Site Characterization Report -Through 2011

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

Prepared for
Flint Hills Resources Alaska, LLC

December 2012

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List of Abbreviations and Acronyms

AAC	Alaska Administrative Code
ACLs	alternative cleanup levels
ADEC	Alaska Department of Environmental Conservation
ADHSS	Alaska Department of Health and Social Services
ADNR	Alaska Department of Natural Resources
ADOT&PF	Alaska Department of Transportation & Public Facilities
AFCEE	Air Force Center for Engineering and the Environment
A:N ratio	aromatics vs. naphthenes
ARARs	Applicable or Relevant and Appropriate Requirements
ARCADIS	ARCADIS, US, Inc.
AST	aboveground storage tank
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
AWCD	Air-Water Capillary Pressure Drainage
Barr	Barr Engineering Company
BGS	below ground surface
BOD	biological oxygen demand
BTEX	benzene, toluene, ethylbenzene, and xylenes
BWT	below the water table
C	carbon
^{12}C	light carbon isotope
^{13}C	heavy carbon isotope
CA	tank farm containment area
CCV	continuing calibration verification
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	cubic feet per second
CMS	Corrective Measures Study
CMT	continuous multi-channel tubing
COC	contaminants of concern
COD	chemical oxygen demand
COI	contaminant of interest
COBC	Compliance Order by Consent
COPC	contaminant of potential concern
COV	coefficient of variation

cP	centipoise
CP	Cleanup Plan
CSM	Conceptual Site Model
CSP	Contaminated Sites Program
CU	crude unit
DCM	dichloromethane
DEM	digital elevation model
DNAPL	dense nonaqueous-phase liquid
DRO	diesel range organics
DVD	digital video disc
DZM	discrete-zone monitoring
EB	equipment blank
EDD	electronic data deliverable
ESI	Environmental Standards, Inc.
EU	extraction unit
FHRA	Flint Hills Resources Alaska, LLC
FID	flame ionization detector
FNSB	Fairbanks North Star Borough
FPM-C	Free Product Mobility – Centrifuge Method
FPM-WD	Free Product Mobility – Water Drive Method
ft/day	feet per day
ft/ft	foot per foot
ft MSL	feet above mean sea level
FS	Feasibility Study
g	grams
g/cm^3	grams per cubic centimeter
g/day	grams per day
GAC	granular activated carbon
GC/FID	gas chromatography with flame ionization detector
GC-IRMS	gas chromatography – isotope ratio mass spectrometry
GeoTek	GeoTek Alaska, Inc.
gpm	gallon per minute
gpm/ft	gallons per minute per foot
GPR	ground penetrating radar
GRO	gasoline range organics

GVEA	Golden Valley Electrical Association
HHRA	Human Health Risk Assessment
Homestead	Homestead Drilling Company
IDW	investigation-derived waste
in/yr	inches per year
IRAP	Interim Removal Action Plan
IRB/SRB	iron- and sulfate-reducing bacteria
IRIS	Integrated Risk Information System
ITRC	the Interstate Technology & Regulatory Council
K	hydraulic conductivity
lbs/day	pounds per day
LCM	LNAPL Conceptual Model
LCS	laboratory control sample
LCSD	LCD duplicate
LIF	laser-induced fluorescence
L/kg	liters per kilogram
LNAPL	light nonaqueous-phase liquid
LOQ	limit of quantitation
LPSA	Laser Particle Size Analysis
MAROS	Monitoring and Remediation Optimization System
MAPCO	MAPCO Petroleum, Inc.
mg	milligram(s)
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mg sulfolane/bd	milligrams of sulfolane per bead
mL	milliliter
mL/min	milliliters per minute
MNA	monitored natural attenuation
MS	matrix spike
MSD	MS duplicate
MSDS	Material Safety Data Sheet
MSL	mean sea level
MTBE	methyl tert-butyl ether
MTG	migration-to-groundwater
MW	monitoring well

NAPL	nonaqueous-phase liquid
NPR	North Pole Refinery
NSZD	natural source zone depletion
PAN	parcel account number
OD	outside diameter
ORP	oxidation reduction potential
PAH	polynuclear aromatic hydrocarbon
PCA	principal component analysis
PDB	Pee Dee Belemnite
PFD	Process Flow Diagram
PIANO	paraffins, isoparaffins, aromatics, naphthenes, olefins
PID	photoionization detector
P:I ratio	paraffins vs. isoparaffins
PLFA	Phospholipid fatty acid analysis
POE	Point-of-Entry
ppb	parts per billion
ppm	parts per million
PQL	quality assurance/quality control
PVC	polyvinyl chloride
QA	quality assurance
QC	quality control
qPCR	quantitative polymerase chain reaction
RCRA	Resource Conservation and Recovery Act
Reiss	Reiss Remediation, LLC
RFA	RCRA Facility Assessment
RFI	RCRA Facility Investigation
ROW	right-of-way
RPD	relative percent difference
RRO	residual range organics
RSC Report	Revised Site Characterization Report
RSL	regional screening level
SAP	Sampling and Analysis Plan
SC/CAP	Site Characterization Report and Corrective Action Plan
SCL	soil cleanup level
SCR	Site Characterization Report

SCR-2011	Site Characterization Report – Through 2011
SCRA-2012	Site Characterization Report – 2012 Addendum
SCWP	Site Characterization Work Plan
SGS	SGS Environmental Services, Inc.
SIM	selected ion monitoring
SIR	Supervisor Incident Report
SOP	standard operating procedure
SPAR	Division of Spill Prevention and Response
ss	stainless steel
SVOC	semivolatile organic compound
SWI	Shannon & Wilson, Inc.
SWPT	single well pumping test
SWTT	single well tracer test
TAH	total aromatic hydrocarbons
TaqH	total aqueous hydrocarbons
TCP	traffic control plan
The City	The City of North Pole, Alaska
TKN	total kjeldahl nitrogen
TMB	trimethylbenzene
TOC	total organic carbon
TPT	Technical Project Team
UCL	Upper Confidence Limit
UIC	Underground Injection Control
ULS	ULS Services, Inc.
University of Oklahoma	University of Oklahoma Organic Geochemistry/Stable Isotope Laboratories
USCOE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UST	underground storage tank
UVOST	ultraviolet optical screening tool
VOC	volatile organic compound
VPT	vertical profile transect
WELTS	Well Log Tracking System
Williams	Williams Alaska Petroleum, Inc.

WQA	Water Quality Association
WWTP	wastewater treatment plant
yd^3	cubic yards
YSI	Yellow Springs Instruments
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter
‰	per mil
°C	degrees Celsius
°F	degrees Fahrenheit

Executive Summary

This *Site Characterization Report – Through 2011* (SCR-2011) has been prepared to provide a description of site characterization tasks that have been completed through 2011 because of the Williams Plume (hereinafter referred to as the "plume") and the results of those tasks for the Flint Hills Resources Alaska, LLC (FHRA) North Pole Refinery (NPR), located in North Pole, Alaska. The tasks were proposed and described in the *Site Characterization Work Plan* (SCWP) (Barr, 2010b) and the subsequent *Site Characterization Work Plan Addendum (*SCWP Addendum) (ARCADIS, 2011a), and *Scope of Work for Additional Site Characterization Activities* (ARCADIS, 2011c). The results of tasks proposed in the *2012 Site Characterization Work Plan* (2012 SCWP) (ARCADIS, 2012c) will be reported in the *Site Characterization Report - 2012 Addendum* (SCRA-2012), to be submitted on January 25, 2013.

Groundwater monitoring data collected during the first three quarters of 2012 have been reported in the quarterly monitoring reports. Fourth quarter 2012 groundwater monitoring data will be presented in the *Fourth Quarter 2012 Groundwater Monitoring Report*, to be submitted by March 1, 2013.

Data gathered during Site Characterization were used to complete a *Human Health Risk Assessment* (HHRA). The HHRA estimates the nature and probability of adverse health effects in humans who may be exposed to chemicals associated with NPR. The draft was submitted December 30, 2011. The Revised Draft Final HHRA was submitted May 23, 2012.

Data have also been used to construct the computational groundwater model, the draft of which was submitted on December 19, 2011. The groundwater model is being submitted as Appendix Q of this report. The version of the groundwater flow model presented in this report was based on data collected through the end of the third quarter of 2011. Development of the model has continued using data collected subsequent to the third quarter of 2011; the most up-to-date version of the model will be discussed with ADEC at a meeting scheduled for January 9, 2013.

The data are feeding into an *Onsite Feasibility Study* (Onsite FS) by FHRA and an *Offsite Feasibility Study* (Offsite FS), to be completed by the party responsible for the offsite plume. The FS process is being completed in general accordance with the United States Environmental Protection Agency (USEPA) Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance. The initial draft Onsite FS was submitted on April 13, 2012, followed by a subsequent draft on May 25, 2012. The initial draft Offsite FS was submitted on August 31, 2012.

These efforts will support the selection of permanent remedies in coordination with ADEC that will be presented in a draft Cleanup Plan (CP). As part of this effort, ADEC has requested that FHRA temporarily suspended work on the Onsite FS, Offsite FS, and CP in order to allow additional time for data collection and evaluation. ADEC also directed FHRA to prepare and implement an addendum to the Interim Removal Action Plan (IRAP) (Barr, 2010a). The IRAP Addendum will be submitted by January 18, 2013.

Established quarterly monitoring and reporting will continue, and interim response action implementation will continue for specific concerns. The Final Cleanup Plan will include establishing compliance monitoring networks and ongoing monitoring, sampling, and analysis plans.

In a letter to FHRA dated August 18, 2011, ADEC listed priorities for the NPR site per 18 Alaska Administrative Code 75 to include:

1. Eliminate the current exposure to sulfolane.
2. Pursue aggressive onsite remediation.
3. Establish a monitoring network that adequately measures the success of the remediation at eliminating offsite contaminant migration and removing the contamination onsite.
4. Achieve and maintain source control.
5. Determine the extent of the contamination downgradient and potential for movement of the plume in order to develop a remedial strategy that will control exposure for the duration of time it takes to achieve final cleanup levels via engineered and/or natural mechanisms.
6. Complete an evaluation of risk that accounts for all exposure pathways and cumulative risk.

FHRA has conducted significant work toward achieving these priorities. Some specific measures implemented toward these priorities include:

- **Eliminate the current exposure to sulfolane.** FHR has conducted sampling of approximately 500 private wells throughout the groundwater plume area. Sulfolane has been detected in approximately 280 wells and permanent alternative water supply solutions are being provided to all impacted properties. City water has been extended to some properties, and those outside the city service area can choose among three options for alternative water. Through 2011, 139 point of entry (POE) treatment systems have been installed, 85 bulk water tanks have been installed. 26 properties have chosen ongoing bottled water service as their permanent solution, and 41 garden tanks have been installed for those outside the City water main system. Some properties required more than one alternative solution because of multiple dwellings on one property. Long-term alternative water solutions have also been provided to some properties located within the plume boundary area that have wells yielding water without sulfolane detections. Sixty-one property owners who remain on bottled water service have not yet selected a permanent solution option. Additionally, FHR has established a buffer zone around the known contamination plume where private wells have been sampled and bottled water is being provided as a precautionary measure to prevent exposure to sulfolane.

- **Pursue aggressive onsite remediation.** The approved Interim Removal Action Plan (Barr, 2010a) has been implemented and is ongoing. Measures completed through 2011 include:

    a. Significant upgrades to the groundwater recovery system, including adding new recovery well R-42, replacing recovery wells R-20 and R-35, installation of seven additional LNAPL recovery systems, pump and piping upgrades, and cleaning of well screens in 3 existing recovery wells;

    b. Upgrades to the groundwater treatment system, including the addition of sand filters and granulated activated carbon (GAC) vessels to remove suspended solids and sulfolane, redundant prefilters, enlarged pumps in the gallery pond, and other measures to increase the capacity and reliability of the treatment system;

    c. Significant soil and groundwater investigation has been conducted and will be the basis for evaluating additional remediation measures that may be necessary, either as part of the permanent remedy through the feasibility study process or as additional interim remedial actions as appropriate.

  During 2012, FHRA began installing four additional recovery wells to replace at R-21, R-39, and R-40, and to augment capture in the R-21 area. ADEC has directed FHRA to prepare and implement an IRAP Addendum. The IRAP Addendum will be submitted by January 18, 2013.

- **Establish a monitoring network that adequately measures the success of the remediation at eliminating offsite contaminant migration and removing the contamination onsite.** Significant field work has been completed to expand the monitoring network to include approximately 200 onsite and offsite monitoring wells, approximately 50 observation wells, and 20 recovery wells. The current well networks have characterized much of the nature and extent of contamination, and may become part of the long-term monitoring networks. The Vertical Profile Transect (section 2.3.1.7) provides a much more detailed cross section of the onsite plume than has been previously known. Other topics, such as the nature of sulfolane contamination subpermafrost in the plume area are less understood at present. A work plan describing the use of private wells to evaluate deep impacts has been submitted to ADEC (ARCADIS, 2012a) and will be executed once access to the wells has been secured.

- **Achieve and maintain source control.** Measures to eliminate releases of all contaminants have included reviews of records to identify past spills and releases and correct any systemic weaknesses found, aggressive inspection and testing of refinery sump systems to increase integrity and reliability, plant-wide focus on spill prevention and control, and strong preventive maintenance programs for plant piping, tanks, and equipment systems. Any contamination hot spots or apparent residual source areas identified through the current soil sampling effort will be responded to by evaluating interim measures or through the focused feasibility study evaluations, with the goal of properly addressing hot spots or residual areas that may be acting as sources of contamination to groundwater.

- **Determine the extent of the contamination downgradient and potential for movement of the plume in order to develop a remedial strategy that will control exposure for the duration of time it takes to achieve final cleanup levels via engineered and/or natural mechanisms.** Through 2011, efforts have been focused on determining the extent and nature of the downgradient plume, including the installation of 73 offsite monitoring wells (and well nests) to determine plume and permafrost locations, and plume movement and horizontal and vertical gradients; the review of hundreds of private well records and logs to enhance understanding and interpretation of the private well sampling data; and the development of a robust regional groundwater model as a tool to support remediation and protective measures. An additional 45 offsite wells were installed in 2012, to continue downgradient plume delineation, permafrost delineation, and gradient evaluation. Results of the 2012 work will be reported in the SCRA-2012.

  Numerous studies have been initiated to evaluate in-situ geochemical and biological mechanisms to increase understanding and support the feasibility study process, including groundwater sampling for geochemistry and natural attenuation parameters, isotopic studies, subsurface microbiological characterization, tracer testing, injectability testing, air sparge pilot testing, plus a number of degradation bench studies. Much of this work is ongoing and will lead to improved confidence in the selection of control and remediation measures to achieve final cleanup goals.

- **Complete an evaluation of risk that accounts for all exposure pathways and cumulative risk.** The Draft Human Health Risk Assessment (HHRA) was submitted to ADEC December 30, 2011 to address all exposure pathways and cumulative risks. The Revised Draft Final HHRA, submitted May 23, 2012, presented potential site-specific alternative cleanup levels (ACLs) for COPCs that contribute to the majority of the risk or hazard. A representative range of potential ACLs for the primary risk/hazard driving COPC, sulfolane, was developed based on a range of toxicity criteria and exposure assumptions. .

Key site characterization results, conclusions, and recommendations are summarized here from Section 7.

ES-1 Potential Sources of Contamination

Based on a review of historical documents through 2011, the primary contributors to sulfolane impacts to groundwater are likely the result of wastewater releases from sump 02/04-2 and Lagoon B. Subsequent source assessment work was completed in 2012. Conclusions will be presented in the SCRA-2012. The results were also incorporated into the groundwater model that will be discussed with ADEC at a meeting scheduled for January 9, 2013.

Contributions of sulfolane to the environment from discrete surface spills, including spilled fuels, appear less significant than the subsurface wastewater releases. The LNAPL currently present onsite does not appear to be contributing significant sulfolane to the groundwater. Product releases throughout the life of the refinery are the primary sources of the LNAPL, BTEX, and other petroleum contaminants onsite.

ES-2 Contaminants of Concern

The constituents of potential concern for human health were identified in accordance with ADEC guidance. Additional soil and groundwater Contaminants of Concern screening was conducted based on evaluation of COPC data collected during the recent onsite soil and groundwater investigations, and during ongoing groundwater monitoring in 2012. COPC screening is described in detail in the HHRA (ARCADIS, 2012b).

ES-3 Physical Setting

NPR and the area surrounding North Pole is located on the Tanana River Floodplain. The geology of the area is dominated by a thick sequence of unconsolidated alluvial deposits up to 600 feet thick. The aquifer generally consists of highly-transmissive alluvial sands and gravels. The water table in the area is shallow, typically occurring within 15 feet of the ground. The water table has fluctuated vertically up to four feet since 2007. The data collected through 2011 suggest vertical gradients were primarily downward in April 2011 and upward in July 2011. When encountered, the top-of-permafrost depths ranged from six feet to 151.5 feet BGS in the study area. Residential well logs indicate the bottom of the permafrost ranges from 14 to 245 feet BGS. Moving northwest from NPR, it appears that the top of permafrost becomes shallower. The upper surface of the permafrost appears to be deepest near NPR, and also near Badger Slough. Permafrost modifies localized groundwater flow and contaminant transport in the Tanana River Valley. In the plume area, groundwater, and therefore sulfolane, may be migrating around and over the permafrost formations.

