is therefore considered protective of human health.

Ecology (2015a) guidance on the VOC trichloroethene (TCE) indicates that the state MCL should be adjusted downward to 4 micrograms per liter (µg/L) from the 5 µg/L specified in 246-290-310 WAC. This

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[2] Water Quality Standards for Groundwaters of the State of Washington (173-200 WAC) are not applicable during cleanup actions under MTCA.

adjusted state MCL is lower (i.e., more conservative) than the adjusted Method B formula value, and is used here as the CUL for TCE. The preliminary groundwater CULs and the source of the CUL are presented in Table 5.2.

5.5.2 Surface Water Cleanup Levels

For surface water, possible CUL values were obtained from the following federal and Washington State chemical-specific applicable regulatory criteria (Table 5.3):

- National recommended water quality criteria (pursuant to 33 US Code, Section 304[a] of the Clean Water Act) for human health and freshwater aquatic life;
- Water quality standards for surface waters of the State of Washington (173-201A WAC) that are protective of the human health ingestion pathway and ecological health pathway (freshwater standards); and
- Washington State MTCA surface water cleanup levels (173-340-730 WAC) using Method B (standard formula values) that are protective of the human health ingestion pathway and the ecological health pathway (freshwater standards).

Select metals are hardness dependent and as such CULs are derived by calculating the site-specific hardness-corrected chronic freshwater criteria. These hardness dependent metals are noted in Table 5.3.

5.5.3 Landfill Gas Cleanup Levels

For LFG, CUL values were obtained from Washington State criteria for municipal solid waste landfills operating criteria (173-351-200 WAC).

5.5.4 Soil Gas Cleanup Levels

For soil gas, CUL values were obtained from the Ecology (2016a) draft guidance for evaluating soil vapor intrusion in Washington State and related screening level updates. Available soil gas regulatory criteria are noted for shallow and deep soil gas in Table 5.4.

6.0 INTERIM ACTIONS

This section presents information on interim cleanup actions conducted in the EPZ area of the CHRLF since 1993. These actions have targeted groundwater, leachate, and LFG.

6.1 Groundwater Extraction

A 29-well groundwater extraction system operated from October 1, 1993 through July 27, 2010. System performance was evaluated in 2004 and 2006 through 2009. Review of pumping data indicated several wells were dry or had failed (CH2M HILL/UES, 2004b). The extraction wells were rehabilitated through well redevelopment in November 2006 through March 2007 (AMEC-Geomatrix 2008a). Following redevelopment, the wells experienced rapid regrowth of microbial material that caused biofouling and plugging of the well screen area. This deterioration of the extraction wells limited the groundwater extraction system performance and reduced the overall system well yield. The annual target-design groundwater production was estimated at 14,700,000 gallons, but the system produced approximately 868,000 gallons in 2004/2005 or about 6 percent of the design volume (AMEC-Geomatrix, 2008a).

Following redevelopment of the extraction wells in 2006 and 2007, the highest producing wells (EW-14, EW-20, and EW-22) were pump-tested. Even these wells could not sustain flow and did not influence groundwater levels close to the pumping well because of post-development biofouling (AMEC-Geomatrix, 2009). The pump-test results also indicate that the low recovery rates limited the extraction well zone of influence, inhibited the ability of the extraction well system to control groundwater migration, and confirmed that the system does not meet the design requirements (AMEC-Geomatrix, 2009, 2008a). In response to these findings, KCSWD shut down the system on July 27, 2010, and put in place a monitoring program to compare hydraulic gradients under pumping and non-pumping conditions. Until the RI sampling began, groundwater quality at the extraction wells had not been evaluated since extraction system shutdown.

The extraction wells are screened at many variable depths, but generally as follows:

- 20–40 feet bgs within the weathered glacial till/glacio-lacustrine (EW-2 and EW-11 through EW-27);
- 30–60 feet bgs within the uppermost stratified drift (EW-1 and EW-3 through EW-10); and
- Less than 20 feet bgs within the weathered glacial till/glacio-lacustrine (EW-28 and EW-29).

Common to all extraction wells are filter sand packs that extend well above the screened interval to less than 11 feet bgs in all cases, and generally to 7–8 feet bgs. In some cases, for example EW-7 and EW-11, the filter pack extends from the till into the stratified drift. These extraction wells were designed to maximize recovery and the extended filter packs were intended to intercept as much perched groundwater as possible. Thirty-four years later and based on the current CSM, these long filter sand pack intervals could be serving as preferential flow pathways for perched groundwater, allowing enhanced downward transport through lower permeability till and glacio-lacustrine to the more permeable stratified drift via the significantly more permeable filter sand pack (estimated 1 x10^{-2} cm/sec). This preferential groundwater flow pathway represents a potential transport pathway for impacted perched groundwater, especially considering the number of extraction wells. Furthermore, these wells may also serve as conduits for vertical LFG migration.

In summary, the effectiveness and performance of the groundwater extraction system has been limited based on the following observations:

- EPZ low permeability—The extraction wells are screened in soils of very low permeability, which causes low yield and limits the zone of influence to a small area around the well. This condition, in turn, limits the mass removal rate for COCs. The same low-permeability conditions render the perched zones unsuitable as a drinking water source because the required potable water pump rate of 0.5 gpm cannot be achieved (173-340-720(2)(i) WAC).

- Biofouling—The documented growth of microbial material clogs the well screen and decreases the function of the well over time. Even after multiple attempts to rehabilitate and redevelop the wells, the design production rates for the system have not been met.
- Well construction—The long filter sand packs designed to maximize recovery may function as a potential preferential pathway for movement of both groundwater and LFG along the outside annular space of the well. Impacted shallow perched groundwater in the glacial till/glacio-lacustrine units could readily migrate vertically into the stratified drift unit along the filter sand pack interval. In addition, the long filter sand pack may allow LFG to migrate along the well borehole and to interact with the multiple perched groundwater zones.

6.2 Leachate Collection

The leachate collection system adjacent to the EPZ area has not changed significantly since the closure-related activities in the early 1990s.

6.3 Landfill Gas Collection

Past actions to control LFG migration in native soils in the EPZ area include installation, operation, and maintenance of the LFG collection system and engineered cover systems; installation of a separate utility flare to provide treatment of low quality LFG; and the addition of LFG extraction wells in refuse or in native soils to improve LFG migration control. The focus of interim action work was routine monthly flow adjustments to meet LFG collection objectives of controlling LFG migration without causing over-extraction that could lead to atmospheric air intrusion.

Previous investigations characterized LFG conditions in and around the EPZ area, including vertical LFG migration from the bottom of the Main Hill, where refuse was placed on native material without a bottom liner (Aspect, 2010), and zones of influence for the LFG collection system (AMEC-Geomatrix/HEC, 2011). Recently, the *LFG Data Summary, Analysis and Alternative Report* (AECOM 2015b) provided additional information on LFG conditions in the Main Hill area.

The summary of LFG findings from the *East Main Hill Perched Zones Technical Memorandum* (Aspect, 2010) are excerpted below:

- Landfill gas migrated beyond the LFG control system within the stratified drift beneath the EPZ area. It appeared likely the gas migrated from the refuse area of the Main Hill to the more permeable stratified drift materials beneath the glacio-lacustrine deposits. As LFG migrated upward in response to barometric pressure changes, its discharge was largely blocked by the saturated, low-permeability silt in the glacio-lacustrine unit and instead forced through more permeable pathways. Vacuum influence around E-29C-S suggested a pathway in this area, as did dry groundwater extraction wells such as EW-20. Lateral migration to more distant areas with soils of greater permeability could also provide a discharge pathway. An impact on the perched groundwater was possible in these preferential pathways, although chlorinated VOCs in the gas appeared to attenuate with more distal movement.

- Active LFG migration was much less significant to the north in the NESPZ, where the higher proportion of carbon dioxide to methane at shallower depth indicated a greater degree of methane oxidation. In general, the shallower the soils and the longer the flow pathway, the more complete the oxidation process.
- The shallow fill/weathered glacial till did not appear to be a significant gas-to-groundwater pathway as the shallower LFG was depleted in chlorinated VOCs throughout the EPZ area.

Selected conclusions and recommendations from the landfill gas influence testing analysis at East Main Hill (AMEC-Geomatrix/HEC, 2011) are excerpted below:

- In the East Main Hill, an older area of the landfill, significant amounts of soil were used to backfill areas of differential settlement during filling and prior to final closure activities. Due to the configuration and final grading of the East Main Hill, refuse depths taper along the perimeter. The relatively shallow depths, combined with a significant amount of added fill soil may contribute to the observed highly variable nature of connectivity.
- Installation of replacement and new wells in areas of deeper refuse (greater than 70 feet) was recommended for locations where influence testing indicated an absence of connectivity. These wells would ideally tap into additional refuse pockets potentially contributing to gas migration under the landfill. Prior to well installation, liquid levels from adjacent wells should be measured to determine the optimum depth to set the screened interval. Well construction and abandonment should comply with current KCSWD practices. The suggested candidates for rehabilitation or replacement are:
    - E-46 (CHE00046) and E-51 (CHE00051) have had no gas flow and exhibited high oxygen concentrations. Neither E-46 nor E-51 were included in the 2006 or 2008 vertical well video inspection surveys, so their physical condition is unknown. Our recommendation is to conduct a video inspection of E-46 and E-51 to determine if rehabilitation should be conducted. If rehabilitation is not a viable option, replacement well(s) should be installed in refuse immediately uphill of the current location(s). New identifiers (CHE00066 and CHE00067) should be assigned, as recommended by KCSWD.

Landfill gas corrective actions reported by KCSWD between 2010 and 2013 focused on enhanced monitoring, influence testing, optimization, and expansion of the LFG collection system along the western property boundary. In addition, “the *Cedar Hills Regional Landfill Mitigation Plan for Landfill Gas* was completed and sent to the DPHSKC and the WDOE on November 21st 2011” (from Section 8.1.1 of the

2011 Annual Report). In 2011, KCSWD connected gas probe GP-57 to the Main Hill East Header LFG collection system due to the routine measurement of high methane concentrations at that location. Active LFG collection at GP-57 began in January 2012, and methane concentrations subsequently decreased at other nearby locations as described in Section 7.5.

Selected conclusions and recommendations regarding the LFG collection system from the Data Summary, Analysis, and Alternatives Report (AECOM, 2015) are excerpted below:

- The primary goal of the LFG collection system at CHRLF was to control LFG migration while providing for the safe and environmentally friendly use or disposal of LFG. The existing LFG collection system was determined to be successfully achieving this goal.
- However, because landfill is a dynamic biochemical process, the LFG collection system needs to be robust and evolve with the landfill. For example, when the BEW facility was constructed at CHRLF in 2009, landfill Operations staff needed to transfer as much high-quality LFG to the BEW facility as possible. while simultaneously ensuring that the LFG collection system control migration and provide for the safe and environmentally friendly disposal of any LFG not transferred to BEW. To meet these needs, LFG was separated into high-quality LFG meeting BEW operating requirements and low-quality LFG, which is isolated through a control network and flared continuously at the North Flare Station’s skid-mounted flare. Five key recommendations were presented to achieve migration control objectives, minimize air intrusion, and maximize LFG collection. These recommendations include the following:
    1. Isolation valves inspection/replacement—Test, repair, and/or replace any potentially leaking butterfly isolation valves;
    2. Low-quality LFG control network expansion—Expand control network for low-quality LFG collection;
    3. System leak inspection/repair—Test, repair, close, disconnect, and/or repurpose collectors demonstrating any symptoms of air intrusion;
    4. Throttling valve improvements—Install new throttling valves designed to provide a wider range of operating control; and

KCSWD has implemented the recommendations by AECOM, or has plans to implement these recommendations as described below.

1. Two isolation valves were replaced in February 2016 to address potential leaks between the high-quality header and the lower quality header.
2. Lower quality LFG from the East Main Hill system has been sent to the skid-mounted flare for treatment since 2012, allowing high quality LFG from the Central Header and other cells to be sent to BEW. To improve LFG migration control in the East Main Hill area, KCSWD plans to

expand the lower quality LFG collection points along the Central Header that are directed to the skid-mounted flare once the long-term data evaluation proves that these changes are effective in improving the quality of collected LFG (T. Ghofrani, personal communication, November 7, 2016).

3. KCSWD monitors critical main headers daily to support LFG collection system balance and leak detection. Four interior leaks were repaired by September 2015 (W. Grant, personal communication, October 28, 2016). To improve LFG migration control in the East Main Hill area, KCSWD plans to continue identifying and repairing leaks in the LFG collection system, including potential leaks between the monitoring assembly near the header and wellhead described in Section 7.5.
4. Precision flow control valves were installed at four interior monitoring assemblies in July 2016 as part of a pilot test. KCSWD is evaluating the performance of these precision valves on the quality of LFG collected. To improve LFG migration control in the East Main Hill area, KCSWD plans to evaluate the expanded use of precision valves at the conclusion of the on-going pilot test.

7.0 NATURE AND EXTENT OF CONTAMINATION

7.1 Screening of RI Data

Groundwater at CHRLF has been tested for chemical constituents since the early 1990s. Analytes have included metals, VOCs, semivolatile organic compounds (SVOCs), polychlorinated biphenyls, pesticides and herbicides, and conventional water quality parameters. Many constituents have never been detected in groundwater and thus were not considered for evaluation during the RI. Instead, the RI focused on analysis of 173-351-990 WAC Appendix I and II parameters (in addition to selected project-specific MNA parameters) with particular attention toward COPCs identified in the Work Plan (Aspect, 2015) requiring further evaluation if they were, in fact, present at levels of potential concern. Appendix D contains tables presenting the analytical results for samples collected from January 2015 through March 2016. This dataset includes data collected by KCSWD during routine groundwater, surface water, and leachate monitoring events, and those collected by Aspect during the RI. Appendix D also contains tables summarizing, by analyte, the frequency of detection, and the maximum, minimum, and average detected concentrations.

Many of the wells tested during the RI had limited or no historical analytical data associated with them. Therefore, the data collected during the period of the RI (June 2015 through March 2016) provide the most comprehensive dataset for many wells located within the EPZ area. The data collected during the RI also represent current conditions.

The purpose of screening the RI data is to identify parameters that may present a concern to human health and the environment using the regulatory criteria to identify hazardous substances requiring further evaluation. The parameters retained as COCs were determined by comparing the RI-generated data with CULs; constituents whose concentrations exceed CULs during the RI are considered COCs. The results of this screening are presented in Tables 7.1 through 7.6, and COCs are summarized in Table 7.7.

7.1.1 Groundwater

Parameters analyzed and detected in groundwater samples are summarized in Appendix D Tables D3 (for perched groundwater) and D4 (for regional groundwater). Of the 116 parameters for which perched groundwater samples were analyzed, only 68 were detected in more than one sample. The detected compounds included field parameters, conventional groundwater quality parameters, metals (total and dissolved), and a suite of VOCs.

Regional groundwater samples were analyzed for the same parameters as perched zone groundwater; however, only 32 compounds were detected in more than one sample. The detected compounds also included field parameters, conventional groundwater quality parameters, metals (total and dissolved), but only two VOCs.

7.1.1.1 Groundwater COC Selection

Table 7.1 summarizes the data presented in Appendix D, presenting the minimum and maximum detected concentrations for each COPC, the well location where the highest concentration was detected, the number and frequency of CUL exceedances, whether the COPC is a COC and therefore retained for the FS, and the justification for that status. Of the compounds that were detected during the RI, only 16 were detected at concentrations above their respective CULs. Specifically, CULs in perched groundwater samples were exceeded for nitrate; total dissolved solids (TDS); total and dissolved arsenic, iron, manganese, and zinc; total lead; chloroform; cis-1,2-dichloroethene (cis-1,2-DCE); methylene chloride; TCE; and VC. CULs were not exceeded for chloride, 1,1-dichloroethane, 1,2-dichloroethane, or benzene. These latter compounds (previously identified as COPCs in the Work Plan) were therefore eliminated from consideration as COCs for the FS.

The next step in the COC selection process is to further evaluate the compounds with CUL exceedances. Nitrate had a detection frequency of 72 percent, but exceeded the CUL in only a single sample (EW-13). Therefore, nitrate is not considered a COC and was not carried forward into the FS. TDS was detected in all samples, but exceeded the CUL only 18 times. The maximum TDS concentration was observed at MW-47. The CUL for TDS is a secondary MCL, set for aesthetic and taste standards and is not based on toxicity or carcinogenic effects in humans. For this reason, TDS is not considered a COC and was not carried forward into the FS.

For the metals, only arsenic, iron, and manganese were retained for further evaluation in the FS. Zinc exceeded the CUL in only 1 percent of the RI samples, all from EW-9. Because dissolved zinc has not been observed at any other locations in the EPZ area and because its frequency of exceedance is so low and limited to a single location, it was not retained as a COC for the FS.

For the VOCs, chloroform; cis-1,2-DCE; methylene chloride; and TCE were detected above CULs only once. Methylene chloride is also a known common laboratory contaminant and detections of this compound are suspect. Because of the isolated nature of the CUL exceedances, and the suspect nature of methylene chloride, these VOCs were not retained as COCs for the FS.

Of the regional groundwater detections, only total and dissolved arsenic, iron, and manganese were detected at concentrations exceeding CULs.

The COCs with more than one CUL exceedance retained for the FS are:

- Dissolved metals—Arsenic, iron, and manganese;
- Total metals[3]—Arsenic; and
- VOCs—Vinyl chloride.

7.1.1.2 Sample Collection Technology Comparison

A component of the RI included a comparative evaluation of groundwater sampling technology. Perched groundwater samples were collected from selected wells using traditional low-flow sampling methodology, PDB samplers, and RPP samplers. The theory behind PDB and RPP samplers is that they rely on free movement of the groundwater through the sampler and passively collect the groundwater sample. VOCs and metals diffuse across the passive sampler until the concentrations within the sampler equilibrates with concentrations in the surrounding groundwater system. Passive samplers offer the advantages of limited disturbance to the surrounding groundwater system, the absence of purge water for disposal after the event, time efficiency, and cost efficiency. Conventional low-flow samples were also collected from wells where PDB and RPP samplers were deployed during the RI. The low-flow samples were analyzed for the standard list of RI analytes. The PDB samples were analyzed for VOCs analysis and the RPP samples were analyzed for dissolved metals.

The comparison of low-flow and PDB results is presented in Table 7.2, and the comparison of low-flow and RPP results is presented in Table 7.3. For each parameter detected, these tables present the difference in concentration, the percent difference from the low-flow sample result, and the overall average difference for each sample. For 21 of 29 of the VOCs detected in PDB samples, concentrations were higher than those in the low-flow samples. The analyte-specific average difference in concentration between the two methods ranged from 0 μg/L (no difference) to 0.32 μg/L, and the average percent difference ranged from -45 percent to 500 percent.

For the 44 detections of dissolved metals, concentrations in the RPP samples were less than those in the low-flow samples, on average by 10 to 14 percent, depending on the analyte. The average difference in

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[3] Total iron and total manganese were eliminated as COCs because they are not required analytes per criteria for municipal solid waste landfills at 173-351 WAC.

concentration ranged from 0.04 mg/L to 2.18 mg/L. When the RPP sample concentrations were higher, however, the average increase was 31 to 46 percent.

In terms of ease of deployment, the PDBs were very easy to deploy at the targeted screened interval but the RPPs were not. The RPP samplers are deployed one atop the next; the sheer number of RPP samplers required to collect an adequate volume of groundwater for analysis spanned the entire length of the saturated part of the screen. The RPP groundwater samples collected thus represented the entire screened interval instead of a targeted depth. Furthermore, only the laboratory's minimum sample volume could be achieved.

In conclusion, PDBs appear adequate for collection of samples for VOC analyses, with data of sufficient quality for routine monitoring; however, this method may not be appropriate for closure monitoring. RPPs do not seem to be a viable option for metals sampling at the EPZ area: it is difficult to obtain adequate sample volume and, because of the length of the sample string across the screened interval, to obtain representative sample material.

7.1.2 Surface Water

Parameters analyzed and detected in surface water samples during the RI are tallied in Appendix D, Table D5. The stream at SW-E1 was dry from May through October 2015 (for half of the RI sample events), so samples collected by KCSWD were included in this evaluation to bolster the dataset. Table 7.4 presents summarizes the data, presenting the number of detections; frequency of detection; maximum, minimum, and average detected concentrations; and a comparison to CULs. Thirty-two conventional groundwater parameters, field parameters, and total and dissolved metals were detected in more than one in surface water sample, although none exceeded its respective CUL. VOCs were not detected in any of the surface water samples. Therefore, surface water is not carried forward as a medium of concern in this RI.

7.1.3 Soil Gas

Appendix D, Tables D7 and D8 present the shallow and deep soil gas data organized by sampling location. The data are then further distilled in Appendix D, Tables D9 and D10 to show the minimum, maximum, and average detected concentrations, and detection frequency. The number of VOCs detected in two or more locations is 26 for shallow soil gas sampling locations and 20 for deep soil gas sampling locations. With a few exceptions, the VOCs detected in deep soil gas were also detected in shallow soil gas samples. Table 7.5 summarizes the comparison to the most conservative CULs (if available) for each parameter. Naphthalene exceeded its CUL in both shallow and deep soil gas sampling locations, while chloroform exceeded its CULs in one shallow soil gas location during the initial sample event (July 2015).

All of the detected naphthalene concentrations in the shallow and deep soil gas samples during the first sampling event were similar, ranging only between 4.81 micrograms per cubic meter (µg/m^3) and 10.1 µg/m^3; the limited range of concentrations makes these findings suspect. However, the absence of naphthalene in the gas sample from one well casts doubt on the possibility of laboratory cross-contamination. The suspect nature of the naphthalene detections triggered further investigation into the potential for cross-contamination or other analytical error. A formal data validation was conducted, the chromatographs were reviewed, the laboratory (Fremont Analytical) reviewed all its internal QA/QC, and laboratory reanalyzed samples with remaining volume. With no indications that the data were false or that cross-contamination had been introduced, the naphthalene results were determined to be valid.

Nevertheless, a second soil gas sampling event was conducted in May 2016 at the same soil gas sampling locations. The samples were analyzed using a different analytical method (EPA Method TO-17) better suited for naphthalene detection. The soil gas samples from the latter event were analyzed at Eurofins laboratory. None of the naphthalene detections could be replicated.

The highly variable nature of soil gas monitoring, and the effects of LFG migration and barometric pressure drops have been demonstrated at this and other landfill sites. However, at this time it is unclear whether the inability to replicate the naphthalene results was due to barometric or LFG conditions at the time of sampling, or to some other variable. Because of this uncertainty, soil gas is carried forward into the FS as a potentially impacted medium. If the naphthalene detections in soil gas reflected actual conditions, they may have resulted from LFG migration.

As mentioned in Section 3.2.7, which describes discussing deviations from the RI Work Plan, the gas probes nearest to Passage Point could not be located, and thus the RI is lacking soil gas data close to the facility. The issues raised during the soil gas investigation are discussed further in Section 8.5 (Remedial Investigation Conclusions).

7.1.3.1 Soil Gas COC Selection

The only compound carried forward to the FS for soil gas is naphthalene, a compound that had not been listed as a COPC because it had not been included as an analyte during previous investigations.[4] None of the COPCs identified in the Work Plan (Aspect, 2015) were detected in soil gas during the RI at concentrations exceeding Ecology vapor intrusion screening levels (SLs) presented in the revised draft *Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Action* (Ecology, 2016a).

7.1.4 Leachate

All leachate data are presented in Appendix D, Table D6, organized by sampling location, and a summary is presented in Table 7.6. Leachate data for manhole MH-17N are limited: the location was dry during the first two RI sampling events, and it is not routinely sampled by KCSWD. Compounds detected in more than one leachate sample included conventional parameters, 13 total metals, and 8 VOCs.

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[4] A regulatory screening level for naphthalene was not available until 2015, when Ecology reevaluated vapor intrusion screening values and established a cancer potency factor for naphthalene.

Unlike groundwater, surface water, and soil gas, leachate does not have promulgated CULs. Instead, constituents detected in leachate are evaluated qualitatively to see if they are also detected in groundwater in Section 8.2. Of the metals, VOCs, and conventional parameters detected in leachate during the RI, constituents with a detection frequency greater than 50 percent include barium, calcium, cobalt, copper, iron, magnesium, manganese, nickel, potassium, selenium, sodium, zinc, and VOCs (toluene; 1,4-dichlorobenzene; 2-butanone; acetone; chloromethane; ethylbenzene; xylene; and VC).

7.1.5 Reporting Detection Limits and CULs

The second part of the preliminary screening evaluation is comparing CULs to laboratory reporting detection limits (RDLs). For groundwater, none of the CULs are below RDLs. For surface water, the CULs for cadmium, iron, and lead are below the corresponding RDLs, in most of these cases, by an order of magnitude. None of these metals were detected in surface water above the RDL during the RI sampling events.

For soil gas, SLs are below RDLs for 1,1,2,2-tetrachloroethane; 1,2-dibromoethane; 1,3-butadiene; acrolein; benzyl chloride; bromodichloromethane; chlorodibromomethane; hexachlorobutadiene; and naphthalene. Of these compounds, only naphthalene was detected at concentrations above the RDLs and was, therefore, carried forward in the FS evaluation. As with groundwater, MTCA allows for the CUL to be replaced by the RDL when the CUL is not practically achievable. The remaining VOCs were not carried forward in the FS.

Table 7.7 lists the final COCs for the EPZ area carried forward in the FS.

7.2 Groundwater Quality

This section describes the nature and extent of impacted perched groundwater in the EPZ area. This discussion also evaluates water quality parameters that, while not identified as COCs, represent landfill-related variables indicating impacts other than CUL exceedances. The combined set of parameters includes:

- Alkalinity—A measurement of the ability of water to neutralize (buffer) an acid. Alkalinity in groundwater above background levels can indicate landfill-related impacts. Bicarbonate alkalinity in groundwater can form from dissolution of carbonate and silicate minerals from aquifer material by dissolved carbon dioxide gas (carbonic acid) from either landfill leachate or LFG.
- Chloride—A naturally occurring, conservative ion that is also found in landfill leachate. As a conservative ion, dissolved chloride concentrations remain relatively unchanged by natural chemical processes in groundwater (except for mixing).[5] More typically present in landfill leachate,

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[5] In contrast, non-conservative ions change concentrations as the result of natural chemical processes such as water-rock interactions.

chloride is not a significant component of LFG and thus not indicative of LFG impacts. Chloride in groundwater above background levels could originate from landfill leachate.

- Sulfate—An ion that occurs naturally and in landfill leachate. Under adequate reducing (anaerobic) conditions, such as those typical of a landfill environment, sulfate is converted to hydrogen sulfide. Dissolved methane gas in groundwater also causes chemically reducing conditions under which sulfate is converted to hydrogen sulfide. Concentrations of sulfate in groundwater above background levels can indicate whether reducing conditions are occurring.
- Methane—Naturally occurring methane results under reducing conditions. At landfills, where a large percent of LFG by volume is methane, methane that contacts groundwater may dissolve into the aqueous medium. To the extent that LFG mobilizes other COCs, the presence of elevated concentrations of dissolved methane in groundwater indicates potential impacts by other COCs.
- Iron and manganese—Naturally occurring, nonconservative metals in groundwater that also occur at elevated concentrations in landfill leachate. Because of their nonconservative nature, dissolved iron and manganese are common when geochemical processes (water-rock interactions) cause reducing groundwater conditions. Conversely, in oxidized groundwater, iron and manganese form hydroxide (rust-like) mineral grain coatings. The concentrations of these metals relative to background values helps reveal whether groundwater is undergoing geochemical changes.
- Arsenic—Naturally occurring, nonconservative metal in groundwater that has been detected above the CULs in both upgradient and downgradient monitoring wells at CHRLF. Arsenic mobility in groundwater is enhanced by alkaline pH and by moderately reducing conditions. The concentration of arsenic relative to background helps reveal whether groundwater is undergoing geochemical changes.
- Tetrachloroethylene (PCE), TCE, cis-1,2 DCE, and VC—Chlorinated VOCs of anthropogenic in origin that occur in both landfill leachate and LFG. They are commonly present in LFG because of their high vapor pressure and low solubility. These compounds are collectively referred to in this report as chlorinated VOCs.

7.2.1 East Perched Zone Groundwater

Figures 7.1 through 7.6 and 7.10 provide supporting groundwater quality information and depict the extent of impacted groundwater, localized near the base of refuse. The extent figures were developed using the maximum concentration of each COC detected in samples analyzed for the RI at each EPZ area monitoring well. At wells depicted in red, at least one COC was detected at a concentration exceeding its CUL. At wells depicted in orange, COCs were detected, but at concentrations below CULs. At wells depicted in green, COCs were not detected during the RI. The localized nature of the impacted groundwater is illustrated on Figures 7.1 through 7.6 and 7.10. Groundwater results from stratified drift wells representing the NESPZ indicate this groundwater is not impacted by the landfill. The SSPZ is characterized by a very small area of impacted groundwater around EW-6. Most of the impacts groundwater is found in the shallow glacial till/glacio-lacustrine units that comprise the ESPZ; even there, the impact is limited to the area along the base of the Main Hill refuse.

The following subsections present a focused description of the extent of contamination for each class of COCs. Table 7.8 presents a summary of the monitoring well evaluation and identifies exceedances and statistical trends (if available) to aid the discussion and evaluation of the extent figures.

7.2.1.1 Conventional Parameters

Nitrate exceeded its CUL only in EW-13 and only on a single occasion and is not a COC. TDS had a CUL exceedance frequency of 12 percent, with exceedances in MW-47, EW-6, EW-14, EW-16, and EW-19, as indicated in Appendix D, Table D1. The wells where conventional parameters exceeded their respective CULs were isolated to the SSPZ near EW-6 and the extraction wells in the ESPZ along the Main Hill eastern refuse boundary. However, the CUL for TDS is a secondary MCL set for aesthetic purposes and is not a calculated value based on toxicity or carcinogenicity. As such, TDS and nitrate were not retained as a COCs for the FS. However, TDS can be a general indicator of the presence of dissolved ions. Conventional water quality parameters, such as alkalinity and chloride, and ions calcium and magnesium can also be used to support the evaluation of groundwater for potential LFG and leachate impacts, regardless of CULs.

Elevated alkalinity is a common indicator of LFG effects in groundwater (Kerfoot et al., 2004). LFG increases alkalinity when carbonic acid dissolves calcium- and magnesium-containing minerals and thus increases the bicarbonate concentration (alkalinity) in groundwater. Increases in calcium and magnesium, as well as alkalinity, are considered to be a result of LFG.

Alkalinity is also present in landfill leachate but the two alkalinity sources can be distinguished because leachate alkalinity co-occurs with chloride and LFG alkalinity does not. Figure 7.1 depicts the maximum alkalinity and chloride concentrations observed in EPZ area wells during the RI. Alkalinity greater than 100 mg/L was observed in nearly all groundwater extraction wells (EW series wells), MW-47, MW-50, and MW-103; at these same wells, chloride concentrations were relatively low (generally less than 10 mg/L). In contrast, the wells determined to be unimpacted by the landfill leachate (EB-1, EB-2, and MW-29, as noted in Section 3.2.7 discussing deviations from the Work Plan) had alkalinity concentrations between 13 mg/L and 47 mg/L and chloride concentrations less than 10 mg/L. This indicates that groundwater in the vicinity of the extraction wells is influenced by LFG, which is causing an increase in alkalinity, but not an increase in chloride. The exception to this pattern occurs at EW-6 and EW-7 where higher chloride concentrations (up to 51 mg/L) indicate a possible slight leachate impact in this area.

Appendix E presents concentration plots for alkalinity and chloride for the EPZ area wells (EB-6D, MW-30A, MW-47, and MW-62) with historical groundwater results. Trends in alkalinity concentration over time are notably different for MW-30A, MW-47, and MW-62. In MW-30A, alkalinity increased until about 2013, at which time the concentrations began declining. In contrast, MW-47 alkalinity concentrations are steadily increasing, while MW-62 alkalinity concentrations appear to cycle seasonally between 40 mg/L and 100 mg/L.

Calcium and magnesium concentrations provide additional evidence that LFG has influenced groundwater in the vicinity of the extraction wells. Calcium and magnesium concentrations observed at EW-13 through EW-29 (average of more than 40,000 μg/L) are an order of magnitude higher than those observed at the unimpacted, apparent background wells EB-1, EB-2, and MW-29 (average of 5,800 μg/L calcium and 1,283 μg/L magnesium), thus demonstrating the effect of LFG on carbonic acid dissolution of calcium- and magnesium-containing minerals. These findings are consistent with a MSW landfill case study by Kerfoot et al. (2004), who noted that groundwater concentrations of alkalinity, calcium, and magnesium increased proportionately with the carbon dioxide content of the LFG.

7.2.1.2 Metals

Figure 7.3 depicts the maximum extent of dissolved metal COCs in shallow perched groundwater. Dissolved arsenic exceeded the CUL in 8 percent of the RI samples, representing 12 wells distributed widely across the EPZ area. Arsenic was not detected in the apparent background wells MW-29, EB-1, and EB 2, indicating that elevated arsenic concentrations observed in other wells downgradient of the Main Hill result from geochemical changes to groundwater caused by landfill processes. Specifically, arsenic (among other metals such as barium, iron, and manganese) occur naturally in soil, and their occurrence in groundwater can depend on local groundwater oxidation-reduction (redox) conditions.[6] For example, the highest arsenic concentrations were detected in wells where dissolved oxygen was less than 1 mg/L. Arsenic was retained as a COC for the FS.

Mann-Kendall and Theil-Sen statistical trend tests were conducted using the ProUCL statistical program (EPA, 2013) on the last 10 years of arsenic data from EB-6D, MW-30A, and MW-47. The tests indicated insufficient evidence for statistical trends in EB-6D and MW-30A, and a statistically significant decreasing trend in MW-47. Appendix E presents arsenic statistical trend plots for these wells.

Dissolved iron and manganese exceeded CULs in 16 percent and 23 percent of the RI samples, respectively. Iron and manganese are routinely measured in groundwater at landfills because they are often leached from soils by the anaerobic (reduced) groundwater produced during landfill refuse decay. In general, iron and manganese concentrations in the wells located downgradient of the Main Hill within the EPZ area were 2 to 3 orders of magnitude greater than those at EB-1, EB-2, and MW-29.

Although iron and manganese were retained as COCs for the FS, they are COCs of low concern as their elevated nature is indicative of geochemical changes resulting from LFG effects. Once the selected remedy

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[6] Although not directly sensitive to redox, arsenic and barium are strongly adsorbed to iron oxides and oxyhydroxides or manganese oxides and can be released under reducing conditions.

is in place and the geochemistry of the perched zones is modified, these “co-located” COCs can be expected to fall to below CULs.

Appendix E presents concentration plots for arsenic, iron, and manganese for the EPZ wells (EB-6D, MW-30A, MW-47, and MW-62) with historical groundwater results. Of note are the dissolved metals trend plots for EB-6D and MW-47. Arsenic levels for EB-6D are erratic and often above the CUL, while iron and manganese, although above CULs, appear to exhibit declining trends. In contrast, arsenic levels for MW-47 are largely below the CUL and appear to display a decreasing trend, while iron and manganese display increasing trends. As the landfill continues to age, methane production decreases and groundwater slowly becomes less anaerobic, the iron and manganese concentrations will continue to decline, as has been the case in EB-6D, MW-30A, and MW-62 since the installation of landfill infrastructure (Appendix E Figures E1, E2, and E4). Kerfoot et al. (2004) also suggest that increases in manganese concentrations can be attributed to the ability of methane in LFG to reduce manganese IV to soluble manganese II.

MTCA allows CULs for metals to be adjusted to site-specific background concentrations (173-340-700 through 173-340-750 WAC). However, because the localized perched groundwater of the EPZ is downgradient from the Main Hill landfill area, reasonably close upgradient monitoring wells would be located within the landfill refuse boundary and thus not representative of local background conditions. The most viable wells within the EPZ area that could function as site-specific background are EB-1, EB-2, and MW-29, located on the north end of the NESPZ. Of the COCs detected in groundwater in the NESPZ, only iron and manganese have been detected in EB-1, EB-2, and MW-29. Maximum dissolved concentrations at these wells ranged from 12 µg/L to 40 µg/L for iron, and from 3.18 µg/L to 11 µg/L for manganese. These concentrations are 2 to 3 orders of magnitude below the maximum concentrations detected in impacted EPZ wells. Arsenic was not detected in these wells, and thus, background concentrations would be considered below the laboratory RDL.

7.2.1.3 Volatile Organic Compounds

VOCs exceeding CULs in the EPZ area were chloroform, cis-1,2-DCE, methylene chloride, TCE, and VC; however, only VC had more than one CUL exceedance. VC is the only VOC retained as a COC for the FS, having 26 exceedances (or 17 percent frequency) during the RI. VC was the primary COC that triggered the MTCA process at the CHRLF EPZ area (exceedance of MSW landfill regulatory criteria at MW-47). Current conditions depicted on Figure 7.5 indicate that VC also exceeds its CUL in the SSPZ near EW-6 and EW-7, and in the ESPZ from EW-14 at the north end to EW-29 at the south end. The highest concentrations were found at MW-47 and EW-14. Figure 7.5 also shows that VOCs, including VC, were not detected in horizontally downgradient wells (MW-102, MW-103, MW-104, and EB-6D) in the ESPZ. This indicates that the VC contamination in the ESPZ attenuates before reaching horizontally downgradient wells, and is localized to the area of the ESPZ adjacent to the Main Hill refuse boundary.

Appendix E presents concentration plots for selected VOCs for the EPZ area wells (EB-6D, MW-30A, MW-47, and MW-62); a long historical data record is available for these wells. EB-6D has been non-detect for

VOCs since groundwater sampling began, except for benzene, which was detected at concentrations well below CULs in 1994–1995. MW-30A historically presented with elevated concentrations of all VOCs, all of which have now attenuated to below CUL or non-detect concentrations. MW-47 remains the most contaminated well in the EPZ area. The MW-47 correlation plots presented in Appendix E depict increasing concentrations of cis-1,2-DCE (albeit at concentrations below CULs), overall decreasing concentrations of VC above the CUL, non-detect TCE, increasing concentrations of 1,1-dichloroethane, and sporadic occasional benzene and 1,2-dichloroethane concentrations below CULs.

Mann-Kendall and Theil-Sen statistical trend tests were conducted using the ProUCL statistical program on the VC data from MW-47. The tests indicate a statistically significant decreasing trend for the full dataset (1992 to 2016), with a Theil-Sen slope of -0.0506 but a statistically significant increasing trend for the last 10 years (2006 to 2016), with a Theil-Sen slope of 0.0347 at 5 percent significance. The statistical trend graphs generated by the program for MW-47 are also presented in Appendix E.

The correlation plots for MW-62 are presented in Appendix E. They indicate that 1,1-dichloroethane is the only VOC consistently detected in this monitoring well in the last 5 years, and that concentrations have clearly been attenuating over time.

Figure 7.7 depicts the relationships between geochemical parameters alkalinity, calcium, magnesium, and chloride, and total VOCs as evidence of the relationship between LFG influence and VOCs. Figure 7.7 was developed using the RI data (June 2015 through March 2016) for perched wells within the EPZ area. EW-7 had an anomalously high total VOC concentration (driven by a single high chloroform detection) and was omitted from this evaluation. Kerfoot et al. (2004) observed the positive correlation between increasing alkalinity, calcium, and magnesium concentrations and total VOC concentrations in groundwater at a landfill impacted by LFG, and also noted no relationship between chloride and total VOC concentrations. Figure 7.7 generally confirms a small positive relationship between total VOC concentrations and alkalinity, calcium, and magnesium, while also verifying the absence of correlation between total VOC concentrations and chloride.

7.2.1.4 Extent of East Perched Zone Groundwater Impacts

The extent of groundwater impacts in the EPZ area is depicted on Figure 7.10, and Table 7.8 presents a summary of EPZ-impacted groundwater by well. The extent of EPZ area groundwater impacts depicted in Figure 7.10 is defined by the presence of dissolved metals and VC in groundwater at concentrations above CULs. Specifically, there are two distinct areas of dissolved metals impacts:

- Stratified drift—SSPZ bound by EW-07 to the north, EW-10 to the south, and EB-6D to the east; and
- Glacial till/glacio-lacustrine units—ESPZ bound by MW-47 to the north, MW-50 to the south, and MW-103 and MW-104 to the east.

The areal extent of dissolved metals impacts in the EPZ area likely results from the wider distribution of reducing groundwater conditions in the SSPZ and ESPZ. The vertical extent of dissolved metals in the EPZ area remains predominantly within the shallow glacial till/glacio-lacustrine units within the ESPZ; however, one pocket of dissolved metals contamination occurs in the deeper stratified drift zone t in the SSPZ, as depicted on Figure 7.10

There are also two distinct areas of VC water quality impacts, with some overlap with the areas of dissolved metals-impacted groundwater:

- Stratified drift - SSPZ around EW-6; and
- Glacial till/glacio-lacustrine units - ESPZ bound by MW-47 to the north and EW-29 to the south.

The areal extent of VC EPZ area impacts is much smaller than that of dissolved metals contamination, with the VC contamination limited to the vicinity of the groundwater extraction wells along the Main Hill refuse boundary. The vertical extent of VC impact is largely limited to the shallow glacial till/glacio-lacustrine units, while only with one very limited area of deeper stratified drift impact at EW-06. The VC impacted groundwater is thus predominantly limited to the shallow low-permeability soils. The extent of impacted perched groundwater in the EPZ area depicted on Figure 7.10, and was utilized in the FS to calculate impaired groundwater volumes and cost estimates to evaluate remedial alternatives.

7.2.2 Regional Aquifer Water Quality

Defining the vertical extent of hazardous substances is required by MTCA under 173-340-350(7)(c)(iii)(G) WAC. Regional Aquifer groundwater data were analyzed to evaluate the vertical extent of COC exceedances in the EPZ area. Appendix D, Table D2 presents all groundwater results for Regional Aquifer wells within the EPZ area; Table D4 summarizes the frequency of detections in the Regional Aquifer for each parameter, and includes maximum, minimum, and average concentrations. Table 7.1 presents a frequency and detection summary of the COCs in comparison to CULs. Figures 7.2, 7.4, and 7.6 provide supporting Regional Aquifer groundwater quality information, and depict the extent of groundwater impacts. The extent figures were developed using the maximum concentration of each COC detected at each Regional Aquifer monitoring well within the EPZ area sampled between 2015 and 2016 by KCSWD. At wells depicted in red, at least one COC was detected at a concentration exceeding its respective CUL. At wells depicted in orange COCs were detected but at concentrations below CULs. At wells depicted in green COCs were not detected during the RI time period. The following subsections present a description of the extent of contamination for each class of COC.

7.2.2.1 Conventional Parameters

There were no conventional parameter CUL exceedances in the Regional Aquifer. Maximum alkalinity and chloride concentrations are depicted on Figure 7.2. Alkalinity and chloride concentrations in Regional Aquifer groundwater are relatively consistent. The range of maximum alkalinity concentrations in the

Regional Aquifer (49 mg/L to 132 mg/L) is smaller than that in the EPZ area shallow groundwater (13.7 mg/L to 697 mg/L). As discussed in the *Regional Aquifer Technical Memorandum* (Aspect, 2011), background alkalinity of 50 to 60 mg/L is shown by the northwestern landfill upgradient monitoring wells MW-84 and MW-73 (56 mg/L, median 2009 values) and south landfill upgradient monitoring wells MW-83 and MW-76 (62 and 46 mg/L, median 2009 values). Alkalinity is about twice background levels in the EPZ area Regional Aquifer monitoring wells MW-67, MW-68, and MW-93 (Figure 7.2). In the other Regional Aquifer monitoring wells sampled during the RI, maximum alkalinity concentrations were at or slightly above the background alkalinity concentrations. The elevated concentrations of alkalinity in selected EPZ area Regional Aquifer monitoring wells may be an indication of fugitive LFG (Aspect, 2011).

Chloride concentrations in the Regional Aquifer were less than 10 mg/L, and generally consistent with the concentrations detected in the EPZ area shallow groundwater (with the exception of EW-6 and EW-7).

7.2.2.2 Metals

Figure 7.4 depicts the maximum extent of metals COCs in the Regional Aquifer. Only dissolved arsenic, was detected in Regional Aquifer wells at concentrations exceeding the CUL.

Redox conditions also affect water quality, as reducing or oxidizing conditions can mobilize naturally occurring metals. Redox conditions can explain natural occurrences of metals, such as arsenic, iron, and manganese, but can also be affected by LFG and leachate. Data for selected metals detected in some areas of the CHRLF at elevated concentrations, were analyzed to understand the relative effects of naturally occurring and landfill-induced redox conditions on the distribution and trends in iron, manganese, arsenic, and sulfate.

Under regulatory criteria for MSW landfills (173-351-410 WAC), the CHRLF facility must establish background conditions in hydraulically upgradient monitoring wells or other wells that represent background water quality. Regional Aquifer metals background was evaluated in historical reports such as the *Regional Aquifer Technical Memorandum* (Aspect, 2011). Groundwater quality in upgradient CHRLF Regional Aquifer monitoring wells has been impacted by the Queen City Farms Superfund Site, confounding comparison of water quality trends in upgradient and downgradient monitoring wells for the south half of the CHRLF. The flow path analysis provided in the *Regional Aquifer Technical Memorandum* (Aspect, 2011) identifies monitoring wells MW-84 and MW-73, in the northwest landfill area, as additional upgradient water sources for groundwater beneath the northern area of the landfill property. However, these background wells are not located within the EPZ area.

Arsenic concentrations throughout the Regional Aquifer are low, largely undetected in most monitoring wells (Aspect, 2011). Where detected, the arsenic concentrations and pattern of distribution suggest that it falls within naturally occurring background levels. Historically, the highest arsenic concentrations were found in upgradient monitoring well MW-64 (located just south of the EPZ area) and MW-99. Within the new data collected during the RI, dissolved arsenic at MW-68 (maximum of 22.7 μg/L) exceeded the CUL of 5 µg/L. A Mann-Kendall statistical trend analysis conducted for arsenic in MW-68 for the entire dataset available for that well (late 1999 through 2016) indicates a statistically significant increasing trend. The graphical output and results of that analysis are presented in Appendix E.

Dissolved arsenic from MW-80 (5.77 µg/L) and MW-91 (7.46 µg/L) was also slightly elevated above the Washington State natural background level and CUL of 5 µg/L. However, these concentrations are well within the ambient groundwater quality in the Issaquah Creek Valley Groundwater Management Area, whose documented arsenic concentrations range as high as to 9.8 µg/L (King County Ambient Groundwater Monitoring Program, 2005), and are considered to be within the range of regional background. Therefore, MW-68 is the only Regional Aquifer well within the EPZ area with dissolved arsenic at concentrations above the CUL and regional background level. Monitoring well MW-80 is located downgradient of and along a groundwater flow path from MW-68. The decrease in dissolved arsenic concentrations between MW-68 and MW-80 indicates significant attenuation along the flow path.

No other dissolved metals exceeded CULs in the Regional Aquifer. Only total iron exceeded CULs in the Regional Aquifer monitoring wells within the EPZ area evaluated during the RI period. As noted in the *Regional Aquifer Technical Memorandum* (Aspect, 2011), elevated iron and manganese are not unexpected in the shallower portions of the Regional Aquifer locally impacted by LFG or leachate. As groundwater in the Regional Aquifer flows northward and laterally beneath the landfill, it appears there are local areas of elevated total iron concentrations. Iron may be brought into solution by methane-induced reducing groundwater conditions and more-limited recharge beneath some portions of the landfill.

There is no evidence that the arsenic detected in MW-68 is due to vertical migration of groundwater from the EPZ. In particular, for monitoring wells located along intersecting groundwater flow paths from beneath the unlined Main Hill, it is asserted that the elevated metals and reducing conditions are the result of LFG impacts. As groundwater migrates northward to monitoring well MW-68, its chemistry is affected by LFG interactions as expressed by the increase in alkalinity. Iron and manganese are reduced by LFG-related effects; hence dissolved concentrations of these metals are slightly more elevated at MW-68. The reducing condition also contributes to dissolution of naturally occurring sulfate minerals. Monitoring well MW-93, located upgradient of MW-68, has shown elevated and increasing sulfate trends in recent years. Monitoring well MW-93 is inferred to have iron-reducing, but not sulfate-reducing, geochemical conditions. Naturally occurring sulfur-bearing minerals are brought into solution by anoxic groundwater created by LFG, and are converted to sulfate where weaker reducing conditions occurred, such as at monitoring well MW-93. In contrast, at monitoring well MW-68, the LFG impact is greater (as inferred by elevated alkalinity and iron), and the stronger reducing conditions lead to lower sulfate concentrations.

Groundwater from a large area of the CHRLF facility converges near monitoring well MW-80, located downgradient from monitoring well MW-68 and within the EPZ area. Landfill gas impacts (lower alkalinity, iron, and manganese) are diminished compared to monitoring well MW-68, as groundwater converges and mixes within this well's water quality detection zone. The groundwater is still a calcium-magnesium bicarbonate type, but sulfate concentrations have increased relative to those at MW-68 likely because weaker reducing conditions allow sulfide to convert to sulfate.

Despite total iron concentrations above its CUL in certain Regional Aquifer wells within the EPZ area, dissolved iron did not exceed its CUL. Because the Regional Aquifer located below the CHRLF has been impacted by the upgradient Queen City Farms Superfund Site, and because dissolved iron was not detected above its CULs, iron was not retained as COC for the Regional Aquifer for evaluation in the FS.

7.2.2.3 Volatile Organic Compounds

No VOCs were detected in Regional Aquifer monitoring wells within the EPZ area. Figure 7.6 depicts the extent of nondetect results for VOCs reported for the RI time period.

7.2.2.4 Extent of Regional Aquifer Groundwater Impact

The only location within the Regional Aquifer in the EPZ area with impaired groundwater quality results from elevated dissolved arsenic levels is at MW-68. Arsenic was therefore carried forward for evaluation in the FS.

7.2.3 Geochemical Conditions and Natural Attenuation

Natural attenuation processes (biodegradation, mineralization, dispersion, sorption, volatilization, and stabilization) reduce the mass, toxicity, mobility, volume, or concentration of contaminants. These processes are controlled by the biogeochemical character of the groundwater system and its constituents. This characteristic is assessed through the monitoring of selected physical and chemical parameters, which define the geochemical potential of the groundwater system and its ability to promote natural attenuation of COCs. Geochemical and natural attenuation monitoring is used to assess the following:

- Whether the groundwater is aerobic or anaerobic;
- The presence of anaerobic biological/microbial activity, and whether this activity is dissolving metals from the groundwater system matrix material;
- The stages of anaerobic degradation processes;
- Whether samples are collected from the same groundwater system;
- Whether chlorinated VOC reduction is occurring;
- Whether chlorinated VOCs are undergoing biological transformation; and
- Whether organic carbon is available in the groundwater system (excluding anthropogenic carbon) for reductive dechlorination.

Parameters to assess natural attenuation of COCs were measured in groundwater monitoring wells during the RI. The evaluation of natural attenuation as a potential remedial alternative was undertaken to support the FS in determining the viability of MNA as a remedial alternative for the EPZ area. The parameters presented in the following table were analyzed in the field or by the laboratory; results are summarized. in Appendix D.

Parameter	Primary Use
Alkalinity	Alkalinity measures the buffering capacity of groundwater. Elevated alkalinity downgradient of a landfill often indicates that leachate or LFG is entering the groundwater system.
Aromatic and chlorinated hydrocarbons	Primary target analytes for MNA
Arsenic	Determine if anaerobic activity is solubilizing arsenic from groundwater system formation.
Chloride	Final product of chlorinated solvent reduction. Also primary water quality parameter. Elevated chloride downgradient of a landfill often indicates that leachate is entering the groundwater system.
Dissolved oxygen	Direct field measurements of dissolved oxygen concentrations. Concentrations less than 1 mg/L indicate anaerobic conditions.
Iron II	Iron state that confirms effective reducing conditions due to depletion of oxygen, nitrate, and manganese.
Manganese	Presence of dissolved manganese confirms effective reducing conditions, solubilizing manganese from the groundwater system formation.
Methane, ethane, and ethene	Presence of these dissolved gases in groundwater indicates whether LFG is entering the groundwater system. The presence of ethene is also used to indicate that VC is degrading via biological transformations. The presence of methane can also suggest degradation of benzene, toluene, ethylbenzene, and xylenes (BTEX) via methanogenesis.
Nitrate/nitrite	Redox couple that confirms the effective reducing conditions in a landfill; nitrate can act as an electron donor/substrate for microbial respiration under depleted oxygen conditions.
Oxidation reduction potential (ORP)	Groundwater parameter with influential relationship on biologically mediated degradation of contaminants.
pH	pH needs to be near neutral for critical attenuation processes. Aerobic and anaerobic processes are pH-sensitive.
Sulfate/sulfide	Redox couple that confirms the effective reducing conditions in the groundwater system; sulfate is an effective electron donor for reductive dechlorination of chlorinated VOCs; sulfide precipitates iron, manganese, and arsenic.
Total organic carbon	To determine if reductive dechlorination is possible in the absence of anthropogenic carbon.

Source: Adapted from EPA, 1998, “Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater”

The continued reductive dechlorination of VC is dependent on the geochemical parameter of redox potential, and most of the natural attenuation parameters in the table above are examples of redox-sensitive compounds, whose concentrations can be used to confirm the redox conditions in the groundwater system. These parameters are key to evaluating geochemical conditions that support the degradation process of reductive dechlorination of chlorinated VOCs and assess the mobility of metals in groundwater. The EPA developed numerical criteria for the parameters listed in the table above to evaluate whether conditions present in a groundwater system are favorable for reductive dechlorination. Table 7.9 presents a summary of the MNA evaluation conducted in accordance with the *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents* (EPA, 1998). As per the technical protocol, the evaluation was conducted on the portion of the EPZ area with the greatest impacts, which is in the ESPZ vicinity of MW-47 to the north down to EW-29 in the south. The results of the MNA evaluation offer strong evidence of anaerobic biodegradation (reductive dechlorination) of the groundwater, supporting other indications that natural attenuation processes are under way.

Reductive dechlorination is a primary element for degradation of chlorinated VOCs at landfills where high moisture content and methanogenic conditions favor rapid degradation. Through the reductive dechlorination process, PCE and TCE typically degrade to DCE isomers (cis- and trans-1,2-DCE) and then to VC. Natural attenuation of chlorinated VOCs by reductive dechlorination is already known to be occurring at the EPZ area based on the following observations:

- TCE and PCE are ubiquitous solvents with historical uses in household and commercial cleaning products and dry-cleaning processes. They are common constituents at municipal solid waste landfills and likely have been present in shallow groundwater in the EPZ area at elevated concentrations. However, TCE is now at concentrations less than its CUL and is no longer of concern, except for the concentrations detected at EW-25. PCE measured during the RI was detected infrequently and at concentrations below its CUL.
- DCE isomers and VC are specialized chemicals with no known industrial uses in western Washington. When present in western Washington groundwater , they originate from the degradation of TCE and PCE by reductive dechlorination. DCE isomers were found at concentrations less than CULs and are no longer a concern.
- VC also undergoes degradation by reductive dechlorination to form nontoxic ethene, which is present in shallow groundwater throughout the EPZ area (see Appendix D, Tables D1 and D3). The highest ethene concentrations were detected in the extraction wells with the highest VC concentrations, indicating that conditions are favorable for VC reductive dechlorination.

The multiple lines of evidence of active reductive dechlorination in the EPZ area provides strong support for MNA as a viable remedial alternative for groundwater, as discussed further in the FS.

7.3 Surface Water Quality

Table 7.4 presents the frequency of detection for constituents analyzed in surface water and compares the results to CULs. None of the surface water samples exceeded CULs. For this reason, surface water as a medium for contaminant migration was not carried forward in the FS.

7.4 Soil Gas Quality

Table 7.5 presents a summary of the CUL exceedances in shallow and deep soil gas samples. Both naphthalene and chloroform were detected above respective CULs in shallow soil gas samples during the first soil gas sampling event (July 2015), while only naphthalene was detected in deep soil gas samples above CULs, also during the first sampling event. None of the VOCs were detected above CULs during the second soil gas sampling event (May 2016). The naphthalene exceedances could not be replicated during the second sampling event.

The extent of VOCs and methane in soil gas is depicted in Figures 7.8 (shallow soil gas) and 7.9 (deep soil gas). As shown in Figure 7.8, naphthalene was detected in each of the shallow soil gas probes evaluated at concentrations above CULs during the first soil gas sampling event. These detections were widely distributed throughout the EPZ area near the base of refuse and also along the landfill property boundary. Methane was only detected using the multi-gas field instrument in two of the gas probes during the purge or at the time of sampling, which is also depicted on Figure 7.8. The probe with the highest naphthalene detection is located along the property boundary, while the probe with the highest methane concentration at the time of sample collection was GP-58, located in the EPZ where the most heavily impacted shallow groundwater is present.

7.5 Landfill Gas Extent

LFG periodically extends across and beneath the vadose zone within the EPZ area, based on monitoring results at gas probes. Figure 7.11 shows a plot of the methane concentration statistics observed at gas probes completed within the EPZ area with methane levels exceeding 5 percent from July 2010 through December 2013. This “box and whisker” plot shows the maximum, 90th percentile, average, 50th percentile, and minimum methane concentrations. Figures 7.12 and 7.13 present the extent of the maximum methane concentrations (as percent methane by volume) in gas probes, gas extraction wells, and groundwater extraction wells in the glacial till/glacio-lacustrine and stratified drift, respectively. Methane has been detected at concentrations greater than 5 percent by volume in native soil gas probes beyond the LFG collection system, indicating that LFG migration has occurred, and likely has the potential of occurring in the future if LFG collection is not optimized in the East Main Hill.

KCSWD has implemented corrective actions in order to address LFG migration at the landfill. A separate utility flare was installed to provide treatment of low-quality LFG and low-quality LFG from the East Main Hill

Header was redirected to this utility flare. In 2012 to improve LFG migration control in the EPZ, gas probe GP-57 was connected to the East Main Hill Header to actively collect LFG beyond the extent of refuse.

Review of the LFG East Header and Central Header operational data suggests additional improvements in LFG system operation and balancing could be made. A comparison of LFG collection objectives is illustrated in Appendix F, which presents Tables 6 and 7 from a recent LFG analysis (AECOM, 2015b). These tables list the LFG collector IDs and characteristic LFG conditions based on measurements made from January 2011 through November 2013, with the collector IDs color-coded to distinguish the LFG quality. For this comparison, methane and oxygen concentrations were color-coded according to Solid Waste Association of North America (SWANA) guidance (SWANA, 1997) for LFG collection depicting levels of migration control ranging from “relaxed” to “very aggressive.” Most LFG collection points in the Main Hill without a bottom liner were operated from mid-2010 through 2013 to provide “relaxed” to “moderate” LFG migration control.

To illustrate the potential changes in LFG conditions over time, average LFG concentrations for extraction wells connected to the East Header were calculated based on measurements made between July 2015 and June 2016 (Table 7.10). Similar to Table F-1, Table 7.10 shows LFG collector IDs and characteristic LFG conditions, with methane and oxygen concentrations color coded according to SWANA guidance for LFG collection for various levels of migration control. Based on this latter analysis of LFG collection measurements, the following observations are made:

- Eleven wells provided “relaxed” or “moderate” LFG migration control;
- Twenty-one wells provided “aggressive” or “very aggressive” LFG migration control;
- Twenty-nine wells appeared to be infeasible for LFG collection because of low methane concentration (less than 25 percent by volume) and high oxygen concentration (greater than 3 percent by volume); and
- Eleven wells exhibited both high methane and high oxygen concentrations, indicating possible leaks of atmospheric air into the conveyance piping between the wellhead and the monitoring point.

During a site visit in June 2016, it was noted that the productivity of several LFG collections wells along the East Header may be limited because of water blockages at low points along laterals (W. Grant, personal communication, October 28, 2016). These low points may have developed over time, due to differential settlement, cover modifications for stormwater control, or other reasons.

8.0 CONCEPTUAL SITE MODEL

The CSM for the EPZ area was developed from historical land use, existing environmental data, and the contaminant fate and transport processes that control the migration of COCs in the natural environment. A schematic representation of the CSM is presented on Figure 8.1. The schematic depicts the physical setting, nature and extent of contamination, and fate and transport processes. The following sections describe the components of the CSM and evaluate potential exposure pathways and receptors. The RI conclusions are presented at the end of this section.

8.1 Physical Conceptual Site Model

As discussed in Section 4.6, the EPZ is comprised of two zones of perched groundwater east of the landfill's Main Hill. Both zones are saturated areas of shallow groundwater of limited lateral and vertical extent.

