

Flint Hills Resources Alaska, LLC

Conceptual Site Model

North Pole Refinery
North Pole, Alaska

December 2013



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Conceptual Site Model

North Pole Refinery
North Pole, Alaska

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Our Ref.:
B0081981.0048

Date:
December 2013

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Acronyms and Abbreviations

1,3,5-TMB	1,3,5-trimethylbenzene
ACL	alternative cleanup level
ADEC	Alaska Department of Environmental Conservation
AFFF	aqueous film-forming foams
ARCADIS	ARCADIS U.S., Inc.
AWS Program	Alternative Water Solutions Program – Management Plan
Barr	Barr Engineering Company
bgs	below ground surface
city	City of North Pole, Alaska
COC	constituent of concern
CSM	Conceptual Site Model
CU #1	Crude Unit #1 Wash Area
CU #2 EU	Crude Unit #2 Extraction Unit
Earth Resources	Earth Resources Corporation of Alaska
Ecological CSM	Ecological Conceptual Site Model
FHRA	Flint Hills Resource Alaska, LLC
FTA	Fire Training Area
Geomega	Geomega, Inc.
HHRA	human health risk assessment
LNAPL	light nonaqueous phase liquid
MAPCO	MAPCO Alaska Petroleum, Inc.
mg/kg	milligrams per kilogram
NPB	northern property boundary
NPR	North Pole Refinery
offsite	area located outside the NPR property boundary, primarily in the downgradient north-northwest direction



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onsite	area that is located within the property boundary of the FHRA NPR
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonate
POE	point of entry
PPRTV	provisional peer-reviewed toxicity value
Revised Draft Final HHRA	Revised Draft Final Human Health Risk Assessment
SGP	South Gravel Pit
site	North Pole Refinery, an active petroleum refinery located on H and H Lane in North Pole, Alaska
SWA	Southwest Former Wash Area
SWI	Shannon & Wilson, Inc.
USEPA	United States Environmental Protection Agency
Williams	Williams Alaska Petroleum, Inc.
µg/L	micrograms per liter
°F	degrees Fahrenheit



1. Introduction

This document presents a Conceptual Site Model (CSM) for the North Pole Refinery (NPR), an active petroleum refinery located on H and H Lane in North Pole, Alaska (site). A CSM for an environmental site describes how chemicals were historically released to the environment, how the contamination moved and where it is present now, how those chemicals affect people and other living things, and activities that are ongoing to protect people from being exposed to those chemicals. This CSM will support development of the final cleanup plan for the site.

The CSM is based on extensive environmental assessment activities that have been conducted at the site over the past 26 years, with the majority of activities occurring since 2009. The data, analyses, and conclusions in this CSM are the product of a collaborative effort among Flint Hills Resources Alaska, LLC's (FHRA's) consulting team members. That team includes qualified professionals in a variety of technical disciplines from four environmental consulting firms: ARCADIS U.S., Inc. (ARCADIS), Shannon & Wilson, Inc. (SWI), Barr Engineering Company (Barr), and Geomega Inc. (Geomega). FHRA has engaged these firms to perform various tasks on the project. This CSM, therefore, encompasses contributions from professionals from each firm in the text and figures presented.

The assessment included a thorough review of historical chemical use at the facility, collection of water and soil samples from the surface and subsurface, geophysical studies, and computer simulation of the movement of contamination in the subsurface. Detailed technical discussions of these topics are presented in the extensive library of site characterization reports, interim remedial action plans, groundwater monitoring reports, and additional documentation cited throughout this CSM. Citations are generally provided in the endnotes and references are summarized in Appendix A.

2. Site Description

The NPR is located on 240 acres inside the city limits of North Pole, Alaska. The employees of the facility produce approximately 1 million gallons of petroleum products¹ a day from crude oil feedstock from the Trans-Alaska Pipeline System. The refined petroleum products made at the facility are used throughout the region.

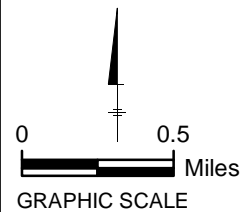
The NPR was built in 1976 and 1977 by Earth Resources Corporation of Alaska (Earth Resources) and refinery operations began in August 1977. Earth Resources leased the refinery property from the State of Alaska, which owned the refinery land. MAPCO, Inc. acquired Earth Resources in 1980, and continued operations under a newly formed company, MAPCO Alaska Petroleum, Inc. (MAPCO). In 1998, Williams Alaska Petroleum, Inc. (Williams) acquired MAPCO through a stock purchase, thereby succeeding to MAPCO's operations. Williams and its predecessor MAPCO operated the NPR on state-owned land for almost 25 years, up until 2004. FHRA purchased the refinery assets from Williams effective April 1, 2004, along with the refinery land, which Williams had acquired from the State of Alaska shortly before the transaction with FHRA. FHRA has owned and operated the NPR since then. The major refinery features include crude oil processing units, tank farms, truck and rail-loading racks, wastewater treatment lagoons, storage areas, and two flooded gravel pits (the North and South Gravel pits).

CITY: HIGHLANDS RANCH, CO DIV/GROUP: ENV/IM DB: BGriffith LD: G FRANCE
 Path: W:\GISPrj\GISPROJECTS\ENV\FHR_AK\NorthPoleRefinery\CSM\November2013\MXD\Fig 1-1 Facility_Location.mxd Date: 11/26/2013 Time: 7:12:22 AM



LEGEND:

 FHRA PROPERTY BOUNDARY



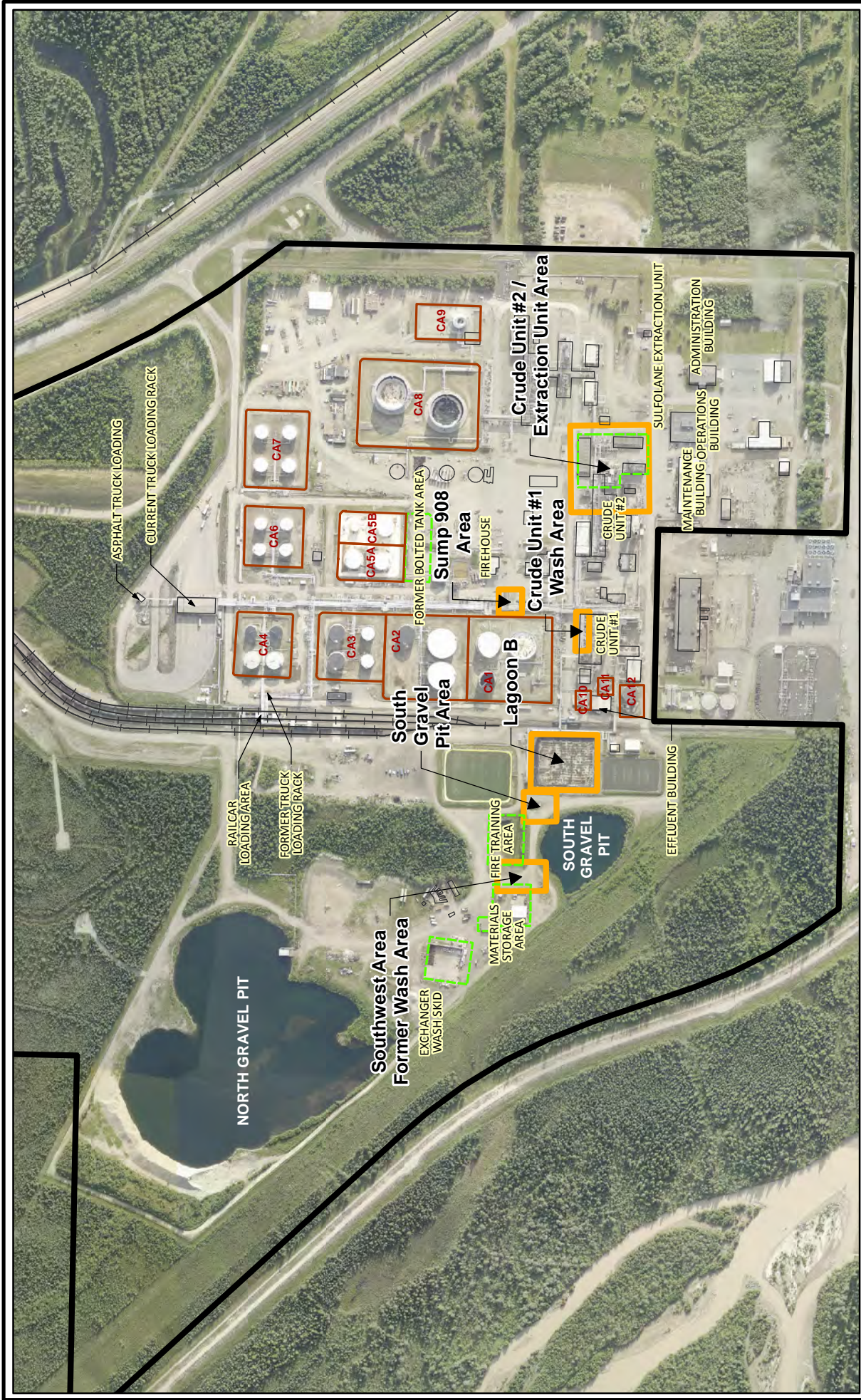
Note:
 Image provided courtesy of Pictometry International 2012



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CONCEPTUAL SITE MODEL

FACILITY LOCATION

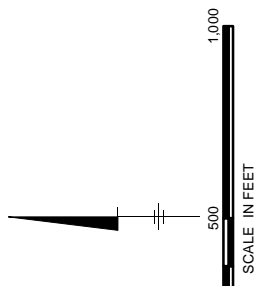
 **FIGURE 1-1**



Legend

- Bermed Containment Areas (CA)
- Approximate Area
- Source Areas
- FHRA Property Boundary

Notes:
 -The Fire Training Area is lined for containment purposes
 -Image provided courtesy of Pictometry International 2012



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CONCEPTUAL SITE MODEL

FACILITY FEATURES AND SOURCE AREA LOCATIONS

C:\Users\Borlth\Documents\Work\GIS\PR\GIS\EN\GIS\EN\FHR_AK\NorthPoleRefinery\CSM\November2013\MD\Fig 2-1 Facility Features - Source Areas.docx.mxd Date: 12/18/2013 Time: 8:04:54 PM



3. Contaminants of Concern and Sources

Releases of petroleum to the environment were documented as early as 1977 and sulfolane releases began shortly after the initial use of sulfolane, which commenced in September 1985 once the extraction unit was constructed. Petroleum releases occurred from tanks, distribution piping, sumps, loading racks, and process units. Sulfolane releases were primarily related to sumps, facility maintenance, and wastewater management activities.

Chemical and wastewater releases at the site have resulted in soil and groundwater impacted with sulfolane, petroleum hydrocarbons, and perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), which are the constituents of concern (COCs) at the site. Groundwater in the area has also been affected by regional groundwater quality issues unrelated to the NPR. These issues include high levels of naturally occurring arsenic and iron, other documented chemical releases from other businesses in the area, and waste discharges to groundwater from domestic sources such as septic systems.

3.1 Sulfolane

Sulfolane is a solvent used in the petroleum refining process. The NPR started using sulfolane in September 1985. Facility operations and maintenance activities generated sulfolane-rich wastewater that was collected in sumps that directed the wastewater to the facility wastewater treatment system, which included treatment and storage lagoons.

Sulfolane is the only contaminant associated with refinery processes that extends beyond the site boundary. A timeline of sulfolane use, offsite discovery in groundwater, and FHRA response to the discovery of sulfolane is shown on Figure 3-1.

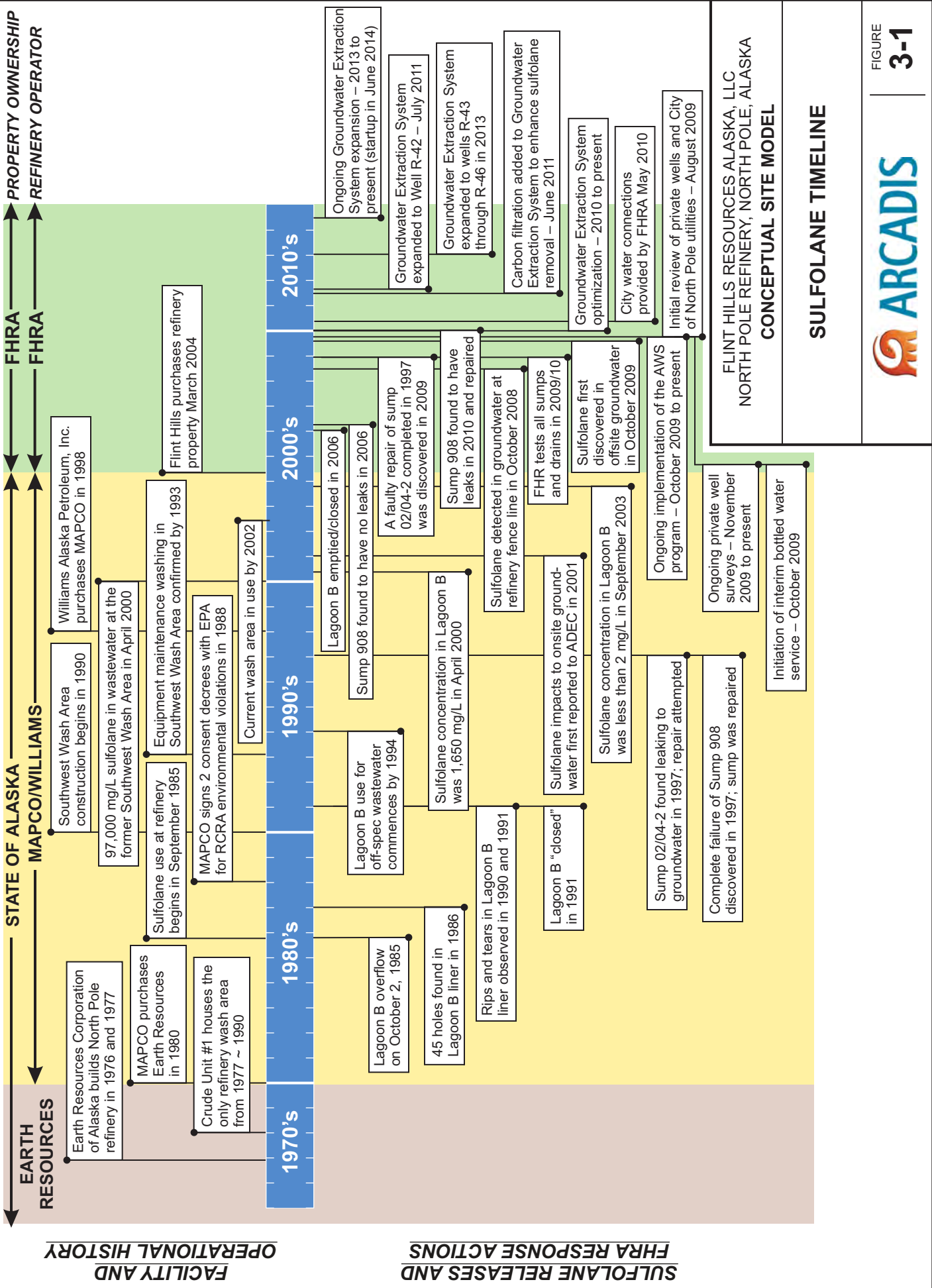


FIGURE 3-1

The major sources of the sulfolane historically released to the environment were:

