Imagine the result

Flint Hill Resources Alaska, LLC

Interim Remedial Action Plan Addendum

North Pole Refinery
North Pole, Alaska

January 2013

ARCADIS

for Gina France
Project Engineer

Andrew Ohrt
Senior Engineer

Brad Koons
Principal Engineer

Rebecca Andresen
Technical Expert

Interim Remedial Action Plan Addendum

North Pole Refinery
North Pole, Alaska

Prepared for:
Flint Hill Resources Alaska, LLC

Prepared by:
ARCADIS U.S., Inc.
430 First Avenue North
Suite 720
Minneapolis
Minnesota 55401
Tel 612 339 9434
Fax 612 336 4538

Our Ref.:
B0081981.0030

Date:
January 2013

Tables

Figures

Appendices

Acronyms and Abbreviations

AAC	Alaska Administrative Code
ACL	alternative cleanup level
Addendum	Interim Remedial Action Plan Addendum
ADEC	Alaska Department of Environmental Conservation
API	American Petroleum Institute
ARCADIS	ARCADIS U.S., Inc.
AS	air sparge/air sparging
ASTM	ASTM International
Barr	Barr Engineering Company
bgs	below ground surface
BOD	biochemical oxygen demand
BTEX	benzene, toluene, ethylbenzene, and xylene
BWT	below water table
city	North Pole, Alaska
CMT	continuous multichannel tubing
COC	constituent of concern
COD	chemical oxygen demand
CSM	conceptual site model
cy	cubic yards
DNR	Alaska Department of Natural Resources
DO	dissolved oxygen
DPR	dual-phase recovery
FHRA	Flint Hills Resources Alaska, LLC
FNSB	Fairbanks North Star Borough
FS	feasibility study

ft^2	square foot
ft^3/day	cubic feet per day
GAC	granular activated carbon
GC/MS	gas chromatography/mass spectrometry
gpm	gallons per minute
GVEA	Golden Valley Electric Association
IRAP	Interim Remedial Action Plan
ITRC	Interstate Technology & Regulatory Council
LNAPL	light nonaqueous phase liquid
NFIP	National Flood Insurance Program
NPR	North Pole Refinery
NSZD	natural source zone depletion
O&M	operation, maintenance, and monitoring
PID	photo ionization detector
PJD	Preliminary Jurisdictional Determination
power plant	electrical generating facility
psi	pounds per square inch
RCRA	Resource Conservation and Recovery Act
Revised Draft Final HHRA	Revised Draft Final Human Health Risk Assessment
ROI	radius of influence
RSAP	Revised Sampling and Analysis Plan
scfm	standard cubic feet per minute
SCR-2011	Site Characterization Report – Through 2011
SCR-2012	Site Characterization Report – 2012 Addendum
SFHA	Special Flood Hazard Area
SGS	SGS North America, Inc.

site	FHRA North Pole Refinery, an active petroleum refinery located on H and H Lane in North Pole, Alaska
TIC	tentatively identified compound
U.S.	United States
USACE	U.S. Army Corps of Engineers
VOC	volatile organic compound
VPT	Vertical Profiling Transect
WWTP	wastewater treatment plant
µg/L	micrograms per liter
°F	degrees Fahrenheit

Executive Summary

This Interim Remedial Action Plan Addendum (Addendum) proposes additional interim remedial actions to address light nonaqueous phase liquid (LNAPL) and groundwater impacts at the Flint Hills Resources Alaska, LLC (FHRA) North Pole Refinery, an active petroleum refinery located on H and H Lane in North Pole, Alaska (site). This Addendum focuses on constituents of concern (COCs) identified in the Revised Draft Final Human Health Risk Assessment (ARCADIS U.S., Inc. [ARCADIS] 2012a) and data collected during site characterization activities as reported in the Site Characterization Report – Through 2011 (SCR-2011; Barr Engineering Company [Barr] 2012a) and the Site Characterization Report – 2012 Addendum (SCR-2012; ARCADIS 2013).

LNAPL and groundwater data presented in the SCR-2011 (Barr 2012a) and SCR-2012 (ARCADIS 2013) indicate that impacts are present across the developed areas of the site and groundwater impacts extend downgradient. This Addendum supplements the Interim Remedial Action Plan (IRAP) submitted in September 2010 that presented a plan to optimize the existing remediation system to aggressively address LNAPL and sulfolane-impacted groundwater on site (Barr 2010). This Addendum provides the scope and layout of additional proposed onsite interim remedial actions to further reduce the potential for migration of sulfolane-impacted groundwater offsite and to reduce LNAPL mass at the site.

The following interim remedial actions are proposed for implementation:

- Expanded groundwater extraction and dual-phase LNAPL recovery
- Air sparge barrier
- Expanded LNAPL recovery

For this Addendum, FHRA uses the 14 micrograms per liter (µg/L) alternative cleanup level (ACL) referenced by the Alaska Department of Environmental Conservation (ADEC) in its July 19, 2012 letter (ADEC 2012a). This Addendum is submitted subject to the positions and reservations expressed by FHRA in its August 20, 2012 letter (FHRA 2012).

1. Introduction

ARCADIS U.S., Inc. (ARCADIS) prepared this Interim Remedial Action Plan Addendum (Addendum) on behalf of Flint Hills Resources Alaska, LLC (FHRA) for the FHRA North Pole Refinery (NPR), an active petroleum refinery located on H and H Lane in North Pole, Alaska (site). This Addendum proposes additional onsite remedial activities and supplements the Interim Remedial Action Plan (IRAP) submitted in September 2010 (Barr Engineering Company [Barr] 2010). This Addendum does not directly address sulfolane-impacted groundwater in the offsite area related to the Williams plume.

It is acknowledged that in 18 Alaska Administrative Code (AAC) 75.990(115), the Alaska Department of Environmental Conservation (ADEC) defines the term “site” as an “area that is impacted, including areas impacted by the migration of hazardous substances from a source area, regardless of property ownership.” For this Addendum, the term “onsite” is the area that is located within the property boundary of the FHRA NPR, and the term “offsite” is the area located outside the property boundary in the downgradient north-northwest direction, based on the approximate extent of the dissolved-phase sulfolane plume detected at concentrations above the laboratory limit of detection (approximately 3 micrograms per liter [µg/L]).

COCs were previously evaluated in the Site Characterization and First Quarter 2011 Groundwater Monitoring Report (Barr 2011a), the Site Characterization Work Plan Addendum (ARCADIS 2011a), the Site Characterization Report – Through 2011 (SCR-2011; Barr Engineering Company [Barr] 2012a) and the Site Characterization Report – 2012 Addendum (SCR-2012; ARCADIS 2013). The Revised Draft Final Human Health Risk Assessment (Revised Draft Final HHRA; ARCADIS 2012a) evaluates whether concentrations of site-related constituents in groundwater pose a risk to onsite and offsite receptors.

The IRAP (Barr 2010) presents a plan to optimize the existing remediation system to aggressively address light nonaqueous phase liquid (LNAPL) and sulfolane-impacted groundwater on site. This Addendum provides the scope and layout of additional proposed onsite interim remedial actions to aggressively treat sulfolane contamination, further reduce the potential for migration of sulfolane-impacted groundwater offsite, and to reduce LNAPL mass at the site. The site location, facility features and layout are shown on Figures 1-1 through 1-4.

1.1 Site Priorities

In a letter to FHRA dated August 18, 2011 (ADEC 2011), the ADEC listed priorities for the site per 18 AAC 75. FHRA has focused its work to address the ADEC's priorities and significant work has been completed toward achieving them. The interim remedial actions proposed below continue to address the site priorities through aggressive remediation of sulfolane and LNAPL onsite and monitoring of remedial progress.

1.2 Report Organization

This Addendum is organized as follows:

- *Section 1 – Introduction*. This section describes the purpose and organization of this Addendum.
- *Section* 2 – *Background and Current Remedial Operations*. This section provides some historical perspective and describes ongoing interim remedial activities.
- *Section 3 – Phase 8 Monitoring Wells.* The section provides proposed wells along the north property boundary and additional wells along the VPT.
- *Section 4 – Proposed Interim Remedial Actions*. This section introduces the supplemental interim remedial actions proposed to address contamination at the site. This section describes conceptual designs and specifications for selected interim remedial strategies.
- *Section 5 – Waste Management Plan*. This section presents provisions for handling waste generated during remedial implementation and routine operations and maintenance (O&M) and performance monitoring of the remediation systems at the site.
- *Section 6 – Implementation Schedule*. This section summarizes FHRA's proposed schedule for implementation of the scope of work summarized in this Addendum.
- *Section 7 – References.* This section lists the sources of information cited in this Addendum.

2. Background/Characterization

This section describes the general physical site conditions, the current site conceptual model, and ongoing remedial actions at the site. The site history and site characterization activities are discussed in the SCR-2011 (Barr 2012a), the SCR-2012 (ARCADIS 2013), and quarterly groundwater monitoring reports.

2.1 Site Description

The 240-acre site is located just inside the city limits of North Pole, Alaska (the city). The city is located approximately 13 miles southeast of Fairbanks, Alaska, within Fairbanks North Star Borough (FNSB; Figure 1-1). NPR is an active petroleum refinery that receives crude oil feedstock from the Trans-Alaska Pipeline. The site was developed in the mid-1970s and operations began in 1977. A detailed facility map is included in Appendix A.

Three crude oil processing units are located in the southern portion of the site, making up the process area. Tank farms are located in the central portion of the site. Truck-loading racks are located immediately north of the tank farms and a railcar-loading rack is located west of the tank farms. Previously, a truck-loading rack was located between the railcar-loading rack and the tank farms, near the intersection of Distribution Street and West Diesel. Wastewater treatment lagoons, storage areas, and two flooded gravel pits (the North and South Gravel pits) are located in the western portion of the site. Rail lines and access roads are located in the northernmost portion of the site. Along the southern site boundary, partially surrounded by the NPR, is an electrical generating facility (power plant) operated by Golden Valley Electric Association (GVEA). FHRA representatives indicated that the power plant burns heavy aromatic gas oil (diesel 4) produced at the site. The property south of the site and the GVEA power plant is occupied by the Petro Star, Inc. Refinery. An expanded site plan is presented on Figure 1-4.

Immediately north of the site are residential properties and the city's wastewater treatment plant (WWTP). The North Pole High School is located immediately north and west of the WWTP and the residential properties. An undeveloped parcel, owned by the Alaska Department of Natural Resources (DNR), lies between the site and the WWTP. The Tanana River is located to the south and west, flowing in a northwesterly direction toward Fairbanks. East of the site is property that is residential or undeveloped, the Old Richardson Highway, and the Alaska Railroad right-of-way.

2.2 Physical Setting

The site and surrounding area are located on a relatively flat-lying alluvial plain that is situated between the Tanana River and Chena Slough (locally known as Badger Slough). The site is located on the Tanana River Floodplain. Up to 2 feet of organic soils are typically found in the undeveloped portions of the site. A discontinuous silt and silty sand layer that varies in thickness from 0 to 10 feet typically occurs beneath the organic soils. Alluvial sand and gravel associated with the Tanana River are present below the organic soil and silty layers. Depth to bedrock has been estimated at 400 to 600 feet below ground surface (bgs).

North Pole is located within an area of Alaska characterized by discontinuous permafrost (Ferrians 1965). Permafrost tends to act as a confining unit, impeding and redirecting the flow direction of groundwater (Glass et al. 1996). Based on regional information (Williams 1970, Miller et al. 1999), permafrost is assumed to be absent beneath the Tanana River.

The aquifer beneath the alluvial plain between the Tanana River and Chena Slough generally consists of highly transmissive sands and gravels (Cederstrom 1963, Glass et al. 1996). The Tanana River has a drainage area of approximately 20,000 square miles upstream of Fairbanks (Glass et al. 1996). Near the site, this aquifer is reportedly greater than 600 feet thick (at least 616 feet thick near Moose Creek Dam) (Glass et al. 1996). Beyond the zones of influence of the site groundwater recovery system, groundwater flow directions are controlled by discharge from the Tanana River to the aquifer and from the aquifer to Chena River, as described by Glass et al. (1996). Variations in river stage through time are believed to be the primary cause of variations in flow direction through the aquifer between the rivers (Lilly et al. 1996, Nakanishi and Lilly 1998). Based on data from U.S. Geological Survey water table wells, the flow direction varies up to 19 degrees from a north-northwesterly direction to a few degrees east of north. The flow direction trends to the north-northwest in spring and more northerly in the summer and fall (Glass et al. 1996).