8.1.1 East Shallow Perched Zone

- The ESPZ consists of low-permeability glacial till/glacio-lacustrine silt units that impede downward groundwater recharge, resulting in a laterally discontinuous area of year-round saturation. Recharge to these units occurs via infiltration of direct precipitation, infrequent and incidental spillage from overfilling of dust control tanker trucks, and seepage from adjacent wetlands.
- COC-impacted groundwater is predominantly limited to the shallow, low-permeability, glacial till/glacio-lacustrine units within the ESPZ. Migration of groundwater in the ESPZ, while very limited, is predominantly downward toward the thick unsaturated zone above the Regional Aquifer. The 280-foot-thick unsaturated zone above the Regional Aquifer, with its very low unsaturated hydraulic conductivity, acts as a buffer zone between the ESPZ groundwater and the Regional Aquifer. Groundwater quality within the Regional Aquifer is assessed by several monitoring wells downgradient of the ESPZ.
- Horizontal groundwater movement in the ESPZ is very slow (on the order of 1 to 2 feet/year) because of the low-permeability properties of the glacial till/glacio-lacustrine unit. Several seasonally dry extraction wells bordering the western side of the ESPZ indicate that saturated horizontal flow is limited. Thus, if any groundwater moves beyond the low-permeability glacial till/glacio-lacustrine unit, it would migrate into the underlying more permeable stratified drift. However, because of the thickness of the unsaturated zone and the relatively slow nature of unsaturated migration, the travel time for fluids to reach the Regional Aquifer is estimated at 159 years. This lengthy travel time through the unsaturated stratified drift is favorable for buffering and attenuation of any vertically migrating impacted groundwater.

8.1.2 Northeast Shallow Perched Zone (NESPZ)

- There is no impacted groundwater in the NESPZ.
- The NESPZ occurs in the vicinity of Stream 3. Perched water in this zone occurs within stratified drift, where downward infiltration is slowed by siltier, less permeable zones.

- There appears to be little hydraulic connection between the ESPZ and the NESPZ. The NESPZ is north of the ESPZ and the two areas are separated by a seasonally unsaturated zone (see Figure 1.3). Groundwater migrating from the higher-elevation ESPZ appears to migrate vertically downward. Some limited horizontal connection between the zones could occur at relatively shallow depths within more permeable layers of the glacial till; however, no impacted groundwater has been observed in the NESPZ.
- Surface water in Stream 3 is at a higher elevation than the perched water table and is in a losing condition during some parts of the year; during the wet season, high groundwater levels create a gaining condition in Stream 3. When a stream is in a losing condition, surface water contributes to groundwater. Under gaining conditions, groundwater contributes to surface water. No impacted water has been observed in Stream 3.

8.2 Contaminants and Sources Summary

The constituents detected in groundwater and soil gas in the EPZ area at concentrations exceeding CULs are metals (arsenic, iron, and manganese), and VOCs (naphthalene and vinyl chloride). Ultimately, the refuse itself in the unlined Main Hill area is the source of contamination at the CHRLF. LFG generated from the refuse in the unlined Main Hill area is the primary source of groundwater quality impacts in the EPZ area; it is also a source of methane and VOCs in soil gas. The contaminant migration pathway is described in the following sections.

8.2.1 Landfill Gas

In LFG-driven contamination scenarios, the pathway begins as VOC vapors expelled from the refuse comingle with LFG. VOCs in the migrating gas dissolve into the soil porewater that subsequently migrates to the water table. VOCs can also dissolve directly into groundwater at the gas-groundwater contact (Walter et al., 2003).

Two LFG migration pathways have been identified for the EPZ area (Aspect, 2010): the shallow pathway through the fill and weathered glacial till overlying the perched groundwater, and the deeper pathway in the unsaturated stratified drift underlying the glacial till/glacio-lacustrine deposits. The stratified drift underlying the ESPZ has been identified as a pathway for LFG migration. The LFG migrates from the unlined Main Hill refuse and moves preferentially via more permeable pathways through the glacial till and into the coarser native stratified drift. Where possible, the LFG diffuses upward into the low-permeability glacio-lacustrine soils or migrates upward through available preferential permeable pathways. Preferential pathways are present distant from the source, such as in the more permeable stratified drift to the northeast. Preferential pathways may also occur within the glacial till/glacio-lacustrine units. For example, preferential pathways may occur in areas of seasonally dry wells, particularly in the groundwater extraction wells that have long unsaturated sections of sand filter packs.

The presence of LFG pathways in the EPZ area is indicated by methane and VOC detections in shallow and deep gas probes. The extent of VOC concentrations in shallow and deep soil gas during two soil gas sampling events (July 2015 and May 2016) is presented on Figures 7.8 and 7.9; the extent of methane concentrations (2009 through 2013) is presented on Figures 7.12 and 7.13. Shallow soil gas methane levels (by volume) in EPZ area gas probes and monitoring wells were greater than 16 percent in GP-58, 0.3 percent in MW-104, and 3.2 percent in GP-60. The deep soil gas methane levels were far higher and more widely distributed throughout the EPZ area and seasonally saturated zone. For example, methane levels in soil gas (by volume) before the RI sampling was conducted were 7.2 percent at EW-7 (in 2009), 16.3 percent at EW-11 (in 2009), 20.9 percent at GP-55 (in 2013), and 43.7 percent at GP-57 (in 2014).

Methane concentrations measured during the RI soil gas sampling events, depicted in Figures 7.8 and 7.9, present a much more limited distribution and concentrations of methane; however, they are snapshots of conditions. Figure 7.12, depicting methane concentration statistics for selected gas probes from monthly readings from 2009 to 2013, supports the assertion that the shallow unsaturated zone overlying the EPZ area is not a significant pathway through which LFG can impact the perched groundwater (Aspect, 2010). Methane was generally not detected, or detected at low concentrations; carbon dioxide concentrations indicate that the methane oxidizes and mixes with aerobic soil before reaching these shallow unsaturated zones.

An analysis of VOCs in LFG was performed to evaluate potential partitioning of VOCs from LFG into groundwater in 2009 and 2010 (Aspect, 2010; Table 8.4). VOCs were generally absent at shallow depth probes, beneath both the NESPZ and the ESPZ. In contrast, VOCs were detected in two of the deeper, stratified drift gas probes (GP-55 and GP-59, around groundwater extraction well EW-25 and groundwater monitoring well MW-47, respectively). LFG from gas probe GP-55 contained PCE, TCE, cis-1,2-DCE, and VC, as well as other VOCs. LFG in GP-59 contained primarily VC. During the RI, gas samples were also collected from selected shallow and deep gas probes and selected monitoring wells in the EPZ area and analyzed for VOCs, as discussed in earlier sections. Aromatic and chlorinated VOCs were detected in both shallow and deep gas probes, including PCE, TCE, and cis-1,2-DCE. VC was not detected in gas samples collected during the RI.

Table 8.1 presents a comparative summary of the VOCs detected in EPZ area groundwater, leachate, LFG (from Flare #1 Inlet), and soil gas. The strong correlation between the VOCs detected in groundwater, LFG, and soil gas indicates they have the same source. The following VOCs were detected in all three media, as highlighted on Table 8.1: 1,1-dichloroethane, acetone, benzene, cis-1,2-DCE, ethylbenzene, methane, PCE, toluene, TCE, and VC. In contrast, very few VOCs were detected in both leachate and groundwater. These analyses indicate that LFG beneath the ESPZ has the potential to function as an ongoing source of groundwater quality and soil gas impacts.

LFG in the EPZ area has two potential sources: the unlined Main Hill refuse; the network of vertical and horizontal LFG collection infrastructure (Appendix B, Figure B-3) in localized areas of the EPZ and throughout the eastern portion of the Main Hill. The long filter sand packs in the groundwater extraction wells may provide preferential pathways for migration of LFG to water-bearing zones within the EPZ. Insufficient control of LFG collection through the existing infrastructure and blockages in the infrastructure are the likely causes for fugitive LFG in the EPZ area.

8.2.2 Leachate

Landfill leachate impacts can be inferred when chloride concentrations in groundwater are higher than background values. Some of the current impacts to groundwater in the SSPZ, near EW-6 and EW-7, may be attributable to the comingling of a historical leachate source with ongoing LFG sources. Although chloride was detected below the CUL in all EPZ area wells, chloride concentrations in EW-6 and EW-7 (maximum detections of 51.8 mg/L and 39.4 mg/L, respectively) are elevated above the background chloride concentration observed in other EPZ area wells (median value of 2 mg/L).

Historical leachate impact is also indicated by historically elevated chloride concentrations in the unsaturated zone and ESPZ groundwater dataset for MW-30A, MW-47, and MW-62 (see Appendix E concentration plots). The maximum leachate impact to this area occurred in late 1992 through 1996, before a rapid decline in concentrations was observed. Stable chloride concentrations since that time indicate that cover and leachate collection system improvements have controlled this historical leachate source (Aspect, 2011). For comparison, fresh groundwater in many areas of Washington contains less than 10 mg/L of chloride (USGS, 2000). The chloride concentrations in MW-29, MW-30A, and MW-47 have all stabilized at concentrations less than 10 mg/L. These low levels appear to be attributable to fresh, unimpacted groundwater.

As indicated on Table 8.1, leachate from the unlined Main Hill contains a limited number of VOCs. A few of these VOCs were also detected in groundwater, specifically 1,4-dichlorobenzene, acetone, chloromethane, ethylbenzene, toluene, and VC.

Chloride and COC concentrations indicative of leachate in the unsaturated zone near MW-30A, EW-6, and EW-7 may be the result of deficient leachate management facilities in this area. Appendix B, Figure B-2 depicts the leachate infrastructure in the EPZ area. The vicinity of MW-30A, EW-6, and EW-7is characterized by an area in which horizontal collectors appear to be absent, as indicated by the blank spot between CO 13(B), CO-14, and MH-28N. Furthermore, the E1-E1´ and E6-E6´ cross sections, presented on Figures 4.3 and 4.6, also depict some of the leachate collection infrastructure in the vicinity of the northern extraction wells. These cross sections indicate that the leachate infrastructure was installed at very shallow depths in comparison to the depths of the screens of wells where historical high chloride concentrations were detected, including the currently slightly elevated chloride concentrations in EW-6 and EW-7. The wells located in the seasonally saturated zone are screened anywhere from 5 to 25 feet below perforated leachate collection lines.

8.2.3 Source Evaluation

In an effort to distinguish the main source of contaminants to EPZ groundwater and to focus the remedy evaluation in the FS, several lines of evidence were evaluated. First, analysis of time-series concentration plots presented in Appendix E indicates that while leachate and LFG impacts have historically affected monitoring well MW-47, leachate impacts (represented by chloride concentrations) have dissipated, while ongoing LFG effects (increasing alkalinity) are evident.

Second, data on dissolved methane, alkalinity, and chloride in the EPZ area wells were evaluated to determine whether the source of impact is LFG or leachate. The results of that evaluation are presented in Table 8.2, showing that the following wells are likely influenced by LFG:. EB-6D, EW-6, EW-7, EW-9, EW-10, EW-11, EW-14 through EW-21, EW-25, EW-26, EW-27, EW-29, MW-30, and MW-47. The influence of LFG on groundwater quality in EW-25, EW-26, and MW-30A is further supported by the LFG-to-groundwater partitioning assessment presented in Table 8.4.

As shown in Table 8.2 by orange highlighting, EW-6, EW-7, and EW-14 may also be impacted by leachate. This is supported by data evaluated in the final line of evidence.

A final line of evidence used water quality monitoring parameters and ratios to evaluate groundwater quality data for indication of impacts from leachate releases. The principal theory (Mulvey and Brisbane, 1996) is that the concentrations of native cations and certain ratios increase notably when leachate breakthrough occurs. The parameters and ratios that were evaluated included calcium and magnesium, the ratio of sodium to potassium, the ratio of chloride to TDS, the ratio of calcium to potassium, the ratio of chloride to bicarbonate, the ratio of chloride to sulfate, and a special ratio known as the L/N[7] ratio. These parameters and ratios, in addition to total VOCs, were calculated for the EPZ area apparent background wells (EB-1 and EB-2), potential landfill leachate-impacted wells (EW-6, EW-7), the potential LFG-impacted well (EW-14), and leachate samples collected as part of the RI from FS-3 and MH-17N.

The results of the ratio evaluation are summarized in Table 8.3. In general, there were no remarkable indications that any of the groundwater was impacted by leachate. For example, the L/N ratios for leachate samples were the highest of the group (as they should be), but the apparent background wells had the next highest ratio results, followed by EW-14, and then EW-6 and EW-7.

No remarkable differences among the wells were noted in the ratios of chloride to sulfate, chloride to bicarbonate, chloride to TDS, or sodium to potassium. The calcium-to-potassium ratios for EW-6 were high compared to background, but the comparable ratio in leachate samples ratios were the lowest of all, indicating that leachate did not drive that ratio result for EW-6.

Finally, the calcium and magnesium results were also reviewed. Although calcium and magnesium are often reported as leachate indicator parameters, the presence of LFG can cause the dissolution of calcium

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[7] L/N Ratio = (K + NH4)/(Mg + Ca + Na) x 100

and magnesium carbonate minerals by carbonic acid, and, in turn, an increase in alkalinity, calcium, and magnesium in groundwater (Kerfoot et al., 2004). The data presented in Table 8.3 appear to provide evidence that the dissolution of alkalinity, calcium, and magnesium by carbonic acid from LFG is actively under way at the EPZ; EW-14 had the highest calcium and magnesium concentrations, ahead of EW-6, EW-07, and the leachate samples. Kerfoot et al. (2004) noted that leachate and LFG impacts can be differentiated because leachate results in elevated chloride, sodium, or TDS above background concentrations and LFG does not exert the same influence. Table 8.3 indicates that, indeed, sodium and TDS were elevated in EW-6, EW-7, and EW-14 above concentrations in the apparent background wells (EB-1 and EB-2), but that chloride was only slightly elevated in EW-6 and EW-7. It is likely that the chloride in EW-6 and EW-7 reflects residual or historical leachate effects. LFG influence is supported by the general lack of obvious differences in the leachate parameters and ratios between background (EB-1 and EB-2), EW-6 and EW-7 (the potential leachate-impacted wells), and EW-14 (the LFG impacted well).

8.3 Fate, Transport, and Attenuation Processes

8.3.1 Fate and Transport

The following sections present an evaluation of the fate and transport of COCs in groundwater and soil gas within the EPZ area. As discussed in the following sections, the primary contaminant fate and transport processes include:

- Migration of LFG from refuse followed by dissolution of VOCs from LFG to the water table.
- Leaching of constituents from refuse by infiltrating precipitation and migration of leachate.
- Migration of COC-affected groundwater to potential receptors.
- Migration of soil gas (methane and VOCs) to potential receptors.

8.3.1.1 Migration of LFG From Refuse

The majority of LFG generated by waste in the Main Hill is controlled by the LFG collection system. Some of the methane in LFG is oxidized *in situ.* Some of the LFG escapes the influence of the LFG collection system and migrates through the native unsaturated zone soils in the area of the ESPZ, based on VOCs and LFG observed in gas probes and effects on groundwater. LFG migrates predominantly through the unsaturated stratified drift, to a lesser extent in the shallow unsaturated zone overlying the ESPZ, and via preferential pathways such as landfill infrastructure (Figure 8.1). The deep LFG, whose migration is blocked throughout much of the ESPZ by the presence of low-permeability glacio-lacustrine silts and perched groundwater, may contact groundwater via preferential pathways, such as dry extraction wells, other landfill infrastructure, or zones of soil with higher permeability. LFG migration through these pathways is propelled through the vadose zone by the flux of barometric pressure changes, with falling barometric pressure causing migration of the LFG, which corresponds with methane and VOC detections in EPZ area monitoring locations. LFG migrating through the vadose zone contains VOCs that interact with groundwater at the capillary fringe either through dissolution to soil porewater, where they are then available migrate to shallow EPZ groundwater, or via the comingling of groundwater and LFG at the gas-groundwater contact. This interaction at the capillary fringe is the most significant mass transfer mechanism for the LFG-to-groundwater pathway (Morris, undated). LFG causes VOCs, in particular VC and its parent products, to partition into groundwater. Furthermore, the comingling of groundwater and LFG generates geochemically reducing conditions (e.g., redox conditions) accompanied by dissolution of naturally occurring metals, which is illustrated at this site by the elevated dissolved arsenic, iron, and manganese concentrations in shallow groundwater of the ESPZ. VOC concentrations in the shallow LFG are relatively depleted compared to those in the deeper LFG at probes close to the refuse boundary.

8.3.1.2 Migration of Leachate from Refuse

Leaching of constituents from refuse is a normal process at a landfill, at rates that depend upon refuse age and stage of decomposition. Most often, landfills are designed with infrastructure to collect leachate and prevent it from comingling with groundwater or from seeping at the landfill surface. However, if leachate collection infrastructure does not capture all the leachate generated, leachate may migrate from the refuse through the native soils or via other preferential pathways, such as landfill infrastructure. Historically, groundwater in the EPZ area was impacted by leachate (see Appendix E chloride concentration plots), but over time, this impact has attenuated such that little evidence of leachate migration from the refuse to groundwater is currently observed.

8.3.1.3 Migration of COC-affected Groundwater to Potential Receptors

Perched groundwater is the primary transport medium through which COCs migrate in the EPZ (other than LFG migration itself). Perched groundwater is sourced from infiltrating precipitation and seepage from wetlands. Groundwater migration, and thus COC transport, through the EPZ is limited by the lateral and vertical constraints of the geologic units, the thickness of the unsaturated zone between the EPZ and the Regional Aquifer, and the chemical properties of the COCs. COCs that are being mobilized are the result of the decomposition of refuse, and will continue to be generated for years. The key to reducing or preventing mobilization is capturing the constituents before they interact with groundwater.

The COC-impacted groundwater is comprised of two distinct zones containing the main constituents: VC and dissolved metals. The groundwater impacts are largely confined to the weathered glacial till/glacio-lacustrine and stratified drift units. The VC-impacted groundwater plume is located adjacent to the toe of the Main Hill refuse, extending nearly the entire length of the ESPZ, in addition to an isolated area in the SSPZ surrounding EW-6. VC-impacted groundwater has not migrated very far and is limited to the toe of refuse. Three mechanisms could account to the limited migration: VC’s nonpolar nature creates a strong affinity to partition to organic matter in the weathered glacial till/glacio-lacustrine and stratified drift units, these geologic units are characterized by limited hydraulic conductivity, and reductive dechlorination processes are at work.

The dissolved metals COC-impacted groundwater extends across most of the ESPZ, at concentrations decreasing with distance from the refuse boundary. An isolated small area of dissolved metals-impacted groundwater is located in the SSPZ between the NESPZ and the ESPZ. Migration of arsenic is often limited because of its strong sorption to weathered glacial till/glacio-lacustrine and stratified drift unit soils. The distribution of dissolved metals in the EPZ area is due not to migration of the dissolved metals, but rather to the distribution of reducing conditions caused as LFG migrates, which in turn dissolves metals from minerals in the weathered glacial till/glacio-lacustrine and stratified drift unit soils.

8.3.1.4 Migration of COC-affected Soil Gas to Potential Receptors

Volatilization of COCs from groundwater to soil gas is not a transport pathway for this RI/FS because groundwater near potential receptors is not impacted. Rather, it appears that soil gas is affected by migration of LFG through native unsaturated soil and preferential pathways, such as landfill infrastructure and zones of more permeable soils. This transport mechanism is shown by the percent levels of methane that have historically been observed (Figures 7.12 and 7.13). Groundwater volatilization into soil gas would not result in these levels of methane. VOCs present in the LFG migrate through the vadose zone and are thus present as soil gas.

LFG as a source to soil gas is represented by the detection of methane and VOCs in gas probes, groundwater extraction wells, and monitoring wells throughout the EPZ area. The link between LFG as a source of VOCs to both groundwater and soil gas is shown by the commonality between VOCs detected in groundwater, LFG, and soil gas, as depicted in Table 8.1. Based on the results of the 2015 RI soil gas survey, it appears that soil gas with COC concentrations above CULs may extend to the property boundary; however, follow-up sampling in 2016 could not confirm these results.

8.3.2 Groundwater Attenuation

Attenuation of constituents detected in groundwater in the EPZ area is occurring, as illustrated by the historical concentration plots and the statistical trend results presented in Appendix E.

The unsaturated zone between the EPZ area wells (completed in the stratified drift) and the Regional Aquifer wells (completed in the advance outwash and pre-Vashon glacial deposits) provides for attenuation of COCs, and reduces the potential impact on groundwater quality in the Regional Aquifer. This is shown by the lack of detections of any VOCs in Regional Aquifer wells within the EPZ area.[8] It has been estimated that the unsaturated thickness between the ESPZ and Regional Aquifer is on the order of 280 feet. This thick unsaturated zone underlying the ESPZ is expected to attenuate COCs during the migration process as evidenced by the groundwater quality observed in the EPZ area of the Regional Aquifer.

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[8] Note that VOCs have been detected in Regional Aquifer wells elsewhere on the CHRLF property—in CHRLF monitoring wells downgradient from the Queen City Farms Superfund Site. Parts of the CHRLF act as an attenuation zone for VOCs and other compounds migrating downgradient from Queen City Farms.

8.3.2.1 Metals

Metals transported in groundwater typically occur in the dissolved phase, and attenuate quickly with increasing distance from the source via natural geochemical processes such as precipitation and adsorption. Metal COCs in the EPZ area originate not from a source release but from transformation of minerals in surrounding soil under reducing conditions. As organic matter in the refuse at a landfill degrades microbially, oxygen in the groundwater system is consumed and reducing conditions are created. Reducing conditions also arise from anaerobic conditions after methane gas from decomposing refuse enters the groundwater, and from metabolic processes during reductive dechlorination. Reductive leaching of metals that had been bound to soil particles in the groundwater zone results in elevated concentrations of iron, manganese, and, locally, arsenic at the downgradient edge of a landfill.

Arsenic concentrations, despite being elevated above CULs in outer wells (MW-102, MW-103, and MW-104),were lower than those detected in extraction wells along the refuse boundary. For example, arsenic at EW-20 was detected at a maximum concentration of 43.1 µg/L during the RI, but horizontally downgradient at MW-103 and MW-104, at maximum concentrations reduced to 8.49 µg/L and 5.41 µg/L, respectively. Likewise, arsenic detected in the Regional Aquifer is undergoing attenuation as it is transported in groundwater, as indicated by the decrease in concentration in arsenic from MW-68 to downgradient well MW-80.

Iron and manganese also exceed CULs in EPZ area groundwater. In general, the highest concentrations of these metals were detected in wells along the refuse boundary (where geochemical processes causing reduced groundwater are most pronounced), and attenuation horizontally downgradient from the refuse appears to be occurring. Iron and manganese appear to coincide with areas where arsenic exceedances are observed, likely due to the reducing nature of the groundwater causing metals dissolution.

8.3.2.2 VOCs

VOCs transported in groundwater occur in the aqueous phase. Various processes including absorption, dispersion, and biological decomposition affect transport and drive attenuation. These factors, referred to as natural attenuation, can occur in aerobic and anaerobic environments, albeit at differing rates and via different metabolic pathways. Based on the redox and geochemical conditions observed during the RI, and as discussed in Section 7.2.3 and presented in Table 7.9, natural attenuation in the EPZ shallow groundwater is under way through the mechanism of anaerobic biodegradation. The breakdown of chlorinated VOCs is mediated by reductive dechlorination.

Reductive dechlorination generates chlorinated ethenes at landfills where high moisture content and methanogenic conditions favor rapid degradation. Typically, through the reductive dechlorination process, PCE and TCE degrade to DCE isomers (cis-1,2-DCE and trans-1,2-DCE) and then to VC. Natural attenuation of chlorinated VOCs by reductive dechlorination is already known to be occurring at the EPZ area based on the geochemical conditions for VOCs presented in Section 7.2.3.

8.3.3 Soil Gas Attenuation

Similar to groundwater, soil gas attenuates with distance from its source. The farther the gas must travel through the subsurface, the more likely it is that COC concentrations present in the gas will be reduced. Attenuation of vapors in the soil results from the same processes that control vapor transport, including diffusion, advection, sorption, and transformation reactions (EPA, 2008). Dilution also occurs. For example, in assessing VI into building structures, Ecology established attenuation factors of 10 between sub-slab soil gas and indoor air, and 100 between deep soil gas and indoor air (Ecology, 2016). However, actual attenuation factors may be different because of temporal and spatial variability at the site of concern.

8.4 Pathways of Exposure and Receptors

Potential exposure pathways for COCs in the EPZ area were introduced in Section 5. This section evaluates whether these exposure pathways are active under current or potential future uses on and off the CHRLF property, based on the data presented in the preceding sections and the pathway-specific CULs identified in Section 5.

Exposure pathways identified in Section 5 that are applicable to metal COCs are limited. Metal COCs are not volatile and have limited mobility. The three metals COCs are arsenic, iron, and manganese. Arsenic is classified as a human carcinogen, and thus the MCL takes into account human health exposure. Iron and manganese CULs were set very high because these metals exhibit very low toxicity to humans; although COCs, iron and manganese are not of primary concern to human health.

Exposure pathways for volatile COCs under current and potential future uses are discussed below by medium. A summary of exposure pathways under current and future uses is presented in Table 8.5. Some of the potential pathways and receptors presented in Section 5 are not active, based on evaluation of the RI data or when factoring in the CHRLF operational environmental control systems that are in place. All the exposure pathways and receptors evaluated are listed in Table 8.5, and each is assigned a status as potentially active, mitigated, incomplete, or not applicable. Active exposure pathways for human and ecological receptors that represent an existing or potential future risk on and off the EPZ area are summarized below.

8.4.1 Human Receptors

The EPZ area contains landfill facility buildings, landfill infrastructure, Passage Point residential buildings, asphalt roads, and utilities. Potential exposure pathways for VOCs in groundwater include direct contact, ingestion, transport to air and surface water. The following potential exposure pathways and human receptors were identified as active.

8.4.1.1 Direct Human Exposure via Dermal Contact

This is an active exposure pathway for both above- and below-ground workers in the EPZ. Above- and below-ground workers in the EPZ have the opportunity to be exposed via direct contact with EPZ groundwater, including water from the non-potable groundwater well in the EPZ area routinely used by landfill workers. Residents at Passage Point are unlikely to come in direct contact with EPZ groundwater. To mitigate this pathway, CHRLF should notify County workers and agencies or companies with utilities in the area of the presence of impacted EPZ groundwater. This is both a current and potential future exposure pathway addressed in the FS.

8.4.1.2 Ingestion Exposure

Ingestion of impacted groundwater by humans is considered a mitigated pathway. The mitigation in place is that there are no drinking water wells located within a 1,000-foot buffer of the landfill, as per 173-351 WAC landfill regulations. Only non-potable wells are located within the landfill boundary.

8.4.1.3 Inhalation Exposure to Groundwater Volatilization

Active inhalation exposure to volatilizing groundwater applies only to below-ground workers. To mitigate this pathway, KCSWD project representatives will notify King County workers and agencies or companies with utilities in the area of the VOC-impacted EPZ groundwater. This exposure can be mitigated, however, if proper health and safety precautions are implemented to prevent unacceptable exposure by affected below-ground workers. There are currently no buildings located over the area of VOC-impacted EPZ groundwater. However, should any future buildings or landfill structures be constructed above the VOC-impacted area, the exposure can be mitigated by implementing engineering controls and using proper health and safety precautions to protect workers from unacceptable exposures.

8.4.1.4 Inhalation Exposure to LFG

Active inhalation of LFG is potentially possible only by indoor residents at Passage Point. Shallow and deep soil gas CULs developed for the protection of indoor air were used to identify VOC exceedance. However, the actual exposure to inhalation of VOCs at Passage Point is unknown, given the distance between the probe where the exceedances were noted and the facility. Routine LFG monitoring data for the interior of Passage Point indicates frequent low-level detections of methane (i.e., at concentrations well below the 100 ppm 173-351 WAC regulatory limit for off-site structures) during times of low barometric pressure. Routine detection of methane during periods of low barometric pressure indicates that LFG is migrating to the facility and that there is the potential for receptors to be exposed to co-located VOCs in LFG via inhalation. It is recommended that this exposure pathway be reevaluated further, specifically by installing gas probes closed to the Passage Point facility to provide baseline VOC data by which to monitor effectiveness of the remedy. This is both a current and potential future exposure pathway that will be addressed in the FS during baseline and post-remedy performance monitoring.

For indoor above-ground and outdoor below-ground landfill workers, this is a mitigated exposure pathway in that landfill operational health and safety procedures are in place to protect workers from unacceptable exposures.

8.4.1.5 LFG Discharge to Groundwater

This is a known, active exposure pathway that is driving the exposure to above-referenced receptors. This is both a current and potential future exposure pathway addressed in the FS.

8.4.1.6 Leachate Direct Contact

This is an active exposure pathway that is mitigated for indoor above-ground and outdoor below-ground landfill workers. The pathway is mitigated by landfill health and safety procedures in place to protect workers from unacceptable exposures.

8.4.1.7 Leachate Discharge to Groundwater

This is a known, historically active exposure pathway. However, concentration plots presented in Appendix E identify that the leachate impacts to groundwater have diminished considerably over time to the point where the leachate-to-groundwater pathway is limited. The viability of this pathway will continue to decrease as the landfill ages and leachate production slows.

8.4.2 Ecological Receptors

The only ecological exposure medium evaluated for the RI was surface water, as soil contamination is not a medium of concern for the EPZ. However, through the evaluation of RI data it was determined that no surface water contamination is present, and thus there are no active ecological exposure pathways or threatened ecological receptors.

The EPZ area qualifies for an exclusion from the terrestrial ecological evaluation consistent with Chapter 173-340-7491(1)(a) WAC because any soil contaminated with hazardous substances is contained below the landfill geomembrane cover system, and thus is located below the POC established under 173-340-7490(4) WAC. Institutional controls are not required under this exemption; however, institutional controls already required for landfill closure their use will be verified as part of the MTCA process for the EPZ area.

8.5 Remedial Investigation Conclusions

The following presents the conclusions of the RI. Based on these conclusions, the MTCA site boundary can be defined for use in the FS.

8.5.1 Conclusions

8.5.1.1 Groundwater

The RI confirms that LFG is the primary source causing CUL exceedances of arsenic, iron, manganese, and VC in shallow EPZ groundwater. These four constituents were retained as COCs for the FS. Iron and manganese exceedances are the result of redox conditions in groundwater, and appear to follow an attenuation pattern similar to that of arsenic. However, neither iron nor manganese is of primary concern for the EPZ area as their very high CULs reflect their low toxicity to humans. Furthermore, it is understood that the control of the source of VC to groundwater will also control the arsenic, iron, and manganese concentrations.

Trend analysis for arsenic and VC in wells with available historical data indicates either no trends or statistically significant decreasing trends, except for VC in MW-47. When the entire period of record is used (1992 to 2016 for this well), the VC concentrations display a statistically significant decreasing trend, but when only the last 10 years of data are used (2006 to 2016), concentrations display a statistically significant increasing trend. None of the extraction wells have had sufficient data collected for statistical trend analyses.

Investigation and monitoring data have been used to map the lateral and vertical extent of the arsenic- and VC-impacted groundwater. VC-impacted EPZ groundwater is limited to a narrow area at the base of the Main Hill refuse boundary. The arsenic-impacted EPZ groundwater extends farther afield to the outer EPZ area monitoring wells, where concentrations are near the CUL, indicating significant attenuation between the wells at the base of the refuse and those positioned downgradient.

Arsenic exceeds CULs in three wells in the Regional Aquifer; however, concentrations at two of these wells are within regional background levels. The highest concentration of arsenic in the EPZ portion of the Regional Aquifer was measured at MW-68, with significant attenuation observed between this well and the downgradient well MW-80. Iron and manganese exceedances in the Regional Aquifer are within general landfill site-specific background concentrations.

Potentially active exposure scenarios for groundwater are direct contact by above- and below-ground workers and inhalation by below-ground workers. Active pathways that are mitigated include ingestion by residents and inhalation by potential future above-ground indoor workers.

8.5.1.2 Surface Water

Surface water was not found to be impacted by landfill activities or the groundwater-to-surface water pathway.

8.5.1.3 Landfill Gas

LFG is the source of EPZ groundwater and soil gas impact. The mapped extent of LFG impact in soil gas, based on methane detections exceeding the regulatory limit of 5 percent by volume, indicates an isolated shallow zone LFG-impacted area near MW-47 in the ESPZ, and a deeper zone LFG-impacted area dispersed across the base of refuse in the SSPZ and ESPZ. This extent is consistent with the mapped extent of LFG-impacted groundwater, which also appears to be confined to the vicinity of the base of refuse in the SSPZ and ESPZ.

Gas probes nearest the Passage Point facility as originally scoped in the RI/FS Work Plan, could not be field-located, having been obstructed, destroyed, or never completed. Baseline soil gas data in the vicinity of Passage Point are therefore not available. It is recommended that the FS include installation of gas probes near Passage Point to generate this baseline information, which can then be used to assess the degree to which the remedy mitigates LFG migration within the EPZ. It is recommended that additional soil gas sampling take place during falling barometric pressure events (e.g. barometric pressure less than 30 inches of mercury and falling) to further evaluate the potential extent of VOC-impacted LFG near Passage Point.

Selected sections of the LFG collection system were examined during site visits. The LFG collection system along the East Header appeared to be in relatively good balance based on 2015 and 2016 measurements. It appears that 11 LFG extraction wells providing “relaxed” to “moderate” LFG migration control could be operated at higher flow rates to provide “aggressive” LFG migration control. However, overaggressive application of vacuum in some cases can lead to landfill fires, so careful monitoring of LFG temperature is warranted during application of “aggressive” LFG control. It also appears that 11 LFG extraction wells exhibit both high methane and high oxygen concentrations, a condition that may warrant further evaluation of the LFG collection system infrastructure for leaks and possible upgrades. Additional maintenance of the LFG collection system may include locating and fixing water blockages at low points in collection laterals and removing collected water from extraction wells.

If LFG collection from extraction wells completed in refuse is not adequate for proper LFG migration control, existing EPZ area gas probes and groundwater extraction wells may be evaluated for use as additional LFG collection points. For example, gas probe GP-57 was connected to the LFG collection system in 2011.

Potentially active exposure pathways and receptors for LFG are the LFG-to-groundwater pathway and VOC inhalation by indoor residents. Mitigated pathways and receptors include inhalation by indoor above-ground workers and outdoor below-ground workers.

8.5.1.4 Leachate

For this RI, leachate was evaluated only in the context of the leachate-to-groundwater pathway. Historically, leachate was found to be a source of impact to EPZ groundwater; concentration trend plots and current groundwater monitoring results indicate that leachate is now a limited, isolated low-level source to groundwater. The primary area for potential leachate impact to groundwater is at EW-6.

The only potentially active exposure pathway is discharge to groundwater. The mitigated pathways and receptors include the direct contact by above-ground indoor workers and below-ground outdoor workers.

8.5.2 MTCA “Site” Boundary

The MTCA definition of a “Site” or “Facility” is a facility where there is a confirmed release of a hazardous substance that requires remedial action. The MTCA Site definition for the EPZ area includes those areas delineated on Figure 7.10 where COCs exceed CULs, and those areas depicted on Figure 7.8 where soil gas exceeds CULs. More specifically, the MTCA Site is bound by GP-62 to the northwest, GP-20 to the northeast, GP-15 to the southeast, and EW-29 to the southwest.

9.0 REMEDIAL ACTION REQUIREMENTS

This section identifies the requirements that must be met for a cleanup alternative to comply with federal and state regulations. In addition to evaluation of ARARs pertinent for cleanup actions, this section also proposes groundwater and soil vapor cleanup standards for the EPZ area, identifies the area and volume that exceeds CULs, and identifies RAOs. Cleanup requirements for the EPZ area are evaluated in terms of MTCA and landfill closure requirements.

Cleanup standards consist of two components:

1. Contaminant- and medium-specific CULs defined by regulatory numerical criteria (contaminant concentrations) that are protective of human health and the environment; and
2. The specific location or POC at which the CULs must be met.

The cleanup standards are used as the basis for developing medium-specific RAOs for the remedial action alternatives evaluated in the FS.

9.1 Applicable State and Federal Laws (ARARs)

ARARs are discussed in Section 5.2 in the context of developing CULs for the site. Here, ARARs are discussed in the context of cleanup actions and cleanup standards. MTCA requires that all cleanup actions comply with applicable local, state, and federal laws, which are defined as “legally applicable requirements and those requirements that the department determines…are relevant and appropriate requirements.” The applicable local, state, and federal laws are identified in this section, and the compliance requirements of potentially applicable laws and regulations are evaluated in Section 11. Ecology will make the final determination as to whether the requirements have been appropriately identified, and are legally applicable or relevant and appropriate.

The starting point for ARARs is regulations (173-340 WAC) that address implementation of a cleanup and define cleanup standards under the MTCA statute (RCW 173.105D). The following ARARs were considered when developing and screening the FS remedial alternatives:

- The **Washington Dangerous Waste Regulations** (Chapter 173-303 WAC) would apply if dangerous wastes are generated, and **United States Department of Transportation and Washington State Department of Transportation regulations** regarding transport of hazardous materials (49 CFR Parts 171-180) would apply if regulated material is transported off-site as part of the cleanup action. However, there is no expectation that dangerous wastes will be generated during the cleanup action; furthermore, any waste generated as part of the cleanup action would likely remain on-site.

- The **Washington Solid Waste Handling Standards** (Chapter 173-350 WAC) regulate handling, treatment, or off-site disposal of nonhazardous solid waste.
- The **State Environmental Policy Act (SEPA)** (Chapter 197-11 WAC) and the SEPA procedures (Chapter 173-802 WAC) ensure that state and local government officials consider environmental values when making decisions. The SEPA process begins when a permit application is submitted to an agency, or an agency proposes to take some official action, such as implementing a MTCA Cleanup Action Plan (CAP). Completion of a SEPA checklist would be required prior to initiating remedial construction activities.
- The cleanup action would be regulated under the **Washington Clean Air Act** (RCW 70.94) as implemented through 173-400 WAC and 173-460 WAC. The regulations of the **Puget Sound Clean Air Agency** would also be applicable. The substantive requirements would include avoiding the creation of conditions that would significantly degrade the ambient air quality or cause exceedance of applicable air quality standards. These requirements are currently met with active LFG treatment operations, and no incremental or further requirements are anticipated with the proposed cleanup action.
- **Washington State Water Well Construction Regulations** (Chapter 173-160 WAC) regulate groundwater well installation and decommissioning as part of the cleanup action.
- The **Archeological and Historical Preservation Act** (16 USCA 496a-1) would be applicable if any subject materials are discovered during any grading or excavation activities associated with the cleanup action.
- **Occupational Safety and Health Administration** and **Washington Industrial Safety and Health Act** regulations (29 CFR 1910.120; 296-62 WAC) govern worker safety during cleanup action execution. Compliance would be achieved through preparation and implementation of a site-specific health and safety plan with appropriate controls, worker training and certifications, and occupational monitoring.
- **Solid Waste Landfill Closure Requirements** (173-304 and 173-351 WAC) apply to ongoing operations and to closure activities. The 173-304 WAC regulations govern typical closure requirements that are relevant to the EPZ area based on the disposal and closure history of the Main Hill. The current regulations for municipal solid waste facilities, 173-351 WAC, are also pertinent because other CHRLF Areas continue to accept waste.
- **State Water Pollution Control Act** (RCW 90.48) provides for the protection of surface water and groundwater quality. Surface water was not identified as a medium of concern in the RI, so surface water ARARs were not considered for the FS.

- **Washington State Hazardous Waste Management Act** (RCW 70.105) (Chapter 70.105 RCW; Chapter 173-303 WAC) regulations implement the State Hazardous Waste Management Act of 1976 as amended, as well as RCRA. Unlike RCRA, which defines hazardous wastes as those solid wastes designated by 40 CFR Part 261 and regulated as hazardous and/or mixed waste by EPA, 173-303 WAC distinguishes between different types of wastes, including dangerous, extremely hazardous, and mixed waste. For the FS, as with RCRA, these regulations apply to wastes (i.e., soil or water) generated at the site during investigation and interim measure activities.
- **Solid Waste Management-Reduction and Recycling** (RCW 70.95) regulations establish programs for solid waste handling, recovery, and recycling for the purpose of preventing pollution and conserving resources of the state. For the FS, these regulations apply to wastes (i.e., soil or water) generated at the site during investigation and interim measure activities.

9.2 MTCA Cleanup Requirements

MTCA requires that the selected remedy protect human health and the environment under specified exposure conditions. Per 173-340-360(2)(a) WAC, cleanup actions must satisfy four "threshold"[9] criteria:

- Protect human health and the environment;
- Comply with cleanup standards (173-340-700 through WAC 173-340-760 WAC);
- Comply with applicable local, state, and federal laws (173-340-710 WAC); and
- Provide for compliance monitoring (173-340-410 WAC and 173-340-720 through 173-340-760 WAC).

In addition, 173-340-360(2)(b) WAC specifies three other criteria that alternatives must achieve:

- Use permanent solutions to the maximum extent practicable;
- Provide for a reasonable restoration time frame; and
- Consider public concerns (173-340-600 WAC).

Because of the typical size and history of landfills, Washington State has determined that it is impracticable to treat or move the refuse from a municipal solid waste landfill, and has outlined specific requirements that allow a municipal solid waste landfill to be closed in place in a manner that meets the MTCA criteria identified above. As a starting point, MTCA uses the closure requirements promulgated in 1985 as MFS for Landfills (173-304 WAC) as the preferred remedy requirements (refer to 173-340-710(7)(c) WAC) and then modifies them as needed to meet MTCA cleanup requirements. Also applicable for the CHRLF are the Criteria for Municipal Solid Waste Landfills (173-351 WAC) since other CHRLF Areas continue to accept

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[9] A level that which must be exceeded for a cleanup action to be considered satisfactory.

waste and are currently regulated under the 173-351 WAC. The approach of the FS is to use MFS (173-304 WAC) as a starting point, and a relevant and appropriate requirement for defining the MTCA remedy for the CHRLF EPZ area.

9.3 Landfill Closure Requirements

While the focus of this RI/FS for the EPZ area is not located within the closed Main Hill area where waste has been placed, it is within the boundary of the regulated CHRLF. Furthermore, the quality of groundwater in the EPZ has been affected by the adjacent landfill activities and processes. As such, the landfill closure requirements should be considered in the development of remedial alternatives for the EPZ area. Closed landfills are considered under MTCA to be sites that have used "containment of hazardous substances" as the preferred remedy.

KCSWD (2015) recently evaluated a reclamation process involving landfill mining at the CHRLF Main Hill. The Main Hill landfill mining goals included increasing landfill "air-space," potentially mitigating groundwater issues, eliminating LFG migration issues, recovering recyclables, and improving land use. The estimated volume of refuse in the Main Hill that was considered for landfill mining was 18.3 million cubic yards. The cost of landfill mining and relocation of the Main Hill refuse was estimated at $146 million dollars. Given that the benefit for this source-removal option was ranked as medium, there was no increase in the CHRLF property value, and a cost 1 to 2 orders of magnitude greater than other alternatives, the landfill mining option was not carried forward in the FS. Therefore, the closed Main Hill is considered a containment site as per the MTCA definition as defined below.

Under 173-340-740(6)(f) WAC), MTCA defines the expectation for containment sites as follows:

> *WAC 173-340-740(6)(f) The department recognizes that, for those cleanup actions selected under this chapter that involve containment of hazardous substances, the soil cleanup levels will typically not be met at the points of compliance specified in (b) through (e) of this subsection. In these cases, the cleanup action may be determined to comply with cleanup standards, provided:*
>
> > *(i) The selected remedy is permanent to the maximum extent practicable using the procedures in WAC 173-340-360;*
> >
> > *(ii) The cleanup action is protective of human health. The department may require a site-specific human health risk assessment conforming to the requirements of this chapter to demonstrate that the cleanup action is protective of human health;*
> >
> > *(iii) The cleanup action is demonstrated to be protective of terrestrial ecological receptors under WAC 173-340-7490 through 173-340-7494;*
> >
> > *(iv) Institutional controls are put in place under WAC 173-340-440 that prohibit or limit activities that could interfere with the long-term integrity of the containment system;*

> *(v) Compliance monitoring under WAC 173-340-410 and periodic reviews under WAC 173-340-430 are designed to ensure the long-term integrity of the containment system; and*
>
> *(vi) The types, levels, and amount of hazardous substances remaining on-site and the measures that will be used to prevent migration and contact with those substances are specified in the draft cleanup action plan.*

9.4 Presumptive Remedy Requirements

EPA's *Presumptive Remedy for CERCLA Municipal Landfill Sites Directive* (EPA, 1993)[10] was based on the agency's experiences at multiple solid waste landfill sites and reflected a growing body of knowledge regarding the key components for long-term containment remedies at solid waste landfills. This FS uses ideas from EPA's landfill presumptive remedy process to refine the MTCA remedial action for the CHRLF EPZ area, while continuing to treat MFS and 173-351 WAC as key ARARs. The remedial alternatives and preferred remedy described in the FS follow the concepts presented in MTCA, MFS, 173-351 WAC, and EPA's guidance, and uses the term "presumptive remedy" to remind the reader of the large body of knowledge regarding solid waste landfills and their long-term care.

Components of a presumptive remedy for a source area (e.g., extent of refuse) include the following:

- Landfill cap including stormwater controls;
- Source area groundwater controls to contain plume, including leachate collection and treatment, if needed;
- LFG collection and treatment; and
- Institutional controls to supplement engineering controls.

The presumptive remedy guidance does not address remedial actions for impacted groundwater beyond the source area or long-term monitoring, as groundwater impacts should not occur if the presumptive remedy is effectively controlling landfill sources; however, these components are required under MFS, 173-351 WAC, and MTCA. This RI/FS, therefore, adds the following as components of the presumptive remedial action:

- Consideration of downgradient impacted groundwater; and
- Long-term groundwater monitoring.

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[10] Subsequent updates to the original Presumptive Remedy Guidance can be found at http://www.epa.gov/superfund/policy/remedy/presump/clms.htm.

The components of the containment presumptive remedy identified above meet both the MTCA requirements for cleanup and the closure and post-closure requirements of MFS and 173-351 WAC. Each component is described in more detail in Section 10 of the FS.

9.5 Cleanup Levels

The proposed CULs for groundwater and soil gas are described in the following sections. Final CULs will be selected by Ecology and presented in the CAP for the EPZ area.

9.5.1 Groundwater Cleanup Levels

The perched groundwater zones are not used as a drinking water source and cannot be used in the future for a drinking water source because they do not meet potable water pump rate requirements of 0.5 gpm. However, a formal non-potable demonstration has not been approved by Ecology, so the maximum beneficial use of groundwater beneath and immediately downgradient of the EPZ area is specified as drinking water. Drinking water standards are presented as groundwater CULs (refer to Table 7.1) as they provide the most conservative protection for potential receptors. The CULs presented in this table for COCs include MTCA Method A/Natural Background levels for arsenic, MTCA Method B for iron and manganese, and a modified MTCA Method B for VC. Groundwater standards for the protection of surface water are not relevant for the FS (groundwater in the NSPZ discharges seasonally to Stream 3, where chlorinated VOCs were not detected and all detected parameters were less than selected surface water CULs).

9.5.2 Soil Gas Cleanup Levels

The existing facilities above the EPZ area include landfill-related infrastructure and a residential facility (Passage Point). The appropriate CULs for the facility are the MTCA Method B standards for VOCs contained in Ecology's *Guidance for Evaluating Soil Vapor Intrusion in Washing State: Investigation and Remedial Action* (Ecology 2016) (refer to Table 7.5). These CULs will be used during the baseline and performance monitoring implemented as part of the selected remedy to evaluate the performance of the remedy at controlling the migration of VOCs contained within LFG.

9.5.3 Landfill Gas Compliance Levels

LFG compliance levels are provided in 173-351 WAC and include maintaining methane levels below 25 percent of the lower explosive limit (LEL) in facility structures; at less than 100 parts per million by volume in off-site structures; and at or below the LEL (5 percent methane) at the property boundary and beyond. LFG collection operational limits are provided in the New Source Performance Standards (40 CFR Part 60), and include limits for temperature, oxygen, and nitrogen to prevent conditions that could allow a subsurface landfill fire. Higher operating values are allowed on a case-by-case basis, and would likely be required for nitrogen to provide "aggressive" LFG migration control, as defined by SWANA.

9.5.4 Points of Compliance

MTCA and the current landfill regulations at 173-351 WAC each have definitions for POC. The MTCA definition is “point or points where cleanup levels established… shall be attained.” This term includes both standard and conditional POCs (i.e., POCs when certain conditions are met). A conditional POC for a particular medium is available only as provided in 173-340-720 through 173-340-760 WAC. Standard POCs for groundwater under MTCA are established throughout the CHRLF site. The POC under 173-351 WAC is within 150 meters (492 feet) from the waste management unit boundary (e.g., the base of the Main Hill refuse boundary). According to MTCA 173-304-710(7)(c), the municipal solid waste closure requirements in 173-351 WAC shall be minimum requirements for cleanup actions conducted under MTCA. Therefore, for this FS, the landfill definition of POC will be implemented.

The standard air POC is above a landfill. Application of these standards at the POC is complicated by the inability of ambient air measurements to distinguish among compounds released from the landfill, those present in urban ambient background, and those in use at the operational facility. Therefore, it is customary for air standards at landfills to monitor compliance with air CULs by monitoring the performance of the LFG system and methane levels at landfill property boundary perimeter gas probes. For soil gas and the evaluation of VI, the POC will be indoor air.

9.6 Areas and Volumes Exceeding Cleanup Levels

The areas of VOCs and dissolved metals exceeding respective CULs in EPZ shallow groundwater are depicted on Figure 7.10. Areas exceeding CULs in perched groundwater were estimated at 85,000 square feet for VOCs and 693,000 square feet for dissolved metals. These estimates are based on the average groundwater elevation measured within the area exceeding CULs an assumed saturated thickness of 29 feet for VOCs, and an assumed saturated thickness of 25 feet for dissolved metals. This 4-foot difference in saturated thicknesses is consistent with previous evaluations that indicated decreasing saturation of the glacial till/glacio-lacustrine units towards the east (Aspect, 2010). At an assumed total porosity of 25 percent, estimated volumes of groundwater exceeding CULs are 4,600,000 gallons for VOCs and 30,800,000 gallons for dissolved metals.

9.7 Remedial Action Objectives

RAOs are specific conditions to be achieved by remedial alternatives that meet cleanup standards and provide protection of human health and the environment. The RAOs consider the applicable exposure pathways (Section 5.4) and reflect concentrations of COCs that are protective of receptors via the potential exposure pathways. Based on the CSM (Section 8), the following RAOs are addressed in this FS:

- Reduce groundwater COC concentrations posing a potentially unacceptable human health or ecological risk;

- Prevent direct contact of current and future workers and occupants to exposure of impacted groundwater;
- Prevent groundwater COCs from discharging to surface water (Stream 3) at concentrations above surface water CULs;
- Reduce soil vapor concentrations posing a potential VI exposure risk; and
- Control LFG migration to eliminate the source of COCs to groundwater and air emission risk.

Each RAO will be achieved by eliminating the associated exposure pathway. The pathways can be rendered inactive through contaminant removal or treatment to meet chemical- and medium-specific cleanup standards (CULs at POC; Section 9.5.4), and through institutional and engineering controls (e.g., containment) to prevent exposure.

10.0 SCREENING OF REMEDIAL TECHNOLOGIES

MTCA allows for an initial screening of cleanup action alternatives, when appropriate, to reduce the number of alternatives carried forward to the detailed analysis. MTCA stipulates that cleanup action alternatives may be eliminated from further consideration in the FS if they consist of either of the following:

- Alternatives that, based on a preliminary analysis, obviously do not meet the minimum requirements specified in 173-340-360 WAC (including clearly disproportionate costs); and
- Alternatives or components that are not technically possible.

This section identifies and screens remedial technologies that may be effective cleanup action components in satisfying the RAOs defined in Section 9.7. Technology screening considers technical implementation, the RAOs, applicable state and federal laws described in Section 9.1, and site-specific conditions such as the subsurface conditions and contaminant distribution. The remedial technologies retained after this screening process are then used to assemble remedial alternatives (Section 11).

10.1 Institutional Controls

Institutional controls are administrative or engineered mechanisms for ensuring the long-term performance of cleanup actions. Institutional controls do not physically alter conditions at a cleanup site and do not, or are not intended to, reduce the mobility, toxicity, or volume of contamination at a site as part of the remedial alternative. While not considered a stand-alone remedial technology, institutional controls would be an integral cleanup action component where contaminants exceeding CULs remain in the EPZ area.

Institutional controls involve administrative/legal tools to provide notification regarding the presence of contaminated materials; regulate the disturbance/management of these materials and the cleanup action components; and provide for long-term care of cleanup actions including long-term monitoring. Under MTCA, the legal instruments for applying institutional controls are termed environmental covenants, and are equivalent to restrictive covenants for a specific property or portion of a property. Examples of institutional controls include:

- Fences and warning signage to restrict access to the CHRLF or to specific areas of it;
- Deed restrictions, such as restrictions on land use, construction, and soil excavation without Ecology approval; and
- Use restrictions and monitoring requirements to prevent disturbance of caps or other engineered controls.

Institutional controls can be effective and implementable under a wide range of conditions, for all contaminants and media, and generally apply to the entire EPZ area.

Institutional controls are retained as a component for development of remedial alternatives.

10.2 Monitored Natural Attenuation of Groundwater

Natural attenuation is the reduction of groundwater COC concentrations through a combination of naturally occurring physical, chemical, and/or biological processes, such as sedimentation, sorption, dispersion, and biodegradation. Some natural processes (e.g., sorption of hydrophobic organic compounds to organic carbon in soil) act as containment mechanisms, while others (e.g., biodegradation of compounds by native microorganisms) act as *in situ* treatment mechanisms.

Chlorinated VOCs in groundwater are biodegraded naturally by native microorganisms. TCE, cis-1,2-DCE, and VC are degraded to the nontoxic end products ethene or ethane. Periodic monitoring of groundwater documents that the processes are occurring at the desired rates.

Redox-sensitive metals occur in groundwater because the reducing conditions created by LFG lead to reductive dissolution of arsenic, iron, and manganese present in native EPZ materials. Natural attenuation mechanisms are also amenable under reducing conditions. However, the redox conditions created by LFG must be converted to more oxidizing conditions to permanently immobilize metals and prevent their entry or reentry into groundwater.

While MNA may have a longer restoration time frame compared to other treatment options, COCs are permanently transformed and with minimal disruption to operations. MNA is effective for the EPZ COCs, easy to implement, and of relatively low cost compared to other remediation technologies. Therefore, this alternative is retained both as a stand-alone remedy and as a component for other remedial alternatives.

10.3 Capping

Cap installation and stormwater management are components of a landfill presumptive remedy as well as closure requirements discussed in Section 9.3. Landfill caps minimize infiltration of stormwater into the refuse, prevent its direct contact with buried wastes, control the formation of leachate, and thus reduce the potential that compounds will leach to groundwater, Cap design and permeability vary with the stage of the landfill, and with the condition of the underlying and downgradient groundwater. In all cases, the landfill cap must be designed to reduce the migration of compounds from the refuse to the groundwater. Capping is not a relevant technology because the East Main Hill is capped.

10.4 Landfill Gas Collection and Treatment

LFG collection and treatment is a component of the landfill presumptive remedy as well as closure requirements discussed in Section 9.3. This technology is ongoing at the CHRLF Main Hill and other Areas, although increased application is considered in this FS to address EPZ groundwater- and soil gas-impacted media.

LFG control technologies include infrastructure to collect, convey, and treat LFG to comply with government regulations, and to control odors and uncontrolled releases that may pose safety and health concerns. LFG control objectives generally focus on off-site migration, on-site accumulation control, or both. LFG control systems addressing migration and accumulation can be categorized as active, passive, or a combination of both. LFG control may be completed by a gas collection and treatment system or by monitoring to ensure that the LFG remains at safe levels. Various gas systems can meet this requirement and the final design is based on the stage of a landfill and the conditions of the LFG itself. The LFG system must be designed to capture the gas within a landfill, ensure that the gas does not migrate outside of the landfill boundary, and ensure that the gas is discharged safely. In addition to a collection system, the LFG controls may include provisions to protect buildings, utility corridors, and other surface and subsurface structures. Controls such as these, including vapor barriers and passive venting systems, ensure that the LFG does not enter these structures, and provides safety to human health and the environment. The existing LFG collection system is described in Section 6.3 and depicted on Figure B-3 in Appendix B.

As detailed in Section 8.1, LFG is the primary source of groundwater and soil gas impacts in the EPZ area and, therefore, expanded LFG collection is a suitable technology for development of remedial alternatives. Several applications are considered in the remedial alternatives:

- Optimized LFG control—The optimization of or modifications to the existing East Main Hill LFG collection system to enhance performance for purposes for achieving CULs for the EPZ area;
- Perimeter LFG control—The collection of LFG from native materials within the EPZ area; and
- Expanded LFG control—The addition of LFG extraction wells within the refuse footprint on the East Main Hill.

These applications of LFG collection technology are discussed in detail in the remedial alternative development text in Section 11.

10.5 Leachate Extraction and Treatment

Leachate extraction and treatment is a component of the landfill presumptive remedy as well as closure requirements discussed in Section 9.3, and is ongoing at the CHRLF. Two methods are typically implemented to prevent leachate intrusion into the groundwater system. The first is control of groundwater by minimizing the amount of groundwater that interacts with the refuse. This control can be achieved by keeping the landfill bottom above the water table lining stormwater ditches, tight-lining stormwater conveyance systems, designing groundwater collection systems to route flow to areas outside of refuse, and other engineered solutions. The second method involves collecting and treating leachate. If the groundwater is not contaminated, then leachate control may not be required. Both control methods are currently applied at CHRLF.

Based on the detailed discussion in Section 8.1.2, leachate is not a significant source to groundwater in the EPZ area. Accordingly, neither leachate extraction nor treatment is retained for remedial alternative development. However, both remain as components of the existing environmental control system at the CHRLF; the leachate extraction and treatment system must be operated and maintained through landfill operations and closure. Minor leachate impacts identified in the EW-6 and EW-7 area are addressed through MNA, whose monitoring objectives include measurement of leachate indicator parameters and thus to reveal inadequacies in the leachate extraction and treatment system.

10.6 Groundwater Extraction and Treatment

In some applications, the migration of impacted groundwater can be controlled by modifying hydraulic gradients, extracting the groundwater, and removing contaminant mass through *ex situ* treatment. Extraction wells or trenches intercept impacted groundwater, which is then treated and either reinjected or discharged to a designated location, such as a sanitary sewer or surface water body, depending on COC concentrations. Transmissivity of the aquifer, chemical properties of the groundwater zone, and biofouling are important factors in the effectiveness and long-term operation of a groundwater extraction system.

An aging groundwater extraction system is in place in the EPZ area. Its 29 extraction wells operated from 1993 until 2010, when it was shut down for poor performance, as discussed in Section 6.1. The extraction system’s poor performance was primarily due to the very low permeability of the glacial till/glacio-lacustrine units, but was compounded by intensive biofouling. Certain wells in this extraction well infrastructure, with long filter sand packs could possibly be retrofitted with unsaturated screen sections and thus serve as LFG extraction wells. Therefore, the retrofit from groundwater to LFG extraction will be evaluated in Section 11.1.2. The groundwater extraction and treatment technology is not retained for remedial alternative development.

10.7 Permeable Reactive Barrier

Permeable reactive barriers (PRBs) are continuous barriers of chemical or biological material physically emplaced in groundwater zones perpendicular to groundwater flow to react with and biodegrade contaminants. PRBs both treat impacted groundwater and prevent further migration within the saturated zone. These barriers can be constructed of zero-valent iron to degrade VOCs through abiotic mechanisms. PRBs are also demonstrated to be effective at removing dissolved metals from groundwater through various mechanisms, including sorption, precipitation, coprecipitation, and biologically mediated mechanisms. PRBs are a barrier technology and can achieve cleanup levels in groundwater at their installed location and downgradient, but they do not treat source-area impacts in the unsaturated zone or hydraulically upgradient from their installed location. PRBs are typically implemented when removal of the source is not possible or cost-effective.

While PRBs are potentially effective for the COCs in groundwater and could be installed as a barrier at the base of the East Main Hill slope, the technology would not address LFG (the primary source to EPZ area impacts); would not address downgradient soil vapor issues; and would represent, relative to potential benefits, disproportionately high capital costs for the required heavy construction and materials. PRBs are not retained for remedial alternative development.

