Flint Hills Resources Alaska, LLC

SECOND SEMIANNUAL 2016 ONSITE GROUNDWATER MONITORING REPORT

North Pole Terminal
North Pole, Alaska
DEC File Number: 100.38.090

January 31, 2017

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Prepared for:

Flint Hills Resources Alaska, LLC

Prepared by:

Arcadis U.S., Inc.
1100 Olive Way
Suite 800
Seattle
Washington 98101
Tel 206 325 5254
Fax 206 325 8218

Our Ref.:

B0081981.0076

Date:

January 31, 2017

Genevieve Magdziuk
Environmental Engineer

Gina Withy
Project Engineer

Rebecca Andresen
Vice President

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ACRONYMS AND ABBREVIATIONS

AAC	Alaska Administrative Code
ADEC	Alaska Department of Environmental Conservation
APOC	alternative point of compliance
Arcadis	Arcadis U.S., Inc.
Barr	Barr Engineering Company
BTEX	benzene, toluene, ethylbenzene, and xylenes
bwt	below the water table
COC	constituent of concern
DNR	Alaska Department of Natural Resources
DRO	diesel-range organics
FHRA	Flint Hills Resources Alaska, LLC
FHRA correspondence	FHRA correspondence to ADEC dated May 6, 2016
GAC East	original treatment system
GAC West	expanded groundwater recovery and treatment system
g/day	grams per day
gpm	gallons per minute
GRO	gasoline-range organics
GRTS	groundwater remediation and treatment system
lb/day	pound per day
LNAPL	light nonaqueous phase liquid
LTM Plan	Long-Term Monitoring Plan – 2015 Update
MAROS	Monitoring and Remediation Optimization System
NGP	North Gravel Pit
NSZD	natural source zone depletion
OCP	Final Onsite Cleanup Plan
OMM Plan	Operations, Maintenance, and Monitoring Plan – 2015 Update
Onsite RSAP	Revised Onsite Sampling and Analysis Plan
Onsite SCR – 2013	Onsite Site Characterization Report – 2013 Addendum
report	Second Semiannual 2016 Onsite Groundwater Monitoring Report

reporting period	third and fourth quarters of 2016
SGP	South Gravel Pit
site	Flint Hills Resources Alaska, LLC North Pole Terminal, located on H and H Lane in North Pole, Alaska
SOP	standard operating procedure
SWI	Shannon & Wilson, Inc.
VPT	vertical profile transect
µg/L	micrograms per liter

1 INTRODUCTION

On behalf of Flint Hills Resources Alaska, LLC (FHRA), Arcadis U.S., Inc. (Arcadis) prepared this Second Semiannual 2016 Onsite Groundwater Monitoring Report (report) for the FHRA North Pole Terminal, located on H and H Lane in North Pole, Alaska (site). This report summarizes onsite field activities completed during the third and fourth quarters of 2016 (reporting period) as described in Section 3 and in Table 1-1.

The data, analyses, and conclusions presented in this report are the product of a collaborative effort among FHRA's consulting team members. The team includes qualified professionals in a variety of technical disciplines from three environmental consulting firms: Arcadis, Shannon & Wilson, Inc. (SWI), and Barr Engineering Company (Barr). FHRA engaged these consulting firms to perform various tasks for the project. Pursuant to 18 Alaska Administrative Code (AAC) 75.335(c)(1), this report was prepared and submitted by a Qualified Environmental Professional. Samples were collected and analyzed in accordance with 18 AAC 75.355(a). The sampling and analyses for this reporting period were completed in accordance with the following documents, which were prepared by a Qualified Environmental Professional and approved by the Alaska Department of Environmental Conservation (ADEC):

- Final Onsite Cleanup Plan (OCP; Arcadis 2014)
- Long-Term Monitoring Plan – 2015 Update (LTM Plan; Arcadis 2015)
- Operations, Maintenance, and Monitoring Plan – 2015 Update (OMM Plan; Barr 2015)
- Revised Onsite Sampling and Analysis Plan (Onsite RSAP; Arcadis 2016)
- FHRA correspondence to ADEC dated May 6, 2016 (FHRA correspondence; FHRA 2016)
- ADEC correspondence to FHRA dated August 17, 2016 (ADEC 2016)

Third and fourth quarter 2016 groundwater monitoring were conducted in accordance with the LTM Plan (Arcadis 2015), OMM Plan (Barr 2015), changes requested by ADEC and noted in FHRA correspondence (FHRA 2016), and expanded groundwater recovery and treatment system (GAC West) shutdown approval in ADEC correspondence (ADEC 2016). Additionally, an update to the Onsite RSAP is included as Appendix A of this report.

The site, offsite area, and the site's physical setting are described in the conceptual site model, which was presented as Appendix A of the Onsite Site Characterization Report – 2013 Addendum (Onsite SCR – 2013; Arcadis 2013). The site is shown on Figure 1-1. Current and historical site features are shown on Figure 1-2. An onsite site plan is presented on Figure 1-3.