ES-4 Soil Impacts

Data collected through 2011 indicated that most of the onsite soil impacts appeared to be confined to areas of known releases, with the exception of metals that appear to be related to the background geology. Benzene soil impacts in the western portion of NPR do not appear to correlate with the aerial extent of the BTEX groundwater plume. Data collected during 2012, to be reported in the SCRA-2012 indicate the majority of sulfolane impacts to soil correlate with the sulfolane plume at the water table Areas of BTEX and sulfolane-impacted soils have been identified at the site. Soil impacts related to other COPCs (i.e., not BTEX or sulfolane) correlate with benzene-impacted areas at the site. FHRA recommended further investigations of several areas onsite, and prepared the 2012 SCWP (ARCADIS, 2012c). Results will be presented in the SCRA-2012.

A laboratory drain investigation identified limited soil contamination, but determined that additional soil assessment in this area is not warranted at this time.

Offsite, sulfolane was not detected in garden surface soil samples. This indicates that sorption of sulfolane to these surface soil samples did not occur when these soils were irrigated with groundwater containing dissolved-phase sulfolane. Due to the nature of sulfolane and the results for these soil samples, and the fact that FHRA is providing an alternative water supply for gardening, further evaluation of risks associated with this pathway is not necessary.

ES-5 LNAPL

LNAPL investigation activities completed at the site are being used to estimate LNAPL recoverability and establish remedial goals for addressing LNAPL onsite. LNAPL accumulations or sheens have been observed in 32 observation and monitoring wells from 2006 through 2011. Data collected through 2011 indicate the LNAPL smear zone is generally approximately 3 feet thick and generally occurs from 7 to 10 feet BGS.

Forensic analysis shows that LNAPL samples can be broadly segregated into three categories: samples dominated by Jet A, naphtha-like samples, and a mixture of Jet A and naphtha. Each of the samples collected are considered to have undergone some degree of weathering and are not considered to be fresh product or to represent a recent release.

LNAPL at NPR is mobile within the interior and fringe of the LNAPL plume and has the potential to migrate if LNAPL recovery ceases or hydrogeologic conditions change at the site. The recoverability assessment determined that LNAPL recovery in certain areas of the facility via hydraulic methods may produce sufficient LNAPL to cause a beneficial reduction in overall LNAPL mass.

An evaluation of LNAPL Natural Source Zone Depletion indicates that depletion is occurring through a combination of dissolution and biodegradation in the saturated zone and through volatilization and biodegradation in the unsaturated zone. The quantitative evaluation of NSZD processes indicates an ongoing total volumetric depletion rate of up to 2,030 gallons/year.

Additional LNAPL characterization was proposed in the 2012-SCWP (ARCADIS, 2012c). Results will be presented in the SCRA-2012.

ES-6 Groundwater Impacts

The benzene plume is confined to the developed portion of the NPR property, and does not extend to the property boundary or beyond. The 2010 and 2011 5-µg/L footprints appear to be similar to the footprint in 2002. Statistical evaluation indicates BTEX concentrations are stable or decreasing at most monitoring locations within the BTEX plume footprint.

Numerous wells have been installed onsite and offsite to delineate the sulfolane plume horizontally and vertically. The area of impact extends approximately three miles downgradient from NPR. Onsite the impact is approximately 1,250 feet wide, however, it widens to approximately 11,000 feet offsite. Onsite, along the vertical profile transect, sulfolane has been detected at a depth of 80 feet.

Offsite monitoring well data indicate the presence of sulfolane in the suprapermafrost aquifer. Sulfolane has also been detected in samples collected from private wells, including several reported to be installed in the subpermafrost aquifer at depths greater than 200 feet. No offsite monitoring wells have been installed in the subpermafrost aquifer and the mechanism by which sulfolane has entered these deep private wells has not been determined. A work plan for the use of private wells to evaluate deep impacts was submitted to ADEC in June 2012 (ARCADIS, 2012a); FHRA will execute the plan once access to the wells has been obtained. FHRA will continue to work with ADEC to develop an approach to evaluate these subpermafrost results. FHRA continues to provide alternative water supplies to those residents with impacted wells.

FHRA has used site specific data including contaminant concentrations, hydraulic conductivity and hydraulic gradient to derive mass flux of 0.19 lb/day across the vertical profile transect, located along the northern edge of the developed refinery.

GRO, DRO and iron were the only COPCs other than BTEX and sulfolane detected above ADEC groundwater cleanup levels during third and fourth quarter 2011 reporting periods and are associated with the known petroleum contamination on site. None of the remaining COPCs were detected at concentrations exceeding cleanup levels in samples collected in, or downgradient of the anticipated source zones.

COPCs were further evaluated in 2012 as part of the site specific risk assessment, and an additional round of COPC sampling was conducted during the first quarter 2012 groundwater sampling event. Results were presented in the quarterly monitoring reports.

ES-7 Response to LNAPL Accumulation in New Delineation Wells

As described in Section 2.5.1, seventeen observation wells were installed between September 13 and October 15, 2011, as proposed in the SCWP Addendum, for the purpose of gauging LNAPL onsite. On October 22, 2011 LNAPL was observed in northern observation wells O-11 and O-13 in the truck-loading rack area and in wells O-7 and O-9 on the eastern side of the tank farm (Figure 12). FHRA completed response actions including a follow-up inspection that identified sealant concerns at Truck Lane #1 and 2 sump basins, a resealing of all truck lane catch basins, a forensics evaluation of LNAPL collected from wells on the northern portion of the site that indicates that the LNAPL present in onsite wells is weathered, and an evaluation of dissolved-phase BTEX concentration data in downgradient wells that did not indicate migration of BTEX constituents nor the presence of LNAPL.

ES-8 Natural Attenuation Evaluation

MNA data collected to date consist of four rounds of quarterly data. Principal component and discriminant analysis conducted using these data suggest sulfolane attenuation associated with less reducing or mixed-redox conditions and, potentially, interactions of impacted groundwater with surface water inputs. These findings are consistent with FHR's ongoing work associated with elucidating the sulfolane removal mechanisms observed across the air stripper and sand filter in the onsite remediation system. Based on the results of the MNA analysis, it is recommended that nitrate, sulfide, TKN, and total phosphorus be removed from the MNA analyte list.

Subsurface microbiological characterization work has shown that microbial populations at the site are measurable and can be characterized within a reasonable deployment time frame (83 days) using Bio-Traps. The seeding study indicates sulfolane was successfully loaded onto the Bio-Trap Bio-Sep beads. Leaching of sulfolane can occur from the Bio-Traps over a 60 day period, however, the potential mass loading is insignificant compared to the current mass of sulfolane present in the aquifer, and enough residual sulfolane is present after 60 days to complete ^{13}C analysis to determine whether or not microbial uptake of the ^{13}C-labeled sulfolane has occurred.

FHRA recommends proceeding with Phase 2 as proposed in the 2012 SCWP (ARCADIS, 2012c) with the modifications subsequently agreed upon with ADEC based on the comments to the 2012 SCWP (ARCADIS, 2012c).

A method was successfully developed to complete laboratory analysis of the Phase 1 samples and to complete this study. Analysis of the sulfolane samples indicates that fractionation of stable carbon isotopes in sulfolane potentially due to natural degradation processes is occurring at the site. An apparent shift of stable carbon isotope ratios is observed between the sampled onsite wells and the downgradient offsite well MW-182A. Preliminary calculations indicate the site-specific sulfolane stable carbon isotope fractionation factor is approximately 0.3‰ and is considered sufficiently large to demonstrate degradation of sulfolane in site groundwater despite anoxic conditions in the aquifer. Additional evaluation of the Phase I data, coupled with the Phase II data and additional research underway by UAF is needed to confirm this site-specific sulfolane stable isotope fractionation factor.

Based on the results from Phase I, FHRA completed Phase 2 sampling using a revised scope of groundwater sampling and analysis as presented in the 2012 SCWP (ARCADIS, 2012c) with the modifications subsequently agreed upon with ADEC based on the comments to the 2012 SCWP

(ARCADIS, 2012c). Select wells from Phase 1 wells were sampled again to determine if isotopic ratios vary over time and if those changes are measureable.

ES-9 Surface Water Assessment

Sulfolane has not been detected in water samples collected from the onsite gravel pits and Badger Slough, indicating that the shallow plume does not have a measurable impact on these features.

Sulfolane was detected in piezometers installed near the east bank of the North Gravel Pit and near two off-site gravel pits located near well MW-161. However, the offsite piezometers were installed when the nearby gravel pits were frozen. The collected samples may be more representative of groundwater samples, rather than pore-water samples at the groundwater-surface water interchange. Laboratory results from a piezometer installed to the northeast of monitoring well MW-164 did not show detectable concentrations of sulfolane. Results from the pore-water investigation are presented in Section 3.12.2.

ES-10 Updated CSM

The Conceptual Site Model is updated as new data are collected. Because only sulfolane has been detected offsite, two separate CSM graphical forms have been prepared to more clearly portray and distinguish potential exposure pathways for the onsite and offsite receptors.

Potential current and future onsite receptors may be exposed to constituents in surface and subsurface soils by direct contact including incidental ingestion of soil, dermal contact with soil, and inhalation of constituents adhered onto dust particles that have been released by wind erosion into ambient (outdoor) air.

The only known current offsite COPC is dissolved-phase sulfolane. Because sulfolane is not volatile and is not readily absorbable by skin, the only sulfolane exposure route evaluated for potential offsite receptors is ingestion. Inhalation of wind-blown dust containing COPCs from onsite was also evaluated for offsite receptors. Ingestion of groundwater and ingestion of surface water are complete pathways for offsite receptors. FHRA is providing clean drinking water sources to the owners of private wells that have sulfolane present. FHRA is also providing clean irrigation water sources for those residents growing garden produce.

ES-11 Cleanup Actions

Cleanup actions have focused on implementation of the IRAP in order to maximize the effectiveness of NPR's groundwater and LNAPL recovery systems. As noted above, ADEC directed FHRA to prepare and implement an IRAP Addendum. The IRAP Addendum will be submitted by January 18, 2013. Dates to complete the Onsite FS, Offsite FS, and CP have yet to be determined.

Optimization of the existing pump and treat remediation system resulted in increased capture of impacted groundwater onsite. Additional optimization efforts completed in 2011 include improvements to the recovery well discharge piping and installation of a new recovery well (R-42) to increase horizontal and vertical capture of impacted groundwater in the western area of the refinery, and the replacement of recovery wells R-20 and R-35. FHRA is also in the process of installing four additional recovery wells to replace R-39 and R-40, and to augment capture in the R-21 area. These new recovery wells will have dual-phase capability which will allow a higher groundwater recovery rate while maintaining LNAPL recovery with a skimmer system.

A recovery well pumping test was performed to evaluate the horizontal and vertical capture of the groundwater recovery system and provide information for updating the groundwater flow model. Utilizing the pumping test information, FHRA completed the capture zone modeling of the groundwater recovery system. Results indicate the recovery wells provide a high degree of capture at current pumping rates.

A review of the trends in groundwater data through 2011 was completed in the monitoring wells most immediately downgradient of the recovery system (and within the sulfolane plume) as these locations will be the first to show improvement following the IRAP improvements. The trends at the five wells indicated the sulfolane concentration downgradient of the groundwater recovery system is generally decreasing. In 2011, the sulfolane mass recovery by the groundwater recovery system was 0.46 pounds lb/day, averaged over the entire year.

From 1986 through the end of 2011, over 391,000 gallons of LNAPL have been recovered at the North Pole refinery. Annual recovery volumes have generally decreased as remediation has progressed and the volume of recoverable LNAPL has decreased. As part of the IRAP, seven additional product recovery systems were installed. Following cleaning of recovery well screens, LNAPL recovery increased for a few months, with a high of 1,150 gallons in October 2011.

FHRA has completed interim removal actions in accordance with the IRAP to aggressively address onsite LNAPL and contaminated groundwater. The recovered groundwater is pumped to a treatment system that removes LNAPL and dissolved-phase contaminants. The recovered groundwater discharges to a prefilter for solids removal, a coalescer for LNAPL removal, and air strippers for removal of VOCs before accumulating in the Gallery Pond. The recovered groundwater in the

Gallery Pond is then pumped through a sand filter and GAC system, which were installed as part of the IRAP improvements to remove suspended solids and sulfolane. Since the sand filters and GAC system went online in June, the sulfolane concentration at the Final Effluent has been below the LOQ in every monitoring event, showing complete removal of sulfolane from the recovered groundwater.

FHRA is conducting an air sparge pilot study to evaluate the removal efficiency of sulfolane in groundwater. The results of this pilot test will be utilized to evaluate air sparge as a potential remedial action as part of the upcoming onsite and offsite feasibility studies.

FHRA is also evaluating the data from a sulfolane degradation bench test to better understand the sulfolane removal mechanism that has been observed across the air strippers, gallery pond, and sand filters in the onsite remediation system. The results will be used during the evaluation of remedial alternatives in the Feasibility Studies.

ES-12 Groundwater Model

The draft groundwater model was submitted to ADEC on December 19, 2011 and a subsequent version of the model, based on data collected through the third quarter of 2011 is submitted as Appendix Q of this report. The model will be used as a predictive tool to evaluate the future of the sulfolane plume. It will also be used to evaluate the effectiveness of the current groundwater pump and treat system, and it will be used during the Onsite FS to evaluate other remedial alternatives, such as enhancements to the current system. The latest version of the groundwater model will be discussed with ADEC at a meeting scheduled for January 9, 2013.

ES-13 Schedule

Site characterization tasks proposed in the SCWP, SWCP Addendum, and *Scope of Work for Additional Site Characterization Activities* are ongoing and continued through 2012. Additional work proposed in the 2012 SCWP was completed in 2012. Results will be presented in the SCRA-2012, to be submitted in January 2013.

FHRA is following the schedule outlined below:

Task	**Completion Date**
Draft Groundwater Model	December 19, 2011 (completed)
Draft Human Health Risk Assessment	December 30, 2011 (completed)
Draft Revised Site Characterization Report	December 31, 2011 (completed)

Task	Completion Date
Revised Site Characterization Report	March 16, 2012 (completed)
Groundwater Model (Appendix Q of the RSC Report)	March 16, 2012 (completed)
Draft Final Human Health Risk Assessment	April 9, 2012(completed)
Draft Onsite Feasibility Study	April 13, 2012 (completed)
Revised Draft Final Human Health Risk Assessment	May 23, 2012 (completed)
2012 Site Characterization Work Plan	May 24, 2012 (completed)
Draft Final Onsite Feasibility Study	May 25, 2012 (completed)
Draft Offsite Feasibility Study	August 31, 2012 (completed)
Site Characterization Report–Through 2011 (this document)	December 28, 2012
Groundwater Model (Appendix Q of this document)	December 28, 2012
Updated Groundwater Model Meeting	January 9, 2013
Interim Removal Action Plan Addendum	January 18, 2013
Site Characterization Report - 2012 Addendum	January 25, 2013
Final Onsite Feasibility Study	To be determined
Final Offsite Feasibility Study	To be determined
Draft Cleanup Plan	To be determined
Final Cleanup Plan	To be determined

ES-14 Reporting

FHRA will report the results of groundwater monitoring on a quarterly basis. Results of the 2012 site characterization tasks will be reported in the SCRA-2012. The TPT meetings and the Site Characterization and Remediation subgroup meetings will also be used as opportunities to provide updates, propose changes to work, and discuss results.

1.0 Introduction

This *Site Characterization Report (Through 2011)* (SCR-2011) has been prepared to provide a description of site characterization tasks that have been completed through 2011 because of the Williams Plume (hereinafter referred to as the “plume”) and the results of those tasks for the Flint Hills Resources Alaska, LLC (FHRA) North Pole Refinery (NPR), located in North Pole, Alaska. The tasks were proposed and described in the *Site Characterization Work Plan* (SCWP) (Barr Engineering Company [Barr], 2010b), the *Site Characterization Work Plan Addendum* (SCWP Addendum) (ARCADIS, US, Inc. [ARCADIS], 2011b), and *Scope of Work for Additional Site Characterization Activities* (ARCADIS, 2011c) in order to update the Conceptual Site Model (CSM), as requested by the Alaska Department of Environmental Conservation (ADEC). The results of subsequent work completed as proposed in the *2012 Site Characterization Work Plan* (2012 SCWP) (ARCADIS, 2012b) are being separately reported in the *Site Characterization Report - 2012 Addendum (SCRA-2012)* (ARCADIS, 2012c). Routine groundwater monitoring results have been, and will continue to be reported in Quarterly Monitoring Reports.

In 18 AAC 75.990(115), ADEC defines the term “site” as an “area that is contaminated, including areas contaminated by the migration of hazardous substances from a source area, regardless of property ownership”. However, solely from an ease of terminology standpoint, for the RSC Report and the subsequent Feasibility Studies, the term “onsite” is the area that is located within the FHRA property boundary, and the term “offsite” is the area located off the property in the downgradient north-northwest direction, and is based on the approximate extent of the dissolved-phase sulfolane plume detected at concentrations above laboratory reporting limits.

The original schedule to complete site characterization, construct a groundwater model, conduct Feasibility Studies, and develop a Cleanup Plan was mandated in an August 18, 2011, letter from ADEC to FHRA. A revised schedule was adopted on February 16, 2012, to allow adequate time to revise the groundwater model as requested by ADEC, and to allow for verification of analytical soil data following a prolonged process to address interference issues. Due to the compressed nature of the schedule, many of the efforts that would be typically completed sequentially were being completed concurrently. In October 2012, ADEC instructed FHRA to cease work on the Onsite Feasibility Study (FS), the Offsite FS, and Cleanup Plan in order to allow additional time for data collection and evaluation.