2.3 Current Conceptual Site Model

An updated ADEC conceptual site model (CSM) form was presented in the Revised Draft Final HHRA (ARCADIS 2012a) and is attached to this Addendum as Appendix B. The CSM form was completed per the Policy Guidance on Developing Conceptual Site Models (ADEC 2010) and will continue to be refined as additional data are collected.

2.4 Ongoing Interim Remedial Activities

The ongoing remediation actions at the site include active groundwater recovery and treatment, active LNAPL recovery and recycling, and LNAPL natural source zone depletion. The remediation system is described and evaluated in the SCR-2011 (Barr 2012a). Additional status updates have been provided in the quarterly groundwater monitoring reports (ARCADIS 2012b). The current components of the active remediation systems are described below:

- Groundwater recovery from five recovery wells (R-21, R-35R, R-39, R-40, and R-42).

- Recovered groundwater is treated through a prefilter for solids removal, a coalescer for LNAPL removal, and four air strippers for removal of volatile organic compounds (VOCs) before accumulating in the Gallery Pond. The groundwater from the Gallery Pond is then pumped through sand filters for solids removal and a 4-vessel granular activated carbon (GAC) system for sulfolane removal. The layout of the groundwater recovery and treatment system is shown on Figure 2-1 and a process flow diagram of the system is shown on Figure 2-2.

- Pneumatic LNAPL recovery systems are continuously operated at MW-138, R-20R, R-21, R-35R and R-40. Additional pneumatic LNAPL recovery systems are operated seasonally at R-32, R-33 and S-50. The LNAPL recovery system currently utilized at S-50 was previously installed at O-2, but was moved due to low LNAPL recovery. FHRA also uses a hand-held product recovery pump at other locations (e.g., R-39) if LNAPL is present and recovery is possible.

The system described above includes improvements completed as part of the IRAP (Barr 2010); additional interim actions currently planned are described in Section 2.4.2. To provide background for the existing system capabilities and performance as part of the overall comprehensive remedial strategy, this Addendum summarizes current operating conditions and performance through the end of 2012 for groundwater recovery and treatment (Section 2.4.1), LNAPL recovery (Section 2.4.3), and natural source zone depletion (NSZD; Section 2.4.4).

2.4.1 Groundwater Recovery and Treatment

Table 2-1 summarizes the volume and discharge rate of recovered groundwater from the treatment system during 2009, 2010, 2011, and 2012. Groundwater recovery for each year is summarized below:

- 2009: 69,200,000 gallons
- 2010: 107,100,000 gallons
- 2011: 136,900,000 gallons
- 2012: 188,300,000 gallons

As shown in the groundwater recovery totals above and in Table 2-1, FHRA has continued to increase total groundwater recovery.

Pumping rates for the individual recovery wells are measured weekly and the average for 2012 for each well is shown in the table below. This table also presents the total and percent runtimes for 2012. The system reliability improvements completed as part of the 2010 IRAP have resulted in increased runtime and, as shown below, each recovery well maintained a runtime of greater than 99 percent.

Location	Third Quarter 2012 – Average Flow Rate	Third Quarter 2012 Runtime	Percent Runtime
R-21	45 gpm	8,760 hours	99.7%
R-35R	88 gpm	8,772 hours	99.9%
R-39	82 gpm	8,739 hours	99.5%
R-40	52 gpm	8,772 hours	99.9%
R-42	116 gpm	8,762 hours	99.7%

Note:

gpm = gallons per minute

Recovered groundwater is pumped to an onsite groundwater treatment system that removes any entrained LNAPL and dissolved-phase contaminants. The groundwater treatment system process flow diagram is provided on Figure 2-2. Section 5 of the SCR-2011 (Barr 2012a) evaluates the performance of the groundwater treatment system and results are provided in the quarterly groundwater monitoring reports; thus, the results are not reiterated in this Addendum. However, results of the treatment system effectiveness are summarized below:

- The air stripper towers effectively removed the majority of dissolved-phase hydrocarbons from the recovered groundwater prior to discharge to the Gallery Pond.

- A sand filter system and a GAC filter system were installed to remove sulfolane and any remaining benzene, toluene, ethylbenzene, and xylenes (BTEX) constituents (if present).

- BTEX and sulfolane concentrations at the GAC system effluent have been below the limit of quantitation during every monitoring event since the GAC system went online on June 9, 2011.

- During multiple monitoring events, substantial sulfolane reduction has been observed across the air strippers and between the air stripper outlets and the GAC vessel inlet. As described in the SCR-2011 (Barr 2012a), sulfolane is relatively non-volatile and reduction across the air strippers and between the air stripper outlets and the GAC vessel inlet was not expected. FHRA performed additional bench-scale testing to potentially identify the mechanism for this degradation; results were presented in Appendix B of the Draft Final Onsite Feasibility Study (ARCADIS 2012c). Because the air strippers have been in use since FHRA began operations at the refinery, it is expected that this removal process has been occurring through the years of operation. As the system has been upgraded, removal would have increased.

2.4.2 Replacement Groundwater Recovery Wells

FHRA is in the process of completing installation of four additional recovery wells (R-43, R-44, R-45, and R-46). These new wells will replace R-39 and R-40, and augment capture in the R-21 area. Recovery wells existing prior to 2012 are shown on Figure 2-1. A technical memorandum describing the proposed recovery wells was submitted to ADEC on September 14, 2012, and approval of the plan was received from the ADEC on October 3, 2012 (ADEC, pers. comm. 2012b). The technical memorandum was updated to provide additional information, as communicated to ADEC and its contractors, and the updated version is included as Appendix C along with email communications regarding the original technical memorandum.

The proposed wells are designed with dual-phase capability to allow for a greater increase in both groundwater and LNAPL recovery. The proposed design includes deeper wells with larger diameter casings and longer screened intervals compared to the existing recovery wells. Each proposed well will have a submersible groundwater recovery pump and a floating LNAPL skimmer pump.

2.4.3 Light Nonaqueous Phase Liquid Recovery

FHRA continues to perform LNAPL recovery via skimmer systems in wells MW-138, R-20R, R-21, R-35R, and R-40 (Figure 2-1). Seasonally-operated LNAPL skimming systems are installed at R-32, R-33 and S-50. Manual product recovery is also currently completed with a vacuum truck or portable product pump at O-11, O-13, O-27, R-18, R-22, R-32, R-34, and R-39. The recovered LNAPL from the systems is accumulated in product storage tanks and is periodically recycled within a refinery process unit. Additional LNAPL is recovered by the groundwater recovery system and is removed by the coalescer installed ahead of the air stripper.

Table 2-2 summarizes the LNAPL recovery during 2012. During this period, 2,625 gallons of LNAPL were recovered. The majority of the recovery during the reporting period was from recovery wells R-20R, R-21, R-32, R-35R, and R-40; monitoring well MW-138; and the coalescer.

Table 2-3 summarizes LNAPL recovery at the site since 1986. From 1986 through the end of 2012, approximately 393,949 gallons of LNAPL were recovered.

2.4.4 Natural Source Zone Depletion

NSZD is a combination of natural processes that reduce the mass of LNAPL through time. The SCR-2011 (Barr 2012a) presents a qualitative assessment and quantitative estimate of NSZD. Results of the qualitative assessment across the site showed a decreasing trend in electron acceptors (proceeding downgradient) and increasing trend in biodegradation transformation products through the LNAPL-impacted areas. Biodegradation of LNAPL is occurring through a combination of dissolution and biodegradation in the saturated zone and volatilization and biodegradation in the unsaturated zone.

3. Phase 8 Well Installation

FHRA proposes to install new monitoring well nests along the north property boundary. These wells will be utilized to confirm performance of the proposed interim remedial activities and that groundwater cleanup levels in Table C of 18 AAC 75, or site-specific ACLs in the case of sulfolane, for the following listed COCs: sulfolane, naphthalene, benzene, xylenes, and 1,3,5-TMB, GRO and DRO are being achieved at the property boundary over time. The proposed Phase 8 monitoring wells may be incorporated into the sulfolane groundwater monitoring network during future groundwater monitoring events, following development and an initial sampling event.

3.1 Phase 8 Wells at the North Property Boundary

Seven new well nests, with approximately 33 new wells, are proposed along the north property boundary to evaluate the extent of sulfolane concentrations at the property margin as shown on Figure 3-1. One well at each of these locations will be advanced to permafrost (or 150 feet in depth) to document the depths to the top of permafrost, if encountered. The proposed wells will require clearance of vegetation and construction of access roads in the undeveloped portions of the site.

Each well nest will be composed of a water table well, a well screened above the top of permafrost and additional wells at variable depths as summarized on Table 3-1. The proposed vertical spacing of wells at each location is dependent on the location of each nest relative to the centerline of the plume; wells closer to the centerline of the plume have a more dense vertical spacing. Installation of Phase 8 wells in the undeveloped areas of the site is pending approval of the Preliminary Jurisdictional Determination (PJD) and a 404 permit from the United States Army Corps of Engineering (USACE). It is anticipated that the PJD and 404 permit application will be submitted by January 31, 2013. These proposed Phase 8 wells will also be included in the 2013 Site Characterization Work Plan.

3.2 Phase 8 Monitoring Well Installation

Because permafrost is often encountered at variable depths downgradient from the facility process areas, drilling at each location has the potential to encounter permafrost. If encountered, permafrost will be logged in accordance with the procedures described in the Revised Sampling and Analysis Plan (RSAP; ARCADIS 2012d). The maximum depth proposed for deep borings is 150 feet bgs, top of permafrost (if encountered), or the maximum operational depth of the drill rig procured to complete the work. The locations of specific onsite wells that are proposed to be installed to delineate permafrost are presented in Table 3-1 and on Figure 3-1.

Where possible, the deepest well at each location will be installed first and the water table well second. This will allow the project team to add or remove proposed wells as needed. Final spacing of remaining wells will be determined based on the evaluation of subsurface conditions. For example, if permafrost is observed closer to the ground surface, fewer wells will be installed. Conversely, if permafrost is not observed within 130 feet of the ground surface, an additional well may be added. Geologic logging at each well nest will be completed only on the deepest well boring.

Soils samples will be screened using a photoionization detector, and soil samples with readings exceeding 20 parts per million are proposed to be containerized and submitted to SGS Laboratories in Anchorage, Alaska (SGS). The submitted samples will be analyzed for the following:

- BTEX by USEPA Method 8021
- Gasoline Range Organics (GRO) by AK Method 101
- Diesel Range Organics (DRO) by AK Method 102
- Sulfolane by USEPA modified Method 8270D with Isotope Dilution

Drilling, soil sampling, soil classification, soil screening, permafrost classification, and monitoring well installation will be completed in accordance with the procedures described in the RSAP.

4. Proposed Interim Remedial Actions

FHRA proposes to upgrade the current groundwater extraction system with additional recovery wells and install an onsite air sparge (AS) barrier downgradient of the current groundwater extraction system. These interim actions are proposed to further reduce the potential for offsite sulfolane migration above the 14 µg/L ACL over time. Also included is an update to the LNAPL removal activities proposed in the IRAP (Barr 2010). Figure 4-1 shows the approximate location of each proposed remedial action. The performance monitoring well networks are shown on Figures 4-2 and 4-3. This section discusses each of the proposed interim remedial actions for the site.

4.1 Upgraded Groundwater Extraction System and Light Nonaqueous Phase Liquid Dual-Phase Recovery

Upgrades to current groundwater extraction and LNAPL dual phase recovery (DPR) system and continued operation of that system are proposed to treat shallow sulfolane-impacted groundwater. The system upgrades will increase the capacity of the system to extract groundwater and further improve the operational efficiency of the system.

The proposed upgrades include installation of additional and replacement groundwater recovery wells at locations and depths that were determined through groundwater modeling. The model-based upgrades were proposed to the ADEC in the Proposed Replacement Recovery Wells Technical Memorandum (Barr 2012b; Appendix C) and approved via email. The upgrade work was initiated in October, 2012 and is expected to be completed in approximately April 2013.

4.1.1 Basis for Technology Selection

Multiple groundwater treatment technologies were evaluated in the Onsite FS (ARCADIS 2012c). The following summarizes the findings of that report with respect to groundwater extraction.

Effectiveness: The groundwater extraction system has been shown to capture sulfolane-impacted groundwater. The groundwater treatment system is effective at treating sulfolane in the extracted groundwater.

Implementability: The groundwater extraction system is already in place and the proposed upgrades are readily implementable. The services and materials required for groundwater extraction system operation are widely available.

Cost: The capital costs were considered low and operation and maintenance costs were considered high in the spectrum of considered remedial technologies.

4.1.2 Historical System Operations

Operation of the groundwater extraction system currently involves groundwater recovery from five recovery wells (R-21, R-35R, R-39, R-40, and R-42) as discussed in Section 2.4.2. The groundwater extraction system has been effective at removing sulfolane and LNAPL from the aquifer.