2 CURRENT GROUNDWATER MONITORING PROGRAM AND METHODS

Monitoring conducted during the third and fourth quarters of 2016 included:

- Groundwater elevation measurements
- Light nonaqueous phase liquid (LNAPL) thickness and migration monitoring
- Groundwater sampling and analysis of sulfolane
- Groundwater sampling and analysis of other constituents of concern (COCs; benzene, toluene, ethylbenzene, and xylenes [BTEX]; gasoline-range organics [GRO], and diesel-range organics [DRO]).

Table 1-1 summarizes the field activities completed during the reporting period. Monitoring methods and well construction details are summarized in the Onsite RSAP (Appendix A). One deviation from the plans above was noted during the reporting period: Monitoring wells MW-305-CMT-8 and S-39 were dry during the reporting period and were not sampled.

3 GROUNDWATER MONITORING RESULTS

Groundwater impacts have been characterized and continue to be monitored through the analysis of water-level gauging data and groundwater samples collected from onsite monitoring wells. This section presents the results of water-level gauging and groundwater analyses of onsite well samples. Data are summarized in Tables 3-1 through 3-9.

Historical groundwater elevation and LNAPL thickness measurements, and BTEX, GRO, DRO, sulfolane, and geochemical analytical results are included as Appendix B. Analytical laboratory reports are included as Appendix C. A data quality evaluation including ADEC quality assurance/quality control checklists is included as Appendix D. Field data sheets are included as Appendix E.

3.1 Groundwater Elevation

Depth to water measurements for the site-wide semiannual monitoring event were collected from monitoring wells on September 12 and 13, 2016, during third quarter 2016. Potentiometric maps are included for each monitoring zone: water table, 10 to 55 feet below the water table (bwt), 55 to 90 feet bwt, and 90 to 160 feet bwt (Figures 3-1 through 3-4). During the reporting period, the general direction of the horizontal hydraulic gradient was interpreted to be to the north-northwest, which is consistent with historical groundwater data. Groundwater elevations and horizontal hydraulic gradients were within the range of historical groundwater data. Depth to water measurements collected in the reporting period for other programs include groundwater remediation and treatment system (GRTS) hydraulic capture zone evaluation (Appendix M) and FHRA operator gauging (Appendix B).

Groundwater well field parameters and elevations are summarized in Tables 3-1 and 3-2, respectively. Groundwater elevation measurements collected as part of the GRTS hydraulic capture performance monitoring are presented in Section 5.1.

In addition to manual water-level measurements, automated measurements were collected with transducers from selected onsite wells and well nests. Groundwater elevation hydrographs were prepared from these automated data in accordance with the standard operating procedure (SOP; SWI 2013) using the most recent survey data. Error ranges, calculated in accordance with the method outlined in the SOP (SWI 2013), are shown on the well nest hydrographs presented in Appendix F. A detailed evaluation of transducer data and hydraulic gradients through 2013 is provided in Appendix 6-B of the Onsite SCR – 2013 (Arcadis 2013) and updated in Appendix M.

Surface water level measurements were recorded from gauging points located at the North Gravel Pit (NGP) and South Gravel Pit (SGP) on September 13, 2016. Data are summarized in Table 3-2 and on Figure 3-1. Historical gauging data are summarized in Appendix B.

3.2 Light Nonaqueous Phase Liquid Monitoring Results

LNAPL migration observations and thickness measurements were collected from a network of monitoring, observation, and recovery wells screened across the water table according to the LTM Plan (Arcadis 2015) and FHRA correspondence (FHRA 2016). Additionally, LNAPL was gauged throughout the reporting period during monitoring events outside of the LNAPL migration and thickness networks. A comprehensive LNAPL gauging table is presented in Appendix G.

3.2.1 Light Nonaqueous Phase Liquid Extent

Per the LTM Plan (Arcadis 2015) and FHRA correspondence (FHRA 2016), LNAPL migration observations were made from wells along the perimeter of the LNAPL plume. LNAPL was not observed in any of the LNAPL migration monitoring wells during the reporting period. Results are summarized in Table 3-3.

3.2.2 Light Nonaqueous Phase Liquid Thickness

Per the LTM Plan (Arcadis 2015) and FHRA correspondence (FHRA 2016), LNAPL thickness was measured in wells within the LNAPL thickness monitoring well network. These results are included in Table 3-4, and maximum thickness data measured during each quarter of the reporting period are presented on Figures 3-5 and 3-6. Additionally, LNAPL was gauged during the following monitoring events throughout the quarter: groundwater elevation monitoring, groundwater sampling and field parameter collection, vertical gradient monitoring, hydraulic capture monitoring, and FHRA operator gauging. A comprehensive table including gauging data from each monitoring event conducted at the site during the reporting period is included in Appendix G.

LNAPL thickness measurements during the reporting period are similar to historical results. LNAPL recovery results are discussed in Section 4.3.