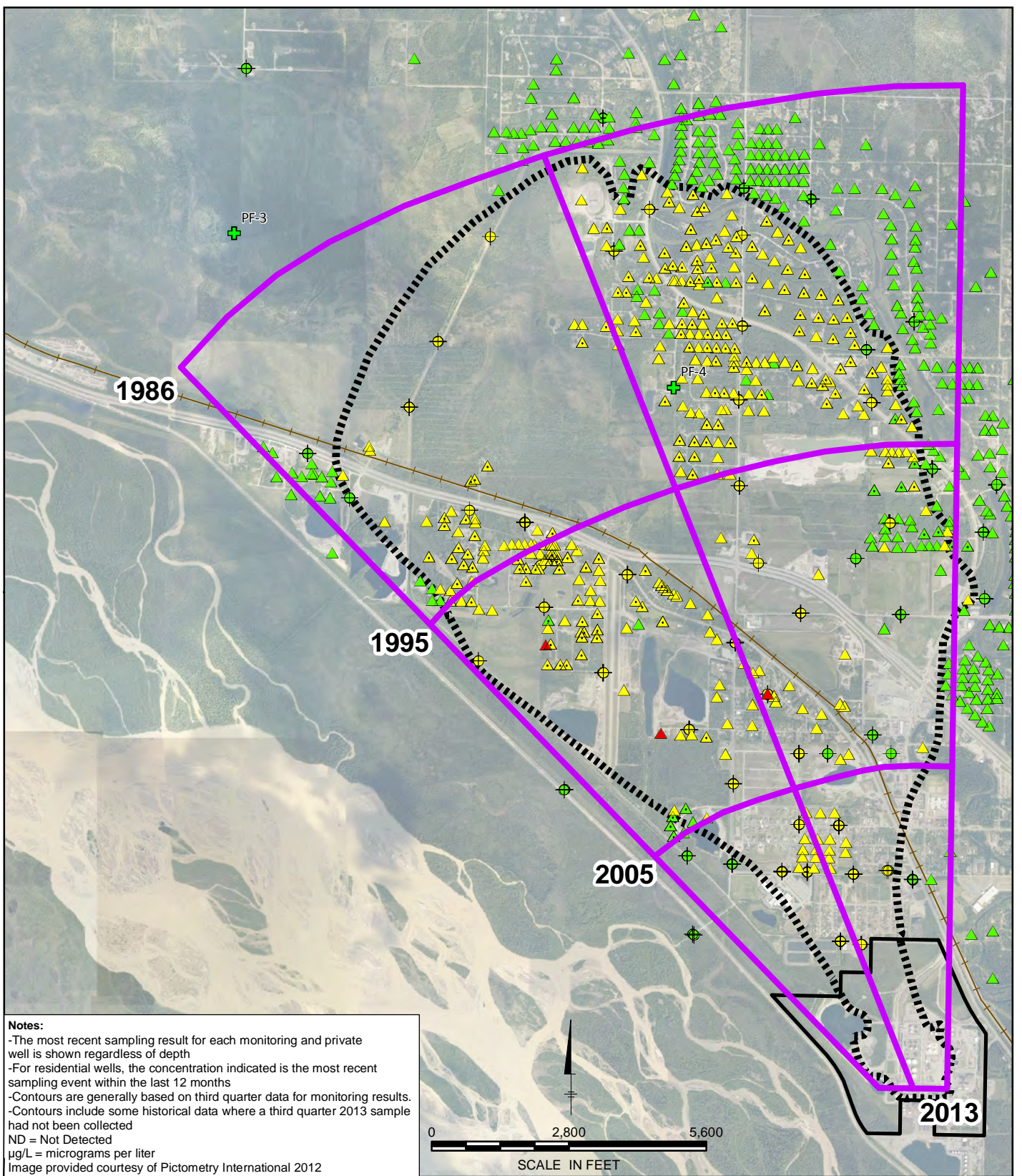
- The Crude Unit #2 Extraction Unit (CU #2 EU) where sulfolane was used to extract aromatics from crude oil stock to make gasoline
- Wastewater collection sumps constructed below the ground surface
- Equipment maintenance wash areas
- A wastewater lagoon that stored concentrated sulfolane-containing wastewater

A minor source of sulfolane is located at an abandoned overflow ditch between Lagoon B and the South Gravel Pit (SGP). The sulfolane source areas are shown on Figure 2-1 and summarized in Table 1.

Table 1. Sulfolane Primary Source Areas

Source Type	Source Area
Sump	Sump 02/04-02 ²
	Sump 908 ³
Wash Area	Crude Unit #1 Wash Area (CU #1) ⁴
	Southwest Former Wash Area (SWA) ⁵
Wastewater Lagoon	Lagoon B ⁶
Process Unit	CU #2 EU

Figure 3-2 presents the evolution of the sulfolane plume in groundwater based on estimates of the year sulfolane was released to the environment. The sulfolane transport time was influenced by sulfolane movement into and out of zones of relatively low-permeability soil via diffusion as discussed in Section 6. The Velocity Arcs subsequent to 1985 represent releases that have been documented to have predominantly occurred prior to 2004 and, as discussed further in this document and other Site Characterization reports, continued to contribute residual sulfolane to the subsurface since the time of release. As shown on the figure, the sulfolane impacts furthest downgradient were the result of sulfolane released in 1985 (Section 4.1).



Notes:
 -The most recent sampling result for each monitoring and private well is shown regardless of depth
 -For residential wells, the concentration indicated is the most recent sampling event within the last 12 months
 -Contours are generally based on third quarter data for monitoring results.
 -Contours include some historical data where a third quarter 2013 sample had not been collected
 ND = Not Detected
 µg/L = micrograms per liter
 Image provided courtesy of Pictometry International 2012

Legend

- | | |
|---|-------------------------------------|
| ⊕ Monitoring Well | ▲ Private Well Sulfolane Results |
| ▲ Point-of-entry treatment system sample collected | ▲ Not Detected |
| ⊕ Permafrost Boring | ▲ 3.1 - 362 µg/L |
| ⊕ Approximate Sulfolane Isoleth | ▲ >362 µg/L |
| ⊕ Regardless of Depth in µg/L | ● Monitoring Well Sulfolane Results |
| ⊕ Velocity Arcs (calculated using a plume transport velocity of 2 feet per day) | ● Not Detected |
| ⊕ FHRA Property Boundary | ● 3.1 - 362 µg/L |
| | ● >362 µg/L |

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SULFOLANE PLUME EXTENT AND APPROXIMATE RELEASE DATE


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FIGURE
3-2

3.2 Petroleum Hydrocarbons

An extensive review of documented petroleum releases from 1977 to 2009 is presented in the Site Characterization Report – 2011 (Barr 2012). These releases occurred from tanks, distribution piping, sumps, loading racks, and process units.

Crude oil and refined petroleum products are made up of hundreds of compounds. Most of these compounds pose no threat to human health or the environment. The compounds that are found in petroleum impacts at the site that present a potential human health or environmental risk are naphthalene, benzene, total xylenes, and 1,3,5-trimethylbenzene (1,3,5-TMB).

3.3 Perfluorooctane Sulfonate and Perfluorooctanoic Acid

PFOS and PFOA were found in some formulations of aqueous film-forming foams (AFFFs) up until 2002. Generally, AFFF is used to extinguish fires where water cannot be used effectively, such as petroleum fires. Foams were used by staff at the facility to conduct firefighting training exercises and in some ‘hot work’ (e.g., welding or grinding) situations. The NPR has a lined Fire Training Area (FTA; shown on Figure 2-1) located in the southwestern part of the site that was used for these fire-training activities. Live fire-training activities have not been conducted at the NPR since 2009.

FHRA searched records on firefighting foam purchases made by the NPR to determine whether PFOS and PFOA-containing fire-fighting foams were stored or used at the NPR. The available records, dating back to 1999, indicate that no PFOS or PFOA containing foams were purchased since that time by the NPR. However, no records were available prior to 1999 due to changes in ownership and record keeping practices.⁷

3.4 Cleanup Levels

In correspondence dated July 14, 2012, Alaska Department of Environmental Conservation (ADEC) indicated that an alternative cleanup level (ACL) of 14 micrograms per liter ($\mu\text{g/L}$) should be applied for dissolved-phase sulfolane at the site in the development of remedial action objectives and in evaluation of remedial alternatives. This ACL was based on a provisional peer-reviewed toxicity value (PPRTV) for sulfolane that was derived by the United States Environmental Protection Agency (USEPA) in January 2012, and on exposure assumptions developed by ADEC. In the May 2012 Revised Draft Final Human Health Risk Assessment (Revised Draft Final HHRA; ARCADIS U.S., Inc. [ARCADIS] 2012a), the PPRTV used with the ADEC-selected exposure parameters was called the PPRTV Scenario. The Revised Draft Final HHRA (ARCADIS 2012a) also presented the ARCADIS Scenario, using a scientifically supported toxicity value and exposure parameters selected by ARCADIS after data and literature review. The toxicity value and many of the exposure parameters differed between scenarios. Using the ARCADIS Scenario, there were no current or future offsite receptors identified through the risk assessment that exceed the acceptable hazard index or excess lifetime cancer risk, and the resulting sulfolane ACL was 362 $\mu\text{g/L}$.

FHRA concludes that an ACL of 362 µg/L is the most appropriate and scientifically defensible ACL for the site. Accordingly, sulfolane concentrations in groundwater in the onsite and offsite areas are compared to an ACL of 362 µg/L for this CSM.

Other compounds identified as COCs at the site are benzene, xylenes, naphthalene, and 1,3,5-TMB. Site-specific groundwater and soil cleanup levels for onsite contaminants were determined based on site-specific exposure mechanisms and receptors.⁸

PFOS and PFOA were detected at the site following the completion of the HHRA. Groundwater alternative cleanup levels for PFOS and PFOA are not site-specific and were based on USEPA calculations for Regional Screening Levels.⁹ PFOS and PFOA were detected in soil in the lined FTA where the impacts will not come in contact with groundwater. Therefore, the same calculator was used to calculate appropriate screening levels for onsite outdoor workers (direct-contact).¹⁰

Soil and groundwater ACLs for COCs are summarized in Table 2.¹¹

Table 2. Soil and Groundwater ACLs

COC	Groundwater ACL (µg/L)	Soil ACL (mg/kg)
Sulfolane	362	0.999
Benzene	590	2.85
Xylenes	3,470	27.6
Naphthalene	31.8	0.731
1,3,5-TMB	92.4	1.02
PFOS	1.3	54.7
PFOA	3.1	137

4. Release Mechanisms

4.1 Sulfolane

Wastewater was released to the subsurface from leaks in sumps used to gather the wastewater for processing, spills and overspray in wash areas, and leaks and overflows in the wastewater treatment system. The first known overflow of Lagoon B after sulfolane use began occurred in October 1985. Sulfolane management practices at that time indicate that it is likely that the wastewater discharged to the ground surface from that overflow contained sulfolane.

The primary mechanisms by which sulfolane was historically released to the environment were:

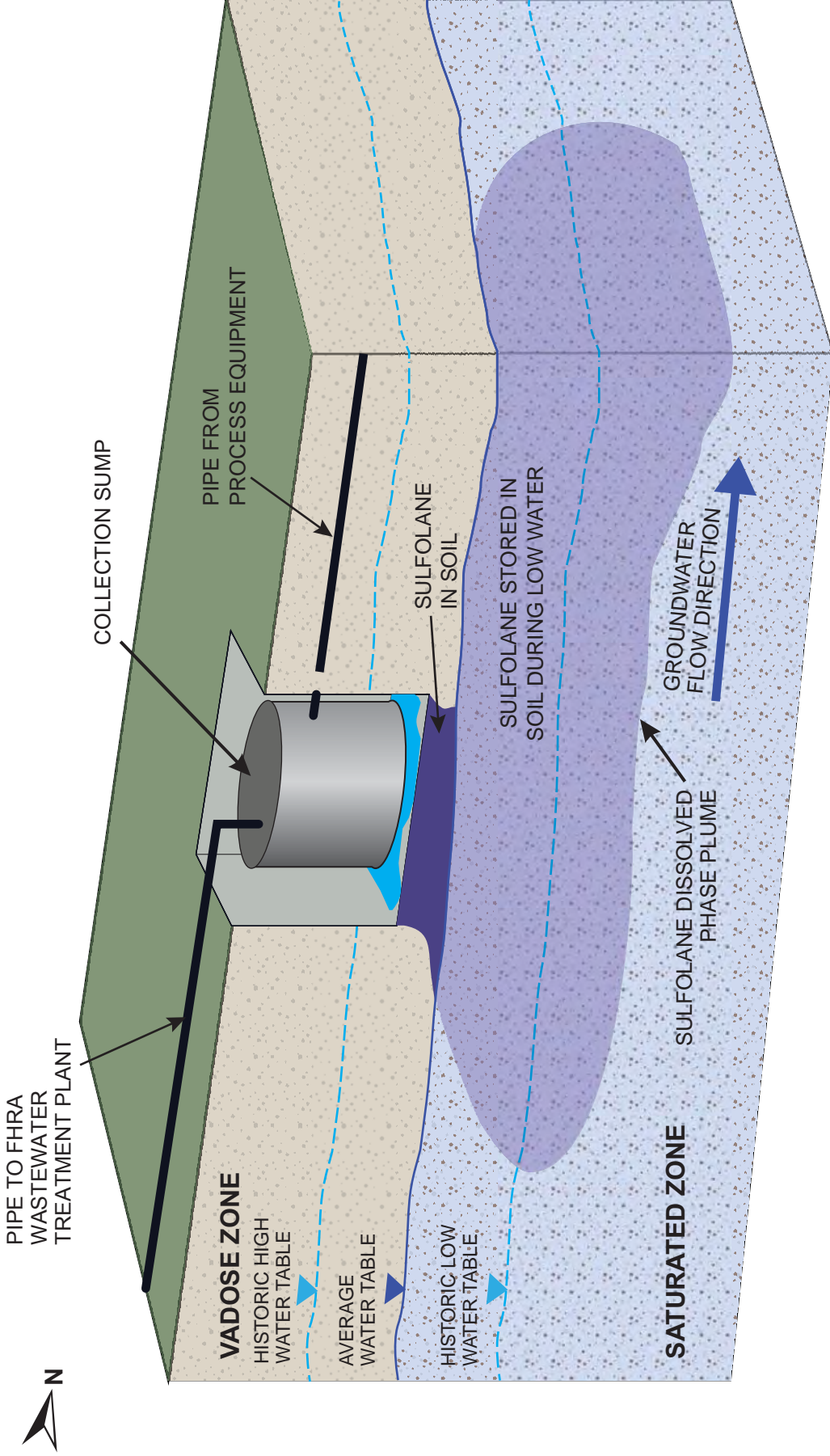
- Leaking wastewater collection sumps constructed below the ground surface. A conceptual illustration of a collection sump related release is shown on Figure 4-1.