4.1.3 Performance Metrics

Performance monitoring will be conducted to confirm the continued effectiveness of the groundwater extraction system. Hydraulic capture of the sulfolane and BTEX plumes will be assessed using fluid level and groundwater quality data. LNAPL mass reduction will be assessed by monitoring LNAPL volumetric recovery rates from the DPR system and measurement of LNAPL transmissivity.

4.1.3.1 Groundwater

4.1.3.1.1 Hydraulic Capture

FHRA will measure groundwater elevations in select monitoring wells and nests to evaluate horizontal and vertical capture of the system. The measurements will be used to generate water table elevation contour plots. Evaluations of groundwater capture will be included in the quarterly groundwater monitoring reports. Additionally, following startup of the replacement recovery wells, groundwater elevation measurements will be incorporated into the groundwater flow model to further evaluate hydraulic capture of the system.

- The performance monitoring network will include the following locations as shown on Figure 4-3: MW-113, MW-125, MW-130, MW-135, MW-136, MW-137, MW-175, MW-186 A/B/E, MW197 A/B, MW-309-15/66, MW-334-15/65, O-2, O-3, O-4, O-5, O-6, O-19, R-14A, R-22, S-43, S-44, S-50, and S-51.
- Groundwater elevations will be measured regularly and dataloggers are currently installed in several of the wells listed above and provide additional groundwater elevation data for capture evaluation.

4.1.3.1.2 Contaminant Capture

FHRA will monitor sulfolane and BTEX concentrations in monitoring wells upgradient and downgradient of the groundwater extraction system and will evaluate trends. FHRA currently provides an evaluation of contaminant trends at five downgradient monitoring wells in the quarterly groundwater monitoring reports. This evaluation will be expanded to include a treatment zone well (O-2) and additional downgradient monitoring wells plus upgradient monitoring wells.

- The upgradient monitoring locations (Figure 4-2) include: O-6, O-19, MW-113, MW-130, MW-175, MW-186 A/B/E, and S-43.
- The downgradient monitoring locations (Figure 4-2) include: MW-127, MW-129, MW-139, MW-142, MW-145, MW-154A/B, MW-309-15/65, MW-334-15/65, O-3, O-4, O-12, O-24, and O-26. Several of wells including MW-139, MW-142 and MW-154A/B may be within the treatment zone of the AS barrier. When operation of the AS barrier is initiated, these four wells will be removed from this performance monitoring well list.
- Many of the upgradient and downgradient monitoring locations are currently monitored on a routine basis as defined in the RSAP.

In addition to the evaluation of hydraulic capture and contaminant trends at the monitoring wells, FHRA will continue to monitor BTEX and sulfolane concentrations at each active recovery well on a monthly basis through 2013. The mass recovery rate for each recovery well will be calculated and reported to the ADEC in the quarterly groundwater monitoring reports.

4.1.3.2 Light Nonaqueous Phase Liquid

DPR LNAPL recovery performance will be evaluated by recording the volume of LNAPL recovered. These data in conjunction with groundwater extraction rates will be used to calculate LNAPL transmissivity over time. Also, LNAPL baildown testing data from nearby monitoring wells will be used to measure LNAPL transmissivity in those wells. As LNAPL is recovered from the subsurface, the transmissivity will decrease due to the decrease in LNAPL saturation. Because LNAPL recoverability and transmissivity are interrelated, the volume recovery rate will also decrease.

4.1.4 Performance Monitoring Well Network

LNAPL DPR will recover LNAPL from the groundwater extraction wells via in-well LNAPL skimming pumps. The performance monitoring network is summarized below:

- Monthly measurements of LNAPL volume recovered and calculation of LNAPL transmissivity from the groundwater extraction wells as discussed in Section 4.3.4.2.

- Semiannual LNAPL baildown testing at monitoring wells within the zone of influence of the groundwater extraction system (MW-186A, MW-334-15, O-2, R-14A, S-39, S-50 and S-51), if sufficient LNAPL is present (greater than 0.5 foot).

4.1.5 Permitting Requirements

Recovery well R-42 began operation upon issuance of an amended temporary water use permit (TWUP A2011-48) from the DNR. In addition to the temporary water use permit for R-42, groundwater extraction from the historical recovery wells is conducted under DNR water use permit LAS24907. FHRA received the Amended Temporary Water Use Authorization TWUP A2011-48 on October 3, 2012 to account for increased extraction rates associated with the new and replacement extraction wells.

On September 29, 2011, the ADEC issued an administrative extension of Wastewater Disposal Permit 2005-DB0012. FHRA is currently reviewing proposed operational changes and an application to amend this permit is forthcoming. Discharge monitoring reports are currently submitted monthly by FHRA to the ADEC.

4.2 Air Sparge Barrier

An air sparge barrier is proposed to treat groundwater downgradient of the groundwater extraction system to further reduce the potential for off-site sulfolane migration above the 14 µg/L ACL. The proposed air sparge barrier alignment is shown on Figure 4-4.

4.2.1 Basis for Technology Selection

Multiple groundwater treatment technologies were evaluated in the Onsite FS (ARCADIS 2012c). The following summarizes the findings of that report with respect to air sparging.

Effectiveness: As demonstrated by the 2012 Air Sparge Pilot Test (Appendix D), air sparging is an effective technology to treat sulfolane-impacted groundwater. Implementation of the proposed on-site air sparge system will provide an additional remedial barrier beyond the groundwater extraction system to minimize future migration of sulfolane downgradient of the treatment areas, at levels above the 14 µg/L ACL

Implementability: Air sparging is a proven, conventional technology that is readily implementable to address on-site sulfolane impacts, as proposed in this IRAPA. The services and materials required for air sparge system construction and operation are widely available.

Cost: The capital and operation and maintenance costs were considered moderate in the spectrum of considered remedial technologies.

4.2.2 2012 Air Sparge Pilot Test Summary

An air sparge pilot test was conducted in 2012 at the facility. The pilot test was initiated by FHRA to evaluate the site-specific effectiveness of AS for in-situ treatment of sulfolane-impacted groundwater. Observations made from the ongoing AS pilot test are summarized below:

- Radius of influence (ROI) testing indicates that an air flow of 30 standard cubic feet per minute (scfm) through a shallow sparge well (approximately 25 feet below water table [BWT]) will deliver oxygen throughout the saturated zone with a ROI greater than 15 feet based on dissolved oxygen (DO) measurements.

- Groundwater samples collected from AS pilot test wells demonstrated sustained decreases of sulfolane within the treatment zone.

- The degree and rate of sulfolane removal correlated with increased DO concentrations.

- Sulfolane was removed during both continuous and pulsed operation of the AS.

- The dissolved iron and dissolved manganese concentrations in groundwater decreased during operation of the AS system. This result was anticipated based on the introduction of oxygen into the aquifer creating aerobic conditions resulting in oxidation and precipitation of reduced iron and manganese.

Overall the pilot test demonstrated that AS is an effective remedial technology to stimulate in-situ degradation of sulfolane at the site (Appendix D) and provided information that supports design of the full-scale air sparge system.

4.2.3 Sulfolane Aerobic Degradation Intermediates Summary

Determination of the mechanism of aerobic sulfolane degradation through observation and documentation of intermediates was not a planned objective of the AS pilot or bench studies (Appendix D and Onsite FS Appendix B; ARCADIS 2012c). Nonetheless, observations made over the course of FHRA's bench testing and pilot testing programs have consistently demonstrated the loss of sulfolane without any clear indication of the formation of aerobic degradation intermediates. Technical literature describes some biological and abiotic processes by which aerobic sulfolane degradation *may* occur under certain conditions. However, like the work that FHRA has completed to date, the peer-reviewed literature does not provide any direct determination of the mechanisms for aerobic sulfolane degradation via observation and documentation of the presence of any intermediates.

Samples from both the air sparge pilot treatment zone and bench tests have been analyzed for tentatively identified compounds (TICs) via gas chromatography/mass spectrometry (GC/MS), and no accumulation of potential degradation intermediates has been observed. Members of the Technical Project Team (TPT) Chemistry Subgroup reviewed the available laboratory data and concluded that there was no evidence of sulfolane-related breakdown products in the laboratory chromatograms. This suggests that any sulfolane intermediates that are detectable by GC/MS either are not formed at all, or if they are formed, are labile and quickly mineralized. This finding confirms others previously reported in the literature. For example, Greene et al. (2000) showed that sulfolane is readily biodegraded under aerobic conditions using controlled laboratory experiments, and potential intermediates (such as 4-hydroxy-butane sulfinic acid or butanol) were never detected (although sought), suggesting that any potential sulfolane intermediates would not accumulate under aerobic conditions.

The FHRA technical team has reviewed the available technical literature in light of what has been observed in bench and pilot tests. In addition, FHRA retained Dr. Lisa Gieg, professor at the University of Calgary and author of peer-reviewed literature on the topic of aerobic sulfolane degradation, to aid in the review. Potential aerobic sulfolane degradation intermediate compounds were predicted by Dr. Gieg, and the toxicology of these compounds were evaluated by ARCADIS toxicologists. The following sections summarize FHRA's current understanding of the potential aerobic degradation mechanisms, potential intermediate compounds and toxicological information for potential intermediate compounds identified. Finally the potential implications for performance monitoring of the AS barrier system are evaluated.

4.2.3.1 Bench Testing Tentatively Identified Compounds Analysis

As previously presented in the SCR-2011 (Barr 2012a) and Appendix B to the FS (ARCADIS 2012c), abiotic mechanisms may play a role in the degradation of sulfolane in the Sulfinol process (Oasis 2010). Onsite remediation system sampling and the bench testing suggest that abiotic sulfolane destruction, if it occurs, is a rapid process, with a half-life on the order of hours (ARCADIS 2012c, Appendix B). According to the literature, the abiotic destruction of sulfolane via the pathways described above appears to be an exothermic reaction (Wellisch et al. 1964). This indicates that cold temperatures would not be expected to slow the reaction.

The conditions necessary for abiotic destruction of sulfolane via this mechanism appear to be:

- Presence of iron/manganese oxides
- Active oxidation of iron by DO

As described in Appendix B of the Onsite FS (ARCADIS 2012c), Barr conducted a series of three bench tests to investigate the potential reasons for sulfolane removal that was occurring across the air strippers, gallery pond, and sand filters at the onsite remediation system. Observations were made during the third and final bench test to potentially understand the possible reaction pathway for sulfolane degradation documented across the onsite remediation system.

Testing was conducted at Barr's water treatment laboratory using lab-synthesized groundwater spiked with reagent-grade sulfolane. Test results demonstrated that sulfolane reduction was associated with backwash solids from the sand filters and also indicated that the rate of sulfolane reduction was greatest under aeration and at lower pH (6). As previously described, the sulfolane degradation reactions are likely to be rapid processes once initiated; therefore, the bench testing included specific tests in which solids were filtered to stop potential degradation reactions that might be mediated by metals associated with suspended solids. Several of the treatments exhibiting sulfolane removal, each sample's associated filtered solids (as well as the spiked control sample) were analyzed by GC/MS for TICs in order to identify potential intermediates of sulfolane degradation.

Barr reported the tentative identification of several potential sulfolane-related breakdown products in the treatments through their review of the TIC data; however, a subsequent thorough review of the available laboratory data (including electronic data files) by both quality assurance chemists from Environmental Standards, Inc. and Shane Billings of UAF indicated that accumulation of degradation intermediates was not evident in the bench testing samples.

4.2.3.2 Air Sparge Pilot Test Tentatively Identified Compounds Analysis

As discussed in Appendix D, the laboratory completed a review for TICs to scan for potential intermediate byproducts of sulfolane degradation during each completed air sparge pilot test monitoring event. The TIC scans completed as part of each sampling event were examined for potential sulfolane degradation intermediates based on the following criteria:

- Chromatographic peaks that were flagged by the lab, and
- Were not in the laboratory method blanks, and
- Were not internal standards or surrogate compounds, and
- Were present in downgradient wells but not the upgradient well

While some chromatographic peaks were sporadically detected over the course of the pilot test, they were generally present in both upgradient and downgradient wells and inconsistently present from one event to the next.