3.2.3 Natural Source Zone Depletion Assessment Results

Twelve monitoring wells were sampled for natural source zone depletion (NSZD) parameters to evaluate the potential for NSZD to occur at the site. Sample locations are summarized in the LTM Plan (Arcadis 2015). LNAPL was not present in any of the NSZD monitoring wells. Field parameters were collected from all 12 monitoring wells and are presented in Table 3-1. Natural attenuation parameters (iron, manganese, sulfate, and methane) are presented in Table 3-5 and on Figure 3-7.

Biodegradation and dissolution of the submerged portion of the LNAPL can be assessed by comparing the chemical composition of groundwater upgradient from the source zone with groundwater immediately downgradient. Biodegradation of petroleum hydrocarbons results in a decrease in electron acceptor concentrations and a corresponding increase in biodegradation transformation products between upgradient and within and/or downgradient from the LNAPL plume. For further discussion of the NSZD process see the Onsite SCR - 2013 (Arcadis 2013).

A comparison of the upgradient and source zone/downgradient data indicates the following:

- Sulfate concentrations decrease from upgradient monitoring locations to the source zone monitoring locations, indicating sulfate reduction from anaerobic degradation.
- Dissolved iron increases from upgradient monitoring locations to the source zone monitoring locations, indicating iron reduction from anaerobic degradation.

- Dissolved manganese increases from upgradient monitoring locations the source zone monitoring locations, indicating manganese reduction from anaerobic degradation.
- The methane concentration increased from upgradient locations to the source zone monitoring locations, indicating carbon dioxide reduction or organic acid fermentation from anaerobic degradation.

This spatial comparison of upgradient and source zone natural attenuation parameters shows a clear decreasing trend in electron acceptor and an increasing trend in biodegradation transformation products, which indicates that biodegradation of LNAPL is occurring in the submerged portion of the LNAPL body. Downgradient parameters do not continue to show this trend, because concentrations appear to have reached background conditions in downgradient wells owing to distance from the source zone. Dissolved oxygen was measured at nominal levels from 0.05 to 1.53 milligrams per liter in the NSZD network monitoring wells, indicating that oxygen was not readily available as an electron acceptor and the aquifer is naturally anoxic.

3.2.4 Transmissivity Testing

LNAPL baildown and transmissivity tests were not conducted during the reporting period; insufficient LNAPL was present in wells planned for testing. The historical data table for the baildown tests is presented in Appendix H and historical plots of LNAPL transmissivity for wells R-21 and R-40 are included in Figures 3-8a and 3-8b.

3.2.5 Groundwater Extraction-Enhanced Light Nonaqueous Phase Liquid Recovery

No LNAPL transmissivity calculations were performed during the reporting period. Insufficient LNAPL was recovered from recovery wells R-21 and R-40. Time series plots for groundwater extraction-enhanced LNAPL recovery at R-21 and R-40 during previous monitoring events are included on Figures 3-8a and 3-8b, respectively. The historical data tables for the groundwater extraction-enhanced recovery data are presented in Appendix I.

3.3 Onsite Monitoring Well Sampling

Onsite wells included in the other COCs monitoring network in the LTM Plan (Arcadis 2015) and FHRA correspondence (FHRA 2016) were sampled for BTEX, GRO, and DRO during the reporting period. Results are summarized in Table 3-6. Figure 3-9 presents analytical results for benzene, including the inferred extent of the dissolved-phase benzene distribution within the suprapermafrost aquifer at the site.

Analyses for sulfolane were completed on groundwater samples collected from the wells identified in the LTM Plan (Arcadis 2015) and FHRA correspondence (FHRA 2016), including wells that are on a monthly performance monitoring schedule for the GRTS, as described in the OCP (Arcadis 2014). Sulfolane analytical results are summarized in Table 3-7 and on Figures 3-10 through 3-16, which show the inferred extent (based on current and past data) of the dissolved-phase sulfolane distribution at the water table, 10 to 55 feet bwt, and 55 to 90 feet bwt, within the suprapermafrost aquifer at the site. In accordance with the updated sampling schedule (Arcadis 2016), no data were collected during fourth quarter 2016 from the interval at 90 to 160 feet bwt.

Groundwater samples were collected from the alternative point of compliance (APOC) wells to evaluate the vertical distribution of sulfolane concentrations. Sample results collected from the APOC, which includes well clusters MW-301 through MW-306, MW-101-25A, MW101-60, MW-141-20, and MW-143-20, are summarized in Table 3-8 and on Figures 3-10 through 3-16. Sulfolane concentrations for the APOC wells are also summarized in Table 3-8 and on Figures 3-17 and 3-18. Sulfolane concentrations continue to decline along the APOC, with the shallow data at the MW-304 well nest showing the highest residual concentrations. The MW-304 well nest is located near the historical longitudinal axis of the plume and, according to tracer studies, is likely influenced by dual-porosity characteristics (Arcadis 2013).