Conceptual Site Model

North Pole Refinery
North Pole, Alaska

- Routine equipment washing in former wash areas that resulted in overflows and/or overspray to the surrounding ground surface. A conceptual illustration of a former wash area-related release is shown on Figure 4-2.
- Leaking and overflowing wastewater from Lagoon B that stored concentrated sulfolane wastewater. A conceptual illustration of the Lagoon B related release is shown on Figure 4-3.
- Potential mechanical or other operations-related releases from historical operations in and around the CU #2 EU where sulfolane was used to extract aromatics from crude oil in the production of gasoline.

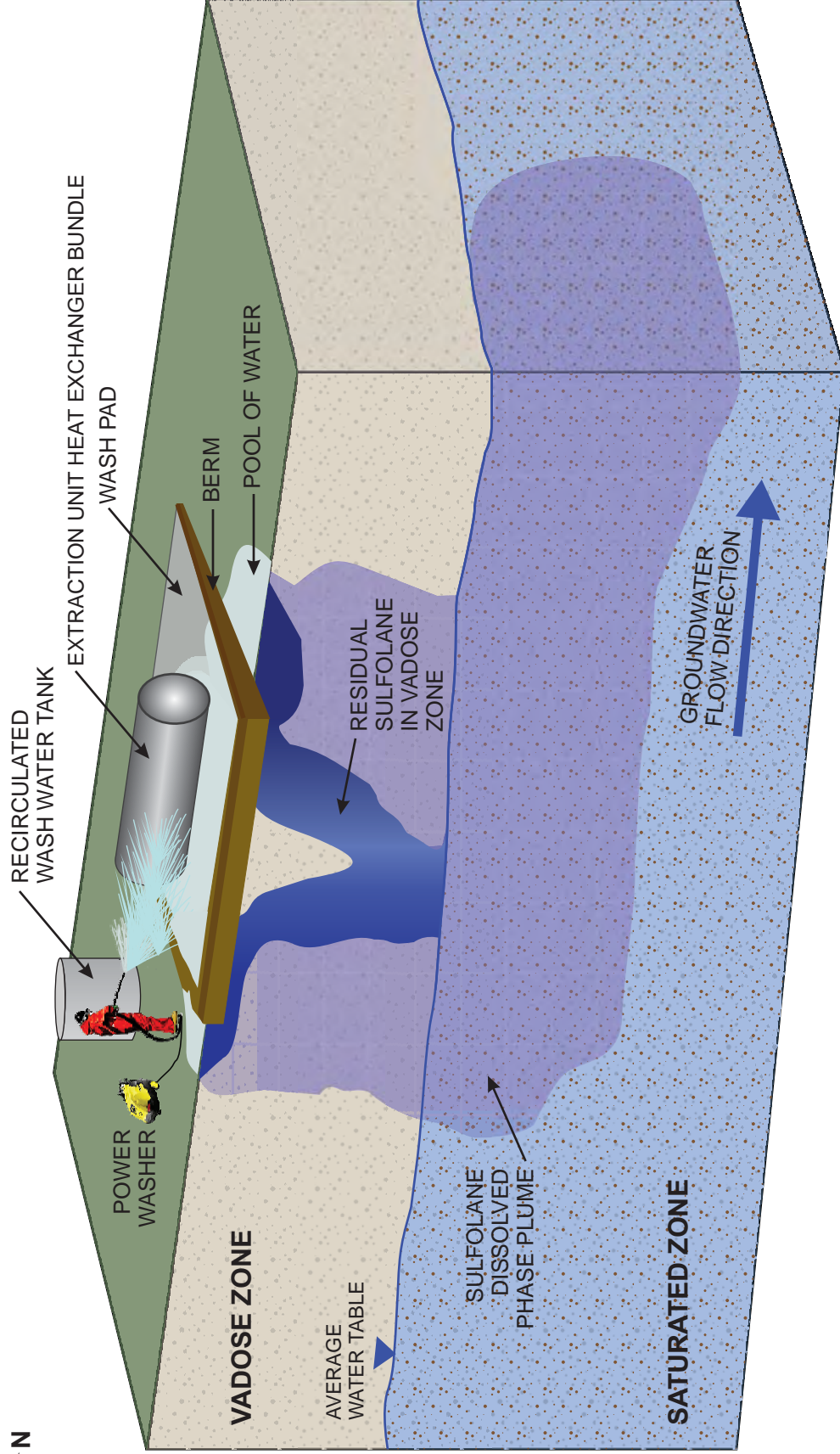


NOTE:
NOT-TO-SCALE, CONCEPTUAL ILLUSTRATION
ONLY.
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**SULFOLANE RELEASE MECHANISM 1:
COLLECTION SUMPS**





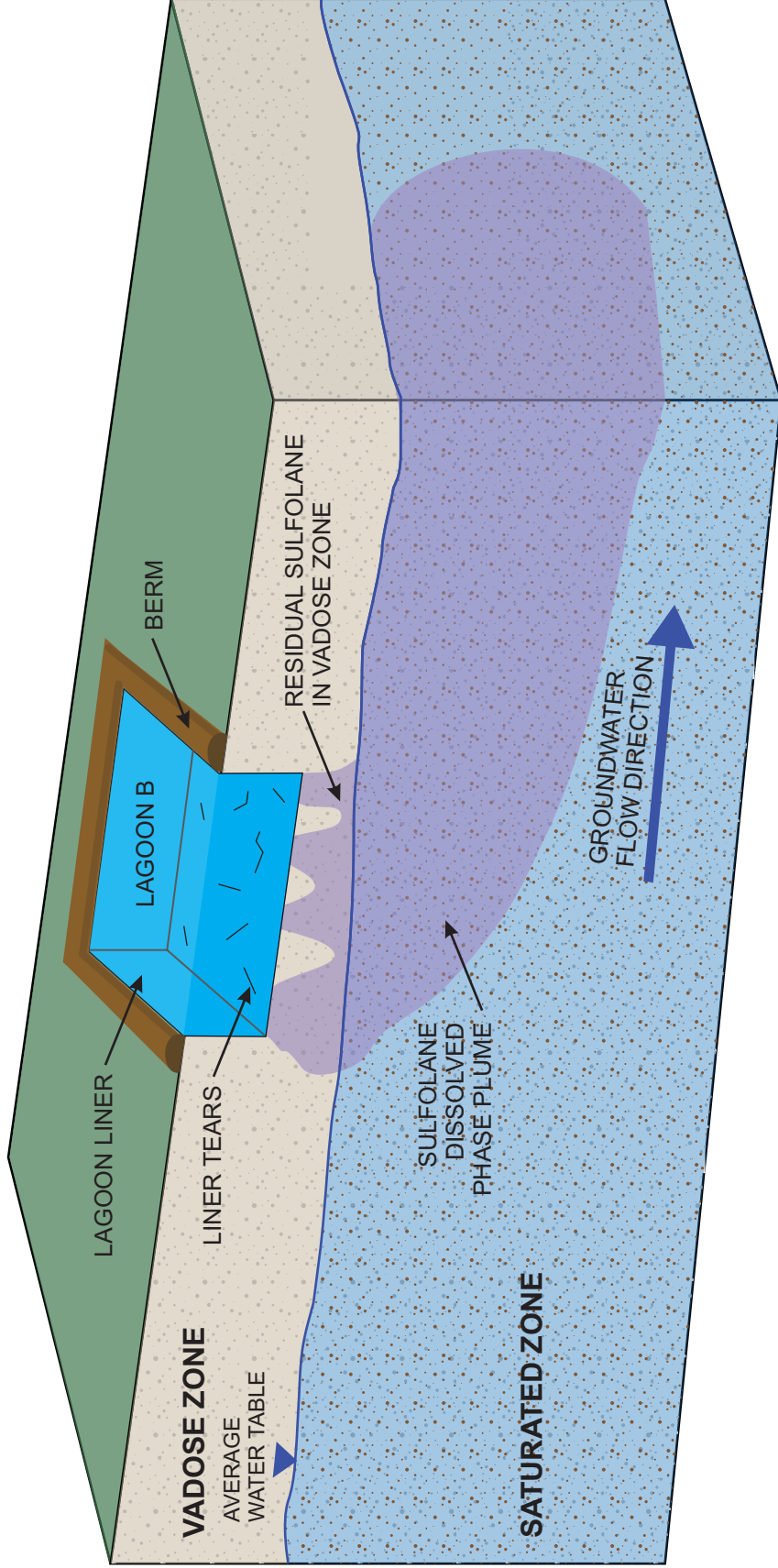
NOTE:
NOT-TO-SCALE; CONCEPTUAL ILLUSTRATION ONLY.

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**SULFOLANE RELEASE MECHANISM 2:
FORMER WASH AREAS**



FIGURE
4-2



NOTE:
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**SULFOLANE RELEASE MECHANISM 3:
LAGOON B**



4.2 Petroleum Hydrocarbons

Multiple releases of various petroleum products due to equipment failure, process upset, or human error have occurred at the refinery since it began operating in 1977. The largest documented release of petroleum was approximately 60,000 gallons of JP-4 jet fuel in 1980 from leaking above ground storage tanks (known as the former bolted tanks) located immediately south of containment areas CA5A and CA5B shown on Figure 2-1.

Petroleum is minimally soluble in water and less dense than water. Therefore, the petroleum resides in the subsurface at and near the intersection between groundwater and the soil matrix above the groundwater table (vadose zone) as light nonaqueous phase liquid (LNAPL). The LNAPL is in direct contact with both groundwater and soil gas. Soluble compounds within the petroleum slowly dissolve from the LNAPL into groundwater and volatile compounds slowly volatilize into soil gas.

4.3 Perfluorooctane Sulfonate and Perfluorooctanoic Acid

PFOS and PFOA were likely introduced to the environment from fire-fighting foams containing both compounds during fire-fighting training activities in the FTA (shown on Figure 2-1).

5. Impacted Media

Environmental impacts at the NPR and in areas downgradient from the NPR have been extensively characterized. A partial list of the environmental assessment activities is presented in Table 3.

Table 3. Summary of Environmental Assessment Activities

Assessment Technique	# Completed Onsite
Soil borings advanced	227
Monitoring wells installed	504
Soil samples collected and analyzed	1,032
Groundwater samples collected and analyzed	7,069

Notes:

Cumulative boring, monitoring well and sample numbers are approximate and since 2009. In addition to traditional soil and groundwater sampling, site characterization efforts have also included investigations to assess LNAPL, soil gas, surface water and geophysical subsurface data.

Soil, groundwater, and soil gas are impacted within the site boundary. Groundwater is impacted in some areas downgradient of the refinery. Surface water (the Badger Slough and onsite gravel pits) sampled by FHRA prior to 2013 and samples collected from the onsite North Gravel Pit in 2013 did not contain detectable concentrations of sulfolane.¹² Sulfolane concentrations detected in pore water near offsite gravel pits in 2011-2012 were used in the HHRA as a proxy for sulfolane concentrations in surface water and did not indicate unacceptable risk to human receptors through exposure to surface water.¹³ In addition,

sulfolane does not bioaccumulate and no risk to ecological receptors was identified.¹⁵ The contaminants affecting impacted media onsite and offsite are summarized in Table 4.

Table 4. Contaminants Affecting Impacted Media

Location	Media	Sulfolane	Petroleum Hydrocarbons	PFOS/PFOA
Onsite	Soil	X	X	X
	Groundwater	X	X	X
	Soil Gas		X	
Offsite	Groundwater	X		
	Irrigated Residential Garden Produce (potentially) ¹⁶	X		

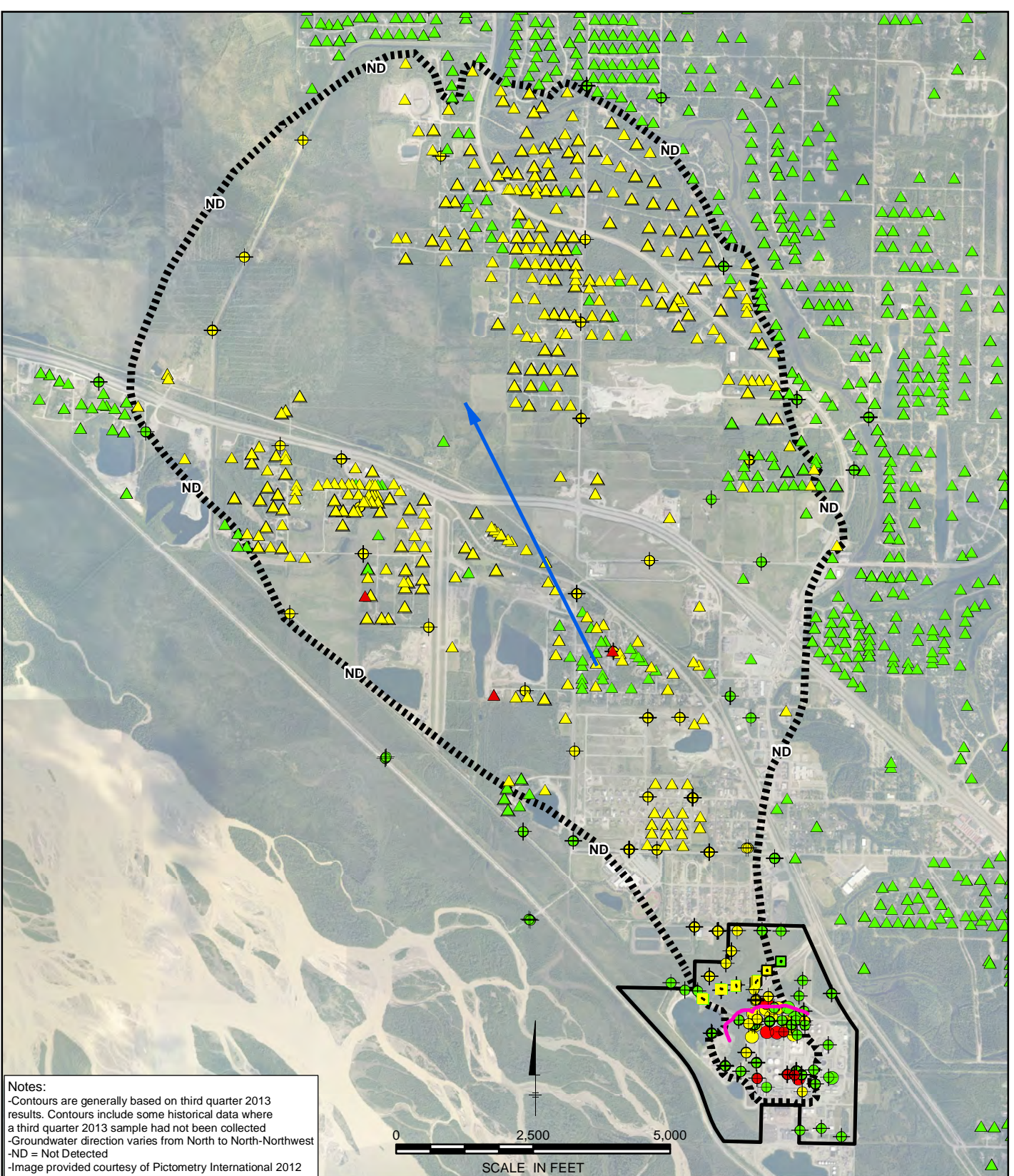
5.1 Sulfolane Distribution in Soil and Groundwater

The most significant sulfolane impacts to onsite soil are found in the shallow soil matrix above the groundwater table in areas where known sulfolane releases to the environment occurred: the SWA, Sump 908, the former overflow ditch at the South Gravel Pit, CU #1, CU #2 EU, and Lagoon B.