4.2.3.3 Additional Evaluation of Potential Intermediates of Sulfolane Degradation

FHRA retained the services of Dr. Lisa Gieg, an Assistant Professor at the University of Calgary and noted researcher in the field of organic contaminant degradation to further evaluate the potential for accumulation of intermediates. Dr. Gieg previously conducted studies on aerobic degradation of sulfolane. Through collaboration with Dr. Gieg and review of the available information, the FHRA technical team identified the following possible intermediates of aerobic sulfolane degradation:

Potential Biological Degradation Intermediates Under Aerobic Conditions:

- 4-Hydroxy-butane sulfinic acid
- Butanol
- Butyraldehyde
- Butanoic acid

Potential Abiotic Degradation Intermediates Under Aerobic Conditions:

- Butane-1-sulfinate
- Octane-1,8-sulfinate

Potential Biological Degradation Intermediates From Abiotic Intermediates Under Aerobic Conditions:

- 4-Hydroxy butane sulfinate
- Butanol
- Octane-1-sulfinate
- 8-Hydroxy-octanesulfinate
- Octanol

A technical memorandum with a brief summary of potential aerobic degradation intermediates and pathways discussed in peer-reviewed literature and a summary of the most likely potential aerobic degradation pathways and intermediates based on previous abiotic and biodegradation studies with sulfolane is included as Appendix E.

Several of the identified compounds are naturally occurring compounds that may be associated with the natural processes in the aquifer. They would also be highly biodegradable and would be used by a broad range of microbial communities as food sources. The following section summarizes the evaluation of the toxicity of these potential intermediates.

4.2.3.4 Toxicological Evaluation of Potential Intermediates

Several chemical structures have been identified as potential biotic or abiotic breakdown intermediates of sulfolane. It is not known if these chemical species are formed or, if they were formed, whether they would be stable in the environment. ARCADIS reviewed the available toxicological data on these compounds and analogous structures to determine if any toxicological information was available. In the absence of toxicological data, ARCADIS completed predictive toxicological modeling to predict their potential toxicological properties of those compounds. Since many of the compounds do not have available toxicity data, modeling was completed for sulfolane to evaluate the reliability of the predictive model.

In all cases, the potential intermediates are known or predicted to be less toxic than sulfolane. Detailed results of the literature search and predictive model runs are presented in Appendix F.

4.2.3.5 University Investigations

As discussed above, a review by Shane Billings, a research chemist at the University of Alaska – Fairbanks (UAF), of the TIC scan data collected by Barr during bench testing supports previous conclusions that intermediate compounds were not detected in the laboratory analysis (pers. com., December 7, 2012). Evaluation of the analytical methods and identification of degradation intermediates is ongoing within the Degradation Subgroup.

The UAF is currently conducting several laboratory studies to directly evaluate the potential for sulfolane degradation under various environmental conditions, including aerobic conditions, and the mechanisms that would be responsible for that degradation. As part of this work, UAF will identify potential sulfolane-degrading bacteria present in groundwater and soil at the site. These results will be incorporated into the evaluation of degradation mechanisms and potential intermediates.

4.2.3.6 Summary

The conclusion of the FHRA technical team is that it is highly unlikely that there will be accumulation of sulfolane degradation intermediates during air sparging. This conclusion is based on laboratory and field investigations previously discussed, a review of available literature on the degradation of sulfolane, a review of available literature about what sulfolane intermediates may be expected and by consultation with a leading expert in the field of organic contaminant degradation in aquatic systems.

Peer-reviewed published laboratory studies focusing on sulfolane biodegradation have shown that sulfolane is readily biodegraded under aerobic conditions (studies cited in Appendix E). Biodegradation studies conducted in the laboratory are ideal for identifying metabolic intermediates that may form during the biodegradation of any contaminant because they typically involved closed, controlled environments where intermediates can potentially accumulate transiently over time and be identified. Such biodegradation studies were conducted with sulfolane by Greene et al. (2000) wherein potential sulfolane intermediates were sought in controlled laboratory incubations.

Aside from the innocuous end-products carbon dioxide and sulfate, other predicted sulfolane intermediates (e.g. shown in Appendix E) were never detected (Greene et al., 2000). This result suggests that sulfolane biodegradation intermediates do not accumulate, even under ideal laboratory /test conditions. Bench scale tests conducted by Barr confirmed this lack of accumulation of potential sulfolane intermediates. Furthermore, toxicological assessments of potential sulfolane intermediates showed that these are known or predicted to be less toxic than sulfolane (Appendix F). As stated above, any proposed intermediates of sulfolane degradation (biotic or abiotic) are of lower concern than sulfolane because they would not be expected to accumulate, and have lower toxicity than sulfolane.

Analytical data from both the air sparge pilot treatment zone studies and laboratory bench tests have been analyzed for chemical compounds, including TICs, via GC/MS analyses, and no accumulation of potential degradation intermediates has been observed. The lack of detectable breakdown products during bench testing and AS pilot testing demonstrates that any sulfolane degradation intermediates that are detectable by GC/MS either are not formed, or if they are formed, are labile and easily degraded by a wide range of microbial communities or abiotic processes. Technical literature describes some biological and abiotic processes by which aerobic sulfolane degradation *may* occur under certain conditions. An evaluation of potential degradation pathways and intermediate products performed by the FHRA project team resulted in a list of possible degradation pathways and degradation intermediates (Appendix E).

Although there is no evidence that any intermediate chemicals *are* formed in the aquifer, the next step in the FHRA project team's evaluation process was to investigate whether such chemicals might be harmful to human health or the environment *if* they were formed and accumulated in the groundwater. A review of available toxicological information for the potential degradation intermediates conducted by ARCADIS concluded that aerobic degradation of sulfolane via air sparging is highly unlikely to produce degradation intermediates that are more harmful to human health and the environment than sulfolane itself (Appendix F). Each of the possible intermediate compounds has a lower measured or predicted toxicity than sulfolane. Four of the compounds (butanoic acid, butyraldehyde, butanol, and octanol) are approved food additives by the U.S. Food and Drug Administration and are all compounds that occur in nature. Because they are naturally occurring they may be associated with the natural processes in the aquifer. They would also be highly biodegradable and would be used by a broad range of microbial communities as food sources.

4.2.4 Basis of Design

The results and observations of the pilot test and groundwater quality data from groundwater samples collected in and near the proposed AS barrier alignment are the primary basis for design for the full-scale AS barrier system. The results from future air sparge design testing described below, FHRA engineering standards, and ARCADIS' experience with similar air sparge systems are also factors in the design basis.

4.2.4.1 Air Sparge Barrier Alignment and Depth

The AS barrier will span the width of the sulfolane plume downgradient of the developed areas of the site. AS well depths are proposed based on sulfolane concentrations exceeding the 14 µg/L ACL detected in monitoring wells at the VPT transect from third quarter 2011 through third quarter 2012 and from hydropunch data collected from June through August 2012. Figure 4-5 presents a plan view of the AS barrier. Figure 4-6 shows a cross-section of the AS barrier extending from AS-102I to AS-110S with recent sulfolane concentration data. Performance data from literature demonstrates that placing the top of the well screen approximately 5 feet below the bottom of the contaminated zone is preferable (Battelle 2002), and is considered in this design.

The barrier will be comprised of air sparge wells at variable depths based on the observed depth of sulfolane. Three well configurations will be used to span the vertical extent of sulfolane impacts:

- Shallow AS wells at depths of 45 feet bgs
- Intermediate AS wells at depths of 85 feet bgs
- Deep AS wells at depths of approximately 100 feet bgs

The deep AS wells will target sulfolane concentrations present at depth in the area of monitoring wells MW-154A and MW-154B. Due to the sulfolane concentration of 59.3 µg/L detected in April 2012 in well MW-154B (screened from 90 to 95 feet bgs). It is anticipated that the depth of the proposed deep AS wells will be approximately 100 feet bgs as shown on Figure 4-6 due to the presence of permafrost found at that depth during advancement of MW-154B. However, the well depth may be increased if permafrost is not observed at the previously measured depths during air sparge well installation.

The AS treatment zone will be suprapermafrost. In order to maximize treatment of sulfolane near the permafrost contact, and to achieve a more complete cross section of treatment zone, AS wells installed in areas with permafrost will be installed approximately two-to-three feet into the permafrost as needed to achieve the proposed design depth or the maximum depth achievable; AS wells will not be installed more than 3 feet into permafrost to allow adequate air flow through the top portion of each well screen. Partial installation of the well screen into the permafrost will not reduce air flow out of the well because air flow will be focused out of the top of the screen. It is anticipated that this may induce melting of permafrost to a limited extent immediately adjacent to each borehole over the course of system operation. However, the benefit of additional treatment area outweighs the potential localized changes in the distribution of permafrost in this area of the site

Additional site characterization in the vicinity of the MW-154 well nest to evaluate sulfolane concentrations deeper than the screened interval of MW-154B and the presence of permafrost will be proposed in the 2013 Site Characterization Work Plan. Installation of a well that will provide these data is planned for the first half of 2013 as weather allows to support the final design of the AS barrier.

4.2.4.2 Air Sparge Well Spacing

The air sparge well spacing was selected based on the findings of the 2012 Air Sparge Pilot Test and ARCADIS' extensive experience with these types of systems in similar geologic settings. The AS barrier design includes:

- 10 shallow depth (45 feet bgs) AS wells (AS-101S through AS-110S),
- 21 intermediate depth (85 feet bgs) AS wells (AS-101I through AS-116I and AS-124I through AS-128I) and
- Seven deep (estimated to be 100 feet bgs; approximately 90 feet BWT) AS wells (AS-116D through AS-122D).

The shallow AS wells will be spaced 25 feet apart and are expected to operate with a ROI of 15 feet based on the observed ROI during the pilot testing described in Appendix D. The intermediate and deep wells (85 and 100 feet bgs) will be spaced 35 feet apart, respectively (center to center). Based on ARCADIS' experience with deep aquifer sparging, the deep AS wells are anticipated to operate with a ROI of approximately 25 feet. The deep well ROI is based on and will be confirmed prior to full-scale construction through the design testing proposed in Section 4.2.5 and subsequently validated during the initial period of operation of the system. The proposed distance between AS wells is less than twice the ROI to allow overlap in the treatment zone created by each individual well and to improve remedial performance.

4.2.4.3 Injection Air Flow Rate and Pressure

The anticipated air flow rate of approximately 30 scfm to each individual AS well is based on results from the AS pilot test. Compressed air will be supplied at a flow rate of 30 scfm per injection well and at the minimum injection pressures presented in the table below.

Well Depth (feet)	Depth to the Top of the Screened Interval (feet)	Estimated Minimum Injection Pressure (psi)
45	40	15
85	80	30
100	95	37

Note:

psi = pounds per square inch

The calculated injection pressures are equal to the hydrostatic pressure (the pressure exerted by a fluid at equilibrium due to the force of gravity) at each location, assuming a depth to groundwater of 10 feet bgs. The actual injection pressure will be the sum of the hydrostatic pressure plus the pore entry pressure (the pressure required to introduce a fluid into the soil pore structure), which is anticipated to be low based on the site geology.

The minimum injection pressure is less than the calculated aquifer fracture pressure (the pressure at which damage may occur to the natural geologic formation or well construction may be compromised), which is reasonably estimated to be 0.73 times the depth below ground surface to the top of the air injection well screened interval (Battelle 2002). The fracture pressures will not be exceeded to reduce the potential for localized fracturing of the geologic formation. The estimated fracture pressures are summarized in the following table.

Well Depth (feet)	Depth to the Top of the Screened Interval (feet)	Estimated Fracture Pressure (psi)
45	40	29
85	80	58
100	95	69

Adjustments to the flow rate and injection pressure will be made based on design testing proposed to obtain the optimal operational settings for the system.

Sparging will be pulsed to decrease the risk of substantial hydraulic conductivity reduction due to sustained permeability reduction related to air-filled pore space, which may reduce groundwater flow through the barrier. Pulsing has the added benefit of reducing the energy consumption of the system.

The optimum pulsing frequency will be determined during the first month of system operation. The pulsing schedule used for the former pilot test (6 hours on/6 hours off) will be used as a starting point for the design testing and will be revised, as necessary, based on oxygen delivery. Pulsed sparging will also allow the time required for temporary sparge-influenced hydraulic gradients to dissipate after terminating flow in an AS well.

4.2.4.4 Air Sparge Well Design

The AS wells will be constructed of a 2-inch-diameter steel riser with a 0.010-inch stainless steel wire-wrapped screen. Wire-wrapped steel screen will be used to allow more efficient air flow from the well into the aquifer when compared to PVC or other steel well screens manufactured via alternative processes. The depth of AS wells will vary depending on the depth of impacted groundwater as shown on Figure 4-6. The well screen will be approximately 5 feet long and placed within a coarse sand filter pack up to a height of 2 feet above the screen and entirely below the groundwater table. A 1-foot-long sump will be installed below the screen to allow settling of finer-grained aquifer materials within the well. The filter pack sand will be specified during the design based on historical borings and lithology observed. The AS well design is shown on Figure 4-7.