10.8 Groundwater Impermeable Barrier

Impermeable vertical barriers are walls installed in the groundwater zone to prevent the migration of impacted groundwater. Common materials for impermeable barriers include slurries (usually containing bentonite); sheet pilings made of steel, vinyl, or other materials; and grout curtains. This technology may be implemented to divert the flow of impacted groundwater around drinking water wells, wetlands, or streams. They may also be used to contain and isolate impacted soil and groundwater, preventing it from mixing with clean groundwater. When barriers are used for containment, they may also require a system to pump out groundwater that builds up in the isolated area. Impermeable barriers only contain contamination; they do not transform or reduce COCs.

Impermeable barriers would prevent perched, contaminated groundwater from migrating off-site, but would not be effective at controlling downward migration to the Regional Aquifer. Containment at the depths of the Regional Aquifer (on the order of more than 250 feet) is not considered technically feasible. An impermeable barrier in the perched zone would not be cost-effective, and would not reduce contaminant concentrations or address LFG as the source of groundwater impacts. This technology is not retained for remedial alternative development.

10.9 Air Sparging

Air sparging entails direct injection of air into the saturated zone via wells (also known as “sparge points”) screened below the water table. Air sparging is a well-demonstrated technology for removing VOCs from groundwater primarily through volatilization. Air sparging could also potentially immobilize dissolved metals from groundwater by changing groundwater redox conditions from reducing to more oxidizing. Oxidation could transform the valence state of metals, resulting in direct precipitation, but also oxidize the native mineral surface, creating sorption sites for dissolved metals in groundwater.

Air sparging would likely be implemented using an array of wells connected via subsurface piping to a compressor. Air sparging could be applied in a transect of sparge points (sparge curtain) at the base of the East Main Hill slope. Valving and instrumentation would be provided to monitor and control the air injection rate at each well or group of wells. Pilot testing would be conducted to determine optimum well spacing, air injection rates, and other design parameters.

Because of the relatively low concentrations of COCs in groundwater, the low permeability of the glacial till/glacio-lacustrine material in the EPZ, and the likelihood that new wells designed for sparging would be very costly, air sparging is not retained as a technology for development of remedial alternatives.

10.10 Summary of Retained Technologies

Table 10.1 lists the remedial technologies discussed in this section, indicates specific contaminant/media combinations for which each technology is potentially applicable, and indicates technologies retained for development of remedial alternatives. The retained technologies include:

- Institutional controls
- MNA of groundwater
- LFG collection and treatment

11.0 SCREENING OF REMEDIAL ALTERNATIVES

The retained remedial technologies have been assembled into four remedial alternatives that achieve the RAOs for the EPZ area. This section describes the remedy components for each alternative and how the alternatives would be implemented. Each remedial alternative is considered to meet MTCA threshold requirements (173-340-360(2)(a) WAC), as detailed in Section 11.3.1. Alternatives 1, 2, 3, and 4 progressively add cleanup activities that increase both permanence and cost.

All remedial alternatives share four features: institutional controls, decommissioning of groundwater extraction wells, MNA of groundwater; and installation of LFG probes in the vicinity of Passage Point.

11.1 Remedial Alternative Common Elements

The following sections describe the basis and assumptions used for developing FS-level cost estimates for the elements common to all alternatives.

11.1.1 Institutional Controls

As part of the containment presumptive remedy, institutional controls are typically implemented at a landfill to ensure the integrity of the containment systems, and to ensure the safety and health of the users of the landfill. Typical controls include long-term operation and maintenance (O&M) plans, and activity restrictions and implementation procedures. Institutional controls for this cleanup action focus on additional controls necessary for the EPZ area that are incremental to those required or already in place at the CHRLF.

Following the approval of this RI/FS, a Draft CAP and the environmental covenant will be developed. The environmental covenant will be finalized in the Final CAP. Using Ecology's (2015b) model environmental covenant as a template, a site-specific covenant will be developed and likely require:

- Access of Ecology personnel for inspection and review of records, and to determine compliance with the selected remedial action;
- Compliance with the selected remedial action presented in this RI/FS and the subsequent Draft CAP;
- Ongoing O&M of the selected components of the remedial action. This will likely include the LFG collection and treatment systems, long-term groundwater monitoring, and any other engineered controls. These requirements will be based on Operations, Maintenance, and Monitoring Plans; a Compliance Monitoring Plan; or remedial system design reports that will need to be prepared and submitted to Ecology;
- Worker safety for utility O&M, and roadway improvements and maintenance;
- Future subsurface construction in the EPZ area comply with the preferred remedial alternative;
- Notifying Ecology if any conveyance of the property is desired. Adequate and complete provision for ongoing O&M of the remedial action components must be accounted for in any property conveyance;
- Land-use restrictions requiring that the landfill buffer zone always include the EPZ area, and prohibiting any activity that could cause release or exposure to the environment of a hazardous substance from the EPZ area, while allowing improvements of the property;
- Prohibition of groundwater use except for monitoring and remedial purposes as described in the Draft CAP or 5-year review process;
- Prohibition of water supply wells within 1,000 feet of the CHRLF, consistent with existing state law; and
- Ongoing evaluation of VI potential and construction of vapor controls beneath existing or future buildings.

The environmental covenant will be developed to ensure that the proposed remedial actions are properly implemented and maintained. It will also ensure that the remedial action remains protective of human health and the environment, and that the necessary maintenance and monitoring occur at the EPZ area in coordination with Ecology.

11.1.2 Groundwater Extraction Well Decommissioning

A series of groundwater extraction wells was operated from 1993 through 2010 to control migration of impacted groundwater in the EPZ area. The system did not meet the performance expectations and was shut down in 2010. Extraction well performance issues are discussed in Section 6.1.

With the extraction system no longer operational, and groundwater extraction eliminated from consideration as a preferred remedy component, this FS considers the current conditions of the extraction wells as they pertain to future use in the cleanup action.

Because the groundwater extraction system could not meet the design purpose and because its wells act as vertical LFG and groundwater conduits, decommissioning is proposed for the extraction wells and related system. However, it may be feasible to repurpose the wells to extract LFG:

- **Long-term monitoring**—Ten-foot screen lengths are the appropriate vertical resolution for groundwater and compliance monitoring and for the EPZ area, given three different stratigraphic units over a 40-foot depth. While the extraction wells have 10-foot screens, the large filter packs effectively increase the monitored interval and confound the interpretation of water quality data. The 6-inch well diameter requires longer purge times and produces more purge water that requires management as an investigation-derived waste, which directly impacts cost for long-term monitoring. Therefore, the extraction wells are not suitable for MNA or compliance monitoring.
- **Groundwater extraction**—The challenges associated with operating the extraction wells, as discussed in detail in Section 6.1.1 and based on these challenges, groundwater extraction and treatment technology was not retained as a technology for alternative development.
- **LFG and soil vapor collection**—The long interval of the filter pack creates a preferential flow pathway by which LFG can migrate from the stratified drift to the glacial till/glacio-lacustrine units, potentially contributing to the LFG-to-groundwater pathway and soil vapor concentrations. Well decommissioning would remove this potential preferential flow pathway. On the other hand, however, the existing system also creates a LFG collection opportunity. LFG collection could be implemented at wells with sufficient LFG concentrations and a sufficiently exposed unsaturated well screen section, as determined during predesign activities.

Based on this evaluation, a selected few wells may be used for LFG extraction.

For purposes of cost estimating, it is assumed that 26 of the 29 extraction wells would be abandoned by overdrilling and bentonite backfill. This decommissioning also includes decommissioning of the above-ground infrastructure associated with the groundwater extraction system.

11.1.3 MNA of Groundwater

MNA of groundwater is a fundamental component common to all remedial alternatives evaluated in this FS. MNA is evaluated as a stand-alone remedial alternative; the assumptions associated with the MNA component are described in detail in Section 11.2.1.

11.1.4 LFG Probe Installation

As discussed previously, several of the gas probes originally scoped in the RI/FS Work Plan, located nearest the Passage Point facility, could not be field-located, having been obstructed, destroyed, or never completed. Spatial coverage of VOC in soil gas and LFG data near Passage Point is therefore insufficient. To establish baseline data, installation of replacement gas probes at two locations near Passage Point is proposed. Each location will consist of three gas probes with discrete screened depth intervals. It is recommended that baseline sampling for the presence of VOCs and LFG be conducted during falling barometric pressure events (e.g. less than 30 inches of mercury and falling). After remedy implementation, routine VOC and LFG sampling events (also during falling barometric pressure events) from the proposed new gas probes will yield data by which to evaluate the performance of the selected remedy in terms of mitigating LFG migration within the EPZ area. For cost estimating purposes, it assumed the LFG probes will be sampled annually for the first five years of remedy operation.

11.2 Description of Remedial Alternatives

The remedial alternatives, which are presented in order of increasing permanence and cost, have the following descriptive titles:

- Alternative 1— MNA of groundwater;
- Alternative 2—Optimized LFG control, and MNA of groundwater;
- Alternative 3—Perimeter gas collection, optimized LFG control, and MNA of groundwater; and
- Alternative 4—Perimeter gas collection, expanded LFG control, and MNA of groundwater.

The remedial technologies that make up each alternative (i.e., the remedy components) are summarized in Table 11.1. Conceptual layouts are depicted on Figures 11.1 through 11.4 for Alternatives 1 through 4, respectively, and depict the areas and specific locations for application of each alternative component.

Alternative cost estimates are presented in Appendix G. The quantities presented in Appendix G are conceptual and were developed from existing information as preliminary (FS planning level) cost estimates and for comparison of remedial alternatives. After a remedy is selected, additional data will be gathered , as necessary, to refine quantities and specific locations, and to prepare design-level engineering cost estimates. The following sections describe the remedial alternatives in detail.

11.2.1 Alternative 1: MNA of Groundwater

Alternative 1 relies on MNA combined with institutional controls to achieve RAOs and cleanup standards established in Section 9. The implementation of an MNA remedy would entail monitoring of general chemistry and geochemical parameters, monitoring of COCs to evaluate geochemical conditions and demonstrate that MNA processes are occurring, and monitoring to identify any changes in site conditions that warrant a contingency action.

The following remedial components are included in Alternative 1:

- Institutional controls (refer to Section 11.1.1
- LFG probe installation (refer to Section 11.1.4)
- MNA monitoring at (Figure 11.1):
    - Fifteen existing/replacement EPZ locations
    - Regional groundwater wells, MW-68 and MW-80
- MNA monitoring for the following analytes (analytical method shown in parentheses):
    - EPZ COCs
        - TDS (SM2540C)
        - Dissolved metals (As, Fe, Mn; EPA 6020A)
        - Total arsenic (EPA 6020A)
        - VOCs (EPA 8260C)
    - Geochemical indicators
        - Ammonia, nitrate-N, nitrite-N (SM 4500)
        - Total suspended solids (SM 2540D)
        - Total organic carbon (SM 5310-B)
        - Chloride, sulfate (SM 4110B)
        - Bicarbonate and alkalinity (SM2320-B or EPA 310.1)
        - Dissolved methane, ethane, ethene (RSK 175)
    - Field parameters
- MNA monitoring would be conducted at these frequencies:
    - Quarterly for years 1–5
    - Semiannual for years 5 and on

  - Annual data evaluation and reporting for duration of alternative.

These components and associated assumptions were used to develop estimates of capital and O&M costs for this alternative.

The net present value cost for Alternative 1 is estimated at $2,596,000. This cost was derived assuming a 30-year O&M period and a 1.2 percent discount rate. The detailed cost estimate and assumptions for Alternative 1 are presented in Appendix G.

11.2.2 Alternative 2: Optimized LFG Control and MNA of Groundwater

Alternative 2 relies on optimized LFG control, MNA, and institutional controls to achieve RAOs and cleanup standards established in Section 9. Relative to Alternative 1, Alternative 2 adds operational changes to the existing LFG collection system for a portion the CHRLF Main Hill with no additional collection infrastructure. The optimization of LFG control consists of two modifications: changing operating conditions from relaxed/moderate to aggressive/very aggressive as defined in the SWANA (1997), and adding selected flow-control devices on collection laterals tied into the East and Central Header series. The addition of the flow-control devices allows improved monitoring and flow adjustments necessary for aggressive/very aggressive operating conditions. The proposed locations of these optimized LFG control components are shown on Figure 11.2. The following scope was assumed for costing and alternative screening:

- Institutional controls (refer to Section 11.1.1)
- LFG probe installation (refer to Section 11.1.4)
- MNA program (as described in Section 11.2.1)
- Implementation of aggressive/very aggressive LFG collection on the East Main Hill area. It is assumed that this would take 1 week of effort to implement.
- Installation and monitoring of flow control devices on East and Central Header series. QED precision control valves would be installed at approximately eight header locations (conceptual locations shown on Figure 11.2).
- Optimized LFG control would require 3 weeks per year of LFG operator effort and 2 weeks per year of LFG engineer effort (for data evaluation and recommendations) for the duration of Alternative 2.

The scope described for Alternative 2 is based on preliminary analysis to allow cost estimating and screening alternatives. The assumed scope is representative of the alternative magnitude; however, the specific scope is subject to additional data evaluation, coordination with KCSWD Operations, and other field considerations.

The net present value cost for Alternative 2 is estimated at $3,526,000. This cost was derived assuming a 30-year O&M period and a 1.2 percent discount rate. The detailed cost estimate and assumptions for Alternative 2 are presented in Appendix G.

11.2.3 Alternative 3: Perimeter Gas Collection, Optimized LFG Control, and MNA of Groundwater

Alternative 3 relies on perimeter gas collection, optimized LFG control, MNA, and institutional controls to achieve RAOs and cleanup standards established in Section 9. Relative to Alternative 2, Alternative 3 adds perimeter collection of gas in the EPZ area near the base of the East Main Hill slope through select existing GP- and EW- locations. The proposed GP- locations would be instrumented for gas collection and connected to an existing collection header in the EPZ area. As proposed in Section 11.1.2, select EW- locations would be retrofitted to allow gas collection. The proposed locations of these perimeter collection points are shown on Figure 11.3. The following scope was assumed for costing and alternative screening:

- Institutional controls (refer to Section 11.1.1)
- LFG probe installation (refer to Section 11.1.4)
- MNA program (as described in Section 11.2.1)
- Optimized LFG control (as described in Section 11.2.2)
- Connection of LFG collection to three existing GP pairs:
    - GP-59/60
    - GP-57/58
    - GP-55/56
- Connection of LFG collection to three existing EW locations. Prior to design activities, wells will be identified based on the extent of LFG in the EPZ area, and well screen intervals. The target wells will be rehabilitated and vacuum influence tests will also be performed on these wells. Pending completion of these predesign activities to determine which locations are best suited, the following three locations are assumed to support the FS:
    - EW-17, EW-22, and EW-27;
    - LFG collection would be conveyed to the existing LFG collection line the EPZ area; and
- These perimeter gas control elements would require 2 weeks per year of LFG operator effort and 2 weeks per year for LFG engineer effort (to conduct data evaluation and recommendations) for the duration of the remedial action.

The scope described for Alternative 3 is based on preliminary analysis to allow cost estimating and alternative screening. The assumed scope is representative of the alternative magnitude; however, the specific scope is subject to additional data evaluation, coordination with KCSWD Operations, and other field considerations.

The net present value cost for Alternative 3 is estimated at $3,994,000. This cost was derived assuming a 30-year O&M period and a 1.2 percent discount rate. The detailed cost estimate and assumptions for Alternative 3 are presented in Appendix G.

11.2.4 Alternative 4: Perimeter Gas Collection, Expanded LFG Control, and MNA of Groundwater

Alternative 4 relies on perimeter gas collection, expanded LFG control, MNA, and institutional controls to achieve RAOs and cleanup standards established in Section 9. Relative to Alternative 3, Alternative 4 adds additional LFG collection wells on the East Main Hill. These additional locations comprise the difference between expanded and optimized LFG collection. The proposed locations of these new LFG collection wells are shown on Figure 11.4. The following scope was assumed for costing and alternative screening:

- Institutional controls (refer to Section 11.1.1)
- LFG probe installation (refer to Section 11.1.4)
- MNA program (as described in Section 11.2.1)
- Perimeter gas collection (as described in Section 11.2.3)
- Expanded LFG collection—Installation of four new LFG collection wells to an approximate depth of 250 feet, and completed with high-density polyethylene (HDPE) casing and 50 feet of HDPE screen.

The proposed locations of the LFG collection wells are conceptual; however, the four locations are assumed necessary to prevent the LFG migration pathway through the underlying stratified drift to the EPZ area.

The net present value cost for Alternative 4 is estimated at $4,398,000. This cost was derived assuming a 30-year O&M period and a 1.2 percent discount rate. The detailed cost estimate and assumptions for Alternative 4 are presented in Appendix G.

11.3 Feasibility Study Evaluation Criteria

This section discusses the minimum requirements and procedures for selecting cleanup actions under MTCA (173-340-360 WAC).

11.3.1 MTCA Threshold Requirements

Cleanup actions selected under MTCA must meet four “threshold” requirements identified in 173-340-360(2)(a) WAC to be accepted by Ecology. All cleanup actions must:

- Protect human health and the environment;
- Comply with cleanup standards;
- Comply with applicable state and federal laws; and

- Provide for compliance monitoring.

11.3.2 MTCA Selection Criteria

When selecting from remedial alternatives that meet the threshold requirements, the following three criteria, identified in 173-340-360(2)(b) WAC), must be evaluated:

- **Use permanent solutions to the maximum extent practicable**—A disproportionate cost analysis (DCA) is conducted to assess the extent to which the remedial alternatives address this criterion. The general procedure for conducting a DCA is described in Section 11.3.3 but the DCA is presented in Section 11.5.
- **Provide a reasonable restoration time frame**—MTCA places a preference on remedial alternatives that can achieve the cleanup standards sooner rather than later. Factors to be considered in evaluating whether an alternative provides for a reasonable restoration time frame are identified in 173-340-360(4)(b) WAC.
- **Consider public concerns**—Consideration of public concerns is an inherent part of the site cleanup process under MTCA. The Draft FS report is issued for public review and comment, and Ecology determines whether changes to the report are needed in response to public comments.

11.3.3 MTCA Disproportionate Cost Analysis

A DCA is conducted to determine whether a cleanup action uses permanent solutions to the maximum extent practicable. This is done by evaluating the relative benefits and costs of remedial alternatives. Seven criteria are considered in the evaluation as specified in 173-340-360(3)(f) WAC:

- **Protectiveness**—Overall protectiveness of human health and the environment, including the degree to which existing site risks are reduced, time required to reduce the risks and attain cleanup standards, on-site and off-site risks during implementation, and improvement in overall environmental quality.
- **Permanence**—Degree to which the alternative reduces the toxicity, mobility, or volume of hazardous substances, including the adequacy of destroying hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of treatment, and the characteristics and quantity of the treatment residuals. This criterion incorporates the selection criterion ”use permanent solutions to the maximum extent possible.”
- **Cost**—Remedy design, construction, and long-term O&M costs to implement the alternative.
- **Long-term effectiveness**—Degree of certainty that the alternative will successfully and reliably address contamination that exceeds applicable CULs until CULs are attained, the magnitude of the

residual risk with the alternative in place, and the effectiveness of controls to manage treatment residue and remaining wastes.

- **Short-term risk management—**The risks to human health and the environment during construction and implementation of the alternative, and the effectiveness of measures that will be taken to manage such risks.
- **Implementability—**Technical feasibility of the alternative; the availability of necessary off-site facilities, services, and materials; administrative and regulatory requirements; scheduling, size, and complexity of the alternative; monitoring requirements; access for construction, operations, and monitoring; and integration with existing facility operations and other current or potential remedial actions.
- **Consideration of public concerns—**Degree to which alternative reflects concerns from individuals, community groups, local governments, tribes, federal and state agencies, and other interested organizations; will be addressed by Ecology responding to public comments on this Draft RI/FS report and the subsequent Draft CAP.

The DCA is based on a comparative evaluation of an alternative's cost against the other six criteria (environmental benefits). Per 173-340-360(3)(e)(i) WAC), cost is disproportionate to benefits if the incremental cost of an alternative over that of a lower-cost alternative exceeds the incremental benefits achieved by the alternative over that of the lower-cost alternative.

11.4 Evaluation with Respect to MTCA Threshold Requirements

The four remedial alternatives are evaluated for compliance with the MTCA threshold criteria in this section.

11.4.1 Protection of Human Health and the Environment

Alternatives 2, 3, and 4 would be protective of human health and the environment. The potential for exposure via groundwater consumption, and VI would be addressed using institutional controls. LFG remedial components of Alternatives 2, 3, and 4 would control LFG migration and mitigate the LFG source to groundwater and soil gas.

11.4.2 Compliance with Cleanup Standards

Alternatives 2, 3, and 4 would comply with groundwater, soil gas, and LFG CULs or SL criteria. Groundwater CULs would be achieved through natural attenuation , and landfill gas and soil gas cleanup standards would be achieved through active collection components associated with Alternatives 2, 3, and 4. Alternative 1 is not expected to comply with groundwater cleanup standards, given continued contributions to groundwater concentrations via the LFG pathway in excess of the natural attenuation rates observed in groundwater. Alternative 1 is also not expected to achieve LFG and soil gas cleanup standards.

11.4.3 Compliance with Applicable State and Federal Laws

Potentially applicable state and federal laws are identified and discussed in Section 9.1, and were considered in developing CULs and the remedial alternatives. The four alternatives are expected to comply with all applicable state and federal laws because the required engineering design and agency-review process would include steps to ensure compliance. Many of the laws may affect implementation, but would do not have a significant effect on the fundamental viability of a remedial alternative. The means of compliance would be documented in the remedial design, and other preconstruction documentation to be prepared during the design phase.

11.4.4 Provisions for Compliance Monitoring

All four alternatives would provide for compliance monitoring. Health and safety protocols outlined in a required site-specific health and safety plan would provide protection monitoring. Periodic groundwater sampling and analysis would provide both performance and confirmation monitoring for all alternatives.

11.4.5 Threshold Requirements Evaluation Conclusion

Based on the above evaluation, Alternatives 2, 3, and 4 are all expected to comply with the MTCA threshold criteria. Alternative 1 does not comply with MTCA threshold criteria because, in the absence of remedial action to reduce the source of LFG to groundwater and soil gas and associated exposure pathways, it is not expected to provide protection of human health and the environment. Furthermore, Alternative 1 is not expected to comply with LFG and soil gas cleanup standards.

11.5 Disproportionate Cost Analysis

As discussed in Section 11.3.3, a DCA is performed to evaluate whether a cleanup action uses permanent solutions to the maximum extent practicable. The DCA quantifies the environmental benefits of each remedial alternative, and then compares alternative benefits versus costs. Costs are disproportionate to benefits if the incremental cost of a more permanent alternative over that of a lower-cost alternative exceeds the incremental benefits achieved by the alternative over that of the lower-cost alternative. Alternatives that exhibit disproportionate costs are considered “impracticable” under MTCA.

The DCA is performed in the following sections and summarized in Table 11.2. Environmental benefit was quantified by first rating the alternatives with respect to each of the six criteria, as discussed in Section 11.3.3 (cost is not considered in quantifying environmental benefit). Rating values were assigned on a scale of 1 to 10, where 1 indicates the criterion is satisfied to a very low degree, and 10 indicates the criterion is satisfied to a very high degree. Consistent with FS and cleanup action plans for other Ecology cleanup sites, each criterion was assigned a weighting factor as follows:

- Overall protectiveness—30 percent;
- Permanence—20 percent;

- Long-term effectiveness—20 percent;
- Short-term effectiveness—10 percent;
- Implementability—10 percent; and
- Consideration of public concerns—10 percent.

A MTCA benefits ranking was then obtained for each alternative by multiplying the six rating values by their corresponding weighting factors, and summing the weighted values. Finally, the benefits ranking of each alternative was divided by the alternative's estimated cost to obtain a benefit/cost ratio, which is a relative measure of the cost-effectiveness of the alternative.

11.5.1 Protectiveness

All three retained remedial alternatives would protect human health and the environment by addressing exposure pathways as follows:

- Institutional controls would prevent direct contact with and ingestion of exposure of impacted groundwater.
- Institutional controls would prevent construction resulting in VI exposure risk.

LFG alternative components will reduce the source to groundwater and soil gas concentrations and associated exposure pathways with increasing degrees of protectiveness. Alternative 2 relies on operational changes of existing LFG collection systems to optimize LFG control, an action anticipated to provide protection via reduced groundwater and soil gas concentrations in the EPZ area. Alternative 3 provides an incrementally greater degree of protectiveness with the additional perimeter gas control for removal of groundwater and soil gas concentrations not addressed with the optimized LFG control. Finally, Alternative 4 provides even greater protectiveness from the expanded LFG collection through new LFG collection wells installed in the Main Hill to prevent ongoing LFG transport to the EPZ area.

Based on the above considerations, Alternatives 2, 3, and 4 were assigned overall protectiveness ratings of 6, 8, and 9, respectively (Table 11.2).

11.5.2 Permanence

The EPZ area is adjacent to an operating landfill that will remain an ongoing source to EPZ area groundwater and soil gas impacts. The LandGEM model indicates that the Main Hill will continue to contribute more than 100 cubic feet per minute of methane through 2040. The permanence of any cleanup action requires continued long-term operations through the effective "source term" controlled by the landfill operations and associated LFG-generation lifetime. Given the required long-term operation of all LFG components, incremental permanence of the remedial alternatives is due to the differences in LFG and perimeter gas collection components.

Alternative 3's inclusion of additional perimeter gas control provides only a small increase in permanence relative to Alternative 2 of, since that element does not address the source, but just treatment at the point of exposure. Alternative 4 provides much greater permanence as the new collection wells address LFG closer to the point of generation, and would be more effective at preventing migration of LFG to the EPZ area.

Based on the above considerations, Alternatives 2, 3, and 4 were assigned overall protectiveness ratings of 4, 4, and 7, respectively (Table 11.2).

11.5.3 Long-term Effectiveness

All three alternatives rely on groundwater MNA for achieving groundwater cleanup levels; however, the control of the LFG source to groundwater is more critical to the long-term effectiveness. Long-term effectiveness would be ensured through the implementation of contingency actions for groundwater, if determined necessary by groundwater monitoring. However, contingency actions for groundwater are not anticipated to be necessary based on the LFG components of each remedial alternative. Given the long-term operation of LFG and perimeter components, all three remedial alternatives are expected to be effective over the long-term.

With each alternative, the additional remedial components provide a small increase in long-term effectiveness and rankings of 7, 8, and 9 were assigned for Alternatives 2, 3, and 4, respectively.

11.5.4 Short-term Risk Management

For all alternatives, the short-term risks to workers and the public are limited to worker safety during cleanup action implementation and can be managed through the on-site health and safety program. The specific tasks with risks include installation of flow-control devices on operating collection lines (Alternatives 2, 3, and 4), equipment decommissioning to retrofit EW- locations (Alternatives 3 and 4), installation of new conveyance lines (Alternatives 3 and 4), and drilling of new LFG collection wells (Alternative 4 only). Based on these limited short-term risks and management, rankings of 9, 8, and 7 were assigned for Alternatives 2, 3, and 4, respectively.

11.5.5 Implementability

In general, implementability decreases with increased complexity of the alternatives. Overall, the implementability of all alternatives is moderate due to ongoing LFG operations. Implementation of the increased LFG operations may compete with time to maintain existing operations. It is assumed the perimeter gas collection initial implementation would be led by a consultant in coordination with KCSWD Operations, and that King County would assume long-term operations. The drilling associated with Alternative 4 presents some unique implementation challenges.

Based on the above considerations, Alternatives 2, 3, and 4 were assigned overall protectiveness ratings of 6, 5, and 3, respectively (Table 11.2).

11.5.6 Consideration of Public Concerns

Ecology considers and responds to all public comments received on the Draft RI/FS and Draft CAP documents as part of the cleanup process under MTCA. Such feedback will, as a matter of course, be sought later in the MTCA process. Meanwhile, all three alternatives were assigned an equal rating of 10 for consideration of public concerns.

11.5.7 Benefit/Cost Ratios

The MTCA benefits rankings, estimated costs, and benefit/cost ratios for the four remedial alternatives are presented at the bottom of Table 11.2 and graphically on Figure 11.5. As noted, the MTCA benefits ranking is obtained for each alternative by multiplying the values assigned for the six evaluation criteria by their corresponding weighting factors, and summing the weighted values. The benefit rankings are 6.5, 7.1, and 7.9 for Alternatives 2, 3, and 4 respectively.

The benefit/cost ratio, which is a relative measure of cost-effectiveness, is obtained by dividing each alternative’s benefits ranking by its estimated cost. Alternative 2 has the highest benefit/cost ratio, at 1.84 (Table 11.2).

11.6 Evaluation of Reasonable Restoration Timeframe

As noted in Section 11.5.7, the cleanup alternative identified by the DCA as most cost-effective (i.e., Alternative 2) must also provide for a reasonable restoration time frame. Alternative 2 is expected to comply with cleanup standards within a reasonable restoration time frame. The restoration time frame is highly dependent on preventing LFG migration to the EPZ area and continued impacts to EPZ area groundwater and soil gas. Alternative 2 relies on optimized operations of the existing LFG collection infrastructure to achieve cleanup standards, and the monitoring data suggest that enhancements of LFG collection can be made. Once LFG migration to the EPZ area has been mitigated, groundwater and soil gas impacts will naturally attenuate and cleanup standards achieved. On this basis, Alternative 2 is expected to provide for a reasonable restoration time frame.

12.0 PREFERRED ALTERNATIVE

Data from the RI portion of this Draft RI/FS (i.e., Sections 1 through 8) were used in the FS process to develop four remedial alternatives for the EPZ area. The alternatives were then evaluated against criteria defined by MTCA. The evaluation included comparative assessment of the environmental benefits and costs of each alternative to determine the alternative that uses permanent solutions to the maximum extent practicable (i.e., the “preferred” alternative).

12.1 Preferred Remedial Alternative

The preferred alternative for the EPZ area is Alternative 2 (Figure 11.2), which consists of the following elements:

- Institutional controls;
- LFG probe installation
- Decommissioning of groundwater extraction wells;
- MNA of groundwater; and
- Optimization of the LFG operations on portions of the CHRLF Main Hill including:
    - Changing operating conditions from relaxed/moderate to aggressive/very aggressive as defined in SWANA (1997); and
    - Adding selected flow-control devices on collection laterals tied into the East and Central Header series.

The selected cleanup action will be presented in the Draft CAP, which will describe the cleanup action and specify cleanup standards and compliance monitoring requirements. Following public review of the CAP, the remedy will be implemented in phases, including (as applicable) predesign investigation, remedy design, permitting, construction, development and filing of institutional controls, and long-term compliance monitoring.

Based on the screening conducted in Section 11, Alternative 2 will comply with the RAOs set forth in Section 9.7, and the requirements of MTCA as evaluated in the Section 11. If monitoring indicates that the implemented alternative does not comply, contingency actions would be implemented. The additional components of Alternatives 3 and 4 would be implemented to provide additional control of LFG migration, protection of human health and the environment, and compliance with cleanup requirements.

12.2 Operations, Maintenance, and Monitoring

This section addresses the required long-term monitoring that is part of the presumptive remedy for landfills. To ensure that the remedy is effective and provides long-term protection of human health and the environment, groundwater, LFG, and soil gas must be monitored. The O&M and monitoring requirements discussed in this section apply to the EPZ area only and do not supersede routine detection monitoring, operations, or maintenance for the rest of the landfill.

This section provides an overview of monitoring systems for each medium. The final groundwater monitoring locations, sampling frequency, and analytes will be provided in a Compliance Monitoring Plan in the Draft CAP.

12.2.1 Groundwater Monitoring

The goal of groundwater monitoring is to confirm that the landfill remedy is performing as expected, and to determine when groundwater COC comes into compliance. The long-term monitoring plan for the EPZ area will be further defined as part of the Draft CAP. The discussion below is designed to set expectations regarding the scope of the groundwater monitoring program.

12.2.1.1 Proposed Monitoring Well Network

MTCA regulation 173-340-710 7(c) specifies that for the selection of cleanup requirements at municipal solid waste landfills, closure requirements in 173-304 WAC shall be considered the minimum requirements for cleanup actions. Furthermore, MTCA also allows for Ecology to determine that the closure regulations governed by 173-351 WAC may be applicable and appropriate, if the landfill qualifies as a 173-351 WAC landfill. As such, the groundwater monitoring program established to evaluate the progress of the selected remedy in the EPZ area will rely on the definition of POC wells, per 173-351 WAC, whereby POC wells must be established within 150 meters (492 feet) from the landfill waste boundary.

The EPZ monitoring well network proposed for long-term compliance monitoring in the EPZ area is presented in Table 12.1. This table evaluates all monitoring wells included in the RI, identifies those currently monitored by KCSWD, presents a proposed monitoring schedule for compliance monitoring, specifies the purpose served by the well, and the explains the rationale for selection. The SAP for CHRLF indicates that the sample locations, frequency, and analytical testing scheme for the EPZ in the SAP are to be reevaluated as part of the MTCA process. In total, Table 12.1 identifies five POC wells and eight performance monitoring wells in the EPZ area. Additionally, 12 EPZ monitoring wells have been selected for routine water level monitoring for continued delineation of the extent of the ESPZ and NESPZ. Figure 12.1 depicts the proposed monitoring well network. Six of the proposed performance monitoring wells are new wells to be installed as replacements for the groundwater extraction wells proposed for decommissioning or retrofitting.

No changes are proposed for Regional Aquifer monitoring wells. These wells serve as detection monitoring locations required under the existing permit for the landfill, and represent adequate spatial coverage for the purposes of the EPZ compliance monitoring as well.

12.2.1.2 Proposed Analytical Schedule

The Main Hill area of the landfill stopped receiving waste in the mid-1980s and received a permanent cover in 1991. Groundwater monitoring for the Main Hill has occurred since 1989, if not earlier, and as such, has yielded a monitoring dataset of considerable size for several of the EPZ wells that provide trends for select COCs. The concentration plots for select EPZ wells indicate that many of the COC concentrations have steadily decreased over time, and the geochemical condition of the EPZ area is amendable to natural attenuation, lending support for MNA as a component of the preferred remedy. Table 12.2 presents an evaluation of analytes and proposes the analyte schedule for future monitoring.

12.2.1.3 Reporting

During the first 5 years after the CAP implementation, reporting will occur annually. Further details will be provided in the Draft CAP. Monitoring and reporting requirements beyond this period will be resolved as part of Ecology's ongoing site review process.

12.2.2 Soil Gas Monitoring

Additional monitoring of VOCs in soil gas is recommended to evaluate the performance of the LFG component of the preferred remedy. Replacement of the gas probes near Passage Point and sampling of probes for VOCs is recommended for development as a baseline prior to remedy implementation. These replacement gas probes will also be useful during routine landfill gas monitoring as described below. Once soil gas has been eliminated as a potential exposure pathway, the gas probe monitoring will then be conducted to evaluate performance of the LFG remedy.

12.2.3 Landfill Gas Monitoring

LFG monitoring in the EPZ area is conducted by KCSWD, using gas probes installed at strategic locations to measure LFG composition and pressure. The gas probes are used to determine the nature and extent of LFG migration in EPZ area native soils. Monitoring of these gas probes is required to determine compliance with Ecology and SKCPH regulations requiring that methane levels at and beyond the CHRLF property boundary not exceed the methane LEL (typically, 5 percent by volume). In addition, the regulations require that methane levels not exceed 100 parts per million by volume in on-site or off-site building structures. Details on the LFG monitoring program are presented in the CHRLF Landfill Gas Operation and Maintenance Manuel Update (HEC, 2013). The gas probe monitoring also provides performance information for adjustments to the Main Hill LFG extraction system. When methane levels exceed 20 percent of the LEL at gas probes, LFG extraction wells within a 1,000-foot radius of the gas probe are evaluated for possible LFG collection flow adjustments (HEC, 2013).

LFG monitoring is currently conducted by KCSWD monthly at all gas probe locations identified in the EPZ area. Parameters that are typically measured include methane, oxygen, carbon dioxide, and static pressure. The specific gas probe location and monitoring requirements will be presented in the Draft CAP and compliance monitoring plan.

12.3 Anticipated Schedule

The Final RI/FS is scheduled to be submitted 30 days after receipt of agency comments on the Agency Draft RI/FS. Following the approval of the Final RI/FS, a draft CAP and an environmental covenant will be developed; a schedule for these documents has not been established at this time.

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14.0 Limitations

Work for this project was performed for the King County Solid Waste Division (Client), and this report was prepared in accordance with generally accepted professional practices for the nature and conditions of work completed in the same or similar localities, at the time the work was performed. This report does not represent a legal opinion. No other warranty, expressed or implied, is made.

All reports prepared by Aspect Consulting for the Client apply only to the services described in the Agreement(s) with the Client. Any use or reuse by any party other than the Client is at the sole risk of that party, and without liability to Aspect Consulting. Aspect Consulting's original files/reports shall govern in the event of any dispute regarding the content of electronic documents furnished to others.

TABLES

Table 2.1 - Summary of EPZ Explorations

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Well(s)[2]	Installation Date	Installed By/Reference[1]	Comments
Soil Borings/Geoprobe Explorations			
EPZ-BH-1	Jun-06	Aspect 2007	Evaluate extent of perched zones to the east/characterize hydrogeology.
EPZ-BH-2 through EPZ-HG-15	Aug-09	Aspect 2010	Provide data on thickness of shallow fill/till soils/collect LFG data for siting permanent probes.
East Perched Zone Monitoring Wells and Piezometers			
MW-23	May-83	SEA 1984	Likely installed during initial site characterization activities. Dry well decommissioned January 2009.
MW-29, MW-30	Jun-83	SEA 1984	Installed during initial site characterization actitvities.
MW-30A	Sep-89	SEE 1991b	Replaces MW-30, which was decommissioned during 1989 final closure of Main Hill.
MW-47	May-85	SEE 1991b	Installed as part of Cedar Hills Site Development Plan Project.
MW-50	Jun-85		
MW-62 and MW-63	Feb-90	SEE 1991	Installed as part of first extensive investigation of EPZ by SEE 1991. MW-62 was intially referred to as MW-60. MW-63 was initally referred to as MW-61.
EB-1 through EB-5, EB-5S	Jun-, Jul-90	SEE 1991	Installed as part of first extensive investigation of EPZ by SEE 1991.
EB-6, EB-7	Nov-90	SEE 1991	Installed as part of first extensive investigation of EPZ by SEE 1991.
MW-102 through MW-104	Jan-09	Aspect 2010	Evaluation of extent of perched zones and area of impacted groundwater
Regional Aquifer Monitoring Wells Within EPZ Project Area			
MW-67 and MW-68	Apr-93	CH2M Hill/UES 2004	Installed as part of Regional Aquifer characterization.
MW-75	Sep-99	CH2M Hill/UES 2004	Installed as part of Regional Aquifer characterization.
MW-80	Feb-01	CH2M Hill/UES 2004	Installed as part of Regional Aquifer characterization.
MW-81	Oct-00	CH2M Hill/UES 2004	Installed as part of Regional Aquifer characterization.
MW-87	Nov-00	CH2M Hill/UES 2004	Installed as part of Regional Aquifer characterization.
MW-91	Jan-02	CH2M Hill/UES 2004	Installed as part of Regional Aquifer characterization. Used for aquifer testing of Regional Aquifer.
MW-93	Jun-02	CH2M Hill/UES 2004	Installed as part of Regional Aquifer characterization.
MW-99	Aug-02	CH2M Hill/UES 2004	Installed as part of Regional Aquifer characterization. Replaced MW-44.
Groundwater Extraction Wells			
EW-1 through EW-29	May- to Oct-92	HLA 1993	Groundwater remediation.
Gas Probes			
GP-1	May-85		
GP-7, GP-8, GP-15 through GP-20	Mar- to Jul-88	SEE 1991	
GP-ATC-5 through GP-ATC-8	Oct-86		
GP-55 through GP-62	Oct-09	Aspect 2010	Provide data on fugutive LFG, assess potential for LFG impacts on groundwater
LFG Extraction Wells			
E-29A through E-29D	NA	NA	Boring logs have not been located.

Notes:

[1] Installation references for SEA 1984 is presumed based on the date of the well installation. If reference is blank, then no reference information is known.

[2] - Well list does not include secondary water level locations.

EPZ = East Perched Zone
LFG = landfill gas
SEA = Sweet Edwards Associates
SEE = Sweet Edwards Emcon
HLA = Harding Lawson Associates
UES = Udaloy Environmental Services
NA = Not Available

Table 2.2 - Well Construction Information

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Aquifer	Well ID	Historical Boring Log ID (if different)**	Well Diameter (in)	Stick up (ft)	TOC Elevation (ft MSL)***	Well Completion Depth (ft bgs)	2015 Aspect Measured Depth to Bottom (ft btoc)	Screened Interval (ft bgs)	Filter Pack Interval (ft bgs)	Screened Geologic Unit	Comments/Notes
Perched	MW-29	NA	3	1.27	532.92	27	NA	18 - 27	NA	Stratified Drift	Turbidity clears up during purge.
Perched	MW-30A	NA	2	0.76	568.43	35	36.3	25 - 35	15 - 35.5	Stratified Drift	Low yielding well. Purge time is approximately 1 hour.
Perched	MW-47	NA	2	1.04	634.60	44	41.5	23.5 - 43.5	21 - 44.5	Weathered Till / Glacio-Lacustrine	
Perched	MW-48	NA	2	0.85	594.49	47	47.2	37 - 47	NA	Weathered Till / Glacio-Lacustrine	
Perched	MW-50	NA	2	0.82	637.02	38	38.9	27.5 - 37.5	25.5 - 37.5	Weathered Till / Glacio-Lacustrine	Purges dry and very slowly recharging (approx. ~ 0.03 ft in 20 minutes).
Perched	MW-62	NA	2	0.92	556.21	54	55.3	44 - 54	41.5 - 54.5	Stratified Drift	Difficult well to sample. Dry 3 out of 4 quarters. When not dry, typical volume sufficient for only VOAs and partial metals collection.
Perched	MW-63	NA	2	2.06	515.88	17	19.2	11.5 - 16.5	NA	Stratified Drift	Well cap is large welded rectangular box. Occassionally dry.
Perched	MW-102	NA	2	2.75	552.48	49.5	52.3	34.5 - 49.5	32 - 50	Stratified Drift	
Perched	MW-103	NA	2	2.28	639.08	35	36.6	25 - 35	22.5 - 37	Weathered Till / Glacio-Lacustrine	
Perched	MW-104	NA	2	2.76	629.68	32	35.4	22 - 32	19.5 - 35	Weathered Till / Glacio-Lacustrine	
Perched	EB-1	NA	2	1.43	532.30	22	23.4	17 - 22	13 - 23	Stratified Drift	PVC well cap with vapor point.
Perched	EB-2	NA	2	1.9	530.12	24	25.5	13.5 - 23.5	11 - 23.5	Stratified Drift	Historically low recharge and difficult to sample. Redeveloped the well and recharge is adequate.
Perched	EB-3	NA	2	1.5	608.87	40	41.4	35 - 40	31.5 - 41	Stratified Drift	PVC well cap with vapor monitoring point. Large metal object attached to monument cap.
Perched	EB-4	NA	2	2	645.79	35	37.4	30 - 35	20 - 36	Weathered Till / Glacio-Lacustrine	
Perched	EB-5	NA	2	1.5	645.53	60	62.3	55 - 60	50 - 61	Weathered Till / Glacio-Lacustrine	PVC well cap with vapor monitoring point.
Perched	EB-5S	NA	2	1.32	645.91	20	21.9	15 - 20	13 - 20	Weathered Till / Glacio-Lacustrine	PVC well cap with vapor monitoring point.
Perched	EB-6D	NA	2	1.75	589.61	30	31.7	20 - 30	16 - 30.5	Stratified Drift	Dedicated pump and tubing. Occassionally dry.
Perched	EB-7	NA	2	1.91	611.01	56.5	58.2	31 - 56	28 - 57	Stratified Drift	PVC well cap wth vapor monitoring point
Perched	EW-1	EW-17A	6	1.31	552.77	47.67	50.5	31.2 - 40.6	7.5 - 41.5	Stratified Drift	Casing modifications after installation. Construction information modified based on field measurements. Bottom of well is very soft and total depth difficult to measure.
Perched	EW-2	EW-12A	6	1.88	561.02	34.80	35.2	19.3 - 28.6	8 - 29.5	Weathered Till & Stratified Drift	Casing modifications after installation. Construction information modified based on field measurements. Seasonally dry. Restriction below water surface that prevents passive sampler deployment.
Perched	EW-3	EW-16A	6	0.65	559.88	59.70	64.3	44.7 - 54	7.5 - 54.4	Stratified Drift	Casing modifications after installation. Construction information modified based on field measurements.
Perched	EW-4	EW-1A	6	1.12	566.36	69.68	70.8	42.3 - 61.7	NA	Stratified Drift	Casing modifications after installation. Construction information modified based on field measurements.
Perched	EW-5	EW-9A	6	0.95	574.21	46.25	58.1	40.35 - 49.7	7.5 - 50.7	Stratified Drift	Casing modifications after installation. Construction information modified based on field measurements. Well cap in place--possible gas monitoring port attached.
Perched	EW-6	EW-10A	6	0.53	582.63	59.20	62	45.54 - 54.89	8.5 - 55.5	Stratified Drift	Casing modifications after installation. Construction information modified based on field measurements.

Table 2.2 - Well Construction Information

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Aquifer	Well ID	Historical Boring Log ID (if different)**	Well Diameter (in)	Stick up (ft)	TOC Elevation (ft MSL)***	Well Completion Depth (ft bgs)	2015 Aspect Measured Depth to Bottom (ft btoc)	Screened Interval (ft bgs)	Filter Pack Interval (ft bgs)	Screened Geologic Unit	Comments/Notes
Perched	EW-7	EW-11A	6	1.61	593.27	45.80	47.3	30.4 - 39.73	7.8 - 40.7	Stratified Drift	Casing modifications after installation. Construction information modified based on field measurements. Seasonally dry.
Perched	EW-8	EW-13A	6	1.45	600.20	54.50	58.2	39.2 - 48.4	8.1 - 48.7	Stratified Drift	Casing modifications after installation. Construction information modified based on field measurements. Water level is sometimes below bottom of screen despite several feet of water at bottom of well.
Perched	EW-9	EW-3A	6	1.87	602.89	46.20	46.5	31.2 - 40.5	7.3 - 41	Stratified Drift	Casing modifications after installation. Construction information modified based on field measurements. Pump removed 6/15/15.
Perched	EW-10	EW-8A	6	1.56	608.71	43.80	47.2	28.28 - 37.6	8.25 - 38.6	Stratified Drift	Casing modifications after installation. Construction information modified based on field measurements. Seasonally dry.
Perched	EW-11	EW-2A	6	1.14	617.44	43.50	47.2	28 - 37.4	8 - 38.0	Glacio-Lacustrine & Stratified Drift	Casing modifications after installation. Construction information modified based on field measurements. Seasonally dry.
Perched	EW-12	EW-21A	6	1.26	623.02	39.80	37.4	22.5 - 31.8	8 - 32.5	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements.
Perched	EW-13	EW-18A	6	1.11	633.76	39.90	40.3	24.4 - 33.7	8.3 - 34.3	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements. Pump in place. Blocking total depth.
Perched	EW-14	EW-4A	6	1.84	633.42	47.90	48.4	32.6 - 42	8.2 - 42.5	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements.
Perched	EW-15	EW-15A	6	1.54	635.09	47.80	45.2	29.6 - 39	4.6 - 39.4	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements.
Perched	EW-16	EW-7A	6	2.33	636.71	43.70	42.3	29.5 - 38.81	8 - 38.65	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements.
Perched	EW-17	EW-5A	6	3.04	637.08	43.50	43	29.5 - 38.9	8.5 - 39.8	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements. Well is silted to just below bottom of screen.
Perched	EW-18	EW-23A	6	1.2	639.59	43.10	41.8	27.4 - 36.7	8.8 - 37.5	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements.
Perched	EW-19	EW-6A	6	2	639.98	44.00	45.2	29 - 38.4	8.5 - 38.95	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements.
Perched	EW-20	EW-22A	6	2.54	638.68	43.20	41.3	28.7 - 38	11 - 38.3	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements. Seasonally Dry. Well is silted to just below bottom of screen.

Table 2.2 - Well Construction Information

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Aquifer	Well ID	Historical Boring Log ID (if different)**	Well Diameter (in)	Stick up (ft)	TOC Elevation (ft MSL)***	Well Completion Depth (ft bgs)	2015 Aspect Measured Depth to Bottom (ft btoc)	Screened Interval (ft bgs)	Filter Pack Interval (ft bgs)	Screened Geologic Unit	Comments/Notes
Perched	EW-21	EW-14A	6	1.42	640.84	39.50	37.2	24 - 33.4	7.5 - 35	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements.
Perched	EW-22	EW-19A	6	0.57	639.48	44.10	40.3	30.5 - 39.8	NA	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements. Well is silted to just below bottom of screen.
Perched	EW-23	EW-20A	6	3.33	640.15	44.50	42.5	30.7 - 40.1	8 - 40.7	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements. Well is silted to just below bottom of screen.
Perched	EW-24	EW-27A	6	1.27	642.84	39.00	38.7	24.1 - 33.4	8 - 34.3	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements.
Perched	EW-25	EW-29A	6	1.59	643.39	38.30	38.6	22.8 - 32	7.8 - 33	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements.
Perched	EW-26	EW-24A	6	1.97	641.99	36.00	34.1	21.1 - 30.5	7.8 - 32.2	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements.
Perched	EW-27	EW-30A	6	2.41	640.53	36.90	37.3	21.7 - 31	8.1 - 31.6	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements. Dedicated pump in place.
Perched	EW-28	EW-31A	6	1.48	640.49	22.80	22.5	7.7 - 17	NA	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements.
Perched	EW-29	EW-28A	6	1.88	638.56	23.60	23.8	8.2 - 17.5	6.2 - 19	Weathered Till / Glacio-Lacustrine	Casing modifications after installation. Construction information modified based on field measurements. Dedicated pump in place but is not operational.
Perched	SG-4	NA	NA	3.44	505.85	NA	NA	NA	NA	NA	3.44 ft represents the measurement in distance from the 0.00 foot label on the stream gage to the top of casing. Top of piezometer casings were calculated by measuring from surveyed stream gage label. Elevation of stream gage at 0.00' is 502.41 ft NVGD29. Elevation of 505.85 ft represents the elevation of the top of piezometer casing.
Perched	SG-5	NA	NA	3.42	490.34	NA	NA	NA	NA	NA	3.42 feet represents the measurement in distance from the 0.00 foot label on the stream gage to the top of casing. Top of piezometer casings were calculated by measuring from surveyed stream gage label. Elevation of stream gage at 0.00' is 486.92 ft amsl NVGD29. Elevation of piezometer casing measured 490.34 ft.
Regional	MW-67	NA	2.5	2.33	516.43	230	NA	216.3 - 230.1*	212.8 - 234.3*	Pre-Vashon Deposits	
Regional	MW-68	NA	2.5	2.28	647.07	353	NA	333.5 - 352.5*	330.5 - 356*	Pre-Vashon Deposits	Well is susceptible to biofouling/scaling. Periodic redevelopment recommended.
Regional	MW-75	NA	4	2.6	532.4	269	NA	258.7 - 268.8*	252.9 - 270*	Pre-Vashon Deposits	Bentonite was identified in groundwater sample collected from this well initially.
Regional	MW-80	NA	4	1.94	530.41	259	NA	249.3 - 258.8*	246 - 265*	Advanced Outwash & Pre-Vashon Deposits	Bentonite was identified in groundwater sample collected from this well initially.

Table 2.2 - Well Construction Information

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Aquifer	Well ID	Historical Boring Log ID (if different)**	Well Diameter (in)	Stick up (ft)	TOC Elevation (ft MSL)***	Well Completion Depth (ft bgs)	2015 Aspect Measured Depth to Bottom (ft btoc)	Screened Interval (ft bgs)	Filter Pack Interval (ft bgs)	Screened Geologic Unit	Comments/Notes
Regional	MW-81	NA	4	1.47	493.66	192	NA	183 - 192.5*	179.1 - 198.5*	Advanced Outwash	
Regional	MW-85	NA	4	2	531.76	257	NA	247.2 - 256.7*	241.2 - 261.5*	Advanced Outwash	
Regional	MW-87	NA	4	2.13	537.31	261	NA	251.3 - 260.8*	246.5 - 262*	Pre-Vashon Deposits	
Regional	MW-91	NA	6	2.31	532.02	289	NA	268.9 - 289*	240.7 - 300.5*	Pre-Vashon Deposits	
Regional	MW-93	NA	4	1.98	632.15	145	NA	310.3 - 320.1*	307.7 - 350*	Pre-Vashon Deposits	
Regional	MW-99	NA	4	1.87	493.64	279	NA	270 - 279*	266.9 - 283.3*	Pre-Vashon Deposits	

Notes:

Primary data source: Aspect, 2007, *Phase I Investigations Groundwater Monitoring Well System Enhancements.*

2015 measurements made by Aspect; depth to bottom of well tagged using water level meter.

Stream gage data source: CH2M Hill and Udaloy, 2004, *Site-Wide Hydrogeologic Report Volume 1*, May 2004.

* = Screened interval and filter pack interval calculated from elevations presented in CH2M Hill and Udaloy, 2004, *Site-Wide Hydrogeologic Report Volume 1*. Well diameter and well installation depth data from Aspect, 2007, *Phase I Investigations Groundwater Monitoring Well System Enhancements*.

** = Data source: Harding Lawson Associates, 1993, *King County Cedar Hills Landfill - Extraction Well Installation Status Report*, prepared for King County Solid Waste Division, May 13, 1993.

*** = Horizontal datum used for the 2016 extraction well survey and historical survey was State Plane Coordinate System (SPCS) Washington North NAD27. Vertical datum used for the 2016 extraction well survey was National Geodetic Vertical Datum 1929 (NGVD29).

ft = feet, ft bgs = feet below ground surface, ft btoc = feet below top of casing, ft MSL = feet above mean sea level, in = inches, TOC = top of casing

NA = Data is not available or unknown.

Screened geologic unit designation derived from boring logs (Appendix A). Weathered Till / Glacio-Lacustrine considered one unit. When two units are presented seperated by "&" it indicates the well is screened in two distinct geologic units. EW wells also have long sand packs that span across multiple units, but only the screened units are reflected above.

Table 2.3 - Gas Probe Construction Information

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Well ID	Stick-up (ft)	Well Diameter (in)	Top of PVC Elevation (ft MSL)	Boring Depth (ft bgs)	2015 Measured Total Depth of Probe (ft btoc)	Screened Interval (ft bgs)	Screened Geologic Unit	Notes
GP-1A	2.41	0.5	639.93	22.5	14	8 - 12	Weathered Till / Glacio-Lacustrine	
GP-1B	2.3	0.5	639.82	22.5	24.8	18.5 - 22.5	Weathered Till / Glacio-Lacustrine	Bottom of screen elevation from boring log above measured elevation.
GP-2A	2.76	0.5	627.03	22.5	12.8	6 - 10	Weathered Till / Glacio-Lacustrine	
GP-2B	2.76	0.5	627.03	22.5	25.2	18 - 22	Weathered Till / Glacio-Lacustrine	
GP-3	0.3	0.5	594.21	63	---	15.5 - 19.5	Weathered Till / Glacio-Lacustrine	Obstructed at 11 feet.
GP-4A	2.43	0.5	605.72	24	11.79	5 - 9	Weathered Till / Glacio-Lacustrine	
GP-4B	2.56	0.5	605.85	24	22.26	15.5 - 19.5	Weathered Till / Glacio-Lacustrine	
GP-5A	1.24	0.5	617.47	75	9.9	6 - 7	Weathered Till / Glacio-Lacustrine	Measured dry (likely obstructed).
GP-5Ba	1.56	0.5	619.33	75	9.5	6 - 7	Weathered Till / Glacio-Lacustrine	
GP-5Bb	1.59	0.5	619.3	75	23.1	22 - 23	Weathered Till / Glacio-Lacustrine	Bottom of screen elevation from boring log above measured elevation.
GP-5Bc	1.58	0.5	619.31	75	32.5	51 - 52	Stratified Drift	Obstructed.
GP-5Bd	1.58	0.5	619.31	75	5.3	63 - 64	Stratified Drift	Bottom of screen elevation from boring log above measured elevation.
GP-6A	1.72	0.5	634.81	203	56	54 - 55	Stratified Drift	Bottom of screen elevation from boring log is above measured elevation. Boring logs just have 4 probes in GP-6A and 4 in GP-6B. Matched boring log depths up with closest field measured depth.
GP-6B	1.6	0.5	634.53	203	116.9	84 - 85	Stratified Drift	Likely obstructed. Boring logs just have 4 probes in GP-6A and 4 in GP-6B. Matched boring log depths up with closest field measured depth.
GP-6C	1.62	0.5	634.75	203	148.7	94 - 95	Stratified Drift	Bottom of screen elevation from boring log above measured elevation. Total depth measured indicates well was mislabeled in field. Boring logs just have 4 probes in GP-6A and 4 in GP-6B. Matched boring log depths up with closest field measured depth. 2007 report suggests the well was mislabeled in the field.
GP-6D	1.66	0.5	634.69	203	98.2	113 - 114	Stratified Drift	Bottom of screen elevation from boring log above measured elevation. Total depth measured indicates well was mislabeled in the field. Boring logs just have 4 probes in GP-6A and 4 in GP-6B. Matched boring log depths up with closest field measured depth. 2007 report identified boring log bottom above measured bottom.
GP-6E	1.53	0.5	634.62	203	72.8	134 - 135	Stratified Drift	Bottom of screen elevation from boring log above measured elevation. Boring logs just have 4 probes in GP-6A and 4 in GP-6B. Matched boring log depths up with closest field measured depth. 2007 report identified boring log bottom above measured bottom.
GP-6F	1.72	0.5	634.81	203	133.1	148 - 149	Stratified Drift	Bottom of screen elevation from boring log above measured elevation. Boring logs just have 4 probes in GP-6A and 4 in GP-6B. Matched boring log depths up with closest field measured depth. 2007 report identified boring log bottom above measured bottom.
GP-6G	1.59	0.5	634.68	203	166.7	163 - 164	Stratified Drift	Bottom of screen elevation from boring log above measured elevation. Boring logs just have 4 probes in GP-6A and 4 in GP-6B. Matched boring log depths up with closest field measured depth. 2007 report identified boring log bottom above measured bottom.
GP-6H	1.44	0.5	634.71	203	89.2	178 - 179	Stratified Drift	Bottom of screen elevation from boring log above measured elevation. Total depth measured indicates well was mislabeled in the field. Boring logs just have 4 probes in GP-6A and 4 in GP-6B. Matched boring log depths up with closest field measured depth. 2007 report identified boring log bottom above measured bottom.
GP-7	1.88	0.5	640.24	58	51.6	48 - 50	Weathered Till / Glacio-Lacustrine	Bottom of screen elevation from boring log above measured elevation.
GP-8	1.46	0.5	642.23	60	46	44.5 - 46.5	Stratified Drift?	Bottom of screen elevation from boring log above measured elevation. 2007 report identified boring log bottom above measured bottom. Screen fully silted? Obstruction at about 6 ft down initially that was broken through during second measurement. Something on the bottom of well.
GP-9	1.42	0.5	644.99	70	39.7	58 - 60	Stratified Drift	Bottom of screen elevation from boring log above measured elevation.