Data gathered during site characterization were used to complete a *Human Health Risk Assessment* (HHRA). The HHRA estimates the nature and probability of adverse health effects in humans who may be exposed to chemicals associated with NPR. The draft was submitted December 30, 2011; a Draft Final was submitted in April 2012; a Revised Draft Final was submitted in May 2012.

Data were also used to construct the computational groundwater model, which was submitted on December 19, 2011. A version of the groundwater model based on data collected through the end of the third quarter of 2011 is being submitted as Appendix Q of this report. Subsequent development of the model has continued; an updated model report will be submitted to ADEC during the first quarter of 2013.

Site characterization data and results of the HHRA and groundwater model will support the Onsite Feasibility Study (Onsite FS) and the Offsite Feasibility Study (Offsite FS), which will be used to evaluate onsite and offsite remedial alternatives. The Onsite FS and Offsite FS are being completed in general accordance with the United States Environmental Protection Agency (USEPA) Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance, such that alternatives will be evaluated against nine criteria as follows:

- Two threshold criteria that relate to statutory requirements that each alternative must satisfy in order to be eligible for selection:
    - Overall protection of human health and the environment and
    - Compliance with Applicable or Relevant and Appropriate Requirements (ARARs)
- Five balancing criteria that are the technical criteria upon which the detailed analysis is primarily based:
    - Long-term effectiveness and permanence;
    - Reduction of toxicity, mobility, or volume through treatment;
    - Short-term effectiveness;
    - Implementability and
    - Cost; and

- Two modifying criteria:
    - State/Support agency acceptance; and
    - Community acceptance.

A draft Onsite FS was submitted on April 13, 2012, with a Draft Final version submitted on May 25, 2012. The draft Offsite FS was submitted on August 31, 2012. As stated above, ADEC is altering the schedule of FS and Cleanup Plan submittal. ADEC has directed deferral of both the Onsite FS and Offsite FS, until a date to be determined, after data to be collected during the 2013 field season is evaluated. In the interim, ADEC has directed FHRA to submit an addendum to the September 2010 *Interim Removal Action Plan* (IRAP) (Barr, 2010a).

The results of the HHRA, groundwater modeling, and Feasibility Studies will be used to prepare a draft Cleanup Plan that includes techniques that are protective of human health, safety and welfare, and of the environment. FHR understands the draft Cleanup Plan and the final Cleanup Plan will be submitted as agreed upon in a Compliance Order by Consent (COBC).

The current site characterization effort began after sulfolane, a chemical used at NPR since 1985 and prior to FHRA's purchase of the facility, was detected at concentrations of 31.6 to 229 micrograms per liter (µg/L) in fifteen offsite monitoring wells that had been installed in September and October of 2009. Following notification to ADEC, FHRA immediately began simultaneous efforts to delineate the extent of the sulfolane plume, test the drinking water supplies of those living in the vicinity of NPR, and provide alternative drinking water supplies to those with impacted wells.

A previous *Site Characterization Report and Corrective Action Plan* (SC/CAP) for NPR, prepared by Shannon and Wilson, Inc. (SWI), was submitted to ADEC in June 2002. As indicated by ADEC, the compound sulfolane was not included in the SC/CAP at that time because it was not a regulated substance. ADEC approved the SC/CAP in January 2006 and included a new requirement that sulfolane would be regulated with a groundwater cleanup goal of 350 µg/L at NPR.

In a letter to FHRA dated March 3, 2010, ADEC indicated that, based on new information related to sulfolane, the January 2002 SC/CAP was no longer sufficiently protective and directed FHRA to prepare the SCWP to address these new conditions. In the letter, ADEC stated its intent to consider 25 parts per billion (ppb) as an interim cleanup level for sulfolane in groundwater. ADEC's letter directed FHRA to submit a *Site Characterization Report* and *Revised Corrective Action Plan* following completion of the site characterization. ADEC also directed FHRA to prepare an IRAP to address the light nonaqueous-phase liquid (LNAPL) and sulfolane-contaminated groundwater present at NPR. A draft SCWP and a draft IRAP were submitted to ADEC on July 23, 2010. ADEC provided preliminary approval to begin work described in the documents on August 7, 2010. The final SCWP and IRAP were submitted on September 20, 2010. As of the submittal date of this report, ADEC has not provided written comments on, or approval of, these final submittals. As stated above, ADEC has verbally requested FHRA to update the IRAP.

A status update on interim cleanup actions is included in this Report. This update does not take the place of the upcoming *Onsite Feasibility Study*, *Offsite Feasibility Study*, or *Cleanup Plan,* which will include a complete evaluation of interim corrective actions as part of remedial alternative evaluation. Additional onsite corrective actions will be evaluated for determination of the final remedies in the *Onsite Feasibility Study*. Design and implementation of the final remedies will be described in the *Cleanup Plan*. A *Cleanup Report* will be submitted following a period of active operation to document the final implementation and to evaluate and demonstrate effectiveness. In addition, an *Offsite Feasibility Study* will be completed by the party responsible for the offsite plume to evaluate potential remedies to address sulfolane-impacted groundwater occurring outside the limits of the NPR property. Technical memoranda have been, and will continue to be prepared and submitted for ADEC approval subsequent to this report to better define the ongoing data collection activities to be completed in support of the feasibility studies.

On December 7, 2010, ADEC requested FHRA to alter its monthly groundwater reporting format. As the monthly reports included a large amount of information not needed for submittal on a monthly basis, the reports were no longer efficient for FHRA to prepare or ADEC to review, and the number of monitoring locations had increased substantially since initiation of the monthly format. At the December 14, 2010, Technical Project Team (TPT) meeting, FHRA proposed a quarterly reporting frequency. FHRA also proposed an outline of the report, which included the results of the interim groundwater monitoring program proposed in the SCWP and updates on remediation progress and system upgrades proposed in the IRAP. At the February 16, 2011 TPT Meeting, ADEC recommended that the *First Quarter 2011 Groundwater Monitoring Report* be combined with the *Site Characterization Report*, submitted on May 31, 2011. The *Second Quarter 2011 Groundwater Monitoring Report* (ARCADIS, 2011d) was submitted on July 29, 2011, and the *Third Quarter 2011 Groundwater Monitoring Report* (ARCADIS, 2011a) was submitted on November 30, 2011. Subsequent quarterly reports are scheduled for submittal by the end of the month following the end of each quarter. Data presented in the 2011 First, Second, and Third Quarter Monitoring Reports are included herein. The *Fourth Quarter 2011 Groundwater Monitoring Report* is combined with this RSC Report.

This report, therefore, includes site characterization and groundwater monitoring data gathered through 2011 and an update of onsite interim remediation progress.

1.1 Project Objectives

The SCWP identified data needs in the understanding of environmental conditions at NPR, and proposed tasks to fill those data needs and update the CSM. Specific objectives of the tasks proposed in the SCWP and SCWP Addendum included the following:

- Update the site Contaminants of Potential Concern (COPCs).
- Identify the historical source(s) of sulfolane and the potential for ongoing releases.
- Improve the understanding of the onsite physical setting and gain an understanding of the offsite physical setting, including the geology, hydrogeology, permafrost, and groundwater geochemistry.
- Characterize the nature and extent of soil impacts at NPR once the COPCs are updated, the spill locations are understood to the extent practical, and sulfolane use is understood.
- Characterize the nature, occurrence, mobility, and recoverability of LNAPL at NPR.
- Improve the understanding of petroleum constituents in groundwater at NPR.
- Complete the delineation of sulfolane in groundwater downgradient of NPR.
- Evaluate the potential for natural attenuation of sulfolane in groundwater downgradient of NPR.
- Assess surface water within the footprint of the offsite sulfolane plume.
- Update the CSM.
- Evaluate the migration of sulfolane in groundwater though analytical modeling.
- Monitor the effectiveness of the corrective measures proposed in the IRAP.

As FHRA has indicated during TPT and Site Characterization Subgroup meetings with ADEC, several of these tasks are ongoing and subsequent data evaluation is yet to be completed. Expansion of the groundwater monitoring network and various soil and groundwater investigations continued in 2012. Results and evaluations not included in this final RSC Report will be presented in future submittals, such as the *SCRA-2012*, feasibility studies or quarterly groundwater monitoring reports.

1.2 Property Description

NPR is located just outside the city limits of the City of North Pole (the City), Alaska. The City is located approximately 13 miles southeast of Fairbanks, Alaska, within Fairbanks North Star Borough (Figure 1). The address of NPR is 1100 H & H Lane, North Pole, Alaska 99705.

NPR is situated on a parcel that is approximately 240 acres in size and located in Section 16, Township 2 South, Range 2 East, Fairbanks Meridian. The latitude and longitude of the approximate center point of FHRA's property is 64.74 N and 147.35 W. The refinery, parcel boundaries, nearby roads and surrounding areas are shown on Figure 2. No institutional controls (e.g., deed restrictions) are currently in place for the property (Horst, 2010).

The layout and features of NPR, including site structures, process crude units (CUs), aboveground storage tanks (ASTs), and tank farm containment areas (CAs) are shown on Figure 3. Additional site detail is shown on a map provided in Appendix A. Three CUs are located in the southern portion of the refinery. The CUs constitute the process area of the refinery. Tank farms and associated CAs are located in the central portion of the refinery. 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 property. With the exception of rail lines and access roads, the northernmost portion of the property is undeveloped (Figure 2).

A potable water source is not present on the property as the City provides potable water to FHRA. As allowed by the facility's water use permits, groundwater and the North Gravel Pit may be drawn upon for fire-suppression purposes.

Flint Hills Resources Alaska, LLC is the current owner and operator of NPR. FHRA and Williams Alaska Petroleum, Inc. are currently in a legal dispute for purposes of determining responsible party status.

1.3 Surrounding Property

To the west of NPR is the Tanana River, which flows in a northwesterly direction towards Fairbanks. NPR is constructed on the Tanana River floodplain. A flood control dike is located immediately west of the FHRA property (Figure 2).

Immediately north of the refinery are residential properties and the City wastewater treatment plant (WWTP). The North Pole High School is located north and west of the WWTP and residential area. The FHRA property that is located adjacent to the residential areas is undeveloped (Figure 2).

East of NPR is property that is residential or undeveloped, the Old Richardson Highway, and Alaska Railroad right-of-way (ROW) (Figure 2)

Along the southern property boundary, partially surrounded by 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 NPR. The property south of NPR and the GVEA power plant is occupied by the Petro Star, Inc. Refinery (Figure 2).

1.4 Site Development, Ownership, and Oversight

NPR is a petroleum refinery that receives its crude oil feedstock from the Trans-Alaska Pipeline. The property was developed as the refinery was constructed in the mid-1970s and operations began in 1977. ADEC and USEPA have been responsible for regulating and overseeing environmental monitoring and remediation at NPR.

In 1982, then owner MAPCO Petroleum, Inc. (MAPCO) began recovering LNAPL from the subsurface using recovery wells. Sulfolane use at NPR began in 1985 when CU #2 (Figure 3) was constructed.

In December of 1986, MAPCO entered into an agreement with ADEC, Compliance Order by Consent 86-3-1-1-224-1 (Compliance Order). In the Compliance Order, MAPCO agreed to:

- Reactivate recovery wells that had been temporarily shut down, install additional recovery wells as needed to collect LNAPL, maintain daily logs for the wells, and monitor the wells for LNAPL;

- Install monitoring wells around the perimeter of NPR and monitor the wells for LNAPL, and conduct corrective action if LNAPL is observed in the wells;

- Test all drinking water supply sources for NPR;
- Complete expansion of the wastewater holding pond.
- Prepare a scope of work for an environmental consulting firm to complete an environmental audit of NPR, designed to:
    - Improve or correct product handling.
    - Identify the source of, reasons for, and corrective action necessary to reduce the hydrocarbons in the holding pond.
    - Identify the source of, reasons for, and corrective action necessary to reduce LNAPL in the ground.
    - Address deficiencies identified in the audit.

In 1988, air strippers were installed to treat impacted groundwater that was pumped from onsite recovery wells.

In 1989, the EPA issued two Administrative Orders on Consent. The first found MAPCO to be operating as an illegal Treatment, Storage, and Disposal Facility and assessed a penalty. The second ordered Corrective Action of NPR, which included:

- Completion of a Resource Conservation and Recovery Act (RCRA) Facility Assessment (RFA).
- Performance of an Interim Measures program to removed hazardous waste from Lagoon B; Tank 192, and Sumps 901, 905, 909-B, and 05-7.
- Completion of a RCRA Facility Investigation (RFI).
- Completion of a Corrective Measures Study (CMS) if determined necessary.

The facility was acquired by Williams Alaska Petroleum, Inc. (Williams), in 1998. CU #3 was constructed in 1998.

In 1999, EPA agreed that the RFA, Interim Measures, and RFI had been completed. At the time, Williams was to develop a Site Characterization Review and interim and long-term corrective action plans. The *SC/CAP* was submitted in 2002. The plan was modified in 2005 in the *Report on Well Installation, Maintenance Activities, and Data Review.*

In 2001, Williams first reported to ADEC that sulfolane was identified in groundwater samples; the 2002 SC/CAP did not include sulfolane as a contaminant of interest in soil or groundwater.

FHRA purchased NPR in 2004. In January 2006 ADEC approved the SC/CAP with four additional stipulations:

1. Two interim cleanup goals were established for NPR
    a. Using existing recovery systems, and in the absence of new releases, reduce the LNAPL plume and the dissolved-benzene plume to the extent practicable.
    b. Prevent expansion of either the LNAPL or benzene plume beyond their respective 2002 extents by using additional remediation as necessary for any new releases.

   New releases were to be addressed to the satisfaction of ADEC and assessed for impact to the LNAPL and benzene plumes. If data indicated that either of the plumes would exceed their respective 2002 limits, then additional remedial efforts were required. ADEC considered the 2002 plume boundaries to be "lines in the sand" and that further expansion of the plumes was not acceptable and must be actively addressed.

2. Determine the source(s) of sulfolane in groundwater at the refinery. Interim cleanup goals for sulfolane were established as follows:
    a. Soil migration to groundwater: 0.943 milligrams per kilogram (mg/kg)
    b. Soil ingestion: 983 mg/kg
    c. Groundwater: 0.35 milligrams per liter (mg/L)

3. The *SC/CAP* would be reviewed every five years and updated as needed.

4. The final cleanup levels for the refinery would be determined when the refinery ceases operations, anticipated to be in approximately 50 years.

Current site characterization efforts began in October of 2009, as discussed above, in response to offsite detections of sulfolane in groundwater.

1.5 Sulfolane Use at NPR

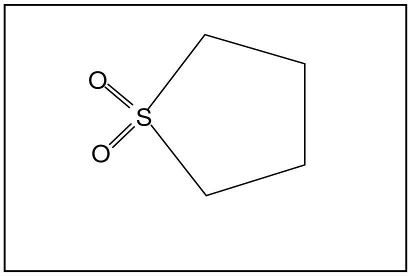
Based on communications with FHRA staff, NPR currently uses sulfolane sold by Chevron Phillips Chemical Company, L.P., under the brand name Sulfolane W. Pure sulfolane is denser than water, but is a solid at room temperature with a melting point of 27.6 degrees Celsius (°C) (Budavari et al. 1996). Sulfolane W is a mixture of 3 percent water, a small amount of monoethylamine, and sulfolane. The Material Safety Data Sheet (MSDS) for Sulfolane W is included as Appendix B. The sulfolane solution is stored in Tank 194 and is used in the Sulfolane Extraction Unit (EU) located in CU #2 (Figure 3). A process flow diagram (PFD) of sulfolane use is included as Appendix C.

1.5.1 Sulfolane Characteristics

Sulfolane is the common name for tetrahydrothiophene 1,1-dioxide (CAS# 126-33-0). It is a colorless, heterocyclic, organic molecule containing sulfur, and is both chemically and thermally stable. Sulfolane has the following physical properties:

- Molecular Weight: 120.17
- Boiling Point: (one atmosphere pressure)545 degrees Fahrenheit (°F)
- Freezing Point: 82 °F (pure)
- Flash Point: 350 °F

Its empirical chemical formula is $C_4H_8SO_2$, and its chemical structure is depicted below:



The oxygen atoms bonded to the sulfur in the ring render the molecule highly polar; as a result sulfolane is miscible with water. It has a vapor pressure at 25°C of 0.0062 mm Hg, indicating it is a relatively nonvolatile compound at this temperature; by comparison, the vapor pressure of the volatile organic compound (VOC) benzene is 94.8 mm Hg at 25°C. The logarithm of the octanol-water partition coefficient (log K_{OW}) for sulfolane is –0.77, indicating it has a much higher affinity for water than organic solvents. For comparison, the very nonpolar benzene molecule has a much higher log K_{OW} (2.13), indicating that at equilibrium benzene will mainly be distributed into the organic rather than the aqueous phase. The low log K_{OW} for sulfolane allows it to be washed from the organic feedstock in the sulfolane extraction process (see below).