AS wells will be installed with a competent annular seal in the borehole above the screened interval, using bentonite. The well will then be sealed with neat cement grout up to grade. Geologic logging will be completed within the screened interval of each well and a complete boring log will be completed per the RSAP on eight AS wells evenly distributed across the length of the barrier.

4.2.4.5 Equipment and Instrumentation

Air sparging equipment including the compressors, air conveyance piping headers and controls will be housed in a dedicated building at the location shown on Figure 4-5. Air distribution lines will be constructed above grade consistent with FHRA engineering standards. Multiple AS wells will be on shared compressed air supply lines from the treatment building to reduce the piping required for air distribution. Each AS line will have dedicated instrumentation to evaluate flow and pressure, including a pressure gauge, flow meter, and coarse and fine valves to modulate flow to the well network. The instrumentation allows for control of individual air injection rates and pressures of wells and to confirm even distribution of air to the AS well network.

4.2.5 Air Sparge Barrier Design Verification and Testing

Conceptually, an AS barrier can be considered an in situ reactor that has a retention time set by the groundwater velocity and the thickness of the barrier. Therefore, the design of an AS barrier for sulfolane degradation requires that the mass of oxygen delivered to groundwater must meet or exceed the mass flux of oxygen demand in groundwater moving through the barrier. The incoming biodegradable organic material and reduced minerals in solution contribute to the oxygen demand flux through the barrier.

The 2012 AS pilot test provided the design basis for effective well spacing for the shallow AS wells. The pilot test has successfully degraded sulfolane and visual observations of bubbling in monitoring wells and in seasonal standing water (i.e., snow melt) above the treatment zone indicates that the injected air in the shallow interval migrates vertically through the aquifer and to the water-table surface. However, the full-scale design will require AS at deeper intervals (approximately 100 feet bgs). Additional design testing will be completed to confirm the assumed operational parameters and ROI of deep AS wells and air injectability in the deep zone. Testing may indicate that the ROI is greater or less than the assumed ROIs and wells will be added or removed based on testing results.

The proposed design testing for the deeper interval will include the installation of intermediate and deep AS wells (75 and 100 feet bgs). The AS pilot test wells will be located within the proposed AS barrier and will be incorporated into the proposed full-scale AS system. Design testing may include the following tests:

- Air flow and pressure step-testing will be completed to determine the appropriate pressure to achieve the desired air flow rate of 30 scfm.

- DO testing and potentially sulfur hexafluoride tracer testing if needed to verify the distribution of injected gas in the aquifer.

Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) analysis of groundwater samples will be conducted during the design testing phase to evaluate the spatial variability of oxygen demand in sulfolane-impacted groundwater at the site.

4.2.5.1 Air Flow and Pressure Step-Testing

A compressor will be connected to the test wells and air will be injected into the aquifer. The air injection line will be outfitted with an air flow measurement element and a pressure gauge. The pressure response related to hydrostatic displacement, pore entry pressure (the pressure required to introduce a fluid into the soil pore structure) and different injection airflow rates will be measured. Based on the results of the AS pilot test, it is anticipated that the injection pressure will be approximately equivalent to the hydrostatic displacement.

The design minimum expected injection pressure for each intermediate and deep well is equivalent to the hydrostatic pressure (the pressure exerted by a fluid at equilibrium due to the force of gravity) or approximately 28 and 39 psi, respectively. Once the sparging pressures have become stable, the sparging flow rate will be increased by 5 scfm in a step-wise fashion and flow rate measurements will be collected. Pressure and flow will be allowed to stabilize prior to initiating the next step.

As discussed above in section 4.2.4.3, the maximum allowable pressures are estimated to be 58 and 69 psi for the intermediate and deep wells, respectively. Pressures this high are not expected to be required and testing will be terminated before achieving 90 percent of the maximum pressures allowable to reduce the potential for damage to the formation or AS wells.

During step-testing, pressure transducers will be installed in the two nearest design testing monitoring wells installed at the water table (AS-MW-16A, AS-MW-16B, AS-MW-17A and AS-MW-17B). The transducers will be used to evaluate hydraulic pressure changes related to air injection and the return of the water table to ambient conditions after completing testing. During testing on well AS-103I, transducers will be installed in the closest water table wells at AS-MW-15A and AS-MW-15B while during testing on well AS-121D transducers will be installed in the closest water table wells at AS-MW-16A and AS-MW-16B. If more than one test is required on each well, the aquifer will be allowed to return to baseline conditions prior to initiating any additional tests.

4.2.5.2 Deep Air Sparge Dissolved Gas Distribution Testing

Tracer testing may be performed on one intermediate (AS-103I) AS well and one deep (AS-121D) AS well. The intent of the AS tracer testing is to verify distribution of injected gas in the aquifer and evaluate the horizontal deflection of injected gas through up to approximately 90 feet of saturated aquifer if measurement of DO alone provides an incomplete or inconclusive result. The tracer test will be conducted by amending the injection airflow stream with conservative gas tracer (sulfur hexafluoride) and monitoring both soil gas (above the water table) and groundwater for sulfur hexafluoride during and after the injection event. Sulfur hexafluoride is non-reactive, has low water solubility similar to oxygen, and low analytical detection limits, making it an ideal tracer gas for studying oxygen delivery in the subsurface. In addition, sulfur hexafluoride concentrations in the Earth’s atmosphere are negligible and the concentrations that will be used during the design test are non-toxic. A Material Safety Data Sheet for sulfur hexafluoride is included as Appendix G.

Eight new AS monitoring well nests with vertically nested wells at each location (27 total design testing monitoring wells) will be installed to monitor AS performance during the pilot test and long-term operation. Construction details for the AS monitoring nests are discussed below.

DO concentrations in groundwater will be measured to evaluate DO distribution in the subsurface during the design test period. DO measurements in the monitoring nests, will be used to confirm the ROI for the deep AS wells. Based on these results, the ROI for AS wells at the site and the number of AS wells may be modified.

If sulfur hexafluoride is used, it will be blended with the injection air stream at a consistent rate (approximately 0.3 percent by volume) for two 6-hour periods within a 24-hour window to mimic two injection cycles of 6 hours on and 6 hours off. Due to the similarity in gas properties, the distribution of sulfur hexafluoride will be similar to the distribution of oxygen once the background oxygen demand is overcome. If sulfur hexafluoride is used, the results will provide a second line of evidence to confirm the ROI for the deep AS wells

Groundwater will be collected for sulfur hexafluoride analysis from the sampling points within the eight AS monitoring nests (AS-MW-15A through AS-MW-15D and AS-MW-16A through AS-MW-16D) on the following schedule:

- Baseline sampling prior to initiating the test
- 1, 2, and 3 hours after initiating each 6-hour cycle (samples will be collected during both on and off cycles)
- Upon completion of each cycle
- 3, 6, and 12 hours after completion of the tracer test

A subset of the groundwater samples will be submitted for analysis for confirmation of the sulfur hexafluoride based on field measurements of sulfur hexafluoride groundwater sample container headspace. Groundwater sample container headspace and soil gas sulfur hexaflouride concentrations will be measured in soil gas samples collected from the monitoring points screened across the water table using an Innova 1312 photoacoustic gas analyzer or similar on the same schedule during the tracer test. Adjustments to the dissolved-phase sampling frequency and/or tracer injection flow rates may be made based on soil gas concentrations observed.

4.2.5.3 Biochemical Oxygen Demand and Chemical Oxygen Demand Sampling and Analysis

The AS barrier will have a set width (equal to twice the ROI) perpendicular to the groundwater flow direction; therefore, the groundwater retention time through the barrier will be fairly constant. Variations in the retention time are proportional to variation in groundwater flow velocities, both spatially and temporally. The objective of the barrier is to provide sufficient oxygen and retention time to degrade the sulfolane as it passes through the barrier. If the presence of elevated sulfolane concentrations increases oxygen demand; the portion of the aquifer that exhibits the highest oxygen demand will be where the sulfolane concentrations are highest (estimated to be two to three times higher than the initial concentration in the pilot area).

BOD and COD analysis of groundwater samples will be conducted to compare the oxygen demand in the current pilot test area with areas of higher sulfolane concentrations. Wells proposed for sampling include MW-142, O-26, MW-304-15, AS-MW-8 and MW-139. Sampling will be completed in conjunction with quarterly monitoring, and samples will be submitted to SGS North America, Inc. (SGS) for analysis.

The BOD test is conducted by supplying oxygen to a sample and measuring oxygen consumption over a 5-day period. This will be representative of the biodegradable material in the aquifer, including sulfolane, labile natural organic matter, and any other readily biodegradable contaminant mass. The COD test is conducted by adding a strong oxidant and will be representative of the BOD plus any inorganic and minimally biodegradable organic species. The BOD/COD data will be used to evaluate the difference in oxygen demand in groundwater between the current, successful pilot test area with the other areas of AS implementation. The data will also be used to evaluate the flux of oxygen demand into the barrier for comparison to the rate of oxygen delivery by the AS system.

4.2.5.4 Air Sparge Design Testing Well Nest Design

Eight temporary design testing monitoring well nests (AS-MW-15A through AS-MW-15D and AS-MW-16A through AS-MW-16D) are proposed for installation within the AS barrier. Each nest will have a variable number of wells (between one and five wells per nest) based on the distance to the AS well. The objective of these well nests is to evaluate sulfur hexafluoride and DO distribution during design testing (Section 4.2.5.2). Figures 4-8 and 4-9 show the detail of conceptual design testing monitoring well nests proposed for each of the two design testing wells, AS-103I and AS-121D, respectively. Each of the wells included in the eight design testing well nests will be installed in individual boreholes.

Design testing wells will be screened at depths corresponding to the treatment zones for the intermediate and deep wells as shown on Figures 4-8 and 4-9, respectively. The design testing monitoring wells with submerged screens will be constructed of 2-inch-diameter Schedule 40 polyvinyl chloride blank casings and 6 inch 0.010-inch slotted PVC screens. A natural sand pack will be allowed to collapse around the screened intervals. Temporary design testing wells will be constructed per the RSAP. Geologic logging per the RSAP will be completed on the deepest monitoring location at each design testing well nest and within the interval of each screen.

4.2.6 Air Sparging Performance Monitoring

The following sections summarize the short-term and long-term air sparging performance monitoring plan. The objectives of the monitoring plans are to:

- Determine the magnitude of sulfolane removal upon startup of the AS barrier
- Demonstrate that sulfolane removal is sustained during routine system operation

4.2.6.1 Short-Term Performance Metrics and Sampling

The primary short-term performance metric for operation of the AS barrier system will be decreased dissolved-phase sulfolane concentrations downgradiant of the barrier. The following additional metrics will be used to evaluate system performance:

- DO concentration measurements in monitoring well nests within the zone of treatment will be used to confirm that air is being delivered at a sufficient flow rate to the treatment zone.

- Injection air flow rate and pressure measurements are within the optimal operational ranges as determined by design testing.

Short-term monitoring will also be completed for sulfolane and field parameters (pH, conductivity, ORP, temperature and DO). Baseline sampling of short-term performance monitoring wells will be completed prior to operation of the full-scale AS barrier system. Field parameter measurements and sampling for iron, manganese, nitrate as nitrogen, sulfate, phosphorus, and total organic carbon will be completed. These data will be used as needed for reference to evaluate future system operation. Additional geochemical parameter data may be collected if needed to evaluate system performance.

4.2.6.2 Short-Term Performance Monitoring Well Network

Table 4-1 summarizes the AS barrier performance monitoring well network. The short-term performance monitoring well network includes existing wells AS-MW-8 and MW-102, temporary design testing wells AS-MW-15C and AS-MW-16C and six additional performance monitoring wells that will be installed to evaluate effectiveness of the proposed remediation system across the barrier. Additional short-term performance monitoring well nests AS-MW-9 through AS-MW-14 will be installed approximately 50 feet downgradient of the center of the treatment zone. The objective of this monitoring well network is to provide an indication of treatment downgradient of the barrier within approximately one month of remediation based on a groundwater velocity of 1.7 feet per day (Appendix Q SCR-2011; Barr 2012a). New performance monitoring wells will be constructed according to the RSAP.

4.2.6.3 Short-Term Performance Monitoring Schedule

Short-term performance monitoring is planned for completion on a biweekly basis for the first two months. Reductions or modifications to the scope of performance monitoring may be necessary; the anticipated startup of this remediation system will occur in late third quarter or fourth quarter 2013 and seasonally cold weather may limit the number of days available for field work. Laboratory analysis of samples collected from the performance monitoring well network will be completed for sulfolane.