3.4 Sulfolane Mass Flux

Mass flux was evaluated using third quarter 2016 results. Methods to calculate mass flux and site-specific geologic input data are included as Appendix J. The Mass Flux Toolkit developed by GSI Environmental for the Department of Defense Environmental Security Technology Certification Program (Farhat et al. 2006) was used to calculate sulfolane mass flux across the vertical profile transect (VPT).

Sulfolane mass flux across the VPT was first calculated with this method from data collected in November 2011 and was estimated at approximately 86 grams per day (g/day; or 0.19 pound per day [lb/day]). A sulfolane mass flux of approximately 3.7 g/day (0.008 lb/day) was calculated for third quarter 2016, less than one-twentieth of the initial flux calculated in samples collected in November 2011 (Figure 3-19). Mass flux rates across the VPT continue to decrease and are presented on Figure 3-20. The zones exhibiting the majority of mass flux are summarized in Table 3-9.

3.5 Statistical Analysis of Benzene and Sulfolane Data

A statistical and graphical evaluation of benzene and sulfolane concentration trends using a Mann-Kendall trend analysis is conducted semiannually during the first and third quarters at monitoring and observation wells to evaluate plume migration and stability and remedial action effectiveness, and to identify relationships between dissolved-phase concentrations, groundwater elevations, and flow directions. The use of the Monitoring and Remediation Optimization System (MAROS) for Mann-Kendall trend analysis was applied to groundwater monitoring data collected since 2006 for sulfolane from monitoring and observation wells. The Mann-Kendall trend analysis was applied to groundwater monitoring data for benzene from monitoring and observation wells since the last detection of LNAPL (historical data were used if LNAPL has never been detected). Wells having a historical presence of LNAPL were excluded from evaluation of the benzene statistical trend. Section 5.2 presents an additional evaluation of the sulfolane and benzene concentration trends for data collected from the performance monitoring network associated with the GRTS since 2011.

The analysis trends are expressed as probably increasing, increasing, probably decreasing, decreasing, stable, or no trend. Results of the Mann-Kendall trend analysis for the reporting period are presented in Tables 1 and 2 and on Figures 1A through 2D of Appendix K and are summarized in the table below.

Parameter Trend	Third Quarter	
	Benzene	Sulfolane
Number of wells	142	295
All results nondetect[1]	89	106
Insufficient data points[1]	6	10
Probably decreasing	0	9
Decreasing	10	100
Probably increasing	1	4
Increasing	2	6
Stable	8	31
No trend	26	29

Note:
[1]Wells with insufficient data points for the statistical analysis (less than four points), but with all results below detection limits, are listed under "all results nondetect."

The results of the trend analyses are discussed below.

3.5.1 Benzene Statistical Evaluation

The Mann-Kendall trend analysis indicated an increasing or probably increasing benzene concentration trend in wells R-46, MW-134-20, and O-24. Based on the benzene time series plots included as Attachment 1 in Appendix K, concentrations appear to be decreasing in well R-46 since October 2014, remain relatively stable in well MW-134-20, and increasing in well O-24. Well R-46 is within the detectable benzene plume at the site and is currently being actively pumped by the recovery system, which is likely influencing dissolved benzene concentrations at this location. O-24 is within the detectable benzene plume at the site, near the downgradient extent. MW-134-20 is on the eastern upgradient extent of the benzene plume and in the reporting period only had an estimated (J-flagged) benzene detection.

3.5.2 Sulfolane Statistical Evaluation

Using statistical approaches to evaluate groundwater monitoring data collected since 2006, increasing or probably increasing trends were observed at only 10 onsite monitoring wells (MW-179B-50, MW-304-96, MW-304-CMT-10, MW-321-65, MW-345-55, MW-345-75, MW-348-65, MW-355-15, S-21, and S-39). Of these, MW-304-96 is outside the detectable sulfolane plume and has not exhibited detections since third quarter 2013. Sulfolane results collected from monitoring well MW-321-65 have typically been non-detect; however, an estimated result greater than the laboratory detection limit but below the laboratory quantification limit was detected during this reporting period. Wells S-21, MW-179B-50 and MW-355-15 are located upgradient or adjacent to the GTRS and are therefore influenced by the groundwater remediation effort; the sulfolane results for these wells were also estimated (J-flagged) concentrations this reporting period.

A visual observation of the concentration trend plots (Attachment 1 of Appendix K) indicates that concentrations at most locations with increasing Mann-Kendall trends have been either stable or decreasing since October 2014. The exceptions include O-27-65, which appears to have a seasonal variation, MW-304-CMT-10, MW-345-55, and MW-345-75. Concentrations have remained less than 20 micrograms per liter (µg/L) in O-27-65, less than 25 µg/L in MW-345-75, and less than 40 µg/L in MW-345-55 and MW-304-CMT-10 since sampling began at these locations. MW-345-55 and MW-345-75 are located adjacent to recovery well R-43, which is likely influencing sulfolane concentrations at this location. Although not reflected as an increasing trend by the Mann-Kendall analysis, an increase in sulfolane concentrations was noted in the fourth quarter at MW-330-20 and MW-372-15. This well is located downgradient of the soil excavation completed in the Southwest Area in 2015.