Table 2.3 - Gas Probe Construction Information

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Well ID	Stick-up (ft)	Well Diameter (in)	Top of PVC Elevation (ft MSL)	Boring Depth (ft bgs)	2015 Measured Total Depth of Probe (ft btoc)	Screened Interval (ft bgs)	Screened Geologic Unit	Notes
GP-11A	2.3	0.5	566.69	100	7.1	6.5 - 7.5	Weathered Till / Glacio-Lacustrine	Full screen silted.
GP-11B	2.32	0.5	566.71	100	NA	23.5 - 25	Weathered Till / Glacio-Lacustrine	Potentially obstructed. Likely mislabeled in the field. Could not get probe down past 3.4 ft btoc.
GP-11C	2.35	0.5	566.74	100	35.2	54.5 - 60	Stratified Drift	Field measurments of well bottom much shallower than boring log indicates. Full screen silted?
GP-11D	2.33	0.5	566.72	100	26.2	91.5 - 93	Stratified Drift	Likely mislabeled in the field. Field measurments of well bottom much shallower than boring log indicates. Full screen silted?
GP-12A	1.71	0.5	567.79	90	8.4	6.5 - 8	Weathered Till / Glacio-Lacustrine	
GP-12B	1.72	0.5	567.8	90	23.4	20.5 - 22	Weathered Till / Glacio-Lacustrine	
GP-12C	1.61	0.5	567.69	90	46.8	44.5 - 469	Stratified Drift	Half screen silted.
GP-12D	1.65	0.5	567.73	90	76.4	73 - 75	Stratified Drift	Bottom of screen elevation from boring log above measured elevation.
GP-13A	0.82	0.5	587.87	89	8.6	6.5 - 8	Weathered Till / Glacio-Lacustrine	Bottom of screen elevation from boring log above measured elevation.
GP-13B	0.8	0.5	587.85	89	22.4	20.5 - 22	Weathered Till / Glacio-Lacustrine	
GP-13C	0.71	0.5	587.76	89	37.8	35.5 - 37	Stratified Drift	Bottom of screen elevation from boring log above measured elevation.
GP-13D	0.69	0.5	587.74	89	78.7	78.5 - 80	Stratified Drift	Full screen silted.
GP-14A	1.93	0.5	613.05	100	69.4	68.5 - 70	Stratified Drift	Full screen silted.
GP-14B	1.91	0.5	613.03	100	88.2	86.5 - 88	Stratified Drift	Full screen silted.
GP-15A	1.1	0.5	618.35	89	8	6.5 - 8	Weathered Till / Glacio-Lacustrine	Possibly obstructed. Bottom not solid. Hitting a rubber stopper?
GP-15C	1.13	0.5	618.38	89	37.6	34.5 - 36	Stratified Drift	Bottom of screen elevation from boring log above measured elevation. Possibly obstructed as bottom does not feel solid. Possibly hitting a rubber stopper?
GP-15D	1.06	0.5	618.31	89	2.8	82.5 - 84	Stratified Drift	Likely mislabeled in the field. Possibly obstructed as bottom does not feel solid. Possibly hitting a rubber stopper?
GP-16A	1.33	0.5	629.8	70	8.1	6.5 - 8	Weathered Till / Glacio-Lacustrine	Possibly obstructed as bottom does not feel solid. Possibly hitting a rubber stopper?
GP-16B	1.36	0.5	629.83	70	20.3	18.5 - 20	Weathered Till / Glacio-Lacustrine	Bottom of screen elevation from boring log above measured elevation. Possibly obstructed as bottom does not feel solid. Possibly hitting a rubber stopper?
GP-16C	1.29	0.5	629.76	70	59.6	58.5 - 60	Stratified Drift	Bottom of screen elevation from boring log above measured elevation. Possibly obstructed as bottom does not feel solid. Possibly hitting a rubber stopper?
GP-17A	1.26	0.5	632.12	43	NA	6.5 - 8	Weathered Till / Glacio-Lacustrine	Tygon tubing in probe--cannot insert water level meter. TOC elevation derived from LiDAR ground surface data plus casing stick-up.
GP-17B	1.28	0.5	632.14	43	NA	15 - 16.5	Weathered Till / Glacio-Lacustrine	Tygon tubing in probe--cannot insert water level meter. TOC elevation derived from LiDAR ground surface data plus casing stick-up.
GP-17C	1.24	0.5	632.1	43	NA	35.5 - 37	Stratified Drift	Tygon tubing in probe--cannot insert water level meter. TOC elevation derived from LiDAR ground surface data plus casing stick-up.
GP-18A	1.49	0.5	603.76	58	NA	6.5 - 8	Weathered Till / Glacio-Lacustrine	Tygon tubing blocking probe--cannot insert water level meter.
GP-18B	1.51	0.5	603.78	58	NA	24.5 - 26	Weathered Till / Glacio-Lacustrine	Tygon tubing in pipe--cannot insert water level meter.
GP-18C	1.38	0.5	603.65	58	NA	43.5 - 45	Stratified Drift	Tygon tubing in probe--cannot insert water level meter.
GP-19A	1.06	0.5	547.3	40	NA	6.5 - 8	Weathered Till / Glacio-Lacustrine	Tygon tubing blocking--cannot insert water level meter
GP-19B	0.9	0.5	547.14	40	NA	14.5 - 16	Weathered Till / Glacio-Lacustrine	Tygon tubing attached to screen blocking--cannot insert water level meter.
GP-19C	1.04	0.5	547.28	40	NA	29.5 - 31	Stratified Drift	Tygon tubing attached to screen blocking--cannot insert water level meter.
GP-20A	1.56	0.5	496.6	95	NA	6.5 - 8	Weathered Till / Glacio-Lacustrine	Tygon tubing blocking well.
GP-20B	1.53	0.5	496.6	95	NA	30.5 - 32	Weathered Till / Glacio-Lacustrine	Tygon tubing blocking well.
GP-20C	1.55	0.5	496.6	95	NA	86.5 - 88	Stratified Drift	Tygon tubing blocking well.
GP45d	1.6	1	566.57	113	115.4	93 - 113	Stratified Drift	

Table 2.3 - Gas Probe Construction Information

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Well ID	Stick-up (ft)	Well Diameter (in)	Top of PVC Elevation (ft MSL)	Boring Depth (ft bgs)	2015 Measured Total Depth of Probe (ft btoc)	Screened Interval (ft bgs)	Screened Geologic Unit	Notes
GP-45I	1.62	1	566.59	76	77.6	56 - 76	Stratified Drift	
GP-45s	1.6	1	566.57	40	41.5	20 - 40	Weathered Till / Glacio-Lacustrine	
GP-55	2.1	1	643.09	70	NA	60 70	Stratified Drift	
GP-56	2.5	1	643.57	20	18.9	6 - 16	Weathered Till / Glacio-Lacustrine	
GP-57	1.98	1	639	66.5	NA	53.5 - 63.5	Stratified Drift	
GP-58	2.25	1	639.81	20	18.8	6 - 16	Weathered Till / Glacio-Lacustrine	
GP-59	2	1	635.45	65.5	NA	53.5 - 63.5	Stratified Drift	
GP-60	4.12	1	635.84	20	20.7	8 - 18	Weathered Till / Glacio-Lacustrine	
GP-61	1.76	1	563.18	65.4	NA	53 - 63	Stratified Drift	
GP-62	1.85	1	565.28	20	18.9	8 - 18	Weathered Till / Glacio-Lacustrine	
GP-ATC-1D	-0.28	0.5	591.01	21	20	15 - 20.5	Weathered Till / Glacio-Lacustrine	
GP-ATC-1S	-0.26	0.5	591.03	21	5.2	4 - 5.5	Weathered Till / Glacio-Lacustrine	
GP-ATC-2	---	---	---	21	2.5	- - -	- - -	Gas probe not installed at this location due to the shallow saturated condition of the gravel backfill in the sewer line trench.
GP-ATC-3D	-0.23	0.5	615.99	21	5.1	15 - 20.5	Weathered Till / Glacio-Lacustrine	Bottom of screen elevation from boring log above measured elevation. 2007 report indicated well might be silted. Suspect well label switched with GP-ATC-3S.
GP-ATC-3S	-0.26	0.5	616.02	21	18.8	4 - 5.5	Weathered Till / Glacio-Lacustrine	Suspect well label switched with GP-ATC-3D.
GP-ATC-4	---	---	---	21	---	4 - 5.5	Weathered Till / Glacio-Lacustrine	Location unknown.
GP-ATC-4	---	---	---	21	---	15 - 20.5	Weathered Till / Glacio-Lacustrine	Location unknown.
GP-ATC-5D	-0.36	6	625.29	21	21	15 - 20.5	Weathered Till / Glacio-Lacustrine	Location unknown.
GP-ATC-5S	-0.33	0.5	625.32	21	5.5	4 - 5.5	Weathered Till / Glacio-Lacustrine	Location unknown.
GP-ATC-6D	-0.38	0.5	619.78	21	19.5	15 - 20.5	Weathered Till / Glacio-Lacustrine	
GP-ATC-6S	-0.38	0.5	619.78	21	4.6	4 - 5.5	Weathered Till / Glacio-Lacustrine	Slight siltation at the bottom of the screen.
GP-ATC-7	---	---	---	22	---	4 - 5.5	Weathered Till / Glacio-Lacustrine	Location unknown.
GP-ATC-7	---	---	---	22	---	15 - 20.5	Weathered Till / Glacio-Lacustrine	Location unknown.
GP-ATC-8D	-0.49	0.5	629.79	22	19.5	15 - 20.5	Weathered Till / Glacio-Lacustrine	Bottom of screen elevation from boring log above measured elevation. 2007 report identified boring log bottom below measured bottom. Slight siltation at bottom of screen.
GP-ATC-8S	-0.35	0.5	629.65	22	4.2	4 - 5.5	Weathered Till / Glacio-Lacustrine	Slight siltation at bottom of screen.

Notes:
ft = feet, ft MSL = feet above mean sea level, ft bgs = feet below ground suface, ft btoc = feet below top of casing, in = inches

Sources of data:
Historical notes obtained from: *Technical Memorandum Phase I Investigations Groundwater Monitoring Well System Enhancements* (October 12, 2007).
CH2M Hill and Udaloy, 1985, Phase 2 -- Site Development Plan, Task 13.0 Geotechnical and Water Quality Field Work, August 1985.
CH2M Hill, 1987, Technical Memorandum: Task 51 - Additional Monitoring Wells and Task 52 - Landfill Gas Migration Investigation, January 1987.
EMCON Northwest, 1993, Operations and Maintenance Manual for Landfill Gas Collection Systems at Cedar Hills Regional Landfill, May 1993.
Hong West & Associates, 1995, Revised Gasprobe and Gas Extraction Well Logs - Landfill Gas Extraction System - SE Perimeter, June 1995.
CH2M Hill, 2004, Cedar Hills Regional Landfill Main Hill Saturated Perched Zone Report, May 2004.
Geomatrix Consultants and Herrera Environmental Consultants, 2006, Dual-Phase Well Facility Evaluation Focus Work Plan, August 29, 2006.

Table 3.1 - RI Water Level Monitoring Locations

Project No. 130088, Cedar Hils Regional Landfill
King County, Washington

Monitoring Wells	Gas Probes			Groundwater Extraction Wells	Gas Extraction Wells	Surface Water Level Gauge Station
MW-29	GP-1A	***GP-12B***	GP-58	EW-1	E-29AD	SG-4
MW-30A	GP-1B	***GP-12C***	GP-60	EW-2	E-29AS	SG-5
MW-47	GP-2A	***GP-12D***	GP-62	EW-3	E-29BD	
MW-48	GP-2B	***GP-13A***	***GP-ATC-1S***	EW-4	E-29BS	
MW-50	***GP-3***	***GP-13B***	***GP-ATC-1D***	EW-5	E-29CD	
MW-62	***GP-4A***	***GP-13C***	***GP-ATC-3S***	EW-6	E-29CS	
MW-63	***GP-4B***	***GP-13D***	***GP-ATC-3D***	EW-7	E-29DD	
MW-102	***GP-5A***	***GP-14A***	GP-ATC-6S	EW-8	E-29DS	
MW-103	***GP-5BA***	***GP-14B***	GP-ATC-6D	EW-9	***E-61S***	
MW-104	***GP-5BB***	GP-15A	GP-ATC-8S	EW-10	***E-61D***	
EB-1	***GP-5BC***	GP-15C	GP-ATC-8D	EW-11	***E-62D***	
EB-2	***GP-5BD***	GP-15D		EW-12	***E-62S***	
EB-3	GP-6A	GP-16A		EW-13	***E-63D***	
EB-4	GP-6B	GP-16B		EW-14	***E-63I***	
EB-5	GP-6C	GP-16C		EW-15	***E-63S***	
EB-5S	GP-6D	GP-17A		EW-16	***E-64D***	
EB-6D	GP-6E	GP-17C		EW-17	***E-64I***	
EB-7	GP-6F	GP-18A		EW-18	***E-64S***	
	GP-6G	GP-18C		EW-19	***E-65***	
	GP-6H	GP-19A		EW-20		
	GP-7	GP-19C		EW-21		
	GP-8	GP-20A		EW-22		
	GP-9	GP-20B		EW-23		
	GP-11A	GP-20C		EW-24		
	GP-11B	***GP-45S***		EW-25		
	GP-11C	***GP-45I***		EW-26		
	GP-11D	***GP45D***		EW-27		
	GP-12A	GP-56		EW-28		
				EW-29		

Notes:

Blue shading indicates primary water level location.

Bold italics indicates secondary water level location.

Table 3.2 - RI Sampling Locations

Project No. 130088, Cedar Hills Regional Landfill
King County, WA

Location ID	PDB Sample	RPP Sample	Conventional Low Flow or Grab Sample	Soil Gas Samples
	Analytes			
	Appendix I VOCs	Appendix II Metals	Appendix I & II Constituents; *MNA parameters	TO-15 VOCs; TO-17 VOCs
Perched Groundwater				
MW-30A	X	X	X	
MW-47	X	X	X	
MW-50			X	
MW-62			X	
MW-102	X		X	X (deep)
MW-103	X		X	
MW-104	X		X	
EB-1			X	
EB-2			X	
EB-6D	X	X	X	X (deep)
EW-2			X	
EW-6			X	
EW-7			X	
EW-8			X	
EW-9			X	
EW-10			X	
EW-11			X	
EW-12			X	
EW-13			X	
EW-14			X	
EW-15			X	
EW-16			X	
EW-17			X	
EW-18			X	
EW-19			X	
EW-20	X	X	X	
EW-21			X	
EW-23			X	
EW-24			X	
EW-25	X	X	X	
EW-26			X	
EW-27			X	
EW-29			X	
Surface Water				
SW-E1			X	
Main Hill Leachate				
MH-17N			X	
FS-3			X	
Shallow (Glacial Till) Soil Gas				
GP-15A				X
GP-16A				X
GP-17A				X
GP-18A				X
GP-19A				X
GP-20A				X
GP-56				X
GP-58				X
GP-60				X
GP-62				X
Deep (Advanced Outwash/Stratified Drift) Soil Gas				
GP-8				X
GP-15D				X
GP-16C				X
GP-17C				X
GP-18C				X
GP-19C				X
GP-20C				X

Notes:

PDB = Passive Diffusion Bag sampler.
RPP = Rigid Porous Polyethylene sampler.
Appendix I and II constituents are defined in WAC 173-351-990.
Monitored natural attenuation (MNA) parameters = ethane; ethene; methane; nitrate/nitrite.
* MNA parameters were only analyzed in groundwater samples.
VOC = Volatile Organic Compound
X = Sample collected. Sample point has only one screened interval.

Table 3.3 - RI Analyte List

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Volatile Organic Compounds - Water and Leachate Samples

CAS	Common Analytical Name	Synonym
67-64-1	Acetone	
107-13-1	Acrylonitrile	
71-43-2	Benzene	
74-97-5	Bromochloromethane	
75-27-4	Bromodichloromethane	
75-25-2	Bromoform	Tribromomethane
75-15-0	Carbon disulfide	
56-23-5	Carbon tetrachloride	
108-90-7	Chlorobenzene	
75-00-3	Chloroethane	Ethyl chloride
67-66-3	Chloroform	Trichloromethane
124-48-1	Dibromochloromethane	Chlorodibromomethane
96-12-8	1,2-Dibromo-3-chloropropane	DBCP
106-93-4	1,2-Dibromoethane	Ethylene dibromide; EDB
95-50-1	1,2-Dichlorobenzene	o-Dichlorobenzene;
106-46-7	1,4-Dichlorobenzene	p-Dichlorobenzene
110-57-6	trans-1,4-Dichloro-2-butene	
75-34-3	1,1-Dichloroethane	Ethylidene chloride
107-06-2	1,2-Dichloroethane	Ethylene dichloride; EDC
75-35-4	1,1-Dichloroethylene	1,1-Dichloroethene; Vinylidene chloride
156-59-2	cis-1,2-Dichloroethene	cis-1,2-Dichloroethylene
156-60-5	trans-1,2-Dichloroethene	trans-1,2-Dichloroethylene
78-87-5	1,2-Dichloropropane	Propylene dichloride
10061-01-5	cis-1,3-Dichloropropene	
10061-02-6	trans-1,3-Dichloropropene	
100-41-4	Ethylbenzene	
591-78-6	2-Hexanone	Methyl butyl ketone
74-83-9	Bromomethane	Methyl bromide
74-87-3	Methyl chloride	Chloromethane
74-95-3	Dibromomethane	Methylene bromide
75-09-2	Dichloromethane	Methylene chloride
78-93-3	2-Butanone	Methyl ethyl ketone; MEK
74-88-4	Methyl iodide	Iodomethane
108-10-1	4-Methyl-2-pentanone	Methyl isobutyl ketone
100-42-5	Styrene	
630-20-6	1,1,1,2-Tetrachloroethane	
79-34-5	1,1,2,2-Tetrachloroethane	
127-18-4	Tetrachloroethylene	Tetrachloroethene; Perchloroethylene
108-88-3	Toluene	
71-55-6	1,1,1-Trichloroethane	Methyl chloroform
79-00-5	1,1,2-Trichloroethane	
79-01-6	Trichloroethylene	Trichloroethene
75-69-4	Trichlorofluoromethane	CFC-11
96-18-4	1,2,3-Trichloropropane	
108-05-4	Vinyl acetate	
75-01-4	Vinyl chloride	
1330-20-7	Xylenes	

Inorganics - Water and Leachate Samples

CAS	Metals
7440-36-0	Antimony
7440-38-2	Arsenic
7440-39-3	Barium
7440-41-7	Beryllium
7440-43-9	Cadmium
7440-47-3	Chromium (Total)
7440-48-4	Cobalt
7440-50-8	Copper
7439-92-1	Lead
7439-97-6	Mercury
7440-02-0	Nickel
7782-49-2	Selenium
7440-22-4	Silver
7440-28-0	Thallium
7440-62-2	Vanadium
7440-66-6	Zinc
14797-55-8	Nitrate
	Field Parameters
	pH
	Conductivity (measured in specific conductance units)
	Temperature
	Static Water Level
	Geochemical Indicator Parameters
7440-70-2	Calcium
71-52-3	Bicarbonate
7439-95-4	Magnesium
14808-79-8	Sulfate
TSS	Total suspended solids
7440-23-5	Sodium
16887-00-6	Chloride
7440-09-7	Potassium
	Alkalinity
7439-89-6	Iron (Dissolved)
7439-96-5	Manganese (Dissolved)
	Leachate Indicators
7664-41-7	Ammonia
	Total Organic Carbon
	Total Dissolved Solids
	Additional MNA Parameters (GW Only)
	Oxidation Reduction Potential
	Dissolved Oxygen
74-82-8	*Methane*
	Nitrate + nitrite
	Ethene and Ethane

Notes:
Parameters in *italics* are those for groundwater sample analysis only. They are for monitored natural attenuation evaluation and are not listed in Appendix I or II of WAC 173-351.

Table 3.3 - RI Analyte List

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Volatile Organic Compounds - Soil Gas Samples

CAS	Common Analytical Name	Synonym
71-55-6	1,1,1-Trichloroethane	TCA
79-34-5	1,1,2,2-Tetrachloroethane	
79-00-5	1,1,2-Trichloroethane	
76-13-1	1,1,2-Trichlorotrifluoroethane	Freon 113
75-34-3	1,1-Dichloroethane	1,1-DCA
75-35-4	1,1-Dichloroethene	1,1-DCE
95-63-6	1,2,4-Trimethylbenzene	
106-93-4	1,2-Dibromoethane	Ethylene dibromide; EDB
76-14-2	1,2-Dichloro-1,1,2,2-tetrafluoroethane	CFC 114, Freon 114
95-50-1	1,2-Dichlorobenzene	
107-06-2	1,2-Dichloroethane	
78-87-5	1,2-Dichloropropane	
108-67-8	1,3,5-Trimethylbenzene	
106-99-0	1,3-Butadiene	
541-73-1	1,3-Dichlorobenzene	
106-46-7	1,4-Dichlorobenzene	
540-36-3	1,4-Difluorobenzene	
78-93-3	2-Butanone	MEK
591-78-6	2-Hexanone	
460-00-4	4-Bromofluorobenzene	
622-96-8	4-Ethyltoluene	
108-10-1	4-Methyl-2-pentanone	
67-64-1	Acetone	
71-43-2	Benzene	
75-27-4	Bromodichloromethane	
75-25-2	Bromoform	
74-83-9	Bromomethane	
75-15-0	Carbon Disulfide	
56-23-5	Carbon Tetrachloride	
108-90-7	Chlorobenzene	
75-00-3	Chloroethane	
67-66-3	Chloroform	
74-87-3	Chloromethane	
110-82-7	Cyclohexane	
124-48-1	Dibromochloromethane	Chlorodibromomethane
75-71-8	Dichlorodifluoromethane	CFC 12, Freon 12
74-95-3	Dichloromethane	
141-78-6	Ethyl Acetate	
100-41-4	Ethylbenzene	
1634-04-4	Methyl tert-Butyl Ether	MTBE
100-42-5	Styrene	
127-18-4	Tetrachloroethene	PCE
109-99-9	Tetrahydrofuran	THF
108-88-3	Toluene	
79-01-6	Trichloroethene	TCE
75-69-4	Trichlorofluoromethane	CFC 11, Freon 11
108-05-4	Vinyl Acetate	
75-01-4	Vinyl Chloride	
540-59-0	cis-1,2-Dichloroethene	
10061-01-5	cis-1,3-Dichloropropene	
179601-23-1	m,p-Xylenes	
142-82-5	n-Heptane	
110-54-3	n-Hexane	

Volatile Organic Compounds - Soil Gas Samples

CAS	Common Analytical Name	Synonym
156-60-5	trans-1,2-Dichloroethene	
10061-02-6	trans-1,3-Dichloropropene	
526-73-8	1,2,3-Trimethylbenzene	
120-82-1	1,2,4-Trichlorobenzene	
96-12-8	1,2-Dibromo-3-chloropropane	DBCP
123-91-1	1,4-Dioxane	
71-36-3	1-Butanol	
540-84-1	2,2,4-Trimethylpentane	Isooctane
611-14-3	2-Ethyltoluene	
75-65-0	2-Methyl-2-propanol	
67-63-0	2-Propanol	Isopropyl Alcohol
107-05-1	3-Chloro-1-propene	
99-87-6	4-Isopropyltoluene	
75-05-8	Acetonitrile	
107-02-8	Acrolein	
107-13-1	Acrylonitrile	
100-44-7	Benzyl Chloride	
64-17-5	Ethanol	
637-92-3	Ethyl tert-Butyl Ether	
87-68-3	Hexachlorobutadiene	
108-21-4	Isopropyl Acetate	
98-82-8	Isopropylbenzene	Cumene
80-62-6	Methyl Methacrylate	
91-20-3	Naphthalene	
115-07-1	Propene	Propylene
98-83-9	alpha-Methylstyrene	
80-56-8	alpha-Pinene	Pinene
5989-27-5	d-Limonene	
123-86-4	n-Butyl Acetate	
111-84-2	n-Nonane	Nonane
111-65-9	n-Octane	Octane
103-65-1	n-Propylbenzene	Propylbenzene
135-98-8	sec-Butylbenzene	
95-47-6	o-Xylene	

Table 4.1 - Hydraulic Conductivity Estimates

AGENCY DRAFT

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Well	Test Date	Screen Length (ft)	Soil Description	Estimated Hydraulic Conductivity (k)	
				(ft/day)	(cm/sec)
Glacio-Lacustrine					
EW-16 (Glacio-Lacustrine)	7/18/92	9.3	SILT	0.01	5.E-06
EW-17 (Glacio-Lacustrine)	8/3/92	9.4	SILT	0.01	5.E-06
EW-19 (Glacio-Lacustrine)	7/23/92	9.4	SILT	0.005	2.E-06
MW-103 (Glacio-Lacustrine)	2/3/09	10	SILT, trace fine gravel, trace fine sand.	*< 0.01*	*< 5E-06*
MW-104 (Glacio-Lacustrine)	5/19/09	10	SILT, trace fine-coarse gravel, trace fine sand.	*< 0.006*	*< 2E-06*
Statified Drift					
EW-4 (Stratified Drift)	6/1/92	19.4	SILTY SAND with gravels and cobbles; GRAVEL with sand, cobbles,boulders	6.40	2.E-03
MW-63 (Stratified Drift)	12/10/90	5	SILTY SAND with gravel	5.39	1.90E-03
MW-102 (Stratified Drift)	2/5/09	15	80% slightly silty fine-coarse GRAVEL, 20% silty gravelly fine-medium SAND, coarse gravel.	0.09	3E-05

Notes:

1. Results for MW-102 through MW-104 were obtained from analysis of calculated recovery versus log time (s-s' vs. log t), per Driscoll (1986).
2. *Hydraulic conductivity values in italics* for MW-103 and MW-104 are maximum estimate. Analysis is based on relatively early recovery data due to slow recovery times. Recovery data collected 1 to 2 days after testing indicate these data provide minimum recovery slopes, and hence provide a maximum hydraulic conductivity estimate.
3. Results for MW-63 from Emcon 1991. Reported K value is based on reported best estimate for MW-63 vicinity.
4. Results for EWs from Harding Lawson Associates (HLA) 1993. Transmissivity values reported by HLA were converted to K values using saturated thickness (b) from base of glacio-lacustrine deposits to static water level as shown on Figure 5 of HLA 1993.
5. ft = feet, ft/day = feet per day, cm/sec = centimeters per second

Table 5.1 - Constituents Of Potential Concern

AGENCY DRAFT

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Group	Analyte	Groundwater	Surface Water	Landfill Gas	Soil Gas
Conventional	Fluoride	X			
Conventional	Total Dissolved Solids	X			
Conventional	Methane			X	
Conventional	Nitrite as Nitrogen	X			
Conventional	Nitrate as Nitrogen	X			
Metals (dissolved)	Arsenic	X	X		
Metals (dissolved)	Cadmium		X		
Metals (dissolved)	Copper		X		
Metals (dissolved)	Lead	X	X		
Metals (dissolved)	Iron	X	X		
Metals (dissolved)	Manganese	X			
VOCs	Benzene	X			X
VOCs	1,1-Dichloroethane (DCA)	X			X
VOCs	1,2-Dichloroethane (1,2-EDC)	X			
VOCs	cis-1,2-Dichloroethene (cis-1,2-DCE)	X			
VOCs	o-Xylene				X
VOCs	Tetrachloroethene (PCE)				X
VOCs	Trichloroethene (TCE)	X			X
VOCs	Vinyl chloride	X			X

Notes:

Constituents of Potential Concern (COPCs) were determined in the Work Plan based on historical, pre-Remediation Investigation (RI) sampling results.

COPCs are refined through evaluation with of RI data with cleanup levels to determine constituents of concern (COCs) for the Feasibility Study (See Table 7.7 for COCs).

VOC = volatile organic compound

Table 5.2 - Groundwater Cleanup Levels And Reporting Detection Limits

AGENCY DRAFT

Project No. 130088, Cedar Hils Regional Landfill
King County, Washington

COPCs[1]	Units	RDL	Groundwater, Method A Cleanup Level, Table Value	Groundwater, Method B Cleanup Level, Most Restrictive Standard Formula Value	Groundwater Modified Value*	WAC 246-290-310 MCLs	COPC Cleanup Levels	Source of Cleanup Level
Conventionals								
Chloride	mg/L	0.1				250	250	MCL
Fluoride	mg/L	0.02		0.64		2	0.64	MTCA B
Nitrate as Nitrogen	mg/L	0.01		25.6		10	10	MCL
Nitrite as Nitrogen	mg/L	0.01		1.6		1	1	MCL
Total Dissolved Solids	mg/L	5				500	500	SMCL
Metals								
Arsenic	µg/L	1	5	0.058		10	5	MTCA Method A / Natural Background
Iron	µg/L	10		11200		300	11200	MTCA B
Lead	µg/L	1	15			15	15	MCL
Manganese	µg/L	1		2240		50	2240	MTCA B
Zinc	µg/L	4		4800		5000	4800	MTCA B
Volatile Organic Compounds								
1,1-Dichloroethane	µg/L	0.2		7.7	76.8	NA	76.8	MTCA B
1,2-Dichloroethane (EDC)	µg/L	0.2	5	0.48	4.81	5	4.81	MTCA B
Benzene	µg/L	0.2	5	0.8	7.95	5	5	MCL
Chloroform	µg/L	0.2		1.4	14.11	80	14.11	Modified MTCA B
cis-1,2-Dichloroethene (DCE)	µg/L	0.2		16	16	70	16	MTCA B
Trichloroethene (TCE)	µg/L	0.2	5	0.54	4	5	4	Modified MCL
Vinyl chloride	µg/L	0.02	0.2	0.029	0.29	2	0.29	Modified MTCA B

Notes:

Shading indicates the cleanup level to be used for screening RI data to determine exceedances and the final Constituent of Concern (COC) list for the FS.

CAS = Chemical Abstracts Services Registry Number

COPC = Constituent of Potential Concern
MCL = Maximum Contaminant Level
MTCA = Model Toxics Control Act
NA = Not Applicable
RDL = Reporting Detection Limit
SMCL = Secondary Maximum Contaminant Level
Cleanup levels and MCLs obtained from Washington State Department of Ecology's Cleanup Levels and Risk Calculations (CLARC) database.

*Modifications to Method B Standard Formula Values allowed under MTCA to account for a target risk of $1x10^{-5}$. Ecology's "CLARC Guidance on Trichlooethylene" (2015) specifed a downward adjustment of the state MCL.

[1] - COPCs listed here were originally identified in Aspect, 2015, East Perched Zones RI/FS Work Plan.

µg/L = micrograms per liter, mg/L =milligrams per liter

Table 5.3 - Surface Water Cleanup Levels

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

COPCs	RDL	Surface Water, Method B, Most Restrictive Standard Formula Value (µg/L)	Surface Water ARAR - Aquatic Life - Fresh/Acute - Ch. 173-201A WAC (µg/L)	Surface Water ARAR - Aquatic Life - Fresh/Chronic - Ch. 173-201A WAC (µg/L)	COPC Cleanup Level	Source of Cleanup Level
Metals						
Arsenic	1	0.098	360	190	0.098	MTCA B
Cadmium*	2	40	0.41*	0.23*	0.23	WAC 173-201A
Copper*	2	2900	2.51*	2*	2	WAC 173-201A
Iron	10			1000	1000	WAC 173-201A
Lead*	1		6.68*	0.26*	0.26	WAC 173-201A

Notes:

Shading indicates the cleanup level to be used for screening Remedial Investigation (RI) data to determine exceedances and the final Constituent of Concern (COC) list for the Feasibility Study (FS).

Shading indicates the RDL is higher than the lowest screening level.

* Hardness-dependent metals. Acute and chronic criteria were calculated using the lowest hardness value observed during the RI sampling period and the calculations presented in 173-201A WAC. These criteria are for the dissolved fraction of these metals.

ARAR = Applicable or Relevant and Appropriate Requirement
COPC = Constituent of Potential Concern
MTCA = Model Toxics Control Act
RDL = Reporting Detection Limit
µg/L = micrograms per liter

Table 5.4 - Soil Gas Cleanup Levels

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Constituents of Potential Concern	Units	Shallow Soil Gas Cleanup Levels[1]	Deep Soil Gas Cleanup Levels[1]
Volatile Organic Compounds			
1,1,1-Trichloroethane	$\mu g/m^3$	76,200	229,000
1,1,2 - Trichlorotrifluoroethane	$\mu g/m^3$	5.2	1,370,000
1,1-Dichloroethane	*$\mu g/m^3$*	*52.1*	*156*
1,1-Dichloroethene	$\mu g/m^3$	3,048	9,140
1,2-Dichlorobenzene	$\mu g/m^3$	3,048	9,140
1,2-Dichloroethane (EDC)	$\mu g/m^3$	3.2	9.62
1,2-Dichloropropane	$\mu g/m^3$	8.3	25
1,3-Dichlorobenzene	$\mu g/m^3$	NA	NA
2-Butanone	$\mu g/m^3$	76,190	229,000
Acetone	$\mu g/m^3$	NA	NA
Benzene	*$\mu g/m^3$*	*10.7*	*32.1*
Bromomethane	$\mu g/m^3$	76.2	229
Carbon disulfide	$\mu g/m^3$	10,667	32,000
Chlorobenzene	$\mu g/m^3$	762	2,290
Chloroethane	$\mu g/m^3$	152,381	457,143
Chloroform	$\mu g/m^3$	3.6	10.9
Chloromethane	$\mu g/m^3$	1,371	4,110
cis-1,2-Dichloroethene (DCE)	$\mu g/m^3$	3.21	9.62
Dichlorodifluoromethane	$\mu g/m^3$	1,524	4,570
Ethylbenzene	$\mu g/m^3$	15,238	45,700
m,p-Xylenes	$\mu g/m^3$	1,524	4,570
Methylene chloride	$\mu g/m^3$	8,333	25,000
Naphthalene	$\mu g/m^3$	2.45	7.35
o-Xylene	*$\mu g/m^3$*	*1,524*	*4,570*
Tetrachloroethene (PCE)	*$\mu g/m^3$*	*321*	*962*
Toluene	$\mu g/m^3$	76,190	229,000
trans-1,2-Dichloroethene	$\mu g/m^3$	3.21	9.62
Trichloroethene (TCE)	*$\mu g/m^3$*	*12.3*	*37*
Vinyl chloride	*$\mu g/m^3$*	*9.3*	*28*

Notes:

Table presents constituents detected in soil gas samples.

[1] Soil gas criteria from Ecology Draft Vapor Intrusion Guidance, updated April 6, 2015 (version 8).

Italic underlined analytes were identified as Constituents of Potential Concern (COPCs) in the Aspect, 2015, East Perched Zones RI/FS Work Plan.
NA = Not Applicable
$\mu g/m^3$ = micrograms per cubic meter

Table 7.1 - Frequency of Cleanup Level Exceedances - Groundwater

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Perched Groundwater

	Cleanup Level			Perched Groundwater Detections (since January 2015)							Exceedances (since January 2015)		Retained For Groundwater Feasibility Study (FS) Alternative	
Constituents of Potential Concern	Units	Proposed Cleanup Level	Source of Cleanup Level	Number of Results (excluding Field Dups)	Number of Samples with Detected Concentration	Detection Frequency	Minimum Detected Concentraion	Maxumim Detected Concentration	Location of Maximum Detection	Date of Maximum Detection	Number of Exceedances of Cleanup Level	Exceedance Frequency	Retained as COC For FS?	Comments
Conventionals														
Chloride	mg/L	250	MCL	145	145	100%	0.217	51.8	EW-6	6/10/2015	0	0%	No	
Nitrate	mg/L	10	MCL	145	104	72%	0.01	14	EW-13	9/11/2015	1	1%	No	Only detected once above cleanup level.
Total Dissolved Solids (TDS)	mg/L	500	SMCL	145	145	100%	42	737	MW-47	8/7/2015	18	12%	No	Secondary MCL set for aesthetic reasons. No human toxicity or carcinogenicity.
Metals (Dissolved, Filtered)														
Arsenic	µg/L	5	MTCA Method A / Natural Background	150	65	43%	1.09	225	EW-16	6/16/2015	32	21%	Yes	
Iron	µg/L	11200	MTCA Method B	150	114	76%	11	57100	EW-16	6/16/2015	24	16%	Yes	
Manganese	µg/L	2240	MTCA Method B	150	126	84%	1.22	8930	EW-16	9/14/2015	34	23%	Yes	
Zinc	µg/L	4800	MTCA Method B	150	80	53%	4.39	7100	EW-09	6/16/2015	2	1%	No	Only detected in EW-9 during two events.
Metals (Total, Unfiltered)														
Arsenic	µg/L	5	MTCA Method A / Natural Background	148	74	50%	1.03	184	EW-16	6/16/2015	38	26%	Yes	
Iron	µg/L	11200	MTCA Method B	148	147	99%	13	61900	EW-16	6/16/2015	26	18%	No	Dissolved iron is the primary concern. Total iron therefor not carried forward in FS.
Lead	µg/L	15	MCL	148	54	36%	1.02	26.5	EW-26	6/15/2015	2	1%	No	Detected in two wells during single events.
Manganese	µg/L	2240	MTCA Method B	148	139	94%	1	10900	EW-16	9/14/2015	31	21%	No	Dissolved manganese is the primary concern. Total manganese therefor not carried forward in FS.
Zinc	µg/L	4800	MTCA Method B	148	101	68%	4.16	9650	EW-09	6/16/2015	2	1%	No	Only detected in EW-9 during two events.
Volatile Organic Compounds														
1,1-Dichloroethane	µg/L	76.8	Modified MTCA B	153	37	24%	0.23	2.51	MW-30A	7/10/2015	0	0%	No	
1,2-Dichloroethane (EDC)	µg/L	4.81	Modified MTCA B	153	2	1%	0.25	0.441	MW-47	6/16/2015	0	0%	No	
Benzene	µg/L	5	MCL	153	17	11%	0.2	3.02	EW-21	12/15/2015	0	0%	No	
Chloroform	µg/L	14.11	Modified MTCA B	153	3	2%	1.44	231	EW-07	6/10/2015	1	1%	No	Limited detections and only one exceedance.
cis-1,2-Dichloroethene	µg/L	16	MTCA Method B	153	71	46%	0.21	20	EW-25	9/15/2015	1	1%	No	Only detected once above cleanup level.
Methylene Chloride	µg/L	5	MCL	153	1	1%	9.09	9.09	EW-07	6/10/2015	1	1%	No	Common laboratory contaminant. Only one detection.
Trichloroethene	µg/L	4	Modified MCL	153	35	23%	0.2	7.71	EW-25	9/15/2015	1	1%	No	Only detected once above cleanup level.
Vinyl Chloride	µg/L	0.29	Modified MTCA B	153	62	41%	0.0207	9.02	MW-47	9/11/2015	26	17%	Yes	

Regional Groundwater

	Cleanup Level			Regional Groundwater Detections (since January 2015)							Exceedances (since January 2015)		Retained For Groundwater Feasibility Study (FS) Alternative	
Constituents of Potential Concern	Units	Proposed Cleanup Level	Source of Cleanup Level	Number of Results (excluding Field Dups)	Number of Samples with Detected Concentration	Detection Frequency	Minimum Detected Concentraion	Maxumim Detected Concentration	Location of Maximum Detection	Date of Maximum Detection	Number of Exceedances of Cleanup Level	Exceedance Frequency	Retained as COC For FS?	Comments
Conventionals														
Chloride	mg/L	250	MCL	52	52	100%	2.48	11.1	MW-75	4/20/2015	0	0%	No	
Nitrate	mg/L	10	MCL	52	34	65%	0.011	1.63	MW-85	7/23/2015	0	0%	No	
Total Dissolved Solids (TDS)	mg/L	500	SMCL	52	52	100%	91.4	363	MW-87	10/16/2015	0	0%	No	
Metals (Dissolved, Filtered)														
Arsenic	µg/L	5	MTCA Method A / Natural Background	52	25	48%	1.02	22.7	MW-68	4/27/2015	8	15%	Yes	Only retained for MW-68. All other arsenic detections are within regional background for King County.
Iron	µg/L	11200	MTCA Method B	52	37	71%	25	4370	MW-87	1/15/2016	0	0%	Yes	Indicative of reducing conditions.
Manganese	µg/L	2240	MTCA Method B	52	42	81%	1.2	469	MW-87	1/15/2016	0	0%	Yes	Indicative of reducing conditions.
Zinc	µg/L	4800	MTCA Method B	52	5	10%	4.41	9.52	MW-93	1/11/2016	0	0%	No	
Metals (Total, Unfiltered)														
Arsenic	µg/L	5	MTCA Method A / Natural Background	52	30	58%	1.13	219	MW-68	1/22/2016	17	33%	Yes	Dissolved arsenic is primary concern. Total arsenic will be retained for comparison purposes only.
Iron	µg/L	11200	MTCA Method B	52	44	85%	11	52400	MW-91	8/6/2015	8	15%	No	Dissolved iron is the primary concern. Total iron, therefore, is not carried forward in FS.
Manganese	µg/L	2240	MTCA Method B	52	43	83%	1.2	1510	MW-91	4/13/2015	0	0%	No	Dissolved manganese is the primary concern. Total manganese, therefore, is not carried forward in FS.
Zinc	µg/L	4800	MTCA Method B	52	5	10%	6.72	9.99	MW-93	1/11/2016	0	0%	No	

Notes:

None of the VOC COPCs were detected in regional groundwater samples.
COC = Constituent of Concern
COPC = Constituent of Potential Concern
FS = Feasibility Study
MCL = Maximum Contaminant Level
MTCA = Model Toxics Control Act
SMCL = Secondary Maximum Contaminant Level
VOC = Volatile Organic Compound
µg/L = micrograms per liter, mg/L = milligrams per liter

Table 7.2 - Comparison of Low-Flow and PDB Results

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

AGENCY DRAFT

		Location	EB-6	EB-6			EW-20	EW-20			EW-25	EW-25			MW-102	MW-102		
		Sample	WB6-150608-	WB6-150608-			EW20150612-	EW20150612-			EW25150615-	EW25150615-			W102150608-	W102150608-		
		Type	LF	PDB		Percent	LF	PDB		Percent	LF	PDB		Percent	LF	PDB		Percent
Group	Analyte	Units	Result	Result	Difference	Difference	Result	Result	Difference	Difference	Result	Result	Difference	Difference	Result	Result	Difference	Difference
BTEX	Benzene	µg/L	< 0.2	< 0.2	0		1.07	1.10	0.03	3%	< 0.2	< 0.2	0		< 0.2	< 0.2	0	
BTEX	Ethylbenzene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
BTEX	m,p-Xylenes	µg/L	0.25	< 0.2	0.05	-20%	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
BTEX	o-Xylene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
BTEX	Toluene	µg/L	0.403	< 0.2	0.203	-50%	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,1,1,2-Tetrachloroethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,1,1-Trichloroethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,1,2,2-Tetrachloroethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,1,2-Trichloroethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,1-Dichloroethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,1-Dichloroethene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,2,3-Trichloropropane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,2-Dibromo-3-chloropropane	µg/L	< 1	< 1	0		< 1	< 1	0		< 1	< 1	0		< 1	< 1	0	
VOCs	1,2-Dibromoethane (EDB)	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,2-Dichlorobenzene	µg/L	< 0.2	< 0.2	0		1.32	1.61	0.29	22%	< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,2-Dichloroethane (EDC)	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,2-Dichloropropane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,4-Dichloro-2-Butene	µg/L	< 100	< 100	0		< 100	< 100	0		< 100	< 100	0		< 100	< 100	0	
VOCs	1,4-Dichlorobenzene	µg/L	< 0.2	< 0.2	0		0.662	0.862	0.20	30%	< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	2-Butanone	µg/L	< 4	< 4	0		< 4	< 4	0		< 4	< 4	0		< 4	< 4	0	
VOCs	2-Hexanone	µg/L	< 4	< 4	0		< 4	< 4	0		< 4	< 4	0		< 4	< 4	0	
VOCs	4-Methyl-2-pentanone	µg/L	< 4	< 4	0		< 4	< 4	0		< 4	< 4	0		< 4	< 4	0	
VOCs	Acetone	µg/L	13.5	< 4	9.50	-70%	< 4	< 4	0		< 4	< 4	0		< 4	< 4	0	
VOCs	Acrylonitrile	µg/L	< 0.07	< 0.07	0		< 0.07	< 0.07	0		< 0.07	< 0.07	0		< 0.07	< 0.07	0	
VOCs	Bromochloromethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Bromodichloromethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Bromoform	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Bromomethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Carbon disulfide	µg/L	0.33	< 0.2	0.13	-39%	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Carbon tetrachloride	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Chlorobenzene	µg/L	< 0.2	< 0.2	0		5.09	5.62	0.53	10%	< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Chloroethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Chloroform	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Chloromethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	0.31	0.11	55%
VOCs	cis-1,2-Dichloroethene (DCE)	µg/L	< 0.2	< 0.2	0		0.797	0.85	0.05	7%	2.94	3.42	0.48	16%	< 0.2	< 0.2	0	
VOCs	cis-1,3-Dichloropropene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Dibromochloromethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Dibromomethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Dichlorodifluoromethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Methylene chloride	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Methyliodide	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Styrene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Tetrachloroethene (PCE)	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		0.576	0.79	0.214	37%	< 0.2	< 0.2	0	
VOCs	trans-1,2-Dichloroethene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		0.32	< 0.2	0.12	-38%	< 0.2	< 0.2	0	
VOCs	trans-1,3-Dichloropropene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Trichloroethene (TCE)	µg/L	< 0.2	< 0.2	0		0.31	0.29	0.02	-6%	2.12	2.38	0.26	12%	< 0.2	< 0.2	0	
VOCs	Trichlorofluoromethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Vinyl acetate	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Vinyl chloride	µg/L	< 0.02	< 0.02	0		0.236	0.257	0.02	9%	< 0.02	< 0.02	0		< 0.02	< 0.02	0	
				Average Difference:	0.20			Average Difference:	0.02			Average Difference:	0.02			Average Difference:	0.002	
				Average Percent Difference:	-45%			Average Percent Difference:	11%			Average Percent Difference:	7%			Average Percent Difference:	55%	

Table 7.2 - Comparison of Low-Flow and PDB Results

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

		Location	MW-103	MW-103			MW-104	MW-104			MW-30A	MW-30A			MW-47	MW-47		
		Sample	W103150616-	W103150616-			W104150608-	W104150608-			W30A150609-	W30A150609-			W47-150616-	W47-150616-		
		Type	LF	PDB		Percent	LF	PDB		Percent	LF	PDB		Percent	LF	PDB		Percent
Group	Analyte	Units	Result	Result	Difference	Difference	Result	Result	Difference	Difference	Result	Result	Difference	Difference	Result	Result	Difference	Difference
BTEX	Benzene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	0.36	0	
BTEX	Ethylbenzene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
BTEX	m,p-Xylenes	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
BTEX	o-Xylene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
BTEX	Toluene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,1,1,2-Tetrachloroethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,1,1-Trichloroethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,1,2,2-Tetrachloroethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,1,2-Trichloroethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,1-Dichloroethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		2.19	2.19	0	0%	0.826	1.28	0.45	55%
VOCs	1,1-Dichloroethene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,2,3-Trichloropropane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,2-Dibromo-3-chloropropane	µg/L	< 1	< 1	0		< 1	< 1	0		< 1	< 1	0		< 1	< 1	0	
VOCs	1,2-Dibromoethane (EDB)	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,2-Dichlorobenzene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,2-Dichloroethane (EDC)	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	0.441	0.24	121%
VOCs	1,2-Dichloropropane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	1,4-Dichloro-2-Butene	µg/L	< 100	< 100	0		< 100	< 100	0		< 100	< 100	0		< 100	< 100	0	
VOCs	1,4-Dichlorobenzene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	2-Butanone	µg/L	< 4	< 4	0		< 4	< 4	0		< 4	< 4	0		< 4	< 4	0	
VOCs	2-Hexanone	µg/L	< 4	< 4	0		< 4	< 4	0		< 4	< 4	0		< 4	< 4	0	
VOCs	4-Methyl-2-pentanone	µg/L	< 4	< 4	0		< 4	< 4	0		< 4	< 4	0		< 4	< 4	0	
VOCs	Acetone	µg/L	< 4	< 4	0		< 4	< 4	0		< 4	< 4	0		< 4	< 4	0	
VOCs	Acrylonitrile	µg/L	< 0.07	< 0.07	0		< 0.07	< 0.07	0		< 0.07	< 0.07	0		< 0.07	< 0.07	0	
VOCs	Bromochloromethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Bromodichloromethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Bromoform	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Bromomethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Carbon disulfide	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Carbon tetrachloride	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Chlorobenzene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Chloroethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		0.29	0.35	0.06	21%
VOCs	Chloroform	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Chloromethane	µg/L	< 0.2	< 0.2	0		< 0.2	1.20	1	500%	< 0.2	0.628	0.43	214%	< 0.2	1.76	1.56	780%
VOCs	cis-1,2-Dichloroethene (DCE)	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		2.13	2.16	0.03	1%	3.84	11	7.16	186%
VOCs	cis-1,3-Dichloropropene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Dibromochloromethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Dibromomethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Dichlorodifluoromethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		4.57	0.74	3.83	-84%
VOCs	Methylene chloride	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Methyliodide	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Styrene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Tetrachloroethene (PCE)	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	trans-1,2-Dichloroethene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	0.408	0.21	104%
VOCs	trans-1,3-Dichloropropene	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Trichloroethene (TCE)	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		1.04	1.2	0.16	15%	< 0.2	0.23	0.03	15%
VOCs	Trichlorofluoromethane	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Vinyl acetate	µg/L	< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0		< 0.2	< 0.2	0	
VOCs	Vinyl chloride	µg/L	< 0.02	< 0.02	0		< 0.02	< 0.02	0		< 0.02	< 0.02	0		6.09	4.02	2.07	-34%
				Average Difference:	0.000			Average Difference:	0.02			Average Difference:	0.01			Average Difference:	0.32	
				Average Percent Difference:	0%			Average Percent Difference:	500%			Average Percent Difference:	58%			Average Percent Difference:	129%	

Range of average differences in PDB concentrations:	0.00	to	0.32
Range of percent difference in PDB concentration:	-45%	to	500%

Notes:
LF = Low flow sample collected after passive sample was removed.
PDB = Passive diffusion bag sample.
Reporting detection limit (RDL) value was used to calculate differences if one of the results was nondetect.
< = Denotes nondetect value.
µg/L = micrograms per Liter

Table 7.3 - Comparison of Low-Flow and RPP Results

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

			Location	EB-6	EB-6			EW-20	EW-20			EW-25	EW-25		
			Sample	WB6-150608-	WB6-150608-			EW20150612-	EW20150612-			EW25150615-	EW25150615-		
			Type	LF	RPP		Percent	LF	RPP		Percent	LF	RPP		Percent
Group	Analyte	Fraction	Units	Result	Result	Difference	Difference	Result	Result	Difference	Difference	Result	Result	Difference	Difference
Metals	Aluminum	D	mg/L		< 0.02				< 0.02				< 0.02		
Metals	Antimony	D	mg/L	< 0.001	< 0.001	0		< 0.001	< 0.001	0		< 0.001	< 0.001	0	
Metals	Arsenic	D	mg/L	0.00468	0.00158	0.003	-66%	0.0398	0.0357	0.0041	-10%	< 0.001	< 0.001	0	
Metals	Barium	D	mg/L	0.0092	0.00953	0.0003	4%	0.02	0.02	0.00		0.00134	0.00106	0.0003	-21%
Metals	Beryllium	D	mg/L	< 0.001	< 0.001	0		< 0.001	< 0.001	0		< 0.001	< 0.001	0	
Metals	Cadmium	D	mg/L	< 0.002	< 0.002	0		< 0.002	< 0.002	0		< 0.002	< 0.002	0	
Metals	Calcium	D	mg/L	5.61	7.31	1.7	30%	34.60	33.90	0.70	-2%	7.21	7.06	0.15	-2%
Metals	Chromium (Total)	D	mg/L	< 0.005	< 0.005	0		< 0.005	< 0.005	0		< 0.005	< 0.005	0	
Metals	Cobalt	D	mg/L	< 0.003	< 0.003	0		< 0.003	< 0.003	0		< 0.003	< 0.003	0	
Metals	Copper	D	mg/L	< 0.002	< 0.002	0		< 0.002	< 0.002	0		< 0.002	< 0.002	0	
Metals	Iron	D	mg/L	5.65	6.83	1.18	21%	12.00	12.20	0.20	2%	0.0538	0.0450	0.0088	-16%
Metals	Lead	D	mg/L	< 0.001	< 0.001	0		< 0.001	< 0.001	0		< 0.001	< 0.001	0	
Metals	Magnesium	D	mg/L	2.93	3.4	0.47	16%	13.10	12.60	0.50	-4%	3.31	3.07	0.24	-7%
Metals	Manganese	D	mg/L	0.223	0.369	0.1460	65%	3.56	3.60	0.04	1%	0.12	0.03	0.0948	-78%
Metals	Mercury	D	mg/L	< 0.0001	< 0.0001	0		< 0.0001	< 0.0001	0		< 0.0001	< 0.0001	0	
Metals	Nickel	D	mg/L	0.0105	< 0.01	0.0005	-5%	< 0.01	< 0.01	0		< 0.01	< 0.01	0	
Metals	Potassium	D	mg/L	1.34	1.65	0.31	23%	1.74	1.85	0.11	6%	0.59	0.64	0.053	9%
Metals	Selenium	D	mg/L	< 0.001	< 0.001	0		< 0.001	< 0.001	0		< 0.001	< 0.001	0	
Metals	Silver	D	mg/L	< 0.003	< 0.003	0		< 0.003	< 0.003	0		< 0.003	< 0.003	0	
Metals	Sodium	D	mg/L	19.6	21.5	1.90	10%	76.60	80.10	3.50	5%	7.70	7.29	0.41	-5%
Metals	Thallium	D	mg/L	< 0.001	< 0.001	0		< 0.001	< 0.001	0		< 0.001	< 0.001	0	
Metals	Tin	D	mg/L		< 0.01				< 0.01				< 0.01		
Metals	Vanadium	D	mg/L	< 0.002	< 0.002	0		0.00278	< 0.002	0.00078	-28%	< 0.002	< 0.002	0	
Metals	Zinc	D	mg/L	0.00882	0.0276	0.0188	213%	0.0126	0.0057	0.0069	-55%	0.04	0.05	0.0024	6%
					Average Difference:	0.26			Average Difference:	0.23			Average Difference:	0.04	
					Average Percent Difference from LF:	31%			Average Percent Difference from LF:	-10%			Average Percent Difference from LF:	-14%	

Table 7.3 - Comparison of Low-Flow and RPP Results

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

			Location	MW-30A	MW-30A			MW-47	MW-47		
			Sample	W30A150609-	W30A150609-			W47-150616-	W47-150616-		
			Type	LF	RPP		Percent	LF	RPP		Percent
Group	Analyte	Fraction	Units	Result	Result	Difference	Difference	Result	Result	Difference	Difference
Metals	Aluminum	D	mg/L		< 0.02				< 0.02		
Metals	Antimony	D	mg/L	< 0.001	< 0.001	0		< 0.001	< 0.001	0	
Metals	Arsenic	D	mg/L	< 0.001	< 0.001	0		0.00494	0.01010	0.00516	104%
Metals	Barium	D	mg/L	0.00368	0.00397	0.0003	8%	0.0354	0.0305	0.0049	-14%
Metals	Beryllium	D	mg/L	< 0.001	< 0.001	0		< 0.001	< 0.001	0	
Metals	Cadmium	D	mg/L	< 0.002	< 0.002	0		< 0.002	< 0.002	0	
Metals	Calcium	D	mg/L	18.20	16.70	1.50	-8%	111	83	28	-25%
Metals	Chromium (Total)	D	mg/L	< 0.005	< 0.005	0		< 0.005	< 0.005	0	
Metals	Cobalt	D	mg/L	< 0.003	< 0.003	0		< 0.003	< 0.003	0	
Metals	Copper	D	mg/L	0.00568	0.00253	0.0032	-55%	< 0.002	< 0.002	0	
Metals	Iron	D	mg/L	0.04	< 0.01	0.03	-75%	2.36	1.17	1.19	-50%
Metals	Lead	D	mg/L	< 0.001	< 0.001	0		< 0.001	< 0.001	0	
Metals	Magnesium	D	mg/L	9.03	8.32	0.71	-8%	52.50	37.20	15.30	-29%
Metals	Manganese	D	mg/L	0.00131	0.00170	0.00039	30%	3.38	4.71	1.33	39%
Metals	Mercury	D	mg/L	< 0.0001	< 0.0001	0		< 0.0001	< 0.0001	0	
Metals	Nickel	D	mg/L	< 0.01	< 0.01	0		< 0.01	< 0.01	0	
Metals	Potassium	D	mg/L	1.50	1.50	0.00	0%	3.76	3.13	0.63	-17%
Metals	Selenium	D	mg/L	< 0.001	< 0.001	0		< 0.001	< 0.001	0	
Metals	Silver	D	mg/L	< 0.003	< 0.003	0		< 0.003	< 0.003	0	
Metals	Sodium	D	mg/L	14.10	13.90	0.20	-1%	17.00	15.60	1.40	-8%
Metals	Thallium	D	mg/L	< 0.001	< 0.001	0		< 0.001	< 0.001	0	
Metals	Tin	D	mg/L		< 0.01				< 0.01		
Metals	Vanadium	D	mg/L	< 0.002	< 0.002	0		< 0.002	< 0.002	0	
Metals	Zinc	D	mg/L	0.0123	0.0149	0.0026	21%	< 0.004	0.02	0.02	413%
					Average Difference:	0.11			Average Difference:	2.18	
					Average Percent Difference from LF:	-10%			Average Percent Difference from LF:	46%	

Range of average difference in RPP concentration from LF:	0.04 mg/L	to	2.18 mg/L
Range of percent difference in RPP concentration from LF:	-14%	to	46%

Notes:

LF = Low flow sample collected after passive sample was removed.

RPP = Rigid porous polyethylene samples

Reporting Detection Limit (RDL) value was used to calculate differences if one of the results was nondetect.

< = Denotes nondetect value.