4.2.6.4 Long-term Performance Monitoring Metrics and Sampling

The long-term performance metric for operation of the AS barrier system will be decreased dissolved-phase sulfolane concentrations downgradient of the barrier. The following additional metrics will be used to evaluate system performance:

- DO concentration measurements in monitoring well nests within the zone of treatment will be used as a performance monitoring metric to confirm that air is being delivered at a sufficient flow rate to the treatment zone.
- Air flow rate and pressure measurements are within the optimal operational ranges as determined by design testing.

Baseline sampling of long-term performance monitoring wells will be completed prior to operation of the full-scale AS barrier system. Field parameter measurements and sampling for iron, manganese, nitrate as nitrogen, sulfate, phosphorus, and total organic carbon will be completed during the baseline sampling event. These data will be used as needed for reference to evaluate future system operation.

The long-term performance monitoring network may change as wells are added or decommissioned, or as site conditions change. Reductions or modifications to the scope of performance monitoring may be necessary; the anticipated startup of this remediation system may occur in the third or fourth quarter of 2013 and seasonally cold weather may limit the number of days available for field work. Laboratory analysis of samples collected from the performance monitoring well network will be completed for sulfolane.

4.2.6.5 Long-Term Performance Monitoring Well Network

Long-term monitoring includes select upgradient and downgradient groundwater monitoring wells which will be sampled and analyzed for sulfolane and BTEX in accordance with the sampling schedule provided in the RSAP. The long-term performance monitoring network is summarized in Table 4-1 of this document and includes 30 wells or well nests that are upgradient, downgradient, and within the treatment zone. These wells were chosen based on the following criteria:

- The wells are outside of the current ROI of the groundwater extraction system.
- No LNAPL is present in the wells.
- The upgradient and downgradient wells are already in place and part of the quarterly monitoring program.

4.2.6.6 Long-Term Performance Monitoring Schedule

Long-term performance monitoring will be completed based on the individual well sampling schedules as summarized in the RSAP.

4.2.6.7 Performance Monitoring Well Design

Performance wells AS-MW-9 through AS-MW-14 will be well nests that will be approximately 50 feet downgradient of the center line of the treatment zone. Each well nest will include a water table well and a second deeper well targeting the interval of treatment. The depth of each deep well will be determined in the field based on observations of permafrost. New performance monitoring wells will be constructed according to the RSAP.

4.2.6.8 Performance Monitoring for Degradation Intermediates

Based on the results of the AS pilot test TIC analyses, it is not anticipated that recalcitrant intermediates are formed during aerobic degradation stimulated by air sparging.

4.2.6.9 Contingency Performance Metrics

If the AS barrier system does not meet design and performance expectations, additional testing will be completed to evaluate and optimize performance. This evaluation may include:

- Groundwater sampling and analysis for iron, manganese, nitrate as nitrogen, sulfate, phosphorus, and total organic carbon
- Groundwater sampling for field parameters, including DO, oxidation-reduction potential, pH, conductivity, and temperature
- Water-table elevation changes (e.g., mounding) within the zone of treatment

Pressure measurements in the saturated zone may also be used to estimate the extent of air saturation and corresponding reduction of water saturation and potential deflection of groundwater flow through the barrier.

4.2.7 Disposal of Contaminated Media

Contaminated groundwater from drilling activities will be disposed of in accordance with the RSAP. Soil generated during installation of the AS barrier will be managed in accordance with the RSAP.

4.2.8 Permitting Requirements

Acquisition of several permits is required prior to initiating construction activities at the site. FHRA has initiated the permitting process. The construction activities will include:

- Construction of a gravel road through the undeveloped area of the site following the AS barrier as shown on Figure 4-4.
- Moving the security fencing from its current location to immediately north of the VPT transect.
- Installation of the aboveground piping, and AS and monitoring wells.
- Construction of a remediation building to house compressors; distribution manifolds; and associated controls, piping, and instrumentation.

Additional permits may be required as determined through the FHRA construction management process.

4.2.8.1 U.S. Army Corps of Engineers Section 404 Permit

Portions of the proposed project area were mapped as wetlands during a 2008 PJD (HDR Alaska, Inc. 2008) and verified by ARCADIS staff on October 1 and 2, 2012. The PJD will be submitted to the U.S. Army Corps of Engineers (USACE) for concurrence.

The USACE regulates activities that impact jurisdictional waters of the United States (U.S.), including wetlands, under Section 404 of the Clean Water Act. A Section 404 permit is required for any placement of fill in waters of the U.S. Because the proposed activities will impact more than $^{1}/_{10}$ acre of wetlands, an individual Section 404 permit is required.

A public notice is required to be distributed to all known interested persons. Individual permits are issued following a full public interest review (usually 30 days in length) of an individual application for a Section 404 permit. Processing time usually takes 90 to 120 days, although the USACE is currently understaffed and processing may take longer.

4.2.8.2 Fairbanks North Star Borough – Floodplain Permit

In response to escalating taxpayer costs for flood disaster relief, Congress established the National Flood Insurance Program (NFIP), which is a voluntary mitigation program administered by the Federal Emergency Management Agency. Under this program, the federal government makes flood insurance available in those communities that practice sound floodplain management. The FNSB is a participating community in the NFIP.

Flood Insurance Rate Maps identify flood hazard areas, including Special Flood Hazard Areas (SFHAs). SFHAs are defined as the area that will be inundated by the flood event having a 1 percent chance of being equaled or exceeded in any given year, also referred to as the 100-year flood. A portion of the project area where installation of a road is planned is mapped as Flood Zone A, which falls under the SFHA.

Construction at the site will require a floodplain permit from the FNSB Department of Community Planning, including a certified statement from a hydrologist or engineer that certifies the road fill will not substantially increase flood heights or velocities.

The Floodplain Permit processing may take up to 30 working days.

4.2.8.3 Construction Permits

Construction permits from the FNSB and the City of North Pole will be obtained prior to initiating any construction activities requiring permits.

4.2.9 Remediation System Design Contingency

The layout and design of the AS barrier presented in the sections above is based on results from the on-going AS pilot testing and ARCADIS's experience with deep aquifer sparging. It is expected that the design presented above will provide complete remediation of sulfolane-impacted groundwater within the treatment zone and sufficient operational flexibility to optimize remedial effectiveness and system operational efficiency. The intent of the proposed design testing is to validate the assumed ROI for the deep and intermediate AS wells or to develop design modifications as necessary to optimize the effectiveness of the system. Therefore, the design presented above may change to reflect the findings of the design testing or modifications required to satisfy FHRA construction and safety requirements. Regardless of potential design modifications, full implementation and winterization of the AS barrier is expected to be complete by October 2013. The schedule for implementation is discussed in Section 6. Performance monitoring will be conducted to evaluate the long-term effectiveness of the remediation system and modifications to the layout or operation of the system will be implemented as needed.

4.3 Updated Light Nonaqueous Phase Liquid Recovery

FHRA proposes to continue current LNAPL skimming operations and continue to evaluate the transmissivity and recoverability of LNAPL in accessible areas of the site. Continuous and seasonal ongoing LNAPL skimming will continue to recover mobile LNAPL, reduce LNAPL mass and reduce the potential for future LNAPL plume expansion. This section provides an update to the previous IRAP submitted in 2010 (Barr 2010).

4.3.1 Basis for Technology Selection

Multiple LNAPL treatment technologies were evaluated in the Onsite FS (ARCADIS 2012c). The following summarizes the findings of that report with respect to LNAPL skimming.

Effectiveness: Consistent recovery of LNAPL has been demonstrated during operation of the existing LNAPL skimming systems. LNAPL recovery will continue to further reduce the LNAPL mass and mobility of the LNAPL.

Implementability: LNAPL skimming is readily implementable as demonstrated by ongoing operations. The services and materials required for LNAPL skimming installation and operation are widely available.

Cost: Capital and O&M were considered low in the spectrum of considered remedial technologies.

4.3.2 Historical Operation

As discussed in Section 2, active remediation is ongoing to recover LNAPL at the site. From 1986 through the end of 2012, approximately 393,949 gallons of LNAPL were recovered at the site. Annual recovery volumes have generally decreased as remediation has progressed and the volume of recoverable LNAPL has decreased.

4.3.3 Updated Basis of Design

4.3.3.1 Skimming Well Selection and Operational Time Frames

To-date volumetric LNAPL recovery rates and LNAPL transmissivities indicate that LNAPL at the site is recoverable. However, additional LNAPL transmissivity data collection is needed to develop a final LNAPL remedial strategy at the site. A revised LNAPL transmissivity data collection plan to support the development of this strategy will be proposed in the 2013 Site Characterization Work Plan. A final LNAPL recovery strategy will be developed in the Onsite Cleanup Plan.

4.3.3.2 Equipment and Implementation

A typical pneumatic skimmer consists of a submersible air-driven pump, with an intake located behind a hydrophobic filter. The intake and filter are located on a vertical slide apparatus; the density of the filter allows the intake to be placed at the LNAPL/water interface.

The typical operational configuration of a skimming system will include the following components:

- Two-inch-diameter monitoring well or four-inch-diameter recovery well
- Compressed air supply for the skimmer pump
- Collection drums for the recovered product
- Well houses to insulate the skimmer systems from freezing conditions

Wells identified for continuous LNAPL recovery will be equipped with a Geotech Keck Spoiler pneumatic skimming unit with a floating, hydrophobic pump intake to target removal of LNAPL. The pump will be equipped with a tank full shut-off switch. Tubing and wiring associated with the skimming devices will be placed above grade. Specifications for the pneumatic LNAPL skimmer systems are included as Appendix H.

Compressed air will be used to run the Geotech Keck Spoiler skimmer pumps and lift LNAPL from the pump intake to the surface, where it will be collected in a 55-gallon drum prior to recycling within the facility. Temporary above-grade connections will be made to existing compressed air manifolds at recovery well locations, where possible. Each recovery well will be equipped with a dedicated LNAPL storage container, complete with overfill prevention controls and secondary containment. Recovery wells and their associated equipment will be housed in dedicated enclosures for locations that are proposed for continuous skimming.

During periods of high water table elevation (generally during the summer months) when the LNAPL smear zone may be submerged, flow of LNAPL into recovery wells is expected to be minimal and skimming may be discontinued until groundwater elevations drop.

At locations where LNAPL transmissivity is found to be low non-continuous or seasonal LNAPL skimming may be proposed. At these locations a Geotech Keck Spoiler may be temporarily installed or a manual portable recovery pump or vacuum truck will be used.

4.3.4 Performance Metric Revision

As discussed in the 2010 IRAP (Barr 2010), LNAPL recovery rates and thicknesses were used to evaluate LNAPL recovery performance. This section provides an update to those performance metrics to include LNAPL transmissivity and remove LNAPL thickness from consideration when evaluating the performance of LNAPL recovery operations. The updated metrics will be used to assess the effectiveness of LNAPL recovery:

- LNAPL transmissivity calculations
- LNAPL recovery volume and LNAPL thickness recovery rate with each well

4.3.4.1 Light Nonaqueous Phase Liquid Transmissivity

LNAPL transmissivity is a measure of LNAPL recoverability within the groundwater environment. The magnitude of LNAPL transmissivity can be used as an infiltration and endpoint criterion for LNAPL mass removal using LNAPL hydraulic recovery systems (American Petroleum Institute [API] 2012).

LNAPL transmissivity will be calculated from data collected during bail-down testing and manual and automated skimming. An LNAPL baildown test is initiated by quickly removing LNAPL accumulated in a well, making it analogous to a groundwater rising-head slug test. The rate of LNAPL flow into the well is a function of soil and LNAPL properties discussed above and the magnitude of the initial hydraulic gradient toward the well developed during LNAPL removal. The baildown test response is influenced by the prevalent fluid levels at the time of testing. A routine LNAPL baildown test program has been initiated that will measure the range of LNAPL transmissivity under different fluid level conditions.

LNAPL transmissivities calculated from baildown testing data will inform and determine the method of LNAPL recovery operations for each well as discussed above. LNAPL recovery in a well will be suspended when the LNAPL transmissivity reaches a value of less than 0.8 ft^2/day (ITRC 2009), which ITRC suggests as the threshold for beneficial reduction in overall LNAPL mass, and recovery rates become insignificant.

4.3.4.2 Light Nonaqueous Phase Liquid Recovery Volume

LNAPL recovery volumes from individual recovery systems will be used as a performance metric to assess the effectiveness of LNAPL recovery. Recoverability of LNAPL generally decreases as remediation progresses and as the volume of recoverable LNAPL decreases. Each recovery system will be monitored monthly to track the volume of product recovered. The locations of the individual systems will be modified, if necessary, to relocate the systems to wells with the highest recovery.