3.6 Nonroutine Activities

During this reporting period, well development was performed at 64 onsite monitoring wells in accordance with procedures outlined in the Onsite RSAP (Arcadis 2016).

4 GROUNDWATER REMEDIATION AND TREATMENT SYSTEM RESULTS AND EVALUATION

This section discusses operating results for the existing GRTS for the reporting period. Ongoing remediation efforts at the site include groundwater recovery and treatment and LNAPL recovery and recycling, as described in Sections 4.2 and 4.3, respectively. The GRTS layout is shown on Figure 4-1 and process flow diagrams for the systems are shown on Figures 4-2a and 4-2b.

On August 31, 2016, the GAC West component of the GRTS was shut down in accordance with approval granted by ADEC in a letter dated August 17, 2016 (ADEC 2016). As part of the shutdown, R-47 and R-48 were turned off and flow from R-42 was routed to the GAC East treatment system. Additional monitoring completed post-shutdown at the request of ADEC is discussed in Section 5.2.3.

4.1 Associated Permits

Treated groundwater from the original treatment system (GAC East) is discharged at the SGP in accordance with wastewater disposal permit 2005-DB0012 issued by ADEC (with subsequent ADEC-approved revisions). Treated groundwater from GAC West was discharged at the NGP in accordance with Final Approval to Operate issued by ADEC (with subsequent ADEC-approved revisions). Groundwater for the purpose of groundwater recovery and treatment is withdrawn in accordance with Temporary Water Use Authorization TWUA A2016-41 issued by the Alaska Department of Natural Resources (DNR).

4.2 Groundwater Recovery and Treatment

The average groundwater recovery rate for the GRTS was 386 gallons per minute (gpm) during the reporting period. This rate was calculated from the combined GAC East and GAC West (through August 31, 2016) flow rates and is consistent with target recovery rates for the GRTS given the GAC West shutdown. The average flow rates (when pumping) and total and percent runtimes for the reporting period are shown in the table below, along with the target flow rate for each well.

Location	Third and Fourth Quarter 2016 Average Flow Rate	Target Flow Range*	Third and Fourth Quarter 2016 Runtime	Percent Runtime
R-21	43.6 gpm	40 to 50 gpm	4,212 hours	95.4
R-35R	51.1 gpm	50 to 65 gpm	4,206 hours	95.2
R-40	16.3 gpm	See R-45 below	4,170 hours	94.4
R-42	68.3 gpm	60 to 85 gpm	4,214 hours	95.4
R-43	61.0 gpm	60 to 85 gpm	4,054 hours	91.8
R-44	60.5 gpm	60 to 70 gpm	3,927 hours	88.9

Location	Third and Fourth Quarter 2016 Average Flow Rate	Target Flow Range*	Third and Fourth Quarter 2016 Runtime	Percent Runtime
R-45	34.2 gpm (with R-40, 50.4 gpm)	50 to 65 gpm (combined with R-40)	3,992 hours	90.4
R-46	30.3 gpm	30 to 40 gpm	4,047 hours	91.6
R-47[1]	65.0 gpm	55 to 80 gpm	1,472 hours	99.6
R-48[1]	95.0 gpm	80 to 120 gpm	1,474 hours	99.6

Notes:

[1] R-47 and R-48 shutdown occurred on August 31, 2016. Average flow rate and percent runtime per well is prior to shutdown.

* Target flow ranges as presented in the OMM Plan (Barr 2015).

Each of the recovery wells maintained a high runtime during the reporting period. Downtime for each recovery well is further discussed in Section 4.6.

4.2.1 Cumulative Groundwater Recovery

Table 4-1 summarizes the volume and rate of groundwater recovered monthly from 2009 through the end of the reporting period. Approximately 102,000,000 gallons of recovered groundwater were remediated during the reporting period.

4.2.2 Groundwater Treatment Performance Evaluation – GAC East

In accordance with the OCP (Arcadis 2014) and the wastewater disposal permit for GAC East, FHRA conducted monthly monitoring of the GAC East effluent during the reporting period. FHRA also conducted multiple additional monitoring events to evaluate performance of the treatment system. Results for the monthly and additional monitoring events are summarized in Tables 4-2a through 4-2d.

The sulfolane concentration measured in the GAC East final effluent was below 15 µg/L and below the detection limit during each monitoring event for the reporting period (Table 4-2a).

BTEX and semivolatile organic compound concentrations measured at the GAC East final effluent were below the discharge limits for the system during each monitoring event (Tables 4-2b and 4-2c). A low-level detection of naphthalene (0.035 J µg/L) was reported in monitoring well MW-106-25; however, this concentration is less than the limit established in wastewater disposal permit 2005-DB0012. Total organic carbon, total suspended solids, iron, and manganese monitoring were performed to evaluate system operation; results are included in Table 4-2d. Analytical laboratory reports are provided in Appendix C.