Sulfolane-affected groundwater extends approximately 3.6 miles from the northern property boundary (NPB) of the refinery and is found offsite in groundwater both above and below permafrost (permafrost is discussed in Section 8). At the NPB, the zone of detectable sulfolane concentrations is estimated to have a width of approximately 1,000 feet. The width of the zone of detectable sulfolane concentrations increases to approximately 1.5 miles (7,900 feet) at the widest point largely due to local groundwater flow direction variability related to groundwater movement around permafrost and seasonal fluctuations in Tanana River stage.

Groundwater monitoring data indicate that sulfolane concentrations are generally detected in the upper 55 feet of the suprapermafrost aquifer. However, in some locations, sulfolane is detected at depths greater than 100 feet below ground surface (bgs). Subpermafrost detections of sulfolane have been encountered at depths of up to 305 feet bgs.¹⁷

Sulfolane impacts to groundwater are delineated by monitoring wells and private wells as shown on Figures 5-1 and 5-2 for the offsite and onsite areas, respectively. Sample collection has been repeated at most private well locations. In general, the repeated monitoring has produced reasonably consistent data and trends, such that the plume boundaries remain definable and generally predictable. The repeated analytical results confirm the delineation of the plume. Figure 5-3 summarizes the most recent groundwater monitoring data from the subpermafrost aquifer, collected during the third quarter of 2013. Also shown on Figure 5-2 is the estimated extent of the capture zone as measured on October 22, 2013.



Notes:
 -Contours are generally based on third quarter 2013 results. Contours include some historical data where a third quarter 2013 sample had not been collected
 -Groundwater direction varies from North to North-Northwest
 -ND = Not Detected
 -Image provided courtesy of Pictometry International 2012

- Legend**
- ⊕ Monitoring Well
 - ⊠ Cluster Well
 - Observation Well
 - ▲ Not Detected
 - ▲ 3.1 - 362 µg/L
 - ▲ >362 µg/L
 - Not Detected
 - 3.1 - 362 µg/L
 - >362 µg/L
 - Approximate Sulfolane Isopleth in µg/L
 - Capture Zone at the Water Table on October 22, 2013
 - ▭ FHRA Property Boundary
 - ➡ Approximate Flow Direction

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**ESTIMATED SULFOLANE PLUME EXTENT IN
 GROUNDWATER - OFFSITE**


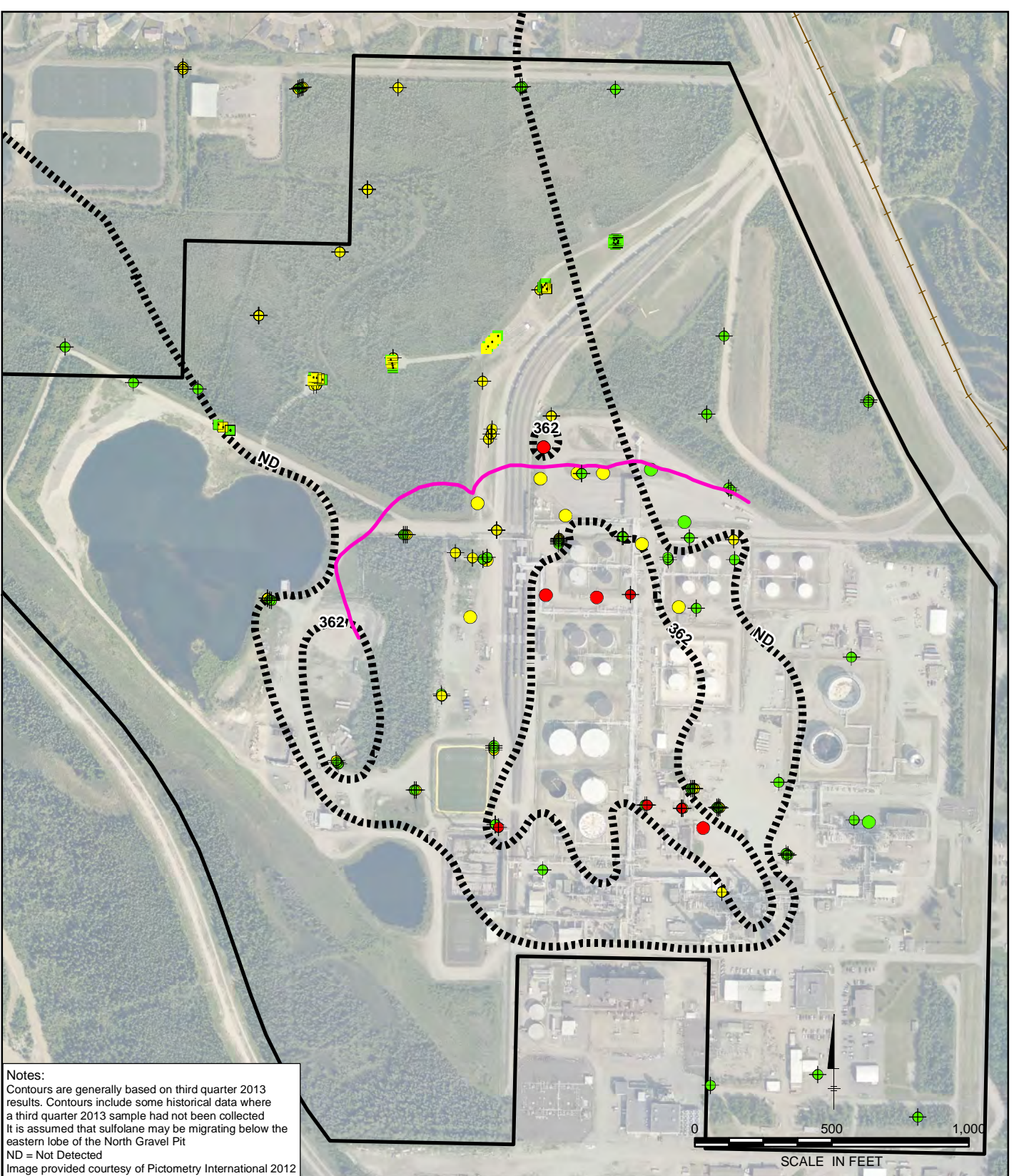
 **ARCADIS**

FIGURE
5-1



Notes:
 Contours are generally based on third quarter 2013 results. Contours include some historical data where a third quarter 2013 sample had not been collected. It is assumed that sulfolane may be migrating below the eastern lobe of the North Gravel Pit.
 ND = Not Detected
 Image provided courtesy of Pictometry International 2012

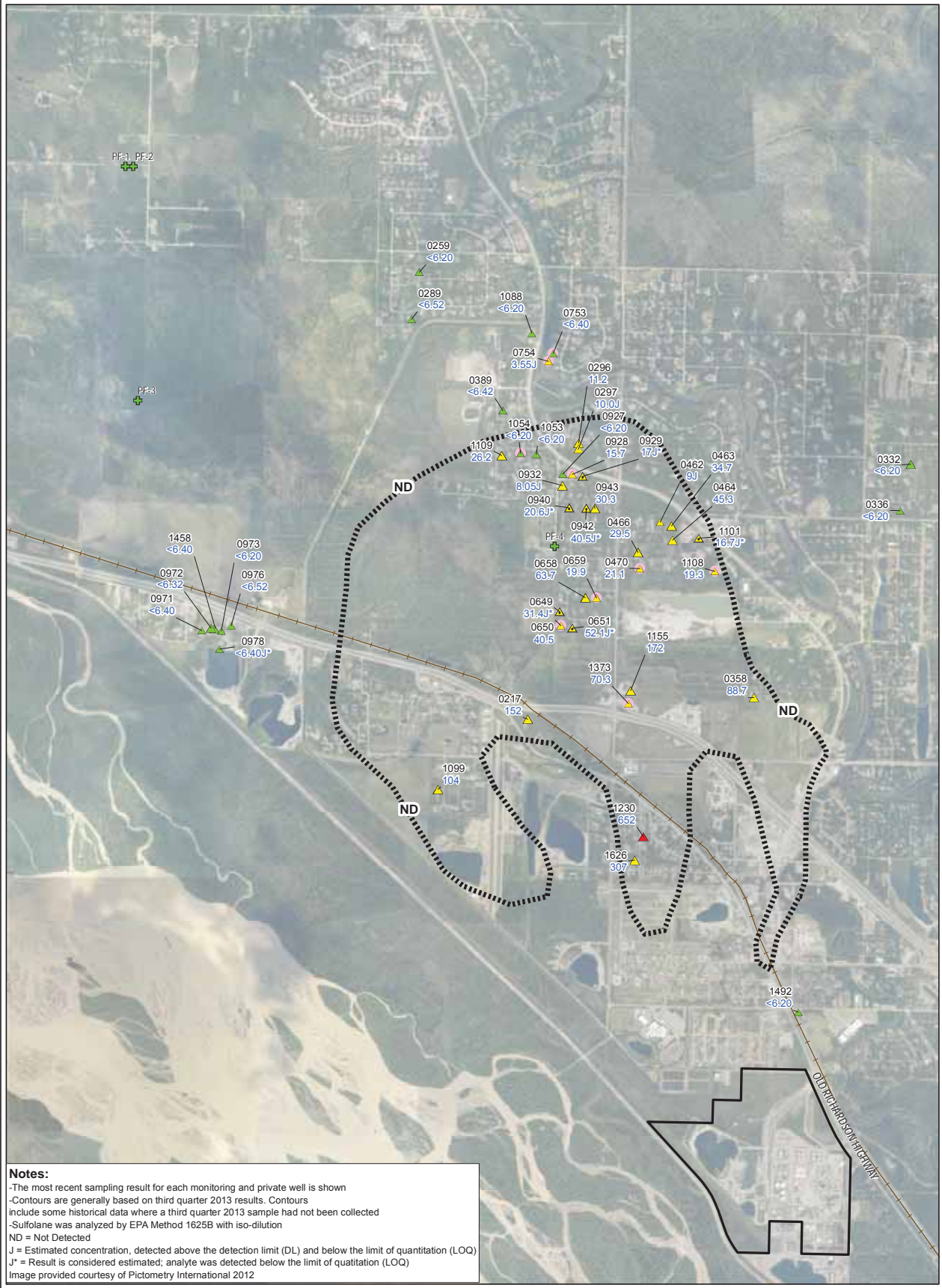
Legend

- ⊕ Monitoring Well
- ⊕ Cluster Well
- Observation Well
- Not Detected
- 3.1 - 362 µg/L
- >362 µg/L
- Approximate Sulfolane Isoleth in µg/L at Water Table
- Capture Zone at the Water Table on October 22, 2013
- FHRA Property Boundary

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**ESTIMATED SULFOLANE PLUME EXTENT IN
 GROUNDWATER - ONSITE**





Notes:
 -The most recent sampling result for each monitoring and private well is shown
 -Contours are generally based on third quarter 2013 results. Contours include some historical data where a third quarter 2013 sample had not been collected
 -Sulfolane was analyzed by EPA Method 1625B with iso-dilution
 ND = Not Detected
 J = Estimated concentration, detected above the detection limit (DL) and below the limit of quantitation (LOQ)
 J* = Result is considered estimated; analyte was detected below the limit of quantitation (LOQ)
 Image provided courtesy of Pictometry International 2012

Legend

- ▲ Point-of-entry treatment system sample collected
- The most recent sample was collected prior to October 2012
- Private Well Sulfolane Results
 - ▲ Not Detected
 - ▲ 3.1 - 362 µg/L
 - ▲ >362 µg/L
- ▲ 104 Sulfolane Concentration (µg/L)
- ▲ < Not detected: detection limit listed
- ▲ 1458 Private Well Location ID
- ⊕ Permafrost at Surface (no shallow groundwater present)
- ⋯ Approximate Sulfolane Isopleth in µg/L
- ▭ FHRA Property Boundary

SCALE IN FEET

0 2,000 4,000

FLINT HILLS RESOURCES ALASKA, LLC
 NORTH POLE REFINERY, NORTH POLE, ALASKA
CONCEPTUAL SITE MODEL

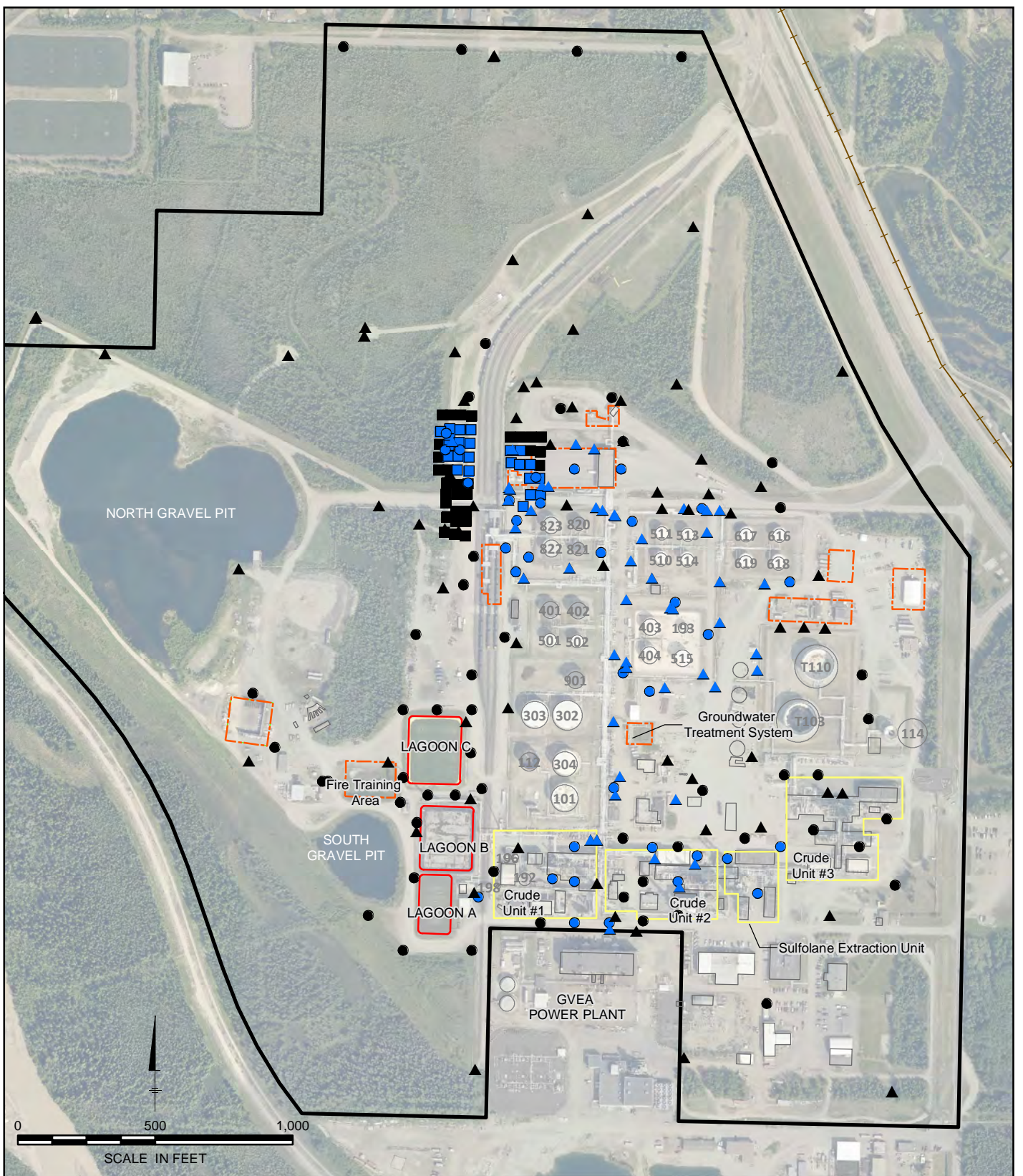
ESTIMATED SULFOLANE PLUME EXTENT IN SUBPERMAFROST GROUNDWATER

FIGURE
5-3



5.2 Petroleum Hydrocarbon Distribution in Soil, Groundwater, and Soil Gas

The LNAPL present at the site has been characterized by forensic analysis as diesel #2, naphtha, Jet A, or mixtures of these fuels with gasoline. Sulfolane was only detected at a concentration above the method reporting limit in one of 13 LNAPL samples collected in 2013 and analyzed for sulfolane. Therefore, LNAPL is not a significant source or sink of sulfolane to groundwater. The extent of LNAPL impacts to soil is shown on Figure 5-4.



