EHS–International, Inc.

# Kent Highlands Landfill Gas Evaluation
# Northwest Landfill Boundary Property Redevelopment

EHSI Project #10887

Prepared for:
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**Seattle Public Utilities**

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## ACRONYM LIST

bgs.....Below Ground Surface
BV.....By Volume (%)
CERCLA.....Comprehensive Environmental Response, Compensation, and Liability Act
EHSI.....EHS-International, Inc.
EPA.....Environmental Protection Agency
GP.....Gas Monitoring Probe
GW.....Gas Extraction Well
HASP.....Health and Safety Plan
ID.....Identification
IDW.....Investigation-Derived Waste
LEL.....Lower Explosive Limit
MBV.....Methane (%) By Volume
MTCA.....Model Toxics Control Act
NPL.....National Priority List / Superfund Site
QA.....Quality Assurance
Qal.....Quaternary Alluvial Deposits
QC.....Quality Control
Qpfc.....Quaternary Pre-Fraser Age Coarse-grained Deposits
Qva.....Quaternary Vashon Advance Outwash Deposits
Qvi.....Quaternary Vashon Ice Contact Deposits
Qvt.....Quaternary Vashon Till Deposits
RI/FS.....Remedial Investigation/Feasibility Study
SAP.....Sampling and Analysis Plan
SPU.....Seattle Public Utilities
wc.....Water Column

# 1.0 EXECUTIVE SUMMARY

EHS-International, Inc. (EHSI) has prepared this Gas Evaluation in association with Parametrix for the City of Seattle Public Utilities (SPU) for the drilling and installation of gas probes near the former SPU Kent Highlands Landfill located on City of Seattle (City) property near Veterans Drive and Military Road South in Kent, Washington (Figure 1). The neighboring property to the north of the landfill has recently undergone redevelopment. North of Veterans Drive the property has been redeveloped into residential apartments and the City of Kent property adjacent north of the landfill and south of the roadway will be developed in the future. The purpose of this Gas Evaluation is to determine background information surrounding the site, document existing information to justify location and completion depths of the new gas probes, record the construction details of the new gas probes, and evaluate whether landfill gas is being captured by the current gas extraction system.

Figure 2 displays the location of the new gas probe, KGP-200, on the northern margin of landfill outside the refuse area, and the location of surrounding historical and existing wells and boreholes. EHSI utilized the subsurface information from these data points to determine the projected drilling sequence at the new gas probe location. Figure 3 displays a cross section (A-A') running west to east across the study area. Figure 4 displays a cross section (B-B') running south to north across the study area.

Based on the data from the existing wells and boreholes, KGP-200 was planned for three gas probes to be drilled and constructed for monitoring shallow, middle and deep landfill gas. On March 13, 14, 15, and 16, the three gas probes were completed using a sonic drilling rig. The deep probe was drilled to 140 feet below ground surface (bgs) and constructed with a screened interval from 118 to 138 feet bgs. The middle probe was drilled to 50 feet bgs and constructed with a screened interval from 39 to 49 feet bgs. The shallow probe was drilled to 15 feet bgs and constructed with a screened interval from 10 to 15 feet bgs.

The details of gas monitoring during drilling and subsequent landfill gas monitoring show the existing gas extraction system on the northwest landfill margin is effective at preventing landfill gas migration off-site.

# 2.0 INTRODUCTION

This Gas Evaluation was prepared for the drilling and installation of additional gas probes at the SPU Kent Highlands Landfill located on City property near Veterans Drive and Military Road South in Kent, Washington (Figure 1). The Kent Highlands Landfill is a closed landfill with a landfill gas collection and monitoring system involving gas extraction wells and gas monitoring probes. The property to the north of the landfill has been partially redeveloped for residential use and future commercial use is also likely.

Washington State Department of Ecology (Ecology) has requested SPU to install additional gas probes to evaluate the potential of landfill gas migration near the new property redevelopment. The purpose of this Gas Evaluation is to summarize background conditions at the site, document the construction details of the new gas probes, and evaluate the current landfill gas extraction system effectiveness to prevent gas migration towards the neighboring redevelopment. The details of the new gas probe location (KGP-200) and surface features of the site are shown on Figure 2.

The Gas Evaluation describes sampling and analysis protocols for completion of gas probes to evaluate landfill gas migration potential in a safe and effective manner while accomplishing the goals of the investigation.

This includes:

- Determine the background subsurface geology with respect to potential contaminant and gas migration
- Determine areas where potential landfill gases may be encountered
- Refine subsurface gas interpretations based on new and existing probes and historical data
- Review existing data from gas extraction system and perimeter gas monitoring probes
- Evaluate gas migration near the new residential development with respect to the new and existing probes
- Determine if gas extraction wells are located properly for mitigation of gas migration
- Recommend any mitigation measures, if necessary
- Prepare and implement a health and safety plan (HASP) to ensure landfill gases do not pose a danger to the site workers

## 2.1 Site Description

The landfill encompasses approximately 113 acres of land located on the hillside and upland just west of the Green River Valley (Figure 1). The landfill is composed of King County parcel numbers 726020115, 1522049066, 1522049008, 1522049007, 1522049012, 002000001, 002000005, 002000010, 002000012, and 002000022. The landfill occupies a historical natural ravine that extended from the Des Moines upland easterly towards the Green River Valley floor. The elevation of the study area near the landfill ranges from 325 feet down to 35 feet above sea level.

SPU utilized the landfill from 1968 to 1986 mainly for disposal of domestic/municipal garbage; however, from 1983 to 1986 disposal of industrial waste and construction debris also occurred. The Site was placed on the National Priorities List (NPL) in 1990 under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The U.S. Environmental Protection Agency (EPA) reached an agreement with Ecology to be lead agency overseeing cleanup actions, and subsequently cleanup at the site has been performed under the regulations presented in the Model Toxics Control Act (MTCA).

Prior environmental reports and cleanup action summaries are presented in:

- Golder Associates, 1982, Draft Report Geotechnical and Hydrological Investigation for the Midway and Kent Highlands Landfill Closures
- Parametrix Inc., 1987, Kent Highlands Landfill Closure Plan
- CH2MHill, 1991, Kent Highlands Landfill Remedial Investigation Report
- CH2MHill, 1992, Kent Highlands Landfill Closure Action Report
- Parametrix Inc., 1993, Final Kent Highlands Landfill Closure and RI/FS
- CH2MHill, 1995, Kent Highlands Landfill Spring Drain Separation
- CH2MHill,1996, Kent Highlands Landfill Groundwater Compliance Monitoring Plan
- CH2MHill, 1996, Kent Highlands Landfill 1996 Groundwater Monitoring Report
- CH2MHill, 1996, Kent Highlands Landfill Post-Closure Operations and Maintenance Manual
- Clayton Environmental Consultants, Inc., 1999, Kent Highlands Landfill Site Health and Safety Plan
- Parametrix Inc., 2000, Technical Memorandum – Installation of Landfill Gas Probes and Gas Extraction Wells, Kent Highlands Landfill
- Ecology, 2003, 2nd Periodic Review for the Kent Highlands Landfill Site
- Ecology, 2009, Periodic Review for the Kent Highlands Landfill

- Ecology, 2014, Fourth Periodic Review 2009-2013 for the Kent Highlands Landfill
- Parametrix Inc., 2015, Kent Highlands Landfill Five-Year Groundwater Monitoring Summary (2009-2013)
- City of Seattle, 2016, Kent Highlands Quarterly Gas Monitoring Results

The current project is related to the recent redevelopment occurring just north of the landfill (Figure 1). Veterans Drive borders the northern portion of the landfill site near the northwest corner of the former landfill (near KGP-32A, Figure 2). The portion of the landfill that is the focus of this investigation is the northwestern-most portion of King County parcel 1522049007. The City of Kent owns an adjoining parcel north of the landfill and south of Veterans Drive (King County Parcel number 1522049170). A residential redevelopment known as the Grandview Apartments is adjoining north of Veterans Drive. The property is addressed 3900 Veterans Drive, Kent, Washington and is listed as owned by the Grandview Apartments LLC (Figure 1).

SPU operates and maintains a landfill gas extraction and monitoring system. Gas extraction wells (labeled GW wells, i.e. KDGW-98, red wells on Figure 2) with screens at varying intervals remove landfill gas through a vacuum pressure system and release it at controlled flare locations. Landfill gas, including methane concentrations, are monitored monthly. Additionally, SPU operates perimeter landfill gas monitoring probes (labeled GP wells, i.e. KDGP-98, green wells on Figure 2) located on the outside of the gas extraction wells along the property boundary. These gas probes are similarly screened at varying intervals to monitor for escaped landfill gas, and are monitored monthly. Quarterly reports are submitted to Ecology.

## 2.2 History of Development

SPU historically operated several gas monitoring probes (KGP-32, KGP-38, KGP-39, KGP-41, KGP-42, KGP-43, and KGP-45) north of the current property boundaries from approximately 1990 through 2005 (Figure 2). These probes were decommissioned around 2005 due to road construction associated with Veterans Drive. Two probes remain active north of Veterans Drive (KGP-44 and KGP-46). In 2005, construction began on Veterans Drive just north of the subject property. In 2006, the overpass for Riverview Boulevard over Veterans Drive was completed. By 2007, Veterans Drive was completed from Military Road (west of the site) down the hill east to Russell Road and across the Green River (Figure 1). By 2009, Riverview Boulevard was completed from the overpass/onramp at Veterans Drive northwards. By June 2016, construction began on the neighboring Grandview Apartments property north across Veterans Drive (Figures 1 and 2). The adjoining City of Kent property south of Veterans Drive remains undeveloped through the present.

# 3.0 BACKGROUND CONDITIONS

## 3.1 Geologic Conditions

As discussed above, the subject property is located on the hillside stemming from the Des Moines upland east and downslope to the Green River Valley (Figure 1). As discussed above, man-made filling of a natural ravine on the hillside occurred from 1968 to 1986. The native surface geology of the subject property is mapped as several different geologic units correlating somewhat with topography. Booth & Waldron (2004) map the upland surface geology of the subject property primarily composed of Quaternary Vashon Till (Qvt) deposits. Lower in elevation, the Qvt directly overlies Quaternary Vashon Advance Outwash (Qva) deposits. Quaternary Pre-Fraser Coarse Grained (Qpfc) deposits are mapped below the Qva at further lower elevations along the historical ravine. At the base of the upland, Quaternary Vashon Ice-

contact (Qvi) deposits are mapped, and at the base of the Green River Valley are Quaternary Alluvial (Qal) deposits. Summaries of the units and their depositional sequence are presented below.

- Man-made fill deposits / landfill refuse deposited at the landfill from 1968 to 1986
- Qal unit is the youngest geologic deposits being composed of sand, silt, gravel, and clay generally deposited by active channel, flood, and overbank deposits of the Green River.
- Qvi deposits are composed of silty sand and gravel stemming from the retreat and end of the Vashon Stade of the Fraser Glaciation which occurred approximately 12,000 years ago. As such, the unit is generally associated with Vashon Recessional Outwash (Qvr) sand and gravel deposits; however, the Qvi was likely in direct contact with the recessional ice margin and thus has a higher silt content.
- Qvt deposits are composed of silt-bound to clay-bound sand and gravel deposits stemming from deposition emanating from the glacial ice sheet occurring during the Vashon Stade of the Fraser Glaciation (approximately 15,000 years ago). These deposits are semi-consolidated and generally serve as a local confining layer for infiltrating groundwater.
- Qva deposits are composed of well stratified sand and gravel deposits stemming from the outwash waters of the advance of the glacial ice sheet during the Vashon Stade of the Fraser Glaciation (more than 15,000 years ago). Due to its coarse-grained nature, the Qva generally contains the regional shallow aquifer.
- Qpfc deposits are composed of weakly to moderately oxidized sand and gravel deposits stemming from a Pre-Fraser age glacial period occurring between the Fraser Glaciation and the Olympia-age nonglacial period (approximately 15,000 to 70,000 years ago). In areas of weak oxidation, the unit may be indistinguishable from the overlying Qva deposits. Groundwater in the unit may also be in hydraulic continuity with Qva deposits forming the regional shallow aquifer.

## 3.2 Hydrogeologic Conditions

The nature of the geologic units and their depositional sequence is important for understanding contaminant and gas migration from the landfill site. Prior environmental investigations show the subsurface geology of the landfill site is complex with perched groundwater zones in addition to the regional confining layers and aquifers. Previous landfill studies have delineated the geologic units of the area into site specific hydrostratigraphic units including: The Landfill Aquifer, Recent Alluvium Aquitard, Recent Alluvium Aquifer, Upper Outwash Aquifer, Middle Outwash Aquifer, Lower Outwash Aquifer, Upper Silt Aquitard, Sand Aquifer, Lower Silt Aquitard, and the Gravel Aquifer. A description of the hydrostratigraphic units is included below:

- The Landfill Aquifer is the uppermost hydrostratigraphic unit and is comprised of perched groundwater and leachate in the fill deposits of the landfill. The area of the proposed gas probes is anticipated to be just north of the fill deposits of the landfill.
- The Recent Alluvium Aquitard is fine-grained silt deposits occurring near land surface within the Green River Valley. This unit serves as a confining layer for the underlying Recent Alluvium Aquifer. The location of the unit is downslope to the east and away from the proposed gas probes.
- The Recent Alluvium Aquifer is composed of water-bearing fine- to coarse-grained sand, silty sands, and sandy silts occurring within the alluvial deposits of the Green River Valley. The unit

is reported up to 100 feet thick in the study area. The location of the unit is downslope to the east and away from the proposed gas probes.

- The Upper Outwash Aquifer is composed of perched groundwater occurring within the sand and silty gravels. Groundwater within the upper outwash aquifer is generally within 20 feet of land surface where it is present.
- The Middle Outwash Aquifer is composed of water-bearing zones within finer-grained silty sand and silt deposits occurring in the middle of the outwash sand unit. This unit is generally a low permeability unit that primarily serves as a confining and/or perching layer as groundwater present in the unit is mostly comprised of thin discontinuous zones.
- The Lower Outwash Aquifer is composed of water-bearing zones of silty and sandy gravel in the lower end of the outwash sand unit. The unit is generally unconfined on the northern portion of the landfill near the proposed gas probes; however, is confined at other areas of the landfill. This hydrostratigraphic unit generally forms the regional shallow aquifer of the Des Moines Upland.
- The Upper Silt Aquitard is composed of low permeability silt, silty clay, and sandy silt occurring beneath the outwash sands. The unit varies in thickness from 30 to 100 feet, but is a prominent hydrostratigraphic marker in the subsurface sequence due to its confining layer properties.
- The Sand Aquifer occurs below the Upper Silt Aquitard and is comprised of sand to sand and gravel. This unit serves as the regional intermediate aquifer of the Des Moines Upland and underlies nearly the entire study area. Near the Green River Valley, the unit is in hydraulic continuity with the Recent Alluvium Aquifer.
- The Lower Silt Aquitard is a relatively thin unit of clayey silt, silt, and silty gravel occurring within nonglacial deposits below the sand aquifer. This low permeability unit serves as a confining layer and was generally encountered on the easternmost portion of the landfill site away from the proposed gas probes.
- The Gravel Aquifer is composed of sand and sandy gravel occurring below the easternmost portion of the landfill site away from the proposed gas probes. This unit is a 30-50-foot sequence of nonglacial sand and gravel deposits that likely serve as the regional sea level aquifer below the Des Moines Upland.

## 3.3 Background Landfill Gas Conditions

We have reviewed and organized existing subsurface data from previous reports. The data points near the new gas probes have been plotted on Figure 2. A total of 37 well logs were reviewed in detail to evaluate subsurface conditions near the new gas probes. Copies of the available well logs are attached in Appendix A. Due to the age of some of the studies, the data points were evaluated for quality regarding site location, geologic detail, and correspondence to nearby data locations and maps. Outliers and non-corresponding data points were flagged for potential failures in quality integrity (poor well log information, little or no geologic details, poor location quality, etc.). The data has been delineated into three primary data sets: groundwater monitoring wells, gas extraction wells, and gas monitoring probes, as presented below. Table A1, included in Appendix A, displays the details of each of the data points surrounding the proposed gas probes. Tables A2, A3, A4, and A5 located in Appendix A delineate the well log types into boreholes (A2), gas extraction wells (A3), gas monitoring probes (A4) and groundwater monitoring points / wells (A5). Historical landfill gas observations were reported in Percent (%) Methane by volume (MBV) or in percent combustible gas by volume. Methane is approximately 44.0 to 53.4% of the landfill gas by volume (CH2MHill 1991). For the purposes of this landfill Gas Evaluation we are conservatively estimating that all the historical combustible gas measured during historical observations

were methane. The Lower Explosive Limit (LEL) for methane is 5% by volume. For the landfill to be in compliance, gas concentrations at the landfill boundary must not exceed the LEL for methane (Ecology, 2003). Many of the historical observations presented in the tables below were made prior to the start of the initial landfill gas control system (ca. 1986) and the current landfill gas extraction system (completed around 1990-1991).