No GAC media changeouts were completed during the reporting period.

4.2.3 Groundwater Treatment Performance Evaluation – GAC West

During the reporting period and prior to shutdown at the end of August, GAC West was sampled at an increased frequency (in addition to the required monthly sampling) to evaluate system performance. Results for monitoring completed at GAC West are included in Tables 4-3a, 4-3b, and 4-3c.

As shown in Table 4-3a, GAC West removed sulfolane and the final effluent was less than 15 µg/L and less than the detection limit during each monitoring event in the reporting period. Quarterly BTEX monitoring was also conducted and the results are shown in Table 4-3b. Results for the GAC West recovery wells (R-42, R-47, and R-48) were less than detection limits and less than the cleanup levels in ADEC Table C (18 AAC 75.345). Iron and manganese monitoring were performed to evaluate system operation and the results are included in Table 4-3c.

Additional sulfolane monitoring results following the GAC West shutdown are included in Table 4-4 and further discussed in Section 5.2.3.

No GAC media changeouts were performed during active operation. Following shutdown of GAC West, the GAC media was removed from the vessels and disposed offsite.

4.3 Light Nonaqueous Phase Liquid Recovery Rates and Recycling

During the reporting period, FHRA performed LNAPL recovery via a skimmer system when adequate LNAPL was consistently present and/or conducted manual recovery using a vacuum truck or portable LNAPL pump at the wells shown on Figure 4-1. LNAPL recovered from the skimmer systems and from manual recovery activities is stored onsite until it is recycled.

LNAPL recovery for the reporting period is summarized in Table 4-5; historical LNAPL recovery at the site since 1986 is summarized in Table 4-6. During the reporting period, 11.7 gallons of LNAPL were recovered; 1,257 gallons of LNAPL were recovered in 2016. From 1986 to present, approximately 398,276 gallons of LNAPL have been recovered. LNAPL gauging data collected as part of the operations and maintenance of the LNAPL recovery efforts are included in Appendix G.

4.4 Benzene, Toluene, Ethylbenzene, and Xylenes Mass Capture

FHRA monitored the BTEX concentrations in recovered groundwater on a monthly (or more frequent) basis to calculate mass removal rates (Table 4-7). Based on the monitoring results, BTEX mass removal averaged 0.88 lb/day and totalled approximately 148 pounds during the reporting period; 262 pounds of BTEX were recovered in 2016.

The BTEX concentrations were less than detection limits in GAC West recovery well samples (Table 4-3b); therefore, GAC West is not included in the mass removal calculations shown in Table 4-7.

4.5 Sulfolane Mass Capture

FHRA monitored the sulfolane concentration in recovered groundwater at each active recovery well; mass recovery rates for each well are summarized in Tables 4-8a and 4-8b for GAC East and GAC West, respectively. During the reporting period, the highest average mass recovery rate was measured in well

R-21 (0.13 lb/day; Table 4-8a). Well R-46 had no measurable recovery of sulfolane and is considered to be outside the sulfolane plume (Table 4-8a).

Table 4-9 summarizes the overall sulfolane mass recovery for the groundwater recovery system. The rates were calculated from sulfolane concentrations measured monthly in the GRTS influent or individual recovery wells. Sulfolane mass removal averaged 0.30 lb/day and, based on the system runtime, totalled approximately 51 pounds during the reporting period; 110 pounds of sulfolane were removed in 2016.

4.6 Summary of Routine and Nonroutine Repairs, Changes, and Maintenance

As described in Section 4.1, GAC West along with R-47 and R-48 were shut down on August 31, 2016. Flow from R-42 was routed to GAC East after the shutdown.

The GRTS maintained a high runtime percentage as demonstrated at the individual recovery wells (Section 4.2.1). A non-routine downtime event occurred at GAC East and wells in September 2016 for removal of solids from the Gallery Pond and replacement of the sand filter media. Four recovery wells (R-43, R-44, R-45, and R-46) had downtime for physical and chemical well rehabilitation but maintained a high overall runtime percentage for the reporting period. A description of the well rehabilitation methods and results is included in Appendix L. Periodic interim well rehabilitation of R-35R, R-43, R-44, R-45, and R-46 was completed during the reporting period. As described in Appendix L, the interim well rehabilitation includes using the Hydropuls® tool to dislodge scale and biological growth. The pumps are not removed from the wells for the interim rehabilitation. The results of the efforts have indicated improvement in preventing excessive drawdown in the recovery wells. Step-drawdown tests are not being performed during the interim rehabilitation work. Table 4-10 summarizes additional downtime for smaller maintenance events and changes in the individual recovery wells or treatment systems during the reporting period.