Legend

- ▲ Monitoring Well with no LNAPL present
- ▲ Monitoring Well with LNAPL present
- Soil Boring with LNAPL present
- Soil Boring with no LNAPL present
- LIF location with LNAPL present
- LIF location with no LNAPL present
- ▭ REFINERY UNITS (HIGH RISK DRILLING WOULD REQUIRE A GPR)
- ▭ INDUSTRIAL ACTIVITY AREAS
- ▭ FHRA Property Boundary

Notes:
 Image provided courtesy of Pictometry International 2012

FLINT HILLS RESOURCES- ALASKA, LLC
 NORTH POLE REFINERY, NORTH POLE, ALASKA
CONCEPTUAL SITE MODEL

ESTIMATED EXTENT OF LNAPL



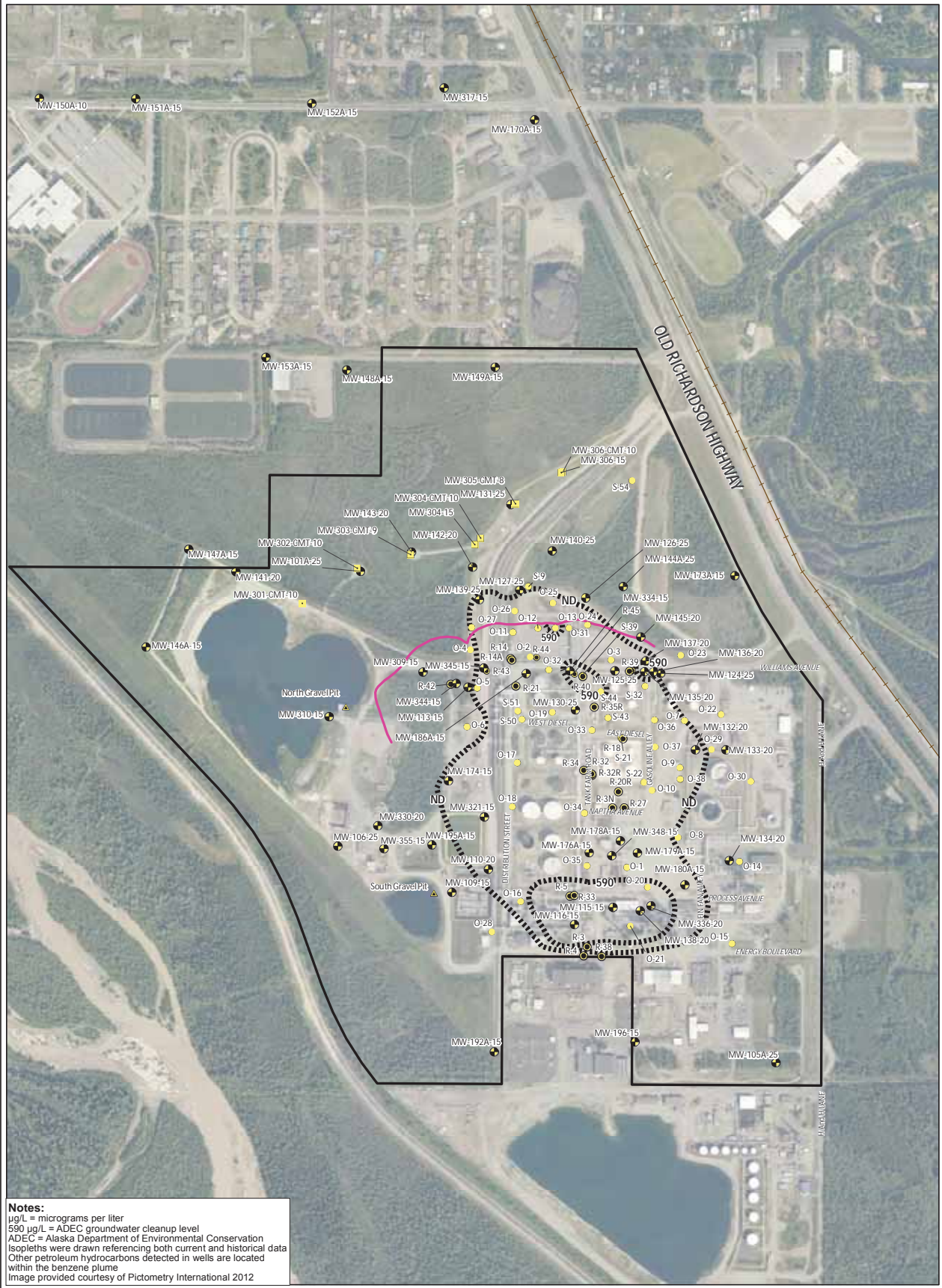
FIGURE
5-4



Conceptual Site Model

North Pole Refinery
North Pole, Alaska

Petroleum hydrocarbon-related impacts to groundwater are only found onsite and occur at shallow depths near the water table and the LNAPL smear zone. The extent of benzene impacts to groundwater is shown on Figure 5-5. The extent of groundwater impacts from other petroleum hydrocarbons is generally consistent with the extent of benzene impacts.



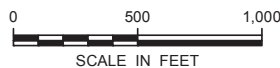
Notes:
 ug/L = micrograms per liter
 590 ug/L = ADEC groundwater cleanup level
 ADEC = Alaska Department of Environmental Conservation
 Isoleths were drawn referencing both current and historical data
 Other petroleum hydrocarbons detected in wells are located
 within the benzene plume
 Image provided courtesy of Pictometry International 2012

Legend:

- Benzene Results**
- Monitoring Well
 - Observation Well
 - Recovery Well
 - Vertical Profile Transect Well
 - ▲ Surface Water
 - Inferred Benzene Isoleth in ug/L

— Capture Zone at the Water Table on October 22, 2013

□ FHRA Property Boundary



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

CONCEPTUAL SITE MODEL

**ESTIMATED BENZENE PLUME
 EXTENT IN GROUNDWATER**



FIGURE

5-5

Soil gas sampling completed in 2013 showed that petroleum hydrocarbons are present in soil gas. The volatile petroleum hydrocarbon constituents found in soil gas are consistent with the reported LNAPL types at the site. Soil gas sampling showed that the concentration of volatile petroleum hydrocarbons in soil gas is much lower in soil gas samples collected half-way between the water table and surface than soil gas samples collected near the groundwater table. This was an expected result, because volatile petroleum hydrocarbons are quickly consumed within the vadose zone by aerobic biodegradation.¹⁸ Therefore, the lateral extent of soil gas impacts is likely similar to the extent of LNAPL.

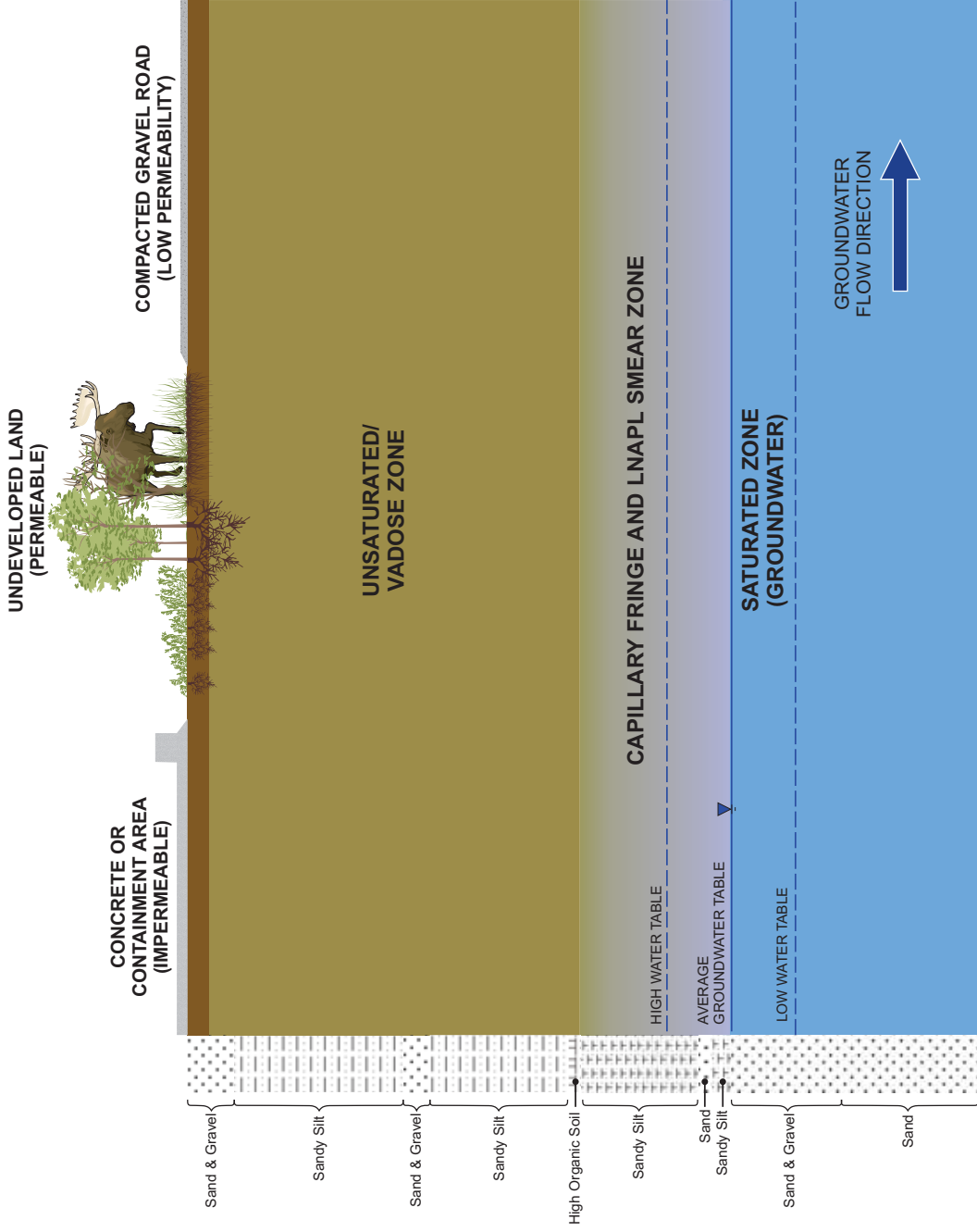
5.3 PFOS/PFOA Distribution in Soil and Groundwater

PFOS and PFOA impacts to soil and groundwater were found in the southwest part of the NPR (Figure 2-1), but were minor. The soil impacts were found in soil above an impervious liner that prevents rainwater or water used during firefighting training from infiltrating to groundwater. The groundwater results showed that PFOA in groundwater was below the applicable ACL and PFOS in groundwater exceeded the ACL. The extent of PFOS impacts to groundwater have been delineated both vertically and horizontally downgradient.¹⁹ PFOS and PFOA characterization is complete for both soil and groundwater.²⁰

6. Transport Mechanisms

Figure 6-1 shows a conceptual model of the shallow subsurface at the site. It includes the three main zones where contaminant transport occurs:

1. Vadose zone
2. Capillary fringe and LNAPL smear zone
3. Saturated zone below the water table



NOTE:
 NOT-TO-SCALE, CONCEPTUAL ILLUSTRATION ONLY.
 EXAMPLE SOIL LOG.

FLINT HILLS RESOURCES ALASKA, LLC
 NORTH POLE REFINERY, NORTH POLE, ALASKA
 CONCEPTUAL SITE MODEL

CONCEPTUAL MODEL
 OF SUBSURFACE

ARCADIS

FIGURE
6-1

6.1 Contaminant Fate and Transport in the Vadose Zone

Sulfolane and petroleum hydrocarbons are present in vadose zone soils at the site. PFOS and PFOA were also found in shallow soil, but the FTA where those contaminants were found is underlain by a synthetic liner where physical site observations, including the presence of standing water, and previous groundwater sampling substantiate that the liner is still functioning. The following mechanisms affect sulfolane and petroleum hydrocarbon fate and transport in the vadose zone:

- *Retention in soil moisture.* Sulfolane is highly soluble, (dissolves readily in water), however site data show that the sulfolane persists in vadose-zone soils long after sulfolane releases occurred. Site data show that up to 92 percent of soil pore space in the vadose zone is filled with water. Sulfolane storage is associated with soil moisture and has been correlated to silt and clay-sized particle content of vadose zone soil and low infiltration rates. Seasonal freezing of moisture in the vadose zone soils further restricts downward migration of sulfolane.
- *Infiltration.* Rainwater and snow melt infiltrate through the impacted vadose zone and transfer petroleum hydrocarbons and sulfolane from the vadose zone to the saturated zone. Infiltration is variable across the site due to seasonal frost, impervious surfaces, road compaction, and snow plowing, and generally thought to be small.
- *Aerobic biodegradation.* Oxygen present in the vadose zone supports aerobic biodegradation of volatile petroleum hydrocarbons, methane in soil gas, and possibly sulfolane in soil moisture.
- *Water table fluctuations.* Seasonal rises in the water table can allow mass that is located in the vadose zone to become part of the saturated groundwater system, and then to migrate along with the flowing groundwater. This could result in seasonal pulses of petroleum hydrocarbons and sulfolane to enter the shallow aquifer system at the source areas.
- *Seasonal frost.* Seasonal frost reduces overall contaminant transport rates because contaminants are immobilized in the frozen soil. The frost duration and depth changes from year to year based on weather.