A report prepared for the Canadian Association of Petroleum Producers (Soil and Water Quality Guidelines for Sulfolane and Diisopropanolamine: Environmental and Human Health; Komex International, Ltd., October 2001 – the "CAPP Report"), notes that "leaching and lateral movement of sulfolane is determined by its low affinity for sorption, low retardation coefficients in sulfolane-contaminated aquifer sediments, and high solubility." The report also observes that sulfolane's high solubility and low retardation coefficients indicate this compound will be highly mobile in the subsurface and will migrate "at a similar velocity to the groundwater flow."

1.5.2 Sulfolane Process

Sulfolane is used at NPR in the "sulfolane process," a liquid-liquid extraction process used to recover high purity aromatics from hydrocarbon mixtures. The refinery processes include desalting, atmospheric distillation, vacuum distillation, and aromatic (sulfolane) extraction. The desalting process removes salt, water and other impurities from the crude oil before it is sent to the crude distillation units. In the atmospheric distillation units the crude oil is separated into gas, naphtha, light distillates, gas oil, and reduced crude. The reduced crude is sent to the vacuum distillation unit to produce asphalt. The naphtha and light distillate are sent to the EU to remove a high octane gasoline blend stock. Several finished products are produced by blending the various process streams.

In the aromatic extraction process, sulfolane is initially mixed with the petroleum feedstock (naphtha and light distillates). The sulfolane extracts the aromatics from the feedstock, and the aromatic-laden sulfolane is sent to a stripper for aromatic removal before returning to the EU. After the aromatics are removed, the residual feedstock (referred to as "raffinate") is sent to a wash tower to have residual sulfolane removed before it is sent out as product.

The only fuel currently produced at NPR that requires the sulfolane process is gasoline. Sulfolane content in gasoline produced at NPR from 1992 through 2009 is shown in Table 1. Data for gasoline produced prior to 1992 are no longer available. The table shows that sulfolane content in gasoline has been reduced since 2004. Military jet fuel (JP4), was produced using naphtha in the sulfolane extraction unit. JP4 production was discontinued in 2005. Sulfolane content data for JP4 are unavailable.

1.6 Release History

Table 2 provides a summary of known releases at NPR. Reported spill events and other known historical releases have been evaluated to determine which may have impacted the environment. The evaluation process is described in Section 2.1.2 and releases are discussed in more detail in Section 3.1.2.

1.7 Groundwater Use and Monitoring Prior to Site Characterization

A network of wells was present at NPR prior to 2009 in response to onsite petroleum releases. As noted above, onsite groundwater is not used as a source of potable water as the City supplies NPR with drinking water. Industrial wells are currently active at NPR and the adjacent GVEA substation, supplying groundwater as nonpotable process water to the respective facilities. Offsite groundwater is used as a potable water source as described in Section 2.6.2.5.

1.7.1 Well Network

1.7.1.1 Monitoring and Remediation Wells

Included in the NPR well network are monitoring wells, observation wells, and recovery wells. The well network prior to October 2009 is shown on Figure 4. Construction details for the wells, including screened intervals, are shown in Table 3.

Monitoring wells are used primarily for groundwater quality monitoring. Observation wells are primarily used to monitor LNAPL. Recovery wells are used to recover LNAPL and impacted groundwater, although many of the recovery wells initially installed are now inactive, but still utilized for groundwater elevation and LNAPL monitoring. Current LNAPL and groundwater recovery operations are discussed in Section 5.1.

Leading up to October 2009, 43 monitoring wells were present at NPR. Construction logs are presented in Appendix D. As reported in Groundwater Investigation (Barr, 2008), sulfolane was first detected in groundwater samples collected from monitoring wells at the property boundary in October 2008. The reported concentrations were less than the interim cleanup goal at that time.

After meeting with ADEC and obtaining offsite property access, FHRA initiated an effort to characterize groundwater downgradient of NPR. Sulfolane was first detected in a sample collected from a downgradient offsite monitoring well in October 2009. Following notification to ADEC, FHRA immediately began simultaneous efforts to delineate the extent of the sulfolane plume, test the drinking water supplies of those living in the vicinity of NPR, and provide alternative drinking water supplies to those with impacted wells. A description of sulfolane plume delineation is presented in Section 2.6.2. Over 200 monitoring wells have been installed onsite and offsite since October 2009.

Prior to October 2009, 28 observation wells were located at NPR; all of the wells were located onsite (Figure 4). As shown in Table 3, the observation wells appear to be screened across or just below the water table. Construction logs for the observation wells are not available for historical observation wells. Twenty-nine observation wells have been installed onsite since site characterization efforts began as described in Section 2.5.1, while several older damaged wells have been decommissioned as described in Section 2.3.1.8, resulting in 47 current observation wells. Logs for the new observation wells are in Appendix D.

Recovery wells are located onsite at NPR; most were installed prior to the recent Site Characterization efforts and implementation of the IRAP. The wells are used to recover LNAPL and impacted groundwater. The recovery wells appear to be constructed across the water table (Table 3); however, construction logs are not available for the historical recovery wells. One new recovery well and two replacement recovery wells have been installed as described in Section 5.1. Currently 20 recovery wells are present at NPR.

Figure 5 shows all of the current wells associated with NPR, and also wells proposed during the Site Characterization Subgroup meetings conducted during the first quarter of 2012. Table 3 shows that the wells were constructed at various depths. A description of the monitoring well depth interval groupings is presented in Section 2.6.2.1. As groundwater elevation data are collected during the additional site characterization, as described below in Section 2.3.4.2, the data are compared to the well screen elevations to determine if these groups are accurate and appropriate.

1.7.1.2 Industrial Wells

Two industrial production wells supply process water for NPR. The approximate location of these wells near Crude Unit #1 is shown on Figure 4. Logs from the Alaska Department of Natural Resources (ADNR) Well Log Tracking System (WELTS) indicate these wells are 60 feet deep (Appendix D). The wells may also be used as a source of fire suppression water.

In addition, a production well and an injection well are located within the GVEA substation south of NPR (Figure 4). ADNR water well records indicate the production well is 80 feet deep and the injection well is 432 feet deep (Appendix D).

1.7.2 Current Monitoring Program

The current groundwater monitoring program consists of groundwater elevation, LNAPL, and groundwater quality monitoring, and is described in Section 2.

1.8 Report Organization

This report has been prepared in general accordance with *the Site Characterization Work Plan and Reporting Guidance for Investigation of Contaminated Sites* (ADEC, 2009b). It is organized into the following sections.

Section 1 – Introduction: a description of this submittal, the site and its development, the events that led up to site characterization, and a summary of the project objectives.

Section 2 – Site Characterization Tasks: a description of the site characterization tasks completed thus far and the methodology used to complete those tasks including deviations from the SCWP and SCWP Addendum. In addition to field work, tasks included the review of historical data and documents and, as such, this section replaces the "Field Work" section listed in the Elements of a Complete Characterization Report from the ADEC Guidance Documents (ADEC, 2009b).

Section 3 – Results and Findings: a presentation of the data gathered thus far during site characterization, including the data that have been presented in the Quarterly Groundwater Monitoring Reports for NPR.

Section 4 – Groundwater Flow and Transport Modeling: a description of the groundwater model that has been constructed for the purpose of simulating the fate and transport of sulfolane from the site.

Section 5 – Status Update on Cleanup Actions: a description of the progress made thus far implementing the IRAP.

Section 6 – Quality Assurance/Quality Control: a description of the Quality Assurance/Quality Control (QA/QC) procedures that were followed to evaluate the quality of the analytical data, and the results of the evaluation.

Section 7 – Conclusions and Recommendations: conclusions and recommendations drawn from the data gathered thus during site characterization.

This bound report includes paper copies of the text, tables, and figures. Appendices are provided as electronic files on the enclosed digital video disc (DVD). Paper copies of specific appendices are available upon request as necessary. The Revised Sampling and Analysis Plan is attached to the end of this submittal as an appendix.

2.0 Site Characterization Tasks

This section describes the methodologies used to complete the tasks that were proposed in the SCWP (Barr, 2010b), SCWP Addendum (ARCADIS, 2011b), and *Scope of Work for Additional Site Characterization Activities* (ARCADIS, 2011c) in order to meet the objectives listed in Section 1.1. The results are used to address data needs, improve understanding of existing data, and update the CSM.

The scope of each task was described in the SCWP, SCWP Addendum, and the Scope of Work for Additional Site Characterization Activities. Any deviations from the proposed scope and the reasons for the deviations are described in the following sections. The field tasks were completed following the procedures described in the Revised Sampling and Analysis Plan (SAP), Appendix B of the SCWP Addendum, to the extent practical. The SAP was revised and resubmitted to ADEC on December 28, 2010 (SWI, 2010) and again on November 3, 2011 as Appendix B of the SCWP Addendum (ARCADIS, 2011b). Deviations from the SAP and the reasons for the deviations are described in the sections below.

Site characterization tasks began in October 2009 with the installation of offsite monitoring wells and have continued into 2012.

2.1 Identify Sources and Release Mechanisms

The identification of source and release mechanisms is important to gain an understanding of where potential impacts may be located, determine the source of groundwater contamination that has migrated beyond the original release location(s), and determine if the release mechanisms are still actively contributing contaminants to the environment. The task was completed with the consideration of process knowledge and facility documentation and operating history. Efforts were focused on petroleum-related issues in general, and sulfolane–related issues in particular, but a thorough evaluation was conducted of known releases at the site in an effort to identify all COPCs. Historic operational information will be updated to the extent additional relevant information is identified.

2.1.1 Locate Potential Sources of Contamination

Potential sources of contamination were determined by contacting FHRA staff and reviewing NPR files, including maps and process diagrams. Information was obtained regarding the locations of product storage tanks; underground storage tanks (USTs); product distribution systems including the truck-loading racks and railcar-loading areas; the wastewater flow path, including the wastewater lagoons, sumps and drain systems; drum storage areas; waste piles; and septic systems. Results of the review are presented in Section 3.1.1.

While it was known that dissolved-phase sulfolane is present in the groundwater at NPR, the mechanism through which it entered the environment was not previously understood. The SCWP noted that a release of pure sulfolane was known to have occurred at NPR, however, the volume was small (150 gallons). Other potential sources were thought to include releases of wastewater containing sulfolane and/or petroleum product containing sulfolane. Historical files and refinery process diagrams were reviewed to determine the areas of NPR in which sulfolane may have been present. The wastewater flow paths have been documented due to the potential for wastewater to contain sulfolane. Results are presented in Section 3.1.1.

During a meeting with ADEC to discuss the SCWP in May 2010, a request was made to present the findings of a USEPA wastewater treatment plant inspection. FHRA is aware of a USEPA inspection of the NPR wastewater treatment plant conducted July 20-22, 2010. The USEPA had no findings and had only two Areas of Concern that related only to documentation items.

2.1.2 Review Spill Events and Historical Releases

FHRA and ADEC files have been reviewed to evaluate known spill events and historical releases. The information gleaned from the review was used to update the contaminants of potential concern, identify release locations and volumes, and determine if adequate cleanup actions had occurred. Results of this review including a listing of the releases are discussed in Section 3.1.2.

Various spill reporting records have been maintained by facility operators. The files were reviewed to obtain information regarding the release volumes and locations, and the cleanup actions performed in response to the releases. Historical records indicate, however, that substantial volumes of materials were released but not documented. During the period of FHRA's ownership, FHRA's policy has been to document all spills regardless of volume. FHRA is not in a position to verify the completeness or accuracy of records that were maintained prior to their ownership of NPR.

2.1.3 Evaluate Potential for Ongoing Release

A systematic evaluation of sumps was completed in 2010 in order to determine if the sumps were contributing contaminants to the subsurface. The results were presented in a letter report to ADEC in December 2010. Investigations completed at specific sumps are discussed in Sections 2.4.2. A map showing sump locations is included in Appendix A.

The sump investigation was part of FHRA's Mechanical Integrity & Inspection Program and Active Awareness program. FHRA staff provided details of these programs, as described in Section 3.1.3.1.

In addition to the inspection program, data gathered during site characterization, groundwater monitoring, and cleanup actions will continue to be used as indicators for ongoing releases. Specific data include LNAPL occurrence, LNAPL analyses (for potential identification of product released and for potential product age determination), and dissolved-phase contaminant trends.

2.1.4 Potential Offsite Sources

Due to the potential for residual sulfolane to be present in fuels, it was thought that sulfolane may be present in the soils and groundwater at other petroleum release sites in the area, unrelated to NPR and that these other potential sources may interfere with the ongoing plume delineation work. SWI searched the ADEC contaminated sites database (http://www.dec.state.ak.us/spar/csp/db_search.htm) for sites that are listed as active, closed, or closed with institutional control. SWI's project files were searched for sites. The search area extended south and southeast from NPR to the Tanana River and flood-control channel, and five miles from NPR in the other directions. A regulatory report was previously obtained from an independent vendor in order to identify potential release sites in the immediate vicinity of NPR and the known plume. Results are discussed in Section 3.1.4.

2.2 Evaluate Potential Contaminants of Concern

In accordance with the SCWP, potential contaminants of concern for NPR were evaluated to determine if any additional constituents should be evaluated in the CSM, if any constituents should be added to or removed from the current list of monitoring parameters, and if these parameters potentially need to be addressed during ongoing and future corrective action. The COPC list was developed by comparing reported spill events and other known historical releases to the list of potential constituents contained in the release. Releases that were not contained, remediated, or otherwise sampled to determine potential release to the environment may contain COPCs.

The constituents of potential concern for human health were identified in accordance with ADEC (2008a; 2008b; 2011c) guidance. COPCs were identified from an initial list of potential constituents of interest (COIs), such as those that were likely used or spilled at the site. Site history, spill records, and previous site characterization studies were used to develop an initial list of COIs Those COIs that have concentrations detected above the laboratory practical quantitation limit (PQL) that exceed ADEC screening levels, were considered COPCs and were carried through the human health risk assessment process. In addition, for each COI the PQLs were also compared with screening levels, and those with PQLs that exceeded screening levels were also selected as COPCs.

An initial list of COIs in soil and groundwater was identified from the SWI (2000; 2001) contaminant characterization studies conducted for the North Pole Refinery in 2000 and 2001. The purpose of the characterization study conducted at the refinery in 2001 was to collect additional soil and groundwater data to address data needs from an earlier site investigation that was conducted in 2000. In general, for both media, the analytical methods used included those for gasoline range organics (GRO), diesel range organics (DRO), residual range organics (RRO), benzene, toluene, ethylbenzene, xylenes (BTEX), selected metals, VOCs, semivolatile organic compounds (SVOCs) including polynuclear aromatic hydrocarbons (PAHs), and sulfolane (for groundwater only).

2.3 Characterize Physical Setting

As noted in the SCWP, a number of data needs existed in the understanding of the physical setting, including the geology, hydrogeology, and permafrost occurrence which are critical factors that determine how contaminants migrate in the subsurface environment. These needs are being filled through the installation of soil borings and monitoring wells, by reviewing private well logs, and by monitoring groundwater conditions at existing and new wells. The following sections describe the techniques and procedures used to accomplish these tasks. Additional tasks, including a geophysical survey, are also described below.

2.3.1 Soil Boring and Well Installation

The following subsections describe the techniques used to install soil borings and monitoring wells, the methods of soil classification and field screening, boring and well naming protocol, and well repair and decommissioning activities. Rationales for boring and well locations, depths, and sampling parameters are located in subsequent sections, including 2.4 (Characterize Soil Impacts), 2.5 (Characterize NAPL), and 2.6 (Characterize Groundwater Impacts).

2.3.1.1 Soil Borings

As proposed in the SCWP Addendum, 83 soil borings (Figure 6) were installed onsite in September and October 2011 in order to further characterize geology and investigate potential soil impacts across operational areas of the site. Their locations were selected to target areas of known impact and areas where potential releases may have occurred. The representative area for each boring location is noted in Table 4. Also noted on Table 4 are any associated spills or known source areas targeted for assessment by the individual borings. The release history was presented in Table 2. Results are described in Section 3.6.2.2.

The soil borings were named using an alpha numeric system (SB-###) and locations were selected to target areas of known contamination, and areas where releases may have occurred. The borings were advanced and sampled at the locations at or near those shown proposed in the SCWP Addendum; minor modifications in the boring locations were occasionally made to avoid subsurface utilities.

Soil boring advancement, soil sampling, soil classification, soil screening and field quality control measures were completed in accordance with the procedures described in the SAP. Boring logs were prepared for each boring and are presented in Appendix D.

2.3.1.2 Monitoring and Observation Wells

Numerous wells have been installed onsite at NPR and at offsite (Figure 7) locations since October 2009, primarily for the purpose of delineating the sulfolane plume, but also to further characterize the physical setting, further delineate the onsite BTEX and LNAPL plumes, evaluate natural attenuation potential, and to monitor the effects of the onsite remediation systems. Well construction details are provided in Table 3. Well construction logs are provided in Appendix D. The wells were installed in accordance with Section 3.3.1 of the Revised SAP, with the exception of monitoring well (MW)-170B, which was constructed of 4-inch polyvinyl chloride (PVC).

Additional information regarding well locations, depths, and rationale are presented in the sections that describe expansion of the LNAPL monitoring network (Section 2.5.1) BTEX network (Section 2.6.1.1), and sulfolane monitoring network (Section 2.6.2.2). Information regarding the grouping of wells into monitoring zones by depth is provided in Section 2.6.2.1.

The wells were installed in six phases. Each phase correlates with a major mobilization to complete field work. The desired approach when timing allowed was to install a group of wells, sample those wells and previously existing wells, and evaluate the data. Resulting data would then be used to plan well locations and depths for following phase.