As further described in Section 5, results of the hydraulic capture events and continued overall declines in concentration in the sulfolane and BTEX plumes north of the GRTS capture zone indicate the effectiveness of the GRTS during the third and fourth quarters of 2016 and preceding quarters. Thus, operation of the GRTS is meeting its performance goals and limited downtime events in the reporting period fell within design expectations.

During this reporting period, a light silvery sheen inconsistent with the behavior of petroleum was observed near the outlet of the South Gravel Pit among windblown organic debris. This was reported and discussed with the ADEC Water Program staff. It was determined to be most likely of an organic origin and not connected with the operation of the GAC East treatment system. Recovery well R-44 was also shut down for brief periods to evaluate the presence and potential impact of a foam in the GAC East gallery pond as noted in Table 4-10. The foam was contained within and removed from the gallery pond.

5 GROUNDWATER REMEDIATION AND TREATMENT SYSTEM PERFORMANCE MONITORING

This section discusses performance monitoring results for the GRTS, as defined in the OCP (Arcadis 2014), including two quarterly hydraulic capture events conducted during the third and fourth quarters of 2016.

5.1 Groundwater Capture Evaluation

Performance monitoring for the GRTS includes hydraulic capture monitoring (quarterly) and water quality assessment (quarterly to annually). Performance monitoring is conducted to confirm the continued effectiveness of the GRTS. Capture of the sulfolane and BTEX plumes was evaluated during the reporting period using groundwater elevation and groundwater quality data. Measured depth to water, calculated hydraulic heads, and capture zone estimates are presented in Appendix M.

The capture evaluation results indicate that operation of the GRTS at rates achieved throughout the third and fourth quarters of 2016 supports meeting the combined groundwater extraction and treatment system performance standard of 15 µg/L at the APOC (Arcadis 2014), with the possible exception of expected rebounding concentrations related to wells R-47 and R-48 being idled (ADEC 2016). Appendix M provides additional detail regarding the capture zone evaluation.

5.2 Concentration Trend Evaluation

FHRA evaluates the concentration data for sulfolane (quarterly or semiannual sampling frequency) and benzene (semiannual or annual sampling frequency) to identify any recent trends that may be influenced by remediation measures and to evaluate the performance of the GRTS.

5.2.1 Sulfolane

Table 5-1 summarizes FHRA's interpretation of sulfolane concentration trends since 2010 at individual GRTS performance monitoring wells to identify the effects of enhanced groundwater remediation; wells are generally presented in the table from west to east. The performance monitoring wells identified in Table 5-1 are categorized based on location relative to the treatment zone; each area is summarized below:

- *Upgradient*. Sulfolane concentration trends for performance monitoring wells located upgradient from the GRTS treatment zone are generally decreasing or stable. It is likely that the upgradient locations are minimally influenced by operation of the GRTS; these trends are believed to primarily be the result of a decreasing stored sulfolane mass in upgradient source areas.
- *Within the treatment zone*. Sulfolane concentration trends for monitoring wells located within the treatment zone are decreasing or stable, with the following exceptions:

  - Since 2011, sulfolane concentrations in well O-5 have fluctuated between 100 and 260 µg/L. The variation may be the result of GAC West recovery wells operation, which altered the flow paths in the area prior to capture.
  - Sulfolane concentrations in wells MW-345-55 and MW-345-75 have shown seasonal variation with an overall increase from 2013 through fourth quarter 2016, which may be the result of increased pumping in R-43 and subsequent altering of flow paths in the area prior to capture.
  - Sulfolane concentrations increased in MW-370-15 and MW-370-55 during the fourth quarter 2016. These monitoring wells are located adjacent to recovery well R-48, which was shut down in third quarter 2016 as discussed in Section 4. The increased concentrations are likely due to the elimination of dilution that was occurring with R-48 operating.
- *Downgradient*. Sulfolane concentration trends for monitoring wells located downgradient from the treatment zone are decreasing or stable. A fluctuation was noted in both MW-154A-75 and MW-154B-95 during fourth quarter 2016, to concentrations just greater than 20 µg/L.

In addition to the trends presented in Table 5-1, a low concentration zone has developed immediately north (downgradient) of the recovery wells (Figures 3-14, 3-15, and 3-16). Overall downward trends in concentration and mass flux at the APOC are consistent with the source controls and operation of the GRTS. As previously noted, GAC West was shut down on August 31, and post-shutdown monitoring is discussed in Section 5.2.3.

5.2.2 Benzene

Performance monitoring for benzene occurred during third quarter 2016, with the exceptions noted in Section 2. Table 5-2 summarizes FHRA's interpretation of benzene concentration trends since 2010 in individual performance monitoring wells to identify the effects of enhanced groundwater remediation, which are generally presented from west to east. The performance monitoring wells identified in Table 5-2 are categorized based on location relative to the treatment zone; each area is summarized below:

- *Upgradient*. Of the seven monitoring wells located upgradient of the GRTS, three wells are consistently nondetect. Concentrations had been increasing in well MW-130-25, but results of the two most recent monitoring events may indicate stabilization. Three wells were not sampled due to the presence of LNAPL.
- *Within the treatment zone*. Ten of the 13 treatment zone monitoring wells have decreasing or stable concentrations. Three of the 13 monitoring wells were not sampled due to the presence of LNAPL.
- *Downgradient*. Eleven of the 12 downgradient wells have stable or decreasing concentrations. Increasing concentrations of benzene were noted in well O-24.