6.2 Contaminant Fate and Transport in the Capillary Fringe and LNAPL Smear Zone

The effective diameter of soil pores is small enough to cause capillary rise in groundwater. This phenomenon results in a zone of saturated soil pores above the groundwater table that is known as the capillary fringe. The thickness of the capillary fringe is related to soil type; finer-grained soil has a thicker capillary fringe.

Groundwater elevations measured in a shallow groundwater well near NPR have varied more than 4 feet between 2001 and 2013,²⁰ driven primarily by variation in discharge of the Tanana River. This leads to seasonal variations in the location of the capillary zone and base of the vadose zone.

LNAPL in the subsurface responds to groundwater table fluctuation because it is less dense than groundwater and therefore buoyant. Through time groundwater table fluctuations create a vertical zone of LNAPL-affected soil, which is referred to as the smear zone.

The following mechanisms affect LNAPL and sulfolane fate and transport in the capillary fringe and LNAPL smear zone:

- *Volatilization.* Volatile constituents in LNAPL in contact with soil gas volatilize into soil gas.
- *Dissolution.* Soluble constituents in LNAPL in contact with groundwater dissolve into groundwater
- *Groundwater table fluctuations.* Groundwater may come into contact with sulfolane-impacted water in the capillary fringe causing seasonal pulses of contaminant to the aquifer.
- *Aerobic and anaerobic biodegradation.* Petroleum hydrocarbons are readily degraded by native soil bacteria under aerobic and anaerobic conditions. Site data show that the LNAPL is degrading at a rate of up to approximately 2,200 gallons per year for every acre of LNAPL plume. Sulfolane in the capillary fringe may also be subject to aerobic biodegradation.
- *Mobility.* Based on multiple lines of evidence the overall LNAPL plume is stable and it is unlikely that the LNAPL footprint will expand in the future.²²

6.3 Contaminant Fate and Transport in the Saturated Zone

The saturated zone is the sediment matrix below the groundwater table, considered as the aquifer. The pores spaces within the aquifer matrix are generally completely filled with groundwater. Some gas may be present in the saturated zone near the water table due to groundwater table fluctuations and anaerobic generation of gas (methane) where LNAPL is present. The following mechanisms affect sulfolane and petroleum hydrocarbon fate and transport in the saturated zone:

- *Advection.* Contaminants are transported by the bulk movement of flowing groundwater that moves both vertically and laterally. Groundwater movement is influenced on a local scale by variations in grain size of the aquifer soil matrix. Groundwater movement may be influenced by small changes in groundwater density and viscosity due to groundwater temperature variation. Permafrost also influences the magnitude and direction of advective flow. Advection occurs in the interconnected pore spaces of the aquifer soils, referred to as mobile porosity.
- *Groundwater dispersion.* Groundwater flow at the pore scale is chaotic. Groundwater flow diverges and converges around soil grains and groundwater flows faster through large soil pores in the soil matrix than smaller soil pores. This chaotic flow at the pore scale results in mechanical mixing of groundwater, including mixing unimpacted groundwater or recharge water with contaminated groundwater, which causes contaminant dilution and spreading at the macro (plume) scale both vertically and horizontally.

The degree of contaminant spreading is further enhanced by aquifer heterogeneity and the presence of permafrost, and is a scale dependent phenomenon.²³

- *Diffusion.* Contaminants move from areas of high concentration to areas of low concentration. In heterogeneous soils such as those found at the site, contaminant fate and transport via advection and dispersion will primarily occur in the relatively higher permeability zones. Contaminants will also be transported into or out of relatively low-permeability zones via diffusion (i.e., dual-porosity effects). In the early time of groundwater plume development the contaminant concentration is highest in the higher permeability zones and contaminants diffuse into lower permeability zones. This acts to reduce the rate of sulfolane migration relative to groundwater flow. In the later time of groundwater plume development, contaminant concentrations can be higher in the lower permeability materials and contaminants diffuse from lower permeability to high permeability zones. This prolongs the time required for sulfolane to be washed from the aquifer system.
- *Hydrophobic retardation.* Contaminants adsorb onto solid organic particles naturally present in soils due to the molecular structure of the contaminant. The degree of adsorption is also related to the amount of natural organic material that is present in the soil. Sulfolane does not readily adsorb onto organic particles so this process does not significantly affect sulfolane transport.²⁴ Hydrophobic retardation does significantly affect transport for contaminants such as benzene and naphthalene.
- *Degradation.* Contaminants that are dissolved in groundwater are degraded by native soil bacteria under aerobic and anaerobic aquifer conditions or are degraded abiotically through chemical reactions. Biodegradation of dissolved petroleum hydrocarbons in the saturated zone is significant and results in complete mineralization of hydrocarbons in groundwater within the refinery property. Scientific studies have shown that sulfolane degrades when oxygen is present in groundwater. Field studies conducted at the refinery also found that sulfolane degrades readily under aerobic conditions.
- *Seasonal changes in groundwater flow:* Groundwater generally flows to the north-northwest from the NPR. Seasonal variability in groundwater flow direction on the order of 19 degrees has been observed. The seasonal variability in groundwater flow is primarily caused by seasonal fluctuations in the stage of the Tanana and Chena Rivers, in addition to seasonal fluctuations in precipitation amounts and freeze-thaw cycles. This variability in groundwater flow direction increased the lateral extent of sulfolane found in groundwater.
- *Bifurcation around permafrost bodies, also known as diverging flow.* As groundwater flows from an area with no permafrost into an area where permafrost is present, a portion of the groundwater will flow upward into the suprapermafrost aquifer and a portion downward into the subpermafrost aquifer. Groundwater may also flow vertically through unfrozen zones (taliks). Bifurcation of groundwater flow vertically and horizontally around permafrost zones also occurs and exerts a control on groundwater flow and transport patterns, depending on the extent and distribution of permafrost.

- *Preferential pathways due to changes in geology.* The geology at the site is highly heterogeneous and consists of many soil layers that have variable properties and permeabilities. Soils with relatively higher permeabilities will create preferential pathways which will provide the majority of groundwater flow through the soil. These preferential pathways will also be responsible for the majority of solute mass transport.
- *Attenuation.* Attenuation is defined as the combined physical, chemical, and biological processes and mechanisms, including those described above, that reduce the mass or concentration of a contaminant in groundwater over time or distance from the source. Attenuation occurs naturally, but can be enhanced by engineered remediation measures.

6.4 Contaminant Fate and Transport in Surface Water

The refinery is bordered on the west by the Tanana River, and on the east and northeast by the Badger Slough. There are also ditches, gravel pits and ponds, and numerous wetlands within the affected area. Contaminants may be discharged to surface water bodies that are gaining (groundwater is flowing into the surface water body). The contaminants that enter the surface water body are subject to biologic and abiotic processes unique to surface water features (volatilization to the atmosphere, biodegradation, abiotic degradation, and photocatalytic destruction). Sulfolane is subject to aerobic biodegradation, abiotic degradation, and photocatalysis. Sulfolane has not been observed in surface water, either due to low discharge rates into surface water bodies, high degradation rates, or a combination of both.

Surface water bodies that are losing (surface water is flowing into groundwater) are not impacted by sulfolane. However, losing surface water bodies are substantial sources of oxygen influx into the aquifer and stimulate *in-situ* degradation of contaminants.

7. Geology

The site and the surrounding North Pole area are located on a flat-lying alluvial plain that is situated between the Tanana River and Chena Slough (locally known as Badger Slough). The NPR is located on the Tanana River Floodplain. The sediments that comprise the Tanana River valley were laid down primarily by the ancestral Tanana and Chena rivers, which carried sediment in channels that flowed at different locations across the valley floor through time. These former river channels deposited gravel, sand and silt based on the velocity and volume of flow through time, and by the type of sediment carried. These sediments gradually filled the valley to its present level. As the ancestral Tanana and Chena rivers migrated across the valley, former channels were abandoned and in some cases are in direct connection with other channel deposits that lie above or below. The coarser river deposits have created more permeable zones within the aquifer that result in preferential pathways for the flow of groundwater and sulfolane. These preferential pathways likely contribute to the shape of the zone of detectable sulfolane concentrations in both the lateral and vertical extents.

Depth to bedrock has been estimated at 400 to 600 feet bgs and is at least 616 feet thick near Moose Creek Dam.²⁵ The depth to bedrock shallows toward the east and north as the alluvium pinches out at the mountainous areas.

8. Permafrost

Permafrost is subsurface soil or ground that is frozen (i.e., below 32 degrees Fahrenheit [°F]) for 2 or more consecutive years. Permafrost within the vicinity of North Pole, Alaska is discontinuous; it occurs at significant thicknesses locally, but unfrozen zones are present, for instance, beneath the NPR. Permafrost affects groundwater flow by creating localized regions of converging and diverging horizontal and vertical groundwater movement around the impervious permafrost bodies. The diverging and converging groundwater flow patterns can have a significant influence on contaminant distribution. Based on permafrost investigation activities and groundwater monitoring data, it was determined that groundwater flow through a talik, or unfrozen zone (flow pathway), is one mechanism responsible for migration of sulfolane-impacted groundwater to the subpermafrost zone. A conceptual illustration of the zone of detectable sulfolane concentrations and a talik are shown on Figure 8-1.

Local well drillers report that the permafrost in the North Pole area is present in most areas, but the thickness and surface elevation are variable. Permafrost extends to the ground surface at some locations within the affected area. Thawing associated with heat sources (e.g., urban development or large water bodies) can create discontinuities in the permafrost. In contrast, undeveloped lands that do not have water bodies and are vegetated generally preserve permafrost.

9. Hydrogeology

9.1 Precipitation and Climate

The Tanana Valley has a subarctic climate with long, cold winters and short, relatively warm summers. The average annual temperature is 27 °F, ranging from a mean minimum January temperature of negative 18 °F to a mean maximum July temperature of 72 °F, with an average annual precipitation of approximately 11 inches.²⁶ The extreme changes due to the regional climate and associated weather patterns influences the fate and transport of contaminants at the site.

9.2 Groundwater

The aquifer is an unconsolidated alluvial fill deposited by the ancestral rivers that flowed through the valley. The aquifer consists of discontinuous layers of sand, gravel and silt. The water table is present beneath the site at approximately 10 feet bgs and may fluctuate up to 4 feet seasonally. Groundwater gradients and flow directions vary approximately 19 degrees seasonally and the regional direction of groundwater flow is toward the north-northwest.²⁷ The regional aquifer is absent in places where bedrock extends to surface. Where the aquifer is present it is largely unconfined and can be greater than 600 feet thick. Permafrost may create locally-confined conditions within the regional aquifer, and lenses of silt may have the same effect. Where permafrost is present, the saturated aquifer above it is designated as the “suprapermafrost aquifer” and the “subpermafrost aquifer” is the zone of unfrozen groundwater below the permafrost.

9.2.1 Suprapermafrost Aquifer Characteristics

The suprapermafrost aquifer is an unconfined aquifer and is recharged by surface-water features, precipitation infiltration, and snow melt. Groundwater wells are commonly installed in the suprapermafrost aquifer. The groundwater in this aquifer is used as a water supply by some Fairbanks North Star Borough residents. In some places, permafrost extends to or near the ground surface resulting in no suprapermafrost aquifer in those areas.

The groundwater flow direction in the suprapermafrost aquifer generally varies approximately 19 degrees from a north-northwesterly direction to a few degrees east of north, depending primarily on discharge in the Tanana River. The flow direction trends to the north-northwest in winter and early spring and more northerly in the summer and fall, and correlates with variations in the Tanana River stage. Hydraulic conductivity values measured by FHRA range five orders of magnitude from approximately 0.1 to 17,000 feet per day, which demonstrates the heterogeneity of the aquifer materials at a variety of scales. The mean sulfolane transport velocity at the site is estimated at approximately 2 feet per day, although local variability in aquifer materials can cause sulfolane to migrate at higher and lower rates.

9.2.2 Subpermafrost Aquifer Characteristics

The subpermafrost aquifer is confined by the permafrost layer above and may be semi-confined in areas of discontinuous permafrost. The subpermafrost aquifer near the refinery comprises mixtures of sand and gravel. The subpermafrost aquifer serves as a water supply in areas near the site; some Fairbanks North Star Borough users have deep water supply wells that draw water from the subpermafrost aquifer.

Subpermafrost monitoring wells have not been installed because drilling through the permafrost may create vertical contaminant migration pathways through the permafrost. Therefore, information on groundwater flow direction and hydrogeology of the subpermafrost aquifer is based on data collected from a network of private wells in the subpermafrost aquifer, drilling logs from those wells, and a general understanding of regional geology and hydrogeology based on published literature. The distribution of sulfolane in the subpermafrost aquifer indicates that the overall groundwater flow direction is to the north-northwest.

9.2.3 Groundwater Flow Between the Subpermafrost and Suprapermafrost Aquifers

Permafrost acts as a physical barrier to vertical and horizontal groundwater flow. In areas where permafrost is not present, there is potential for mixing of groundwater between the subpermafrost and suprapermafrost aquifers. In addition to the “bifurcation around permafrost bodies” and “preferential pathways due to changes in geology” mechanisms described above in Section 6.3, an additional mechanism that may induce groundwater flow between the aquifers in areas where permafrost is not present is:

- *Vertical flow due to pressure gradients.* Groundwater moves vertically from areas of high hydraulic head to areas of low hydraulic head. Pressures in the subpermafrost and suprapermafrost aquifers vary seasonally and flow will vary between upward and downward.

9.3 Surface Water – Groundwater Interactions

Important surface-water features near the site include the Tanana and Chena rivers, tributaries of the Tanana and Chena rivers including Badger Slough, Ditch C (a flood control drainage ditch), and numerous onsite and offsite gravel pits. Local groundwater flow directions change in response to changes in flow and stage (river level) in the Tanana and Chena rivers. When the Tanana River stage is high, surface water infiltrates into the underlying groundwater system; when the Tanana River stage is low, groundwater flows toward and discharges into it.

The stages of the Tanana and Chena rivers are controlled by regional climate processes and subject to annual variations associated with seasonal temperature and precipitation. The Tanana River is a high-energy braided system affected by melting snow and ice in the spring, snow and glacial melt from the Alaska Range during the summer months, and precipitation during the late summer and fall. The Chena River is a low-energy meandering system and flow and stage is primarily affected by melting snow and ice in the spring and early summer, and precipitation during the late summer and fall.

Groundwater generally flows down valley, but groundwater in the NPR area has a component of flow from the Tanana River toward the Chena River. Ditch C is primarily a gaining surface water feature and is controlled by the local groundwater levels, and in the event of a flood receives runoff.