### 3.3.1 Nearby Groundwater Monitoring Points

Six well and probe locations (KPZ-2B, KMW-7A, KMW-7B, KGP-38CD, KDGW-94A, and KDGW-94B) near the new gas probes have been historically used to monitor groundwater levels. Figure 2 shows the location of these monitoring points. Three of those locations have multiple monitoring depths. Table 1, below, summarizes the well log data for each of the existing groundwater monitoring points.

**Table 1: Groundwater Monitoring Point Details**

| Location ID | Land Elev. (feet) | Screen Interval (feet bgs) | Notes on Methane Concentrations from Drilling (year of completion/observations) |
|---|---|---|---|
| KPZ-2B | 305.2 | 280-285 | NA (1982) |
| KMW-7A | 253 | 155-165 | 1.75% MBV at 30' bgs, 0.25% MBV at 50' bgs, 1% to 1.75% MBV from 55' to 70' bgs, 0.25% MBV at 80' bgs, 0.25% MBV at 110' bgs, >5% MBV from 120' to 130' bgs, 3.75% MBV at 135' bgs, >5% MBV at 143' bgs, 1% to 2% MBV from 145' to 165' bgs (1990) |
| KMW-7B | 253 | 240-250 | Same as KMW-7A, but None Detected >170' bgs (1990) |
| KGP-38CD* | 300.5 | NA | Not recorded during drilling (2004) |
| KDGW-94A | 261.3 | 26-74 | None Detected (1990) |
| KDGW-94B | 259.2 | 108-148 | None Detected (1990) |

NA – Not Available *KGP-38CD is the deep probe located at KGP-38B

As noted in the table, methane gas was detected in KMW-7A above 5% MBV from 120 to 130 feet and at 143 feet at the time of drilling in 1990. Methane was also detected below 5% BV at 30 feet, 50 feet, 55 to 70 feet, 80 feet, 110 feet, 135 feet, and 145 to 165 feet bgs. The reported methane concentrations in KMW-7A at the time of drilling were significant compared to other monitoring wells.

Water levels reported in the 2009-2013 groundwater monitoring summary report (Parametrix, 2015) for the five well locations (Figure 2) are presented in Table 2, below. The water levels presented in the report show a general west to east gradient following topography for the Sand Aquifer.

**Table 2: Groundwater Monitoring Points - Recent Water Level Information**

| Location ID | Land Elev. (feet) | Screen Interval (feet bgs) | WL Elevation 2/23/2009 | WL Elevation 8/3/2009 | WL Elevation 8/30/2010 | WL Elevation 8/29/2011 | WL Elevation 9/4/2012 | WL Elevation 9/9/2013 |
|---|---|---|---|---|---|---|---|---|
| KPZ-2B | 305.2 | 280-285 | 150.88 | 156.81 | 157.69 | 160.21 | 160.13 | 159.10 |
| KMW-7A | 253 | 155-165 | 116.81 | 116.356 | 116.77 | 117.86 | 117.81 | 117.74 |
| KMW-7B | 253 | 240-250 | 114.84 | 114.80 | 115.24 | 116.34 | 116.00 | 115.77 |
| KGP-38CD* | 300.5 | 196x | 141.83 | 141.49 | 142.18 | 145.33 | 143.53 | 141.13 |

| Table 2: Groundwater Monitoring Points - Recent Water Level Information | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Location ID** | **Land Elev. (feet)** | **Screen Interval (feet bgs)** | **WL Elevation 2/23/2009** | **WL Elevation 8/3/2009** | **WL Elevation 8/30/2010** | **WL Elevation 8/29/2011** | **WL Elevation 9/4/2012** | **WL Elevation 9/9/2013** |
| KDGW-94B | 259.2 | 108-148 | 121.82 | 121.61 | 121.87 | 123.51 | 123.39 | 122.98 |

X – Estimated based on limited details, WL – Water Level, *KGP-38CD is the deep probe located at KGP-38B

The data presented in the table show consistent water levels over the period of several years suggesting minimal annual changes in the Sand Aquifer.

There are three historical groundwater monitoring wells (KPZ-1, KPZ-2A, and KMW-6) that are no longer present near the new gas probes. These wells were located on the northern margin of the landfill and later abandoned/ decommissioned as they became obsolete with respect to the overall study (Figure 2). Table 3, below, displays the historical completion and water level information from the wells.

| Table 3: Historical Groundwater Monitoring Wells | | | |
|---|---|---|---|
| **Location ID** | **Land Elev. (feet)** | **Screen Interval (feet bgs)** | **WL Elevation (Year)** |
| KPZ-1 | 269 | 220-270 | 159.6 (1977) |
| KPZ-2A | 305.2 | 118-123 | NA (1982) |
| KMW-6 | 326.7 | 102-132 | 229.3 (1990) |

WL – Water Level

No methane data are available for either of these wells from their respective well logs.

### 3.3.2 Nearby Gas Extraction Wells

There are eleven nearby gas extraction wells (KDGW-94A, KDGW-94B, KDGW-95, KDGW-96, KDGW-97, KDGW-97A, KDGW-98, KSGW-99, KSGW-101, KDGW-101, and KDGW-102) currently being utilized to remove subsurface methane near the new gas probes. These wells collect and extract landfill gas to ensure minimal off-site migration on the northern perimeter of the landfill. Figure 2 displays the location of these wells along the northern landfill margin. Table 4 summarizes the completion zones for each of the wells and notes on methane encountered during drilling in 1990.

| Table 4: Landfill Gas Extraction Wells | | | |
|---|---|---|---|
| **Location ID** | **Land Elev. (feet)** | **Screen Interval (feet bgs)** | **Notes on Methane Concentrations from Drilling (year of completion/observations)** |
| KDGW-94A | 261.3 | 26-74 | None Detected (1990) |
| KDGW-94B | 259.2 | 108-148 | None Detected (1990) |
| KDGW-95 | 264.1 | 27.5-82.5 | None detected (1990) |
| KDGW-96 | 268.7 | 30-90 | >5% MBV at 30’ & 80’ bgs, 3% MBV at 60 & 70’ bgs, 2% MBV at 90’ bgs (1990) |
| KDGW-97 | 280 | 30-90 | >5% MBV at 70’ bgs (1990) |

| Table 4: Landfill Gas Extraction Wells | | | |
|---|---|---|---|
| **Location ID** | **Land Elev. (feet)** | **Screen Interval (feet bgs)** | **Notes on Methane Concentrations from Drilling (year of completion/observations)** |
| KDGW-97A | 280 | 95-145 | NA (1990) |
| KDGW-98 | 283.4 | 26-75 | >5% MBV at 40 to 50' bgs (1990) |
| KSGW-99 | 291.8 | 10-35 \| 45-50 | None detected (1990) |
| KSGW-101 | 299.7 | 11-26 | None detected (1990) |
| KDGW-101 | 299.9 | 87-102 | None detected (1990) |
| KDGW-102 | 300.4 | 80-100 | None detected (1990) |

NA – Not Available MBV = Methane by Volume (Note KDGW-94A/94B also in Table 1)

As shown in the table, three of the gas extraction wells encountered methane concentrations above 5% BV during drilling in 1990. These occurred most notably at 30 feet bgs at KDGW-96, 40 to 50 feet bgs at KDGW-98, at 80 feet bgs in KDGW-96, and at 70 feet bgs at KDGW-97. Methane was also encountered ranging from 2% to 3% BV in KDGW-96 at 60 feet, 70 feet, and 90 feet bgs.

### 3.3.3 Nearby Gas Probes and Borings

There are nine gas monitoring probes (KGP-1, KGP-14, KGP-15, KGP-16A, KGP-32A, KGP-38B, KGP-44, KGP-46, and KDGP-98) near the new gas probes on the northern margin of the landfill (Figure 2). The existing gas monitoring probes are completed with individual shallow (S), middle (M), and deep (D) screens. Table 5, below, summarizes the details of the monitoring probes and notes of methane or combustible gas concentrations from the drilling in 1984, 1990, 1991, 1999, and 2004, and gas monitoring completed between 1989 and 1991.

| Table 5: Gas Monitoring Probes | | | | |
|---|---|---|---|---|
| **Location ID** | **Probe Interval** | **Land Elev. (feet)** | **Screen Interval (feet bgs)** | **Notes on Methane Concentrations from Drilling or Completed Probes (year of completion/observations)** |
| KGP-1-S | Shallow | 305 | 9-11 | NA (1984), 0-2% BV ('89-'91) |
| KGP-1-M | Middle | 305 | 63-65 | NA (1984), 12-22% BV ('89-'91) |
| KGP-1-D | Deep | 305 | 88-90 | NA (1984), 50-100% BV ('89-'91) |
| KGP-14-M | Middle | 255 | 71.5-73 | NA (1984), 8-32% BV ('89-'91) |
| KGP-14-D | Deep | 255 | 100.5-101 | NA (1984), 40-75% BV ('89-'91) |
| KGP-15-S | Shallow | 270 | 21-22 | NA (1984), 40-75% BV ('89-'91) |
| KGP-15-M | Middle | 270 | 51-52 | NA (1984), 0-9% BV ('89-'91) |
| KGP-15-D | Deep | 270 | 171-172 | NA (1984), 0-15% BV ('89-'91) |
| KGP-16A-S | Shallow | 278 | 18-23 | NA (1999) |
| KGP-16A-M | Middle | 278 | 40-50 | NA (1999) |
| KGP-16A-D | Deep | 278 | 96-136 | NA (1999) |
| KGP-32A-S | Shallow | 305 | 4-20 | NA (2004) |
| KGP-32A-M | Middle | 305 | 16-43 | NA (2004) |
| KGP-32A-I | Intermediate | 305 | 55-75 | NA (2004) |

| Table 5: Gas Monitoring Probes | | | | |
|---|---|---|---|---|
| **Location ID** | **Probe Interval** | **Land Elev. (feet)** | **Screen Interval (feet bgs)** | **Notes on Methane Concentrations from Drilling or Completed Probes (year of completion/observations)** |
| KGP-32A-D | Deep | 305 | 80-103 | NA (2004) |
| KGP-38B-S | Shallow | 280 | 10-20 | NA (2004) |
| KGP-38B-M | Middle | 280 | 30-50 | NA (2004) |
| KGP-38B-D | Deep | 280 | 140-170 | NA (2004) |
| KGP-44-S | Shallow | 285 | 9-24 | None detected after completion (1991) |
| KGP-44-M | Middle | 285 | 30-55 | None detected after completion (1991) |
| KGP-46-S | Shallow | 288 | 9-19 | None detected after completion (1991) |
| KGP-46-M | Middle | 288 | 27-37 | None detected after completion (1991) |
| KDGP-98-S | Shallow | 280.3 | 15-30 | None detected during drilling (1990) |
| KDGP-98-M | Middle | 280.3 | 42.5-72.5 | >5% MBV at 40 to 50' bgs (1990) |
| KDGP-98-D | Deep | 280.3 | 85-90 | None detected during drilling (1990) |

NA – Not Available

Four older gas monitoring probes KGP-1, KGP-14, KGP-15, and KGP-98 all encountered methane during drilling or in completed probes. Two older gas monitoring probes that are currently north of Veterans Drive, KGP-44 and KGP-46, had no detections of methane following completion. The newer probes KGP-16A, KGP-32A, and KGP-38B, did not have methane detections reported during drilling; however, these wells were completed after the startup of the landfill gas extraction system.

Additionally, there are ten historical gas monitoring probes (B1, KGP-14 S, KGP-16, KGP-32, KGP-38A, KGP-39, KGP-41, KGP-42, KGP-43, and KGP-45) on the northern margin of the landfill and further north below the area of the neighboring Grandview Apartments that contain shallow, middle, and deep screen intervals (Figure 2). Table 6, below, summarizes the historical screen information and notes on methane concentrations encountered during drilling from the logs.

| Table 6: Historical Gas Monitoring Probes | | | | |
|---|---|---|---|---|
| **Location ID** | **Probe Interval** | **Land Elev. (feet)** | **Screen Interval (feet bgs)** | **Notes on Methane Concentrations from Drilling or Completed Probes (year of completion/observations)** |
| B1 | NA | 280 | NA | NA (2004) |
| KGP-14-S | Shallow | 255 | 12-13 | 0-10% BV ('89-'91) |
| KGP-16-S | Shallow | 290 | 18.5-20 | 44-49% BV ('89-'91) |
| KGP-16-M | Middle | 290 | 54.5-56 | 42-44% BV ('89-'91) |
| KGP-16-D | Deep | 290 | 113.5-115 | 3-51% BV ('89-'91) |
| KGP-32-S | Shallow | 324.8 | 5-20 | 0.5-4.5% BV ('89-'91) |
| KGP-32-M | Middle | 324.9 | 20-47.5 | 0.5-2% BV ('89-'91) |
| KGP-32-I | Intermediate | 324.9 | 55-77 | NA (1990) |
| KGP-32-D | Deep | 324.9 | 95-120 | 10-25% BV ('89-'91) |
| KGP-38A-S | Shallow | 300.5 | 10-30 | 0.3-3% MBV (1988) |

| Table 6: Historical Gas Monitoring Probes | | | | |
|---|---|---|---|---|
| **Location ID** | **Probe Interval** | **Land Elev. (feet)** | **Screen Interval (feet bgs)** | **Notes on Methane Concentrations from Drilling or Completed Probes (year of completion/observations)** |
| KGP-38A-M | Middle | 300.5 | 41.2-61.2 | 1.5% MBV at 45' bgs (1988), 0-3% MBV in completed probe (1989) |
| KGP-38A -D | Deep | 300.5 | 176-181 | 0-0.42% MBV (1989) |
| KGP-39-S | Shallow | 268.3 | 10-20 | 2.2% MBV at 10' bgs, 1.5% MBV at 20' bgs (1989), 17.5-58% BV in completed probe ('89-'91) |
| KGP-39-M | Middle | 268.3 | 35-55 | 1% to 4.5% MBV at 30 to 55' bgs (1989), 46-83% BV in completed probe ('89-'91) |
| KGP-39-D | Deep | 268.3 | 120-160 | 3.5% MBV in completed probe, 4% to >5% MBV from 120' to 140' bgs, 0.25% to 2.5% MBV from 165' to 175' (1989), 5-90% BV in completed probe ('89-'91) |
| KGP-41-M | Middle | 277 | 45-55 | 0.5% MBV in completed probe (1991) |
| KGP-41-D | Deep | 277 | 178-190 | 0.005% MBV in in completed probe (1991) |
| KGP-42-S | Shallow | 278 | 10-26 | None detected after completion (1991) |
| KGP-42-M | Middle | 278 | 37-52 | None detected after completion (1991) |
| KGP-43-S | Shallow | 274 | 10-20 | 0.155% MBV in completed probe (1991) |
| KGP-43-M | Middle | 274 | 29-39 | 0.06% MBV in completed probe (1991) |
| KGP-43-D | Deep | 274 | 66-76 | None detected after completion (1991) |
| KGP-45-S | Shallow | 278 | 12-26 | None detected after completion (1991) |
| KGP-45-M | Middle | 278 | 40-50 | None detected after completion (1991) |

NA – Not Available

One historical gas probe, KGP-39, completed near Veterans Drive just south of the Grandview Apartments (Figures 1 and 2) had concentrations of methane detected during drilling or in the completed probes above 5% methane BV as shown in Table 6. All three completed probes (shallow, middle, and deep) from KGP-39 were reported to have greater than 5% methane BV. KGP-32 located further west on Veterans Drive (Figure 2) historically had methane concentrations greater than 5% BV only in the deep gas probe. The shallow gas probe from KGP-32 had concentrations up to 4.5% BV, just below the LEL. The shallow probe from KGP-14 and shallow, middle, and deep probes from KGP-16 all historically recorded methane concentrations greater than 5% BV, however these wells are much closer to the northern margin of the landfill (Figure 2). As discussed further below, the recent gas monitoring and gas extraction system have shown nearly no detections of methane on the northern margin outside of the SPU property in recent monitoring.

# 4.0 SELECTION OF NEW GAS PROBE LOCATIONS

## 4.1 Location and Depth

One location on the northern margin of the site was selected for installing the new gas probes (Figure 2). Three gas probes were drilled and constructed for determining shallow, middle, and deep landfill gas. The location of the new gas probe was labeled KGP-200. (Figure 2). The three new landfill gas probes were

identified by -S (shallow), -M (middle / intermediate layer), and -D (deep). KGP-200 was drilled to a final depth of 140 feet bgs, or within the top of the Sand Aquifer. Below is a summary of the background subsurface conditions on the northern margin and near the new KGP-200 gas probe location.

## 4.2 Anticipated Subsurface Sequence

The 1991 Remedial Investigation/Feasibility Study (RI/FS) included cross-sections showing the approximate location of subsurface gas bearing zones within the hydrostratigraphic units. For the area of the new proposed gas probes, we have summarized the anticipated gas bearing zones with respect to these units as discussed further below.