5.2.3 GAC West Shutdown Monitoring

As previously described, GAC West and recovery wells R-47 and R-48 were shut down on August 31, 2016. As requested by ADEC, the sulfolane monitoring frequency was increased at the following wells to evaluate contaminant rebound:

- MW-370-15 and MW-370-55: increase the monitoring frequency from semiannual to quarterly
- MW-351-55 and MW-351-75: increase the monitoring frequency from semiannual to quarterly (MW-351-15 was already being monitored quarterly)
- MW-302-CMT-20: increase the monitoring frequency from semiannual to quarterly
- MW-302-CMT-70: increase the monitoring frequency from annual to semiannual.

Table 4-4 presents the results of the increased sulfolane monitoring post-shutdown noted above plus additional downgradient wells monitored after August 31, 2016. The results of sulfolane monitoring at downgradient locations sampled in the fourth quarter (i.e., post-shutdown) did not indicate a contaminant rebound in the fourth quarter 2016 because the results were either nondetect or less than the limit of quantitation. These trends are consistent with the dual-porosity mechanism retarding the transport of sulfolane (Arcadis 2013). As noted above, sulfolane concentrations rebounded to expected concentrations in wells MW-370-15 and MW-370-55 (which is adjacent to R-48), but have not yet rebounded in wells MW-351-15, MW-351-55, or MW-351-75, which are located less than 200 feet directly downgradient of the MW-370 well nest. Additional downgradient locations (including the remainder of the MW-302 nest, MW-303 nest, and MW-358 nest) are measured at varying frequencies and were not sampled in the fourth quarter (i.e., post-shutdown), but will be evaluated following future monitoring events.

5.3 Transect Trend Evaluation

To further evaluate the effectiveness of the GRTS, sulfolane concentration trends were evaluated along three longitudinal transects parallel to the groundwater flow path (Figure 5-1). Transects A and B (Figures 5-2 and 5-3) comprise shallow wells (water table and 10 to 55 feet bwt); Transect C (Figure 5-4) comprises deeper wells (55 to 90 feet bwt).

The data presented on Figures 5-2 and 5-3 demonstrate that shallow sulfolane concentrations downgradient from the treatment zone are lower than concentrations upgradient from the treatment zone. In addition, these figures show that decreasing downgradient sulfolane concentrations correlate with increased pumping from the GRTS starting in 2010. This indicates that ongoing groundwater extraction is successfully recovering sulfolane-impacted groundwater and is eliminating the migration of sulfolane-impacted groundwater past the GRTS. Additionally, concentrations measured in deeper wells are decreasing or stable (Figure 5-4).

6 CONCLUSIONS

Groundwater monitoring and sampling events were conducted during the reporting period in accordance with the LTM Plan (Arcadis 2015) and OMM Plan (Barr 2015), FHRA and ADEC correspondence (FHRA 2016, ADEC 2016), and the Onsite RSAP (Arcadis 2016). The GRTS system was operated and monitored in accordance with the OCP (Arcadis 2014) and the OMM Plan (Barr 2015); GAC West was shut down on August 31 in accordance with ADEC approval (ADEC 2016). This section summarizes conclusions based on results of the onsite field activities conducted during the reporting period:

- Groundwater monitoring data collected during the reporting period are consistent with data collected during recent quarters.
- The statistical analyses included in Appendix K show that sulfolane concentrations in 109 wells and benzene concentrations in 10 wells across the plume are decreasing or probably decreasing, while sulfolane concentrations in eight wells and benzene concentrations in three wells across the plume are increasing or probably increasing.
- Sulfolane concentrations and trends continue to decrease in the onsite areas near the downgradient site boundary.
- BTEX concentrations are consistent with historical detections and the core of the BTEX plume appears to be stable. BTEX concentrations continue to be limited to the developed area onsite.
- GAC West and recovery wells R-47 and R-48 were shut down during the reporting period. Concentration rebound effects were minimal.
- The active portion of the GRTS continued to capture and remediate sulfolane- and BTEX-impacted groundwater.
- Concentrations of sulfolane and BTEX in the downgradient portion of the plume adjacent to the capture zone continue to show an overall decline, thus indicating the effectiveness of the GRTS.

7 REFERENCES

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Farhat, S., C. Newell, and E. Nichols. 2006. Mass Flux Toolkit to Evaluate Groundwater Impacts, Attenuation, and Remediation Alternatives. User's Manual. Version 1.0. March.

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