D = Dissolved metal fraction

mg/L = milligrams per liter

Table 7.4 - Frequency of Detections in Surface Water

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Group	Analyte	Units	Total or Dissolved	Number of Sampled Locations	Number of Samples	First Sample Date	Most Recent Available Sample Date	Number of Samples with Detected Concentration	Detection Frequency	Last Sample Date with Detected Concentration	Maxumim Detected Concentration	Minimum Detected Concentraion	Average Detected Concentration	Number of Exceedances of Cleanup Level	Exceedance Frequency	Number of NonDetects with Reporting Limit Above Cleanup Level
Conventionals	Alkalinity, Bicarbonate	mg/l	NA	1	2	12/17/2015	3/14/2016	2	100%	3/14/2016	11.5	8.88	10.2	0	0%	
Conventionals	Alkalinity, Total (AS CACO3)	mg/l	NA	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	18.4	8.15	12	0	0%	
Conventionals	Ammonia as N	mg/l	NA	1	9	1/20/2015	3/14/2016	2	22%	4/21/2015	0.0174	0.0124	0.015	0	0%	
Conventionals	Chloride	mg/l	NA	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	2.12	1.37	1.71	0	0%	
Conventionals	Ethane	µg/l	NA	1	2	12/17/2015	3/14/2016	1	50%	12/17/2015	0.005	0.005	0.005	0	0%	
Conventionals	Ethene	µg/l	NA	1	2	12/17/2015	3/14/2016	1	50%	12/17/2015	0.0094	0.0094	0.0094	0	0%	
Conventionals	Methane	µg/l	NA	1	2	12/17/2015	3/14/2016	2	100%	3/14/2016	0.56	0.43	0.5	0	0%	
Conventionals	Nitrate + Nitrite as N	mg/l	NA	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	1.77	0.249	0.96	0	0%	
Conventionals	Nitrate as N	mg/l	NA	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	1.77	0.249	0.96	0	0%	
Conventionals	Sulfate	mg/l	NA	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	2.46	1.42	1.78	0	0%	
Conventionals	Total Dissolved Solids	mg/l	NA	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	48.9	29	39.6	0	0%	
Conventionals	Total Organic Carbon	mg/l	NA	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	4.82	2.13	3.18	0	0%	
Conventionals	Total Suspended Solids	mg/l	NA	1	9	1/20/2015	3/14/2016	3	33%	4/21/2015	5.58	2.44	3.61	0	0%	
Field Parameters	Dissolved Oxygen	mg/L	NA	1	2	12/17/2015	3/14/2016	2	100%	3/14/2016	10.94	9.05	10.00	0	0%	
Field Parameters	Ferrous Iron	mg/L	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
Field Parameters	Oxidation-Reduction Potential	mV	NA	1	2	12/17/2015	3/14/2016	2	100%	3/14/2016	79.4	-15.4	32.0	0	0%	
Field Parameters	pH	pH units	NA	1	2	12/17/2015	3/14/2016	2	100%	3/14/2016	6.88	6.63	6.76	0	0%	
Field Parameters	Specific Conductance	uS/cm	NA	1	2	12/17/2015	3/14/2016	2	100%	3/14/2016	43.2	40	41.6	0	0%	
Field Parameters	Temperature	deg C	NA	1	2	12/17/2015	3/14/2016	2	100%	3/14/2016	6.9	5.7	6.3	0	0%	
Field Parameters	Turbidity	ntu	NA	1	6	1/20/2015	3/14/2016	6	100%	3/14/2016	5.17	2.35	3.55	0	0%	
Metals	Aluminum	µg/l	D	1	6	1/20/2015	12/14/2015	6	100%	12/14/2015	70.9	50	57.3	0	0%	
Metals	Antimony	µg/l	D	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Arsenic	µg/l	D	1	8	1/20/2015	3/14/2016	0	0%					0	0%	8
Metals	Barium	µg/l	D	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	3.27	2.32	2.86	0	0%	
Metals	Beryllium	µg/l	D	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Cadmium	µg/l	D	1	8	1/20/2015	3/14/2016	0	0%					0	0%	8
Metals	Calcium	µg/l	D	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	4750	3730	4260	0	0%	
Metals	Chromium	µg/l	D	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Cobalt	µg/l	D	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Copper	µg/l	D	1	8	1/20/2015	3/14/2016	0	0%					0	0%	8
Metals	Iron	µg/l	D	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	50.4	15	28.2	0	0%	
Metals	Lead	µg/l	D	1	8	1/20/2015	3/14/2016	0	0%					0	0%	8
Metals	Magnesium	µg/l	D	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	1160	821	982	0	0%	
Metals	Manganese	µg/l	D	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	27.5	1.25	6.93	0	0%	
Metals	Mercury	µg/l	D	1	2	12/17/2015	3/14/2016	0	0%					0	0%	2
Metals	Nickel	µg/l	D	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Potassium	µg/l	D	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	722	390	480	0	0%	
Metals	Selenium	µg/l	D	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Silver	µg/l	D	1	8	1/20/2015	3/14/2016	0	0%					0	0%	8
Metals	Sodium	µg/l	D	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	2610	2170	2410	0	0%	
Metals	Thallium	µg/l	D	1	8	1/20/2015	3/14/2016	0	0%					0	0%	8
Metals	Tin	µg/l	D	1	6	1/20/2015	12/14/2015	0	0%					0	0%	
Metals	Vanadium	µg/l	D	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Zinc	µg/l	D	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Aluminum	µg/l	T	1	6	1/20/2015	12/14/2015	6	100%	12/14/2015	311	92.2	193	0	0%	
Metals	Antimony	µg/l	T	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Arsenic	µg/l	T	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Barium	µg/l	T	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	5.14	2.52	3.66	0	0%	
Metals	Beryllium	µg/l	T	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Cadmium	µg/l	T	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Calcium	µg/l	T	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	5250	3590	4290	0	0%	
Metals	Chromium	µg/l	T	1	8	1/20/2015	3/14/2016	0	0%					0	0%	

Table 7.4 - Frequency of Detections in Surface Water

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Group	Analyte	Units	Total or Dissolved	Number of Sampled Locations	Number of Samples	First Sample Date	Most Recent Available Sample Date	Number of Samples with Detected Concentration	Detection Frequency	Last Sample Date with Detected Concentration	Maxumim Detected Concentration	Minimum Detected Concentraion	Average Detected Concentration	Number of Exceedances of Cleanup Level	Exceedance Frequency	Number of NonDetects with Reporting Limit Above Cleanup Level
Metals	Cobalt	µg/l	T	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Copper	µg/l	T	1	9	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Iron	µg/l	T	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	251	32	109	0	0%	
Metals	Lead	µg/l	T	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Magnesium	µg/l	T	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	1180	892	1010	0	0%	
Metals	Manganese	µg/l	T	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	169	1.62	39.6	0	0%	
Metals	Mercury	µg/l	T	1	8	1/20/2015	3/14/2016	0	0%					0	0%	8
Metals	Nickel	µg/l	T	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Potassium	µg/l	T	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	560	330	458	0	0%	
Metals	Selenium	µg/l	T	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Silver	µg/l	T	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Sodium	µg/l	T	1	8	1/20/2015	3/14/2016	8	100%	3/14/2016	2680	2220	2390	0	0%	
Metals	Thallium	µg/l	T	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Tin	µg/l	T	1	6	1/20/2015	12/14/2015	0	0%					0	0%	
Metals	Vanadium	µg/l	T	1	8	1/20/2015	3/14/2016	0	0%					0	0%	
Metals	Zinc	µg/l	T	1	9	1/20/2015	3/14/2016	0	0%					0	0%	
VOCs	1,1,1,2-Tetrachloroethane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	1,1,1-Trichloroethane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	1,1,2,2-Tetrachloroethane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	1,1,2-Trichloroethane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	1,1-Dichloroethane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	1,1-Dichloroethene	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	1,2,3-Trichloropropane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	1,2-Dibromo-3-chloropropane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	1,2-Dibromoethane (EDB)	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	1,2-Dichlorobenzene	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	1,2-Dichloroethane (EDC)	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	1,2-Dichloropropane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	1,4-Dichloro-2-Butene	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	1,4-Dichlorobenzene	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	2-Butanone	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	2-Hexanone	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	4-Methyl-2-pentanone	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Acetone	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Acrylonitrile	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Benzene	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Bromochloromethane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Bromodichloromethane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Bromoform	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Bromomethane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Carbon Disulfide	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Carbon Tetrachloride	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Chlorobenzene	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Chloroethane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Chloroform	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Chloromethane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	cis-1,2-Dichloroethene (DCE)	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	cis-1,3-Dichloropropene	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Dibromochloromethane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Dibromomethane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Dichlorodifluoromethane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Ethylbenzene	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	

Table 7.4 - Frequency of Detections in Surface Water

AGENCY DRAFT

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Group	Analyte	Units	Total or Dissolved	Number of Sampled Locations	Number of Samples	First Sample Date	Most Recent Available Sample Date	Number of Samples with Detected Concentration	Detection Frequency	Last Sample Date with Detected Concentration	Maxumim Detected Concentration	Minimum Detected Concentraion	Average Detected Concentration	Number of Exceedances of Cleanup Level	Exceedance Frequency	Number of NonDetects with Reporting Limit Above Cleanup Level
VOCs	Methylene Chloride	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Methyliodide	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	o-Xylene	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Styrene	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Tetrachloroethene (PCE)	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Toluene	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	trans-1,2-Dichloroethene	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	trans-1,3-Dichloropropene	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Trichloroethene (TCE)	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Trichlorofluoromethane	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Vinyl Acetate	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	
VOCs	Vinyl Chloride	µg/l	NA	1	2	12/17/2015	3/14/2016	0	0%					0	0%	

Notes:

The number of samples listed excludes field duplicates.

NA = Not Applicable

T = Total

D = Dissolved

Gray font indicates no detections

C = Celsius, µg/L = micrograms per liter; mg/L = milligrams per liter, mV = millivolts, µS/cm = microsiemens per centimeter, ntu = nephelometric turbidity unit

Table 7.5 - Frequency of Cleanup Level Exceedances in Soil Gas

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Shallow Soil Gas

Constituents of Concern	Cleanup Level			Shallow Soil Gas Detections (Since July 2015)							Exceedances (Since July 2015)		Retained For Feasibility Study (FS)	
	Units	Proposed Cleanup Level	Source of Cleanup Level	Number of Results (excluding Field Dups)	Number of Samples with Detected Concentration	Detection Frequency	Minimum Detected Concentraion	Maxumim Detected Concentration	Location of Maximum Detection	Date of Maximum Detection	Number of Exceedances of Cleanup Level	Exceedance Frequency	Retained For FS?	Comments
Voltaile Organic Compounds														
Chloroform	$\mu g/m^3$	3.62	Shallow Soil Gas MTCA B	20	1	5%	4.1	4.1	GP-18A	7/8/2015	1	5%	No	
Naphthalene	$\mu g/m^3$	2.45	Shallow Soil Gas MTCA B	20	10	50%	4.81	10.1	GP-17A	7/8/2015	10	50%	Yes	Nondetects also exceeded CUL during May 2016 event.

Deep Soil Gas

Consituents of Concern	Cleanup Level			Deep Soil Gas Detections (Since July 2015)							Exceedances (Since July 2015)		Retained For Feasibility Study (FS)	
	Units	Proposed Cleanup Level	Source of Cleanup Level	Number of Results (excluding Field Dups)	Number of Samples with Detected Concentration	Detection Frequency	Minimum Detected Concentraion	Maxumim Detected Concentration	Location of Maximum Detection	Date of Maximum Detection	Number of Exceedances of Cleanup Level	Exceedance Frequency	Retained For FS?	Comments
Voltaile Organic Compounds														
Naphthalene	$\mu g/m^3$	7.35	Deep Soil Gas MTCA B	18	8	44%	5.49	9.25	GP-16C	7/8/2015	2	11%	Yes	

Notes:

First sample event in July 2015 analyzed by Fremont Analytical had exceedances for chloroform and naphthalene, by TO-15.

Second sample event in May 2016 analyzed by Eurofins reported no exceedances for VOCs analyzed, by TO-15 and TO-17.

CUL = Cleanup Level

$\mu g/m^3$ = micrograms per cubic meter.

Table 7.6 - Frequency of Detections in Leachate Samples

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Group	Analyte	Units	Total or Dissolved	Number of Sampled Locations	Number of Samples (excluding Field Dups)	First Sample Date	Most Recent Available Sample Date	Number of Samples with Detected Concentration	Detection Frequency	Last Sample Date with Detected Concentration	Maxumim Detected Concentration	Minimum Detected Concentraion	Average Detected Concentration
Conventionals	Alkalinity, Bicarbonate	mg/L	NA	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	435	24.4	134
Conventionals	Alkalinity, Total (as CaCO3)	mg/L	NA	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	435	24.4	134
Conventionals	Ammonia as N	mg/L	NA	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	85	1.43	30.8
Conventionals	Chloride	mg/l	NA	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	305	3.6	102
Conventionals	Ethane	µg/L	NA	1	1	12/11/2015	12/11/2015	0	0%				
Conventionals	Ethene	µg/L	NA	1	1	12/11/2015	12/11/2015	1	100%	12/11/2015	0.0058	0.0058	0.0058
Conventionals	Methane	µg/L	NA	1	1	12/11/2015	12/11/2015	1	100%	12/11/2015	5.4	5.4	5.4
Conventionals	Nitrate	mg/L	NA	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	18.7	0.415	6.68
Conventionals	NIitrate + Nitrite as N	mg/L	NA	2	4	12/11/2015	3/15/2016	4	100%	3/15/2016	2.32	0.415	1.07
Conventionals	Sulfate	mg/L	NA	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	344	7.95	70.3
Conventionals	Total Dissolved Solids (TDS)	mg/L	NA	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	1060	90	433
Conventionals	Total Organic Carbon	mg/L	NA	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	156	9.71	45.1
Conventionals	Total Suspended Solids	mg/L	NA	2	6	6/16/2015	3/15/2016	5	83%	3/15/2016	9.56	1.7	3.95
Field Parameters	Dissolved Oxygen	mg/L	NA	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	10.89	4.79	7.433
Field Parameters	Iron(II), Field	ppm	NA	2	3	9/16/2015	12/17/2015	1	33%	12/17/2015	2	2	2
Field Parameters	Oxidation-Reduction Potential	mV	NA	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	148.6	69.5	100.1
Field Parameters	pH	pH units	NA	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	7.58	5.85	6.69
Field Parameters	Specific Conductance	µS/cm	NA	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	2705	118.1	929.9
Field Parameters	Temperature	deg C	NA	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	16.4	9.4	12.1
Field Parameters	Turbidity	ntu	NA	2	5	9/16/2015	3/15/2016	5	100%	3/15/2016	95.4	5.72	25.3
Metals	Antimony	µg/L	D	1	1	9/16/2015	9/16/2015	0	0%				
Metals	Arsenic	µg/L	D	1	1	9/16/2015	9/16/2015	0	0%				
Metals	Barium	µg/L	D	1	1	9/16/2015	9/16/2015	1	100%	9/16/2015	23.7	23.7	23.7
Metals	Beryllium	µg/L	D	1	1	9/16/2015	9/16/2015	0	0%				
Metals	Cadmium	µg/L	D	1	1	9/16/2015	9/16/2015	0	0%				
Metals	Calcium	µg/L	D	1	1	9/16/2015	9/16/2015	1	100%	9/16/2015	18700	18700	18700
Metals	Chromium	µg/L	D	1	1	9/16/2015	9/16/2015	1	100%	9/16/2015	8.5	8.5	8.5
Metals	Cobalt	µg/L	D	1	1	9/16/2015	9/16/2015	1	100%	9/16/2015	9.6	9.6	9.6
Metals	Copper	µg/L	D	1	1	9/16/2015	9/16/2015	1	100%	9/16/2015	20.1	20.1	20.1
Metals	Iron	µg/L	D	1	1	9/16/2015	9/16/2015	1	100%	9/16/2015	448	448	448
Metals	Lead	µg/L	D	1	1	9/16/2015	9/16/2015	0	0%				
Metals	Magnesium	µg/L	D	1	1	9/16/2015	9/16/2015	1	100%	9/16/2015	8030	8030	8030
Metals	Manganese	µg/L	D	1	1	9/16/2015	9/16/2015	1	100%	9/16/2015	249	249	249
Metals	Mercury	µg/L	D	1	1	9/16/2015	9/16/2015	0	0%				
Metals	Nickel	µg/L	D	1	1	9/16/2015	9/16/2015	1	100%	9/16/2015	37.1	37.1	37.1
Metals	Potassium	µg/L	D	1	1	9/16/2015	9/16/2015	1	100%	9/16/2015	60500	60500	60500
Metals	Selenium	µg/L	D	1	1	9/16/2015	9/16/2015	0	0%				
Metals	Silver	µg/L	D	1	1	9/16/2015	9/16/2015	0	0%				
Metals	Sodium	µg/L	D	1	1	9/16/2015	9/16/2015	1	100%	9/16/2015	180000	180000	180000
Metals	Thallium	µg/L	D	1	1	9/16/2015	9/16/2015	0	0%				

Table 7.6 - Frequency of Detections in Leachate Samples

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Group	Analyte	Units	Total or Dissolved	Number of Sampled Locations	Number of Samples (excluding Field Dups)	First Sample Date	Most Recent Available Sample Date	Number of Samples with Detected Concentration	Detection Frequency	Last Sample Date with Detected Concentration	Maxumim Detected Concentration	Minimum Detected Concentraion	Average Detected Concentration
Metals	Vanadium	µg/L	D	1	1	9/16/2015	9/16/2015	0	0%				
Metals	Zinc	µg/L	D	1	1	9/16/2015	9/16/2015	1	100%	9/16/2015	48.5	48.5	48.5
Metals	Antimony	µg/L	T	2	6	6/16/2015	3/15/2016	2	33%	9/16/2015	20	16	18
Metals	Arsenic	µg/L	T	2	6	6/16/2015	3/15/2016	1	17%	9/16/2015	34	34	34
Metals	Barium	µg/L	T	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	58.3	6.23	24.5
Metals	Beryllium	µg/L	T	2	6	6/16/2015	3/15/2016	0	0%				
Metals	Cadmium	µg/L	T	2	6	6/16/2015	3/15/2016	0	0%				
Metals	Calcium	µg/L	T	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	33300	10900	18700
Metals	Chromium	µg/L	T	2	6	6/16/2015	3/15/2016	2	33%	9/16/2015	18.4	6.8	12.6
Metals	Cobalt	µg/L	T	2	6	6/16/2015	3/15/2016	4	67%	3/15/2016	17.4	3.9	8.78
Metals	Copper	µg/L	T	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	52.7	6.9	24.2
Metals	Iron	µg/L	T	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	26900	329	5390
Metals	Lead	µg/L	T	2	6	6/16/2015	3/15/2016	0	0%				
Metals	Magnesium	µg/L	T	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	15700	3840	7310
Metals	Manganese	µg/L	T	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	740	57	355
Metals	Mercury	µg/L	T	2	6	6/16/2015	3/15/2016	1	17%	9/16/2015	0.16	0.16	0.16
Metals	Nickel	µg/L	T	2	6	6/16/2015	3/15/2016	3	50%	12/17/2015	50.7	15	31.3
Metals	Potassium	µg/L	T	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	72600	2060	22600
Metals	Selenium	µg/L	T	2	6	6/16/2015	3/15/2016	0	0%				
Metals	Silver	µg/L	T	2	6	6/16/2015	3/15/2016	0	0%				
Metals	Sodium	µg/L	T	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	229000	3800	77300
Metals	Thallium	µg/L	T	2	6	6/16/2015	3/15/2016	0	0%				
Metals	Vanadium	µg/L	T	2	6	6/16/2015	3/15/2016	1	17%	9/16/2015	32	32	32
Metals	Zinc	µg/L	T	2	6	6/16/2015	3/15/2016	6	100%	3/15/2016	380	14	171
VOCs	1,1,1,2-Tetrachloroethane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	1,1,1-Trichloroethane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	1,1,2,2-Tetrachloroethane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	1,1,2-Trichloroethane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	1,1-Dichloroethane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	1,1-Dichloroethene	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	1,2,3-Trichloropropane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	1,2-Dibromo-3-chloropropane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	1,2-Dibromoethane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	1,2-Dichlorobenzene	µg/L	NA	2	6	6/16/2015	3/15/2016	1	17%	12/17/2015	0.22	0.22	0.22
VOCs	1,2-Dichloroethane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	1,2-Dichloropropane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	1,4-Dichlotobenzene	µg/L	NA	2	6	6/16/2015	3/15/2016	5	83%	3/15/2016	4.53	0.33	1.35
VOCs	2-Butone	µg/L	NA	2	6	6/16/2015	3/15/2016	3	50%	3/15/2016	75.4	6.49	41.3
VOCs	2-Hexanone	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				

Table 7.6 - Frequency of Detections in Leachate Samples

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Group	Analyte	Units	Total or Dissolved	Number of Sampled Locations	Number of Samples (excluding Field Dups)	First Sample Date	Most Recent Available Sample Date	Number of Samples with Detected Concentration	Detection Frequency	Last Sample Date with Detected Concentration	Maxumim Detected Concentration	Minimum Detected Concentraion	Average Detected Concentration
VOCs	4-Methyl-2-pentanone	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Acetone	µg/L	NA	2	6	6/16/2015	3/15/2016	5	83%	3/15/2016	101	4.8	47.2
VOCs	Acrylonitrile	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Benzene	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Bromochloromethane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Bromodichloromethane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Bromoform	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Bromomethane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Carbon disulfide	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Carbon tetrachloride	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Chlorobenzene	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Chlorodibromomethane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Chloroethane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Chloroform	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Chloromethane	µg/L	NA	2	6	6/16/2015	3/15/2016	2	33%	12/11/2015	0.439	0.21	0.325
VOCs	Cis-1,2-dichloroethene	µg/L	NA	2	6	6/16/2015	3/15/2016	1	17%	6/16/2015	0.23	0.23	0.23
VOCs	Cis-1,3-dichloropropene	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Dibromomethane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Dichlorodifluoromethane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Ethylbenzene	µg/L	NA	2	6	6/16/2015	3/15/2016	2	33%	12/17/2015	0.435	0.41	0.423
VOCs	Methyl iodide	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Methylene chloride	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	O-xylene	µg/L	NA	2	6	6/16/2015	3/15/2016	2	33%	3/15/2016	0.706	0.34	0.523
VOCs	Styrene	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Tetrachloroethene	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Trans-1,2-dichloroethene	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Trans-1,3-dichloropropene	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Trans-1,4-dichloro-2-butene	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Trichloroethene	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Trichlorofluoromethane	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Toluene	µg/L	NA	2	6	6/16/2015	3/15/2016	3	50%	3/15/2016	1.25	0.31	0.845
VOCs	Vinyl acetate	µg/L	NA	2	6	6/16/2015	3/15/2016	0	0%				
VOCs	Vinyl chloride	µg/L	NA	2	6	6/16/2015	3/15/2016	2	33%	3/15/2016	0.096	0.0314	0.0637

Notes:

D = Dissolved, T = Total, NA = Not Applicable

C = Celsius, mg/L = milligrams per liter, mV = millivolt, µg/L = micrograms per liter, µS/cm = microsiemens per centimeter, ntu = nephelometric turbidity unit

Gray font indicates no detections.

Table 7.7 - Constituents Of Concern

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Group	Constituents of Concern	Groundwater	Soil Gas
Metals (Total and Dissolved)	Arsenic	X	
Metals (Dissolved)	Iron	X	
Metals (Dissolved)	Manganese	X	
VOCs	Naphthalene		X
VOCs	Vinyl chloride	X	

Notes:

Constiuents of Concern (COC) list only includes parameters exceeding cleanup levels that are retained for the Feasibility Study.

VOCs = Volatile Organic Compounds

Table 7.8 - Monitoring Well Evaluation Summary

AGENCY DRAFT

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

RI Well	Current Monitoring Status	Constituent of Concern (COC) Cleanup Level Exceedances	Statistically Significant Trend[1]
Perched Zone Wells			
EB-1	--	NA	--
EB-2	--	NA	--
EB-6D	Quarterly	NA	NS (Arsenic); ND (TCE); ND (VC)
EW-2	--	NA	--
EW-6	--	Iron, VC	--
EW-7	--	Arsenic	--
EW-8	--	Manganese	--
EW-9	--	Iron	--
EW-10	--	Arsenic, Iron	--
EW-11	--	NA	--
EW-12	--	NA	--
EW-13	--	NA	--
EW-14	--	VC	--
EW-15	--	Iron, Manganese, VC	--
EW-16	--	Arsenic, Iron, Manganese	--
EW-17	--	Arsenic, Iron, Manganese, VC	--
EW-18	--	Arsenic, Iron, Manganese, VC	--
EW-19	--	Arsenic, Iron, Manganese	--
EW-20	--	Arsenic, Iron, Manganese, VC	--
EW-21	--	Arsenic, Iron, Manganese, VC	--
EW-23	--	VC	--
EW-24	--	--	--
EW-25	--	cis-1,2-DCE, TCE	--
EW-26	--	NA	--
EW-27	--	NA	--
EW-29	--	VC	--
MW-102	WL	NA	--
MW-103	WL	Arsenic	--
MW-104	WL	Arsenic	--
MW-29	WL	NA	--
MW-30A	Quarterly, WL	NA	NS (Arsenic); Decreasing (TCE); NS (VC)
MW-47	Quarterly, WL	Arsenic, Manganese, VC	Decreasing (Arsenic); NS (TCE); Increasing (VC)
MW-50	WL	Arsenic	--
MW-62	Quarterly, WL	NA	ND (Arsenic); Decreasing (TCE); ND (VC)
Regional Aquifer EPZ Wells			
MW-67	Quarterly, WL	NA	--
MW-68	Quarterly, WL	Arsenic	Increasing (Arsenic)
MW-75	Monthly, WL	NA	--
MW-80	Quarterly, WL	Arsenic*	--
MW-81	Quarterly, WL	NA	--
MW-85	Quarterly, WL	NA	--
MW-87	Quarterly, WL	NA	--
MW-91	Quarterly, WL	Arsenic*	--
MW-93	Quarterly, WL	NA	--
MW-99	Quarterly, WL	NA	--

Notes:
-- = Not applicable
EPZ = East Perched Zone
Metals = dissolved fraction
NA = No CUL exceedances
* = Arsenic concentrations, although above CULs are within regional background levels.
Shaded text indicates wells considered to be the most impacted zone for monitored natural attenuation (MNA) evaluation in Table
cis-1,2-DCE = cis-1,2-Dichloroethene
TCE = trichloroethene
VC = vinyl chloride
WL = Water level measurement

Statistical Trend Results:

[1] Mann-Kendall and Theil-Sen Trend tests conducted using ProUCL software. EPZ well dataset was 2006-2016. Regional Well dat

NS = Insufficient statistical evidence of a significant trend.
Decreasing = Sufficient statistical evidence of a decreasing trend.
Increasing = Sufficient statistical evidence of an increasing trend.
ND = Nondetect parameter, so no statistical trend available.

Table 7.9 - Monitored Natural Attenuation (MNA) Evaluation

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Analyte	*Criteria Concentration*[3]	*Scoring Value*[3]	Concentration in Impacted EPZ[2]	Actual Score	Comments and Interpretation
Conventionals					
Alkalinity	*> 2x background*	*1*	21.6 mg/L to 716 mg/L	1	Background alkalinity at MW-29 averages 26 mg/L. Alkalinity could be from interaction of LFG-derived CO_2. Score of 1 because points are not based on compound being a daughter product. Median 223 mg/L; mean 286.44 mg/L.
Chloride	*>2x background*	*2*	0.36 mg/L to 11 mg/L;	2	Elevated in EW 14 and MW-47 area. Background chloride at MW-29 is generally around 2.66 mg/L.
Dissolved Oxygen (DO)	*< 0.5 mg/L*	*3*	0.16 mg/L to 8.51 mg/L	3	Median 0.56 mg/L but more than half results <0.5 mg/L. Most wells in the impacted area have DO < 0.5 mg/L.
Ethene	*>0.01 mg/L or >0.1 mg/L*	*2 or 3*	Max of 0.00032 mg/L	0	
Ethane	*>0.01 mg/L or >0.1 mg/L*	*2 or 3*	Max of 0.0077 mg/L	0	
Iron (II)	*> 1 mg/L*	*3*	Most great than 2 mg/L	3	Areas of high iron (II) coincide with main impact areas. Areas of nondetect iron II correspond to areas of high DO and No3. Median 3 mg/L, mean 3.22 mg/L.
Methane	*>0.5 mg/L*	*3*	Up to 18 mg/L	0	More than half concentrations greater than 0.5 mg/L. Eight impacted wells had methane less than 500 mg/L (EW15,17,18,23-27). No points awarded because methane is part of the LFG source.
Nitrate	*< 1 mg/L*	*2*	0.01 mg/L to 1.40 mg/L	2	Most wells had less than 0.1 mg/L. General absence of nitrates in impacted zone consistent with low DO. MW-50 only well with high DO and low NO_3. Median 0.05 mg/L, Mean 0.21 mg/L.
Oxidation Reduction Potential (ORP)	*<50 mV or <-100 mV*	*1 or 3*	range from -90 mV to 197 mV	1	No ORPs measured less than -100 mV. Wells in most impacted area (EW-17 to EW-29 and MW-47) generally less than 50 mV. Few south impacted wells have ORP >50 mV. Median 32 mV, mean 27.42 mV.
pH	*5 < pH < 9 or 5 > pH > 9*	*0 or -2*	Range from 5.72 to 7.27	0	Within optimal range for reductive pathway.
Sulfate	*<20 mg/L*	*2*	<12 mg/L in impacted areas; nearly all <20 mg/L	2	Only four sulfate values > 20 mg/L and only in EW-27. Mean 7.02, Median 6.02.
Total Organic Carbon (TOC)	*>20 mg/L*	*2*	Range from 1 mg/L to 47.5 mg/L	2	TOC meets EPZ criteria in four wells in most impacted area: EW-16, -17, -18, and -19 (and nearby wells are in 10 to 20 mg/L range).
Aromatic and Chlorinated Volatile Organic Compounds					
BTEX	*>0.1 mg/L*	*2*	< 0.1 mg/L	0	Total BTEX concentrations ranged from ND to 13.11 µg/L. Most total BTEX < 1 µg/L. MW-21 had highest total concentration.
Carbon Tetrachloride		*0*	ND	0	
Chloroethane		*2*	0.23 µg/L to 0.52	2	Daughter prodcut of DCA or VC. Detected at EW-06 and MW-47 only. Likely assocated with VC breakdown in MW-47. No DCA detected in MW-47. Detections not attributed to LFG to groundwater pathway.
Dichloroethene (DCE)[1]	*>80% cis-1,2-DCE*	*2*		0	1,1-DCE all non-detect; trans-1,2-DCE non-detect EW-14 through EW-25; where both cis and trans occur, cis is 82% to 98% of DCE; however, cis-1,2-DCE is present in LFG and, therefore, could be considered source.
1,1-Dichloroethane (DCA)		*2*	ND to 0.83 µg/L	2	Daughter product of TCA under reducing conditions. Detected in EW-24, EW-25, and MW-47. 1,1-DCA present in LFG but it is allowed to be scored if not a daughter product.
Dichloromethane		*0 or 2*	NA	0	Scoring based on whether material released (0) or daughter product of chloroform (2).
Tetrachloroethene (PCE)		*0*		0	No points awarded because PCE is part of the LFG source.
1,1,1-Trichloroethane (TCA)		*0*	Detections in MW-30A historically	0	No points awarded because TCA is presented in LFG source. TCA was detected in MW-30A in 1993/1994. No 1,1,1-TCA during 2015-2016 sample events. DCA detections persist after dissappearance of TCA suggesting degradation.
Trichloroethene (TCE)[1]		*2*		0	TCE is present in LFG. Unknown if TCE detections are daughter product of PCE.
Vinyl Chloride (VC)[1]		*2*		1	Scoring based on whether material released (0) or daughter product of DCE (2).VC likely associated with LFG source as it is present in LFG; however, also likely daughter product. Scored half points as a result.
			Total Score:	**21**	

Notes:

Red text indicates parameters where LFG affects could influence evaluation of MNA process.

[1] - Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source "NAPL")

[2] - Most impacted zone considered the ESPZ from MW-47 in the north to EW-29 in the south.

[3] - *Adapted from USEPA, 1998, Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater, EPA/600/R-98/128.*

BTEX = benzene, toluene, etheylbenzene, xylenes; EPZ = East Perched Zone; ESPZ = East Shallow Perched Zone; LFG = landfill gas; µg/L = micrograms per liter; mg/L = milligrams per liter; mV = millivolts; MNA = monitored natural attenuation; NA = not applicable; ND = non-detect; VC = vinyl chloride

Scoring[3]	*Interpretation*[3]
0 to 5	*Inadequate evidene for anaerobic biodegradation * of chlorinated organics.*
6 to 14	*Limited evidence for anaerobic biodegradation* of chlorinated organics.*
15 to 20	*Adequate evidence for anaerobic biodegradation* of chlorinated organics.*
> 20	*Strong evidence of anaerobic biodegradation* of chlorinated organics.*
	** reductive dechlorination*

Table 7.10 - Landfill Gas Collection System, East Header, 2015-2016

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Location ID	Average Flow (scfm)	Estimated Methane (tpd)	Average Landfill Gas Concentration			Maximum Temperature deg F	Average Pressure	
			Methane (% by vol)	Oxygen (% by vol)	Carbon Dioxide (% by vol)		Static (inches water)	Differential (inches water)
CHE0001B	0	0.0	7.8	12.1	5.6	104	-2.0	0.00
CHE0001C	0	0.0	0.3	18.1	1.8	113	-0.5	0.00
CHE0001D	3	0.0	37.8	2.6	15.4	100	-4.9	0.01
CHE00004	56	0.7	44.3	1.0	28.4	91	-21.8	0.06
CHE00006	8	0.0	51.2	6.4	12.4	99	-16.0	0.00
CHE00009	25	0.1	31.5	0.7	22.5	97	-5.5	0.02
CHE00010	21	0.1	30.9	1.1	20.8	99	-18.8	0.01
CHE00013	14	0.0	18.7	9.4	13.9	108	-8.1	0.01
CHE00014	0	0.0	4.3	16.4	4.4	98	-4.5	0.00
CHE00016	20	0.0	9.3	14.8	7.7	93	-0.7	0.07
CHE00017	5	0.1	39.0	0.2	26.9	92	-22.0	0.01
CHE00018	9	0.1	40.5	0.8	28.7	103	-17.1	0.02
CHE00019	18	0.3	64.0	0.2	35.2	108	-23.3	0.12
CHE00021	12	0.2	62.5	1.6	29.8	100	-23.4	0.04
CHE00022	11	0.1	37.1	0.0	29.4	90	-10.6	0.03
CHE00023	13	0.1	36.1	0.1	28.2	100	-7.6	0.03
CHE00024	14	0.2	44.1	0.0	34.2	94	-8.0	0.03
CHE00026	8	0.1	53.5	0.3	35.1	97	-22.3	0.02
CHE00027	10	0.1	50.3	0.1	32.7	100	-17.3	0.02
CHE00028	0	0.0	2.5	17.3	3.0	92	-0.6	0.00
CHE00030	16	0.3	56.4	0.1	38.9	96	-22.9	0.04
CHE00031	10	0.1	44.8	4.1	27.7	102	-9.8	0.02
CHE00032	17	0.3	55.9	1.4	37.5	105	-22.1	0.09
CHE0032A	1	0.0	30.6	8.2	22.6	99	-18.4	0.00
CHE00033	14	0.2	59.0	0.0	40.3	93	-23.1	0.03
CHE00034	37	0.5	46.2	0.1	33.7	86	-6.6	0.20
CHE00035	18	0.2	45.8	0.0	34.1	93	-8.7	0.05
CHE0035A	0	0.0	0.2	17.4	2.9	105	-10.4	0.00
CHE00036	12	0.2	49.7	0.1	31.1	102	-2.7	0.03
CHE0036A	10	0.0	0.3	20.0	0.9	103	-0.7	0.03
CHE00037	4	0.0	10.5	11.8	10.3	103	-9.1	0.01
CHE00038	5	0.0	5.4	11.2	9.3	99	-1.4	0.06
CHE0038A	0	0.0	0.1	20.4	0.8	96	-0.7	0.00
CHE00039	0	0.0	1.2	18.8	1.7	98	-2.1	0.00
CHE00040	26	0.3	43.5	2.4	29.8	91	-3.3	0.14
CHE0040A	13	0.2	59.2	0.2	38.3	94	-21.9	0.03
CHE00042	4	0.0	24.7	5.8	22.5	99	-6.3	0.02
CHE0042A	0	0.0	1.8	19.4	1.0	103	-9.5	0.00
CHE00043	23	0.3	43.4	0.0	32.3	85	-2.4	0.08
CHE0043A	2	0.0	10.7	12.3	10.6	101	-0.9	0.01
CHE00044	0	0.0	7.2	16.9	5.5	99	-1.2	0.00
CHE0046A	0	0.0	0.1	20.1	1.0	98	-0.1	0.00
CHE00047	0	0.0	5.9	14.4	4.3	97	-14.6	0.00
CHE0047A	11	0.2	61.6	0.1	36.6	96	-23.2	0.02
CHE00048	13	0.1	34.3	0.3	26.6	94	-2.4	0.03
CHE0048A	0	0.0	4.3	14.1	5.8	98	-5.3	0.00
CHE00049	10	0.1	41.6	0.0	31.2	94	-6.1	0.02
CHE0049A	0	0.0	0.1	20.1	1.2	98	-0.3	0.00
CHE00050	14	0.2	48.6	0.6	28.6	97	-17.2	0.04
CHE00052	0	0.0	0.1	20.7	0.2	95	-2.1	0.00
CHE00053	0	0.0	2.9	19.0	2.1	96	-1.5	0.00
CHE00054	2	0.0	34.3	6.7	17.1	101	-7.7	0.01
CHE00055	11	0.1	24.4	3.2	20.3	98	-0.6	0.09
CHE00056	0	0.0	0.1	16.4	3.3	99	-1.1	0.00
CHE0056A	11	0.2	71.5	0.1	28.1	99	-23.4	0.02
CHE0056B	0	0.0	0.1	20.0	0.9	97	-0.4	0.00
CHE00057	0	0.0	0.3	17.2	2.0	99	-10.2	0.00
CHE00066	2	0.0	28.2	8.4	13.9	98	-9.0	0.00
CHE00067	5	0.0	37.5	6.4	22.2	102	-12.6	0.00
CHE00068	8	0.1	32.8	0.1	24.3	111	-5.3	0.02
CHE00069	0	0.0	1.6	18.2	3.1	103	-1.6	0.00
CHE00070	7	0.1	31.7	6.4	24.9	98	-2.7	0.02
CHE00071	34	0.4	42.8	1.2	34.9	98	-6.3	0.18
CHE00E1A	3	0.0	26.4	1.9	18.5	95	-11.7	0.01
CHEGL059	26	0.3	43.3	0.5	35.0	97	-4.0	0.11
CHEGL060	9	0.1	41.3	0.2	29.0	102	-7.8	0.02
CHEGL061	20	0.3	49.8	1.5	35.7	87	-3.8	0.07
CHEGLSE1	0	0.0	15.3	13.7	7.7	93	-9.3	0.00
CHEGLSE2	0	0.0	10.4	17.0	4.4	93	-14.7	0.00
CHEGLSE3	1	0.0	50.6	4.2	19.4	101	-14.6	0.00
CHEGLSE4	1	0.0	33.6	8.4	10.6	101	-15.7	0.00
CHEGLSE5	0	0.0	8.2	16.0	4.1	92	-20.1	0.00
CHEGLSE6	1	0.0	31.0	8.4	10.2	100	-16.1	0.00
CHEGLSE7	2	0.0	37.3	7.3	19.9	97	-19.1	0.00
CHEGLSE8	2	0.0	42.5	5.8	21.8	97	-17.4	0.00
CHEMHFC1	1	0.0	7.9	14.9	6.2	100	-1.5	0.00

Notes:
F = Fahrenheit
scfm = standard cubic feet per meter
tpd = tons per day
% by vol = percent by volume

LFG Migration Control

- 🟩 Relaxed
- 🟩 Moderate
- 🟨 Aggressive
- 🟧 Very Aggressive
- 🟥 Not Viable

Table 8.1 - Volatile Organic Compound Detections by Media

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Volatile Organic Compound	Shallow Groundwater	Leachate	Landfill Gas (Flare #1 Inlet)	Shallow Soil Gas	Deep Soil Gas
1,1-Dichloroethane	X		X		X
1,2-Dichlorobenzene	X				
1,2-Dichloroethane	X		X		
1,2-Dichloropropane			X		
1,2,4-Trimethylbenzene			X	X	X
1,3,5-Trimehtylbenzene			X	X	X
1,3-Dichlorobenzene				X	X
1,4-Dichlorobenzene	X	X	X		
2-Butanone		X	X	X	X
4-Ethyltoluene			X	X	
4-Methyl-2-pentanone			X		
Acetone	X	X	X	X	X
Benzene	X		X	X	X
Carbon disulfide	X			X	
Chlorobenzene	X		X		
Chloroethane	X			X	X
Chloroform	X				
Chloromethane	X	X			
cis-1,2-Dichloroethene	X		X	X	X
Cumene			X		
Dichlorodifluoromethane	X			X	X
d-Limonene				X	
Ethane	X	--	--	--	
Ethene	X	--	--	--	
Ethyl acetate	--	--	--	X	
Ethylbenzene	X	X	X	X	X
Freon 11	--	--	X		
Freon 12	--	--	X		
1,2-Dichlorotetrafluoroethane; Freon 114	--	--	X	X	X
Hexane	--	--	X		
Isopropyl alcohol (manufacturing-strong acid)	--	--	--	X	X
m,p-Xylene			X	X	X
Methane	X		X	X	X
Methylene chloride				X	X
Naphthalene				X	X
Nonane				X	
Octane	--	--	--		X
o-Xylene		X	X	X	X
p-Cymene			X		
Propylbenzene			X	X	
Propylene (propene)				X	
Styrene			X		
Tetrachloroethene	X		X	X	X
Toluene	X	X	X	X	X
trans-1,2-Dichloroethene	X				
Trichloroethene	X		X	X	X
Trichlorofluoromethane				X	
Vinyl chloride	X	X	X	X	X

Notes:

-- Not analyzed.

No shading indicates VOC not detected.

Shading indicates compound detected in groundwater, LFG, and soil gas.

LFG flare data from The Avogadro Group, LLC., 2012.

Soil gas data from Remedial Investigation (RI) and historical sampling event presented in EPZ Technical Memo (Aspect, 2010).

LFG = Landfill Gas

VOC = Volatile Organic Compound

Table 8.2 - Landfill Gas vs. Leachate Indicator Parameters

Project No. 130088, Cedar Hills Regional Landfill

King County, Washington

Parameter	Dissolved Methane	Alkalinity	Chloride
Unit	µg/L	mg/L	mg/L
Location	**Max Result**	**Max Result**	**Max Result**
EB-1	0.29	13.7	2.79
EB-2	2.1	47.3	2.39
EB-6D	2900	81.8	0.849
EW-02	4.5	27.9	3.58
EW-06	440	416	51.8
EW-07	1200	73	39.4
EW-08	230	103	1.33
EW-09	560	54.6	2.64
EW-10	960	249	1.96
EW-11	5100	63.1	0.461
EW-12	0.24	225	3.28
EW-13	880	70.7	5.53
EW-14	14000	697	11
EW-15	4000	458	3.78
EW-16	5200	420	6.37
EW-17	5100	379	2.09
EW-18	160	386	2.99
EW-19	5300	523	3.02
EW-20	3100	397	1.88
EW-21	18000	223	2.83
EW-23	35	102	1.73
EW-24	3.3	83.2	1.27
EW-25	1.8	61.2	0.953
EW-26	9.4	61.6	0.959
EW-27	560	107	3.21
EW-29	7100	215	7.02
MW-102	0.26	66	6
MW-103	2.3	137	6.76
MW-104	170	98.5	2.35
MW-30A	5.9	139	1.7
MW-47	1700	716	7.67
MW-50	3.7	138	2.18
MW-62	2.4	73.8	5.83
Thresholds*	**> 100 µg/L**	**> 100 mg/L**	**> 10 mg/L**

Notes:

Red font color indicates concentration exceeds threshold.

Orange shading indicates wells with LFG and potential leachate to groundwater impact based on relative chloride concentrations in the presence of alkalinity and methane.

Light grey shading indicates wells with LFG to groundwater impact based on relative methane and alkalinity concentrations.

Dark grey shading indicates wells with LFG to groundwater pathway identified through VOC partitioning evaluation presented in Table 8.4.

Max Result = Maximum result for each well from the 2015-2016 Remedial Investigation dataset.

* Thresholds for methane and alkalinity are arbitrarily set. Threshold of 10 mg/L for chloride is indicative of fresh groundwater in many areas of Washington.

LFG = landfill gas, mg/L = milligrams per liter, µg/L = micrograms per liter, VOC = volatile organic compound

AGENCY DRAFT

Table 8.3 - Leachate Parameters and Ratio Evaluation

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

			"Background" Wells								Potential Leachate Impacted Wells							
		Well ID	**EB-1**				**EB-2**				**EW-06**				**EW-07**			
Ratio or Parameter	**Units**	**Date**	6/9/2015	9/9/2015	12/8/2015	3/9/2016	6/9/2015	9/9/2015	12/8/2015	3/9/2016	6/10/2015	9/9/2015	12/16/2015	3/11/2016	6/10/2015	9/9/2015	12/16/2015	3/11/2016
L/N			6.0	5.4	4.8	4.4	6.8	4.7	5.7	5.3	1.9	1.9	2.7	2.3	3.4	6.8	7.7	6.5
Cl/SO$_4$			1.9	1.5	1.5	1.8	1.0	0.9	1.0	1.1	2.5	2.0	1.1	1.4	18.7	0.1	0.2	0.3
Cl/HCO$_3$			0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.1	0.0	0.0
Ca/K			8.3	9.3	10.8	11.6	7.5	12.3	8.2	9.4	26.3	27.8	19.2	21.3	9.7	8.6	6.8	8.6
Cl/TDS			0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.3	0.0	0.0	0.0
Na/K			6.3	7.0	7.4	8.5	5.3	6.2	7.1	7.3	12.5	12.1	8.4	10.6	17.1	3.6	4.1	4.1
Calcium	µg/L		4580	4650	5760	4860	6720	10400	5780	4940	80500	78400	47900	50300	14100	16600	5450	7080
Magnesium	µg/L		1140	1130	1340	1110	1830	2490	1460	1130	44300	39200	24400	29500	4370	4890	1630	2290
Sodium	µg/L		3010	3720	3800	3780	4020	5830	4970	4240	32500	39000	24200	24000	14000	7550	3210	3020
Total Dissolved Solids (TDS)	mg/L		61.3	54	51.3	45.3	67.2	87.9	60	54.7	572	524	295	351	149	162	49.3	54
Total VOC Concentration	µg/L		0	0	0.3	0	0	0	0	0	8.7	6.7	5.4	5.7	23.9	8.7	0.0	1.4

			LFG Impacted Well				Leachate Samples					
		Well ID	**EW-14**				**FS-3**				**MH-17N**	
Ratio or Parameter	**Units**	**Date**	6/12/2015	9/11/2015	12/14/2015	3/16/2016	6/16/2015	9/16/2015	12/11/2015	3/15/2016	12/17/2015	3/15/2016
L/N			3.0	2.9	2.9	3.1	20.8	28.1	11.1	14.5	11.5	9.8
Cl/SO$_4$			1.3	1.3	0.6	1.1	0.7	9.7	0.3	0.7	2.0	2.0
Cl/HCO$_3$			0.0	0.0	0.0	0.0	1.8	0.7	0.1	0.1	0.5	0.3
Ca/K			19.9	20.8	20.3	19.8	0.7	0.3	5.3	4.0	3.0	4.1
Cl/TDS			0.0	0.0	0.0	0.0	0.2	0.3	0.0	0.1	0.2	0.1
Na/K			2.8	2.4	2.8	2.7	3.8	3.2	1.8	1.7	4.7	4.6
Calcium	µg/L		133000	132000	128000	124000	33300	20900	10900	15000	17600	14200
Magnesium	µg/L		74500	68900	70000	60600	15700	8630	3840	4500	6280	4910
Sodium	µg/L		14000	17400	18300	15400	181000	229000	3800	6250	27800	16000
Total Dissolved Solids (TDS)	mg/L		724	734	714	686	1060	1030	90	110	178	129
Total VOC Concentration	µg/L		2.8	3.9	3.4	2.7	5.6	142.9	162.1	23.0	33.6	0.7

Notes:

L/N = $(K+NH_4+NO_3)/(Mg+Ca+Na) \times 100$

Ratios and prameters derived from Mulvey and Brisbane (1996).

LFG = Landfill Gas

VOC = volatile organic compound

µg/L = micrograms per liter

mg/L = milligrams per liter

Sources: Mulvey and Brisbane (1996); Kerfoot et al (2004).

Table 8.4 - Landfill Gas-to-Groundwater Volatile Organic Compound Partitioning

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Landfill Gas Sample Site ID	Groundwater Sample Site ID	Gas Sample Date	Volatile Organic Compounds (VOCs)								
			Vinyl Chloride			1,1-Dichloroethane			cis-1,2-Dichloroethene		
Deep Gas Migration through Stratified Drift			Observed Gas Concentration C_G (µg/m^3)	Calculated Equilibrium Groundwater Concentration C_G/K_H (µg/L) [1]	Observed Groundwater Concentration C_w (µg/L)	Observed Gas Concentration C_G (µg/m3)	Calculated Equilibrium Groundwater Concentration C_G/K_H (µg/L) [1]	Observed Groundwater Concentration C_w (µg/L)	Observed Gas Concentration C_G (µg/m^3)	Calculated Equilibrium Groundwater Concentration C_G/K_H (µg/L) [1]	Observed Groundwater Concentration C_w (µg/L)
GP-55	EW-25	10/29/09	7900	7.1	0.27	170	0.74	0.2 - 0.94	2400	14	17 - 19
		1/19/10	7000	6.3	0.27	420	1.83	0.2 - 0.94	8600	51	17 - 19
	EW-26	10/29/09	7900	7.1	0.76 - 1.2	170	0.74	0.2 - 0.41	2400	14	9.9 - 16
		1/19/10	7000	6.3	0.76 - 1.2	420	1.83	0.2 - 0.41	8600	51	9.9 - 16
	MW-30A	1/19/10	7000	6.3	0.02 - 0.0251	420	1.83	3.32 - 6.9	8600	51	4.6 - 11
	MW-47	1/19/10	7000	6.3	1.4 - 7	420	1.83	0.2 - 0.72	8600	51	0.591 - 2.7
GP-59	MW-47	10/29/09	180	0.2	1.4 - 7	--	--	0.2 - 0.72	--	--	0.591 - 2.7
		1/19/10	610	0.5	1.4 - 7	120	0.52	0.2 - 0.72	120	0.7	0.591 - 2.7
Shallow Gas Migration through Till and Fill											
GP-60	MW-47	10/29/09	35	0.03	1.4 - 7	--	--	0.2 - 0.72	--	--	0.591 - 2.7
		1/19/10	--	--	1.4 - 7	--	--	0.2 - 0.72	--	--	0.591 - 2.7
EW-5	MW-30A	10/29/09	55	0.05	0.02 - 0.0251	420	1.83	3.32 - 6.9	460	2.8	4.6 - 11
		1/19/10	3.1	0.003	0.02 - 0.0251	480	2.09	3.32 - 6.9	390	2.3	4.6 - 11
Henry's Gas Constant (K_H)			1.11			0.23			0.167		

Landfill Gas Sample Site ID	Groundwater Sample Site ID	Gas Sample Date	Volatile Organic Compounds (VOCs)								
			Tetrachloroethene			Trichloroethene			Dichlorodifluoromethane (Freon 12)		
Deep Gas Migration through Stratified Drift			Observed Gas Concentration C_G (µg/m^3)	Calculated Equilibrium Groundwater Concentration C_G/K_H (µg/L) [1]	Observed Groundwater Concentration C_w (µg/L)	Observed Gas Concentration C_G (µg/m^3)	Calculated Equilibrium Groundwater Concentration C_G/K_H (µg/L) [1]	Observed Groundwater Concentration C_w (µg/L)	Observed Gas Concentration C_G (µg/m^3)	Calculated Equilibrium Groundwater Concentration C_G/K_H (µg/L) [1]	Observed Groundwater Concentration C_w (µg/L)
GP-55	EW-25	10/29/09	630	0.8	0.94 - 1.5	940	2.2	3.9 - 5.5	160	0.01	0.2 - 0.5
		1/19/10	1700	2.3	0.94 - 1.5	2800	6.6	3.9 - 5.5	270	0.02	0.2 - 0.5
	EW-26	10/29/09	630	0.8	0.2 - 0.33	940	2.2	0.2 - 1.3	160	--	--
		1/19/10	1700	2.3	0.2 - 0.33	2800	6.6	0.2 - 1.3	270	--	--
	MW-30A	1/19/10	--	--	--	2800	6.6	1.2 - 1.6	--	--	--
	MW-47	1/19/10	--	--	--	--	--	--	270	0.02	0.2 - 8
GP-59	MW-47	10/29/09	--	--	--	--	--	--	310	0.02	0.2 - 8
		1/19/10	--	--	--	--	--	--	1100	0.07	0.2 - 8
Shallow Gas Migration through Till and Fill											
GP-60	MW-47	10/29/09	--	--	--	--	--	--	--	--	--
		1/19/10	--	--	--	--	--	--	--	--	--
EW-5	MW-30A	10/29/09	--	--	--	--	--	--	--	--	--
		1/19/10	--	--	--	--	--	--	--	--	--
Henry's Gas Constant (K_H)			0.754			0.422			16.14		

Notes:

1 Calculated equilibrium groundwater concentration (CG/KH)--the ratio of the measured vapor concentration (CG) and Henry's Law constant (KH); an estimate of a VOC groundwater concentration that would be in equilibrium with a corresponding observed VOC vapor concentration.

Blue shading Indicates gas to groundwater pathway. Equilibrium groundwater concentration calculated from gas concentration is greater than lowest observed groundwater concentration (C_w) for one or more VOCs (($C_G/K_H > C_w$).

-- Indicates VOC not detected in vapor or groundwater.

Groundwater concentration ranges presented in Table 4.1 of EPZ Technical Memorandum (Aspect, 2010).

VOC = volatile organic compound

µg/L = micrograms per liter; µg/m^3 = micrograms per cubic meter

Table 8.5 - Evaluation of Exposure Pathways

East Perched Zones RI/FS Report - CHRLF, King County, WA

Medium	Pathway	Receptors	On-Property		Off-Property		Cleanup Level (CUL) Used to Evaluate Complete Pathways	Evaluation Comments
			Current Use	Potential Future Use	Current Use	Potential Future Use		
Groundwater	Direct Contact EPZ Groundwater	Above-Ground Workers	X	X	--	--	Modified MTCA Method B	Landfill workers. On-property non-potable groundwater well. No evidence of off-property shallow groundwater connected to EPZ.
		Below-Ground Workers	X	X	--	--	Modified MTCA Method B	Landfill workers and below-ground utility workers. No evidence of off-property shallow groundwater connected to EPZ.
		Residents	I	I	--	--	Modified MTCA Method B	No exposure to EPZ groundwater. No evidence of off-property shallow groundwater connected to EPZ.
	Ingestion	Residents	M	M	--	--	Modified MTCA Method B	No drinking water wells within 1,000-foot buffer. No evidence of off-property shallow groundwater connected to EPZ.
	Inhalation / Volatilization to Air	Above-Ground Workers - Indoor	I	M	--	--	Residential Protection of Indoor Air (MTCA Method B)	No landfill buildings are located over VOC impacted groundwater area. Landfill safety procedures in place to protect workers if buildings were constructed.
		Above-Ground Workers - Outdoor	I	I	--	--	Groundwater protection of residential air	No exposure.
		Below-Ground Workers (Outdoor)	X	X	--	--	Groundwater protection of residential air	Landfill workers and below-ground utility workers.
		Residents - Indoor	I	--	--	--	Residential Protection of Indoor Air (MTCA Method B)	No residential buildings located over VOC-impacted groundwater area.
		Residents - Outdoor	I	--	--	--	Groundwater protection of residential air	No residential areas located over VOC-impacted groundwater area.
	Discharge to Surface Water	See **Surface Water**	I	I	I	I	Minimum Surface Water CULs	No surface water impacts.
Surface Water	Direct Contact	Recreational Users	I	I	I	I	Minimum Surface Water CULs	No surface water impacts identified.
		Recreational Fishers	I	I	I	I		
		Aquatic Organisms	I	I	I	I		
	Ingestion	Aquatic or Terrestrial Organisms	I	I	I	I		
	Ingestion of Aquatic Organisms	Recreational Fishers	I	I	I	I		
		Subsistence Fishers	I	I	I	I		
		Aquatic Organisms	I	I	I	I		
Air	VOC Inhalation	Above-Ground Workers - Indoor	M	M	M	M	Residential Protection of Indoor Air (MTCA Method B)	Landfill safety procedures in place to protect workers.
		Above-Ground Workers - Outdoor	--	--	--	--		No pathway.
		Below-Ground Workers (Outdoor)	M	M	--	--		Landfill safety procedures in place to protect workers.
		Residents - Indoor	X	X	X	X		Complete pathway. Requires additional investigation.
		Residents - Outdoor	--	--	--	--		No pathway.
	LFG Discharge to Groundwater	See **Groundwater**	X	X	--	--	Groundwater Protection	LFG impact to groundwater complete pathway. No evidence of LFG to groundwater pathway off-property.
Leachate	Direct Contact	Above-Ground Workers - Indoor	M	M	--	--	Groundwater Protection	Landfill safety procedures in place to protect workers. No evidence of leachate direct contact pathway off-property.
		Below-Ground Workers (Outdoor)	M	M	--	--	Groundwater Protection	
	Discharge to Groundwater	See **Groundwater**	X	X	--	--	Groundwater Protection	Leachate to groundwater complete pathway historically. Decreasing with time. No evidence of leachate to groundwater.

Notes:
X = Potentially Complete Exposure Route and Receptors
M = Potential Exposure Route, Currently Mitigated to Prevent Exposure to Receptors Above Acceptable Levels
I = Incomplete Pathway Based on Available RI Data
-- Potential Exposure Route Not Applicable
EPZ = East Perched Zones
LFG = Landfill Gas
MTCA = Model Toxics Control Act
VOC = Volatile Organic Compound

Table 10.1 - Summary of Remedial Technologies Screening

Project No. 130088, Cedar Hils Regional Landfill
King County, Washington

	Groundwater		Soil Gas	Screening Summary	Retained	
	Metals	VOCs	VOCs			
Media	GW	GW	SG		GW	SG
Institutional Controls(1)	X	X	X	While not considered as a stand-alone alternative, institutional controls are an integral cleanup action component and neccesary to control completed exposure pathways and, therefore, retained.	X	X
Monitored Natural Attenuation (2)	X	X	X	MNA is effective for the site COCs, is easy to implement, and is relatively low cost compared to other remediation technologies. Therefore, this alternative will be retained both as a stand-alone remedy and in combination with other technologies.	X	X
Capping				Included as component of presumptive remedy for landfills and a closure element for the Cedar Hills Regional Landfill; however, not relevant to cleanup requirements for EPZ area and not retained. Main Hill adjacent to EPZ is capped with an engineered geomembrane cover system.		
Landfill Gas Collection and Treatment	X	X	X	LFG is the source of impacted groundwater and soil gas in the EPZ area and therefore, retained for development of remedial alternatives. Several applications of LFG collection are considered in the remedial alternatives.	X	X
Leachate Extraction and Treatment		X		Included as component of presumptive remedy for landfills, existing leachate extraction and treatment are operating adajcent to the EPZ area. However, the RI determined that leachate is not a significant contributor to groundwater impacts in the EPZ area and, therefore, not retained.		
Groundwater Extraction and Treatment	X	X		The operation of the existing groundwater extraction system was discontinued in 2010 due to diminished extraction and mass removal rates. However, groundwater extraction is still considered an applicable technology using less intensive recovery methods and repurposing of existing infrastructure and, thus, retained.		
Permeable Reactive Barrier	X	X		While PRBs are potentially effective for the COCs in groundwater, it would not address LFG (the primary source to EPZ-area impacts), and soil vapor issues. PRBs require significant capital costs that are disproportionate to the potential cleanup benefit. Because of these considerations, PRBs are not retained for remedial alternative development.		
Groundwater Impermeable Barrier	X	X		Impermeable barriers would be a barrier to impacted groundwater and soil gas migration and would require extraction to remove COCs. Capital costs for construction would be very disproportionate to the remedial benefit and, thus, not retained.		
Air Sparging	X	X		Because of the relatively low concentrations in groundwater and the likelihood of requiring new wells designed for sparging at a high cost, air sparging is not retained.		

Notes:

COCs = Constituents of Concern; EPZ = East Perched Zone; GW = Groundwater; LFG = Landfill Gas; MNA = Monitored Natural Attenuation; PRB = Permeable Reactive Barrier; RI = Remedial Investigation; SG = Soil Gas; VOC = Volitile Organic Compound

X = Contaminant/media for which remedial technology is potentially applicable.

1) Institutional controls are measures undertaken to limit or prohibit activities that may interfere with a cleanup action or result in exposure to hazardous substances.

2) Natural attenuation encompasses a variety of naturally occurring removal mechanisms, including sorption, precipitation, dilution, dispersion, and biological transformation.

Table 11.1 - Assembly of Technologies into Remedial Alternatives

AGENCY DRAFT

Project No. 130088, Cedar Hils Regional Landfill
King County, Washington

Remedial Technologies[1]	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**
	MNA of Groundwater	**Optimized LFG Control**[2] **and MNA of Groundwater**	**Perimeter Gas Collection**[3]**, Optimized LFG Control**[2]**, and MNA of Groundwater**	**Perimeter Gas Collection**[3]**, Expanded LFG Control**[4]**, and MNA of Groundwater**
Institutional Controls	X	X	X	X
GW Extraction Well Abandonment	X	X	X	X
Groundwater MNA	X	X	X	X
LFG Collection	--	X	X	X
Perimeter Gas Collection	--	--	X	X

Notes:

X = action included for that alternative.

-- = action not included for that alternative.

GW = Groundwater; LFG = Landfill Gas; MNA = Monitored Natural Attenuation; GP = Gas Probe; EW = Extraction Well

1) Refer to Table 9-1 for a summary screening of remedial technologies.

2) Optimized LFG Control is comprised of operational changes on the existing LFG Collection system on the Main Hill. Changes include installation of flow control devices on LFG System Central & East header series and changing from moderate to aggressive LFG collection on the East Main Hill per SWANA guidance (SWANA, 1997).

3) Perimeter Gas Collection is comprised of collecting LFG and impacted soil gas in the EPZ area and routing to Landfill Flare system. Collection would be achieved through existing GP locations, repurposed EWs, and installation of new LFG extraction wells.

4) Expanded LFG Control is comprised of the same elements described as Optimized LFG Control in addition to new LFG collection wells installed through the landfill refuse in the East Main Hill and screened within the underlying stratified drift.