The well logs near the new gas probe locations show a complex sequence of gray to brown silty sand and gravel with a perched groundwater zone around 30 feet bgs. The silty sand and gravel becomes moist below the perched groundwater then transitions back to a saturated layer above a gray silt and minor clay unit at approximately 75 to 90 feet bgs. The silt formation has a thickness of approximately 50 to 80 feet bgs with occasional coarse lenses that may contain groundwater. The silt then appears to transition into a water bearing silty sand at depth around 150 to 170 feet bgs. Gas bearing zones are anticipated in the unsaturated zones from land surface down to an elevation of approximately 150 feet above sea level. Approximately 150 feet above sea level is the equivalent elevation to the lowest elevation of the base of refuse near the new probes as presented in the 1991 RI/FS. Utilizing the 37 well logs, we developed two cross sections near the new gas probes. Figure 2 displays the location of the cross sections.

### 4.2.1 Cross Section Development and Landfill Gas Probe Depths

Figure 3 displays cross section A to A'. This stratigraphic cross section is generally east-west (Figure 2) across the study area Figure 4 displays cross section B to B'. This stratigraphic cross section is generally north-south across the study area (Figure 2). As shown on cross section A to A' (Figure 3), the Middle Outwash Aquifer is absent near the intersection with B to B' (at KGP-16A) and the Upper Outwash Aquifer and Lower Outwash Aquifer are in continuity in the vicinity of new gas probe KGP-200. On the central portion of cross section A to A' (Figure 3) the Middle Outwash Aquifer phases out between wells KDGP-98 and KGP-16A.

The base of the landfill refuse has been projected onto both cross sections. The base of the refuse is above the top of the Upper Silt Aquitard in the area of the new gas probes. The top of the Upper Silt Aquitard or the bottom of the unsaturated zone within the overlying Lower Outwash Aquifer, whichever is lower, would represent the expected lower extent of landfill gas generated from the degradation of nearby refuse.

# 5.0 GAS PROBE INSTALLATION

The gas probe was installed in accordance with the work plan that is presented in Appendix B.

Holt Services (Holt) was retained as the licensed driller for the project. On March 13, EHSI representatives met the Holt drilling crew for the start of the drilling activities. A site safety meeting was performed, the site-specific HASP and drilling specific concerns were discussed.

Sonic drilling methods were utilized to complete drilling and construction of the probes. Holt utilized a track mounted Terra Sonic TSi 150 drilling rig to drill and construct the gas probes. Samples were recovered using a 4.75-inch diameter sonic core. Holt utilized 6-inch diameter sonic core casing for conductor casing to prevent cross contamination and sidewall collapse.

On March 13 and 14, Holt drilled and constructed the deep probe (KGP-200-D). On March 14, Holt drilled and constructed the shallow probe (KGP-200-S). On March 15, Holt drilled and constructed the middle probe (KGP-200-M). On March 16, Holt constructed the above ground monuments and steel bollards for each of the three probes. Geologic well and construction logs for the three probes are attached in Appendix C.

## 5.1 Stratigraphy

The subsurface geology encountered matched closely with the neighboring probe and well locations. From land surface down to approximately 14 to 16 feet bgs, drilling encountered brown silty fine to medium sand and gravel with the bottom one foot having a perched water table. This unit is typical of the Upper Outwash Aquifer. From approximately 14 to 16 feet bgs down to 36 to 43 feet below ground surface, drilling encountered layers of brown silt-bound sand and gravel, brown silty sand and gravel, brown fine to medium sand, and tan silt layers with two zones of saturation in the silt layers. This unit appears typical of the Middle Outwash Aquifer which was not anticipated to be encountered at KGP-200 based on the nearby well logs. From approximately 36 to 43 feet bgs down to 61 feet below ground surface, drilling encountered brown to gray silty sand and gravel to gray silt-bound sand and gravel with the bottom five feet being saturated. This unit is typical of the Lower Outwash Aquifer. From 61 feet bgs down to 118 feet bgs, drilling encountered gray silt with minor layers of sandy silty and clayey silt. This unit is typical of the Upper Silt Aquitard. From 118 feet bgs down to 140 feet bgs (bottom of the borehole) drilling encountered brown fine to medium sand with occasional gravel and the bottom three to six feet of the zone is water bearing. This unit is typical of the Sand Aquifer.

## 5.2 Gas Monitoring During Drilling

During drilling, EHSI monitored landfill gas using a Landtec Gem2000 plus landfill gas meter and MiniRAE 300 photoionization detector (PID). The landfill gas meter was used to determine safe working conditions and to field screen the sample cores for landfill gas. Methane was detected in several sample cores from KGP-200-D. Methane was not detected in cores from KGP-200-S or KGP-200-M. Table 7, below, summarizes the methane detections in the sample cores. No volatile organic compounds (VOCs) were detected with the PID.

**Table 7: Methane Detections in Sample Cores from KGP-200-D**

| Sample Depth(s) | Methane concentrations |
|---|---|
| 0 – 23 feet bgs | None detected |
| 23 – 25 feet bgs | 0.2% Methane by volume |
| 26 – 28 feet bgs | 0.7% Methane by volume |
| 28 – 30 feet bgs | 0.3% Methane by volume |
| 30 – 34 feet bgs | 0.1% Methane by volume |
| 34 – 36 feet bgs | 0.3% Methane by volume |
| 36 – 37 feet bgs | None detected |
| 37 – 38 feet bgs | 0.7% Methane by volume |
| 38 – 40 feet bgs | 0.6% Methane by volume |
| 40 – 43 feet bgs | None detected |
| 43 – 46 feet bgs | 0.5% Methane by volume |
| 46 – 140 feet bgs | None detected |

During the project:

- No work stoppages occurred due to excessive landfill gas
- Methane was detected in several recovered core samples but at levels less than 1% methane
- Methane was detected at the borehole head at two intervals from KGP-200-D (30 and 40 feet bgs) but at levels of 0.1% Methane by volume
- No hydrogen sulfide, carbon dioxide, or VOCs were detected in the recovered core samples or at the borehole head.

## 5.3 Probe Construction

Following drilling of three boreholes at the KGP-200 location, shallow, middle, and deep gas probes were constructed utilizing ¾-inch diameter Schedule 80 PVC with 0.010-inch slot PVC screens:

KGP-200-S

- Screened interval from 10 to 15 feet bgs
- Pea gravel pack from 8 to 15 feet bgs
- Hydrated bentonite from 2 to 8 feet bgs
- Concrete from 0 to 2 feet bgs
- 3-foot stickup steel monument and 3 bollards

KGP-200-M

- Screened interval from 39 to 49 feet bgs
- Pea gravel pack from 37 to 50 feet bgs
- Hydrated bentonite from 2 to 37 feet bgs
- Concrete from 0 to 2 feet bgs
- 3-foot stickup steel monument and 3 bollards

KGP-200-D

- Screened interval from 118 to 138 feet bgs
- Pea gravel pack from 116 to 140 feet bgs
- Hydrated bentonite from 2 to 116 feet bgs
- Concrete from 0 to 2 feet bgs
- 3-foot stickup steel monument and 3 bollards

Table 8, below, summarizes the completion intervals and probe details.

**Table 8: New Gas Probe Completion Details**

| Location ID | Probe Interval | Land Elev. (feet) | Screen Interval (feet bgs) | Total probe depth (feet below top of casing | Top of casing stickup (feet above ground) |
|---|---|---|---|---|---|
| KGP-200-S | Shallow | 260 | 10-15 | 17.94 | 2.75 |
| KGP-200-M | Middle | 260 | 39-49 | 52.3 | 2.89 |
| KGP-200-D | Deep | 260 | 118-138 | 140.41 | 2.83 |

## 5.4 Decontamination and Investigative Derived Waste

All drilling rods and casing used at the site were pre-cleaned with a pressure washer prior to use. All drilling rods and casing were also decontaminated at the site using a pressure washer and wash trailer between probe locations to prevent cross-contamination.

All investigation derived waste (IDW), or drill cuttings, for this project were assumed non-hazardous and spread out on-site. As noted above, no VOCs were detected in soil screening.

Wash water used for the decontamination of equipment was disposed at the landfill for treatment with the landfills retention pond. Used nitrile gloves and other disposable personal protective gear, disposable sampling equipment, and waste materials were placed in a garbage bag and disposed of by Holt.

## 5.5 Groundwater

As discussed above, groundwater was encountered at several intervals:

- Perched groundwater was first encountered at approximately 15 to 16 feet below ground surface in the Upper Outwash Aquifer. KGP-200-S was constructed just above this groundwater zone. On March 18, the probe was sounded after construction for a static water level but no water was present.
- Groundwater was encountered at two intervals in equivalency to the Middle Outwash Aquifer at approximately 23 feet below ground surface and at approximately 31 feet at KGP-200-M and 43 feet at KGP-200-D with moist unsaturated zones between the saturated layers. KGP-200-M was constructed below the 31- to 36-foot zone with a screen at 39 to 49 feet below ground. Initially on March 18 following construction, the KGP-200-M probe was found blocked with groundwater. Due to the lithology, it was believed the groundwater was from the zone above the screened interval and entered the probe prior to hydration of the bentonite seal. The groundwater in the probe was pumped by Holt and water levels were measured over the course of five hours. Prior to pumping the water level in the probe was 43.71 feet below the top of the casing (40.82 feet below ground). After pumping water levels dropped to 50.95 feet below top of casing and stabilized at approximately 50.82 feet below ground. The middle probe has not been blocked since the initial construction in subsequent monitoring.
- Groundwater was encountered at 56 feet below ground surface in the Lower Outwash Aquifer perching above the Silt Aquitard at 61 feet below ground in KGP-200-D.
- Groundwater was encountered in the Sand Aquifer at approximately 134 feet below ground in KGP-200-D. KGP-200-D was constructed with screen down to 139 feet below ground. On March 16, the static water level measured in KGP-200-D was 139.61 feet below top of casing (136.78 feet below ground surface).

## 5.6 Cross Section Update

Using the newly obtained subsurface data from KGP-200, we have updated the 2017 Cross Section A-A' which transects the northwest margin of the landfill. Figure 3, attached, displays the updated cross section. The updated cross section closely matches with the initial evaluation. As shown on the figure, the main difference from the initial evaluation is it appears Middle Outwash Aquifer is present below KGP-200. Reviewing the well logs of nearby probes KGP15 and KGP-16A, it appears the Middle Outwash Aquifer may also be present at those locations. The key lithologic features of the Middle Outwash Aquifer at KGP-200 include two different saturated silt layers that were encountered with layers of dry sand between.

The Upper Outwash Aquifer was characterized by a shallow perched groundwater layer at the base (approximately 15-16 feet bgs). The Lower Outwash Aquifer was characterized by dry silty sand and gravel to silt-bound sand and gravel with approximately three feet of saturated silty sand and gravel at the base of the unit perching above the Upper Silt Aquitard. The initial cross section evaluation placed the top of the Sand Aquifer at approximately 120 feet bgs with the top of the unit being unsaturated. Drilling encountered the Sand Aquifer unit at 118 feet bgs with the first 19 to 20 feet of the unit being unsaturated.

## 5.7 Documentation

Copies of the EHSI field notes for the investigation are attached in Appendix C. Additionally, photographs of the drilling and sample cores are attached in Appendix C.

Holt bolted the well tags for each of the probes on the exterior of the flush mount monuments. For documentation purposes, the well tag identification numbers include BKX-289, BKX-290, and BKX-291.

## 5.8 Initial Methane Monitoring Results at New Gas Probes

Following installation, methane monitoring was conducted at new gas probes KGP-200-S, M, and D. The initial methane readings beginning on March 16 were zero, but on March 19, a methane concentration of over 2 percent BV was measured at KGP-200-M. SPU initiated more frequent monitoring of the new gas probes and surrounding probes and wells, and methane in KGP-200-M was observed to increase to 19 percent BV on March 27. SPU attempted to increase the vacuum in adjacent extraction well KGW-97A but found that the well was not functioning. Well KGW-97A was repaired and placed under vacuum on March 27, and subsequent methane measurements were zero at all the KGP-200 probes. A graph of the methane measurements at KGP-200 is presented in Figure 5.

The most likely reason gas was initially detected in KGP-200-M was it had migrated beyond the landfill due to throttling back the nearby gas wells to enrich the overall gas concentration reaching the flare. The gas disappeared after the extraction rate was increased and the probe vented. There will be no further throttling of these wells.

# 6.0 EVALUATION OF EFFECTIVENESS OF LANDFILL GAS CONTROL SYSTEM

This section includes a description of ongoing landfill gas operations and monitoring procedures, an evaluation of recent landfill gas conditions in the northwestern area of the landfill compared to historical conditions prior to operation of the gas extraction system, and an evaluation of the initial data collected in the area surrounding new gas probe KGP-200 and along the northwestern border of the site under different barometric pressure conditions.

## 6.1 Landfill Gas Operations and Monitoring Procedures

### 6.1.1 Design Philosophy

The design of the Kent Highlands Landfill gas system includes 5 basic elements:

1. An enclosed John Zinc flare is used to incinerate the landfill gas in a controlled environmental manner.
2. Collection System – includes all the piping, valves, and mechanical equipment to create a vacuum on the landfill to draw landfill gas to the flare.
3. Interior control wells are intended to extract most of the landfill gas created as waste decomposes.

4. Perimeter control wells are intended to create a vacuum curtain around the landfill that captures any landfill gas not controlled by the interior system.
5. Landfill gas compliance probes are outside of the perimeter collection and near the facility's property boundary to confirm that the system is controlling subsurface migrating landfill gas.

### 6.1.2 Current Operating Frequencies

- Flares are continuously monitored to ensure that the mechanical systems are operating properly. Landfill staff routinely inspect the facility 5 days a week and respond to off hour system alarms such as flame failure or temperatures out of permitted range on the enclosed flare.
- The collection system is inspected monthly.
- The interior and perimeter control wells are monitored monthly.
- Landfill gas compliance probes are monitored either monthly or quarterly depending on the compliance status of the probe.

### 6.1.3 Process

Seattle Public Utilities operates the Kent Highlands Landfill with an on-site 6-member team. This team includes a Manager, three (3) Associate Environmental Analysts, a Facility Maintenance Laborer, and a Senior Heavy Equipment operator. All staff have been assigned to the landfill for over 4 years, and have been thoroughly trained in gas system operation. The team conducts all the work at the landfill and can bring in other senior SPU staff, consultant, and vendor resources, as needed.

After each monthly monitoring rounds on the control wells, the manager and the environmental analysts meet to collectively discuss the current performance and trends of the extraction system, as well as, the trends and recent data from the compliance probes. This meeting covers the following:

- Ensures collection system is operating as intended.
- Ensures landfill gas migration is being controlled.
- Changes to control wells settings are discussed and confirmed.
- Determine if any non-routing or follow-up monitoring is required.
- Preventative flare facility and collection system maintenance needs.
- Overall system performance is evaluated.

Following the meeting, the system changes and maintenance needs are performed by the team. Any unanticipated conditions that are encountered trigger additional special meetings.

This team approach to system operations is used to train new staff and allow all team members to actively participate in system operation, which has been successfully practiced since 1991. Over time this process ensures that every team member collectively develops an awareness of system operation guided by the experience of the last 27 years of operation.

A copy of Chapter 7, Landfill Gas Collection and Transmission, from the Operations and Maintenance manual is included in Appendix D.

## 6.2 Recent Methane Concentrations Along the Northwestern Site Boundary

Nine active gas monitoring probes (KGP-1, KGP-14, KGP-15, KGP-16A, KGP-32A, KGP-38B, KGP-44, KGP-46, and KDGP-98) are located on the northern margin of the landfill near the new gas probes (Figure 2). At least one interval in seven of the nine probes were monitored quarterly in 2016. Table 9, below,

summarizes 2016 methane concentrations reported for each of the shallow, middle, and deep probes. As noted in the table, only one probe near the northern margin, KGP-1-D, had any detections of methane during the 2016 gas probe monitoring.