4.4 Active Facility Operational Constraints

The NPR is an operating facility that will continue to be in operation throughout implementation and operation of the proposed interim remedial strategy. Consequently, the active facility infrastructure imposes constraints on the remedial actions by restricting access to LNAPL and groundwater located near and under the existing infrastructure. Modifications to the scope of work proposed below may be necessary based on conflicts with current operations identified during the internal FHRA construction management process.

5. Waste Management Plan

Groundwater extraction, air sparging and LNAPL recovery (DPR, skimming, and manual recovery) are proposed for treatment of hydrocarbon- and sulfolane-impacted groundwater, and LNAPL. It is anticipated that wastewater, soil, LNAPL, and carbon will be generated during operations.

5.1 Groundwater

Extracted groundwater will be treated via the groundwater treatment system. Purge water generated during monitoring, LNAPL skimming, and other remedial or monitoring activities will be treated via the waste water treatment system.

5.2 Soil

Soil generated during well installations and construction activities will be managed per the RSAP.

5.3 Light Nonaqueous Phase Liquid

LNAPL recovered via onsite recovery operations will be recycled through the facility product refining systems.

5.4 Granular Activated Carbon

Spent carbon generated onsite through the groundwater extraction system will be handled and disposed of at regular intervals per the Revised Spent Carbon Management Plan (ARCADIS 2012e). The spent carbon will be transferred to super-sacks and transported to OIT for thermal treatment.

6. Implementation Schedule

FHRA's proposed implementation schedule for the interim remedial strategy described in this Addendum is included as Appendix I. This schedule includes managing design of each alternative through the NPR facility design process, implementation, remediation system start up, O&M and performance monitoring, and installation reporting. O&M and performance monitoring summaries and progress reports will be included in quarterly groundwater monitoring report submittals.

7. References

Alaska Department of Environmental Conservation. 2010. Policy Guidance on Developing Conceptual Site Models. October 2010.

Alaska Department of Environmental Conservation. 2011. Letter to Mr. Loren Garner of Flint Hills Resources Alaska – LLC. August 18, 2011.

Alaska Department of Environmental Conservation. 2012a. Letter to Mr. Loren Garner of Flint Hills Resources Alaska – LLC, Re: EPA Sulfolane Toxicity Values. July 19, 2012.

Alaska Department of Environmental Conservation. 2012b. E-mail to Mr. Loren Garner of Flint Hills Resources Alaska – LLC, Re: NPR Replacement Recovery Wells. October 3, 2012.

American Petroleum Institute. 2012. API LNAPL Transmissivity Workbook: A Tool for Bail-down Test Analysis. American Petroleum Institute, 2012.

ARCADIS U.S., Inc. 2011a. Site Characterization Report Addendum. November 2011.

ARCADIS U.S., Inc. 2012a. Revised Draft Final Human Health Risk Assessment. May 23, 2012.

ARCADIS U.S., Inc. 2012b. Third Quarter 2012 Groundwater Monitoring Report. October 31, 2012.

ARCADIS U.S., Inc. 2012c. Draft Final Onsite Feasibility Study. May 2012.

ARCADIS U.S., Inc. 2012d. Work Plan for Evaluation of Perfluorinated Compounds in the Fire Training Area. August 10, 2012

ARCADIS U.S., Inc. 2012e. Revised Spent Carbon Management Plan. January 2012.

ARCADIS U.S., Inc. 2013. Site Characterization Report – 2012 Addendum. January 2013.

Barr Engineering Company. 2010. Interim Removal Action Plan. Revised September 2010.

Barr Engineering Company. 2011a. Site Characterization and First Quarter 2011 Groundwater Monitoring Report. May 2011.

Barr Engineering Company. 2012a. Site Characterization Report – Through 2011. December 2012

Barr Engineering Company. 2012b. Proposed Replacement Recovery Well Technical Memorandum. March 2012.

Battelle. 2002. Air Sparging Design Paradigm. August 2002.

Cederstrom, D.J. 1963. Ground-Water Resources of the Fairbanks Area Alaska: U.S. Govt. Print. Off., U.S. Geological Survey Water-Supply Paper 1590. 84 p.

Ferrians, O.J. 1965. Permafrost Map of Alaska. U.S. Geological Survey Miscellaneous Investigations Series Map I-445. 1 plate.

Flint Hills Resources LLC. 2012. Letter to Mr. Steve Bainbridge of the Department of Environmental Conservation Division of Spill Prevention and Response. August 20, 2012.

Glass, R.L., M.R. Lilly, and D.F. Meyer. 1996. Ground-water levels in an alluvial plain between the Tanana and Chena Rivers near Fairbanks, Alaska, 1986-93: U.S. Geological Survey Water-Resources Investigations Report 96-4060, 39 p. + 2 appendices.

Greene, E.A.; Beatty, P.H.; Fedorak, P.M. 2000. Sulfolane biodegradation by mixed cultures and a bacterial isolate identified as a *Variovorax* sp. *Arch. Microbiol*. 174: 111-119.

HDR Alaska, Inc. 2008. Flint Hills North Pole Refinery Preliminary Jurisdictional Determination. August 2008.

Interstate Technology and Regulatory Council. 2009. Evaluating LNAPL Remedial Technologies for Achieving Project Goals. LNAPL-2. Washington, D.C.: Interstate Technology & Regulatory Council, LNAPLs Team. www.itrcweb.org.

Lilly, M.R., K.A. McCarthy, A.T. Kriegler, J. Vohden, and G.E. Burno. 1996. Compilation and Preliminary Interpretations of Hydrologic and Water-Quality Data from the Railroad Industrial Area, Fairbanks, Alaska, 1993-94. U.S. Geological Survey Water-Resources Investigations Report 96-4049. 75 p.

Miller, J.A., R.L. Whitehead, D.S. Oki, S.B. Gingerich, and P.G. Olcott. 1999. Ground Water Atlas of the United States: Segment 13, Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands. U.S. Geological Survey Hydrologic Atlas Number 730-N. 36 p.

Nakanishi, A.S., and M.R. Lilly. 1998. Estimate of aquifer properties by numerically simulating ground-water/surface-water interactions, Fort Wainwright, Alaska: U.S. Geological Survey Water-Resources Investigations Report 98-4088, 35 p.

Oasis Environmental. 2010. Sulfolane Technical Assistance and Evaluation Report, North Pole Refinery, Flint Hills Resources Alaska, LLC.

Wellisch, E., E. Gipstein, and O.J. Sweeting. 1964. Cleavage and dimerization of sulfolane. *Journal of Polymer Science*, Part B: Polymer Letters, 2: 39-42.

Williams, J.R. 1970. Ground Water in the Permafrost Regions of Alaska. U.S. Geological Survey Professional Paper 696. U.S. Government Printing Office, Washington, D.C. 83 p.

Tables

Table 2-1
Monthly Groundwater Recovery

Interim Remedial Action Plan Addendum
North Pole Refinery
North Pole, Alaska

Date	Monthly Total (gallons)	Monthly Average (gallons / day)	Monthly Average (gallons / minute)
January 2009	5,637,292	181,848	126
February 2009	4,965,414	177,336	123
March 2009	5,673,504	183,016	127
April 2009	5,845,823	194,861	135
May 2009	6,430,915	207,449	144
June 2009	6,229,883	207,663	144
July 2009	6,316,965	203,773	142
August 2009	6,243,319	201,397	140
September 2009	10,634,423	354,481	246
October 2009	5,114,811	164,994	115
November 2009	0	0	0
December 2009	6,153,173	198,489	138
January 2010	8,676,601	279,890	194
February 2010	9,185,582	328,057	228
March 2010	9,424,363	304,012	211
April 2010	9,914,262	330,475	229
May 2010	9,812,735	316,540	220
June 2010	9,282,464	309,415	215
July 2010	9,325,475	300,822	209
August 2010	9,872,250	318,460	221
September 2010	9,122,386	304,080	211
October 2010	7,700,526	248,404	173
November 2010	7,489,601	249,653	173
December 2010	7,279,463	234,821	163
January 2011	8,605,402	277,594	193
February 2011	7,409,928	264,640	184
March 2011	7,144,062	230,454	160
April 2011	8,034,008	267,800	186
May 2011	8,076,367	260,528	181
June 2011	9,735,245	324,508	225
July 2011	11,838,286	381,880	265
August 2011	12,119,042	390,937	271
September 2011	15,458,620	515,287	358
October 2011	15,492,362	499,754	347
November 2011	16,279,722	542,657	377
December 2011	16,711,381	539,077	374
January 2012	15,645,486	504,381	350
February 2012	15,936,577	515,987	358
March 2012	16,390,112	530,180	368
April 2012	16,010,934	514,711	357
May 2012	14,639,653	472,247	328
June 2012	14,109,044	451,769	314
July 2012	16,721,808	540,994	376
August 2012	16,256,379	523,831	364
September 2012	15,402,121	515,527	358
October 2012	16,377,507	527,101	366
November 2012	15,069,768	503,018	349
December 2012	15,740,566	507,135	352

Table 2-2
2012 LNAPL Recovery

Interim Remedial Action Plan Addendum
North Pole Refinery
North Pole, Alaska

All units in gallons

2012	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
MW-138	20	96	78	92	0	0	0	0	0	0	0	0	286
MW-176-A	0	0	0	0	0	0	0	0	0	4	0	0	4
MW-186-A	0	0	0	0	0	0	0	0	0	1	0	0	1
MW-334-15	0	0	0	0	0	0	0	0	0	11	0	0	11
O-wells	0.3	1.1	1	0	0	0	6	1	2	3	0	1	15.4
S-wells	0	0	0	0	0	0	0	0	0	3	0	1	4
R-14A	0	0	0	0	0	0	0	0	0	0.7	0.0	0.0	1
R-18	30	0	34	10	14	0	1	5	4	2	0	1	101
R-20-R	11	12	20	27	18	20	12	10	4	0	5	6	144
R-21	176	134	106	100	43	19	0	15	4	10	15	8	629
R-22	0	0	0	5	0	0	0	0	0	0	0	0	5
R-32	90	0	50	125	124	26	12	12	2	1	0	12	453
R-33	FROZEN	FROZEN	FROZEN	FROZEN	FROZEN	0	0	0	0	0	0	FROZEN	0
R-34	18	0	8	15	5	0	0	0	0	0	0	0	46
R-35-R	35	69	114	114	17	10	0	0	0	0	0	0	358
R-39	4	3	5	5	0.2	0	0	0	0	0	0	0	17
R-40	50	102	102	116	31	35	9	15	0	0	40	13	512
Coalescer	0	3	0	32	4	0	0	0	0	0	0	0	38
TOTAL	433	419	518	641	255	110	41	57	15	35	60	42	2625

Note: This summary includes only product that has been recovered for recycling. Product that has been recovered but has not yet been removed from the storage tank for recycling is not included in the table.