Table 11.2 - Disproportionate Cost Analysis

Project No. 130088, Cedar Hils Regional Landfill
King County, Washington

			Alternative 1	Alternative 2	Alternative 3	Alternative 4
Remedial Alternative Components:			**MNA of Groundwater[1]**	**Optimized LFG Control and MNA of Groundwater**	**Perimeter Gas Collection, Optimized LFG Control, and MNA of Groundwater**	**Perimeter Gas Collection, Expanded LFG Control, and MNA of Groundwater**
Criteria to Evaluate Use of Permanent Solutions to the Maximum Extent Practicable		**Weighting Factor**	(Note 2)	(Note 2)	(Note 2)	(Note 2)
	Overall Protectiveness	30%	2	6	8	9
			MNA would not be protective as it would not address the required LFG control to achieve cleanup requirements in the EPZ area.	Greater protectiveness than Alt. 1 with the increased effectiveness of LFG Control on the East Main Hill, reducing the source to groundwater and soil gas COC concentrations in the EPZ area.	Greater protectiveness than Alt. 2 due to the gas collection in the EPZ area addressing LFG and soil gas at the potential point of exposure.	Greater protectiveness than Alt. 3 due to the expanded collection of LFG in the stratified drift native materials underlying refuse on the East Main Hill.
	Permanence	20%	2	4	4	7
			Alt. 1 relies on natural attenuation to reduce COC concentrations which may not be permanent due to the continued landfill operation and generation of LFG.	Increased permanence relative to Alt. 1 because optimized LFG Control will collect more LFG before it becomes a source to groundwater and soil vapor in the EPZ area.	The addition of Perimeter Gas collection does not increase permanence relative to Alt. 2.	Alternative 4 would provide signficantly greater permanence due the active LFG collection at the primary pathway to the stratified drift native materials and ultimately the EPZ area.
	Long-Term Effectiveness	20%	3	7	8	9
			Long-term effectiveness would be dependent on the ability of groundwater monitoring and contingency actions (if needed) to prevent groundwater migration to surface water.	Significantly greater long-term effectiveness due to the continued landfill operation and LFG source generation, and the need for more aggressive LFG collection on the East Main Hill.	Provide greater long-term effectiveness with the Permieter Gas collection capturing any LFG not captured by the Optimized LFG Collection.	Provide even greater long-term effectiveness with the Expanded LFG Collection through collection of LFG migrating through stratified drift anticipated to occur for the duration of the cleanup action.
	Short-Term Risk Management	10%	9	9	8	7
			Minimal short-term risks associated with MNA.	Installation of LFG flow-monitoring devices and the potential exposure to LFG are the only potential short-term risks associated with Alt. 2.	Additional short-term risks.	Additional short-term risks associated with drilling through landfill refuse and the potential exposure to LFG, albeit insignificant.
	Implementability	10%	10	6	5	3
			Readily implementable.	Optimization of the LFG Collection System on the East Main Hill may present operational challenges.	Reuse of existing points may not be possible based on condition, or not yield productive LFG collection; however, this implementabillity challenge could be overcome with the installation of new LFG extraction well locations.	Some greater implementability challenges for drilling 200+ feet and installation of extraction wells in the stratifed drift.
	Consideration of Public Concerns	10%	5	10	10	10
				(Note 3)	(Note 3)	(Note 3)
MTCA Benefits Ranking(4)			**4.0**	**6.5**	**7.1**	**7.9**
Estimated Cost(5)			**$2,596,000**	**$3,526,000**	**$3,994,000**	**$4,400,000**
Benefit/Cost Ratio(6)			**1.54**	**1.84**	**1.78**	**1.80**

Notes:

COC = Constituent of Concern, DCA = disproportionate cost analysis, EPZ = East Perched Zone, IC = Institutional Control, LFG = landfill gas, MNA = monitored natural attenuation, MTCA = Model Toxics Control Act, VI = vapor intrusion

1) Alternative 1 does not meet MTCA threshold criteria and is not considered in alternative selection (discussed in Section 11.4.5); however, it is presented in the DCA for illustration purposes.

2) A scale of 1 to 10 is used to rate the alternatives with respect to the criteria, where "1" indicates the criterion is satisfied to a very low degree, and "10" to a very high degree. Rating values are shown in Red.

3) Ecology considers and responds to all public comments received on the Draft Feasibility Study and Draft Cleanup Action Plan documents as part of the cleanup process under MTCA. Therefore, in this Feasibility Study, Alternatives 2, 3, and 4 are given a rating of 10 for consideration of public concerns.

4) The MTCA benefits ranking is obtained by multiplying the rating for each criterion by its weighting factor and summing the results for the five criteria.

5) Net present value costs are estimated in 2016 dollars and were calculated using a discount factor of 1.2 percent. The costs shown are rounded to two significant figures. Itemized cost estimates are provided in Appendix I.

6) The benefit/cost ratio is obtained by dividing the alternative's MTCA benefits ranking by its estimated cost (in $million).

Table 12.1 - Proposed Monitoring Well Network and Point of Compliance Wells

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Well	Current Monitoring Status	Proposed Monitoring	Purpose	Rationale
Perched Zone				
EB-6D	Quarterly	Quarterly, WL	POC, Downgradient	Reduced conditions, but no current arsenic or VC exceedances. Observed elevated LFG parameters (methane, ethane, ethene). Historical arsenic exceedances.
MW-30A	Quarterly, WL	Quarterly, WL	Performance Monitoring	No current exceedances, but near edge of impacted groundwater. Observed low-level LFG influence. Historical VC exceedances.
MW-47	Quarterly, WL	Quarterly, WL	Performance Monitoring	Highest VC detections. Observed elevated LFG parameters. Historical arsenic and VC exceedances.
MW-50	WL	Quarterly, WL	POC, Downgradient	Nondetect VOCs, but arsenic exceedance. Bounds arsenic to the south. Observed low-level LFG parameters.
MW-102	WL	Quarterly, WL	POC, Downgradient	Reduced conditions, but no current arsenic exceedances. VC is nondetect. Observed low-level LFG parameters.
MW-103	WL	Quarterly, WL	POC, Downgradient	Reduced conditions and arsenic exceedances. VC is nondetect. Observed low-level LFG parameters.
MW-104	WL	Quarterly, WL	POC, Downgradient	Nondetect VOCs, but arsenic exceedance. Bounds arsenic to the east. Observed low-level LFG parameters.
New Well (EW-6 and EW-7)	--	Quarterly, WL	Performance Monitoring	Bounds VC and arsenic exceedance areas to the north. Observed elevated LFG parameters.
New Well (south of EW-10)	--	Quarterly, WL	Performance Monitoring	Bounds VC and arsenic exceedances.
New Well (EW-16 and EW-17)	--	Quarterly, WL	Performance Monitoring	Highest arsenic detections. Observed elevated LFG parameters.
New Well (south of EW-21)	--	Quarterly, WL	Performance Monitoring	VC exceedances and highest LFG parameter observations.
New Well (EW-25 and EW-26)	--	Quarterly, WL	Performance Monitoring	Highest TCE detections.
New Well (south of EW-29)	--	Quarterly, WL	Performance Monitoring	Bounds VC to the south.
MW-29	WL	Semiannual, WL	NESPZ p-map	No detections. Historical sampling location, and potentially represents upgradient conditions. Reinitiate sampling at reduced frequency of semiannual.
MW-62	Quarterly, WL	WL	NESPZ p-map	Observed low-level LFG influence. Historical TCE detections, but nondetect last 21 events. Discontinue groundwater monitoring.
MW-63	--	WL	NESPZ p-map	Critical location for delineating extent of NESPZ.
EB-1	--	WL	NESPZ p-map	Critical location for delineating extent of NESPZ.
EB-2	--	WL	NESPZ p-map	Critical location for delineating extent of NESPZ.
EB-5S	--	WL	ESPZ p-map	Critical location for delineating extent of ESPZ.
SG-4	--	WL	NESPZ p-map	Critical location for delineating extent of NESPZ, and evaluating whether stream is in losing or gaining status.
GP-1A	--	WL	ESPZ p-map	Critical location for delineating extent of ESPZ.
GP-2B	--	WL	ESPZ p-map	Critical location for delineating extent of ESPZ.
GP-ATC-3D	--	WL	ESPZ p-map	Critical location for delineating extent of ESPZ.
GP-ATC-6S	--	WL	ESPZ p-map	Critical location for delineating extent of ESPZ.
GP-ATC-8S	--	WL	ESPZ p-map	Critical location for delineating extent of ESPZ.
Regional Aquifer				
MW-60	Quarterly, WL	Quarterly, WL	Downgradient	Provides spatial coverage of regional aquifer.
MW-64	Quarterly, WL	Quarterly, WL	Downgradient	Provides spatial coverage of regional aquifer.
MW-67	Quarterly, WL	Quarterly, WL	Downgradient	Provides spatial coverage of regional aquifer.
MW-68	Quarterly, WL	Quarterly, WL	Downgradient	Elevated total and dissolved arsenic detections. Provides spatial coverage of regional aquifer. Potential LFG impact.
MW-75	Monthly, WL	Quarterly, WL	Downgradient	Evaluate whether elimination from monitoring program is acceptable as it appears redundent (adjacent to MW-91).
MW-80	Quarterly, WL	Quarterly, WL	Downgradient	Provides spatial coverage of regional aquifer. Downgradient from MW-68, so critical for monitoring attenuation.
MW-81	Quarterly, WL	Semiannual, WL	Downgradient at property boundary	Provides spatial coverage of regional aquifer. No exceedances, so reduce monitoring frequency.
MW-85	Quarterly, WL	Semiannual WL	Downgradient at property boundary	Provides spatial coverage of regional aquifer. No exceedances, so reduce monitoring frequency.
MW-87	Quarterly, WL	Quarterly, WL	Downgradient	Provides spatial coverage of regional aquifer.
MW-91	Quarterly, WL	Quarterly, WL	Downgradient	Elevated total arsenic concentrations. Provides spatial coverage of regional aquifer.
MW-93	Quarterly, WL	Quarterly, WL	Downgradient	Provides spatial coverage of regional aquifer.
MW-99	Quarterly, WL	Quarterly, WL	Downgradient	Provides spatial coverage of regional aquifer.
Wells for Decommissioning or Retrofitting as Gas Extraction Wells				
EW-2 thru EW-29	None	None	Construction of the EW's with long filter sand packs is not ideal for sampling isolated perched zones. EW's may provide conduits for LFG migration. Recommend decommissioning or retrofitting for use as LFG extraction wells.	

Notes:

ESPZ = East Shallow Perched Zone; NESPZ = Northeast Shallow Perched Zone; EW = Extraction Wells; GW = groundwater; LFG = landfill gas; LFG parameters = methane, ethane, ethene, and alkalinity; p-map = potentiometric map; POC = point of compliance; TCE = trichloroethylene; VC = vinyl chloride; VOC = volatile organic compound; WL = water level monitoring

-- = not currently monitored

Table 12.2 - Groundwater Analyte List Evaluation

Project No. 130088, Cedar Hills Regional Landfill
King County, Washington

Analyte (RI Dataset Only)	Analyte Detected in Groundwater above CULs	Analyte Detected in LFG Flare	WAC 173-351 Required Parameter[1]	Retain Analyte	Rationale
Field Parameters					
Dissolved Oxygen	---	---	---	Yes	Fundamental parameter for monitoring geochemical processes.
pH	---	---	Yes	Yes	Fundamental parameter for monitoring geochemical processes.
Temperature	---	---	Yes	Yes	Fundamental parameter for monitoring geochemical processes.
Turbidity	---	---	---	Yes	Fundamental parameter for monitoring geochemical processes.
Oxidation Reduction Potential	---	---	---	Yes	Fundamental parameter for monitoring geochemical processes.
Specific Conductance	---	---	Yes	Yes	Fundamental parameter for monitoring geochemical processes.
Geochemical Indicator Parameters					
Calcium	---	---	Yes- Total	Yes	Major ion. Indicator of leachate.
Bicarbonate (HCO3)	--	---	Yes	Yes	Potential indicator of gas to groundwater pathway.
Magnesium	No	---	Yes	Yes	Major ion. Indicator of leachate.
Sulfate	---	---	Yes	Yes	Major ion. Important MNA parameter.
Total Suspended Solids	---	---	Yes	Yes	Fundamental parameter for monitoring geochemical processes.
Sodium	---	---	Yes	Yes	Conservative tracer, major ion.
Chloride	No	---	Yes	Yes	Conservative tracer, major ion.
Potassium	---	---	Yes	Yes	Good leachate indicator.
Total Alkalinity (AS CACO3)	--	---	Yes	Yes	Potential indicator of LFG to groundwater pathway.
Iron	Yes	---	Yes- Dissolved	Yes	Detected above CULs. Important MNA parameter.
Manganese	Yes	---	Yes - Dissolved	Yes	Detected above CULs. Important MNA parameter.
Ethene	---	---	No	Yes	Important MNA parameter.
Ethane	---	---	No	Yes	Important MNA parameter.
Methane	---	Yes	No	Yes	Indicator of LFG. Important MNA parameter.
Leachate Indicators					
Ammonia as N	--	---	Yes	Yes	Potential leachate indicator.
Total Organic Carbon	--	---	Yes	Yes	Fundamental parameter for monitoring geochemical processes.
Total Dissolved Solids	Yes	---	Yes	Yes	Fundamental parameter for monitoring geochemical processes. Potential leachate indicator.
Inorganic Constituents					
Antimony	No	---	Yes- T & D	No	Only detected in one sample.
Arsenic	Yes	---	Yes- T & D	Yes	Detected in groundwater above CULs.
Barium	No	---	Yes- T & D	No	Not detected in groundwater above CULs.
Beryllium	No	---	Yes- T & D	No	Not detected in groundwater.
Cadmium	No	---	Yes- T & D	No	Only detected in one groundwater sample.
Chromium	No	---	Yes- T & D	No	Not detected in two groundwater samples.
Cobalt	---	---	Yes- T & D	No	Detected at 13% frequency. No CULs available.
Copper	No	---	Yes- T & D	No	Detected at 13% frequency. No CUL exceedances. Average detection an order of magnitude below CUL.
Lead	Yes	---	Yes- T & D	Yes	Detected above CULs in two groundwater samples.
Nickel	No	---	Yes- T & D	No	Detected at 8% frequency and no CUL exceedances.
Selenium	No	---	Yes- T & D	No	Not detected in groundwater or leachate.
Silver	No	---	Yes- T & D	No	Not detected in groundwater or leachate.
Thallium	No	---	Yes- T & D	No	Not detected in groundwater or leachate.
Vanadium	No	---	Yes- T & D	No	Detected at 18% frequency and no CUL exceedances.
Zinc	Yes	---	Yes- T & D	Yes	Detected at 50% frequency and two CUL exceedances.
Mercury	No	---	---	No	Not detected in groundwater.
Nitrate	Yes	---	Yes	Yes	Part of nitrogen balance and detected above CUL.
Organic Constituents					
1,1-Dichloroethane (DCA)	No	Yes	Yes	Yes	Detected in 24% of groundwater samples. MW-47 concentration plots indicate increasing concentrations. Important MNA parameter.
1,1-Dichloroethene	No	---	Yes	No	Only detected in one sample. Not analyzed in LFG.
1,2-Dichlorobenzene	No	No	Yes	No	Limited detections in groundwater. No exceedances. No detections in LFG.
1,2-Dichloroethane (EDC)	No	Yes	Yes	No	Detected in only two groundwater samples. No exceedances.
1,4-Dichlorobenzene	No	Yes	Yes	Yes	Highest concentrations in EW-21. No exceedances, but EW-21 detections only slightly below CULs.
Acetone	No	Yes	Yes	No	Common laboratory contaminant.
Benzene	No	Yes	Yes	Yes	Highest concentrations in EW-21. No exceedances, but EW-21 detections only slightly below CULs.
Carbon Disulfide	No	No	Yes	No	Only 3% detection frequency in groundwater at concentrations orders of magnitude below CULs. Not detected in LFG.
Chlorobenzene	No	Yes	Yes	No	Only 12% detection frequency in groundwater at concentrations an order of magnitude below CULs.
Chloroethane	---	No	Yes	Yes	Only 7% detection frequency in groundwater and no CULs available. However, important daughter product of DCA or VC to be used in MNA monitoring.
Chloroform	Yes	No	Yes	No	Only 2% detection frequency in groundwater and only CUL exceedance appears to be an outlier. Not detected in LFG.
Chloromethane	---	No	No	No	No CULs available and not detecting in LFG.
cis-1,2-Dichloroethene (DCE)	Yes	Yes	Yes	Yes	Frequently detected in groundwater and detected above CULs. Daughter product created during reductive dechlorination of chlorinated ethenes.
Dichlorodifluoromethane	No	No	No	No	Some detections in groundwater but at concentrations orders of magnitude below CUL.
Ethylbenzene	No	Yes	Yes	No	Only detected at 1% frequency and below CULs.
Methylene Chloride	Yes	No	Yes	No	Common laboratory contaminant.
Tetrachloroethene	No	Yes	Yes	Yes	Not detected above CULs but important chlorinated ethene parent product to be monitored.
Toluene	No	Yes	Yes	No	Only detected at 5% frequency and below CULs.
trans-1,2-Dichloroethene (DCE)	No	No	Yes	Yes	Frequently detected in groundwater. Daughter product created during reductive dechlorination of chlorinated ethenes.
Trichloroethene	Yes	Yes	Yes	Yes	Frequently detected in groundwater and detected above CULs. Important chlorinated ethene parent product to be monitored.
Vinyl Chloride	Yes	Yes	Yes	Yes	Frequently detected in groundwater and detected above CULs. Daughter product created during reductive dechlorination of chlorinated ethenes.

Notes:

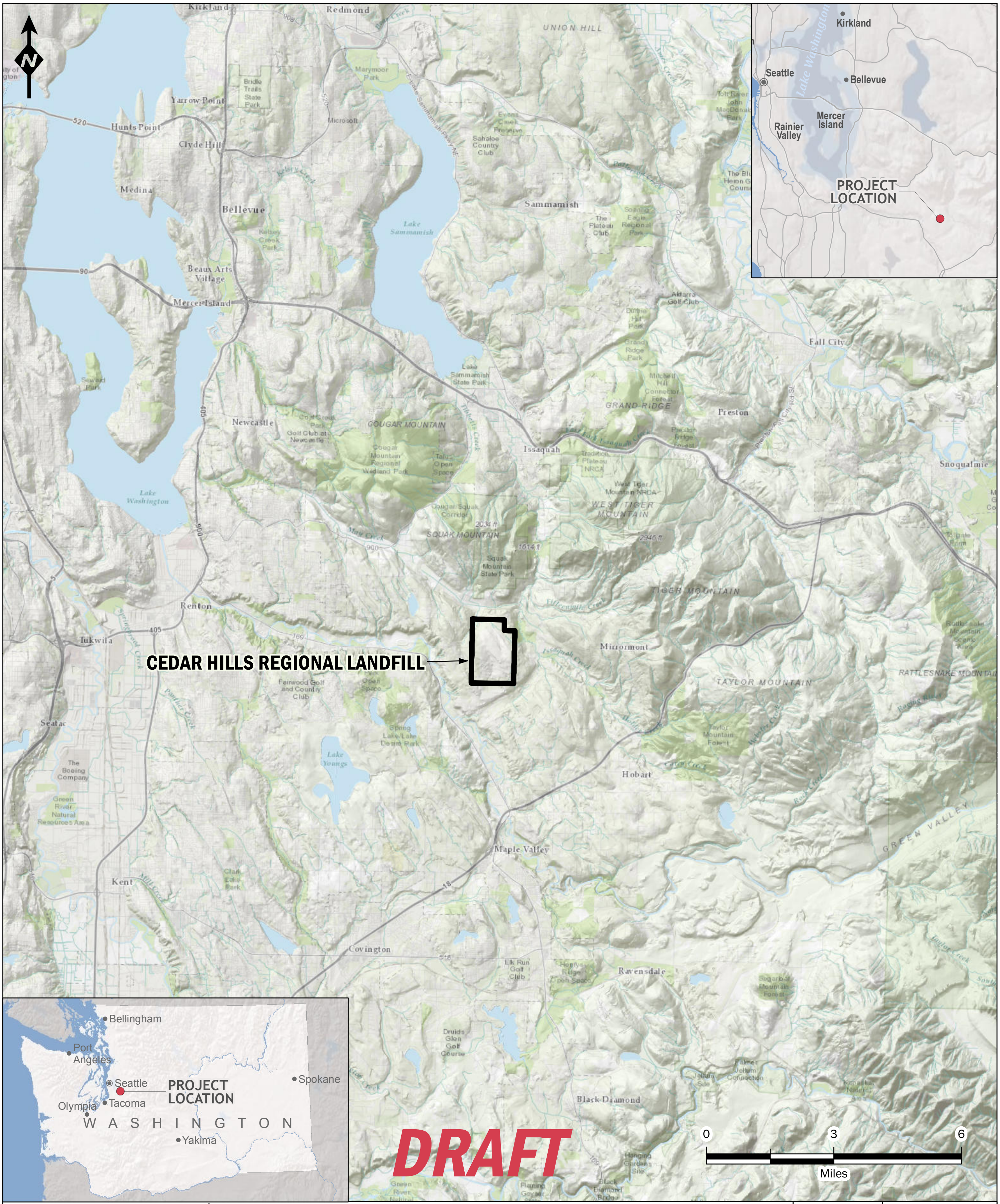
[1] - WAC 173-351 Appendix I and II parameters are required for detection monitoring, unless an alternate groundwater monitoring program is approved by the health department. Not all the Appendix II Organic Constituents are listed in this Table, only those detected above laboratory RDLs during the RI.

LFG flare data from The Avogadro Group, LLC., 2012.

Shading indicates parameter proposed for monitoring of selected remedy.

CULs = cleanup levels, LFG = landfill gas, MNA = monitored natural attenuation, RDL = reporting dection limit, RI = Remedial Investigation

FIGURES



King County

Aspect CONSULTING

Project Location Map
Cedar Hills Regional Landfill
King County, Washington

DATE: Sep-2016	PROJECT NO. 130088
DESIGNED BY: KSL/RAP	
DRAWN BY: KSL/RAP	FIGURE NO. 1.1
REVISED BY: - - -	

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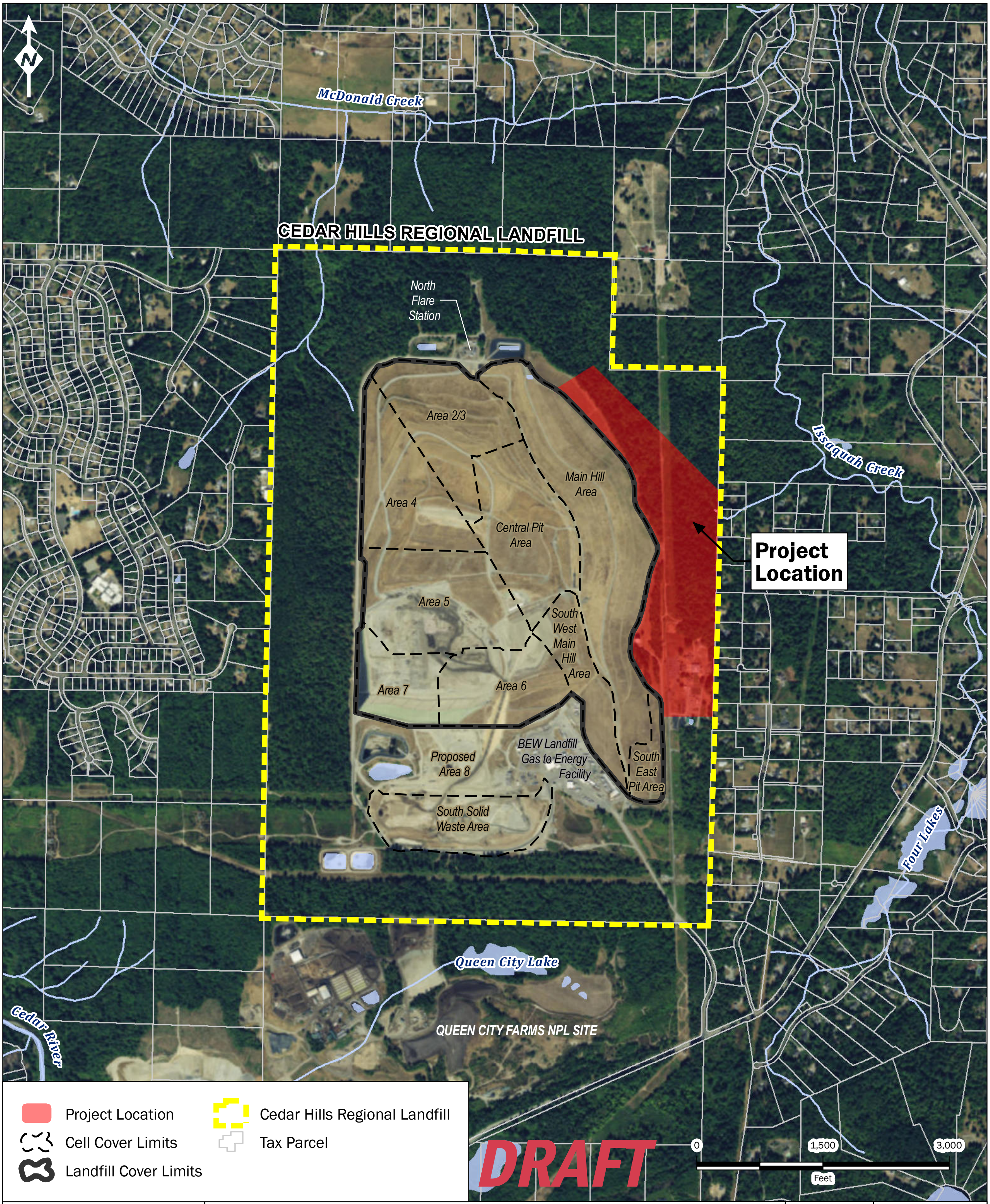

King County

Aspect CONSULTING

Cedar Hills Regional Landfill Property Features

Cedar Hills Regional Landfill

King County, Washington

DATE: Sep-2016

DESIGNED BY: KSL/RAP

DRAWN BY: KSL/RAP

REVISED BY: PPW

PROJECT NO. 130088

FIGURE NO. 1.2

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

[1] Uncertainty in zone boundary indicated by dashed line

[2] Gas probe locations could not be field verified

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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King County

EPZ Features and Monitoring Locations

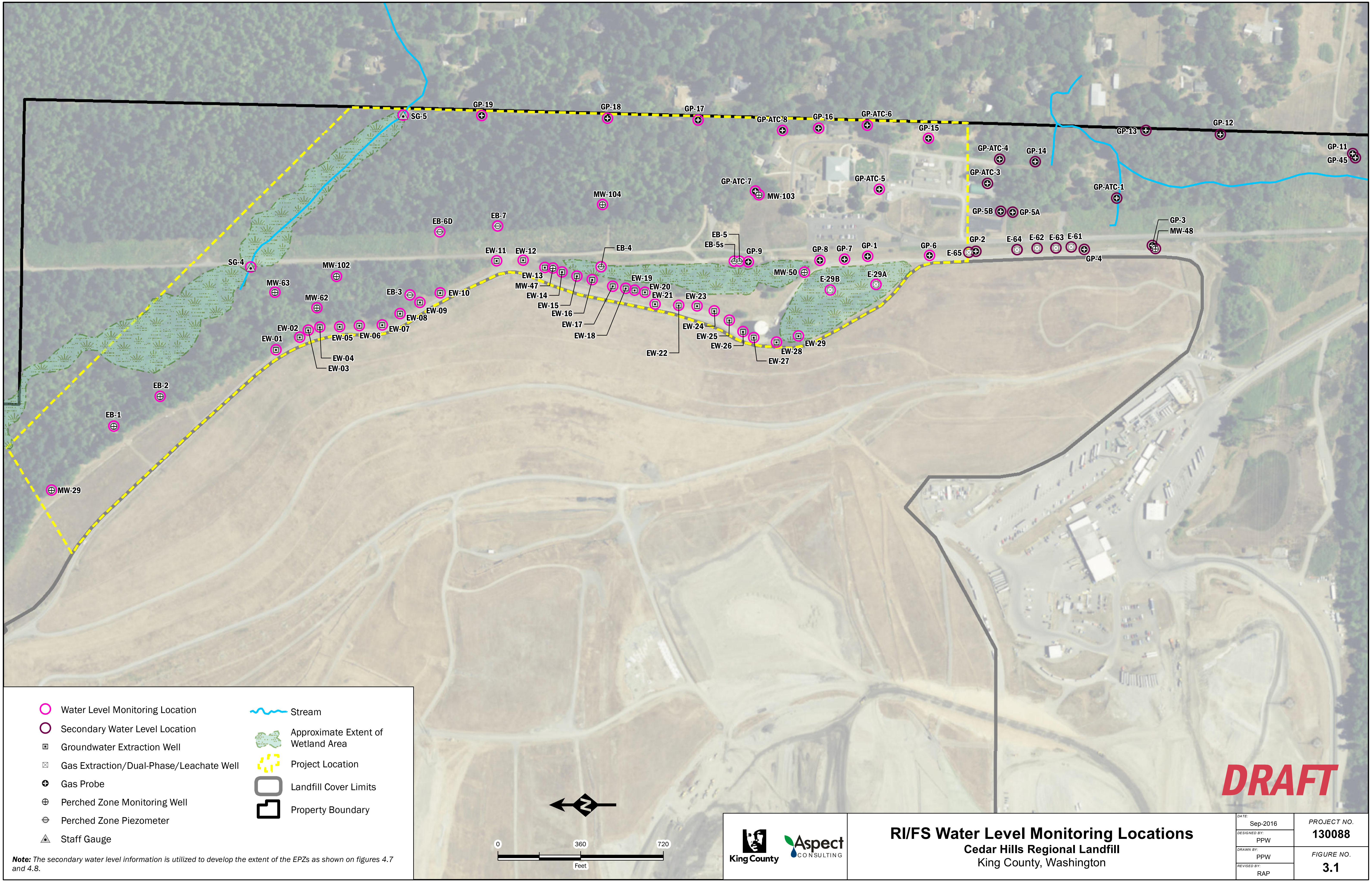
Cedar Hills Regional Landfill

King County, Washington

DATE: Nov-2016
DESIGNED BY: KSL/RAP
DRAWN BY: KSL/RAP
REVISED BY: SDM / RAP

PROJECT NO. 130088

FIGURE NO. 1.3



Note: The secondary water level information is utilized to develop the extent of the EPZs as shown on figures 4.7 and 4.8.

King County

Aspect CONSULTING

RI/FS Water Level Monitoring Locations

Cedar Hills Regional Landfill

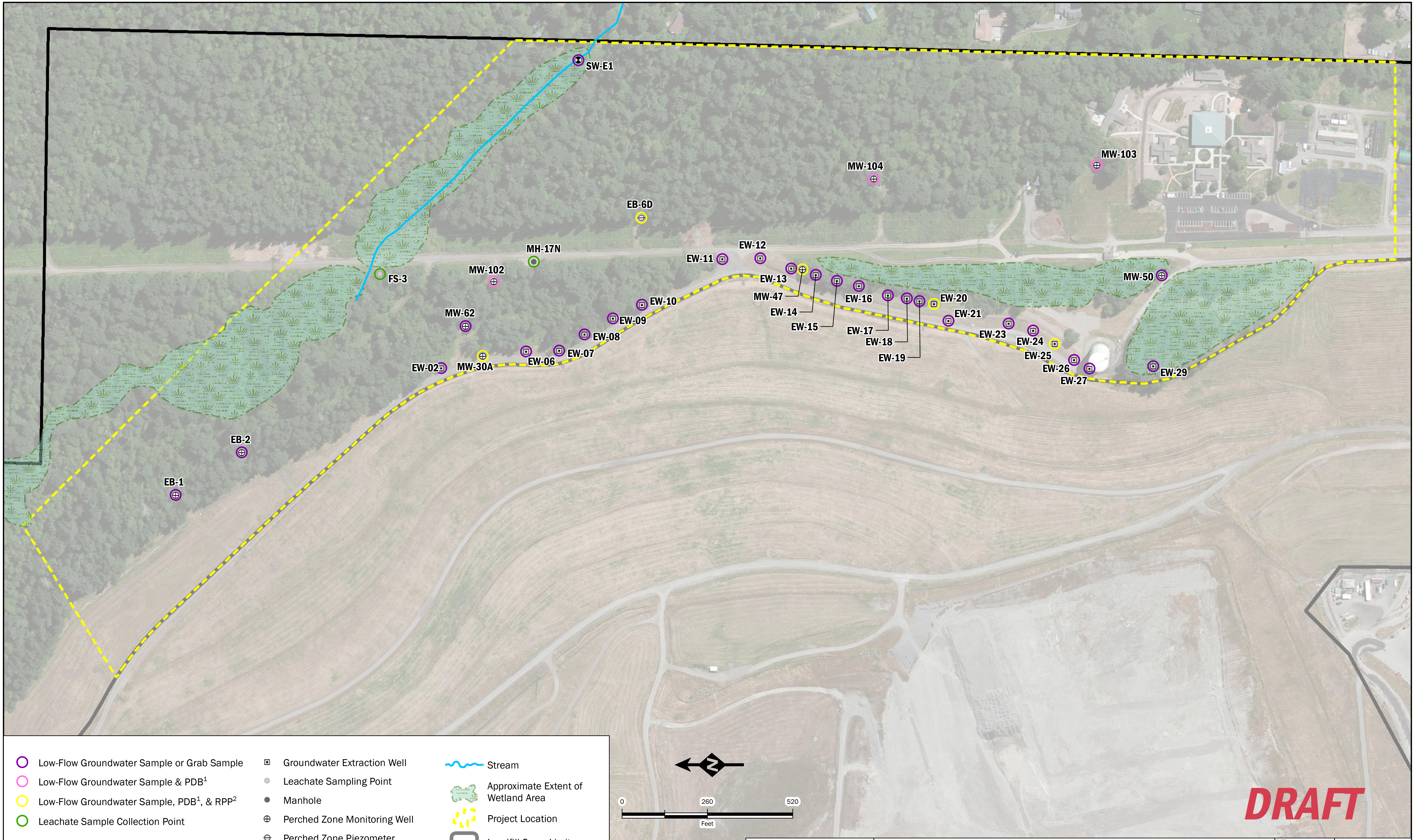
King County, Washington

DATE:	Sep-2016
DESIGNED BY:	PPW
DRAWN BY:	PPW
REVISED BY:	RAP

PROJECT NO.
130088

FIGURE NO.
3.1

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



- ○ Low-Flow Groundwater Sample or Grab Sample
- ○ Low-Flow Groundwater Sample & PDB[1]
- ○ Low-Flow Groundwater Sample, PDB[1], & RPP[2]
- ○ Leachate Sample Collection Point
- ⊡ Groundwater Extraction Well
- ● Leachate Sampling Point
- ● Manhole
- ⊕ Perched Zone Monitoring Well
- ⊖ Perched Zone Piezometer
- ⊗ Surface Water Monitoring Station
- 〰 Stream
- ▨ Approximate Extent of Wetland Area
- ⬚ Project Location
- ▢ Landfill Cover Limits
- ▢ Property Boundary

Notes:

[1]PDB: Passive Diffusion Bag

[2]RPP: Rigid Porous Polyethylene

King County

Aspect CONSULTING

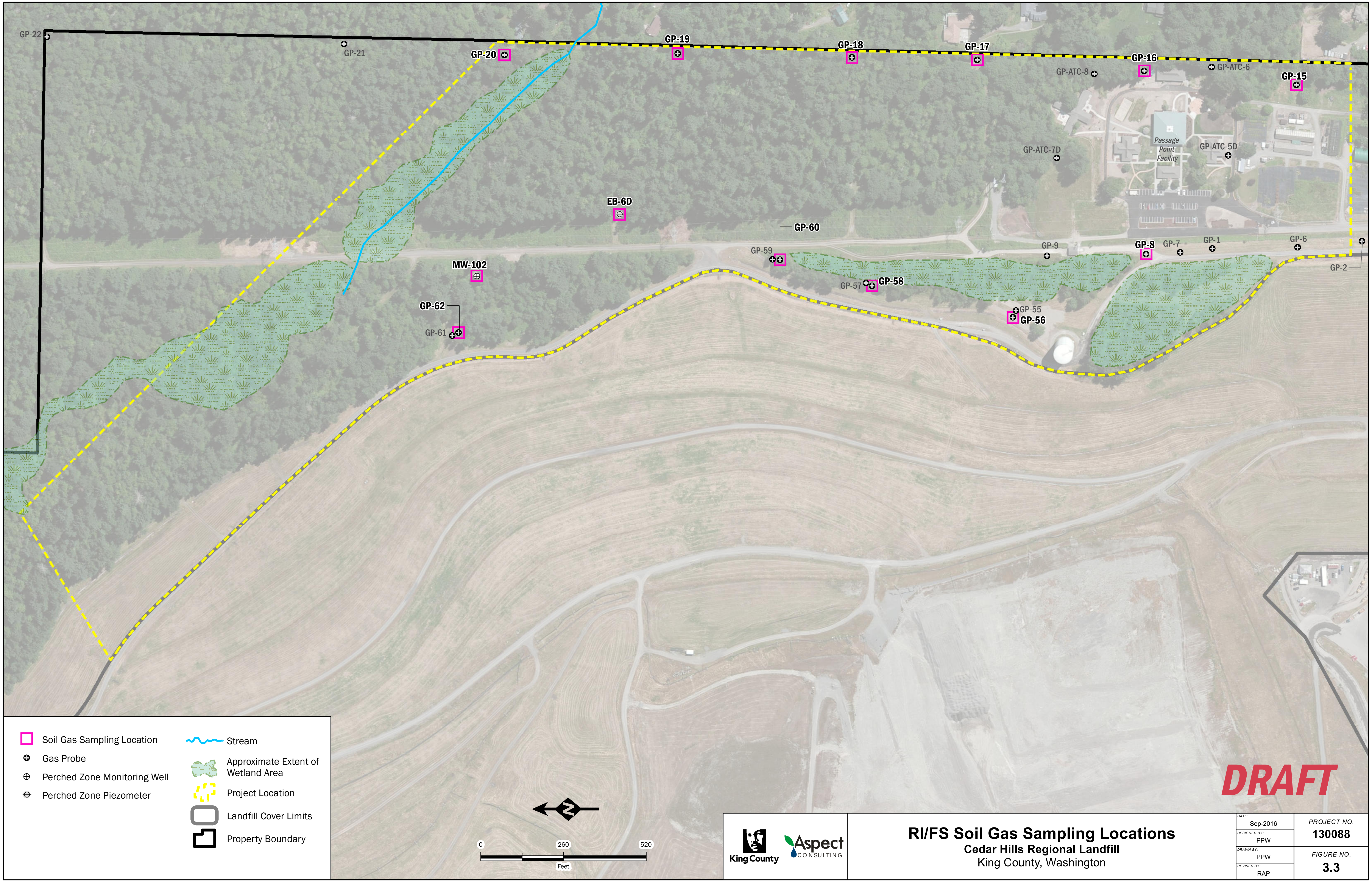
RI/FS Water and Leachate Sampling Locations

Cedar Hills Regional Landfill

King County, Washington

DATE:	Sep-2016
DESIGNED BY:	PPW
DRAWN BY:	PPW
REVISED BY:	RAP
PROJECT NO.	130088
FIGURE NO.	3.2

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



King County

Aspect CONSULTING

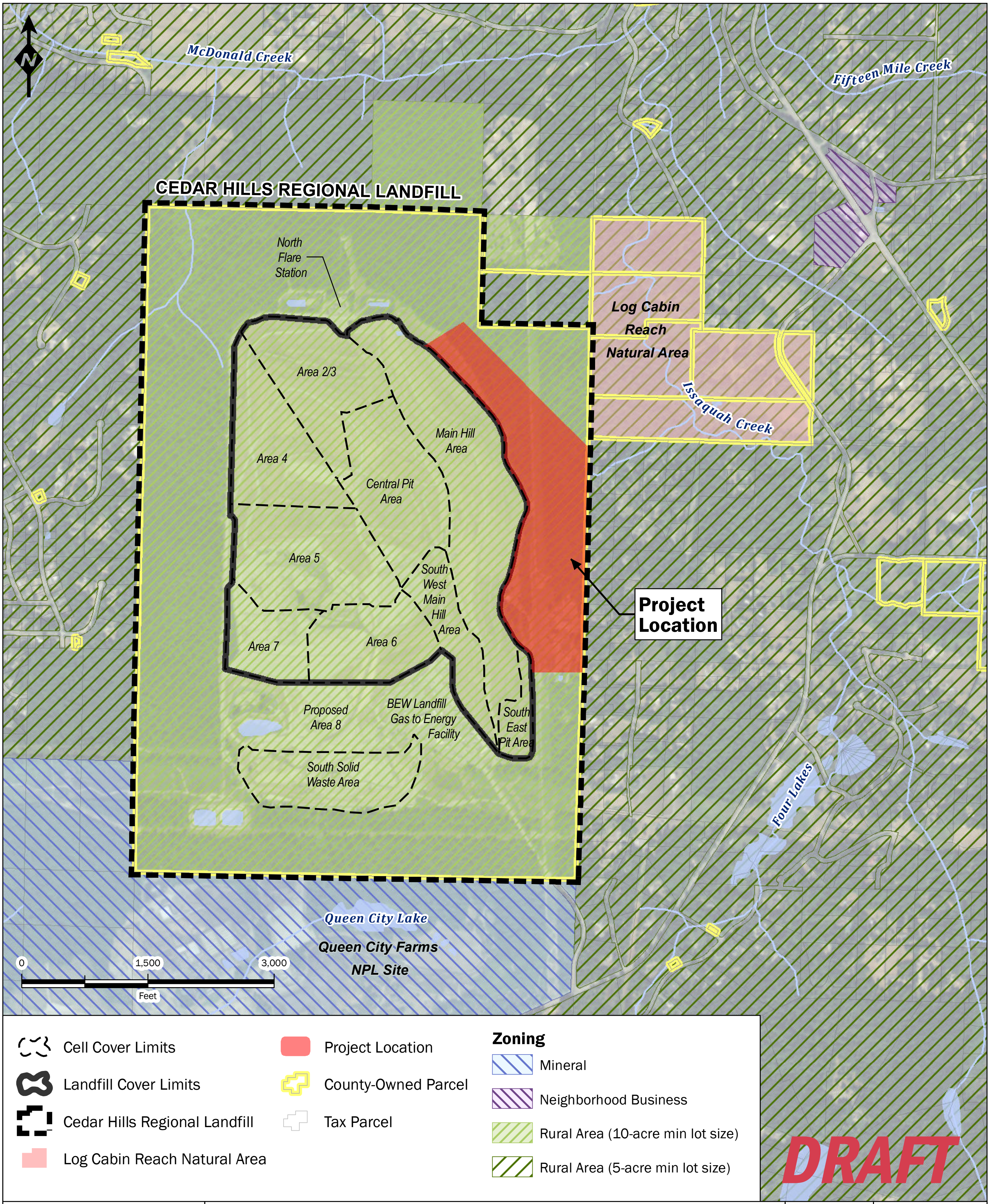
RI/FS Soil Gas Sampling Locations

Cedar Hills Regional Landfill

King County, Washington

DATE: Sep-2016	PROJECT NO. 130088
DESIGNED BY: PPW	
DRAWN BY: PPW	FIGURE NO. 3.3
REVISED BY: RAP	

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



King County

Aspect CONSULTING

Land Use and Zoning

Cedar Hills Regional Landfill

King County, Washington

DATE: Nov-2016	PROJECT NO. 130088
DESIGNED BY: KSL/RAP	
DRAWN BY: KSL/RAP	FIGURE NO. 4.1
REVISED BY: - - -	

Note: Topographic contours derived from King County LiDAR, 2003 (ft, NAVD88).

Aspect CONSULTING

King County

Site Topography and Geologic Cross-Section Locations

Cedar Hills Regional Landfill

King County, Washington

DATE:	Sep-2016
DESIGNED BY:	KSL/RAP
DRAWN BY:	KSL/RAP
REVISED BY:	- - -
PROJECT NO.	130088
FIGURE NO.	4.2

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Legend

▼	Monitoring wells and piezometers. Range in water level for period of record.
▽	Other wells - (gas probe, extraction wells). Orange box indicates length of sand packs.
Dry	No water indicated above 1.75' of the bottom of EWs.
MW-104	Black label indicates monitoring wells and piezometers.
EW-11	Gray label indicates landfill gas extraction well or probe.

DRAFT

SCALE:
1" = 20' (Vert)
1" = 200' (Horiz)

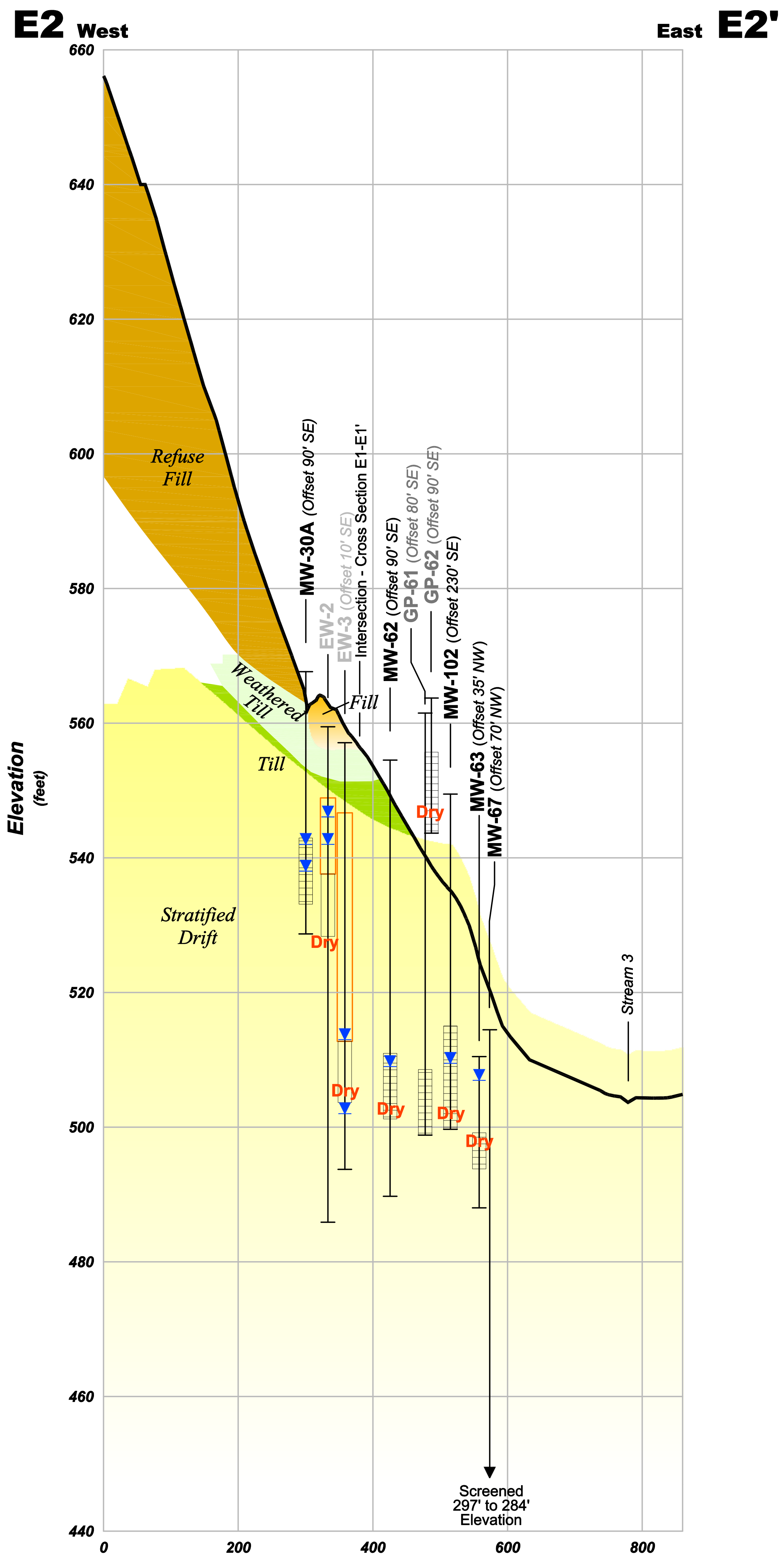
Aspect CONSULTING

King County

Cross-Section E1 - E1'
Cedar Hills Regional Landfill
King County, Washington

DATE: Sep-2016
DESIGNED BY: EWM/JSL
DRAWN BY: PMB
REVISED BY: KSL/SCC

PROJECT NO. 130088
FIGURE NO. 4.3



Legend

▼ Monitoring wells. Range in water level for period of record.

▽ Other range wells - (gas probe, extraction wells). Orange box indicates length of sand packs in EWs.

Dry No water indicated above 1.75' of the bottom of EWs.

MW-104 Black label indicates monitoring wells and piezometers.

EW-11 Gray label indicates landfill gas extraction well or probe.

SCALE:
1" = 20' (Vert)
1" = 200' (Horiz)

Aspect CONSULTING

King County

Cross-Section E2 - E2'

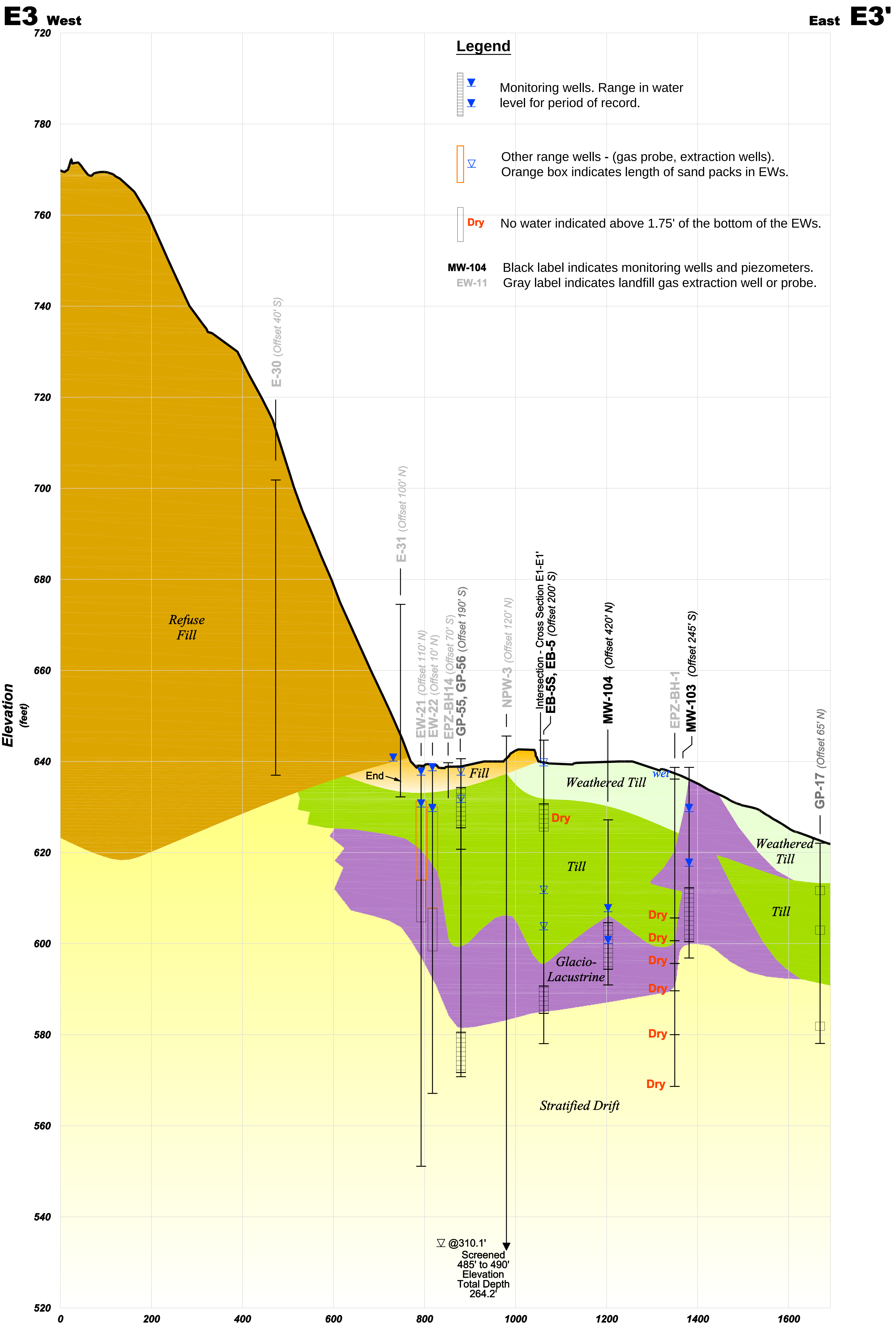
Cedar Hills Regional Landfill

King County, Washington

DATE: Sep-2016
DESIGNED BY: JTL/JSL
DRAWN BY: PMB
REVISED BY: KSL/SCC

PROJECT NO. 130088
FIGURE NO. 4.4

CAD Path: Q:\Cedar Hills\2016-09 RI-FS\040122-33.dwg Section EE2 (11 x 17) || Date Saved: Sep 16, 2016 2:01pm || User: scudd



DRAFT

SCALE:
1" = 20' (Vert)
1" = 200' (Horiz)

Aspect CONSULTING

King County

Cross-Section E3 - E3'

Cedar Hills Regional Landfill

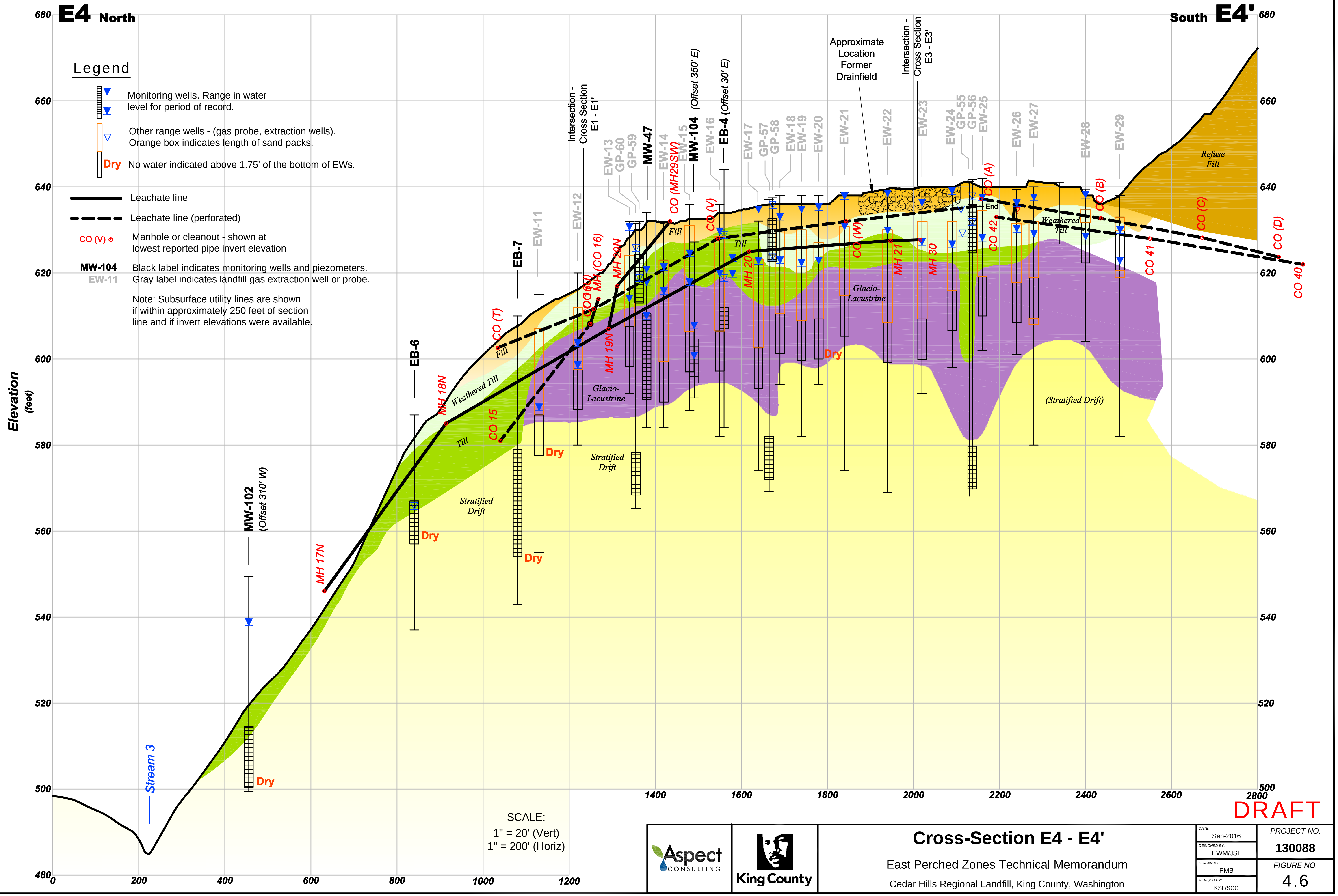
King County, Washington

DATE:	Sep-2016
DESIGNED BY:	EWM/JSL
DRAWN BY:	PMB
REVISED BY:	KSL/SCC

PROJECT NO.
130088

FIGURE NO.
4.5

CAD Path: Q:\Cedar Hills\2016-09 RI-FS\040122-34.dwg Section EE3 (11 x 17) | | Date Saved: Sep 16, 2016 2:04pm | | User: scudd



Legend

Monitoring wells. Range in water level for period of record.

Other range wells - (gas probe, extraction wells). Orange box indicates length of sand packs.

Dry No water indicated above 1.75' of the bottom of EWs.

Leachate line

Leachate line (perforated)

CO (V) ○ Manhole or cleanout - shown at lowest reported pipe invert elevation

MW-104 Black label indicates monitoring wells and piezometers.

EW-11 Gray label indicates landfill gas extraction well or probe.

Note: Subsurface utility lines are shown if within approximately 250 feet of section line and if invert elevations were available.