**Table 9: 2016 Gas Probe Monitoring Data**

| Location ID | Probe Interval | Land Elev. (feet) | Screen Interval (feet bgs) | MBV% 1st Qtr. 2016 Max | MBV % 2nd Qtr. 2016 Max | MBV % 3rd Qtr. 2016 Max | MBV % 4th Qtr. 2016 Max |
|---|---|---|---|---|---|---|---|
| KGP-1-S | Shallow | 305 | 8-10 | 0 | 0 | 0 | 0 |
| KGP-1-M | Middle | 305 | 63-65 | NM | NM | NM | NM |
| KGP-1-D | Deep | 305 | 88-90 | 0.5 | 0 | 0 | 0 |
| KGP-14-M | Middle | 255 | 68-70 | 0 | 0 | 0 | 0 |
| KGP-14-D | Deep | 255 | 157-158 | X | X | 0 | 0 |
| KGP-15-S | Shallow | 270 | 20-23 | 0 | 0 | 0 | 0 |
| KGP-15-M | Middle | 270 | 51-52 | NM | NM | NM | NM |
| KGP-15-D | Deep | 270 | 171-172 | NM | NM | NM | NM |
| KGP-16A-S | Shallow | 278 | 18-23 | 0 | 0 | 0 | 0 |
| KGP-16A-M | Middle | 278 | 40-50 | 0 | 0 | 0 | 0 |
| KGP-16A -D | Deep | 278 | 96-136 | 0 | 0 | 0 | 0 |
| KGP-32A-S | Shallow | 309 | 4-20 | 0 | 0 | 0 | 0 |
| KGP-32A-M | Middle | 309 | 16-43 | X | 0 | 0 | 0 |
| KGP-32A-I | Interme diate | 309 | 55-75 | NM | NM | NM | NM |
| KGP-32A-D | Deep | 309 | 80-103 | X | X | X | X |
| KGP-38B-S | Shallow | 280 | 10-20 | 0 | 0 | 0 | 0 |
| KGP-38B-M | Middle | 280 | 30-50 | 0 | 0 | 0 | 0 |
| KGP-38B-D | Deep | 280 | 140-170 | 0 | 0 | 0 | 0 |
| KGP-44-S | Shallow | 285 | 9-24 | NM | NM | NM | NM |
| KGP-44-M | Middle | 285 | 30-55 | NM | NM | NM | NM |
| KGP-46-S | Shallow | 288 | 9-19 | NM | NM | NM | NM |
| KGP-46-M | Middle | 288 | 27-37 | NM | NM | NM | NM |
| KDGP-98-S | Shallow | 280.3 | 15-30 | 0 | 0 | 0 | 0 |
| KDGP-98-M | Middle | 280.3 | 42.5-72.5 | 0 | 0 | 0 | 0 |
| KDGP-98-D | Deep | 280.3 | 85-90 | 0 | 0 | 0 | 0 |

NM – Not Measured, X - Screen Reportedly Blocked, Note: 0% represents less than instrument detection limit of 0.1%

(Note: 0% methane may reflect from 0 PPM to 500 PPM; Gem-2000's lower detection limit is 0.1% by volume).

Methane concentrations from the landfill gas extraction wells are collected monthly. Table 10, below, summarizes the data as quarterly maximums for the four quarters of 2016.

| Table 10: 2016 Landfill Gas Extraction Well Monitoring Data | | | | | | |
|---|---|---|---|---|---|---|
| **Location ID** | **Land Elev. (feet)** | **Screen Interval (feet bgs)** | **MBV % 1st Qtr. 2016 Max** | **MBV % 2nd Qtr. 2016 Max** | **MBV % 3rd Qtr. 2016 Max** | **MBV % 4th Qtr. 2016 Max** |
| KDGW-94A | 261.3 | 26-74 | 22.40 | 17.10 | 17.20 | 17.60 |
| KDGW-94B | 259.2 | 108-148 | 37.10 | 36.00 | 37.70 | 37.90 |
| KDGW-95 | 264.1 | 27.5-82.5 | 11.80 | 16.90 | 13.30 | 15.20 |
| KDGW-96 | 268.7 | 30-90 | 14.80 | 16.50 | 10.20 | 14.40 |
| KDGW-97 | 280 | 30-90 | 29.40 | 34.10 | 27.50 | 31.40 |
| KDGW-97A | 280 | 95-145 | 0.00 | 0.00 | 0.00 | 0.00 |
| KDGW-98 | 283.4 | 26-75 | 9.40 | 6.90 | 19.00 | 14.50 |
| KSGW-99 | 291.8 | 10-35 \| 45-50 | 0.00 | 0.00 | 0.00 | 0.00 |
| KSGW-101 | 299.7 | 11-26 | 0.00 | 0.00 | 0.00 | 0.10 |
| KDGW-101 | 299.9 | 87-102 | 0.20 | 0.00 | 0.00 | 0.10 |
| KDGW-102 | 300.4 | 80-100 | 46.10 | 58.10 | 57.20 | 63.80 |

## 6.3 Historical and Recent Gas Comparison

Prior to installation of the gas extraction system, methane was present outside the landfill boundary along the northern margin of the landfill as documented in the RI (CH2MHill 1991). The landfill gas extraction system was installed in 1990 consisting of interior control wells and perimeter control wells intended to create a vacuum curtain around the landfill to capture any landfill gas not controlled by the interior system.

To demonstrate that the operation of the gas extraction system has effectively eliminated methane migration outside the site perimeter along the northern margin of the landfill, historical landfill gas data (from the well logs and previous studies, as shown in Tables 4 through 6), were compared with recent landfill gas measured in 2016 (Tables 7 and 8).

Figure 6 displays the historical conditions along the northern margin prior to installation of the landfill gas extraction wells. As shown on the figure, methane was previously detected near Veterans Drive exceeding 5% BV, the LEL and point of compliance level for the landfill boundary. The historical methane extent area encompasses portions of the recently developed Grandview Apartments and all the adjoining City of Kent property south of Veterans Drive.

The 2016 quarterly gas monitoring data are presented in Figure 7. This data shows no detections of methane outside the northern margin (KGP-14, KGP-15, KGP-16A, KPG-32A, KGP-38B, and KGP-98) or near new gas probe location KGP-200. The gas extraction wells located south of the landfill boundary (KDGW-95, KDGW-96, and KDGW-97 had methane concentrations ranging from 10.2% up to 34.1% BV during the same period of monitoring.

Figures 8 and 9 display cross-sections A-A' and B-B' with the historical and recent gas bearing zones noted. Historical gas bearing zones are presented on the left side of the well stick. Recent gas bearing zones are presented on the right side of the well stick. As depicted in the figures, methane is no longer present in

many zones where it was previously found. This demonstrates that the extraction well system has been effective in drawing back gas migration to the landfill boundary and eliminating off-site migration.

## 6.4 Status of Gas Extraction Well Effectiveness

As shown in Tables 7 and 8 above, recent data for landfill gas extraction wells show relatively high levels of methane being extracted while the perimeter gas monitoring probes remain largely non-detect for methane. These data confirm that the gas extraction system vacuum is minimizing or eliminating off-site gas migration. KGP-1-D completed at 88-90 feet bgs was the only perimeter gas monitoring probe that showed methane detections during the 2016 monitoring and the measured concentration was only 0.5 % during one of the four quarters of 2016.

The data from the gas monitoring probes and extraction wells indicate that the positive vacuum is preventing offsite migration of methane to the north. For example, KDGW-97 (screened 30-90 feet bgs) had methane concentrations ranging from 27.5 to 34.1% BV, while the shallow, middle, and deep KGP-16A probes outside the landfill boundary and to the north were non-detect for the same four quarters. Similar comparisons can be seen between KDGW-98 (screened 26-75 feet bgs) which had methane concentrations ranging from 6.9% to 19.0% and KDGP-98 just to the north which had no detections of methane in the shallow, middle, and deep probes for the same time period.

The new gas probes at KGP-200 will provide additional coverage along the northern perimeter of the Site between KGP-16A and KGP-15 to confirm that the conditions there are consistent with existing data. Monitoring at the new probes will confirm that no methane is present and that the radius of influence of the extraction wells extends to this area.

## 6.5 Pressure Gradient Evaluation

During the RI, a study was conducted to evaluate whether changes in either the direction of barometric pressure changes or in the magnitude of the barometric pressure changes influenced landfill gas measurements in the gas probes (CH2MHill 1991). The study determined that neither of these factors showed a statistically significant correlation with landfill gas measurements. Variations in static pressure variations are believed to be related to many factors other than barometric pressure including distance from the landfill, and depth below ground surface.

Data from new gas probes at KGP-200 and other probes and wells in the vicinity were collected to reassess whether barometric pressure had an influence on the data collected. SPU measured static pressures (in inches of water column) at gas extraction wells and probes along the northwestern landfill boundary during three different barometric conditions on March 27, April 10, and April 11, 2018. The March 27 monitoring event was conducted during steady barometric pressure conditions during an overall rising barometric pressure period. The April 10 and April 11 monitoring events were conducted during respective rising and falling barometric pressure conditions. This evaluation was conducted to evaluate whether the monitoring data reflect all conditions representing potential off-site migration of landfill gas.

Depending on whether the barometric pressure is rising or falling, in other words, higher or lower than the soil gas pressure, the difference between the soil gas pressure and barometric pressure allows gas to move either vertically or laterally. When barometric pressure is falling, landfill gas will tend to migrate out of the landfill into surrounding areas. As barometric pressure rises, gas may be retained in the landfill temporarily as new pressure balances are established.

The static pressure data for the three events are presented in Table 11. These data were plotted on geologic cross section A-A' and are presented as Figures 10 through 12. Gas wells and probes within approximately 200 feet of the cross section were projected onto the line of section so that their screened intervals and pressures could be compared.

Barometric pressure readouts from the Site weather station are included in Appendix E. Barometric pressure graphs showing data from the Des Moines Creek (Kent, Washington) hydrographs for these dates are presented on Figure 13 for comparison.

**Table 11. Static Pressure for Gas Wells and Probes for Kent Highlands Landfill**

| | | STEADY | | RISING | | FALLING | |
|---|---|---|---|---|---|---|---|
| | | 3/27/2018 | | 4/10/2018 | | 4/11/20108 | |
| Well/Probe ID | Type | Static Pressure (in/wc) | Notes | Static Pressure (in/wc) | Notes | Static Pressure (in/wc) | Notes |
| KDGW101 | Well | -0.77 | | -1.94 | | -0.86 | |
| KSGW101 | Well | -23.07 | | -22.00 | | -21.45 | |
| KDGW102 | Well | -23.03 | | -21.88 | | -21.49 | |
| KSGW102A | Well | -23.07 | | -21.89 | | -21.43 | |
| KSGW102B | Well | -23.02 | | -21.96 | | -21.45 | |
| KSGW99 | Well | -0.07 | | -0.14 | | 0.00 | |
| KDGW98 | Well | -23.18 | | -21.92 | | -21.58 | |
| KDGW97 | Well | -23.11 | | -22.11 | | -21.57 | |
| KDGW97A | Well | -23.15 | | -21.99 | | -21.53 | |
| KDGW96 | Well | -23.19 | | -22.09 | | -21.52 | |
| KDGW95 | Well | -23.13 | | -22.12 | | -21.58 | |
| KDGW94A | Well | -20.87 | | -19.84 | | -19.18 | |
| KDGW94B | Well | -23.26 | | -22.16 | | -21.49 | |
| 14-M | Probe | 0.01 | | 0.00 | | -0.07 | |
| 14-D | Probe | 0.01 | Blocked | 0.04 | Blocked | -0.11 | Blocked |
| 15-S | Probe | -0.45 | | -2.27 | | -0.44 | |
| 15-M | Probe | -0.02 | Blocked | -0.01 | Blocked | -0.36 | Blocked |
| 15-D | Probe | 0.04 | Blocked | -0.22 | Blocked | -0.22 | Blocked |
| 32A-S | Probe | -0.02 | | -0.11 | | 0.04 | |
| 32A-M | Probe | 0.18 | | -0.43 | Blocked | 0.83 | Blocked |
| 32A-I | Probe | 0.02 | | 0.08 | Blocked | 0.16 | Blocked |
| 32A-D | Probe | 0.05 | Blocked | -0.06 | Blocked | 0.19 | Blocked |
| 1-S | Probe | 0.00 | | 0.01 | | 0.01 | |
| 1-M | Probe | 0.00 | | 0.08 | Blocked | 0.05 | Blocked |
| 1-D | Probe | -15.45 | | -13.21 | | -11.72 | |
| 16A-S | Probe | -2.87 | | -2.07 | | -0.41 | |
| 16A-M | Probe | -2.81 | | -1.99 | | -0.35 | |
| 16A-D | Probe | -7.37 | | -1.86 | | 0.04 | |
| 38B-S | Probe | -0.03 | | 0.00 | | 0.00 | |
| 38B-M | Probe | -1.85 | | 0.00 | | 1.83 | |
| 38C-D | Probe | -0.02 | | 0.02 | | -0.01 | |
| 44-S | Probe | -0.01 | | 0.11 | | -0.05 | |

| Table 11. Static Pressure for Gas Wells and Probes for Kent Highlands Landfill | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | STEADY | | RISING | | FALLING | |
| | | 3/27/2018 | | 4/10/2018 | | 4/11/20108 | |
| Well/Probe ID | Type | Static Pressure (in/wc) | Notes | Static Pressure (in/wc) | Notes | Static Pressure (in/wc) | Notes |
| 44-M | Probe | -0.01 | | -0.13 | | 0.02 | |
| 46-S | Probe | -0.03 | | 0.00 | | -0.08 | |
| 46-M | Probe | -0.29 | | 1.14 | | 2.10 | |
| 17-S | Probe | -0.29 | | -0.07 | | 0.03 | |
| 17-M | Probe | 0.00 | Blocked | 2.45 | Blocked | 0.32 | Blocked |
| 17-D | Probe | -7.06 | Blocked | 1.69 | Blocked | 0.10 | Blocked |
| 200-S | Probe | -3.64 | | -2.67 | | -1.16 | |
| 200-M | Probe | -3.61 | | -2.59 | | -1.16 | |
| 200-D | Probe | -7.33 | | -1.85 | | -0.29 | |
| 98-S | Probe | -0.93 | | 0.36 | | 2.54 | |
| 98-M | Probe | 0.40 | | -0.84 | Blocked | 1.03 | Blocked |
| 98-D | Probe | 0.18 | | -0.33 | Blocked | 1.15 | Blocked |

Most of the static pressures measured in the gas probes along the northwestern landfill boundary were negative under all three barometric pressure conditions, indicating that the radius of influence of the gas extraction wells extends to the probes, thereby preventing landfill gas from moving beyond the property boundary. The only probes located along the property boundary as plotted on the cross section that indicated positive static pressures greater than one inch of water column (wc) were the shallow probe at KDGP-98 (the lower two probes were blocked), and the middle probe at KGP-38B under falling barometric conditions. Methane measurements in these two probes have been zero during recent monitoring events (see Table 9).

The static pressures in the gas probes vary within relatively consistent ranges under different conditions of barometric pressure. This indicates that the monthly monitoring conducted by SPU is representative of the range of conditions present along the landfill perimeter.

Methane measurements in the gas probes provide a more meaningful indication than static pressure of the effectiveness of the gas extraction wells in preventing off-site methane migration. Recently measured methane concentrations in the gas perimeter gas probes, including recent measurements at KGP-200, have consistently been measured at zero (see Table 9 and Figures 5 and 7).

# 7.0 CONCLUSIONS AND RECOMMENDATIONS

## 7.1 Conclusions

### 7.1.1 Effectiveness of Landfill Gas System

The methane data measured at the gas probes, including new probe KGP-200, provide evidence that the extraction wells are providing a continuous vacuum along the property boundary, preventing methane migration off-site. The pressure gradients show the overall vacuum from the landfill gas extraction wells extends north beyond the property boundary with approximately two feet of vacuum pressure near the

extraction wells. The barometric conditions do not appear to alter the effectiveness of the pressure vacuum. These pressure gradient measurements, when combined with the actual methane measurements, confirm the existing gas extraction system is effectively eliminating off-site migration.

### 7.1.2 Future Need for Additional Gas Monitoring Probes

The existing gas monitoring probes, including new probe KGP-200, are currently providing good coverage to monitor the presence of methane along the northern landfill border in the vicinity of the Grandview Development. However, if future property development is planned between the landfill and Veterans Drive, additional probes may be necessary. In particular, an additional set of probes should be considered along the property boundary between existing probes KGP-32A and KGP-98. Although probe KGP-38B currently provides coverage in this area and is between the site and the Grandview development, this probe is located approximately 200 feet from the property boundary. This issue will be revisited once development plans are known for adjoining City of Kent property.

### 7.1.3 Recommendations for Ongoing Landfill Gas Monitoring

SPU will conduct monthly monitoring at gas extraction wells and gas monitoring probes, and quarterly monitoring of available operational probes along the northern Site perimeter for one year to supplement the data obtained from the gas extraction wells. After one year, the usefulness of the data from the operational probes will be evaluated. The objective of the operational probe monitoring will be to confirm that negative pressures are occurring in between extraction wells, thereby providing a perimeter curtain surrounding the landfill to prevent gas migration. The objective of perimeter gas probes will be to confirm that methane migration is not occurring beyond the property boundary.

SPU employees will be responsible for monitoring gas concentrations in the completed gas probes. Data from the completed probes, KGP-200-S, KGP-200-M, and KGP-200-D will be compared to neighboring gas monitoring probes and extraction wells. The completed probes will be monitored monthly along with the neighboring exterior gas monitoring probes to ensure the gas extraction system prevents northern migration of landfill gas towards the neighboring residential development. The new and existing probes that will be monitored on the northern margin are presented below. Monitoring probes that have historically been blocked will not be monitored.