Table 2-3
Historical LNAPL Recovery

Interim Remedial Action Plan Addendum
North Pole Refinery
North Pole, Alaska

Well ID	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012 (through Fourth Quarter)	Well Total (gallons)
R-1	3,243	1,165	340	218	60	35	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Removed July 2008					**5,086**
R-2	1,538	1,546	175	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**3,299**
R-3	39	313	0	42	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**419**
R-4	412	430	110	148	20	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1,140**
R-5&5A	4,170	3,606	978	1,464	1,115	447	316	209	141	321	175	236	222	25	0	0	0	0	0	0	0	0	0	0	0	0	0	**13,425**
R-6	25	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Removed October 2009				**80**
R-7 & 8	14,216	17,108	67	809	1,438	575	1,793	1,693	385	250	0	Removed																**38,334**
R-9	11,011	22,378	744	479	385	510	1,036	565	106	71	23	25	29	12	0	0	0	0	0	0	0	0	0	5	2	0	0	**37,381**
R-10&10A	2,558	5,271	200	352	280	127	0	20	0	0	0	0	0	0	0	0	0	0	0	Removed May 2005								**8,808**
R-11	15,796	14,920	724	241	190	5	0	317	444	117	0	0	0	11	0	0	0	0	0	Removed May 2005								**32,765**
R-12	4,099	0	80	51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**4,230**
R-13	1,044	3,563	79	177	55	0	27	15	62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**5,022**
R-14	4,664	773	125	341	344	48	116	182	96	123	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**6,812**
R-18	0	1,955	5,128	13	0	10	17	0	151	30	0	25	0	0	1	2	0	0	0	0	0	0	0	7	29	5	101	**7,474**
R-19	0	6,106	1,623	106	90	30	138	496	205	9	0	0	0	0	2	0	0	0	0	0	0	0	0	12	14	0	0	**8,831**
R-20/R-20R	0	5,165	28,603	46	281	2,443	2,193	1,131	296	69	123	112	88	115	33	56	16	0	94	46	100	87	49	50	48	34	144	**41,422**
R-21	0	4,859	46,028	767	422	175	370	5,993	6,621	1,441	2,154	1,118	3,364	737	314	207	112	303	786	1,225	157	6,489	2,799	92	2,403	2,254	629	**91,818**
R-22	0	0	411	136	45	101	775	34	0	64	26	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	5	**1,598**
R-23	0	210	147	0	0	15	7	183	71	33	12	5	0	0	0	0	0	0	0	Removed May 2005								**683**
R-24	0	1,070	109	30	0	30	18	254	156	5	40	0	0	0	0	0	0	0	0	Removed May 2005								**1,712**
R-25	0	435	44	20	30	70	91	227	177	62	40	62	5	0	21	0	0	0	0	Removed May 2005								**1,284**
R-26	0	0	26	73	157	149	79	57	47	13	12	2	0	0	0	0	0	0	0	Removed May 2005								**615**
R-27	0	460	477	120	305	124	68	25	55	26	0	9	54	11	3	0	0	0	0	Removed May 2005								**1,737**
R-28	0	35	14	10	78	0	48	40	0	7	0	0	0	0	0	0	0	0	0	Removed May 2005								**232**
R-29	0	0	6	0	0	0	0	40	21	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	4	0	0	**75**
R-30	0	0	10	0	0	0	0	0	26	21	0	14	5	0	0	0	0	0	0	0	0	0	0	3	3	0	0	**82**
R-31	0	2,255	3,452	269	110	350	316	340	343	20	52	85	110	0	6	0	0	0	0	0	0	0	0	0	0	0	0	**7,708**
R-32	0	7,360	5,498	394	543	1,089	1,242	1,074	1,642	555	118	315	602	141	18	56	0	0	0	0	0	0	0	55	318	25	453	**21,497**
R-33	0	0	162	47	290	685	19	112	50	0	25	22	0	0	0	0	0	0	0	0	0	0	0	12	0	10	0	**1,434**
R-34	0	0	201	1,216	4,922	2,734	4,208	3,177	5,923	3,077	508	193	200	407	190	5	155	110	502	327	913	201	0	11	43	4	46	**29,271**
R-35/R-35R	0	0	22	37	1,042	2,659	740	468	26	0	0	0	0	0	4	5	0	0	13	0	0	0	0	18	234	201	358	**5,827**
R-36	0	0	20	23	0	0	191	261	491	0	26	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1,016**
R-37	0	0	8	15	65	1,147	297	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1,532**
R-38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
R-39	0	0	0	0	50	336	40	68	27	0	0	1,261	1,090	6	61	7	4	9	1	4	21	0	58	2	33	46	17	**3,141**
R-40	0	0	0	0	0	141	128	27	0	0	0	0	0	0	28	173	85	85	106	27	211	58	253	46	19	350	512	**2,248**
MW-138													Installed April 2001			0	0	76	352	469	365	367	187	321	216	144	286	**2,783**
S-22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
S-27	0	0	0	0	0	0	0	0	0	0	340	0	0	2	1	0	4	0	0	Removed May 2005								**347**
S-28	0	0	0	0	0	0	0	0	0	0	44	0	0	0	1	3	1	0	0	Removed May 2005								**49**
S-33	0	0	0	0	0	4	0	0	0	28	0	0	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	**37**
S-34	0	0	0	0	0	0	0	0	0	0	38	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	**43**
S-40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	53	0	0	0	0	0	0	0	**53**
S-42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	**6**
S-43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
S-44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	**4**
S-45	0	0	0	0	0	0	0	0	0	0	0	Removed 1997																**0**
S-46	0	0	0	0	0	0	0	0	0	0	50	21	0	Removed May 1999														**71**
S-47	0	0	0	0	0	0	0	0	0	0	92	9	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	**104**
S-48	0	0	0	0	0	0	0	0	0	0	225	44	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	**272**
S-49	0	0	0	0	0	0	0	0	0	0	450	401	181	38	0	1	0	0	0	0	0	0	0	0	0	0	0	**1,071**
S-50	0	0	0	0	0	0	0	0	0	0	0	9	0	0	3	4	4	0	0	0	0	0	0	1	4	0	3	**28**
S-51	0	0	0	0	0	0	0	0	0	0	0	65	0	0	0	1	4	0	0	0	0	0	0	1	0	0	1	**72**
S-52	0	0	0	0	0	0	0	0	0	0	0	70	22	0	3	6	6	0	0	0	0	0	0	0	1	0	0	**108**
O-2																							Installed September 2010			176	0	**176**
O-11																								Installed September 2011			0.4	**0.4**
O-13																								Installed September 2011			2	**2**
Coalescer																						Installed December 2009			264	355	38	**656**
Annual Total	**62,815**	**101,038**	**95,611**	**7,684**	**12,342**	**14,059**	**14,298**	**17,008**	**17,562**	**6,342**	**4,573**	**4,111**	**5,972**	**1,505**	**703**	**537**	**393**	**583**	**1,854**	**2,150**	**1,767**	**7,201**	**3,345**	**635**	**3,634**	**3,603**	**2,595**	**393,921**

Table 3-1
Proposed Phase 8 Monitoring Wells

Interim Remedial Action Plan Addendum
North Pole Refinery
North Pole, Alaska

Well Name	Well Location Description	Proposed Depths (feet bgs)	Well Proposed for Permafrost Delineation	Notes
8-A	North Property Boundary	15 (WT), 25, 35, 50, 80, PF	Yes	1,2,3,4
8-B	North Property Boundary	15 (WT), 20, 40, 60, PF	Yes	1,2,3,4
8-C	North Property Boundary	15 (WT), 35, 50, 80, PF	Yes	1,2,3,4
8-D	North Property Boundary	15 (WT), 35, 50, 80, PF	Yes	1,2,3,4
8-E	North Property Boundary	15 (WT), 25, 35, 50, 65, 80, PF	Yes	1,2,3,4
8-F	North Property Boundary	15 (WT), 35, 50, 80, PF	Yes	1,2,3,4

Notes:

1: Current well names are for planning purposes only. Permanent well names will be applied upon installation.

2: Proposed depths may change based on field observations of permafrost.

3: Permafrost will only be delineated at depths up to 150 feet bgs due to limitations of the drilling equipment.

4: If permafrost is not encountered or encountered below 130 feet bgs, and additional well will be installed and screened at 110 feet bgs.

bgs = below ground surface
WT = water table
PF = permafrost

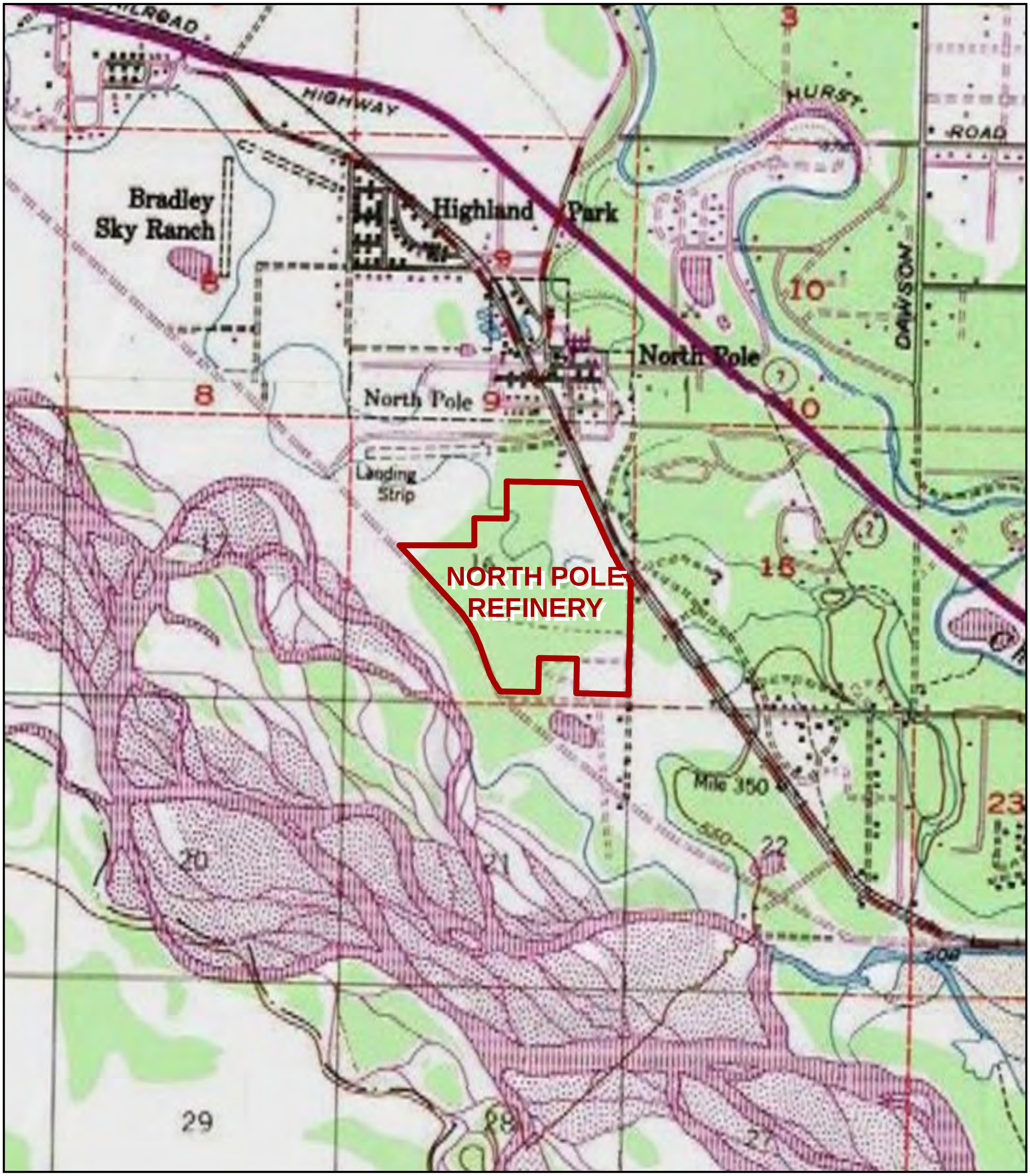
Table 4-1
Proposed Performance Monitoring Networks

Interim Remedial Action Plan Addendum
North Pole Refinery
North Pole, Alaska

Groundwater Extraction System - Sulfolane	Groundwater Extraction System - Hydraulic Capture	Air Sparge (Short-Term)	Air Sparge (Long-Term)
O-2	O-2	MW-102	O-4
O-3	O-3	AS-MW-8	O-12
O-4	O-4	**AS-MW-9 nest**	O-25
O-6	O-5	**AS-MW-10 nest**	O-26
O-12	O-6	**AS-MW-11 nest**	MW-101
O-24	O-19	**AS-MW-12 nest**	MW-101A
O-26	S-43	**AS-MW-13 nest**	MW-102
S-43	S-44	**AS-MW-14 nest**	MW-127
MW-113	S-50	**AS-MW-15C nest**	MW-131
MW-127	S-51	**AS-MW-16C nest**	MW-139
MW-129	R-14A		MW-140
MW-130	R-22		MW-142
MW-139	MW-113		MW-143
MW-142	MW-125		MW-154A
MW-145	MW-130		MW-154B
MW-154A	MW-135		MW-301 nest
MW-154B	MW-136		MW-302 nest
MW-175	MW-137		MW-303 nest
MW-186A	MW-175		MW-304 nest
MW-186B	MW-186A		MW-305 nest
MW-186E	MW-186B		MW-309-15
MW-309-15	MW-186E		MW-309-65
MW-309-65	MW-197A		AS-MW-8
MW-334-15	MW-197B		**AS-MW-9 nest**
MW-334-65	MW-334-15		**AS-MW-10 nest**
	MW-334-65		**AS-MW-11 nest**
	MW-309-15		**AS-MW-12 nest**
	MW-309-65		**AS-MW-13 nest**
			AS-MW-14 nest

Notes:
Bold = proposed well

Figures



LEGEND:

FHRA PROPERTY BOUNDARY

0 0.5 Miles

GRAPHIC SCALE

FLINT HILLS RESOURCES ALASKA, LLC
NORTH POLE REFINERY, NORTH POLE, ALASKA

IRAP ADDENDUM

SITE LOCATION

ARCADIS

FIGURE
1-1

CITY: SF DIV/GROUP: ENV/IM DB: K ERNST LD: G FRANCE PIC: PM: TM: TR:
Project (Project #) B0081981.0006.00001
Path: V:\FHR_AK\NorthPoleRefinery\IRAP_Addendum\MXD\Fig 1-1 SiteLocation.mxd Date: 1/14/2013 Time: 12:28:26 PM