Phase 1 was completed from October 2009 to April 2010, prior to preparation of the SCWP. Phase 2 was completed from September 2010 to November 2010, following submittal of the SCWP and in accordance with the SCWP.

On March 8, 2011, FHRA proposed to install additional monitoring wells to fill gaps in the well network installed during Phases 1 and 2. These wells were designated Phase 3; 17 wells were installed both onsite and offsite between August and early September 2011.

Phase 4 of well installation effort continued filling gaps in the sulfolane and LNAPL monitoring networks; nine wells were installed both onsite and offsite between late September and mid-October, 2011, as proposed in the SCWP Addendum.

Phase 5 involved installing six well nests, also called the Vertical Profile Transect (VPT), perpendicular to the long axis of the sulfolane plume and northwest of the truck-loading area on the refinery property, to assess the vertical distribution of sulfolane from the water table to permafrost or 150 feet below ground surface (BGS) or 140 to 145 feet below the water table (BWT). These wells are described in more detail in Section 2.3.1.7. Eighteen nested wells, plus six using continuous multi-channel tubing (CMT) wells were installed at six locations at the site from early October through early November 2011.

Phase 6 well installation was completed in December 2011, and involved installing wells on the refinery to identify the depth of permafrost at seven onsite locations.

New monitoring wells were named using an alpha numeric system (MW-###) and are numbered consecutively, generally in the order in which they were installed. An alphabetic suffix was added to well numbers to indicate relative well depth for wells installed in nests. An “A” suffix was used for the shallowest well in a nest. Typically, the shallowest well was screened across or near the water table, with the following exceptions:

- At MW-154A, installed in the vicinity of existing water table well MW-139, the screen is set approximately 60 feet BWT.
- At MW-174A, installed in the vicinity of existing water table well MW-111, the screen is set approximately 40 feet BWT.

A “B” suffix was used for the second well in a nest, installed deeper than the A well. B wells were usually completed 10 to 55 feet BWT, with the following exceptions:

- At the MW-144, MW-154, MW-160, and MW-174 well nests, the second wells installed at each (MW-144B, MW-154B, MW-160B, and MW-174B, respectively) were screened 77 to 80 feet BWT;

- At the MW-149 nest, the second well (MW-149B) was installed at the top of apparent permafrost, with the screen set approximately seven feet BWT;
- At the MW-170 nest, the second well installed (MW-170B) was screened approximately 60 feet BWT; and
- At the MW-172, MW-173, MW-195 and MW-197 well nests, the second wells (MW-172B, MW-173B, MW-195B, and MW197B respectively) were screened approximately 138 feet BWT.

The C wells were used for the deepest wells in nests, typically ranging from approximately 55 feet to 160 feet BWT, with the following exceptions:

- At MW-151C, the screen is set approximately 46 feet BWT.

Four "D" wells were installed:

- MW-170D, which was screened approximately 36 feet BWT. This well was given a "D" designation since it was the fourth well installed at this nest, after the installation of deeper wells MW-170B and MW-170C, as described above.
- MW-148D, which was installed in the MW-148 well nest to a depth of approximately 140 feet BWT.
- MW-179D, which was installed in the MW-178 well nest to a depth of approximately 130 feet BWT.
- MW-186D, which was installed to a depth of approximately 125 feet BWT.

The wells installed during Phase 5 were numbered beginning with MW-301. This was done so duplicate samples collected from the existing monitoring well network (i.e., wells MW-101 through MW-199) could be named by labeling them as "MW-2##" without causing confusion. The Phase 5 wells were identified as MW-30#-, with a suffix appended to the well number identifying the depth of the bottom of the well screen (e.g., MW-301-60's screen was set approximately 60 feet BGS or approximately 55 feet BWT). The CMT wells installed during this phase were distinguished as such by identifying them as MW-30#-CMT, so they could be grouped with the monitoring wells in each nest. As with the monitoring wells, the water sampling interval for the CMT wells is identified with a suffix identifying the sampled depth (e.g., MW-302-CMT-10).

Typically no suffix was used for solitary wells (i.e., wells not nested with other wells). Many of these wells were screened within 10 feet of the water table, with the following exceptions:

- MW-175 and MW-177, which were screened at depths of approximately 76 to 80 feet BWT, and
- MW-184 and MW-188, which were screened at depths of approximately 30 feet BWT.

Several preexisting wells named without suffixes are also screened below the water table, including:

- MW-101, MW-102, MW-104, MW-105, screened 50 to 55 feet BWT;
- MW-118 and MW-129, screened approximately 30 feet BWT; and
- MW-125, MW-126, and MW127, screened 10 to 15 feet BWT.

New observation wells were also named using an alpha numeric system (O-#) and are numbered consecutively, generally in the order in which they were installed. Since all observation wells are installed across the water table, no suffix is necessary. Observation wells are typically used for monitoring groundwater elevations and LNAPL thickness. The O-series wells were installed in accordance with the SAP, except for well O-10, which was constructed of 4-inch PVC to allow for possible future use as an LNAPL-recovery well.

2.3.1.3 Permits and Utilities

The SCWP proposed to locate utilities to the extent practical. To date, underground utilities have been located onsite and offsite in preparation for drilling activities related to site characterization.

Wells installed off of FHRA property were placed within The City or Alaska Department of Transportation & Public Facilities (ADOT&PF) ROW, or on Fairbanks North Star Borough (FNSB) property. Traffic control plans (TCPs) were prepared and utilized as necessary for well installations within the ADOT&PF ROW. Temporary use licenses were obtained from FNSB for well installation on FNSB property. Additional permissions were obtained from private land owners as necessary.

Prior to advancing soil borings for offsite well installation or soil sampling, underground utilities were located in coordination with the Alaska Digline and local utility companies. For onsite wells, utilities were located by FHRA refinery personnel and FHRA subcontractor Ray Electric. Additional assistance was provided by GeoTek Alaska, Inc. (GeoTek) and ULS Services, Inc. (ULS), which employed geophysical methods to locate underground utilities. Onsite utilities will continue to be located in this manner as additional site characterization and corrective action tasks are completed.

2.3.1.4 Drilling and Soil Sampling

Soil borings were completed by GeoTek using a track-mounted Geoprobe® rig equipped with direct-push Geoprobe® tooling to collect surface and subsurface soil samples from the borings. The Geoprobe® Macro Core system advanced 5-foot-long PVC-lined samplers for continuous soil sampling.

Most monitoring and observation wells were installed by Homestead Drilling Company (Homestead) of Fairbanks, Alaska, using a truck-mounted drill rig and the hollow-stem-auger technique, under the direction of SWI and/or ARCADIS. The deeper wells (i.e., those greater than approximately 45 feet BWT) were installed with the aid of bentonite drilling mud to counteract heaving sands and provide lubrication for the augers. A SWI or ARCADIS field representative was present during the work. Soil samples were collected using a split-barrel sampler as specified in the SAP, in general accordance with ASTM International (ASTM) D1586 Standard Method for Penetration Test and Split-Barrel Sampling of Soil, as modified from ASTM D1586-99 (using a 3-inch outside diameter [OD] split-barrel sampler and a 340-pound drop hammer with a 30-inch free fall). As described in the SCWP and SAP, soil samples were generally collected at 2.5-foot intervals from the ground surface to the water table and at 5-foot intervals from the water table to 30 feet BGS (20 to 25 feet BWT). In the deeper borings, soil samples were collected from within each 10 to 20-foot interval from the ground surface to the bottom of the boring. Soil samples were classified as described in Section 2.3.2.1 and according to the Unified Soil Classification System. These classifications, used in characterizing the geology, are shown on the boring logs in Appendix D and discussed in Section 3.3.

Soil samples from the soil borings and wells were field-screened for potential volatile organic contaminants using a photoionization detector (PID), as described in the SAP. The field representative also noted the presence of hydrocarbon odors, staining, and oily sheens. Field-screening results are shown on the boring logs in Appendix D. Field-screening results were used to select soil samples for laboratory analysis, as described in Section 2.4.4.1. As stated in Section 2.0 of the SAP, field-screening is not being used as a method to identify the presence of sulfolane.

All investigation-derived waste (IDW), including drill cuttings, was managed in accordance with the SAP.

2.3.1.5 Well Construction

The monitoring and observation wells were installed and constructed by Homestead generally in accordance with the methods outlined in the SCWP, SCWP Addendum and Revised SAP. Monitoring well construction details are presented in Table 3.

Wells installed at or near the water table were typically constructed of 2-inch diameter PVC with 10-foot long well screens, although 5-foot long screens were used for wells MW-150A, MW-151A, MW-152A, and MW-153A. Deeper wells were typically constructed of 2-inch diameter PVC with 5-foot screens, since they do not span the water table and there is no need to account for seasonal water table fluctuations. Wells MW-170B and O-10 were constructed of 4-inch-diameter casing and screen to allow the wells to be used for potential aquifer testing or product recovery in the future. Well screens with slot sizes of 0.010 or 0.020 inches were installed (Table 3), depending on the geology observed during installation.

Homestead completed the majority of offsite wells with monuments set flush with the ground surface, except for wells MW-151C, MW-154A, MW-154B, MW-156B, MW-166A, MW-166B, MW-169A/B, and MW-187, which were installed with aboveground monuments. Homestead completed each of the onsite wells with an aboveground monument.

A registered land surveyor determined the well locations, ground surface elevations, and top-of-casing elevations for the new wells. The top-of-casing elevations for previously installed wells within the monitoring network were resurveyed in November and December 2011. Top-of-riser and ground surface elevation data are included in the well construction summary shown in Table 3.

2.3.1.6 Well Development

The wells were typically developed by SWI no sooner than 48 hours after installation.

During Phase 1 of well installations, due to cold weather conditions and the desire to quickly delineate the sulfolane plume during the 2010-2011 winter season, several wells were developed and sampled sooner than the standard 48-hour period. These included monitoring wells MW-155A, MW-156A, MW-157, MW-158A, MW-159, and MW-160A installed in November 2009; well MW-164A installed in December 2009; well MW-165A installed in January 2010; wells MW-169A and MW-171A installed in February 2010; and well MW-171B installed in March 2010. These wells were developed and sampled during cold weather conditions (temperatures less than -18°C [0°F]) and developed initially by over-purging (greater than 10 well volumes until water was visually clear); each of these sulfolane delineation wells were more thoroughly developed by surging and over-purging in April 2010.

All subsequent monitoring and observation wells were developed in accordance with the Revised SAP. All development water was containerized into drums which were transported to NPR for disposal in FHRA's wastewater treatment system, as described in the Revised SAP.

2.3.1.7 Vertical Profile Transect

As proposed in the SCWP Addendum, between October 18 and 28, 2011, FHRA installed six vertical profiling well clusters to establish the VPT, with the purpose of providing a detailed cross section of the onsite sulfolane plume and to provide information to be used to calculate sulfolane flux. This work comprises the Phase 5 well installations. Each cluster included discrete-zone monitoring (DZM) systems installed within 50 or 60 feet BGS (40 or 55 feet BWT, due to differences in ground surface elevation) and additional monitoring wells below the DZM systems to assess the vertical distribution of dissolved sulfolane impacts and hydraulic properties within the subsurface. DZM systems were installed within a transect of wells (MW-301 through MW-306) shown on Figure 8. A discrete-zone monitoring approach was used to characterize sulfolane impacts in the aquifer to further develop the conceptual site model for groundwater flow in order to determine sulfolane flux, as described in Section 2.6.2.4.

Permanent DZM systems were constructed using CMT. The DZM systems consist of a 1.7-inch-outer-diameter high-density polyethylene tube divided into seven channels. Individual channels were punctured at a specific depth to provide a sample port. Sample ports were covered with stainless-steel mesh to minimize particulate flow into the channel. The channels were sealed below the port to hydraulically isolate the intervals. Drilling was completed by Homestead; RSI Drilling, Inc. installed each CMT.

Boreholes were advanced using hollow-stem auger methods to depths ranging from approximately 50 to 60 feet BGS (40 or 55 feet BWT). Permafrost was not encountered during installation of the DZM wells. During drilling activities below the groundwater table, potable water was used to maintain a driving head in the open borehole to minimize inflow of heaving sand from the formation through the bottom of the hollow-stem auger. Water was used instead of drilling mud to minimize particulate accumulation on the stainless steel mesh surrounding the sample ports.

During borehole advancement, standard penetration tests were conducted every 5 feet and select samples were collected with split-spoon samplers for soil classification and screening. Soil screening was performed in accordance with the SAP. In addition, one soil sample was collected from MW-306-CMT at the 10 to 12 foot BGS interval and submitted to Core Laboratories located in Bakersfield, California for geotechnical analysis, including effective porosity, moisture content and hydraulic conductivity. Data from the samples and tests are presented in the boring logs included as Appendix D. Laboratory analytical reports for the geotechnical analysis are included as Appendix E.

The CMT with sample ports were preconstructed on the surface during borehole advancement. Sample port depths were installed at approximately 10-foot intervals. Observations of lithology during borehole advancement and lithologic data collected from adjacent borings were reviewed to ensure installation of the sample ports in conductive geologic layers. After a borehole was installed to the target depth, the borehole was flushed out with potable water to remove heaving sand that may have entered the boring. The preconstructed CMT was lowered into the borehole through the hollow-stem augers. A 4-foot-thick sand pack consisting of 10/20 sand was centered across the sample ports. Coated bentonite pellets were used to isolate each sample port and sand pack from adjacent ports. The coated bentonite pellets were hydrated when placed above the groundwater table. Each well was completed with a monument and locking well cap. Boring and well construction logs are presented in Appendix D.

The DZM system channels were developed using pumping and surging methods a minimum of 48 hours after well installation. Purge water from drilling and development activities were transported to the NPR oil/water separator for treatment. All soil cuttings were containerized in accordance with the SAP.

2.3.1.8 Well Decommissioning, Repair, and Redevelopment

Following an assessment of the condition and utility of the monitoring, observation, and recovery wells at NPR, it was apparent that some of the wells were not adequate for their intended tasks (e.g., LNAPL monitoring wells screened below the water table), had exceeded their useful life, or were damaged and irreparable. In Section 5 of the SCWP Addendum, FHRA proposed to decommission sixteen of the existing wells. Several wells required repairs and redevelopment due to an accumulation of sediment. This section describes the well decommissioning, repair, and redevelopment activities. Replacement of inadequate LNAPL monitoring locations is described in Section 2.5.1.

2.3.1.8.1 Well Decommissioning

SWI decommissioned wells at NPR in autumn 2011 with assistance from Homestead and Ray Electric. Decommissioning activities generally consisted of excavating around each well to a depth of approximately 2 feet BGS, cutting the well casing at that depth, filling the well with pea gravel, bentonite chips, or grout, capping the well, then backfilling the excavation to the ground surface. Table 5 summarizes decommissioning activities at each well. Nine wells were decommissioned; the onset of winter delayed decommissioning of the remaining eight wells. One of the decommissioned wells was recovery well R-35 (not listed in the SCWP addendum) which failed during the fourth quarter of 2010. Additional information regarding R-35 and its replacement, R-35R, is provided in Section 5.1.4. Decommissioning was completed in accordance with ADEC's *Monitoring Well Guidance* (ADEC, 2011d).

Well decommissioning performed in 2012 will be reported in the SCRA-2012.

2.3.1.8.2 Well Repair and Redevelopment

SWI repaired and redeveloped wells at NPR in autumn 2011 with assistance from Homestead. Twenty-seven wells required repair, redevelopment, or both. Table 6 summarizes repairs and redevelopment activities conducted at each well. Repairs generally consisted of replacing damaged protective monuments, installing new monuments at wells constructed without them, and repairing frost-jacked well casings. Frost-jacking refers to the gradual upward pull on a well as a result of seasonal freeze-thaw cycles; left unchecked; a frost-jacked well can also push a protective steel monument out of the ground. Repairs to frost-jacked wells consisted of cutting a portion of casing from the top of the well. Repairs were completed for seven wells; the onset of winter delayed the repair of the remaining six wells.

Fifteen wells were redeveloped after recent well-depth measurements showed a greater than 1-foot discrepancy from reported construction depths. Well development consisted of pumping water and sediment from each well until the sediment was removed and clear water was obtained. The volume of water pumped from each well ranged from 40 gallons and 95 gallons. Water and sediment removed from the wells were disposed in accordance with the Revised SAP.

Well repair and redevelopment performed in 2012 will be reported in the SCRA-2012.

2.3.1.8.3 Recovery Well Rehabilitation

SWI completed the well condition and performance assessment and rehabilitation work for recovery wells R-21, R-39, and R-40 in August 2011. Assistance was provided by FHRA, M-W Drilling, and

Emerald Alaska, Inc. who provided development and water disposal services. The assessment and rehabilitation process for each well, consisted of the following:

1. Removal of the pump (FHRA, SWI, M-W Drilling);
2. Brushing well to remove biofouling and encrustations from the inner surface of the screen (SWI, M-W Drilling);
3. Pre-rehabilitation video inspection (SWI and M-W Drilling);
4. Short-term pumping test using a vactor truck to obtain base line specific capacity data (SWI, M-W Drilling, Emerald Services, Inc.);
5. Hydropuls® impulse technology to loosen impacted fine sediment, biofouling, and encrustations within the screen interval and surrounding formation (SWI);
6. Pumping of the well at rates varying from 20 gpm to 100 gpm following and also simultaneous with the use of Hydropuls® impulse technology (SWI, M-W Drilling, Emerald Service, Inc.);
7. Repeating Steps 5 and 6 for approximately one day per well;
8. Post-rehabilitation vactor truck pumping test to obtain final specific capacity data (SWI, M-W Drilling, Emerald Services, Inc.);
9. Post-rehabilitation video inspection (SWI, M-W Drilling); and
10. Replacement of production pump (FHRA).