New gas monitoring probes:

- KGP-200 Shallow (Screen 10-15 feet bgs)
- KGP-200 Middle (Screen 39-49 feet bgs)
- KGP-200 Deep (Screen 118-138 feet bgs)

Existing gas monitoring probes:

- KGP-1 Shallow (Screen 9-11 feet bgs)
- KGP-1 Middle (Screen 63-65 feet bgs)
- KGP-1 Deep (Screen 88-90 feet bgs)
- KGP-14 Middle (Screen 71.5-73 feet bgs)
- KGP-14 Deep (Screen 100.5-101 feet bgs)
- KGP-15 Shallow (Screen 21-22 feet bgs)
- KGP-16A Shallow (Screen 18-23 feet bgs)
- KGP-16A Middle (Screen 40-50 feet bgs)
- KGP-16A Deep (Screen 96-136 feet bgs)

- KGP-32A Shallow (Screen 4-20 feet bgs)
- KGP-32A Middle (Screen 16-43 feet bgs)
- KGP-38B Shallow (Screen 10-20 feet bgs)
- KGP-38B Middle (Screen 30-50 feet bgs)
- KGP-38CD Deep (Screen 140-170 feet bgs)
- KDGP-98 Shallow (Screen 15-30 feet bgs)

Existing Gas Extraction Wells:

- KDGW-94A (Screen 26-74 feet bgs)
- KDGW-94B (Screen 108-148 feet bgs)
- KDGW-95 (Screen 27.5-82.5 feet bgs)
- KDGW-96 (Screen 30-90 feet bgs)
- KDGW-97 (Screen 30-90 feet bgs)
- KDGW-97A (Screen 95-145 feet bgs)
- KDGW-98 (Screen 26-75 feet bgs)
- KSGW-99 (Screen 10-35 and 45-50 feet bgs)
- KSGW-101 (Screen 11-26 feet bgs)
- KDGW-101 (Screen 87-102 feet bgs)
- KDGW-102 (Screen 80-100 feet bgs)

Samples collected from these gas monitoring probes and gas extraction wells will be analyzed by SPU, typically for the following:

- Percent Methane
- Percent Oxygen
- Percent Carbon Dioxide
- Percent Water
- Barometric Pressure
- (Optional) Percent Hydrogen Sulfide

In the event that methane is detected in probes along the northeastern site boundary, additional monitoring probes will be checked, including KGP-16, KGP-44, and KGP-46.

### 7.1.4 Data Reporting

The reports will include tables of all gas monitoring data collected during each event. It is recommended that ongoing evaluation of landfill gas data consist of presenting a download of the all monthly monitoring data that includes methane, pressure, and oxygen in the quarterly reports to Ecology.

KGP-200-S, KGP-200-M, and KGP-200-D, the new probes on the northern margin, will also be included in the monthly measurements and reporting.

The key parameters to demonstrate control are: (1) Consistent, continuous negative static pressures in the line of perimeter gas extraction wells and operational gas probes, and (2) Consistent and continuous “zero” gas concentrations measured in perimeter/outside probes.

## 8.0 REFERENCES


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## 9.0 SIGNATURES

This Gas Evaluation was prepared by the undersigned.

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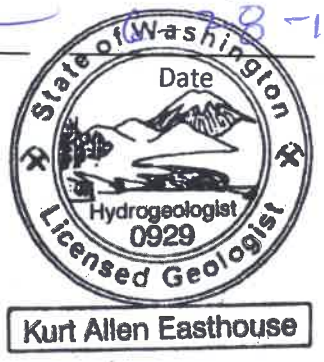
Washington Licensed Hydrogeologist, License #2970

6/29/18
Date

Kurt Easthouse
Washington Licensed Hydrogeologist, License #0929

6-28-18
Date



# FIGURES

IMAGE REF: GOOGLE MAPS, 2017


NORTH

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0 200' 400'
SCALE


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KENT HIGHLANDS LANDFILL

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SEATTLE, WA

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INSPECTORS:

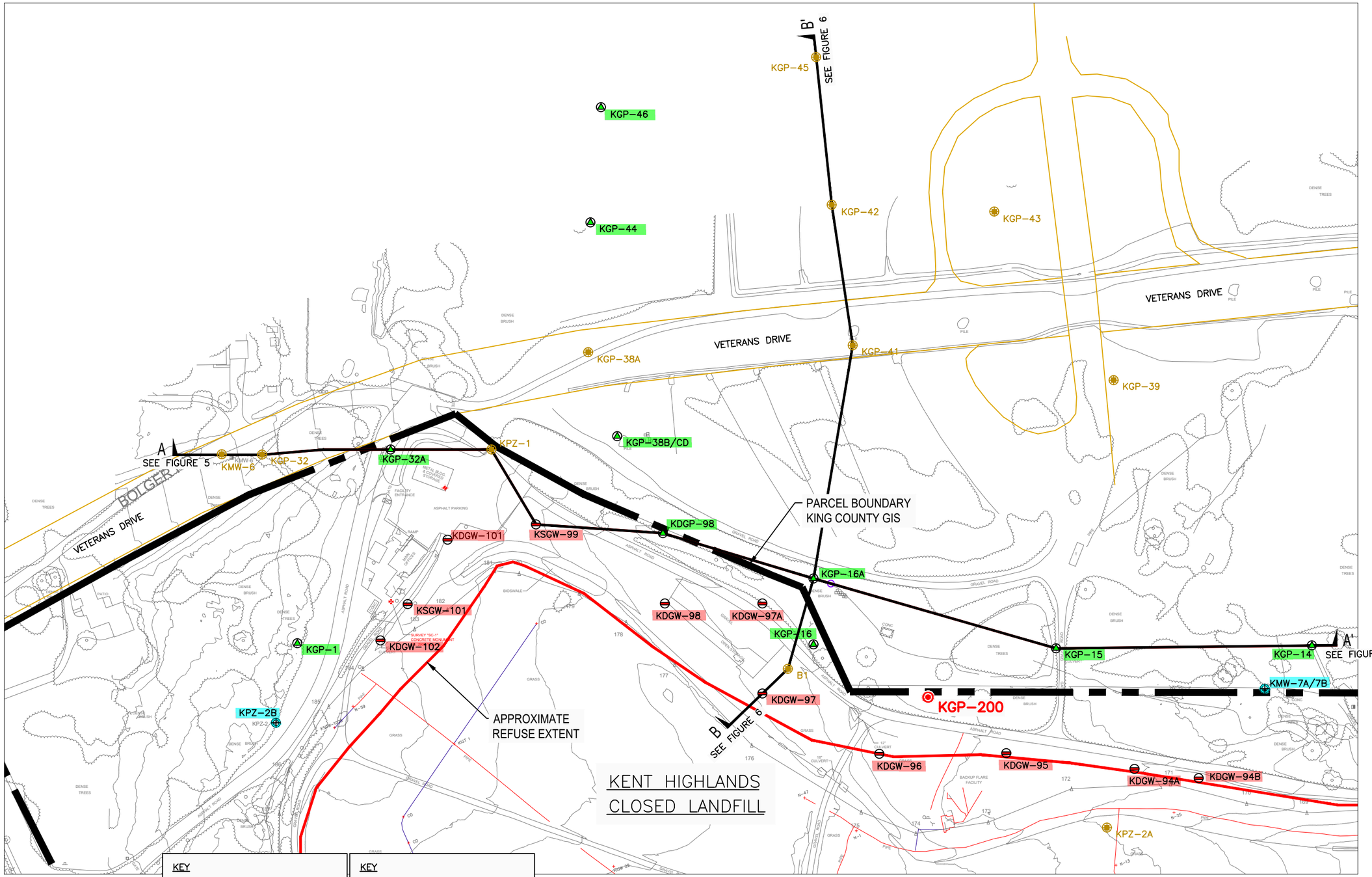
SURVEY DATE:

EHSI PROJECT #: 10887-4.4
DRAWN BY: F DIMALANTA
SCALE: SHOWN
ISSUE DATE: 06/20/18

SITE OVERVIEW

SHEET/FIGURE

1

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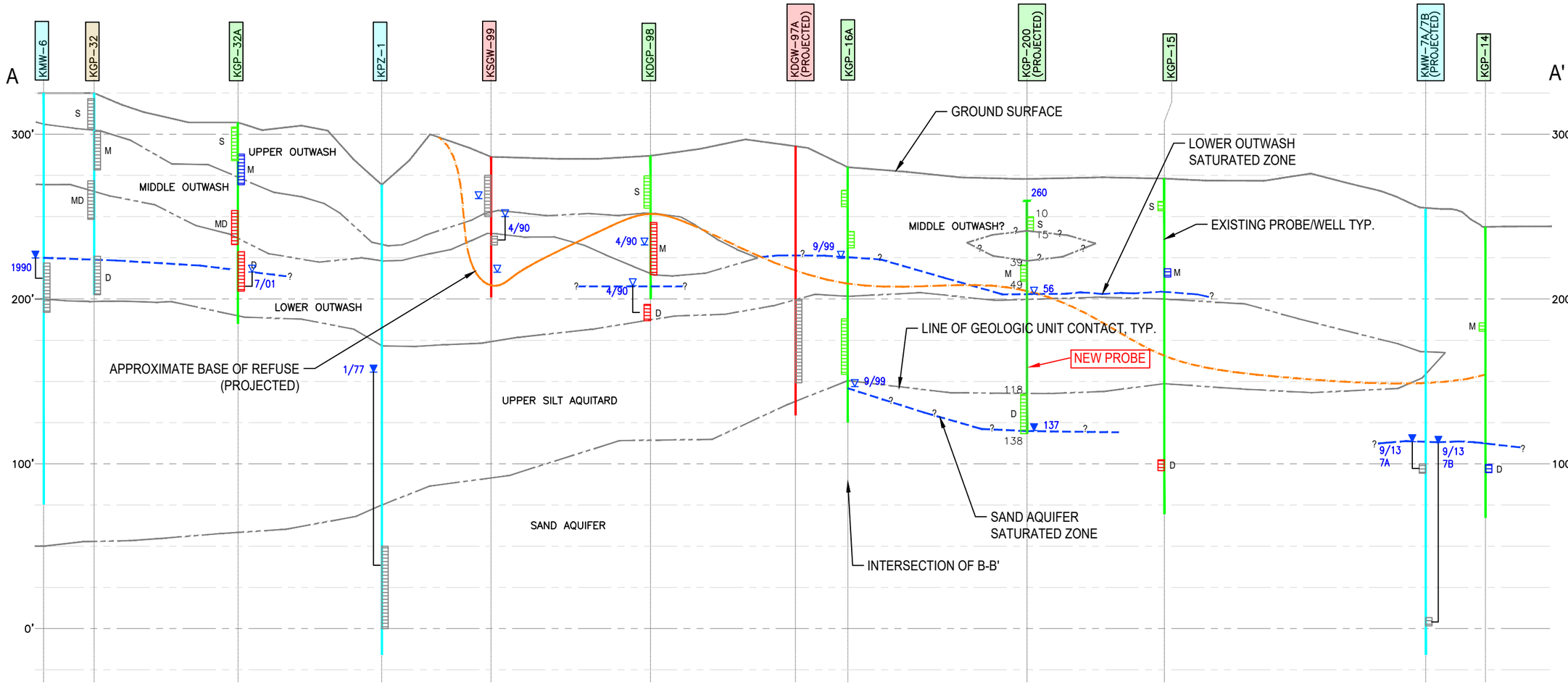
## WELLS/PROBES LOCATIONS

SHEET/FIGURE

2




HORIZONTAL SCALE: 0 100' 200'
VERTICAL SCALE: 0 50' 100'

LEGEND:

- SCREEN INTERVAL
- GRAVEL PACK
- WATER LEVEL IN COMPLETED WELL
- WATER LEVEL AT TIME OF DRILLING
- 7/01 DATE OF WATER LEVEL
- S SHALLOW GAS MONITORING PROBE
- M MIDDLE GAS MONITORING PROBE
- MD MIDDLE/DEEP GAS MONITORING PROBE
- D DEEP GAS MONITORING PROBE

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LEGEND:

- ABC 123 GAS PROBE
- ABC 123 GAS EXTRACTION WELL
- ABC 123 MONITORING WELL/PIEZOMETER
- ABC 123 HISTORICAL PROBE

CURRENT GAS PROBE SCREEN STATUS:

- UNBLOCKED
- INTERMITTENTLY BLOCKED
- ALWAYS BLOCKED


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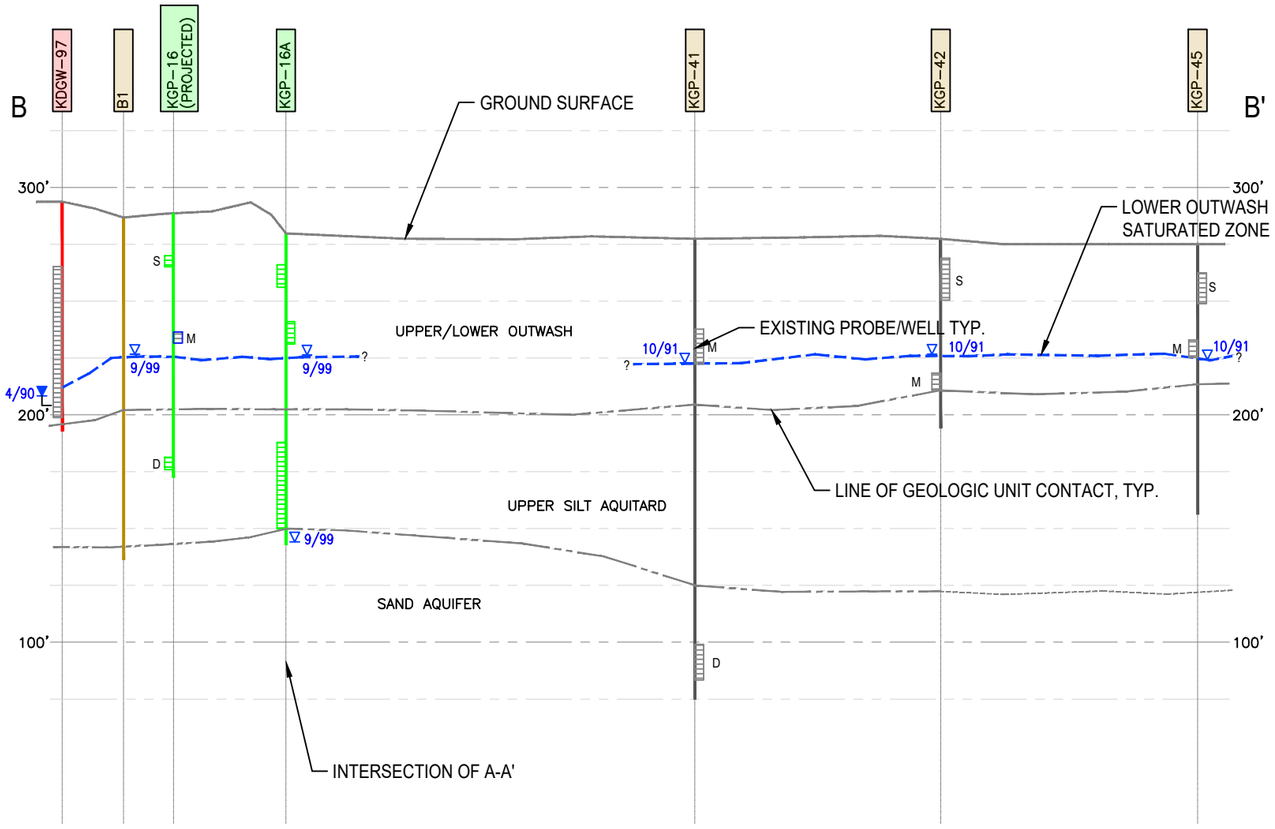
CROSS-SECTION A-A'

SHEET/FIGURE
3




HORIZONTAL SCALE: 0 100' 200'
VERTICAL SCALE: 0 50' 100'

LEGEND:

- SCREEN INTERVAL
- WATER LEVEL IN COMPLETED WELL
- WATER LEVEL AT TIME OF DRILLING
- S SHALLOW GAS MONITORING PROBE
- M MIDDLE GAS MONITORING PROBE
- MD MIDDLE/DEEP GAS MONITORING PROBE
- D DEEP GAS MONITORING PROBE

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LEGEND:

- ABC 123 GAS PROBE
- ABC 123 GAS EXTRACTION WELL
- ABC 123 MONITORING WELL/PIEZOMETER
- ABC 123 HISTORICAL PROBE

CURRENT GAS PROBE SCREEN STATUS:

- UNBLOCKED
- INTERMITTENTLY BLOCKED
- ALWAYS BLOCKED

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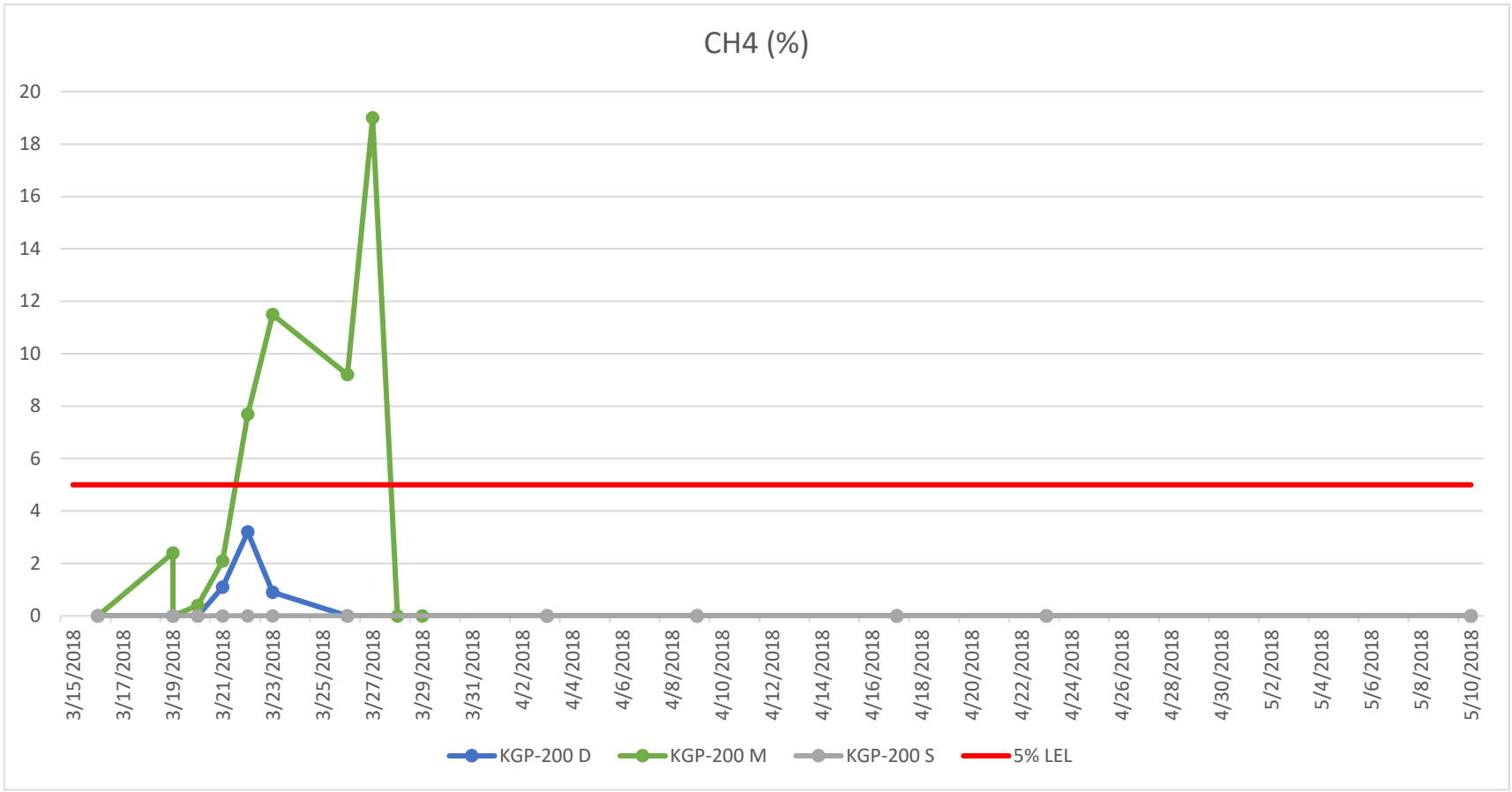
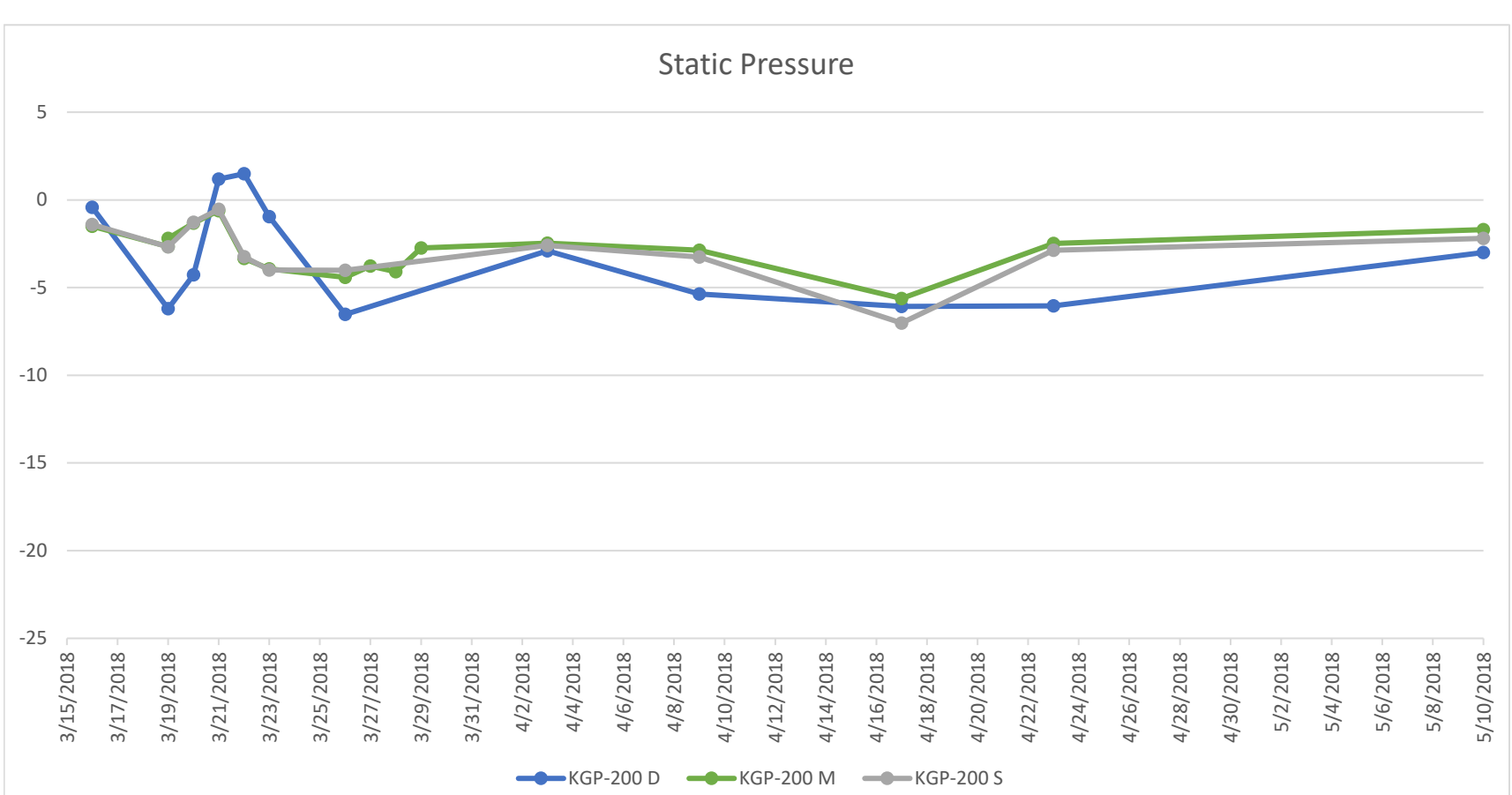
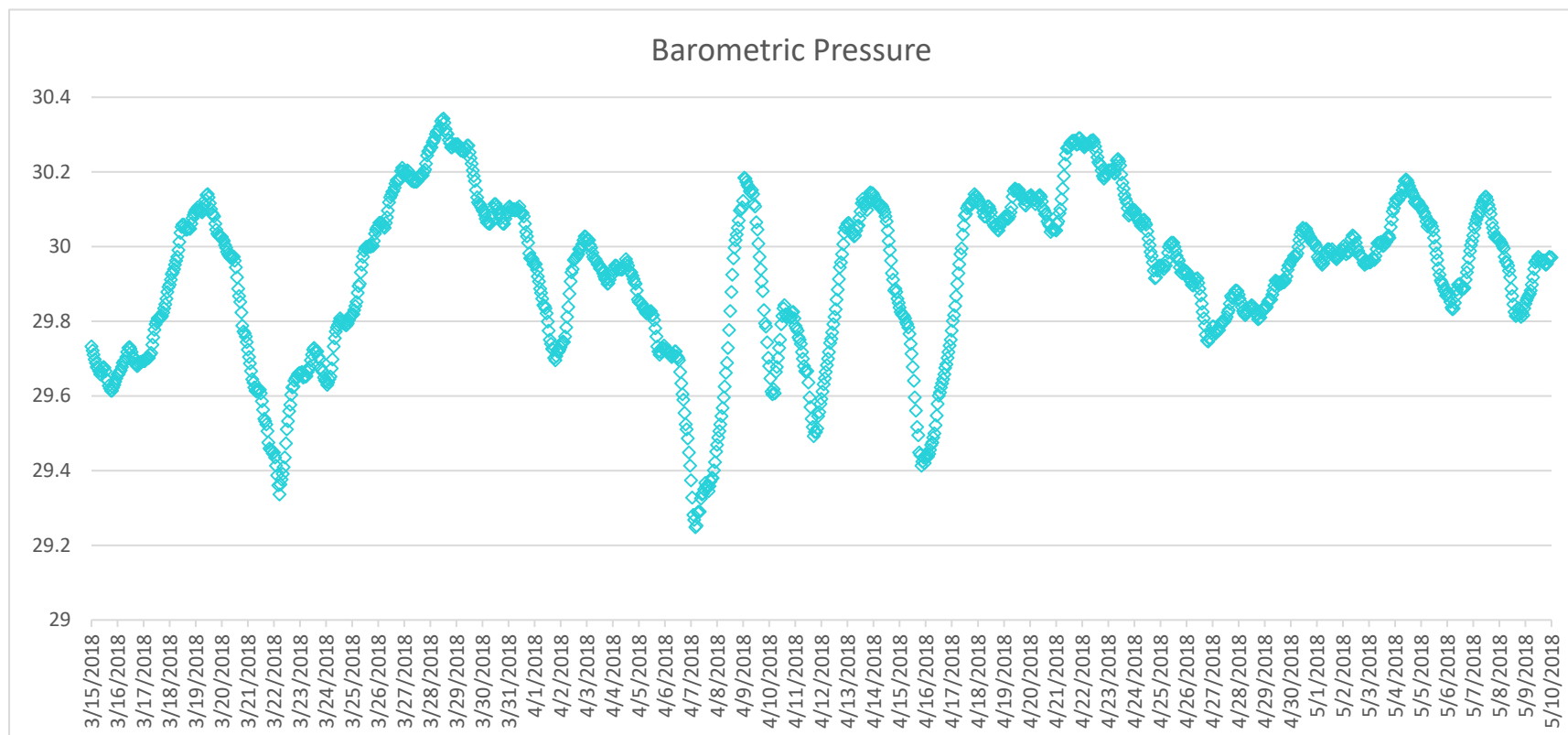
CROSS-SECTION B-B'

SHEET/FIGURE
4



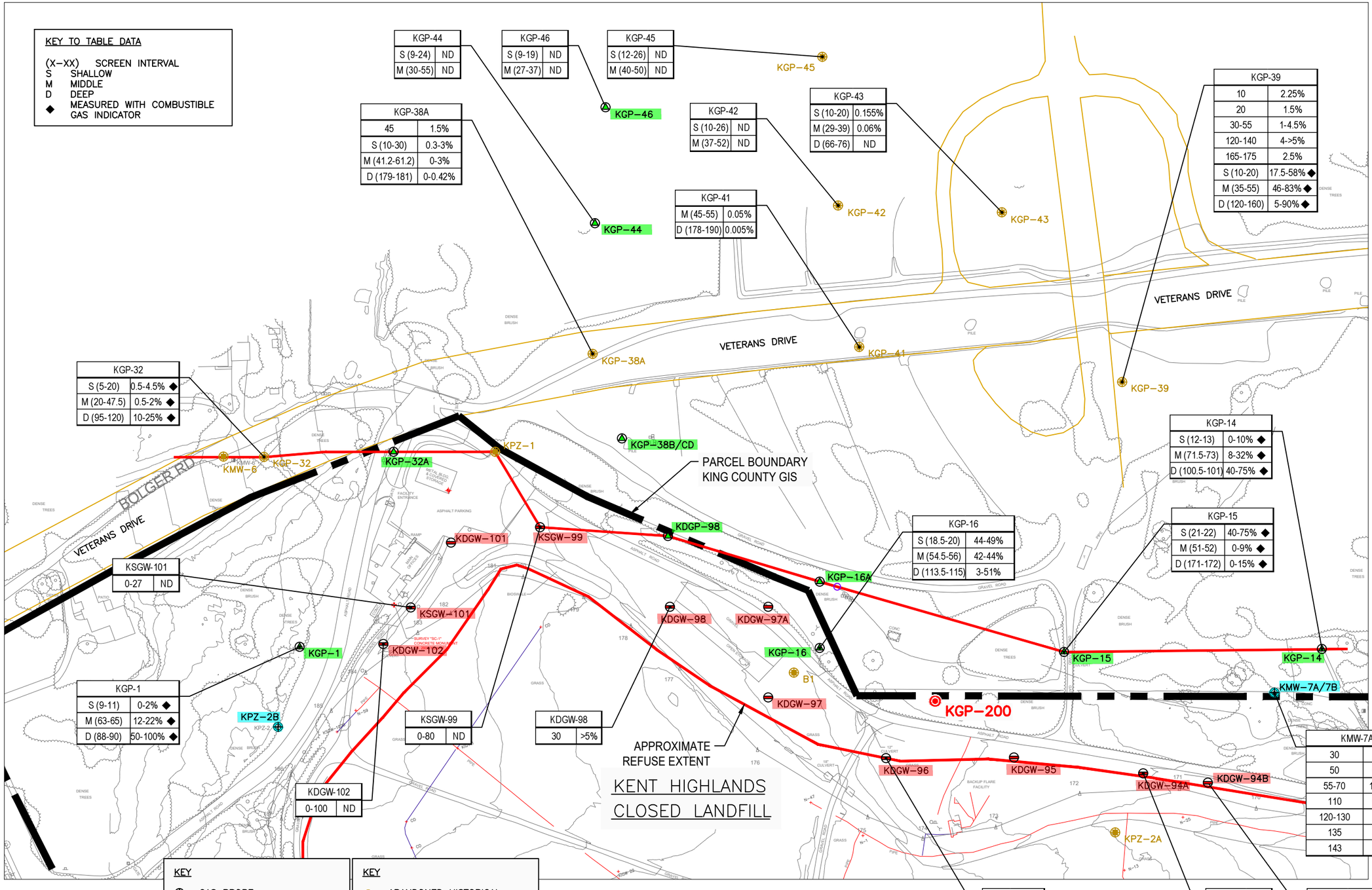




Barometric pressure source: King County Hydrologic Information Center, Northwest Ponds Level Station (Des Moines Creek)
https://green2.kingcounty.gov/hydrology/DataDownload.aspx



**Figure 5**
**Initial Methane Measurements at KGP-200**
**Kent Highlands Landfill**

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HISTORICAL METHANE PERCENT BY VOLUME