The numerous onsite and offsite gravel pits within the area of the zone of detectable sulfolane concentrations are in communication with the groundwater system and have a localized effect on groundwater flow. Water levels in the pits rise and fall in concert with regional groundwater elevation fluctuations.

10. Exposure Routes

A human health CSM²⁸ evaluates potential exposure pathways, potential receptors, and general potential routes of exposure. The completed ADEC Human Health CSM forms are attached as Appendix B.

10.1 Offsite

The only offsite contaminant is dissolved-phase sulfolane. Sulfolane is not volatile and is not readily absorbed by dermal contact, therefore the only exposure pathway deemed complete or potentially complete for sulfolane is ingestion of groundwater, surface water, and farmed foods that may be irrigated with sulfolane-impacted groundwater. Ingestion of surface water was evaluated using off-site pore-water samples as a proxy for surface water samples. The evaluation determined there is no unacceptable risk associated with ingestion of surface water during recreational activities.²⁹ Inhalation of wind-blown dust containing onsite contaminants is also a potential exposure pathway for offsite receptors, but was also shown not to present an unacceptable risk.³⁰

10.2 Onsite

Benzene and sulfolane represent the primary onsite COCs. Potentially complete and significant onsite exposure pathways are presented in Table 5.

Table 5. Potentially Complete and Significant Onsite Exposure Pathways

Current and Future Onsite Receptor	Pathways Evaluated
Indoor commercial/industrial worker	Inhalation of volatile contaminant vapors in indoor air from groundwater.
Outdoor commercial/ industrial worker	Ingestion of, dermal contact with, and inhalation (particulates) of contaminants in surface soil. Inhalation of volatile contaminant vapors in outdoor air volatilized from surface and subsurface soil and groundwater.
Construction/trench worker	Ingestion of, dermal contact with, and inhalation (particulates) of contaminants in surface and subsurface soil. Inhalation of volatile contaminant vapors in trench air from surface and subsurface soil and groundwater. Ingestion of and dermal contact with contaminants in groundwater in excavation trenches.
Adult visitor	Inhalation of volatile contaminant vapors in indoor air from groundwater.

The results of the risk evaluation indicated no unacceptable risk associated with most of the potentially complete onsite pathways.³¹

10.3 Ecological Risk Assessment

No complete exposure pathways for ecological receptors were identified.³² Therefore, there is no ecological risk related to contaminants present onsite or offsite.

11. Potential Receptors

Potential onsite receptors include:

- Indoor and outdoor commercial/industrial workers
- Construction/trench workers
- Adult visitors

Offsite receptors include:

- Indoor and outdoor commercial/industrial workers
- Construction/trench workers
- Adult, child, and infant residents

11.1 Ongoing Remediation

FHRA is currently operating a groundwater extraction system that pumps groundwater from remediation wells at the NPR, treats the extracted groundwater, and discharges the treated water into the SGP under an ADEC-issued permit. Approximately 155 million gallons of groundwater were extracted and treated in 2013 (through September). As of the end of third quarter 2013, approximately 394,400 gallons of LNAPL have been recovered at the NPR since 1978. The groundwater extraction system has been shown to be capturing the majority of the sulfolane-impacted groundwater coming from sulfolane source areas at the site and preventing further movement of sulfolane above the ACL offsite.

In response to the discovery of sulfolane impacts in groundwater, FHRA completed extensive upgrades to the groundwater extraction system to increase the remediation efficacy, expand the width of the groundwater capture zone and increase operational efficiency. While the remedial effort has largely been focused on sulfolane, the groundwater extraction system is also recovering LNAPL and petroleum hydrocarbon-impacted groundwater.

A groundwater extraction system expansion is underway. Additional groundwater extraction wells and a second groundwater treatment system will be installed to the west of the current groundwater extraction well network. The expanded groundwater extraction system will create a capture zone that spans the extent of detectable sulfolane that will capture sulfolane migrating from source areas and prevent future movement of sulfolane offsite. The system expansion is scheduled to be operational by the end of the second quarter 2014.

11.2 Alternative Water Solutions Program

FHRA immediately began sampling private wells of residents and businesses near the NPR upon detection of sulfolane in offsite monitoring wells installed in September and October 2009. A total of 800 private wells have been sampled and 303 alternative drinking water solutions were provided to those with sulfolane-impacted drinking water wells.³³ FHRA additionally offered to collect samples from garden wells for property owners, and properties within the zone of detectable sulfolane concentrations area were offered an outside hose spigot connected to the city water system or were offered a bulk tank for gardening.

FHRA has completed the following mitigation actions to address potential drinking water risks associated with offsite dissolved-phase sulfolane impacts:

- Provided alternative water solutions³⁴ to approximately 300 residences and businesses with wells that have tested positive for sulfolane.
- Established a buffer zone around the known extent of sulfolane where private wells have been sampled and bottled water is provided as a precautionary measure to prevent exposure to sulfolane.



Conceptual Site Model

North Pole Refinery
North Pole, Alaska

As of September 30, 2013, FHRA has installed and maintains 158 point of entry (POE) treatment systems. In addition, 113 bulk water tanks have been installed, 32 properties have chosen ongoing bottled water service as their permanent solution, and 48 garden tanks have been installed for those outside the city's municipal water system. Figure 11-1 summarizes the deployment of alternative water solutions downgradient of the NPR.

FHRA's provision of alternative water solutions to affected residents is set forth in the Alternative Water Solutions Program – Management Plan (AWS Program; Barr 2013).

Figure 11-1 Potable Water Solutions Provided by Flint Hills Resources

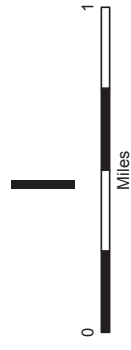
Legend

- Sulfonane not detected
- 3.10 - 362 ppb
- greater than 362 ppb
- Monitoring Well
- Long Term Alternative Water
- City Water Solutions
- Interim Bottled Water Solution
- Water Tank Listed As Water Source During Survey (Outside City Limits)

- Some properties require more than one solution
- New NP City Wells
- Water Main New City Wells
- North Pole City Boundary
- ppb = parts per billion
- 1 ppb = 1 µg/L (microgram per liter)
- 1 µg/L = 0.000000001 g/L (gram per liter)

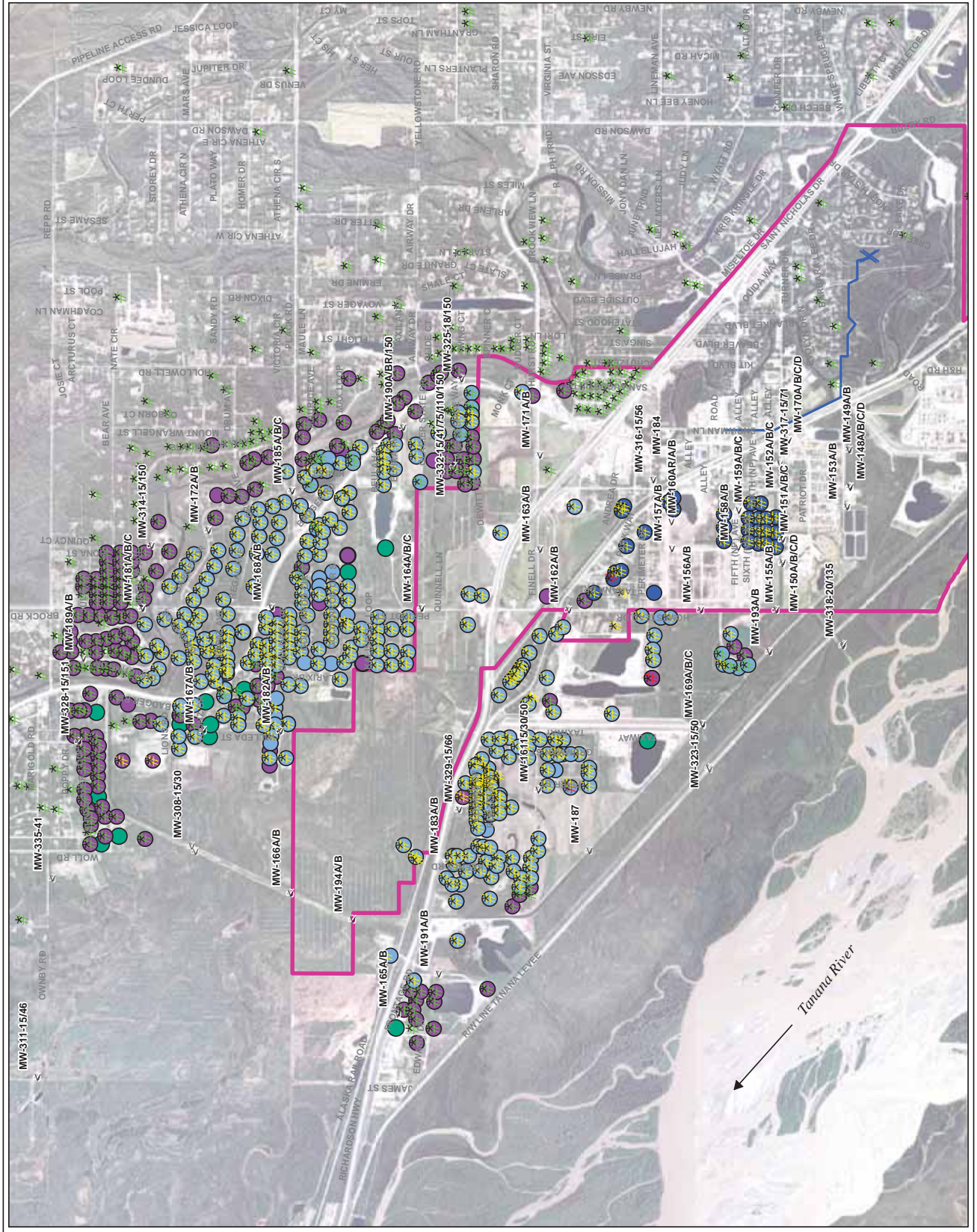
*Interim bottled water delivery will be provided to all locations with a sulfonane detection until a final solution is chosen and installed.

**The latest sulfonane result for a well is presented on this map.



Results for Samples Collected
through June 27, 2013

July 26, 2013





11.3 Potential Exposure Mitigation and Receptor Protection

FHRA is actively mitigating potential exposure risks and protecting receptors through the following ongoing programs:

- Enhanced and expanded operation of the groundwater extraction system and implementation of the proposed upgrades to prevent future migration of sulfolane-impacted groundwater offsite.
- Refinery management practices to protect potential receptors onsite.
- Replacement of the municipal wells owned by the city that were affected by sulfolane with wells that are located outside of the sulfolane affected area.
- Implementation and maintenance of the AWS Program (Barr 2013) to protect offsite receptors.

Endnotes

¹ The primary petroleum products produced at the NPR include JP-4, jet fuels, heating and diesel fuels, gasoline, and asphalt.

² An inspection conducted in 1997 showed that the walls and floors of Sump 02/04-2 were severely corroded. Williams attempted to repair the sump at that time. However, FHRA inspected the sump in 2009 and discovered that a weld installed in 1997 was not properly completed, the sump coating had failed, and the drain lines coming from Crude Unit #2 failed a hydrostatic test. In response, FHRA discontinued use of the drain lines by blocking them off and repaired the sump.

³ Sump 908 was inspected in 1997, 2006, and 2010 and significant deterioration of the sump walls and coatings was discovered. The sulfolane concentration in wastewater managed in Sump 908 was higher in the past, before FHRA operated the refinery. The sulfolane concentration peaked in early- to mid-1990s and has decreased since that time. FHRA repaired Sump 908 in 2010.

⁴ Equipment that came into contact with sulfolane was washed as part of facility maintenance operations. A wash area located within Crude Unit 1 was the only wash area at the facility until 1990. The wash area did not have walls or curbs. Sulfolane-impacted wash water was likely released in this area due to wash overspray and overflow. The strip drain was also likely a source of sulfolane to soil, as indicated by an inspection document that indicates it was originally constructed with concrete that likely cracked and later lined with steel.

⁵ A second wash area was constructed at the site in 1990 in the southwestern portion of the site, immediately west of the FTA. The area is currently used for materials storage; however, one of its former uses was as a wash area for equipment that came into contact with sulfolane. This wash area was constructed of concrete with 6-inch curbs and no walls. Water used for washing operations was collected and reused, which concentrated the sulfolane concentrations in the wash water. Sulfolane-impacted wash water was likely released in this area due to wash overspray and overflow. An aerial photograph taken on July 29, 2002 shows the new wash area in its current configuration west of the previous wash area constructed in 1990. The current wash area has walls to control overspray.

⁶ Wastewater is continuously produced as a part of NPR operations and treated by an onsite wastewater treatment system. A component of the wastewater treatment system is a series of lined lagoons where wastewater is stored and processed. Lagoon B was constructed in 1977 and was the only lagoon on site until Lagoon A was built in October 1987. Lagoon B was removed from continuous operation in 1990. Closure operations for Lagoon B were initiated in 1990 and completed in 1991, at which time the liner was removed and replaced. High-concentration sulfolane wastewater was stored in Lagoon B intermittently from sometime after its closure through 2003. Sulfolane-impacted wastewater was released from Lagoon B to the subsurface through holes in the bottom of the liner as discussed in History of Sulfolane Releases to the Environment at the Flint Hills Refinery, North Pole, Alaska (Geomega 2013a). As summarized by Geomega (2013a), in 1990, more than 45 holes and tears greater than 1 foot in size were observed in the liner and in June 1991, additional tears in the Lagoon B liner were identified.

⁷ The historical use of AFFF at the site is provided in the Perfluorinated Compound Investigation Report (ARCADIS 2013a) and the Site Characterization Report – 2013 Addendum (ARCADIS 2013b)

⁸ Revised Draft Final HHRA (ARCADIS 2012a)

⁹ Regional Screening Levels for Chemical Contaminants at Superfund Sites (USEPA 2013)

¹⁰ Regional Screening Levels for Chemical Contaminants at Superfund Sites (USEPA 2013)

¹¹ Groundwater ACLs for these COCs were calculated using ADEC-accepted exposure scenarios in the HHRA. Soil migration-to-groundwater ACLs for the other COCs were calculated using the risk-based groundwater ACLs and the USEPA Calculator for Regional Screening Levels for Chemical Contaminants at Superfund Sites (http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm).

¹² Surface-water samples have been collected from Badger Slough and from repeated sampling of onsite gravel pits. Sulfolane was not detected above laboratory detection limits in any surface water sample collected.

¹³ Revised Draft Final HHRA (ARCADIS 2012a).

¹⁴ Ecological Conceptual Site Model (Ecological CSM; ARCADIS 2011).

¹⁵ Garden Sampling Project Report (SWI 2013).

¹⁶ As measured in private well PW-1109.

¹⁷ Interstate Technology Regulatory Council 2009.

¹⁸ Perfluorinated Compounds Investigation Report (ARCADIS 2013a)

¹⁹ Onsite Site Characterization Report – 2013 Addendum (ARCADIS 2013b).