R-40 was originally completed at a depth of 25.17 feet with a 10-inch-diameter steel screen installed from a depth of 6.0 to 25.17 feet. The initial video inspection showed encrustations covering an estimated 50 percent of the screen slots. SWI completed the rehabilitation, using Hydropuls® impulse-generation technology, over a two-day period. The pre-rehabilitation average specific capacity was about 4.1 gallons per minute per foot of drawdown (gpm/ft) based on an average pumping rate of 35 gallons per minute (gpm). The post-rehabilitation average specific capacity was 6.8 gpm/ft, based on an average pumping rate of 59 gpm, resulting in a specific capacity improvement of about 66 percent.

R-39 was originally completed at a depth of 25.5 feet with a 10-inch diameter steel screen installed from a depth of 6.25 to 25.5 feet. The initial video inspection showed an estimated 40 percent clogging of the screen slots with biofouling and mineral encrustation. SWI completed the rehabilitation, using Hydropuls® impulse-generation technology, over a two-day period. The pre-rehabilitation average specific capacity was about 10.85 gpm/ft based on an average pumping rate of 10.85 gpm. The post-rehabilitation average specific capacity was about 17.04 gpm/ft based on an average pumping rate of 17.04 gpm, resulting in a specific capacity improvement of about 57 percent.

R-21 was originally completed at a depth of 29.17 feet with a 12-inch-diameter steel screen installed from a depth of 4.17 to 24.17 feet. The video inspection showed an estimated 90 percent clogging of the screen slots with biofouling and mineral encrustation. No damage was observed; however, the biofouling and encrustations may have concealed damaged areas. SWI halted rehabilitation work at R-21 when the Hydropuls® unit hit an obstruction at a depth of approximately 20 feet below the top of the casing. It was determined that the screen was damaged and gravel was entering the well casing. Therefore, the well was repaired as follows:

- Inserted a 10-inch blank casing into the existing well (12-inch) while removing approximately 6 feet of accumulated sediment with a sand bailer to the bottom of the well (approximately 24 feet);
- Inserted five 5-foot 8T-stainless- steel-screen sections (slot sizes top to bottom - 0.050; 0.050; 0.040; 0.040; and 0.040);
- Extracted the 10-inch blank casing; filled the gap between the 12 and 8 inch well screen with pea gravel; and
- Replaced the existing pump.

2.3.2 Geology Characterization

The geology of the site and the offsite study area was characterized using data from the following sources:

- Soil samples collected and classified during the installation of soil borings and wells;
- A Ground-Penetrating Radar survey; and

- Historical soil boring logs, monitoring well logs, and private well logs.

2.3.2.1 Soil Classification

Soil samples collected from borings drilled for well installation and to characterize soil impacts were logged to document subsurface geology. The following characteristics were recorded by the field geologist:

- soil type;
- moisture;
- color;
- odor;
- percent of gravel, sand, and fines;
- angularity;
- structure; and
- permafrost (see Section 2.3.3 for additional information regarding permafrost logging).

These observations are summarized on the boring logs (Appendix D) and were used to classify soil samples using the Unified Soil Classification System. These classifications are shown on the boring logs in Appendix D and discussed in Section 3.3.

2.3.2.2 Ground Penetrating Radar Survey

A geophysical survey was conducted by ARCADIS in October 2010 in order to further define the physical setting, in addition to the tasks proposed in the SCWP. The survey utilized ground penetrating radar (GPR) and was conducted along existing roadways both onsite at NPR and offsite. The objectives of the geophysical survey were to:

- Map the occurrence and distribution of coarse-grained, channel facies deposits within the greater floodplain of the Tanana River that represent potential preferential pathways for groundwater and contaminant transport within the shallow suprapermafrost aquifer; and
- Determine depth to permafrost, if feasible.

GPR is a nonintrusive survey method used to identify variations in subsurface conditions, based on differences in physical properties (specifically, the dielectric constant) of the subsurface materials. The GPR system simply transmits high-frequency electromagnetic waves into the ground and detects the energy reflected back to the surface. Energy is reflected along subsurface interfaces that possess different electrical properties. Reflections typically occur at lithologic contacts or where different subsurface materials exhibit high electrical contrasts, including more highly resistive, coarse-grained sediments in a finer sediment matrix. These reflections are detected by the antenna and processed into an electrical signal which can be used to provide an image of the feature.

Site-specific conditions such as soil type and moisture content control the effective depth of the survey. Conductive soils (i.e., clays) rapidly attenuate the GPR signal and limit the depth of investigation to a few feet or less, whereas resistive soils may allow an investigation depth of 40 feet or more. GPR was found to be effective in the vadose zone and the shallow suprapermafrost aquifer in the vicinity of NPR.

The survey was conducted along the roadways shown on Figure 1 of Appendix F. Approximately 15 linear miles of paved roadway and 5 linear miles of unpaved roadway were surveyed. Specific details of the methodology, including data acquisition and processing, are included in Appendix F. Results are discussed in Section 3.3.

2.3.3 Permafrost Delineation

The SCWP proposed to characterize permafrost occurrence that may affect movement of groundwater. Permafrost observations were, and continue to be compiled from the onsite and offsite well boring logs, logs from previous site investigations, and from available well records to better understand the distribution of permafrost onsite and in the area downgradient from NPR. A three-dimensional representation of the permafrost is being constructed for the fate and transport groundwater model. To that end, historical aerial photographs of the area were obtained and were reviewed to aid in the preparation of permafrost input parameters for the model

Results to date of the permafrost delineation are presented in Section 3.4.

2.3.3.1 Permafrost Observations during Drilling

When encountered during site characterization activities, permafrost was sampled to determine the nature of the frozen soil. The presence of permafrost in soil borings and monitoring wells has been evaluated using several types of information, including direct observation, drill action, and penetration resistance (i.e., blow counts). If frozen soils were suspected, samples were collected from undisturbed soil, then immediately retrieved for visual classification (i.e., the sampler was not floated to the next sample interval before retrieval). Drilling was ceased once frozen soil was confirmed. No recent (i.e., since 2009) site characterization well borings have completely penetrated permafrost and no recent monitoring wells have been installed through the permafrost into the subpermafrost aquifer. All wells have been installed above permafrost in the suprapermafrost aquifer. Onsite monitoring wells MW-102 and MW-104, installed in 1987, were reportedly completed through the permafrost.

The permafrost samples were classified using the ADOT&PF system, based on ASTM D4083 and Linnell and Kaplar, *Description and Classification of Frozen Soils* (1966) in accordance with Section 3.2.4 of the Revised SAP.

2.3.3.2 Permafrost Information from Well Records

Well construction logs were obtained from various sources for permafrost evaluation, including private well owners, the ADNR WELTS database, and the ADEC domestic onsite wastewater disposal system files from 162 subdivisions. A total of 916 well depths and 483 wells logs were obtained. The logs were reviewed for references to permafrost, which were typically noted by the driller as “frozen,” without further definitive classification.

Well logs were tabulated with the lot and block information, address, parcel account numbers (PANs), well depths, date of installation, and depth to top and bottom of permafrost, if available. Available well logs were scanned into electronic format. Some onsite wastewater disposal system application forms in the ADEC files indicated a well depth but did not have a well log; if this was the case, the reported well depth was recorded with a notation that no log was available.

The number of wells that have been sampled for sulfolane and for which well depth information is available is 176; their depth and permafrost information, if available, are shown on Table 7. It is possible that some private wells may have been modified subsequent to installation, and therefore, the depths listed on the logs may not be the intervals from which water is currently being pumped. Depth information has not been located for the remaining 460 private wells sampled for sulfolane (private well sampling is described in Section 2.6.2.5).

2.3.4 Aquifer Characterization

Characterization of the aquifer is critical to understanding the behavior of groundwater in the study area, and the migration of contaminants in the subsurface. Aquifer characterization is being accomplished by analyzing the materials that make up the aquifer, measuring groundwater elevations at various locations, depths, and time to determine flow direction and gradients, and by completing pumping tests as described below.

2.3.4.1 Soil Physical Attributes

As proposed in the SCWP, 109 soil samples were collected from the screened intervals of 75 monitoring and observation wells installed during site characterization activities for analysis of grain-size distribution (gradation) to aid in aquifer characterization. Samples were collected as follows:

- From Phase 1 wells MW-151C, MW-153B, MW-154B, MW-156B, MW-160B, MW-162B, and MW-170C.
- From Phase 2 wells MW-158B, MW-161B, MW-163B, MW-164B, MW-169B, MW-170D, MW-174B, MW-176A, MW-176B, MW-176C, MW-177, MW-178C, MW-179C, MW-181A, MW-181B, MW-182, MW-183, MW-184, MW-185A, MW-185B, MW-186B, MW-186C, MW-187, O-1, O-2, O-3, and O-4.
- Phase 3, 4, and 5 wells MW-144BR, MW-148D, MW-152C, MW-157B, MW-159C, MW-164C, MW-168B, MW-169C, MW-179D, MW-181C, MW-183B, MW-185C, MW-189A, MW-189B, MW-190A, MW-190B, MW-191A, MW-191B, MW-193A, MW-193B, MW-194B, MW-195A, MW-196, MW-302-70, MW-302-80, MW-302-110, MW-303-70, MW-303-80, MW-303-130, MW-304-70, MW-304-80, MW-304-150, MW-305A, MW-305-80, MW-306-70, MW-306-80, MW-306A, O-11, O-13, O-14, O-15, O-16, O-17, O-18, O-20, and O-21.
- Phase 6 Wells MW-186D, MW-195B, MW-197B, MW-198, MW-199, MW-300, and MW-307.

Samples were not collected from several wells due to poor sample recovery.

The samples were analyzed by SWI's soils laboratory in accordance with ASTM D 422-63. Grain-size distribution charts are provided in Appendix E. Results are discussed in Section 3.5.1.

During installation of the CMT wells FHRA collected one soil sample for analysis of effective porosity by ASTM D425, density by API RP 40, hydraulic conductivity by ASTM D5084, and moisture content. Soil samples were collected from MW-306-CMT between 10 to 12 feet BGS. While heterogeneity of soils was visually observed during VPT well installation, no additional samples were collected. . The laboratory report is in Appendix E.

2.3.4.2 Groundwater Gauging

As proposed in the SCWP and SCWP Addendum, FHRA has initiated a program to monitor groundwater levels onsite and offsite, utilizing an extensive network of monitoring wells, observation wells, and recovery wells. The groundwater levels are monitored by both manual and automated means.

2.3.4.2.1 Manual Measurements

Groundwater elevations were calculated from manual depth-to-water measurements that are completed at each monitoring well during each sampling event. Measurements were completed in accordance with the procedures in the SAP. The location and frequency of the groundwater monitoring events are described in Table 8; the monitoring network is shown on Figure 9. Groundwater elevation calculations, used in the analysis of horizontal and vertical gradients, and in monitoring the effects of the onsite groundwater recovery system, are presented in Section 3.5.2

The ability to complete field work during the 4th quarter of 2010 and the 1st quarter of 2011 was affected by the onset of extreme winter conditions. The conditions affected work progress in two ways. First, due to the limited amount of time during which conditions were favorable for field work, and in accordance with the Revised SAP, a priority was placed on completing groundwater sampling before completing groundwater level measurements at wells not scheduled to be sampled. Therefore, groundwater elevations in several wells were not measured. Second, the number of wells which were sampled was restricted due to temperatures below -5°F, increasing snow pack depth, and limited daylight. The Revised SAP noted several issues posing technical challenges to groundwater sampling during cold weather, including compromised sample integrity due to freezing, inaccuracy caused by freezing membranes on water-quality meters and water level gauges, and field equipment calibration drift at cold temperatures. Accordingly, the Revised SAP includes a provision for not collecting samples during periods of extreme cold weather, defined as ambient temperatures or chill factors colder than -5°F. Therefore, several wells were not sampled and, thus, their groundwater elevations were not measured during the fourth quarter of 2010 and the first quarter of 2011.

During the second quarter of 2011, depth to groundwater was measured from wells between April 1 and 27, 2011. Several wells were frozen during the month of April; as a result, additional measurements were collected between May 17 and June 21, 2011.

During the third quarter of 2011, depth to water measurements were collected from wells on July 14 and 15, 2011. A select number of wells are on a monthly gauging schedule and were gauged on August 23 and September 22, 2011.

During the fourth quarter of 2011, depth to water measurements were collected from monitoring wells on October 21 and 22, 2011. A select number of wells are on a monthly gauging schedule and were gauged on December 2 and 7, 2011. Wells on the monthly gauging schedule were not monitored during November 2011 due to cold-weather conditions.

Groundwater elevations for wells in which LNAPL was present were calculated using depth-to-water measurements, the LNAPL thickness measurements, and the specific gravity of the LNAPL, as described in the SAP. LNAPL specific gravities were determined as described in Section 2.5.5. Groundwater elevation data are discussed in Section 3.5.2. Onsite depth to groundwater measurements coupled with onsite LNAPL thickness measurements were used as supporting evidence to confirm the stability of the LNAPL plume and to monitor the effectiveness of the interim removal actions.

2.3.4.2.2 Automated Measurements

In addition to manual water level measurements, measurements were also completed using Global Water WL-16 automated water-level loggers (http://www.globalw.com/products/wl16.html). Each WL-16 is a combined pressure transducer and data logger with automatic barometric pressure and temperature compensation. Each logger was calibrated to provide a direct elevation (above mean sea level) reading and programmed to measure water levels on an hourly basis. Transducers were installed in the suprapermafrost monitoring wells shown in Table 9. The table shows that five well nests were utilized in order to observe differences in groundwater elevations between wells installed at various depths within the suprapermafrost aquifer, in order to observe vertical gradients. Data from the loggers are presented in Appendix G. A complete processing of the information was not possible given the fact that cold weather prevented retrieval of information from the data loggers in a timely fashion. In addition, frost jacking has altered the reference point elevations of several wells. A resurvey of the wells was completed in October 2011. The elevation correction to the data from each well was applied beginning on October 6, 2011. Modifications to the well risers and surveying were done at each well on or near this date. Changes in estimated water levels due to the modifications to the risers ranged from -0.43 feet to 0.86 feet (negative numbers indicate a lower water level after the resurvey and positive numbers indicate a higher water level after the resurvey). Results of the processing of the data are discussed in Section 3.5 and Appendix Y. Currently, FHRA is planning to survey well risers annually to provide tighter control on the effects of frost jacking.

Considerable discussion regarding the installation of additional pressure transducers has occurred during the Site Characterization Subgroup meetings. Transducers will be installed in both existing monitoring wells and new (Phase 7) monitoring wells. FHRA will continue to install transducers in well nests in order to characterize vertical gradients. Proposed transducer locations are discussed in Section 7.3.2.

2.3.4.3 Recovery Well Pumping Test

In accordance with the IRAP, a capture zone test was conducted to monitor performance of the enhanced groundwater remediation system in late August and early September 2011. As described in the IRAP, the goal of the performance monitoring was to evaluate the horizontal and vertical capture of the recovery well system and allow completion of an updated groundwater flow model. As described in the IRAP, enhancements to the groundwater remediation system completed to improve groundwater recovery, and thus capture, included addition of a new recovery well (R-42), cleaning of the existing wells to allow increased groundwater recovery, replacement of discharge piping, and installation of a second prefilter to eliminate a flow restriction. Although not a part of the groundwater capture evaluation, additional corrective actions completed as part of the IRAP included installation of granular activated carbon (GAC) treatment system to remove sulfolane from the recovered groundwater, and addition of LNAPL recovery systems.

In general, the capture zone test consisted of shutting down all five recovery wells, measuring groundwater elevation recovery for 24 hours, then restarting all five recovery wells and measuring drawdown caused by the pumping. Groundwater elevation measurements were collected manually, as described below, and with data loggers and pressure transducers installed in monitoring wells MW-111, MW-113, MW-186A/B/C, MW-125, MW-130, and MW-135 (Figure 10).

The test of the system was conducted sequentially as follows:

- Data loggers and pressure transducers were installed and verified to be working properly in monitoring wells MW-111, MW-113, MW-186A/B/C, MW-125, MW-130, and MW-135. The data recording time interval was set at 30 seconds.

- With the five recovery wells (R-21, R-35R, R-39, R-40, and R-42) operating, water levels were manually measured at the following wells: MW-115, MW-131, MW-140, MW-142, MW-178A, MW-180A, R-21, R-35R, R-39, R-40, and R-42.

- The groundwater recovery pumps were stopped in the five recovery wells.

- Water levels were manually measured at 6, 22, and 24 hours following shutdown at the following locations: MW-115, MW-131, MW-140, MW-142, MW-178A, MW-180A, R-21, R-35R, R-39, R-40, and R-42.

- The recovery wells were restarted and operated at a maximum recovery rate with the flow rate recorded.

- Water levels were manually measured hourly for eight hours at the following wells: MW-115, MW-131, MW-140, MW-142, MW-178A, MW-180A, R-21, R-35R, R-39, R-40, and R-42.

- The pumping rates for NPR production wells and GVEA production and injection wells were recorded.

The results of the aquifer test are described in Section 3.5.1.