SHEET/FIGURE
6

KEY TO TABLE DATA

1 1st QUARTER 2016
2 2nd QUARTER 2016
3 3rd QUARTER 2016
4 4th QUARTER 2016
(X–XX) SCREEN INTERVAL
S SHALLOW
M MIDDLE
D DEEP
B BLOCKED SCREEN/NO SAMPLE

| KGP-16A | S (18-23) | M (40-50) | D (96-136) |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 |

| KGP-38B | S (10-20) | M (30-50) | D (140-170) |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 |

| KDGP-98 | S (15-30) | M (42.5-72.5) | D (85-90) |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 |

| KGP-32A | S (16-43) | M (55-75) | D (80-103) |
|---|---|---|---|
| 1 | 0 | B | B |
| 2 | 0 | 0 | B |
| 3 | 0 | 0 | B |
| 4 | 0 | 0 | B |

| KDGW-101 | (87-102) |
|---|---|
| 1 | 0.2 |
| 2 | 0 |
| 3 | 0 |
| 4 | 0.1 |

| KSGW-101 | (11-26) |
|---|---|
| 1 | 0 |
| 2 | 0 |
| 3 | 0.1 |
| 4 | 0 |

| KGP-1 | S (8-10) | D (88-90) |
|---|---|---|
| 1 | 0 | 0.5 |
| 2 | 0 | 0 |
| 3 | 0 | 0 |
| 4 | 0 | 0 |

| KDGW-102 | (80-100) |
|---|---|
| 1 | 46.1 |
| 2 | 58.1 |
| 3 | 57.2 |
| 4 | 63.8 |

| KSGW-99 | (10-35) (45-50) |
|---|---|
| 1 | 0 |
| 2 | 0 |
| 3 | 0 |
| 4 | 0 |

| KDGW-98 | (26-75) |
|---|---|
| 1 | 9.4 |
| 2 | 6.9 |
| 3 | 19 |
| 4 | 14.5 |

| KDGW-97A | (95-145) |
|---|---|
| 1 | 0 |
| 2 | 0 |
| 3 | 0 |
| 4 | 0 |

| KGP-15 | S (20-23) |
|---|---|
| 1 | 0 |
| 2 | 0 |
| 3 | 0 |
| 4 | 0 |

| KGP-14 | M (68-70) | D (157-158) |
|---|---|---|
| 1 | 0 | B |
| 2 | 0 | B |
| 3 | 0 | 0 |
| 4 | 0 | 0 |

| KDGW-97 | (30-90) |
|---|---|
| 1 | 29.4 |
| 2 | 34.1 |
| 3 | 27.5 |
| 4 | 31.4 |

| KDGW-96 | (30-90) |
|---|---|
| 1 | 14.8 |
| 2 | 16.5 |
| 3 | 10.2 |
| 4 | 14.4 |

| KDGW-95 | (27.5-82.5) |
|---|---|
| 1 | 11.8 |
| 2 | 16.9 |
| 3 | 13.3 |
| 4 | 15.2 |

| KDGW-94A | (26-74) |
|---|---|
| 1 | 22.4 |
| 2 | 17.1 |
| 3 | 17.2 |
| 4 | 17.6 |

| KDGW-94B | (108-148) |
|---|---|
| 1 | 37.1 |
| 2 | 36 |
| 3 | 37.7 |
| 4 | 37.9 |

KGP-45, KGP-46, KGP-44, KGP-42, KGP-43, KGP-38A, KGP-41, KGP-39, KGP-38B/CD, KPZ-1, KGP-32, KMW-6, KGP-32A, KDGW-101, KSGW-99, KDGP-98, KGP-16A, KSGW-101, KDGW-98, KDGW-97A, KDGW-102, KGP-1, KPZ-2B, KGP-16, B1, KDGW-97, KGP-200, KGP-15, KGP-14, KMW-7A/7B, KDGW-96, KDGW-95, KDGW-94A, KDGW-94B, KPZ-2A

VETERANS DRIVE

BOLGER RD

KENT HIGHLANDS LANDFILL

APPROXIMATE REFUSE EXTENT

KING COUNTY GIS PARCEL LINE

APPROXIMATE REFUSE EXTENT

KEY

GAS PROBE
GAS EXTRACTION WELL
GW MONITORING WELL/ WATER LEVEL DATA

KEY

ABANDONED HISTORICAL PROBES/WELLS
PROPOSED PROBE/WELL

0 100' 200'
SCALE

NORTH

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# SEATTLE PUBLIC UTILITIES LANDFILL GAS MANAGEMENT (IN ASSOCIATION WITH PARAMETRIX)

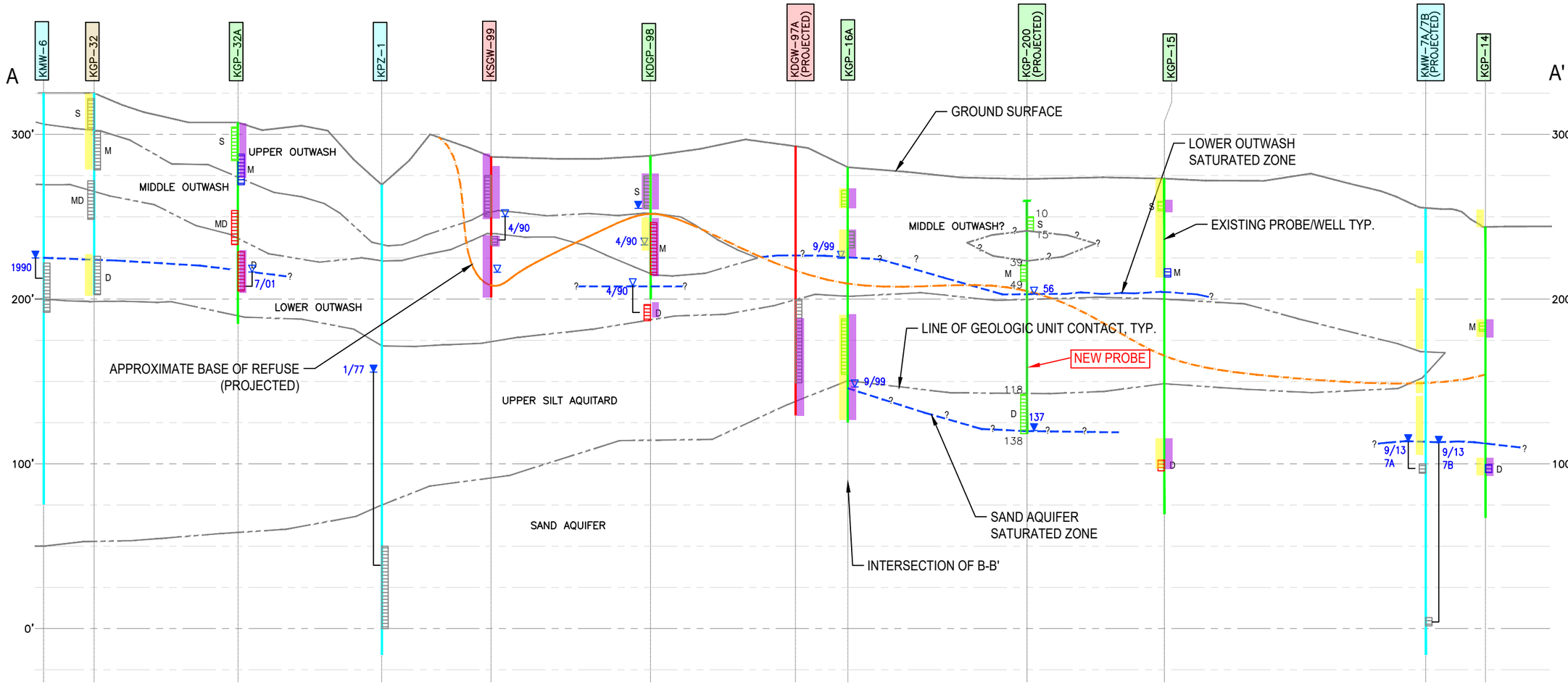
KENT HIGHLANDS LANDFILL
SEATTLE, WA

PROJECT MANAGER: K EASTHOUSE
INSPECTORS:
SURVEY DATE:
EHSI PROJECT #: 10887-4.4
DRAWN BY: F DIMALANTA
SCALE: SHOWN
ISSUE DATE: 06/20/18

## 2016 QUARTERLY MAXIMUM METHANE CONCENTRATION PERCENT BY VOLUME

SHEET/FIGURE

7



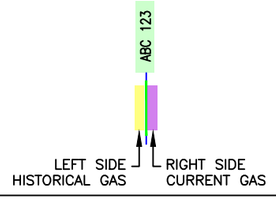

LEGEND:

- SCREEN INTERVAL
- WATER LEVEL IN COMPLETED WELL
- WATER LEVEL AT TIME OF DRILLING
- 7/01 DATE OF WATER LEVEL
- S SHALLOW GAS MONITORING PROBE
- M MIDDLE GAS MONITORING PROBE
- MD MIDDLE/DEEP GAS MONITORING PROBE
- D DEEP GAS MONITORING PROBE

FOR ILLUSTRATIVE PURPOSES ONLY.

LEGEND:

- ABC 123 GAS PROBE
- ABC 123 GAS EXTRACTION WELL
- ABC 123 MONITORING WELL/PIEZOMETER
- ABC 123 HISTORICAL PROBE
- GAS
- NO GAS




HORIZONTAL SCALE: 0 100' 200'
VERTICAL SCALE: 0 50' 100'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Seattle, Washington 98134
Ph: 206.381.1128
Fax: 206.254.4279


KENT HIGHLANDS LANDFILL

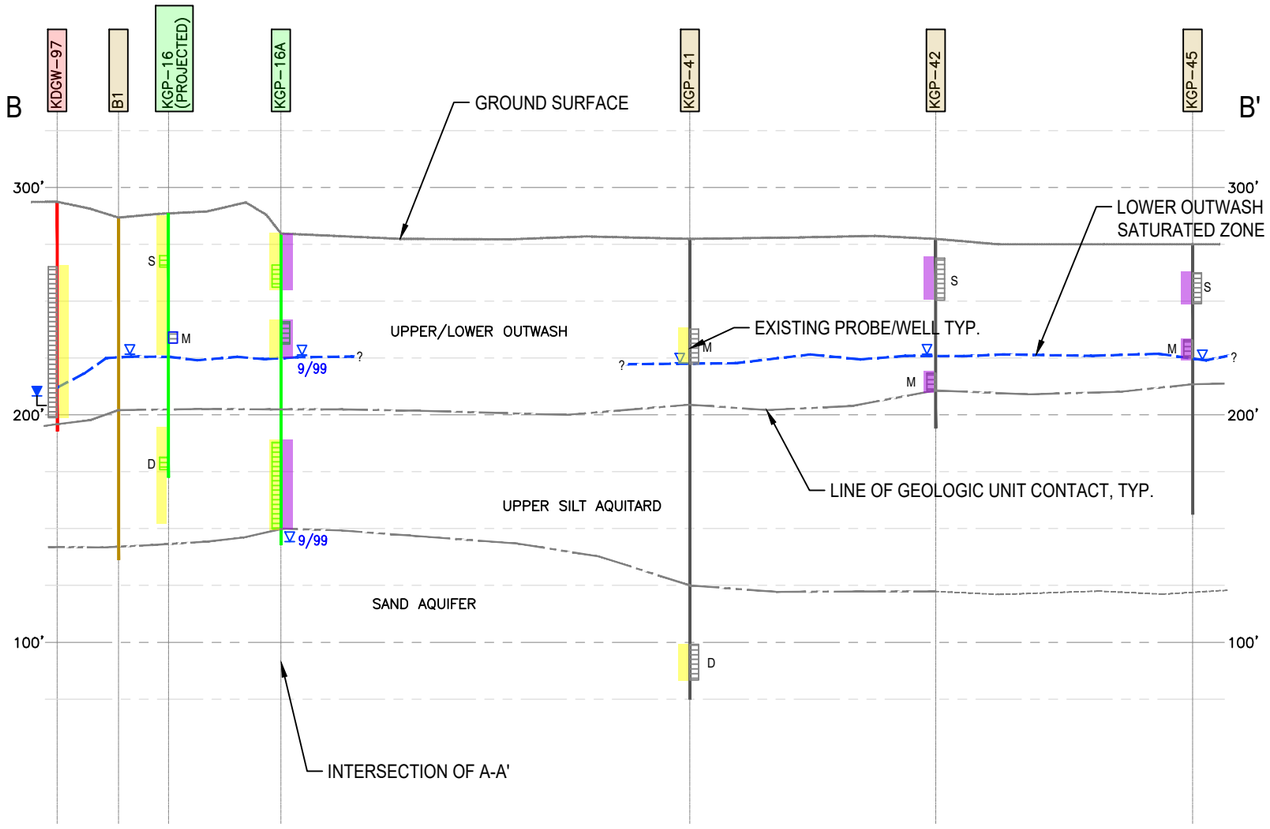
SEATTLE PUBLIC UTILITIES
(IN ASSOCIATION WITH PARAMETRIX)
SEATTLE, WA

PROJECT MANAGER: K EASTHOUSE
INSPECTORS:
SURVEY DATE:
EHSI PROJECT #: 10887-4.4
DRAWN BY: F DIMALANTA
SCALE: SHOWN
ISSUE DATE: 06/20/18

CROSS-SECTION
A-A'
HISTORICAL & CURRENT
LANDFILL GAS

SHEET/FIGURE

8




HORIZONTAL SCALE: 0 100' 200'
VERTICAL SCALE: 0 50' 100'

LEGEND:

- SCREEN INTERVAL
- WATER LEVEL IN COMPLETED WELL
- WATER LEVEL AT TIME OF DRILLING
- S SHALLOW GAS MONITORING PROBE
- M MIDDLE GAS MONITORING PROBE
- MD MIDDLE/DEEP GAS MONITORING PROBE
- D DEEP GAS MONITORING PROBE

FOR ILLUSTRATIVE PURPOSES ONLY.

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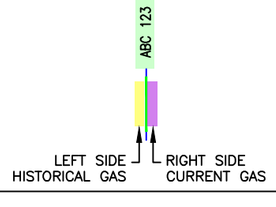
- ABC 123 GAS EXTRACTION WELL
- ABC 123 MONITORING WELL/PIEZOMETER
- ABC 123 HISTORICAL PROBE
- GAS
- NO GAS

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SEATTLE, WA

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SURVEY DATE:
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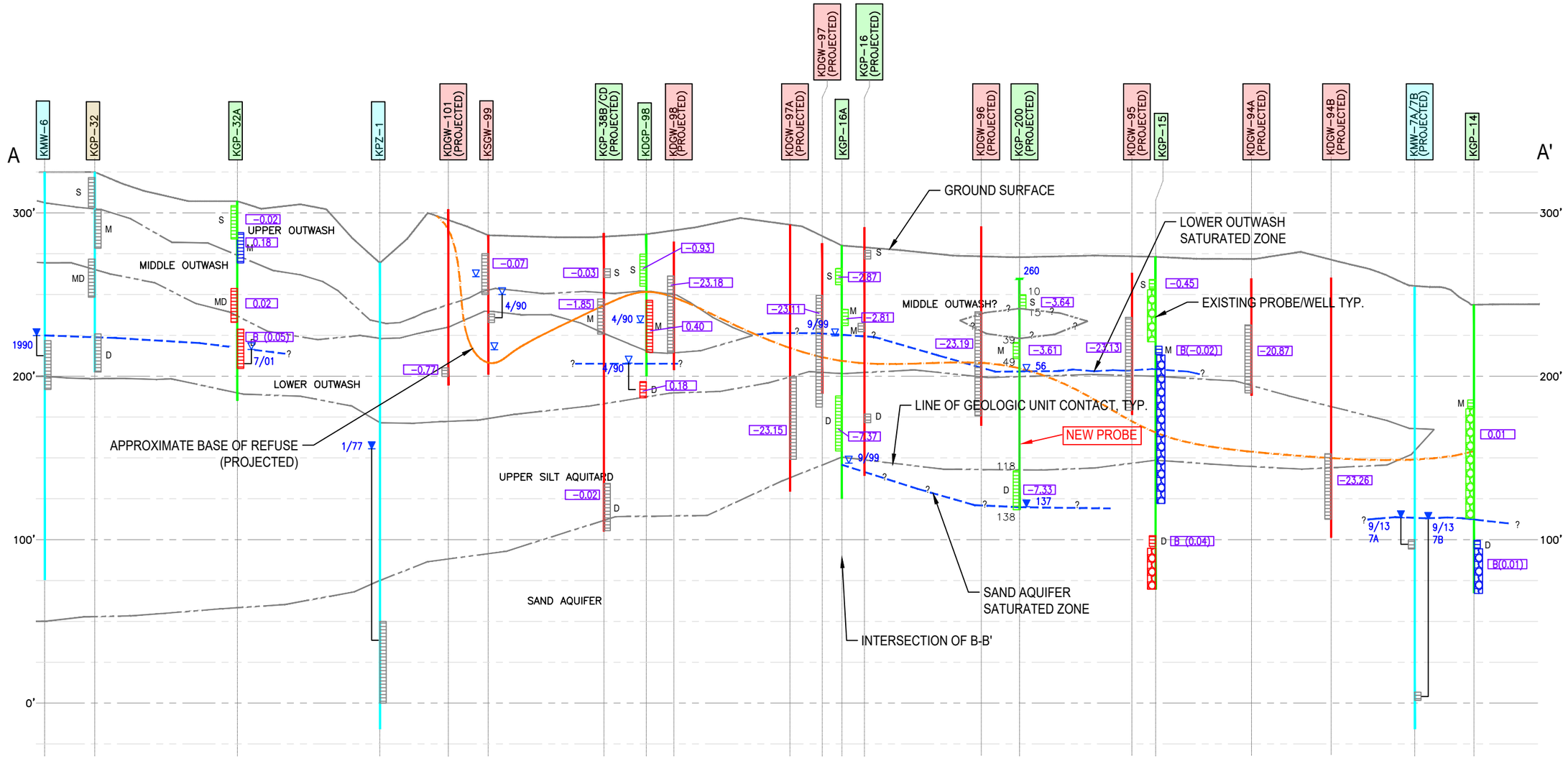
SCALE: SHOWN
ISSUE DATE: 06/20/18

CROSS-SECTION B-B'
HISTORICAL & CURRENT LANDFILL GAS

SHEET/FIGURE
9




HORIZONTAL SCALE: 0 100' 200'
VERTICAL SCALE: 0 50' 100'

LEGEND:

- SCREEN INTERVAL
- GRAVEL PACK
- WATER LEVEL IN COMPLETED WELL
- WATER LEVEL AT TIME OF DRILLING
- 7/01 DATE OF WATER LEVEL
- S SHALLOW GAS MONITORING PROBE
- M MIDDLE GAS MONITORING PROBE
- MD MIDDLE/DEEP GAS MONITORING PROBE
- D DEEP GAS MONITORING PROBE

FOR ILLUSTRATIVE PURPOSES ONLY.