SCALE:
1" = 20' (Vert)
1" = 200' (Horiz)

DRAFT

Aspect CONSULTING

King County

Cross-Section E4 - E4'

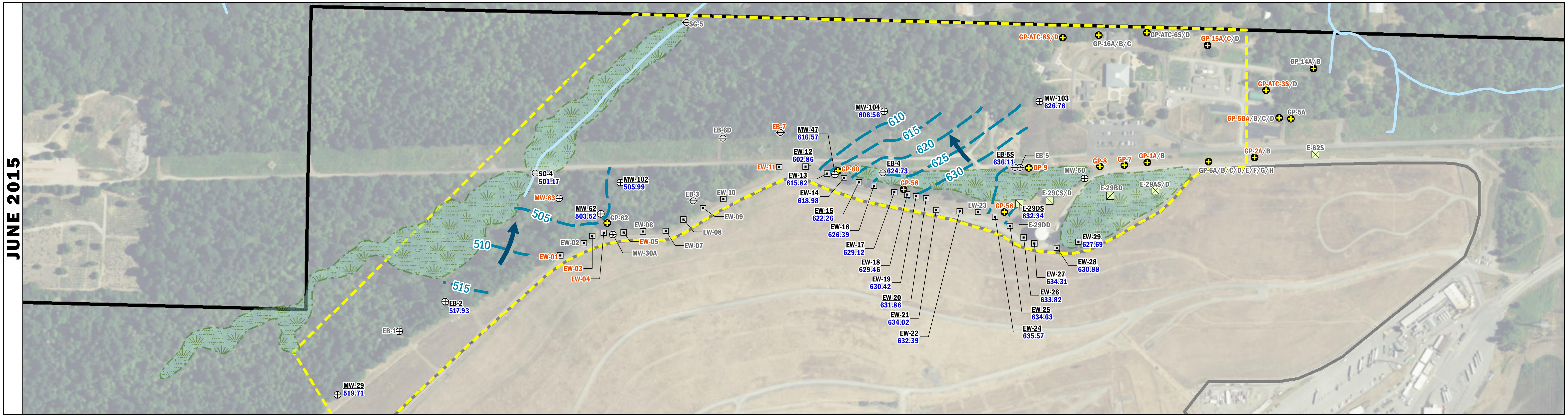
East Perched Zones Technical Memorandum

Cedar Hills Regional Landfill, King County, Washington

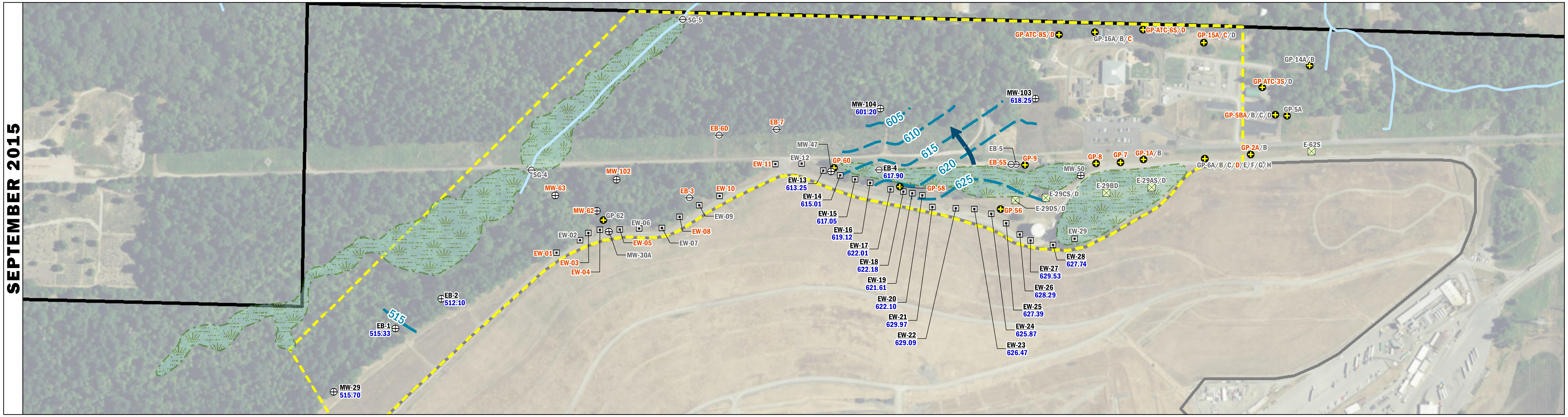
DATE: Sep-2016	PROJECT NO. 130088
DESIGNED BY: EWM/JSL	
DRAWN BY: PMB	FIGURE NO. 4.6
REVISED BY: KSL/SCC	

CAD Path: Q:\Cedar Hills\2016-09 RI-FS\040122-37.dwg Section EE6 (11 x 17) || Date Saved: Sep 16, 2016 10:35am || User: scudd

JUNE 2015



SEPTEMBER 2015



Exploration Location Name
MW-29 **519.71** Exploration Used in Contouring
Water Elevation (ft)

Exploration Location Name
EW-01 Exploration Dry (at time of sampling)

Exploration Location Name
EW-01 Exploration Not Used in Contouring

⊕ Perched Zone Monitoring Well
⊡ Extraction Well
⊖ Perched Zone Piezometer
⊕ Gas Probe
☒ Gas Extraction/ Dual-Phase/ Leachate Well

Interpretive Groundwater Elevation Contour (ft)
Inferred Direction of Horizontal Groundwater Flow
Stream

Approximate Extent of Wetland Areas
Project Location
Landfill Cover Limits
Property Boundary

Note: *Wells selected for contouring based on screened intervals that represent primarily horizontal groundwater gradients.*

N

0 420 840
Feet

DRAFT

King County

Aspect CONSULTING

East Perched Zones Groundwater Potentiometric Map - Dry Season

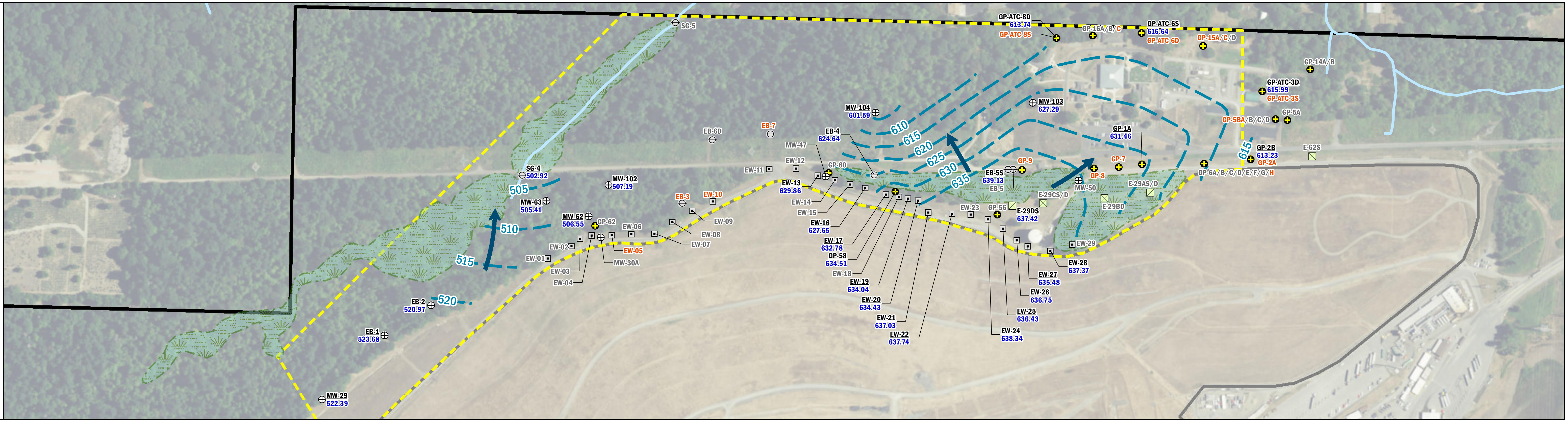
Cedar Hills Regional Landfill

King County, Washington

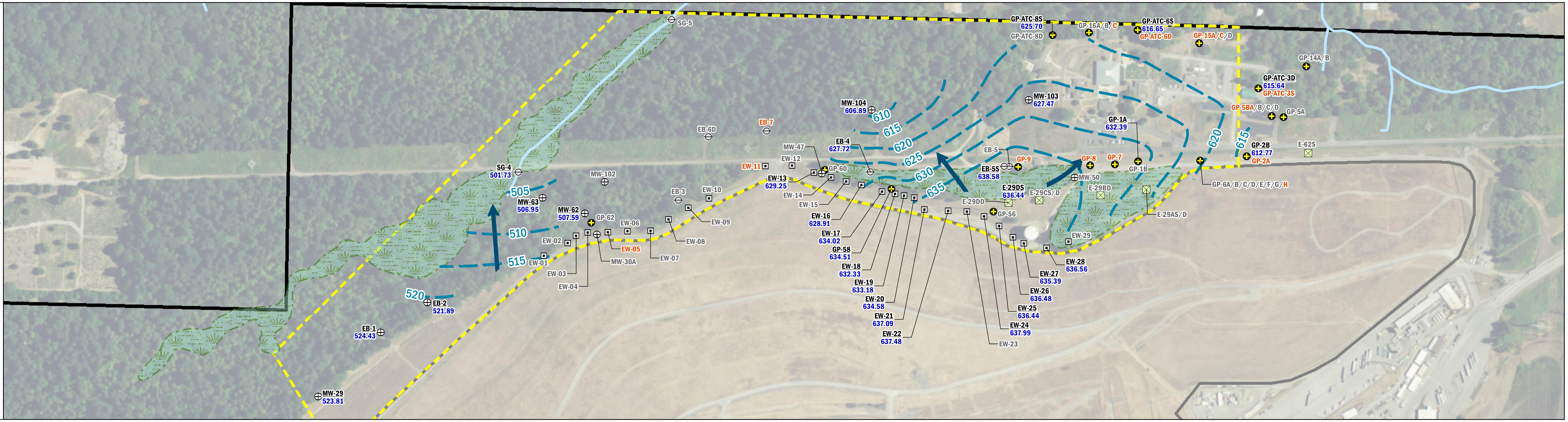
DATE: Sep-2016	PROJECT NO. 130088
DESIGNED BY: PPW	
DRAWN BY: PPW	FIGURE NO. 4.7
REVISED BY: RAP	

Basemap Layer Credits || Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

DECEMBER 2015



MARCH 2016



Exploration Location Name
MW-29 **519.71** Exploration Used in Contouring
Water Elevation (ft)

Exploration Location Name
EW-01 Exploration Dry (at time of sampling)

Exploration Location Name
EW-01 Exploration Not Used in Contouring

⊕ Perched Zone Monitoring Well
⊡ Extraction Well
⊖ Perched Zone Piezometer
⊕ Gas Probe
☒ Gas Extraction/Dual-Phase/Leachate Well

Interpretive Groundwater Elevation Contour (ft)
Inferred Direction of Horizontal Groundwater Flow
Stream

Note: Wells selected for contouring based on screened intervals that represent primarily horizontal groundwater gradients.

Approximate Extent of Wetland Areas
Project Location
Landfill Cover Limits
Property Boundary

0 420 840
Feet

DRAFT

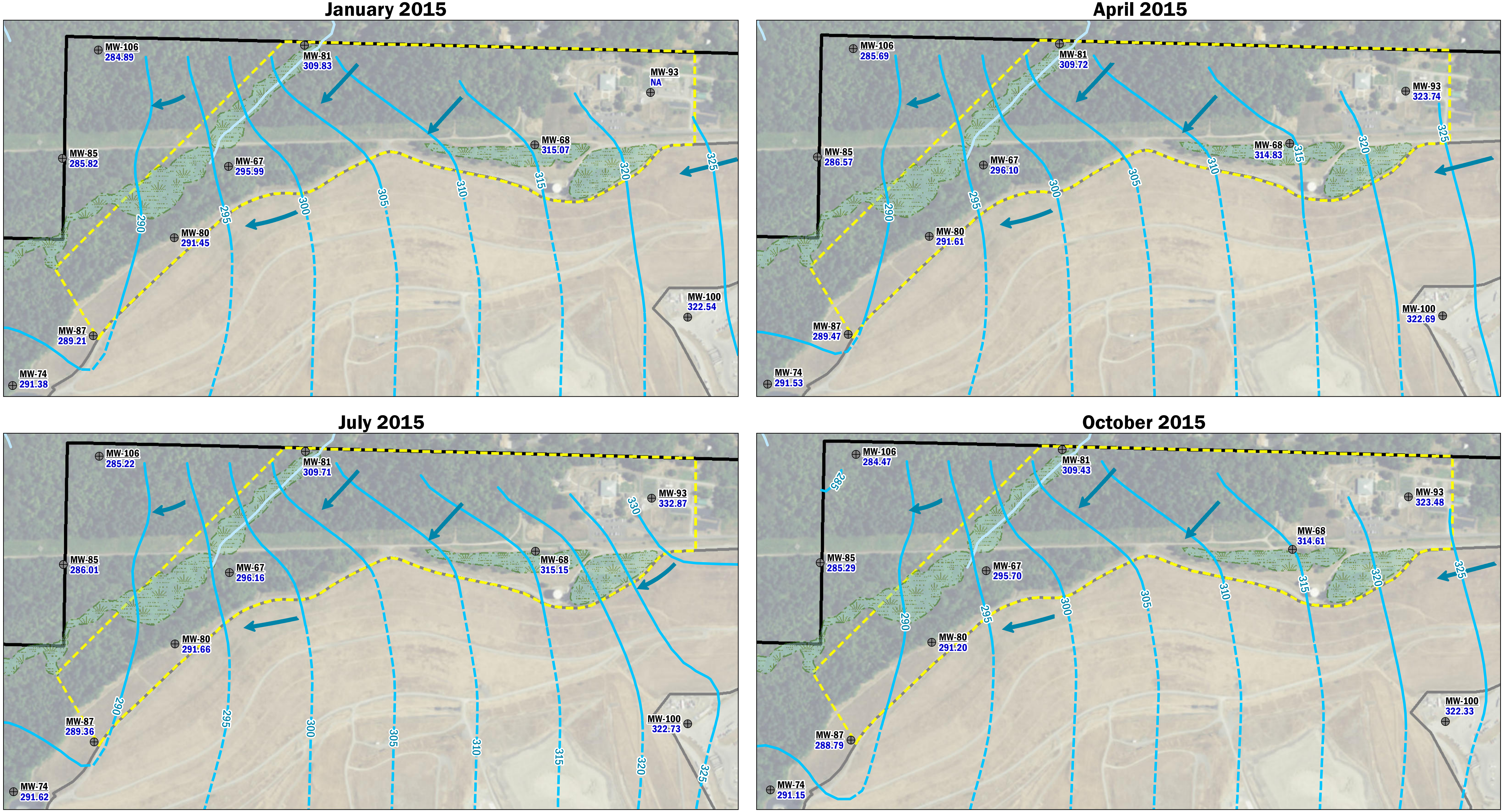
King County
Aspect CONSULTING

East Perched Zones Groundwater Potentiometric Map - Wet Season
Cedar Hills Regional Landfill
King County, Washington

DATE:	Sep-2016
DESIGNED BY:	PPW
DRAWN BY:	PPW
REVISED BY:	RAP

PROJECT NO. 130088
FIGURE NO. 4.8

Basemap Layer Credits | | Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



Note: Water level measurement points contributing to potentiometric surface interpretation are shown. "NA" indicated a result not used in contouring due to lack of measurement or poor data quality.

Basemap Layer Credits | | Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

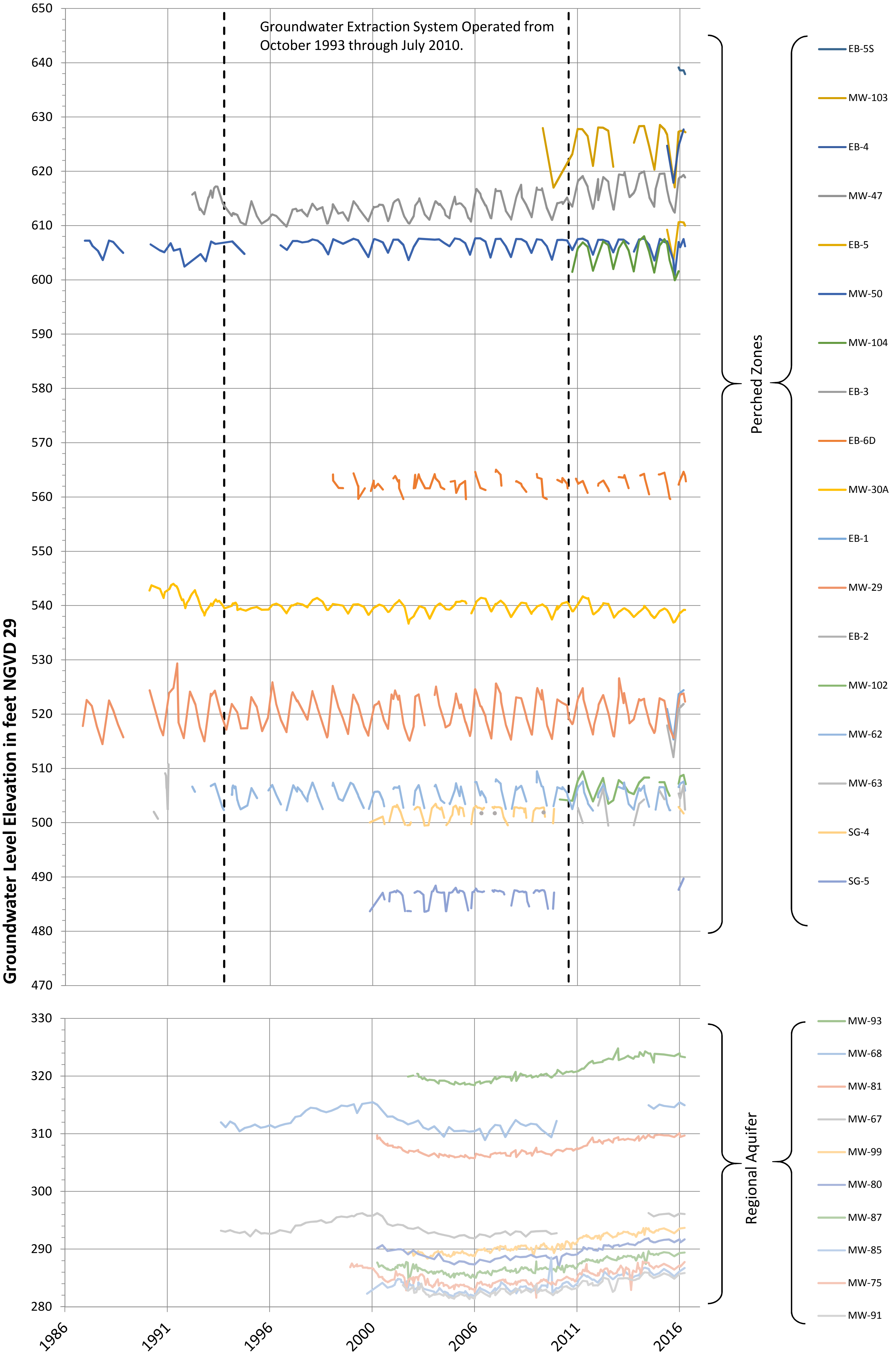
DRAFT

King County

Aspect CONSULTING

Regional Aquifer Groundwater Potentiometric Map
Cedar Hills Regional Landfill
King County, Washington

DATE: Aug-2016	PROJECT NO. 130088
DESIGNED BY: PPW	
DRAWN BY: SDM / RAP	FIGURE NO. 4.9
REVISED BY: RMB	



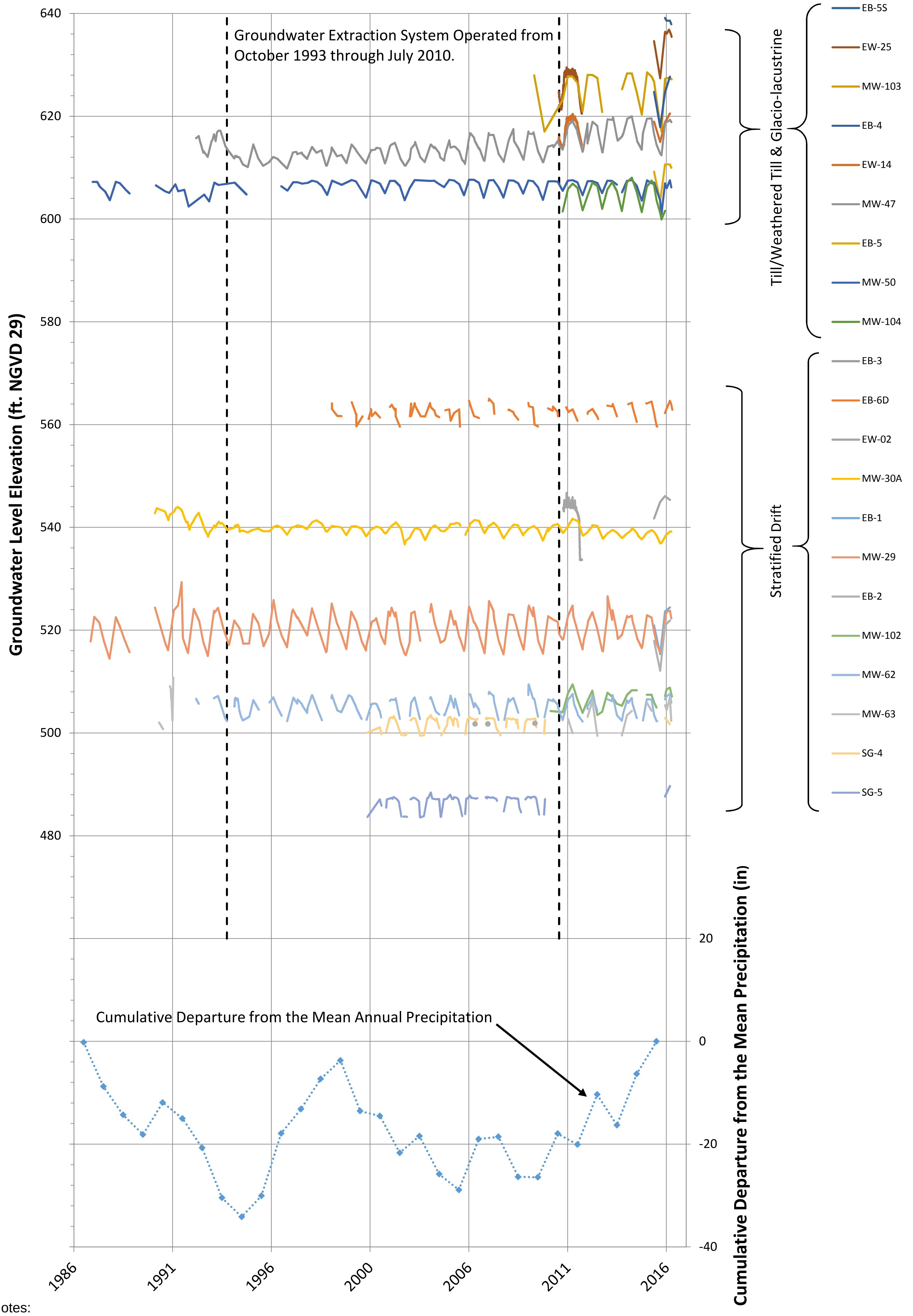
Notes:
- Monitoring wells appear in the legend in the same order they appear in the hydrograph, from highest water level elevation to lowest.
-Dry well measurements are indicated as gaps in the hydrographs in wells MW-63, MW-62, MW-102, MW-29, MW-30A, MW-48, EB-6D, EB-3, EW-11, MW-104, MW-50, MW-103, and EB-5S.
- Periods between measurements of greater than one year are also shown as gaps in the hydrographs.

Figure 4.10
Groundwater Level Hydrograph - Regional and Perched

East Perched Zones RI/FS Report - CRLF
King County, WA

Aspect Consulting
9/12/2016
P:\AECOM Cedar Hills Env Controls E00286E12\Data\Analyses\hydrographs\Water Levels for Hydrographs_2.xlsx

DRAFT

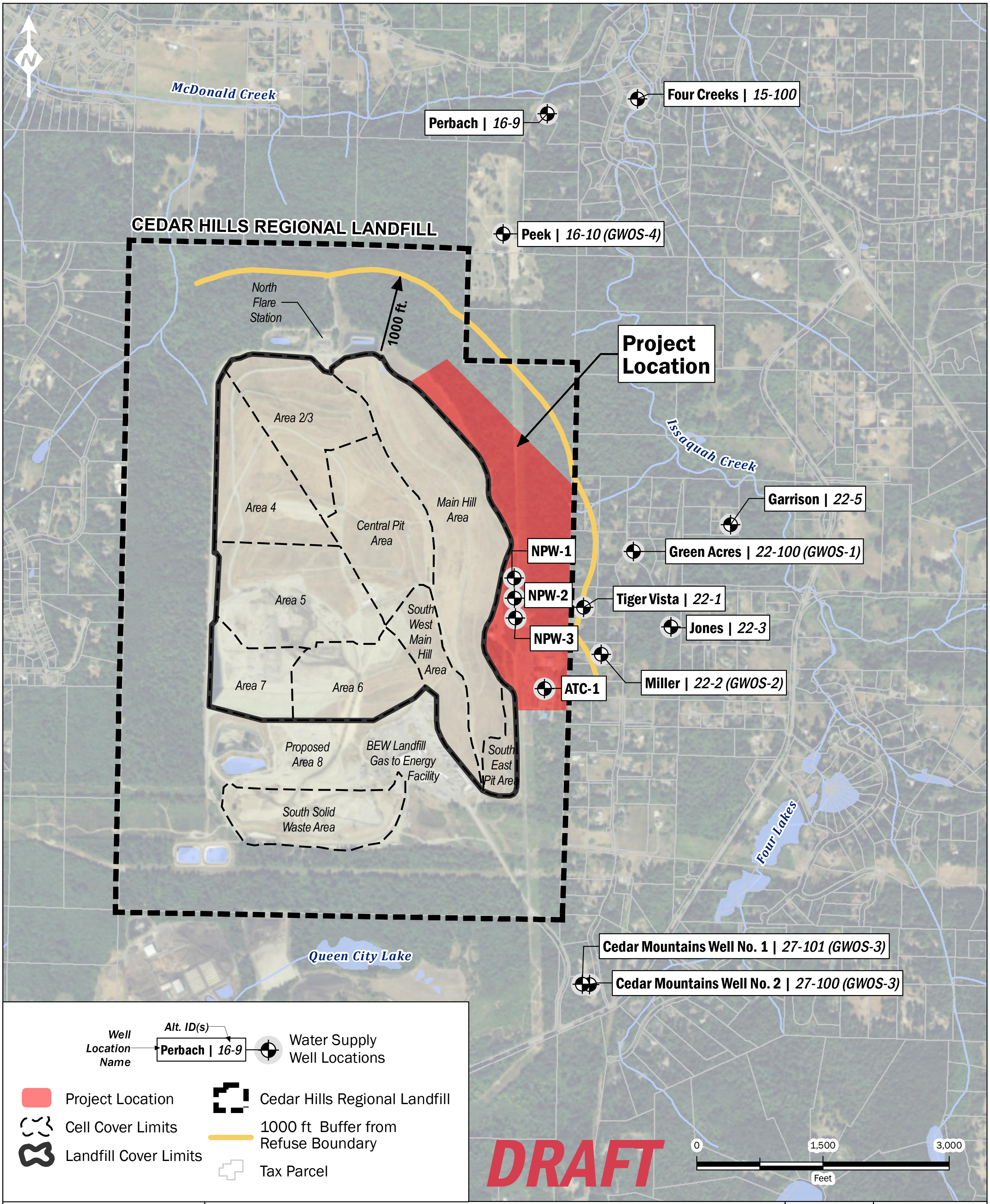


Notes:
- Monitoring wells appear in the legend in the same order they appear in the hydrograph, from highest water level elevation to lowest.
-Dry well measurements are indicated as gaps in the hydrographs in wells MW-63, MW-62, MW-102, MW-29, MW-30A, MW-48, EB-6D, EB-3, EW-11, MW-104, MW-50, MW-103, and EB-5S.
- Periods between measurements of greater than one year are also shown as gaps in the hydrographs.

Aspect Consulting
9/6/2016
P:\AECOM Cedar Hills Env Controls E00286E12\Data\Analyses\hydrographs\Water Levels for Hydrographs_2.xlsx

Figure 4.11
Groundwater Level Hydrograph - Perched

East Perched Zones RI/FS - CHRLF
King County, WA



King County

Aspect CONSULTING

Local Non-Potable and Water Supply Wells

Cedar Hills Regional Landfill

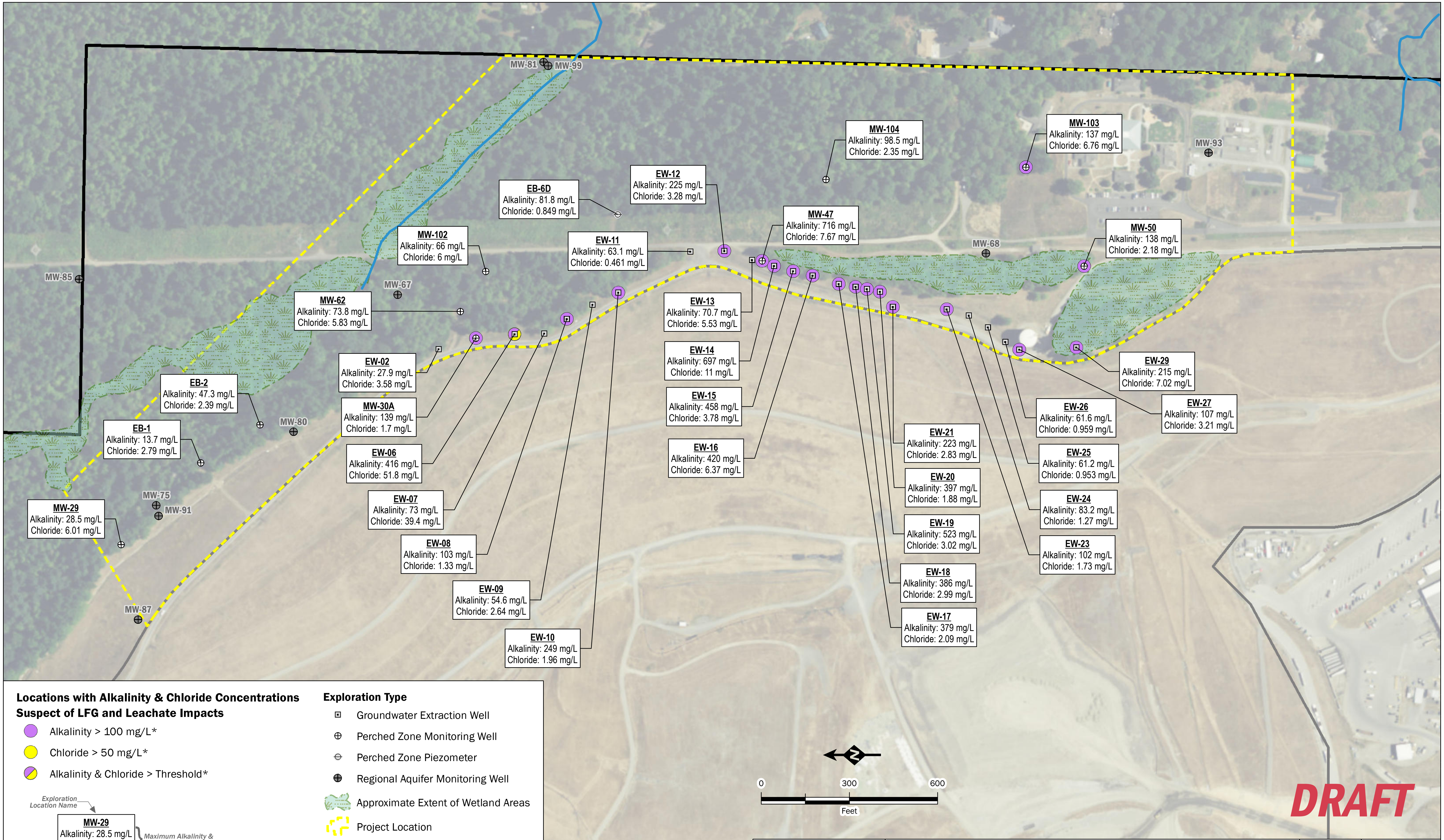
King County, Washington

DATE:	Nov-2016
DESIGNED BY:	KSL/RAP
DRAWN BY:	KSL/RAP
REVISED BY:	PPW

PROJECT NO.
130088

FIGURE NO.
4.12

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



Locations with Alkalinity & Chloride Concentrations Suspect of LFG and Leachate Impacts

- 🟣 Alkalinity > 100 mg/L*
- 🟡 Chloride > 50 mg/L*
- ◐ Alkalinity & Chloride > Threshold*

Exploration Location Name

MW-29
Alkalinity: 28.5 mg/L
Chloride: 6.01 mg/L

Maximum Alkalinity & Chloride Detections

Exploration Type

- ⊡ Groundwater Extraction Well
- ⊕ Perched Zone Monitoring Well
- ⊖ Perched Zone Piezometer
- ⊕ Regional Aquifer Monitoring Well
- 🟩 Approximate Extent of Wetland Areas
- ⬚ Project Location
- ▢ Landfill Cover Limits
- ▢ Property Boundary

Note: *Refer to Table 2.2 for screen elevation data for each well included in RI. *Alkalinity and Chloride thresholds presented here were arbitrarily set at 100 mg/L and 50 mg/L; levels set to indicate potential LFG and leachate impacts in groundwater. Maximum concentration detected 2015-2016.*

King County

Aspect CONSULTING

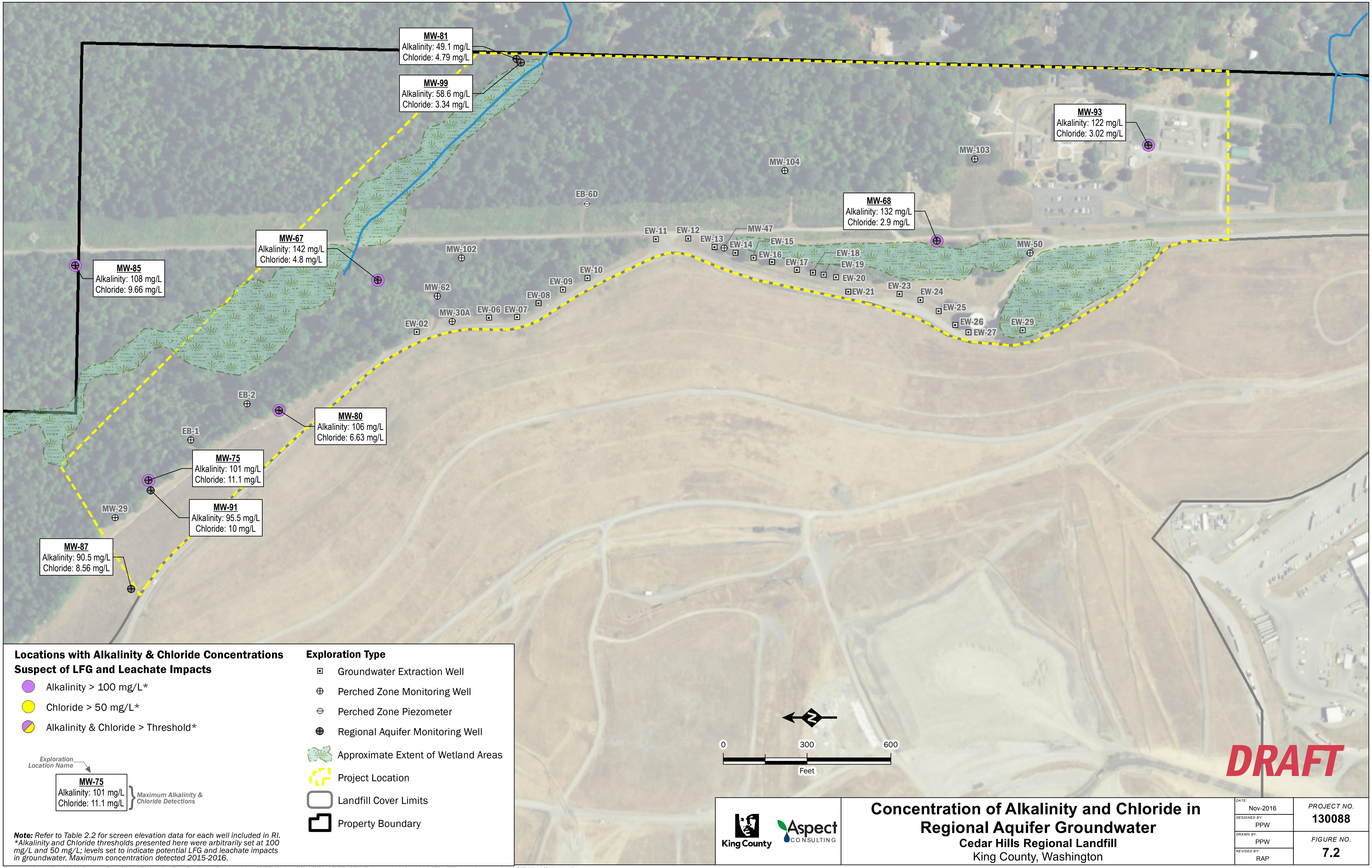
Concentration of Alkalinity and Chloride in Shallow Perched Zone Groundwater

Cedar Hills Regional Landfill

King County, Washington

DATE: Nov-2016	PROJECT NO. 130088
DESIGNED BY: PPW	
DRAWN BY: PPW	FIGURE NO. 7.1
REVISED BY: RAP	

Basemap Layer Credits || Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



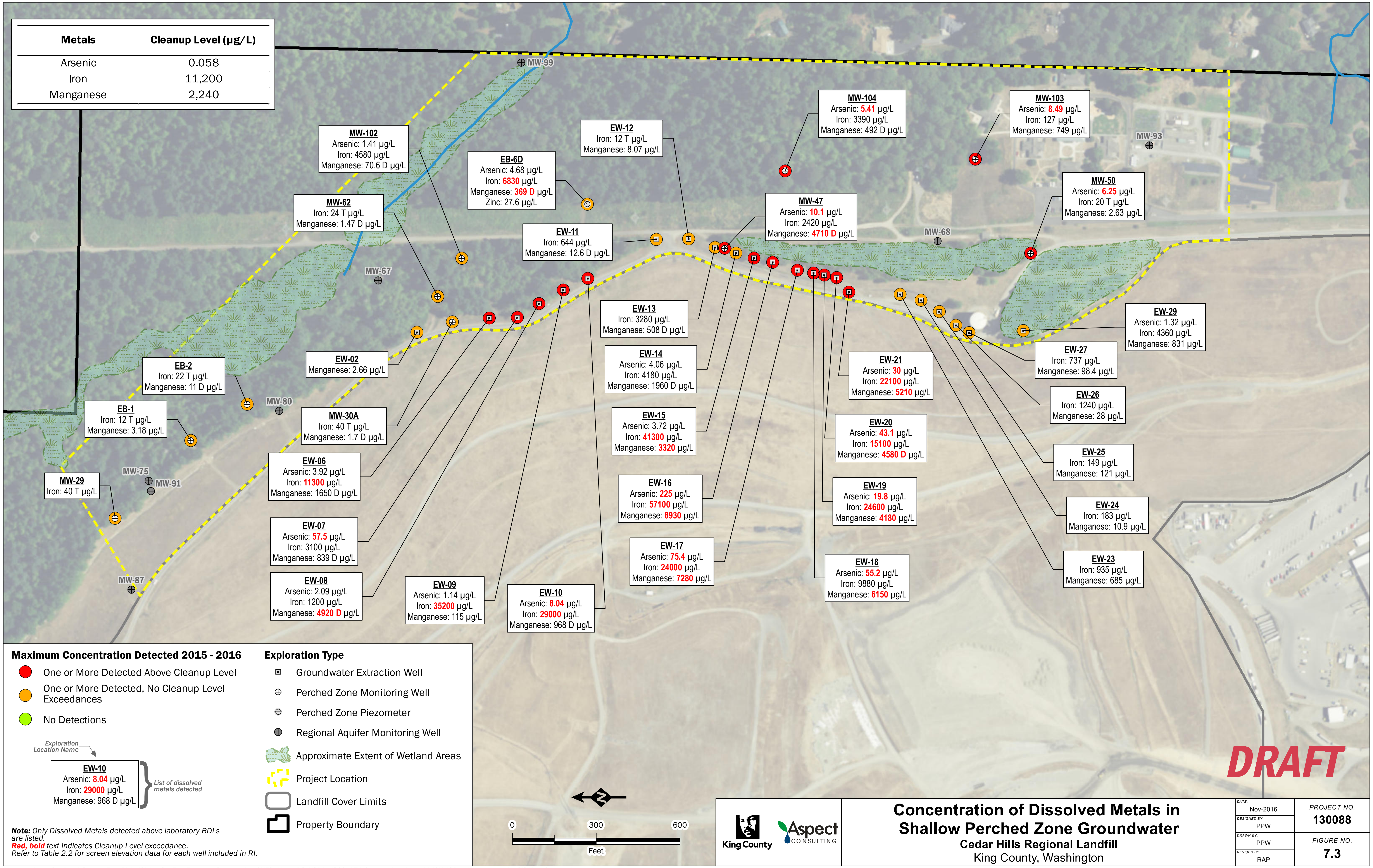
Note: *Refer to Table 2.2 for screen elevation data for each well included in RI.*
**Alkalinity and Chloride thresholds presented here were arbitrarily set at 100 mg/L and 50 mg/L; levels set to indicate potential LFG and leachate impacts in groundwater. Maximum concentration detected 2015-2016.*

Concentration of Alkalinity and Chloride in Regional Aquifer Groundwater

Cedar Hills Regional Landfill
King County, Washington

Basemap Layer Credits || Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Metals	Cleanup Level (µg/L)
Arsenic	0.058
Iron	11,200
Manganese	2,240



Maximum Concentration Detected 2015 - 2016

- 🔴 One or More Detected Above Cleanup Level
- 🟠 One or More Detected, No Cleanup Level Exceedances
- 🟢 No Detections

Exploration Location Name

EW-10
Arsenic: **8.04** µg/L
Iron: **29000** µg/L
Manganese: 968 D µg/L

List of dissolved metals detected

Exploration Type

- ⊡ Groundwater Extraction Well
- ⊕ Perched Zone Monitoring Well
- ⊖ Perched Zone Piezometer
- ⊕ Regional Aquifer Monitoring Well
- Approximate Extent of Wetland Areas
- Project Location
- Landfill Cover Limits
- Property Boundary

Note: *Only Dissolved Metals detected above laboratory RDLs are listed.*
Red, bold *text indicates Cleanup Level exceedance.*
Refer to Table 2.2 for screen elevation data for each well included in RI.

Basemap Layer Credits || Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

King County

Aspect CONSULTING

Concentration of Dissolved Metals in Shallow Perched Zone Groundwater

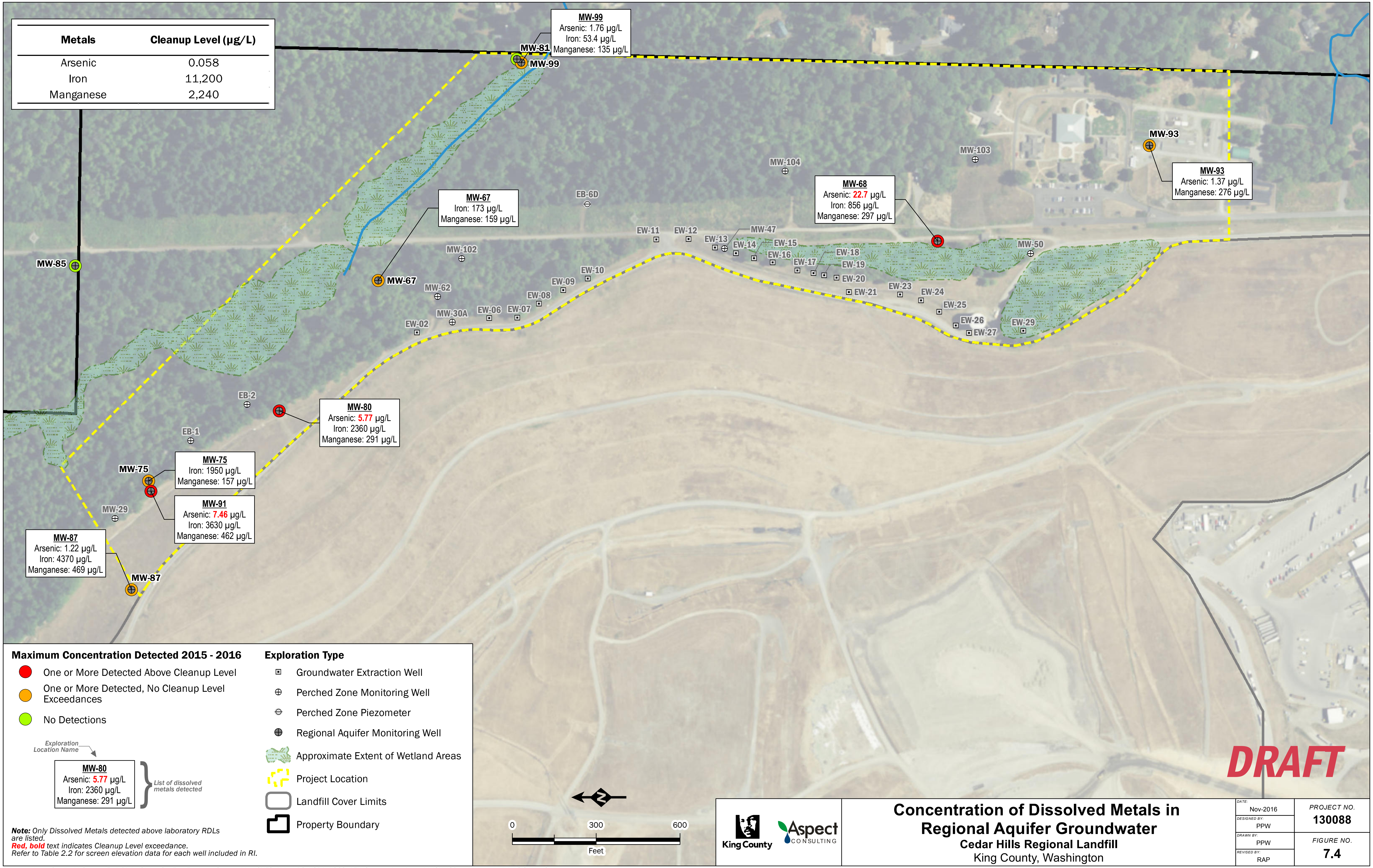
Cedar Hills Regional Landfill

King County, Washington

DATE: Nov-2016
DESIGNED BY: PPW
DRAWN BY: PPW
REVISED BY: RAP

PROJECT NO. 130088

FIGURE NO. 7.3



Metals	Cleanup Level (µg/L)
Arsenic	0.058
Iron	11,200
Manganese	2,240

Maximum Concentration Detected 2015 - 2016

🟥 One or More Detected Above Cleanup Level

🟧 One or More Detected, No Cleanup Level Exceedances

🟩 No Detections

Exploration Location Name

MW-80
Arsenic: **5.77** µg/L
Iron: 2360 µg/L
Manganese: 291 µg/L

List of dissolved metals detected

Exploration Type

⊡ Groundwater Extraction Well

⊕ Perched Zone Monitoring Well

⊖ Perched Zone Piezometer

⊕ Regional Aquifer Monitoring Well

▨ Approximate Extent of Wetland Areas

▭ Project Location

▢ Landfill Cover Limits

▭ Property Boundary

Note: *Only Dissolved Metals detected above laboratory RDLs are listed.*
Red, bold *text indicates Cleanup Level exceedance.*
Refer to Table 2.2 for screen elevation data for each well included in RI.

King County
Aspect CONSULTING

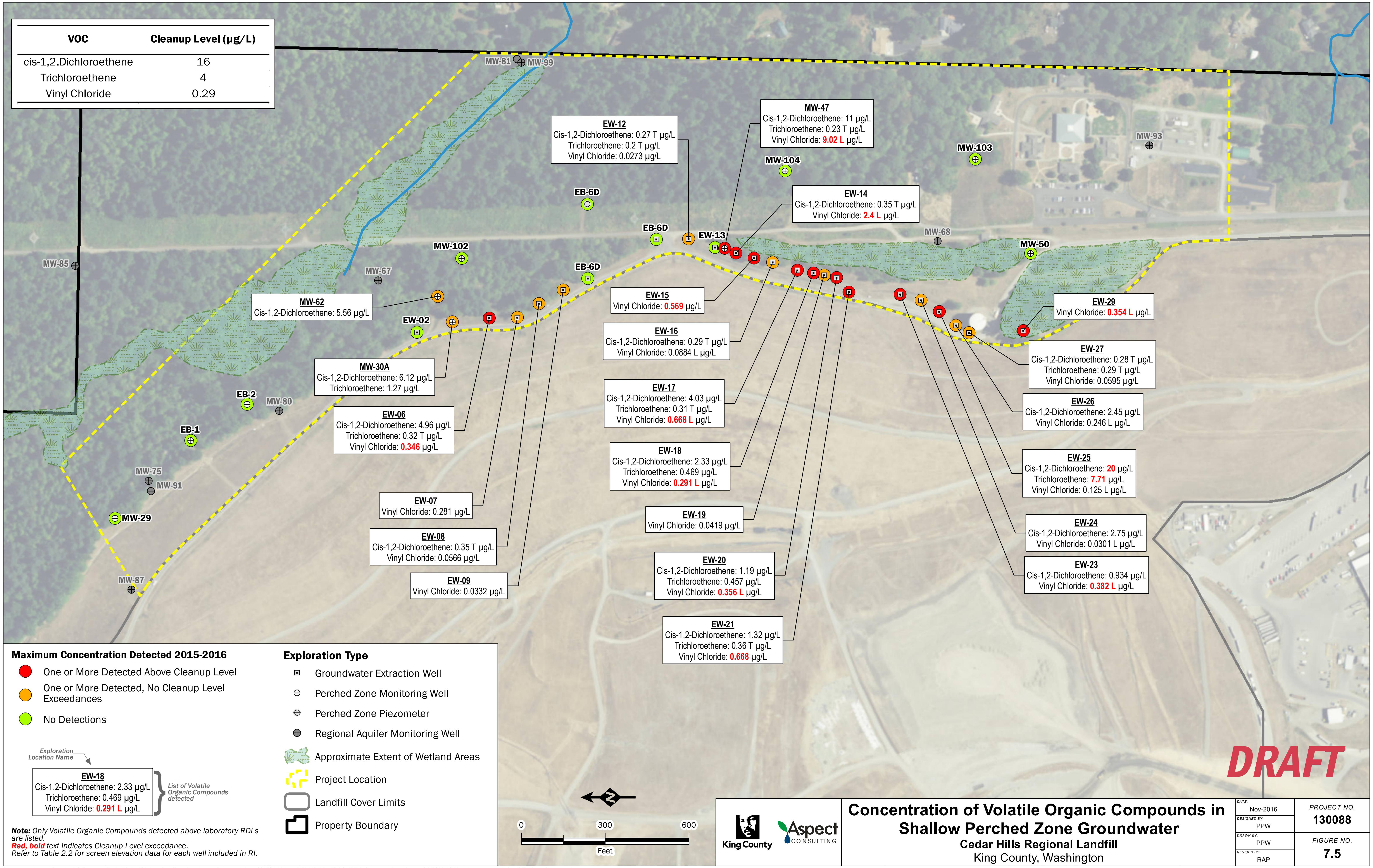
Concentration of Dissolved Metals in Regional Aquifer Groundwater

Cedar Hills Regional Landfill

King County, Washington

DATE:	Nov-2016	PROJECT NO.	130088
DESIGNED BY:	PPW		
DRAWN BY:	PPW	FIGURE NO.	7.4
REVISED BY:	RAP		

Basemap Layer Credits || Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



VOC	Cleanup Level (µg/L)
cis-1,2.Dichloroethene	16
Trichloroethene	4
Vinyl Chloride	0.29

Maximum Concentration Detected 2015-2016

- 🔴 One or More Detected Above Cleanup Level
- 🟠 One or More Detected, No Cleanup Level Exceedances
- 🟢 No Detections

Exploration Location Name

EW-18
Cis-1,2-Dichloroethene: 2.33 µg/L
Trichloroethene: 0.469 µg/L
Vinyl Chloride: **0.291 L** µg/L

List of Volatile Organic Compounds detected

Note: *Only Volatile Organic Compounds detected above laboratory RDLs are listed.*
Red, bold *text indicates Cleanup Level exceedance.*
Refer to Table 2.2 for screen elevation data for each well included in RI.

Exploration Type

- ⊡ Groundwater Extraction Well
- ⊕ Perched Zone Monitoring Well
- ⊖ Perched Zone Piezometer
- ⊕ Regional Aquifer Monitoring Well
- ▨ Approximate Extent of Wetland Areas
- ⬚ Project Location
- ▢ Landfill Cover Limits
- ▢ Property Boundary

King County
Aspect CONSULTING

Concentration of Volatile Organic Compounds in Shallow Perched Zone Groundwater

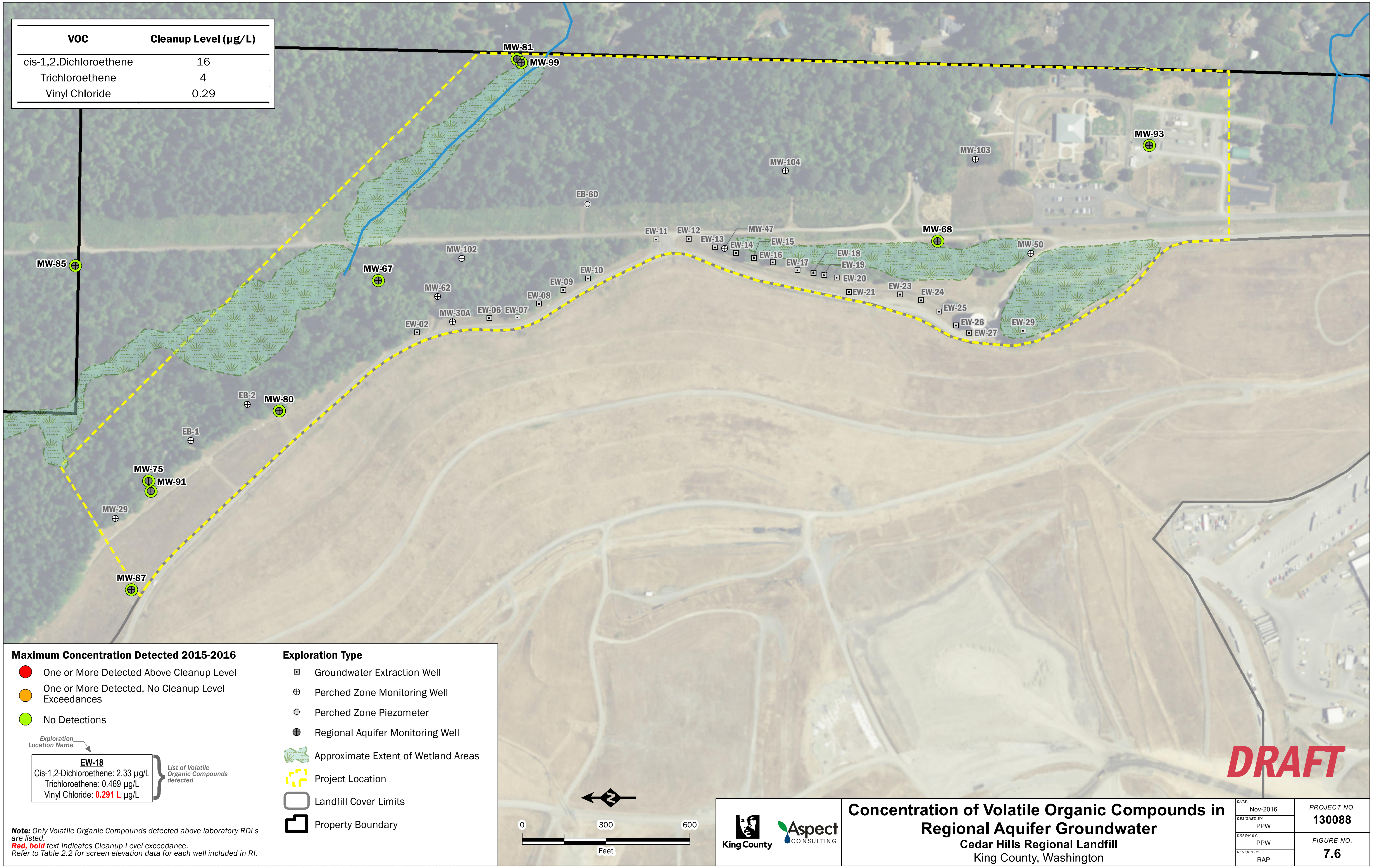
Cedar Hills Regional Landfill

King County, Washington

DATE: Nov-2016	PROJECT NO. 130088
DESIGNED BY: PPW	
DRAWN BY: PPW	FIGURE NO. 7.5
REVISED BY: RAP	

Basemap Layer Credits || Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

VOC	Cleanup Level (µg/L)
cis-1,2.Dichloroethene	16
Trichloroethene	4
Vinyl Chloride	0.29



Maximum Concentration Detected 2015-2016

- 🔴 One or More Detected Above Cleanup Level
- 🟠 One or More Detected, No Cleanup Level Exceedances
- 🟢 No Detections

Exploration Location Name

EW-18
Cis-1,2-Dichloroethene: 2.33 µg/L
Trichloroethene: 0.469 µg/L
Vinyl Chloride: **0.291 L** µg/L

List of Volatile Organic Compounds detected

Exploration Type

- ⊡ Groundwater Extraction Well
- ⊕ Perched Zone Monitoring Well
- ⊖ Perched Zone Piezometer
- ⊕ Regional Aquifer Monitoring Well
- ▨ Approximate Extent of Wetland Areas
- ▭ Project Location
- ▭ Landfill Cover Limits
- ▭ Property Boundary

Note: *Only Volatile Organic Compounds detected above laboratory RDLs are listed.*
Red, bold *text indicates Cleanup Level exceedance.*
Refer to Table 2.2 for screen elevation data for each well included in RI.

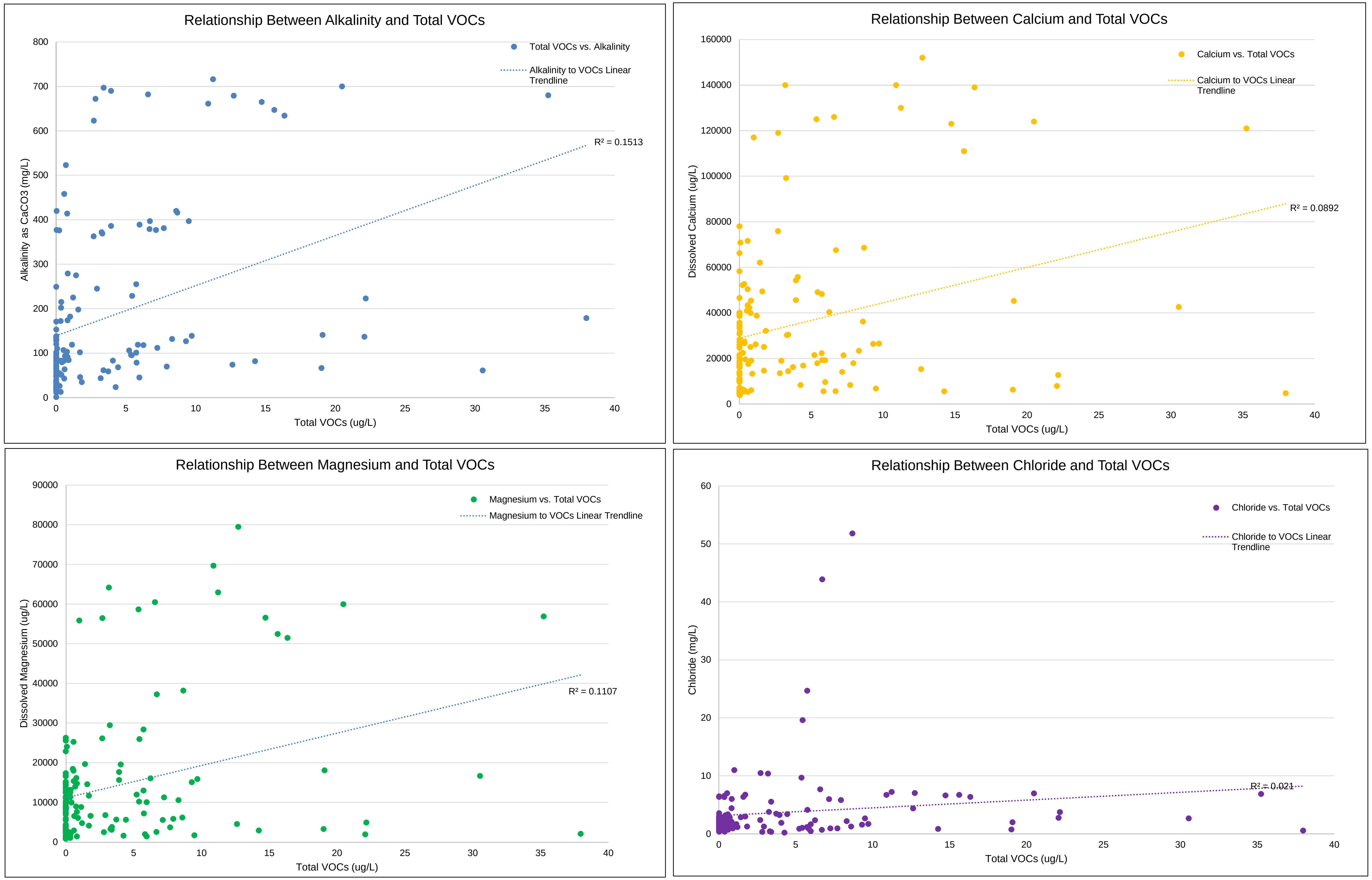
King County
Aspect CONSULTING

Concentration of Volatile Organic Compounds in Regional Aquifer Groundwater

Cedar Hills Regional Landfill
King County, Washington

DATE:	Nov-2016
DESIGNED BY:	PPW
DRAWN BY:	PPW
REVISED BY:	RAP
PROJECT NO.	130088
FIGURE NO.	7.6

Basemap Layer Credits || Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

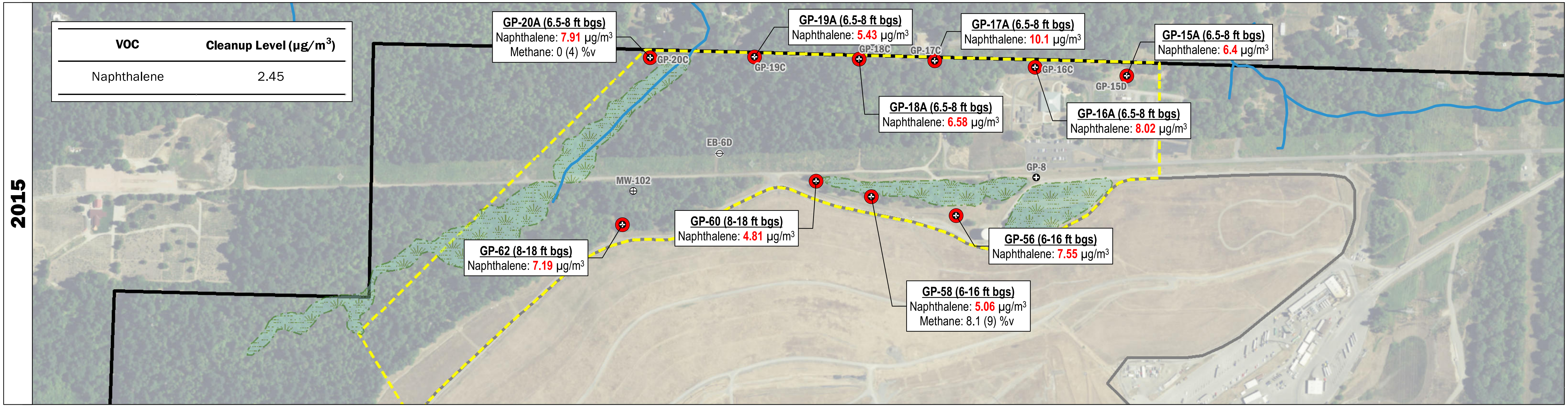


Notes:
EW-7 was eliminated from this dataset, due to an outlier of VOCs that skews the dataset.
R-squared values for alkalinity, calcium, and magnesium indicate small positive linear association between these geochemical parameters and total VOCs.
R-squared value for chloride does not indicate a linear association between with total VOCs.