²⁰ Onsite Site Characterization Report – 2013 Addendum (ARCADIS 2013b).

²¹ The three lines of evidence presented in ARCADIS 2013b are: 1) LNAPL pore velocity, 2) LNAPL pore-entry pressure, and 3) dissolved-phase petroleum hydrocarbon plume stability.

²² Gelhar et al. 1992.

²³ Luther et al. 1988.

²⁴ Glass et al. 1996.

²⁵ The North Pole Groundwater Model Report (Geomega 2013b).

²⁶ Site Characterization Report – Through 2011 (Barr 2012).

²⁷ ADEC Human Health Conceptual Site Graphic Forms were prepared for the onsite and offsite areas. These graphic forms were prepared in accordance with the ADEC Policy Guidance on Developing Conceptual Site Models (ADEC 2010), and were refined based on input from the ADEC and its consultants. An ADEC Human Health Conceptual Site Graphic Form prepared for the offsite area was most recently updated in connection with the Revised Draft Final HHRA (ARCADIS 2012a), was presented in the Draft Final Onsite Feasibility Study (ARCADIS 2012b), and is included in Appendix A of this CSM. An ADEC Human Health Conceptual Site Graphic Form prepared for the onsite area was updated in connection with the Revised Draft Final HHRA (ARCADIS 2012a), and was presented in the Draft Final Onsite Feasibility Study (ARCADIS 2012b), and is included in Appendix A of this CSM. The onsite Human Health Conceptual Site Graphic Form was reviewed with respect to the presence of PFOS and PFOA onsite. Because PFOS and PFOA have similar properties to sulfolane, the potential onsite exposure mechanisms remain unchanged.

²⁸ Revised Draft Final HHRA (ARCADIS 2012a).

²⁹ Revised Draft Final HHRA (ARCADIS 2012a).

³⁰ Potentially complete onsite pathways with unacceptable risk identified in the HHRA were incidental ingestion of groundwater in a trench, dermal contact with groundwater and inhalation of trench air by onsite construction workers (ARCADIS 2012a).

³¹ FHRA submitted an Ecological CSM (ARCADIS 2011) to ADEC in June 2011. The purpose of the Ecological CSM (ARCADIS 2011) was to establish whether environmental contaminants related to site operations that are present onsite, or that have migrated offsite, will come in contact with ecological receptors.

³² As of September 2013.

³³ As described in the AWS Program (Barr 2013), three long-term AWS options have been developed for homeowners with wells containing detectable sulfolane concentrations:

1. An in-home water treatment system that uses the existing well water and treats for sulfolane before water is distributed throughout the residence POE treatment system).

-
2. A bulk water tank option where water would be delivered by a water delivery company from another site to the tank and that water would be distributed throughout the residence.
 3. Long-term bottled water delivery, consisting of 3- or 5-gallon bottles of water, for drinking and cooking, delivered to the residence on a weekly basis.

FHRA has established a buffer zone around the known zone of detectable sulfolane concentrations where private wells have been sampled and bottled water is provided as a precautionary measure to prevent exposure to sulfolane.



Appendix A

References



Appendix A – References

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

ARCADIS U.S., Inc. 2011. Ecological Conceptual Site Model. June 2011.

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

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

ARCADIS U.S., Inc. 2013a. Perfluorinated Compounds Investigation Report. February 15, 2013.

ARCADIS U.S., Inc. 2013b. Onsite Site Characterization Report – 2013 Addendum. December 2013.

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

Barr Engineering Company. 2013. Final Alternative Water Solutions – Management Plan. December 19, 2013.

Gelhar, L.W., Welty, C., Rehfeldt, K.R. 1992. A critical review of data on field-scale dispersion in aquifers. *Water Resources Research* 28(7):1955-1974.

Geomega, Inc. 2013a. History of Sulfolane Releases to the Environment at the Flint Hills Refinery, North Pole, Alaska. January 25, 2013.

Geomega, Inc. 2013b. The North Pole Groundwater Model Report. February 4, 2013.

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., L.M. Gieg, D.L. Coy, and P.M. Fedorak. 1998. Sulfolane Biodegradation Potential in Aquifer Sediments at Sour Natural Gas Plant Sites. *Water Resources*. Volume 32 Number 12. pp. 3680-3688. 1998.

Interstate Technology Regulatory Council. 2009. Evaluating Natural Source Zone Depletion at Sites with LNAPL. April 2009.

Kim C.G., W.P. Clarke, and D. Lockington. 1999a. Anaerobic Biodegradation of Sulfolane in Soil Environment. *Environmental Engineering Research*. Korean Society of Environmental Engineers. Volume 4. Number 3. pp. 185-193. 1999.



Kim C.G., W.P. Clarke, and D. Lockington. 1999b. Feasibility Test of Biological Degradation of Heterocyclic Sulfur Compounds in Anaerobic State. *Journal of Environmental Science and Health, Part A*. Volume 34. Number 4. pp. 899-918. 1999.

Luther, S.M., Dudas, M.J., Fedorak, P.M. 1998. Sorption of sulfolane and diisopropanolamine by soils, clays, and aquifer materials. *Journal of Contaminant Hydrology* 32:159-176.

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.

Shannon and Wilson, Inc. Garden Sampling Project Report. North Pole, Alaska. January 5, 2013.

United States Environmental Protection Agency. 2012. Provisional Peer-Reviewed Toxicity Values for Sulfolane (CASRN 126-33-0). Final. 1-30-2012. Washington, DC: Office of Research and Development, National Center for Environmental Assessment, Superfund Health Risk Technical Support Center. Cincinnati, OH. January.

United States Environmental Protection Agency. 2013. Calculator for Regional Screening Levels for Chemical Contaminants at Superfund Sites. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm. Last accessed November 22, 2013.

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.



Appendix B

ADEC Human Health CSM Forms

HUMAN HEALTH CONCEPTUAL SITE MODEL GRAPHIC FORM

Site: FHR North Pole Refinery - On-Site Only

Completed By: R. Andresen

Date Completed: updated May 21, 2012

Instructions: Follow the numbered directions below. Do not consider contaminant concentrations or engineering/land use controls when describing pathways.

(1) Check the media that could be directly affected by the release.
 (1) if the media acts as a secondary source.

(2) For each medium identified in (1), follow the top arrow and check possible transport mechanisms. Check additional media under (1) if the media acts as a secondary source.

Media

Media	Transport Mechanisms
<input checked="" type="checkbox"/> Surface	<input checked="" type="checkbox"/> Direct release to surface soil <i>check soil</i> <input checked="" type="checkbox"/> Migration to subsurface <i>check soil</i> <input checked="" type="checkbox"/> Migration to groundwater <i>check groundwater</i> <input checked="" type="checkbox"/> Volatilization <i>check air</i> <input checked="" type="checkbox"/> Runoff or erosion <i>check surface water</i> <input type="checkbox"/> Uptake by plants or animals <i>check biota</i> <input type="checkbox"/> Other (list):
<input checked="" type="checkbox"/> Subsurface Soil (2-15 ft bgs)	<input checked="" type="checkbox"/> Direct release to subsurface soil <i>check soil</i> <input checked="" type="checkbox"/> Migration to groundwater <i>check groundwater</i> <input checked="" type="checkbox"/> Volatilization <i>check air</i> <input checked="" type="checkbox"/> Uptake by plants or animals <i>check biota</i> <input type="checkbox"/> Other (list):
<input checked="" type="checkbox"/> Ground-water	<input checked="" type="checkbox"/> Direct release to groundwater <i>check groundwater</i> <input checked="" type="checkbox"/> Volatilization <i>check air</i> <input checked="" type="checkbox"/> Flow to surface water body <i>check surface water</i> <input checked="" type="checkbox"/> Flow to sediment <i>check sediment</i> <input checked="" type="checkbox"/> Uptake by plants or animals <i>check biota</i> <input type="checkbox"/> Other (list):
<input checked="" type="checkbox"/> Surface Water	<input checked="" type="checkbox"/> Direct release to surface water <i>check surface water</i> <input checked="" type="checkbox"/> Volatilization <i>check air</i> <input checked="" type="checkbox"/> Sedimentation <i>check sediment</i> <input checked="" type="checkbox"/> Uptake by plants or animals <i>check biota</i> <input type="checkbox"/> Other (list):
<input type="checkbox"/> Sediment	<input checked="" type="checkbox"/> Direct release to sediment <i>check sediment</i> <input type="checkbox"/> Resuspension, runoff, or erosion <i>check surface water</i> <input type="checkbox"/> Uptake by plants or animals <i>check biota</i> <input type="checkbox"/> Other (list):

(3) Check all exposure media identified in (2).

Exposure Media

- soil
- groundwater
- air
- surface water
- sediment
- biota

(4) Check all pathways that could be complete. The pathways identified in this column must agree with Sections 2 and 3 of the Human Health CSM Scoping Form.

Exposure Pathway/Route

- Incidental Soil Ingestion
- Dermal Absorption of Contaminants from Soil
- Inhalation of Fugitive Dust
- Ingestion of Groundwater
- Dermal Absorption of Contaminants in Groundwater
- Inhalation of Volatile Compounds in Tap Water
- Inhalation of Outdoor Air
- Inhalation of Indoor Air
- Inhalation of Fugitive Dust
- Ingestion of Surface Water
- Dermal Absorption of Contaminants in Surface Water
- Inhalation of Volatile Compounds in Tap Water
- Direct Contact with Sediment
- Ingestion of Wild or Farmed Foods

(5) Identify the receptors potentially affected by each exposure pathway: Enter "C" for current receptors, "F" for future receptors, "C/F" for both current and future receptors, or "-" for insignificant exposure.

Current & Future Receptors

Exposure Pathway/Route	Residents (adults or children)	Commercial or Industrial workers	Site visitors, trespassers or recreational users	Construction workers	Farmers or subsistence harvesters	Subsistence consumers	Other
Incidental Soil Ingestion	C/F	I	C/F	C/F			
Dermal Absorption of Contaminants from Soil	C/F	I	C/F	C/F			
Inhalation of Fugitive Dust	C/F	I	C/F	C/F			
Ingestion of Groundwater							
Dermal Absorption of Contaminants in Groundwater	I						
Inhalation of Volatile Compounds in Tap Water							
Inhalation of Outdoor Air							
Inhalation of Indoor Air							
Inhalation of Fugitive Dust							
Ingestion of Surface Water							
Dermal Absorption of Contaminants in Surface Water							
Inhalation of Volatile Compounds in Tap Water							
Direct Contact with Sediment							
Ingestion of Wild or Farmed Foods							

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 NORTH POLE REFINERY, NORTH POLE, ALASKA

HUMAN HEALTH CONCEPTUAL
 SITE MODEL GRAPHIC FORM -
 ON SITE ONLY



APPENDIX
B

HUMAN HEALTH CONCEPTUAL SITE MODEL GRAPHIC FORM

Site: FHR North Pole Refinery - Off-Site Only

Completed By: R. Andresen

Date Completed: updated May 9, 2012

(1) Check the media that could be directly affected by the release.

(2) For each medium identified in (1), follow the top arrow and check possible transport mechanisms. Check additional media under (1) if the media acts as a secondary source.

Media	Transport Mechanisms
<input type="checkbox"/> Surface Soil (0-2 ft bgs)	Direct release to surface soil <i>check soil</i> <input type="checkbox"/> Migration to subsurface <i>check soil</i> <input type="checkbox"/> Migration to groundwater <i>check groundwater</i> <input type="checkbox"/> Volatilization <i>check air</i> <input type="checkbox"/> Runoff or erosion <i>check surface water</i> <input type="checkbox"/> Uptake by plants or animals <i>check biota</i> <input type="checkbox"/> Other (list):
<input type="checkbox"/> Subsurface Soil (2-15 ft bgs)	Direct release to subsurface soil <i>check soil</i> <input type="checkbox"/> Migration to groundwater <i>check groundwater</i> <input type="checkbox"/> Volatilization <i>check air</i> <input type="checkbox"/> Uptake by plants or animals <i>check biota</i> <input type="checkbox"/> Other (list):
<input checked="" type="checkbox"/> Ground-water	Direct release to groundwater <i>check groundwater</i> <input type="checkbox"/> Volatilization <i>check air</i> <input checked="" type="checkbox"/> Flow to surface water body <i>check surface water</i> <input checked="" type="checkbox"/> Flow to sediment <i>check sediment</i> <input checked="" type="checkbox"/> Uptake by plants or animals <i>check biota</i> <input type="checkbox"/> Other (list):
<input type="checkbox"/> Surface Water	Direct release to surface water <i>check surface water</i> <input type="checkbox"/> Volatilization <i>check air</i> <input type="checkbox"/> Sedimentation <i>check sediment</i> <input type="checkbox"/> Uptake by plants or animals <i>check biota</i> <input type="checkbox"/> Other (list):
<input type="checkbox"/> Sediment	Direct release to sediment <i>check sediment</i> <input type="checkbox"/> Resuspension, runoff, or erosion <i>check surface water</i> <input type="checkbox"/> Uptake by plants or animals <i>check biota</i> <input type="checkbox"/> Other (list):

Instructions: Follow the numbered directions below. Do not consider contaminant concentrations or engineering/land use controls when describing pathways.

(3) Check all exposure media identified in (2).

(4) Check all pathways that could be complete. The pathways identified in this column must agree with Sections 2 and 3 of the Human Health CSM Scoping Form.

(5) Identify the receptors potentially affected by each exposure pathway. Enter "C" for current receptors, "F" for future receptors, "C/F" for both current and future receptors, or "-" for insignificant exposure.

Exposure Media	Exposure Pathway/Route	Residents (adults or children)	Commercial or Industrial workers	Site visitors, trespassers or recreational users	Construction workers	Farmers or subsistence harvesters	Subsistence consumers	Other
<input type="checkbox"/> soil	<input type="checkbox"/> Incidental Soil Ingestion							
	<input type="checkbox"/> Dermal Absorption of Contaminants from Soil							
	<input type="checkbox"/> Inhalation of Fugitive Dust							
<input checked="" type="checkbox"/> groundwater	<input checked="" type="checkbox"/> Ingestion of Groundwater	C/F	C/F	C/F	C/F			
	<input type="checkbox"/> Dermal Absorption of Contaminants in Groundwater							
	<input type="checkbox"/> Inhalation of Volatile Compounds in Tap Water							
<input checked="" type="checkbox"/> air	<input type="checkbox"/> Inhalation of Outdoor Air							
	<input type="checkbox"/> Inhalation of Indoor Air							
	<input checked="" type="checkbox"/> Inhalation of Fugitive Dust	C/F	C/F					
<input checked="" type="checkbox"/> surface water	<input checked="" type="checkbox"/> Ingestion of Surface Water							
	<input type="checkbox"/> Dermal Absorption of Contaminants in Surface Water							
	<input type="checkbox"/> Inhalation of Volatile Compounds in Tap Water							
<input checked="" type="checkbox"/> sediment	<input type="checkbox"/> Direct Contact with Sediment							
<input checked="" type="checkbox"/> biota	<input checked="" type="checkbox"/> Ingestion of Wild or Farmed Foods	C/F						

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