2.3.4.4 Single-Well, Short Duration Pumping Tests

Between November 8 and 14, 2011 FHRA completed 14 single-well, short-duration pumping tests. The scope of work for this testing was submitted to ADEC in November, 2011 (ARCADIS, 2011c). Testing was conducted to characterize the distribution of hydraulic conductivity in the heterogeneous saturated soils at the site.

2.3.4.4.1 Field Methods

Single-well, short-duration pumping tests were completed at onsite locations downgradient of the current remediation system. The selected test locations are located within different groundwater zones to characterize the lateral and vertical variability of hydraulic conductivity within the subsurface. Pumping tests were conducted on the following monitoring wells at the site (Figure 11) and targeted different groundwater zones:

- Water table: MW-101A, MW-127, MW-131, MW-139, MW-143 and MW-144A;

- 10 to 55 feet BWT: MW-101, MW-118 and MW-186B;

- 55 to 90 feet BWT: MW-102, MW-144B, MW-154A and MW-154B; and

- 90 to 160 feet BWT: MW-186C.

The single-well, short-duration pumping tests were generally conducted as proposed in the *Scope of Work for Additional Site Characterization Activities* (ARCADIS, 2011c). One deviation from the proposed testing is that the testing was completed at an approximately constant rate while simultaneously measuring drawdown in the pumping well for approximately 15 to 30 minutes, or until a consistent drawdown was maintained for a sufficient period to allow analysis of the dataset. Testing was originally proposed for 30 to 60 minutes, however, that length of testing was unnecessary because drawdown was generally achieved within a few minutes of initiating pumping activities at each well.

Drawdown in each well was automatically measured with a pressure transducer at 10 second intervals with an electrical data-logging pressure transducer installed in the test wells prior to pumping. The target drawdown during pumping was less than or equal to 20 percent of the height of the prepumping water column in the well. Groundwater was pumped from each well using a centrifugal pump capable of pumping approximately 17 gallons per minute (gpm). The discharge rate was manually measured during the tests to confirm a constant pumping rate. After 15 to 30 minutes, pumping was ceased and water levels in the well were allowed to recover prior to removing the down-hole equipment. A check valve was used to minimize the potential for backflow of water inside down-hole tubing. Groundwater recovery was monitored until the height of the water column in the well returned to within at least 90 percent of the prepumping water level.

Extracted groundwater was temporarily containerized in 55-gallon drums or a 300 gallon water tank provided by NPR. Due to the cold temperatures, each storage container was emptied at the end of each day to prevent freezing. The extracted groundwater was treated via the groundwater treatment system.

Field notes presenting manual discharge measurements are presented in Appendix H. Pressure transducer data collected during the pumping tests are provided in Appendix H.

2.3.4.4.2 Analysis Methods

The parameter estimation program AQTESOLV^{TM} Version 4.50 was used to process the groundwater monitoring data and perform calculations. The time-drawdown data collected during the pumping testing activities were analyzed using a mathematical model representative of a variable-rate pumping test (Theis, 1935). The Theis method assumes that the water-bearing zone is infinite in extent, uniform thickness, homogeneous and isotropic, groundwater flow to the test well is quasi-steady-state (i.e., storage is negligible), the pumping well is 100-percent efficient and there is no well bore storage, and that laminar flow exists throughout the well and water-bearing zone. Hydraulic conductivities were estimated using measured responses from pumping tests at the wells during testing. While recovery data is included in the Theis analysis, it was not directly analyzed due to the speed of the recovery of groundwater in the wells at the site and there not being sufficient data to analyze.

The groundwater extraction system was operational during the pumping tests on wells MW-186B and MW-186C. Due to the short duration of the pump tests and the consistent operation of the remediation system, static conditions are assumed for water levels in each of the test wells near the extraction wells.

2.3.4.5 Single-Well Tracer Testing

As proposed in the *Scope of Work for Additional Site Characterization Activities* (ARCADIS, 2011c), single-well tracer testing (SWTT) was completed to evaluate groundwater flux at each test well location. Single-well tracer test methods are well understood and have a long history of use. Generally, the method involves replacing the water column in a well or borehole with a tracer solution without imposing an artificial head in the aquifer and then measuring the subsequent decline of tracer concentration in the well (Drost et al. 1968, Gaspar and Oncescu 1972, Grisak et al. 1977, and Hall, 1993). The observed rate of tracer washout is used to directly determine groundwater flux, which can be used to estimate groundwater velocity.

Based on the solution for a well-mixed reservoir (for this evaluation, the saturated monitoring well screen and casing) the observed groundwater flux in a monitoring well (q_w) can be calculated from the observed tracer washout rate by:

$$q_w = -\frac{W}{At}\ln\left(\frac{C}{C_o}\right) \qquad \text{(Equation 1)}$$

where q_w is flux through the well, W is volume of water within the well screen, A is the vertical cross section of the well screen, C/C_o is the normalized tracer concentration (observed concentration divided by the initial concentration) at time (t). Based on the q_w value and well construction details, the groundwater flux in the aquifer (q) can be calculated by (Drost, et al, 1968):

$$q_a = \frac{q_w}{\alpha} \qquad \text{(Equation 2)}$$

where α represents the flow focusing effect of the borehole, and is dependent on well-specific construction (Equation 3). This flow focusing factor can be calculated using an initial estimate of aquifer hydraulic conductivity and well construction details.

$$\alpha := \frac{8}{\left(1+\frac{K_3}{K_2}\right)\cdot\left[\left[1+\left(\frac{r_1}{r_2}\right)^2\right]+\frac{K_2}{K_1}\cdot\left[1-\left(\frac{r_1}{r_2}\right)^2\right]\right]+\left(1-\frac{K_3}{K_2}\right)\cdot\left[\left(\frac{r_1}{r_3}\right)^2+\left(\frac{r_2}{r_3}\right)^2\right]+\frac{K_2}{K_1}+\left[\left(\frac{r_1}{r_3}\right)^2-\left(\frac{r_2}{r_3}\right)^2\right]} \quad \text{(Equation 3)}$$

where r_1, r_2, and r_3 represent the well inner radius, well outer radius, and borehole outer radius; and K_1, K_2, and K_3 represent the hydraulic conductivity inside the well, of the well filter pack material, and of the aquifer formation, respectively. For most conditions, however, α is relatively insensitive to the initial hydraulic conductivity estimates, more dependent on well construction, and generally ranges from 2 to 4 (Drost et al. 1968 and Kumar and Nachiappan 2000).

ARCADIS conducted single-well tracer testing at 17 wells using table salt as the tracer to evaluate groundwater flux across the site. Underground Injection Control (UIC) authorization was obtained from the USEPA prior to conducting tracer testing.

Single-well tracer testing targeted wells located along transects across the sulfolane plume from the groundwater extraction wells to downgradient of the FHRA property along North Pole High School Boulevard as shown on Figure 12. The selected wells were screened within the water table groundwater zone to measure the horizontal and vertical variability of groundwater flux throughout the sulfolane plume at this interval. Wells were also chosen in transects roughly perpendicular to the centerline of the sulfolane plume to assess the variability of groundwater flux across the plume. Single-well tracer testing was completed at the following wells in three transects:

- Transect 1: MW-144A, MW-144B and MW-145;
- Transect 2: MW-101A, MW-131, MW-142 and MW-143; and
- Transect 3: MW-150A, MW-151A, MW-152A, MW-155A and MW-170A.

Additional Transect 1 wells MW-113, MW-125, MW-186A, and S-39 are located adjacent to groundwater extraction wells R-42, R-39, R-21, and R-40, respectively. Tracer testing at these well locations was not performed during this mobilization because the groundwater extraction system has not been shut down since the testing was proposed. Additional tracer testing is not planned at this time. Additional wells not specified in the work plan (ARACDIS, 2011) were tested including MW-101, MW-102, MW-139, MW-154A and MW-154B. Monitoring washout in MW-102 was not completed by the end of this event and the datalogger was left in the well to continue data collection for later analysis. These wells also had short-duration pump testing completed on them and the SWTT was completed to determine if the hydraulic conductivity measured in the wells correlated with an associated flux. Field notes are included in Appendix H.

Methods employed to complete the SWTT are described below. Results are presented in Section 3.5.1.3.

2.3.4.5.1 Field Methods

Baseline Conditions

Baseline conditions were measured in each well prior to conducting tracer tests. To determine baseline static water level, each well was opened and the well cap and dedicated tubing, if present in the well, were removed. Dedicated tubing was placed in a new disposable plastic bag and stored at room temperature until replacement following the tracer test. Following removal of dedicated tubing, each well was allowed to equilibrate for several minutes to allow the static water level to stabilize under atmospheric pressure conditions. An electronic water level meter was used to measure static water level to the nearest hundredth of a foot (+/- 0.01 ft).

Following determination of static water level, an Aqua TROLL® 200 data-logging pressure transducer (the “data logger”) was deployed and initially set where the transducer sensor was located at the center of the saturated screen. A colored zip-tie was affixed to the data logger cord to easily reference the center screen depth interval at the top of the well casing. Conductivity readings were calibrated for each data logger using a standard solution prior to deployment. Initially, the data loggers were programmed to record data every 2 to 10 minutes. However, the battery reserves in the mobile PC device connected to the data logger could not tolerate this frequency of data processing over the course of a tracer test. Thus, data loggers were later programmed to collect data every two minutes during baseline measurement and tracer introduction and every 30 minutes during monitoring. Later, data loggers were programmed to collect data every 15 minutes throughout an entire tracer test cycle. Real-time data were recorded periodically in field notes to provide a secondary record.

Baseline temperature and specific conductivity conditions were determined by deploying the data logger, set at the center of the saturated screen, in the well at least one hour prior to tracer introduction. Additionally, baseline conditions throughout the saturated screen interval were determined by profiling the saturated screened interval using the data logger. When performing the depth profiling, the data logger was raised/lowered at 1-foot intervals and temperature and specific conductivity values were allowed to stabilize prior to recording. The data logger was moved gently and slowly through the well column to minimize disturbance to the well. Prior to commencing introduction of the tracer solution, the baseline specific conductivity data were visualized versus time using the graphing function of the mobile PC device to confirm stability of the data as evidenced by a horizontal slope. The average baseline specific conductivity across the screened interval was estimated in the field.

A long-term electronic data-logging pressure transducer was present in monitoring well MW-170A. To complete the single-well tracer testing at this well, the pressure transducer was temporarily removed to allow necessary equipment to be lowered down the well. Upon removal, the pressure transducer was placed in a new disposable plastic bag to prevent cross-contamination and stored at room temperature. The time of removal and replacement of the pressure transducer was recorded in field notes.

Preparation of Tracer Solution

A salt (sodium chloride; noniodized table salt) and potable water tracer solution was introduced after baseline conditions were established. The specific conductivity of the tracer solution was determined based on the average baseline specific conductivity conditions in the well, with the goal of producing a post-test specific conductivity difference of approximately +/- 500 microsiemens per centimeter (µS/cm) (the "target specific conductivity"). The difference in specific conductivity between the baseline and target levels was limited to approximately +/- 500 µS/cm to minimize the potential for density-driven flow of tracer solution. The tracer solution specific conductivity necessary to achieve the target was calculated based on the diameter of the well, the length and volume of the water column, and the volume of tracer solution.

In general, the tracer solutions had specific conductivities of approximately 200 to 500 µS/cm greater than the target specific conductivity in the well to allow for dilution of the solution upon introduction. Shallow wells with smaller water columns generally required less specific conductivity differential between baseline well conditions and the tracer solution, while deeper wells with longer water columns required a greater differential.

The tracer solution was mixed in a clean 5-gallon bucket. The bucket was filled to the approximate 5 gallon mark with potable water. To achieve the calculated tracer solution specific conductivity, salt was introduced into the bucket of potable water in ½ teaspoon intervals while stirring and measuring specific conductivity with a calibrated Yellow Springs Instruments (YSI) 556 Multiprobe System hand-held meter. The tracer solution was allowed to equilibrate for approximately one minute following the addition of salt to obtain an accurate measurement of specific conductivity. The final specific conductivity of the tracer solution was recorded in the field notes.

Tracer Introduction

Before beginning tracer introduction, the static water level was measured. The water level meter was positioned in the well approximately 0.10 foot above static water level during the introduction to collect frequent measurements. Having established baseline conditions in the well, the data logger was already set at center screen. Real-time pressure (i.e., equivalent to depth of water above the Aqua TROLL® 200 sensor), temperature, and specific conductivity measurements were collected initially and recorded periodically in field notes during the introduction of tracer solution. During the test, depth profiles were collected periodically to determine progress towards achieving the target specific conductivity at the bottom, center, and top of saturated screen. During tracer introduction, static water level was maintained within +/- 0.5 foot of the baseline static water level measurement at all times. In general, static water level did not vary more than 0.02 foot during the introduction of tracer solution.

A new graduated 750 milliliter (mL) polyethylene container was used to pour tracer solution into the well at a rate generally ranging from 200 milliliters per minute (mL/min) to 500 mL/min, but not exceeding 1,000-mL/min. The rate of introduction was adjusted based on the impact to static water level in the well in order to maintain constant head. Recirculation of the tracer solution was initially attempted; however, due to below freezing weather conditions, recirculation was not feasible. During introduction, real-time specific conductivity readings were monitored for response to the tracer solution. The times when the tracer introduction started and stopped were recorded in the field notes. In general, less than 5-gallons of solution were needed to reach the target specific conductivity in each well. In deeper wells, 10 to 15 gallons were required. Tracer solution introduced into deeper wells likely displaced water within the screened interval and immediate surrounding aquifer. The approximate volume of tracer solution introduced into each well was recorded in the field notes.

In order to achieve homogenous specific conductivity across the saturated screen, the water column was gently mixed following suspension of tracer solution introduction. Mixing was initially conducted using a new disposable bailer with bailer tip installed to prevent the collection of water. Both the water level meter and the data logger were removed from the well during mixing with a bailer because the two-inch diameter wells are not wide enough to accommodate the equipment and bailer simultaneously. The time when the data logger was removed and replaced during mixing was recorded in the field notes. Once the solution was near reaching equilibration, the data logger was used to gently mix the water column to the target tracer distribution. The mixing device was slowly raised and lowered through the entire water column to promote consistent tracer solution distribution throughout the water column without causing tracer solution to be pushed out into the surrounding formation. After several passes of the mixing device, a depth profile was conducted to measure specific conductivity and temperature at the bottom, center, and top of the saturated screen. When the specific conductance appeared to be homogenous, a detailed depth profile was conducted by raising/lowering the data-logger at 1-foot intervals across the entire saturated screen interval. Temperature and specific conductivity were recorded at each interval following equilibration of the real-time readings. Once specific conductivity across the screened interval varied less than approximately 50 µS/cm, the tracer introduction was considered complete and monitoring of the washout began.

Monitoring Tracer Washout

Following the tracer introduction and stabilization of the target specific conductivity in the well, the data logger was set at center screen. Depth profiles at 1-foot intervals were conducted to obtain temperature and specific conductivity data throughout the saturated screened interval every ten minutes for at least the first thirty minutes. If the rate of change of specific conductivity per ten minute interval was relatively low, then the monitoring interval was adjusted to every thirty minutes for the next hour. After an hour, if the rate of change was still low, then monitoring was adjusted to a one or two hour interval. At the end of the day, if the specific conductivity values recovered to within 50 percent of baseline conditions, the test was concluded. If specific conductivity values were still comparable to the start of the test, the data logger was left in place overnight and depth profiling continued on a daily or twice daily basis until recovery was achieved. Periodically throughout the testing, the water column was gently mixed to provide an average tracer concentration throughout the well while limiting any measurement-induced tracer loss into the aquifer formation. The measured conductance from the midpoint of the well screen was used in the analysis. Decontamination of nondedicated or nondisposable field equipment was conducted using an Alconox® or Simple Green® solution and deionized water rinse between wells to prevent potential cross-contamination.

Analysis Methods

Groundwater flux was determined for each well based on the tracer washout rate and accounting for flow-focusing associated with well construction. Tracer washout data were interpreted by visually fitting a model (Drost et al. 1968 and Hall, 1993) to measured time series specific conductivity data (Attachment A). Initial reduction in specific conductivity during the first one to two hours of measurement are primarily a result of mixing within the well and sand pack, whereas data after this initial period represent specific conductivity reductions caused by ambient groundwater flow through the well. Therefore, the evaluation focused on specific conductivity data collected after one to two hours. Exclusion of the initial data does not impact the analysis, and for this type of evaluation, any portion of the curve/slope, that contains sufficient data points, can be used to estimate groundwater flux within the aquifer.

2.3.4.6 Injectability Testing

As proposed in the *Scope of Work for Additional Site Characterization Activities* (ARCADIS, 2011c), injectability testing was completed to evaluate if aquifer permeability at the site will allow for injection rates compatible with injected fluid-based remedial strategies. Results of this testing will be used to screen injected fluid-based remedial alternatives during preparation of the Feasibility Study and to provide design parameters for a successful large-scale tracer test, if one is considered feasible. To support the test, one injection well and associated monitoring wells were installed west of the rail lines as shown on Figure 13. Injectability testing was completed in March 2012.