Aspect Consulting
October 2016
V:\130088 KC CHRLF Env Control System Mods-E00286E12\Deliverables\RI_FS Report Agency Draft\Figures\Figure 7.7 Alkalinity and Total VOCs Reational Plots.xlsx

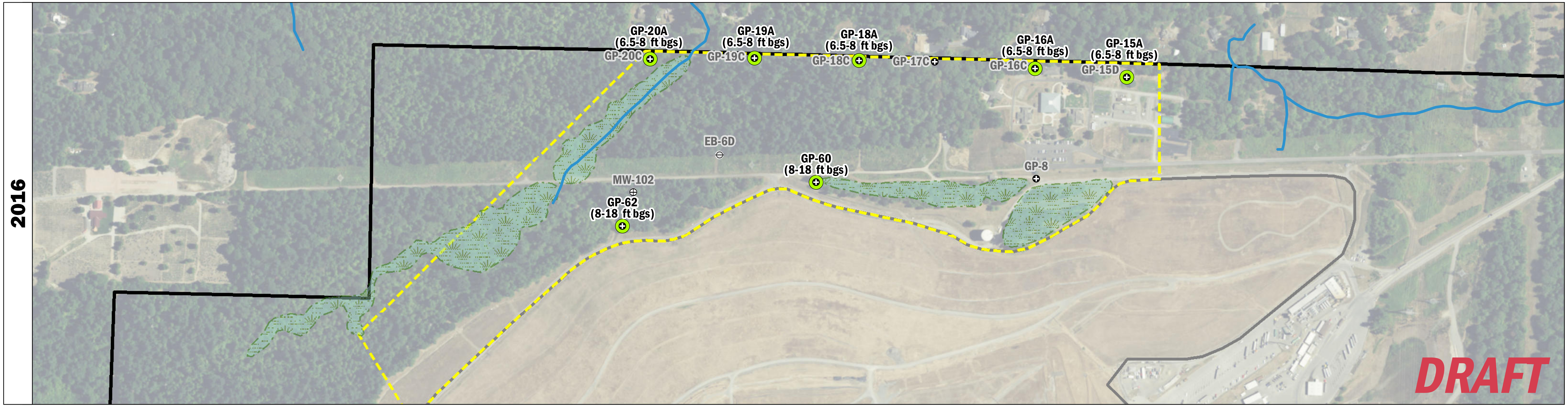
Figure 7.7
Geochemical Parameters and Total VOCs Relational Plots
Remedial Investigation/Feasibility Study
CHRLF, King County, WA

2015



VOC	Cleanup Level (µg/m^3)
Naphthalene	2.45

2016



Maximum Concentration Detected 2015-2016

🔴 One or More Detected Above Cleanup Level

🟠 One or More Detected, No Cleanup Level Exceedances

🟢 No Detections

Exploration Type

⊕ Gas Probe

⊕ Perched Zone Monitoring Well

⊖ Perched Zone Piezometer

Exploration Location Name
Screened Interval

GP-20A (6.5-8 ft bgs)
Naphthalene: **9.25** µg/m³
Methane: 0 (4) %v

List of VOCs and Methane detected
Concentration at Stabilization
Max Detected Concentration

Note: *Only Volatile Organic Compounds and Methane detected above laboratory RDLs are listed.*
Red, bold *text indicates Cleanup Level exceedance.*
Refer to Table 2.2 for screen elevation data for each well included in RI. Gas probe construction information presented in Table 2.3.

Basemap Layer Credits | | Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

🟩 Approximate Extent of Wetland Areas

Project Location

Landfill Cover Limits

Property Boundary

N

0 500 1,000
Feet

King County

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Concentration of Volatile Organic Compounds and Methane in Shallow Soil Gas

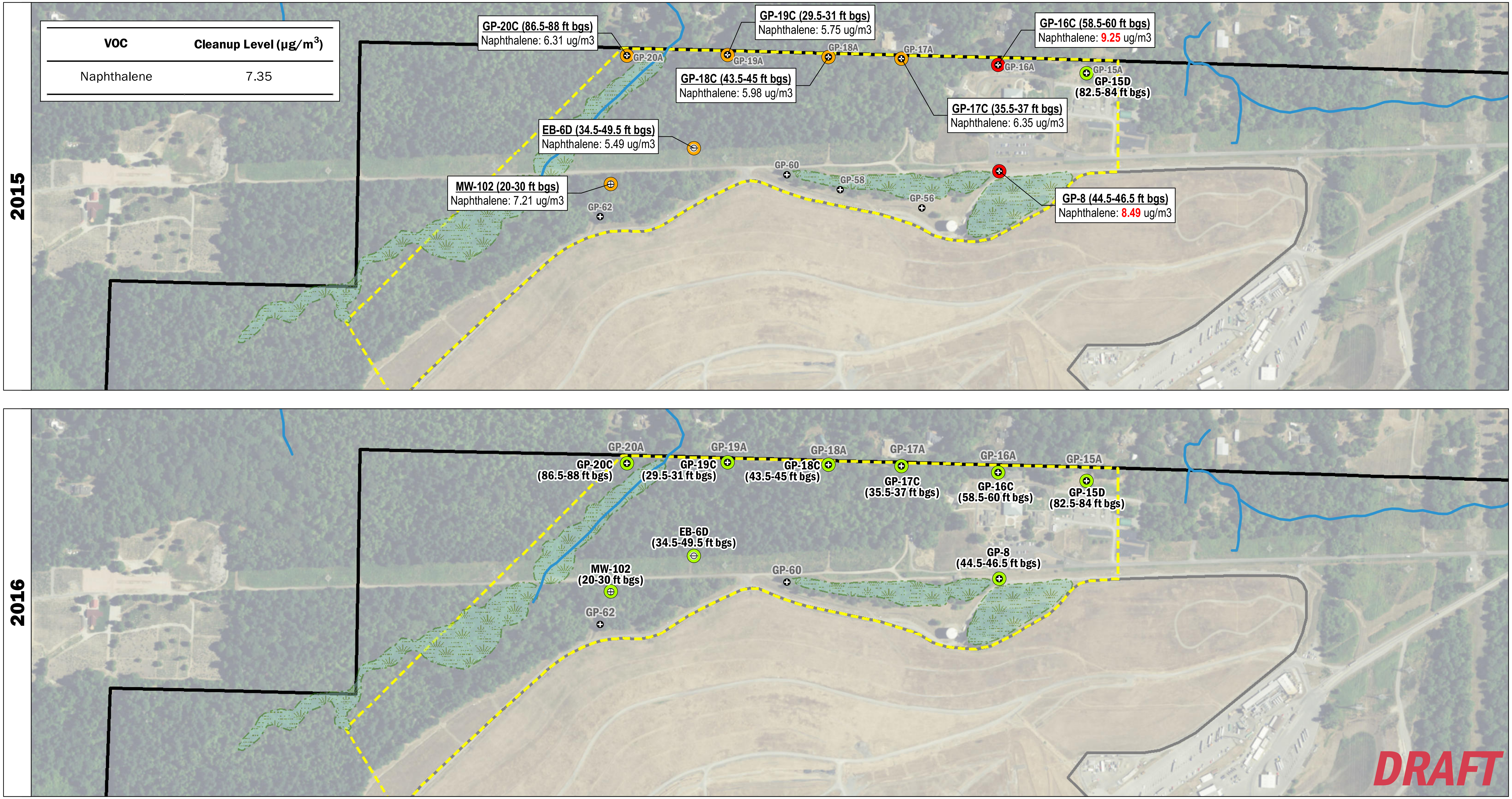
Cedar Hills Regional Landfill

King County, Washington

DATE: Nov-2016
DESIGNED BY: PPW
DRAWN BY: PPW
REVISED BY: RAP

PROJECT NO. 130088

FIGURE NO. 7.8



VOC	Cleanup Level ($\mu g/m^3$)
Naphthalene	7.35

Maximum Concentration Detected 2015-2016

- 🔴 One or More Detected Above Cleanup Level
- 🟠 One or More Detected, No Cleanup Level Exceedances
- 🟢 No Detections

Exploration Type

- ⊕ Gas Probe
- ⊕ Perched Zone Monitoring Well
- ⊖ Perched Zone Piezometer

Exploration Location Name — *Screened Interval*

GP-16C (58.5-60 ft bgs)
Naphthalene: **9.25** $\mu g/m^3$
List of VOCs detected

Note: *Only Volatile Organic Compounds and Methane detected above laboratory RDLs are listed.*
Red, bold *text indicates Cleanup Level exceedance.*
Refer to Table 2.2 for screen elevation data for each well included in RI. Gas probe construction information presented in Table 2.3.

Basemap Layer Credits || Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

- ▨ Approximate Extent of Wetland Areas
- ▭ Project Location
- ▭ Landfill Cover Limits
- ▭ Property Boundary

N

0 500 1,000
Feet

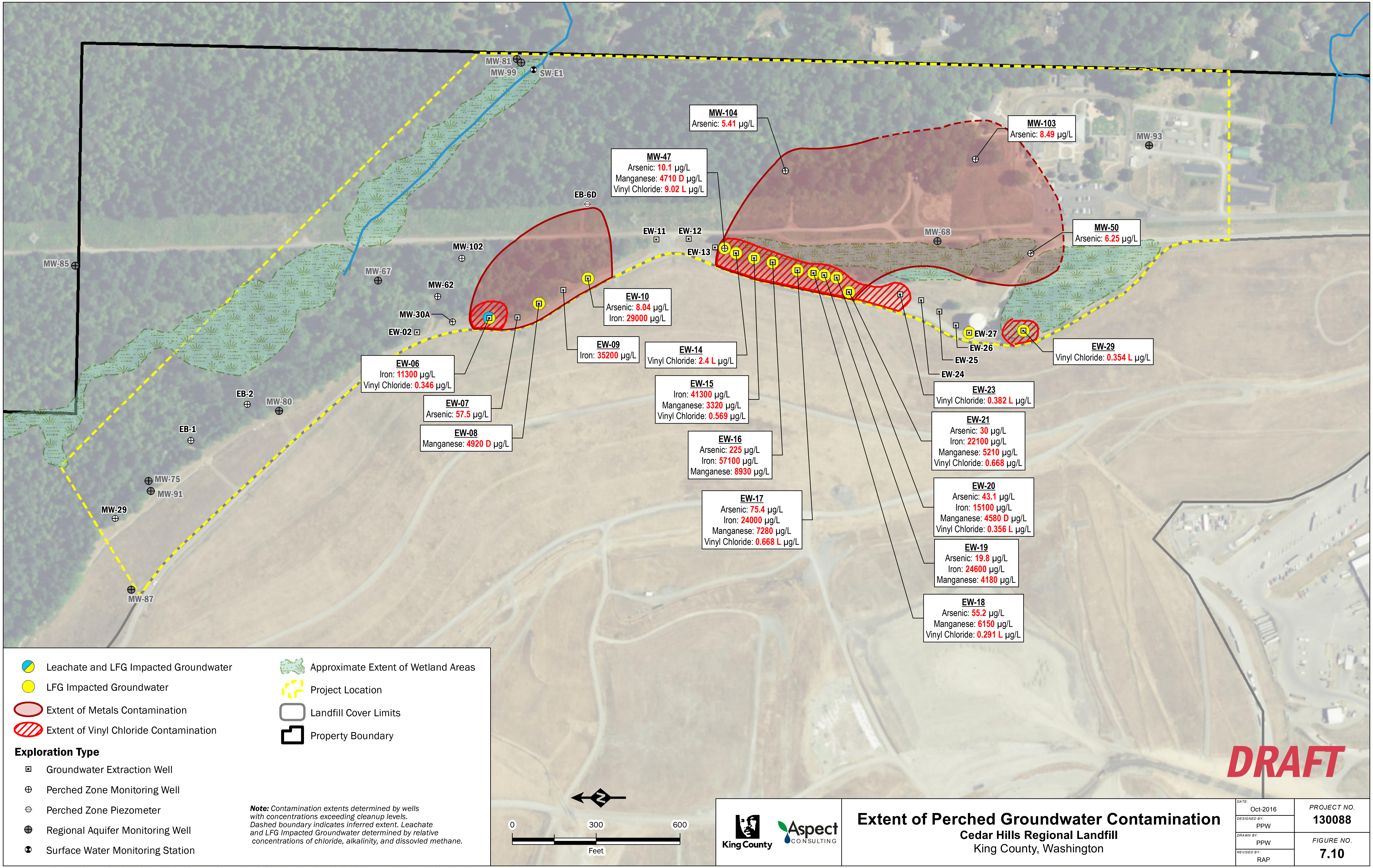
King County
Aspect CONSULTING

Concentration of Volatile Organic Compounds and Methane in Deep Soil Gas

Cedar Hills Regional Landfill

King County, Washington

DATE: Nov-2016	PROJECT NO. 130088
DESIGNED BY: PPW	
DRAWN BY: PPW	FIGURE NO. 7.9
REVISED BY: RAP	



Note: *Contamination extents determined by wells with concentrations exceeding cleanup levels. Dashed boundary indicates inferred extent. Leachate and LFG Impacted Groundwater determined by relative concentrations of chloride, alkalinity, and dissovled methane.*

King County

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Extent of Perched Groundwater Contamination

Cedar Hills Regional Landfill

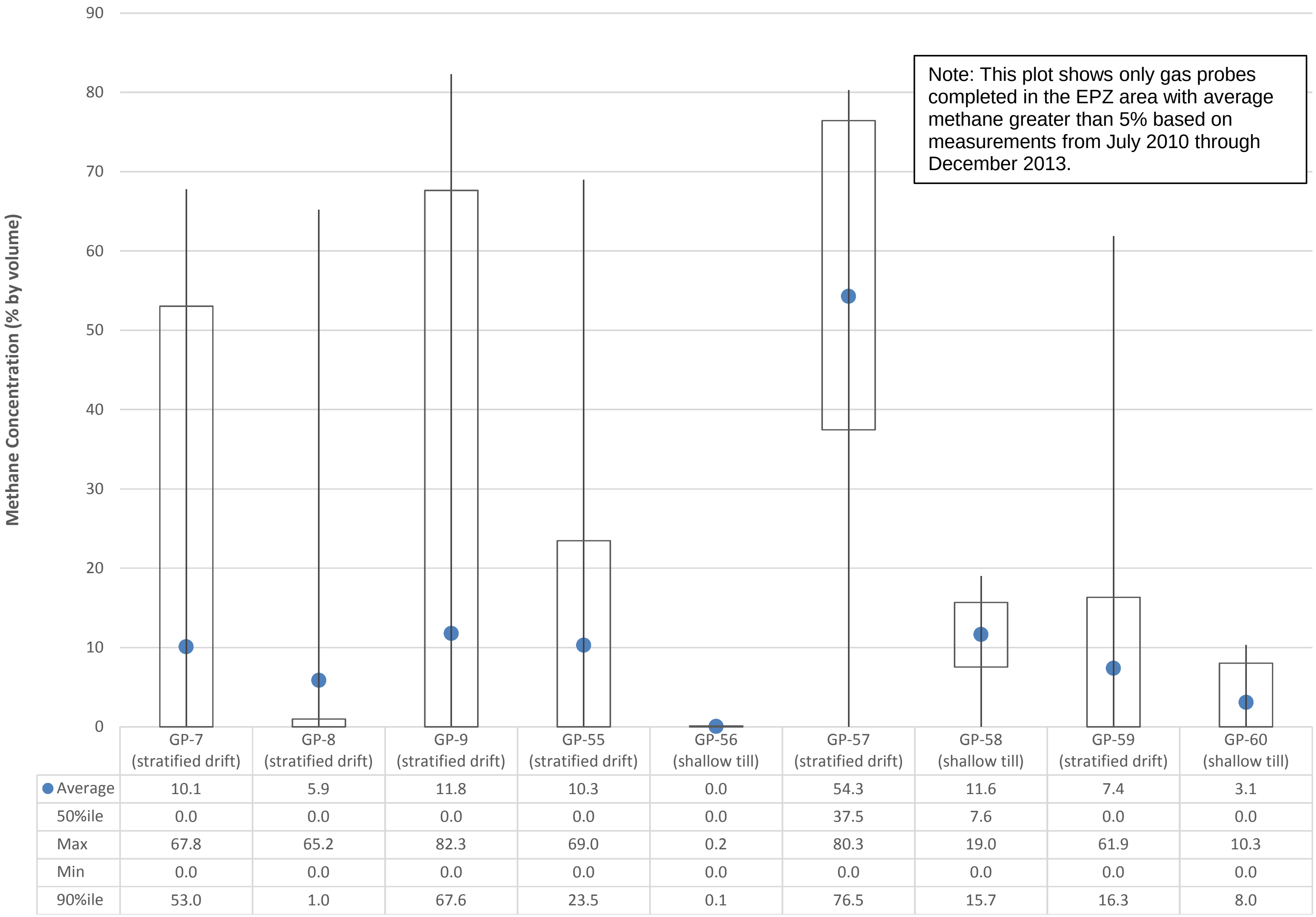
King County, Washington

DATE: Oct-2016
DESIGNED BY: PPW
DRAWN BY: PPW
REVISED BY: RAP

PROJECT NO. 130088

FIGURE NO. 7.10

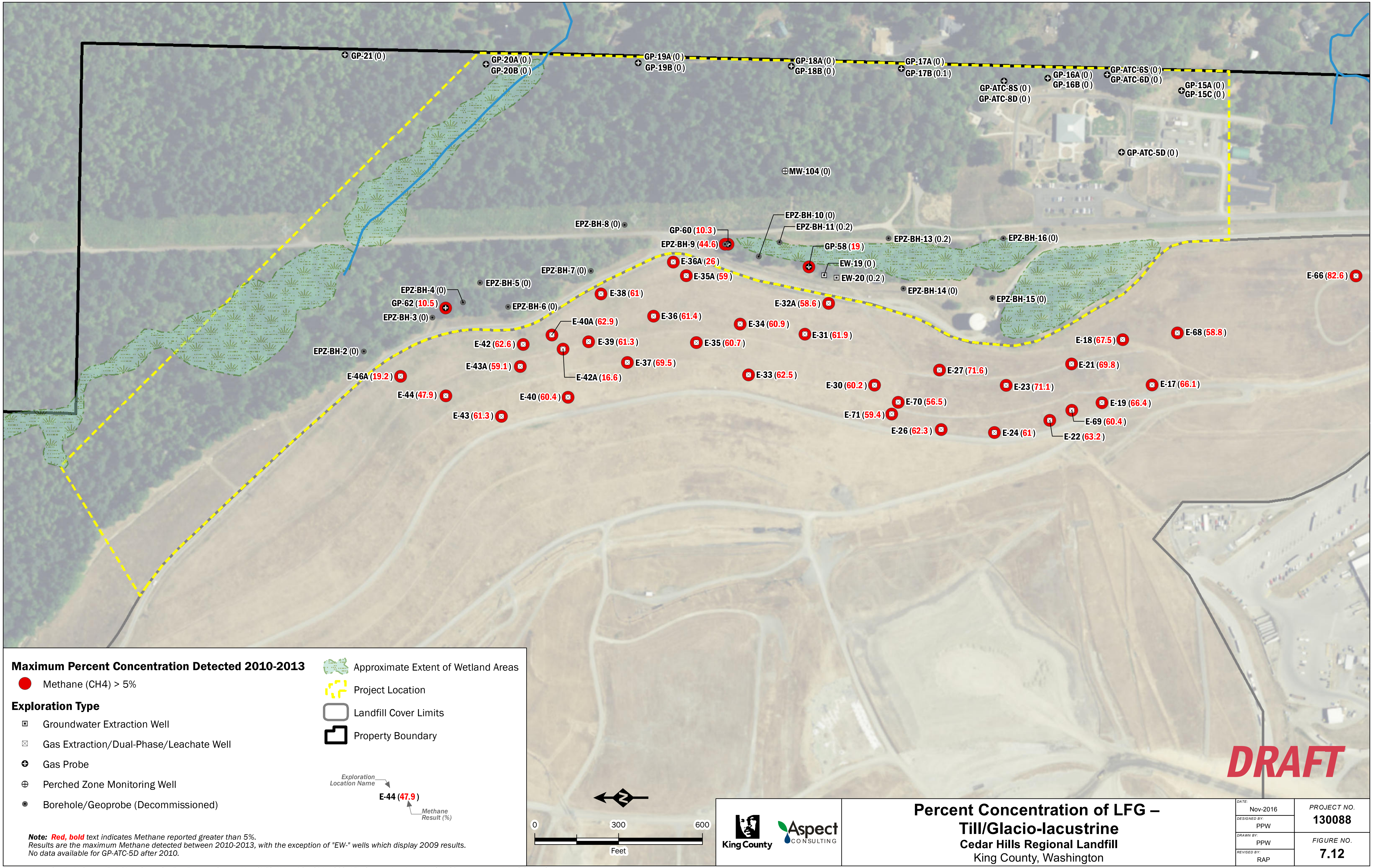
Basemap Layer Credits || Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



Note: This plot shows only gas probes completed in the EPZ area with average methane greater than 5% based on measurements from July 2010 through December 2013.

	GP-7 (stratified drift)	GP-8 (stratified drift)	GP-9 (stratified drift)	GP-55 (stratified drift)	GP-56 (shallow till)	GP-57 (stratified drift)	GP-58 (shallow till)	GP-59 (stratified drift)	GP-60 (shallow till)
● Average	10.1	5.9	11.8	10.3	0.0	54.3	11.6	7.4	3.1
50%ile	0.0	0.0	0.0	0.0	0.0	37.5	7.6	0.0	0.0
Max	67.8	65.2	82.3	69.0	0.2	80.3	19.0	61.9	10.3
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90%ile	53.0	1.0	67.6	23.5	0.1	76.5	15.7	16.3	8.0

Figure 7.11
Methane Concentration Statistics for Selected Gas Probes



Maximum Percent Concentration Detected 2010-2013

● Methane (CH4) > 5%

Exploration Type

- ⊡ Groundwater Extraction Well
- ☒ Gas Extraction/Dual-Phase/Leachate Well
- ⊕ Gas Probe
- ⊕ Perched Zone Monitoring Well
- ⊙ Borehole/Geoprobe (Decommissioned)

- 🟩 Approximate Extent of Wetland Areas
- ▭ Project Location
- ▭ Landfill Cover Limits
- ▭ Property Boundary

Exploration Location Name

E-44 (47.9)

Methane Result (%)

Note: ***Red, bold*** *text indicates Methane reported greater than 5%.*
Results are the maximum Methane detected between 2010-2013, with the exception of "EW-" wells which display 2009 results.
No data available for GP-ATC-5D after 2010.

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King County

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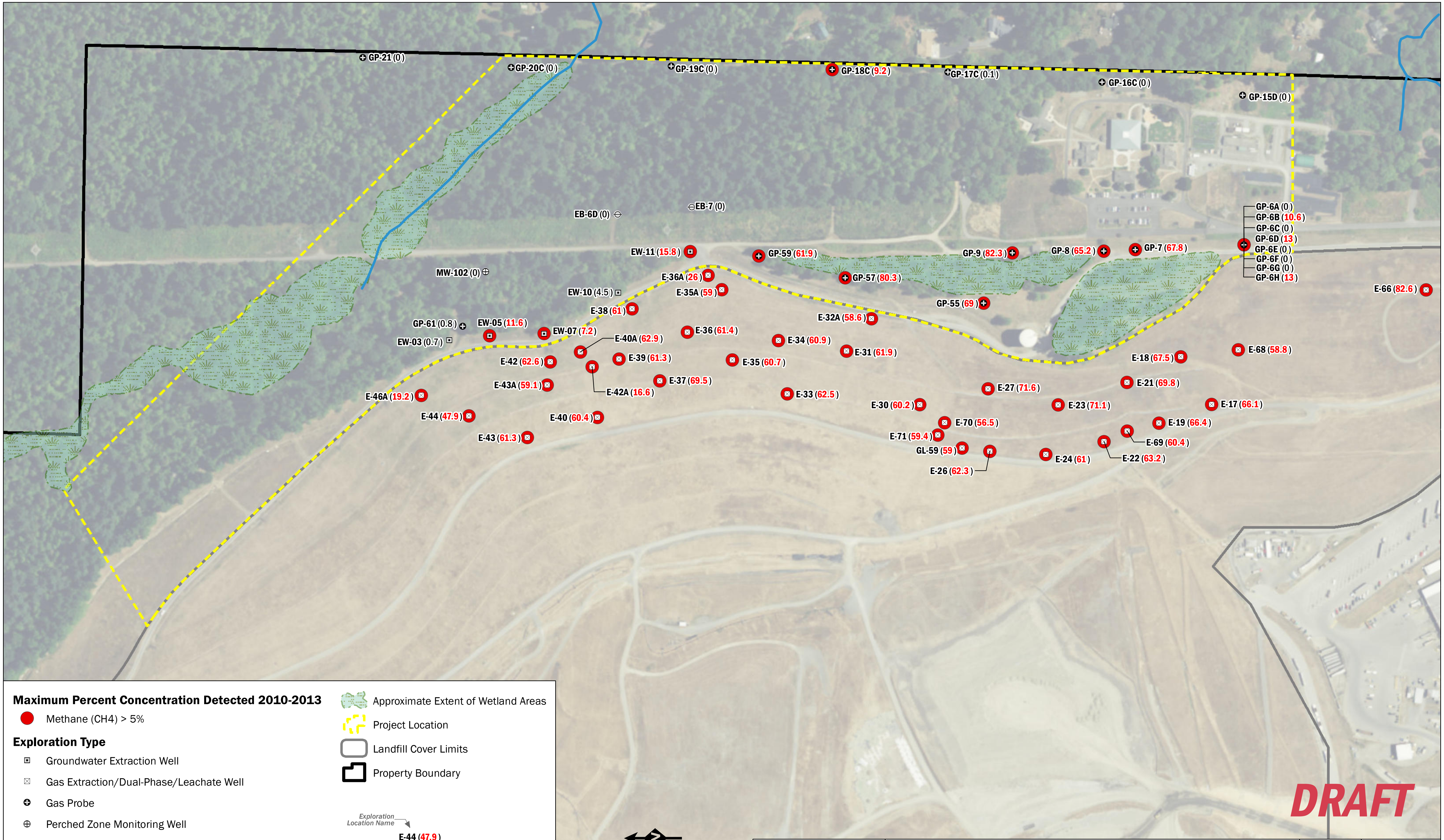
Percent Concentration of LFG – Till/Glacio-lacustrine

Cedar Hills Regional Landfill

King County, Washington

DATE: Nov-2016	PROJECT NO. 130088
DESIGNED BY: PPW	
DRAWN BY: PPW	FIGURE NO. 7.12
REVISED BY: RAP	



Maximum Percent Concentration Detected 2010-2013

● Methane (CH4) > 5%

Exploration Type

- ▣ Groundwater Extraction Well
- ☒ Gas Extraction/Dual-Phase/Leachate Well
- ⊕ Gas Probe
- ⊕ Perched Zone Monitoring Well
- ⊖ Perched Zone Piezometer

- 🟩 Approximate Extent of Wetland Areas
- ▭ Project Location
- ▭ Landfill Cover Limits
- ▭ Property Boundary

Exploration Location Name

E-44 (47.9)

Methane Result (%)

Note: ***Red, bold*** *text indicates Methane reported greater than 5%.*
Results are the maximum Methane detected between 2010-2013, with the exception of "EW-" wells which display 2009 results.

King County

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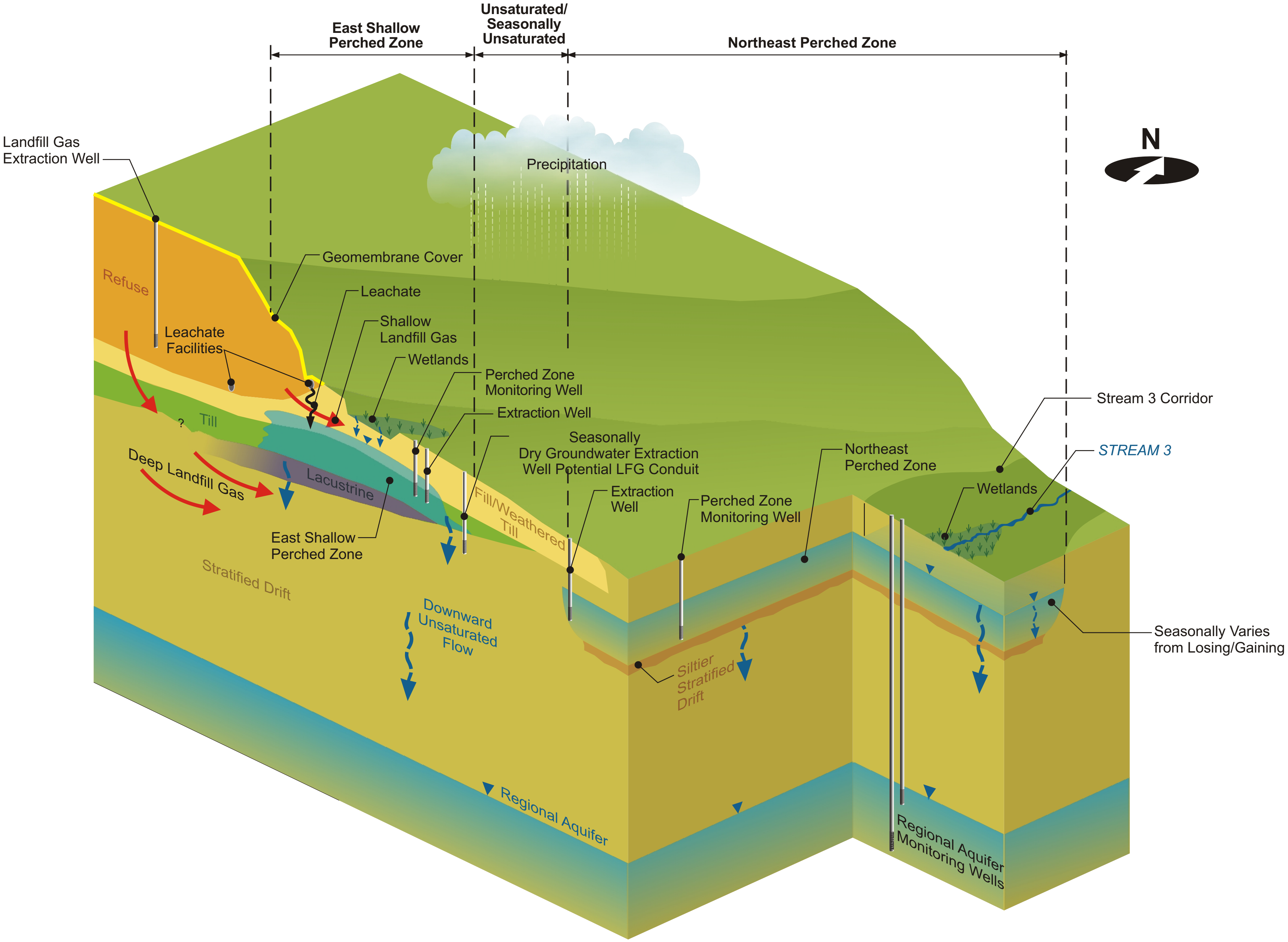
Percent Concentration of LFG – Stratified Drift

Cedar Hills Regional Landfill

King County, Washington

DATE: Nov-2016	PROJECT NO. 130088
DESIGNED BY: PPW	
DRAWN BY: PPW	FIGURE NO. 7.13
REVISED BY: RAP	

Basemap Layer Credits || Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



King County

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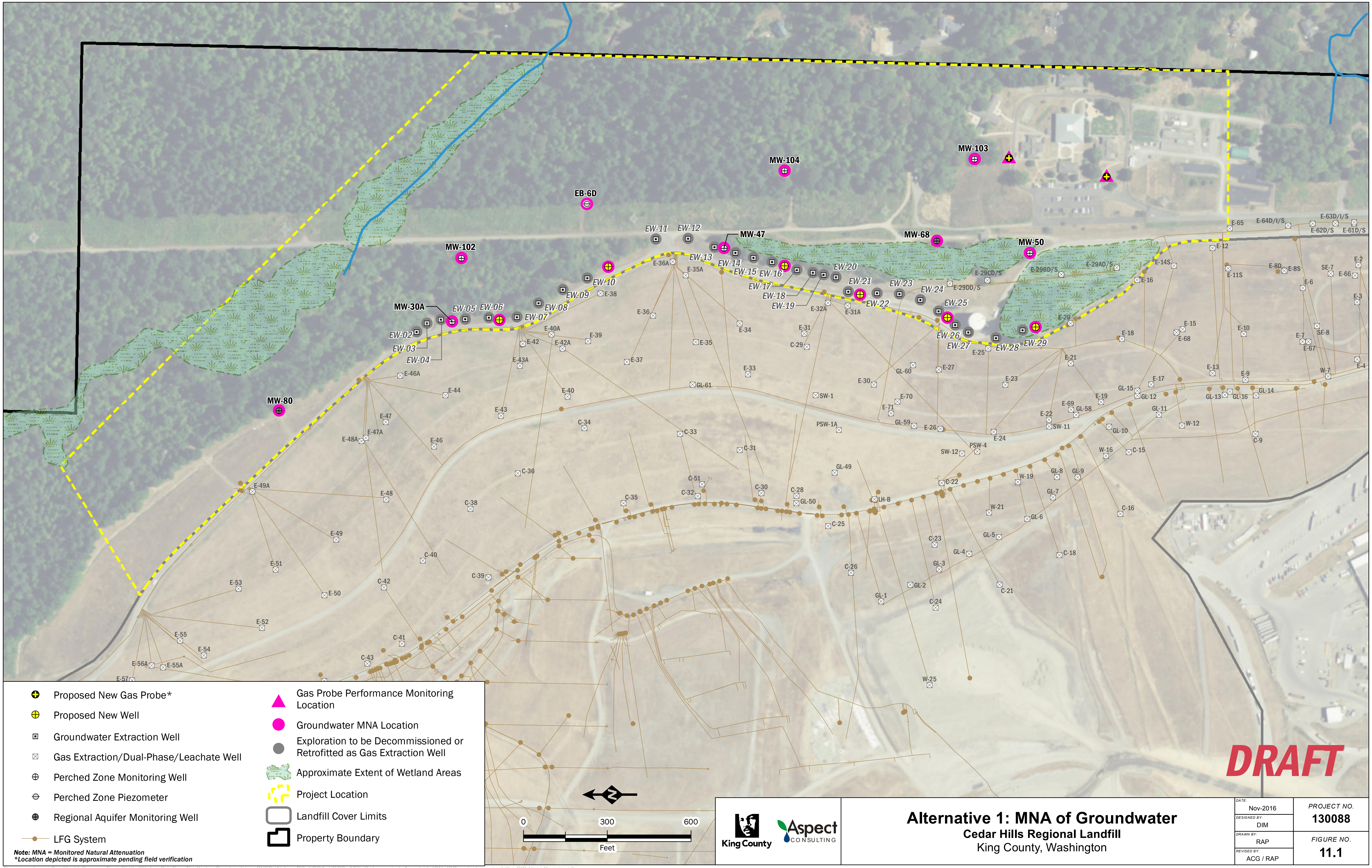
Conceptual Site Model

Cedar Hills Regional Landfill

King County, Washington

DATE: Oct-2014	PROJECT NO. 130088
DESIGNED BY: RAA	
DRAWN BY: RAA	FIGURE NO. 8.1
REVISED BY: RAA	



➕ Proposed New Gas Probe*

⊕ Proposed New Well

⊡ Groundwater Extraction Well

☒ Gas Extraction/Dual-Phase/Leachate Well

⊕ Perched Zone Monitoring Well

⊖ Perched Zone Piezometer

⊕ Regional Aquifer Monitoring Well

—●— LFG System

▲ Gas Probe Performance Monitoring Location

● Groundwater MNA Location

● Exploration to be Decommissioned or Retrofitted as Gas Extraction Well

🟩 Approximate Extent of Wetland Areas

▭ Project Location

▭ Landfill Cover Limits

▭ Property Boundary

Note: MNA = Monitored Natural Attenuation
**Location depicted is approximate pending field verification*

King County

Aspect CONSULTING

Alternative 1: MNA of Groundwater

Cedar Hills Regional Landfill

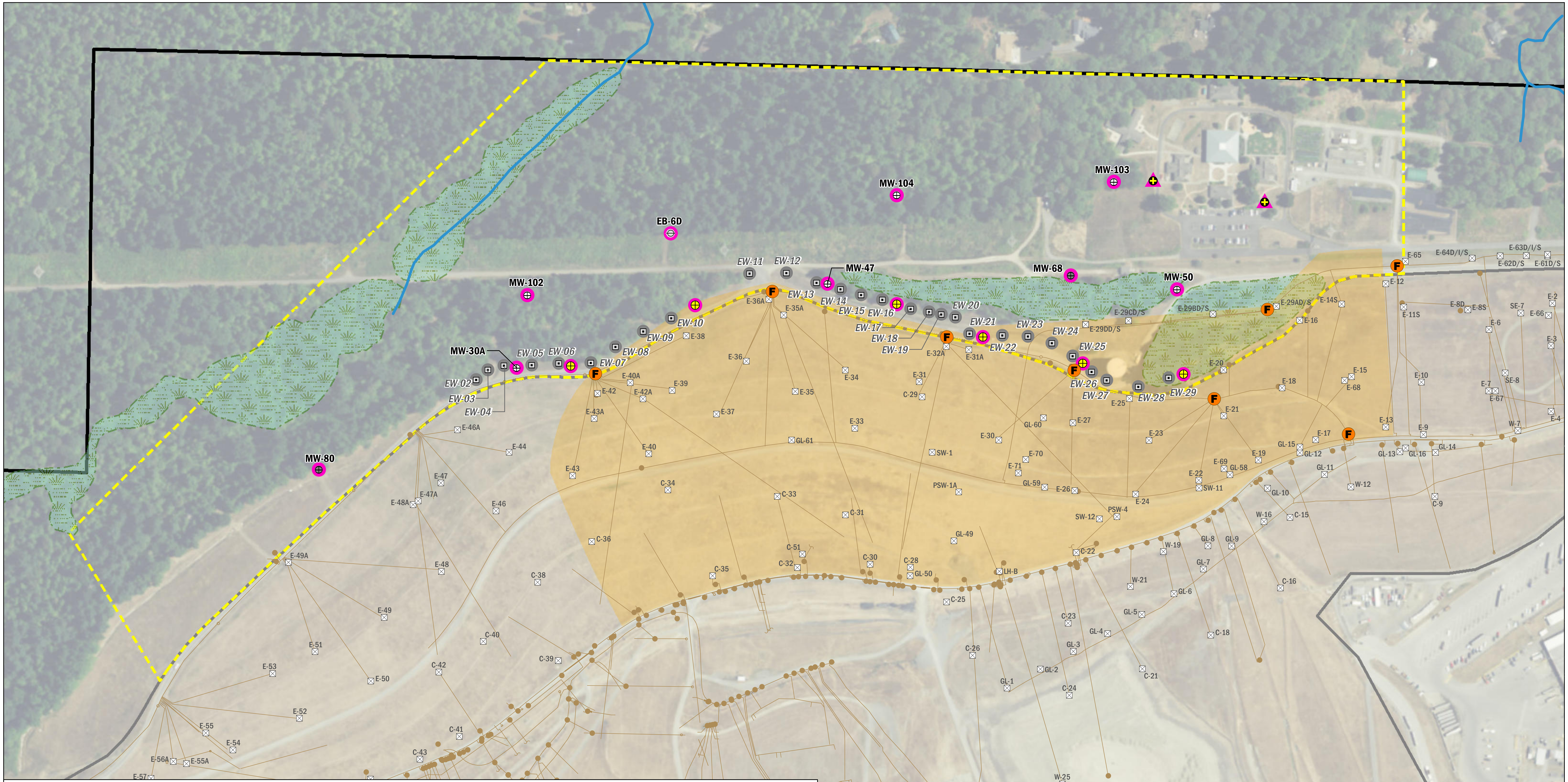
King County, Washington

DATE:	Nov-2016
DESIGNED BY:	DIM
DRAWN BY:	RAP
REVISED BY:	ACG / RAP

PROJECT NO.
130088

FIGURE NO.
11.1

Basemap Layer Credits || Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



- ✚ Proposed New Gas Probe*
- ⊕ Proposed New Well
- ▣ Groundwater Extraction Well
- ☒ Gas Extraction/Dual-Phase/Leachate Well
- ⊕ Perched Zone Monitoring Well
- ⊖ Perched Zone Piezometer
- ⊕ Regional Aquifer Monitoring Well
- ▲ Gas Probe Performance Monitoring Location
- ● Groundwater MNA Location
- ● Exploration to be Decommissioned or Retrofitted as Gas Extraction Well
- F Install Flow Control Device
- Modify LFG Operations from "moderate" to "aggressive" LFG control per SWANA guidance
- LFG System
- Approximate Extent of Wetland Areas
- Project Location
- Landfill Cover Limits
- Property Boundary

N

0 300 600

Feet

Note: MNA = Monitored Natural Attenuation
**Location depicted is approximate pending field verification*

DRAFT

King County

Aspect CONSULTING

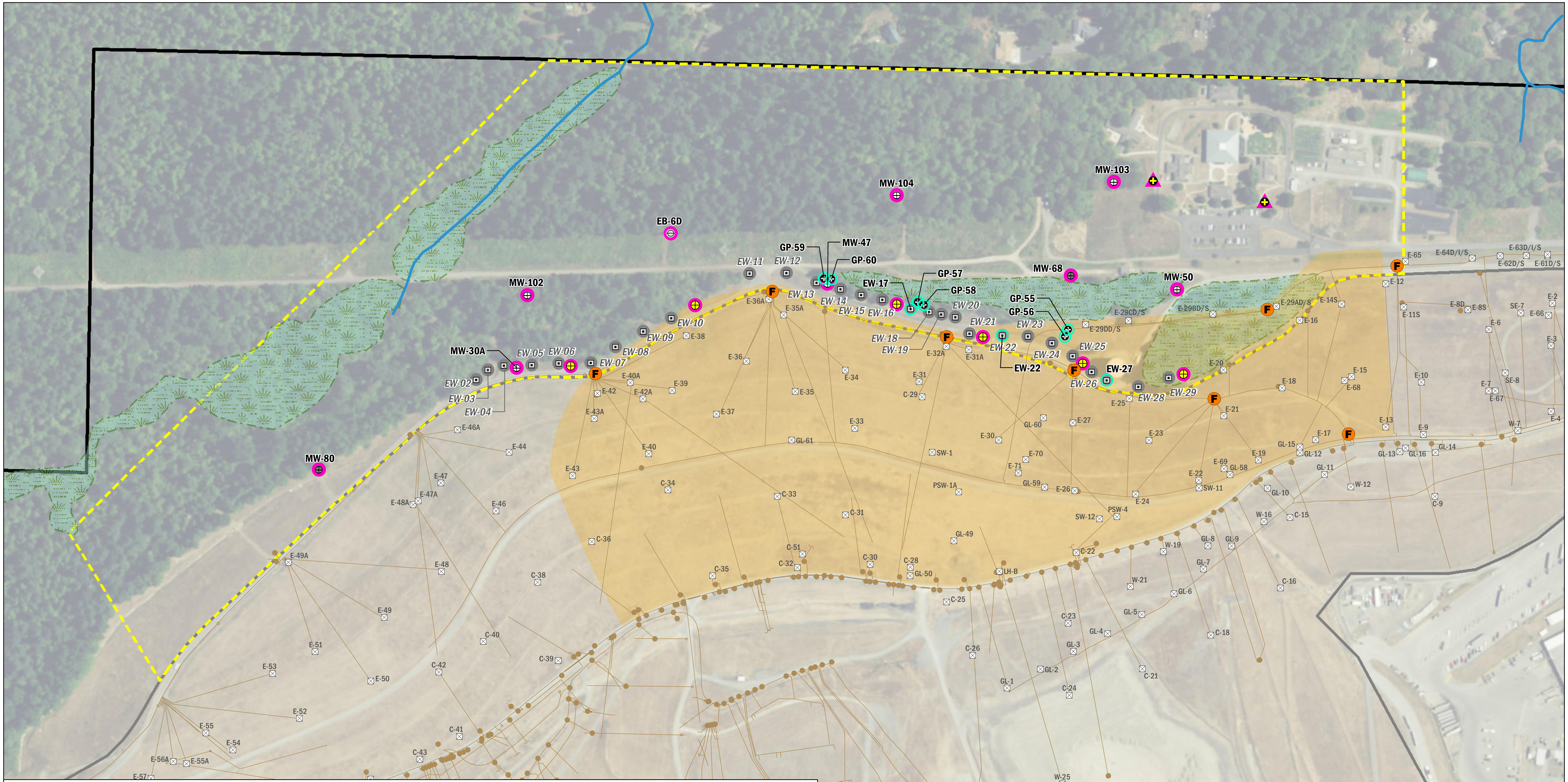
Alternative 2: Optimized LFG Control and MNA of Groundwater

Cedar Hills Regional Landfill

King County, Washington

DATE:	Nov-2016
DESIGNED BY:	DIM
DRAWN BY:	RAP
REVISED BY:	ACG / RAP
PROJECT NO.	130088
FIGURE NO.	11.2

Basemap Layer Credits || Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



- ✚ Proposed New Gas Probe*
- ⊕ Proposed New Well
- ⊡ Groundwater Extraction Well
- ⊠ Gas Extraction/Dual-Phase/Leachate Well
- ⊕ Perched Zone Monitoring Well
- ⊖ Perched Zone Piezometer
- ⊕ Regional Aquifer Monitoring Well
- ▲ Gas Probe Performance Monitoring Location
- ● Groundwater MNA Location
- ● Exploration to be Decommissioned or Retrofitted as Gas Extraction Well
- F Install Flow Control Device
- 🟧 Modify LFG Operations from "moderate" to "aggressive" LFG control per SWANA guidance
- ○ Potential Perimeter Gas Collection Location
- LFG System
- 🟩 Approximate Extent of Wetland Areas
- Project Location
- Landfill Cover Limits
- Property Boundary

Note: MNA = Monitored Natural Attenuation
**Location depicted is approximate pending field verification*

King County

Aspect CONSULTING

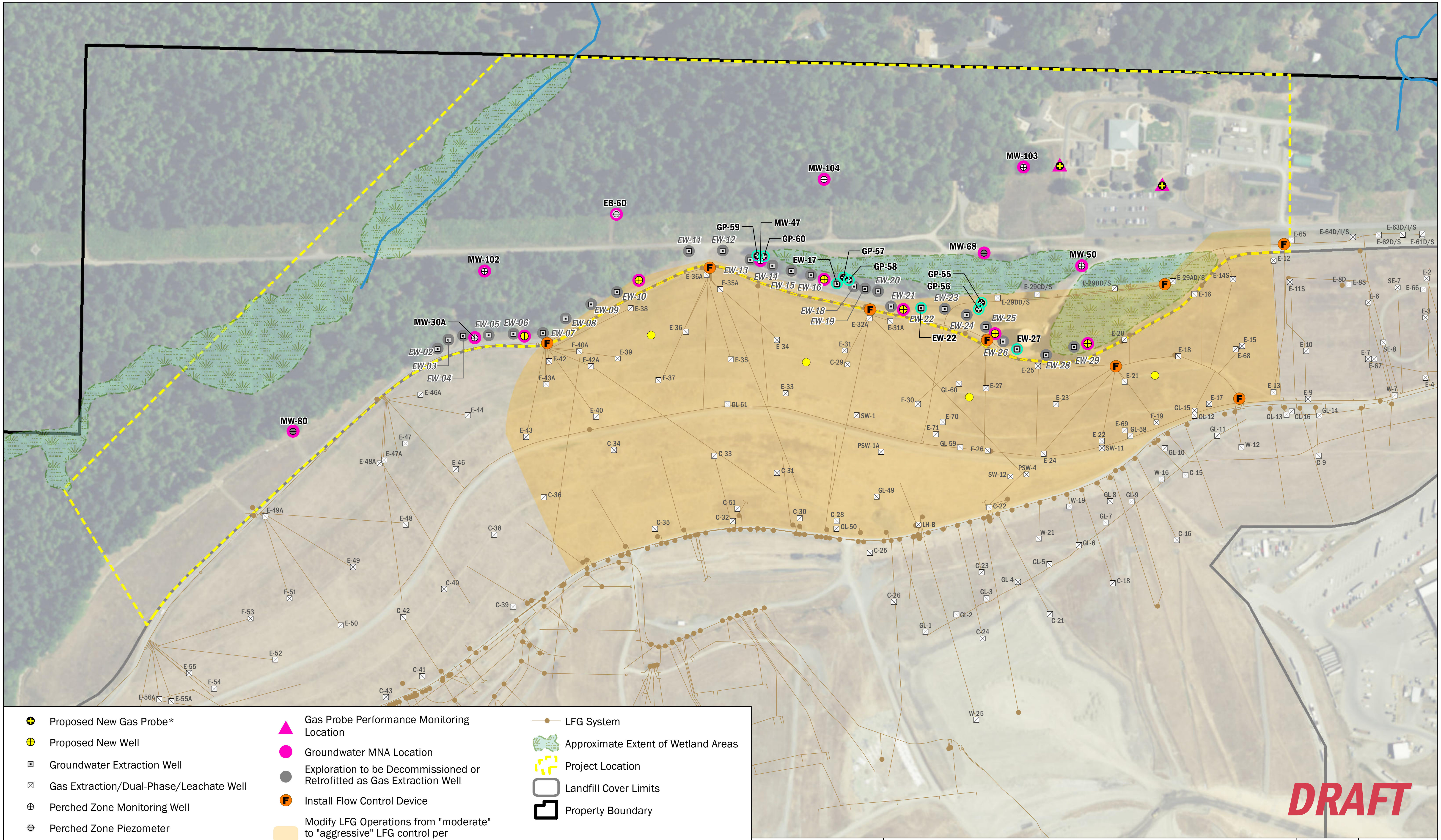
Alternative 3: Perimeter Gas Collection, Optimized LFG Control and MNA of Groundwater

Cedar Hills Regional Landfill

King County, Washington

DATE:	Nov-2016
DESIGNED BY:	DIM
DRAWN BY:	RAP
REVISED BY:	ACG / RAP
PROJECT NO.	130088
FIGURE NO.	11.3

Basemap Layer Credits | | Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



Proposed New Gas Probe*

Proposed New Well

Groundwater Extraction Well

Gas Extraction/Dual-Phase/Leachate Well

Perched Zone Monitoring Well

Perched Zone Piezometer

Regional Aquifer Monitoring Well

Gas Probe Performance Monitoring Location

Groundwater MNA Location

Exploration to be Decommissioned or Retrofitted as Gas Extraction Well

Install Flow Control Device

Modify LFG Operations from "moderate" to "aggressive" LFG control per SWANA guidance

Potential Perimeter Gas Collection Location

New LFG Collection Location
Vertical Extraction Wells Screened in Stratified Drift)

LFG System

Approximate Extent of Wetland Areas

Project Location

Landfill Cover Limits

Property Boundary

0 300 600
Feet

***Note:** New LFG Collection locations shown are preliminary; actual locations would be determined based on further characterization and Landfill constraints.*
MNA = Monitored Natural Attenuation
**Location depicted is approximate pending field verification*

King County
Aspect CONSULTING

Alternative 4: Perimeter Gas Collection, Expanded LFG Control, and MNA of Groundwater

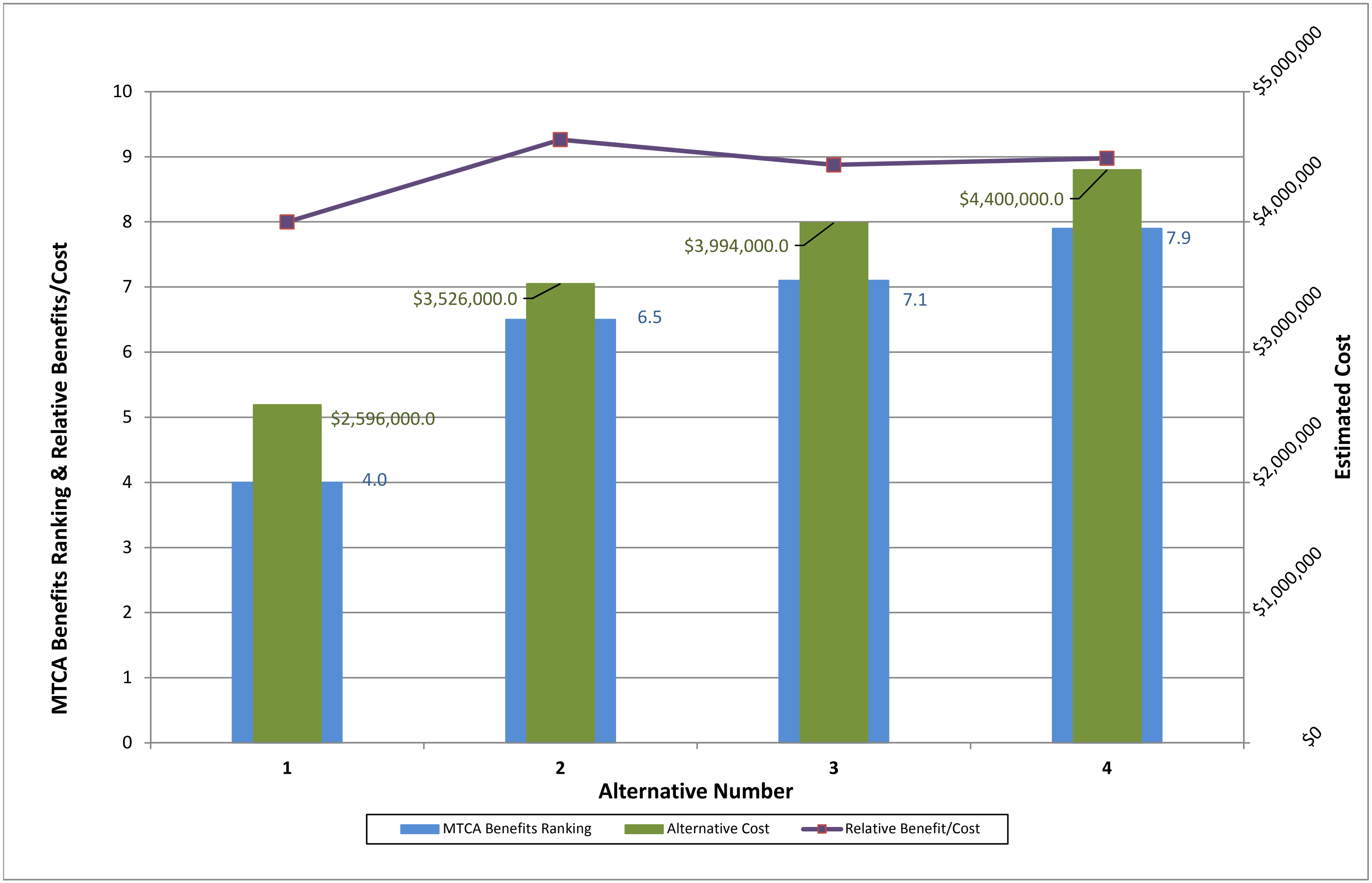
Cedar Hills Regional Landfill

King County, Washington

DATE: Nov-2016	PROJECT NO. 130088
DESIGNED BY: DIM	
DRAWN BY: RAP	FIGURE NO. 11.4
REVISED BY: ACG / RAP	

Basemap Layer Credits || Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

DRAFT



Notes:

1) Present worth costs in 2016 dollars, calculated using a discount factor of 1.2%.

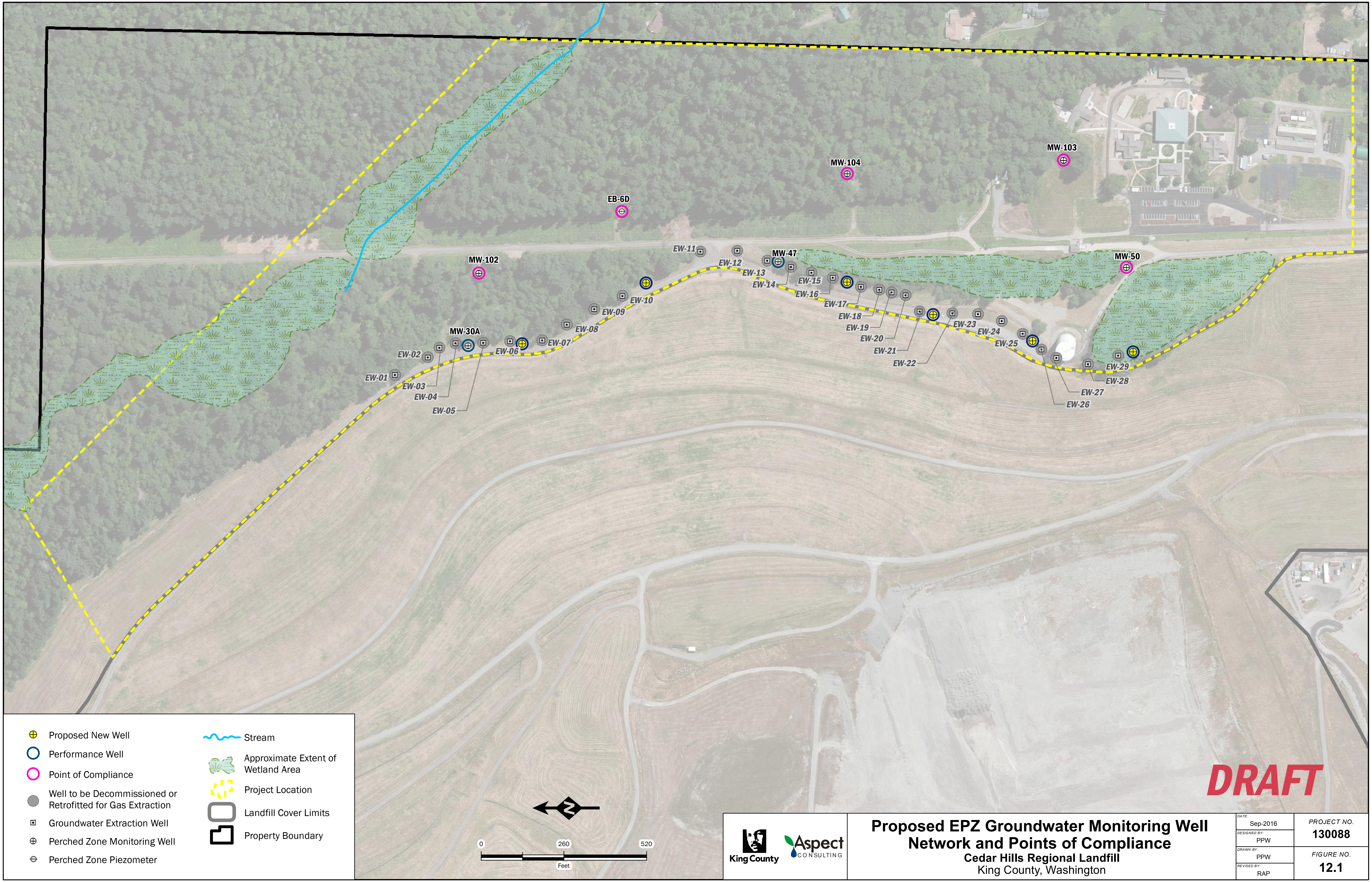
2) The benefit/cost ratio values in Table 11-2 have been multiplied by 5 to scale them appropriately to the left axis, for display purposes only.

3) Alternative 1 does not meet MTCA threshold criteria and is not considered in alternative selection (discussed in Section 11.4.5); however, is presented in the DCA for illustration purposes.

Figure 11.5
Disproportionate Cost Analysis

Remedial Investigation/Feasibility Study
CHRLF, King County, WA

Aspect Consulting
October 2016
V:\130088 KC CHRLF Env Control System Mods-E00286E12\Deliverables\RI_FS Report Agency Draft\Figures\Figure 11.5 Disproportionate Cost Analysis.xlsx



King County

Aspect CONSULTING

Proposed EPZ Groundwater Monitoring Well Network and Points of Compliance

Cedar Hills Regional Landfill

King County, Washington

DATE: Sep-2016	PROJECT NO. 130088
DESIGNED BY: PPW	
DRAWN BY: PPW	FIGURE NO. 12.1
REVISED BY: RAP	

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community