LEGEND:

- ABC 123 GAS PROBE
- ABC 123 GAS EXTRACTION WELL
- ABC 123 MONITORING WELL/PIEZOMETER
- ABC 123 HISTORICAL PROBE
- B (1.26) STATIC PRESSURE OF WATER COLUMN (INCHES) 03/27/18 B = BLOCKED (PRESSURE)

CURRENT GAS PROBE SCREEN STATUS:

- UNBLOCKED
- INTERMITTENTLY BLOCKED
- ALWAYS BLOCKED

NOTE:

1. HYDROSTATIGRAPHY NOT ACCURATE TO ALL PROJECTED WELLS.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SEATTLE PUBLIC UTILITIES LANDFILL
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SEATTLE, WA

PROJECT MANAGER: K EASTHOUSE
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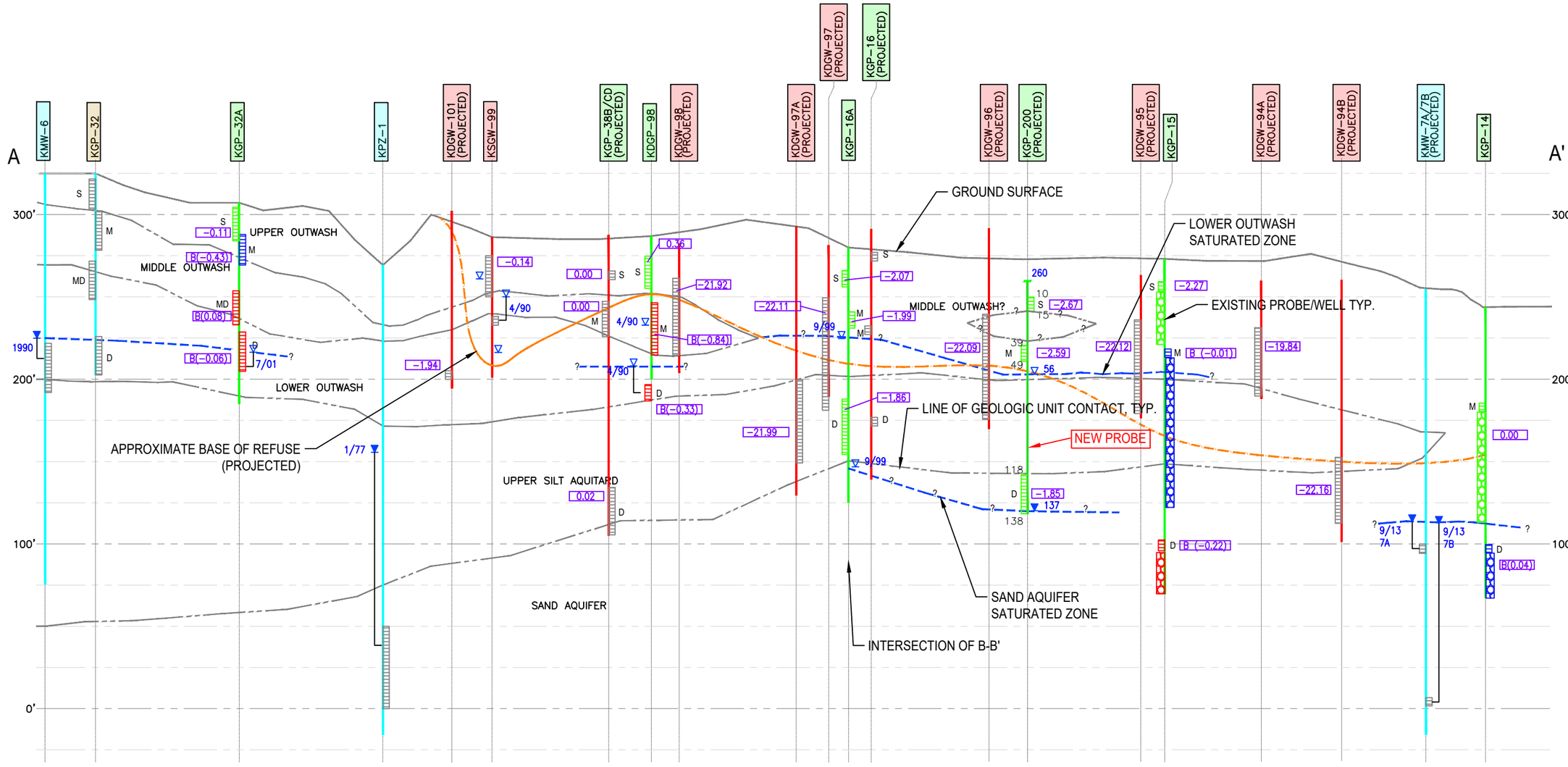
MARCH 27 STATIC PRESSURE -
STEADY BAROMETRIC PRESSURE CONDITIONS
(CROSS SECTION A-A')

SHEET/FIGURE
10




HORIZONTAL SCALE: 0 100' 200'
VERTICAL SCALE: 0 50' 100'

LEGEND:

- SCREEN INTERVAL
- GRAVEL PACK
- WATER LEVEL IN COMPLETED WELL
- WATER LEVEL AT TIME OF DRILLING
- 7/01 DATE OF WATER LEVEL
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- M MIDDLE GAS MONITORING PROBE
- MD MIDDLE/DEEP GAS MONITORING PROBE
- D DEEP GAS MONITORING PROBE

FOR ILLUSTRATIVE PURPOSES ONLY.

LEGEND:

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- ABC 123 GAS EXTRACTION WELL
- ABC 123 MONITORING WELL/PIEZOMETER
- ABC 123 HISTORICAL PROBE
- B (1.26) STATIC PRESSURE OF WATER COLUMN (INCHES) 03/27/18 B = BLOCKED (PRESSURE)

CURRENT GAS PROBE SCREEN STATUS:

- UNBLOCKED
- INTERMITTENTLY BLOCKED
- ALWAYS BLOCKED

NOTE:

1. HYDROSTATIGRAPHY NOT ACCURATE TO ALL PROJECTED WELLS.


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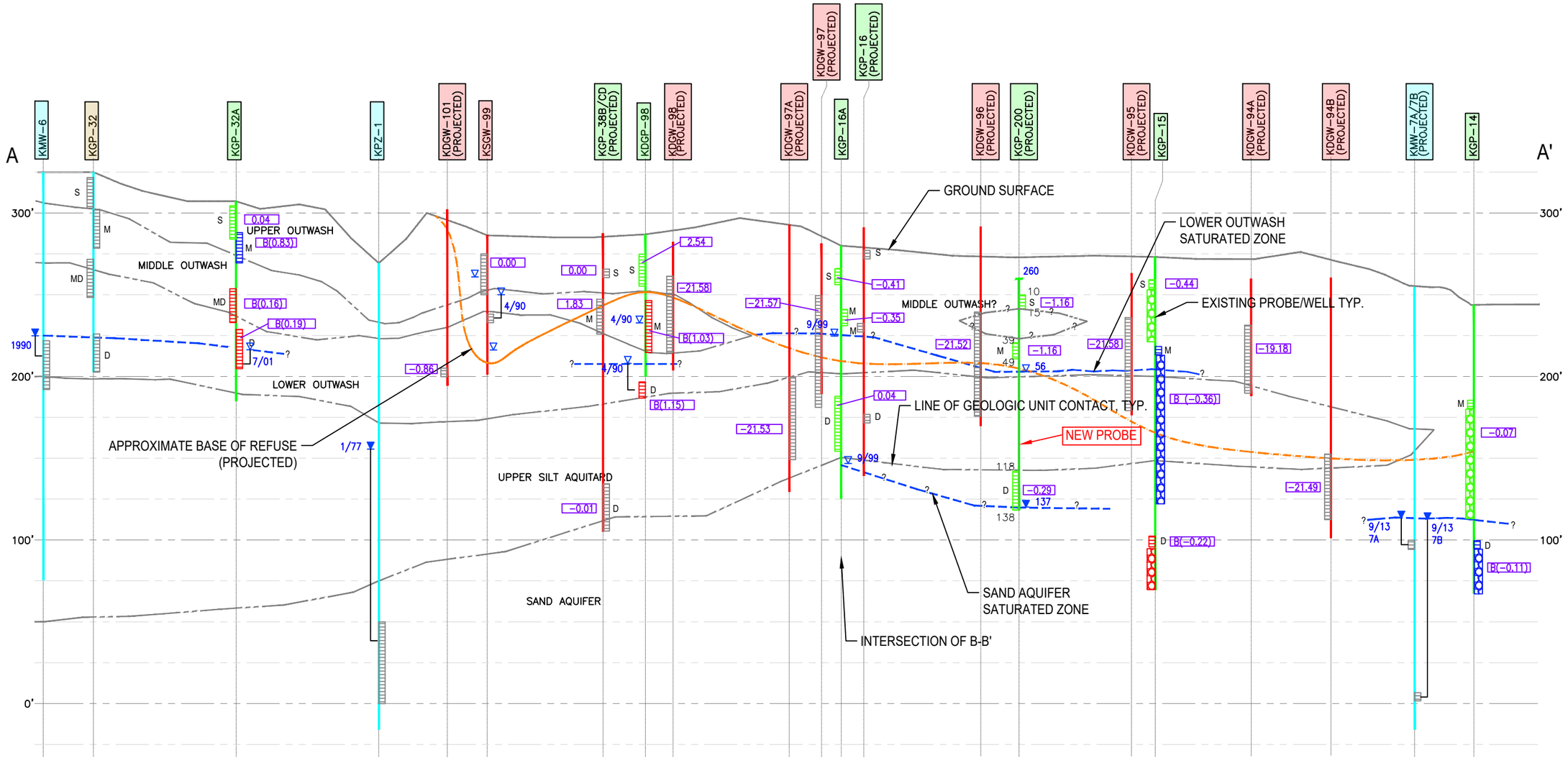
ISSUE DATE: 06/20/18

APRIL 10 STATIC PRESSURE - RISING BAROMETRIC PRESSURE CONDITIONS (CROSS SECTION A-A')

SHEET/FIGURE

11




HORIZONTAL SCALE: 0 100' 200'
VERTICAL SCALE: 0 50' 100'

LEGEND:

- SCREEN INTERVAL
- GRAVEL PACK
- WATER LEVEL IN COMPLETED WELL
- WATER LEVEL AT TIME OF DRILLING
- 7/01 DATE OF WATER LEVEL
- S SHALLOW GAS MONITORING PROBE
- M MIDDLE GAS MONITORING PROBE
- MD MIDDLE/DEEP GAS MONITORING PROBE
- D DEEP GAS MONITORING PROBE

FOR ILLUSTRATIVE PURPOSES ONLY.

LEGEND:

- ABC 123 GAS PROBE
- ABC 123 GAS EXTRACTION WELL
- ABC 123 MONITORING WELL/PIEZOMETER
- ABC 123 HISTORICAL PROBE
- B (1.26) STATIC PRESSURE OF WATER COLUMN (INCHES) 03/27/18 B = BLOCKED (PRESSURE)

CURRENT GAS PROBE SCREEN STATUS:

- UNBLOCKED
- INTERMITTENTLY BLOCKED
- ALWAYS BLOCKED

NOTE:

1. HYDROSTATIGRAPHY NOT ACCURATE TO ALL PROJECTED WELLS.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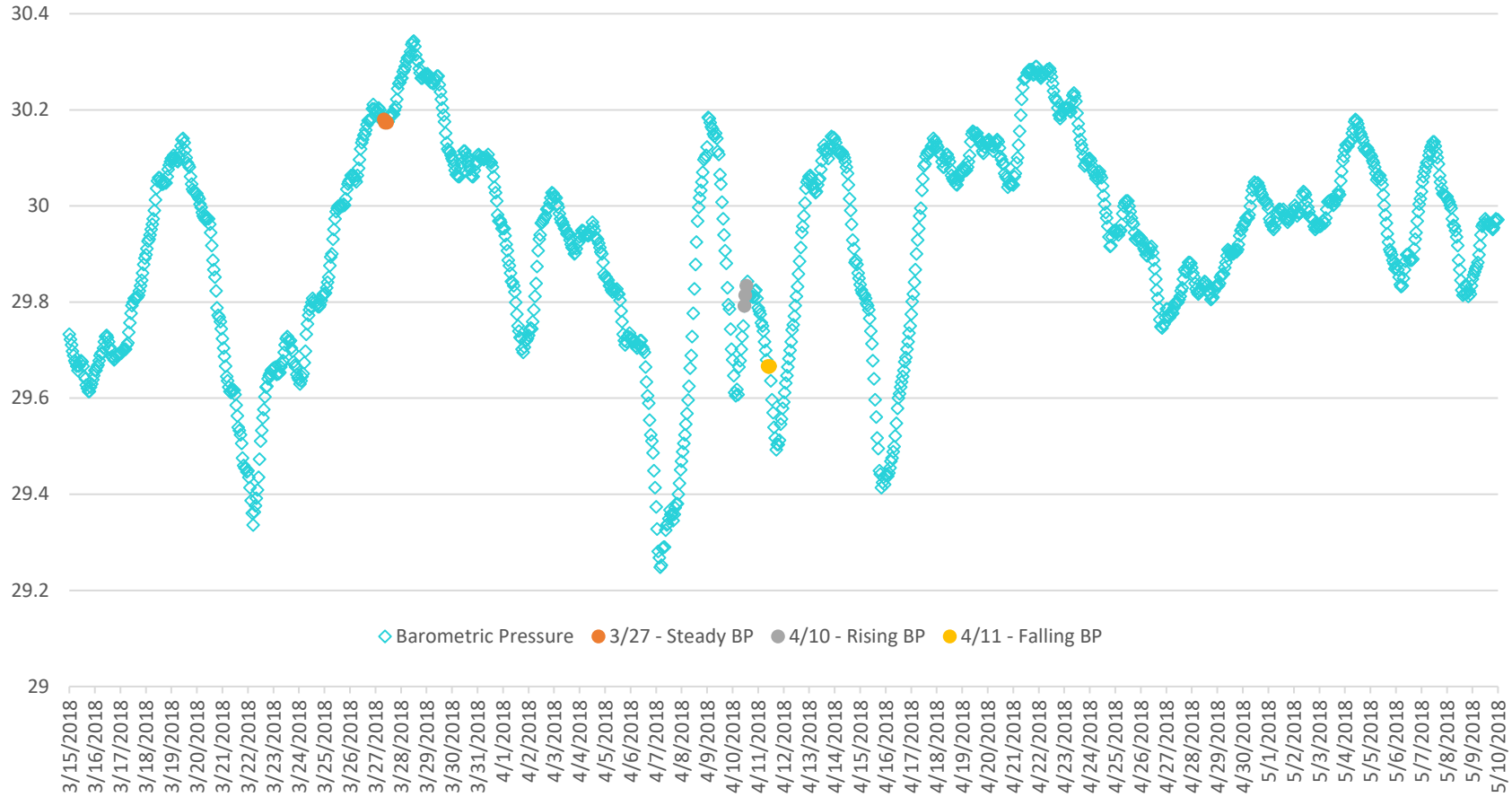
APRIL 11 STATIC PRESSURE - FALLING BAROMETRIC PRESSURE CONDITIONS (CROSS SECTION A-A')

SHEET/FIGURE

12




Barometric pressure source: King County Hydrologic Information Center, Northwest Ponds Level Station (Des Moines Creek)
https://green2.kingcounty.gov/hydrology/DataDownload.aspx



**Figure 13**
**Barometric Pressure Changes During Static Pressure Monitoring Events**

# APPENDIX A

# GAS WELL AND PROBE INFORMATION

# APPENDIX B

# FIELD ACTIVITIES WORK PLAN

# APPENDIX C

# KGP-200 FIELD DOCUMENTATION, PHOTOGRAPHS, AND WELL LOGS

# APPENDIX D

# KENT HIGHLANDS LANDFILL POST-CLOSURE OPERATIONS AND MAINTENANCE MANUAL, CHAPTER 7, LANDFILL GAS COLLECTION AND TRANSMISSION

# APPENDIX E

# BAROMETRIC PRESSURE GRAPHS