2.3.4.7 Large-Scale Tracer Test

As proposed in the *Scope of Work for Additional Site Characterization Activities* (ARCADIS, 2011c), a large-scale tracer test was conducted to estimate hydrogeologic parameters including mobile and immobile porosity, effective in-situ reagent delivery strength, injection volume-to-coverage relationship, mass transport coefficient, and groundwater velocity. Large-scale tracer testing was conducted on the proposed injection well and downgradient monitoring wells located west of the rail lines as shown on Figure 13. Results of the testing will be used to evaluate whether injection-based remedial alternatives are feasible at the site and may provide design specifications for evaluation in the Feasibility Study. Large-scale testing was completed in March 2012 and will be reported in the SCRA-2012.

2.4 Characterize Soil Impacts

Historically, limited investigations of potential soil impacts at NPR have been completed because the water table is very shallow, and the stability of the benzene and LNAPL plumes indicated the pump and treat remediation system was capturing the plumes, including contaminants that could be leaching from potentially impacted vadose zone soils. A summary of historical data gathered during SWI's previous investigations is presented in Section 3.6.1. The sections below discuss the characterization of soil impacts during site characterization, an investigation of NPR sumps, and the NPR laboratory drain investigation.

2.4.1 Historical Soil Data

SWI provided historical soil data from four soil borings, five monitoring well borings, and fifteen surficial soil sampling locations.

The four soil borings were placed during 2001, south of containment area CA5A/5B (boring B-1), east of containment area CA4 (boring B-2), at the southeast corner of containment area CA1 (boring B-3), and west of the railcar-loading area (boring B-4) (Figure 14). One sample from each boring was submitted for laboratory analysis of GRO, DRO, RRO, VOCs, SVOCs, and metals. The samples were collected at depths that ranged from 7.5 to 11.5 BGS, likely near the zone of water table fluctuations (Appendix I).

The five monitoring wells were also installed in 2001. MW-135 was installed near the northeast corner of containment area CA7. The other three wells (MW-139, MW-140, MW-141, and MW-142) were installed downgradient of the current truck-loading area (Figure 14). One sample from each boring, collected near the water table, was submitted for laboratory analysis. All samples were analyzed for GRO and DRO, and RRO. The MW-135 sample was analyzed for VOCs, SVOCs, and metals. The MW-139 and MW-140 samples were analyzed for BTEX and metals. The MW-142 sample was also analyzed for BTEX (Appendix I).

Thirty shallow (three feet BGS or less) soil samples were collected from 15 sampling locations along the railcar-loading area in 2004. All samples were analyzed for DRO and RRO (Appendix I). Results are discussed in Section 3.6.1.

2.4.2 Sump Investigation

In 2009 through 2010, a third-party inspection contractor was retained to inspect the integrity of sumps and drain lines associated with NPR operations. The contractor completed a systematic evaluation to determine if the sumps and drain lines were contributing contaminants to the subsurface. A total of 42 sump systems were inspected; four sump systems were found to have potentially compromised integrity. The four sump systems were identified as the Asphalt Sump (03-6), the Blend Building Sump (05-7), the Tank Farm Truck Kero Sump (922), and the Naphtha 2 Sump (02/04-2) (Figure 14). The results of the investigations at these four sumps were previously presented in a letter report to ADEC in December 2010 (FHRA, 2010), a copy of which, including the investigation details, is provided in Appendix J.

2.4.2.1 Asphalt Sump

The results of the inspection of the Asphalt Sump indicated that leaks were confined to the inner steel shell of the sump. An attempt to remove the inner shell was unsuccessful, so the entire sump was replaced. The gravity drain lines, catch basins, and floor drains influent to the sump were tightness tested using the hydrostatic pressure test method. All elements were found to be leak free (Appendix J).

Approximately 10 cubic yards of soil were excavated during sump replacement in October 2010. Five soil samples were field screened using a PID, and one sample with elevated organic vapor concentrations was selected for laboratory analysis. The samples were analyzed for GRO, DRO, RRO, BTEX, and RCRA metals (Appendix J). Results of the investigation are discussed in Section 3.6.4.

2.4.2.2 Blend Building Sump

The inspection of the Blend Building Sump indicated that corrosion was confined to the inner steel shell of the sump. A six-inch layer of concrete was placed on the floor of the sump and a new floor was welded into place. A new six-inch ring was welded over the corroded portion of the shell. No soil samples were collected near the sump since the area is paved and no excavations were completed at the sump (Appendix J).

The floor drains and cleanout fittings were inspected and three floor drain/trap assemblies and two cleanout fittings were excavated and replaced. Following all repairs to the sump and fittings, a hydrostatic pressure test was completed and the system was found to be leak free (Appendix J).

Two soil samples were collected from below the floor slab during replacement of a floor drain and a cleanout fitting. The samples were analyzed for GRO, DRO, RRO, BTEX, PAHs, SVOCs, and sulfolane (Appendix J). Results of the investigation are discussed in Section 3.6.4.

2.4.2.3 Tank Farm Truck Kero Sump

FHRA did not identify any leak from the Tank Farm Truck Kero Sump, or any integrity issues in the lines that serve the sump. The sump was replaced due to aging and end-of-service life considerations (Appendix J).

Following removal of the sump, a soil sample was collected from beneath the sump's former location in September 2010. Due to high water table conditions and a lack of a suitable alternate sampling location, the sample saturated with groundwater was collected. The sample was analyzed for GRO, DRO, RRO, BTEX, PAHs, SVOCs, and sulfolane. Two samples of the soil that was excavated during sump replacement in October 2010 were analyzed for GRO, DRO, RRO, BTEX, and RCRA metals (Appendix J). The samples were not analyzed for sulfolane since kerosene is not produced in the EU. The rare events in which small amounts of sulfolane may enter kerosene are described in Section 3.1.1.1. Borings SB-117, SB-120, and SB-122, and observation well O-19 were placed in the vicinity of the sump during the 2011 soil investigation. Results of the investigation are discussed in Section 3.6.4.

2.4.2.4 Naphtha 2 Sump

Inspection of the Naphtha 2 sump indicated that the interior shell had been improperly installed in 1997. In addition, a gravity line from CU #2 failed a hydrostatic test. The sump was repaired and the drain line from CU #2 was permanently removed from service. Since the entire area is paved and no excavations were performed during sump repair, no soil samples were collected at that time (Appendix J). Subsequently, three soil borings were installed near the Naphtha 2 sump during the 2011 soil investigation (Section 2.4.4.2). These borings are identified as borings SB-164 (COPC boring), SB-165, and SB-166 on Figure 6. Results from the soil investigation are discussed in Section 3.6.2.2.

2.4.3 Laboratory Drain Investigation

Results of the comprehensive sump and drain inspection program also indicated that the QC laboratory drain lines were found to have potentially compromised integrity. The following text describes the investigation of the laboratory drain lines.

In July 2010, a hydrostatic pressure test of the laboratory drainage piping indicated that the subsurface piping system would not maintain a static water level when the piping system was isolated and filled with water. On July 21, 2010, FHRA reported these test results by letter to ADEC.

In a December 22, 2010 letter, ADEC requested volume estimates and an investigation plan for the four sumps that failed the integrity testing (discussed above in Section 2.4.2) conducted by FHRA. A work plan to assess the laboratory drain lines, and which discussed assessment activities previously conducted for the other failed sumps was submitted to ADEC on March 17, 2011. At the request of ADEC, revisions were made, and the work plan was finalized on March 21, 2011 (ARCADIS, 2011e).

A second round of hydrostatic testing was completed on the laboratory drain lines in March 2011. The additional testing in the laboratory was conducted in an effort to confirm the integrity of the lines in certain portions of the laboratory. The testing confirmed the integrity of the drain lines in the water laboratory, and therefore, no assessment activities were planned in this area (Appendix J).

2.4.3.1 Limited Site Investigation

Five soil borings (SBLAB-1 through SBLAB-5) were installed on March 28 and 29, 2011, beneath the laboratory building to assess the potential for a release from the suspect drain lines, as outlined in the *Laboratory Area Subsurface Investigation Work Plan* (ARCADIS, 2011e). The soil boring locations were selected during a site visit with ADEC in December 2010, and were based on the drain usages in the FHRA QC laboratory and on a hydrostatic evaluation of the drain lines of the laboratory building. The boring locations were placed near drains and drain lines that were classified as "high use" by laboratory personnel, and are lines that also failed hydrostatic integrity testing. The locations of the soil borings are shown in Appendix K. The soil boring installation activities were coordinated and phased to minimize interruptions to laboratory operations.

2.4.3.2 Soil Boring Installation

To access soils beneath the laboratory building, the concrete floor of the laboratory building was cut by a concrete-cutting contractor. Prior to cutting the concrete, FHRA verified the locations of the underground utilities and marked locations suitable for soil boring installation. The boring locations were modified based on the presence of underground utilities in the FHRA QC laboratory, but were placed as close to their proposed locations as possible.

Upon removal of the concrete from each boring location, a hand auger and other manual methods, including breaker bars and post-hole diggers, were used to reach the maximum depth possible. After attempting two boring locations, it was determined that manual methods would not be effective for advancing the borings to the groundwater interface. The presence of large cobbles and unconsolidated fill contributed to borehole collapse as the borings were advanced. After consultation with ADEC, the project team determined to use a vacuum truck to continue borehole clearance to the extent possible. For each location, manual methods were used to advance the boring as deep as possible (generally 2 to 3 feet BGS). A soil sample was collected at the maximum depth of manual clearance at each location for laboratory analysis. The vacuum truck was then used at each location in an attempt to advance the borings to the groundwater interface. Due to continued borehole caving and concerns about compromising the integrity of the laboratory floor, none of the borings could be advanced to the groundwater interface. However, at each location, a second soil sample was collected with the hand auger from below the maximum depth achieved with the vacuum truck (between 4 and 7 feet BGS); this sample interval was also submitted for laboratory analysis. The depths achieved in each of the five soil boring locations per clearance method (manual clearance or vacuum truck) are summarized in Table 10.

2.4.3.3 Field Screening

Field screening of soil samples for volatile organic contaminants was performed continuously during manual soil boring installation activities using a PID and visual classification and in accordance with the SAP. During borehole advancement with the vacuum truck, samples were collected for field screening on approximately two-foot intervals. The organic vapor concentrations were recorded on the boring logs included in Appendix K. Field screening also included a visual inspection of soils for the presence of LNAPL, hydrocarbon odor or hydrocarbon sheen on the soils. Lithologic descriptions and soil classifications were conducted by trained ARCADIS field staff and recorded on the boring logs included in Appendix K.

2.4.3.4 Soil Sample Collection

The subsurface material encountered beneath the laboratory building during soil boring installation was poorly-graded gravel with coarse sand and is assumed to be the compacted gravel bedding placed during construction of the building. Depth to groundwater was estimated to be approximately eight feet below ground surface. Due to the densities of subsurface fill and native soils, the equipment available for use, and borehole sidewall failure, it was not possible to reach the groundwater interface in soil borings SBLAB-1 through SBLAB-5. Soil samples were collected at the base of the manually-cleared portion of the borehole and at the base of the vacuum-cleared portion of the borehole from each soil boring location. ARCADIS field staff collected and handled analytical samples in accordance with the Draft Field Sampling Guidance (ADEC, 2010).

2.4.3.5 Soil Sample Analytical Methods

The soil samples collected during the installation of soil borings SBLAB-1 through SBLAB-5 were submitted to SGS Environmental Services, Inc. (SGS), in Fairbanks, Alaska for analysis of sulfolane, GRO, DRO, VOCs, and SVOCs in accordance with the methods listed in the SAP. In addition, samples were analyzed for residual range organics (RRO) by Alaska Method AK 103 and Resource Conservation and Recovery Act (RCRA) 8 metals by USEPA Method SW6020/7471B. Results of the laboratory drain investigation are presented in Section 3.6.3.

2.4.3.6 Soil Boring Abandonment

As noted previously, the project team was not able to reach the groundwater interface using available boring installation methods. ARCADIS and FHRA consulted with ADEC, and received verbal and email approval to abandon the soil boring locations on March 30, 2011. Soil borings SBLAB-1 through SBLAB-5 were backfilled with hydrated bentonite chips to approximately one foot BGS. Approximately 0.5 feet of soil removed during soil boring installation was then placed above the hydrated bentonite chips in each boring. The concrete cores previously removed were placed back in each borehole to be cemented back in place by FHRA.

All IDW including soil cuttings generated during the soil boring installation and not used as backfill material were managed in accordance with the SAP.

2.4.4 Site Characterization

Soil samples have been collected during three efforts associated with site characterization. First, soil samples were collected onsite and offsite during installation of the monitoring and observation well networks. Second, soil samples were collected from onsite soil borings to investigate potential impacts due to historical releases. Finally, surface soil samples were collected from offsite garden locations downgradient of NPR. The well installation soil sampling is addressed in Section 2.4.4.1, the onsite soil sampling is discussed in Section 2.4.4.2, and the garden-soil sampling is addressed in Section 2.4.4.3. Additional analyses of soils related to LNAPL characterization is described in Section 2.5.4.

2.4.4.1 Soil Sampling During Well Investigation

Groundwater monitoring wells to assess the distribution of LNAPL and dissolved-phase contaminants were installed in several phases during site characterization efforts as described above in Section 2.3.1.2 starting in October 2009 and continuing through 2011. The sequence of LNAPL-delineation well and monitoring well installations are discussed in Sections 2.5.1 and 2.6, respectively.

As discussed in Section 2.3.1.4, soil samples from well borings were field-screened for the presence of volatile organic contaminants in accordance with the Revised SAP. Field-screening results were used to select soil samples for laboratory analysis. Field-screening results are shown on the boring logs in Appendix D.

During Phase 1 of the monitoring well installations (between October 2009 and April 2010), select soil samples were submitted to SGS for laboratory analysis of sulfolane by modified USEPA Method 8270D. Samples were submitted from the following Phase 1 wells: MW-151C, MW-154B, MW-156B, MW-160B, and MW-162B. Sampling depths are shown in Table 11. The results of these analyses are discussed in Section 3.6.2. The QA/QC review of the laboratory data is provided in Section 6.0.

During the Phase 2 monitoring well installation (September and November 2010), one soil sample was to be collected from each boring exhibiting organic vapor concentrations greater than 20 parts per million (ppm), and from each boring drilled onsite at the refinery, as described in the SAP. Soil screening results are discussed in Section 3.6.2. Soil samples from all of the Phase 2 offsite borings exhibited organic vapor concentrations less than 20 ppm; therefore, no samples from these borings were submitted for laboratory analysis. Soil samples from onsite borings yielded organic vapor concentrations up to 1,558 ppm. Soil samples were submitted for laboratory analysis from well borings MW-144B, MW-174A/B, MW-175, MW-176A/B/C, MW-177, MW-178A/B/C, MW-179A/B/C, MW-180A/B/C, and O-1 through O-4. Sample depths are noted in Table 11. The samples were submitted for sulfolane analysis, as well as for BTEX by USEPA Method 8021B, VOCs using USEPA Method 8260B, SVOCs by USEPA Method 8270D, GRO by Alaska Method AK101, and DRO by Alaska Method AK102 in accordance with the SAP. The results of these analyses are discussed in Section 3.6.2. The QA/QC review of the laboratory data is provided in Section 6.0. Laboratory reports are provided in Appendix L.

During the Phase 3 through Phase 6 monitoring well installations in 2011, in accordance with the Revised SAP, analytical soil samples were only to be collected from each monitoring well boring exhibiting organic vapor concentrations greater than 20 ppm, if the borings were not located adjacent to existing wells that had been sampled for soil analytes. No samples were collected due to organic vapor concentrations greater than 20 ppm. However, soil samples were obtained from the borings for monitoring wells MW-192A and MW-192B to collect data to assess the distribution of COPCs as part of the soil investigation described below in Section 2.4.4.2. Accordingly, they were submitted to SGS for analysis of select PAHs by USEPA Method 8270 PAH selected ion monitoring (SIM); select metals by USEPA Method SW6020; sulfolane by USEPA Method SW8270D M with isotopic dilution; total cyanide by USEPA Method SW9013/SW9014; DRO and RRO by Alaska Methods AK102/103; and GRO, SVOCs and VOCs by the methods noted above.

Observation wells were also installed in 2011 to further delineate the LNAPL plume as described in Section 2.5.1. Soil samples were collected from each of those borings following procedures described in the SAP. Samples were obtained from each boring from the surface (i.e., 0 to 2 feet BGS), from the interval with the highest field-screening measurement at or near the water table interface, and approximately 10 feet BWT to help characterize the smear zone. The samples were submitted to SGS for determination of BTEX by USEPA Method 8021B, PAHs by USEPA Method 8270 PAH SIM, and sulfolane by USEPA Method SW8270D M with isotopic dilution. The results of the 2011 soil analyses are discussed in Section 3.6.2.

2.4.4.2 Onsite Soil Characterization

As proposed in the SCWP Addendum, soil characterization was performed onsite. Subsurface soil samples were collected from 83 soil borings in September and October 2011 in order to further characterize geology, investigate potential soil impacts across operational areas of the site, assess the presence or absence of sulfolane in the sampled locations, determine whether and where COPCs may be present in soils, and provide additional soil samples for smear-zone chemical profiling to fill data needs for the LNAPL conceptual model (LCM). In addition, some of the soil characterization data have been used for development of a HHRA (to be submitted under separate cover).

Soil boring locations were selected to target areas of known contamination, and areas where releases may have occurred (Figure 6 and Table 4). The borings were advanced and sampled at the locations at or near those shown proposed in the SCWP Addendum; minor modifications in the boring locations were occasionally made to avoid subsurface utilities.

Soil borings were advanced to depths sufficient to delineate the vertical extent of contamination (based on field screening), or to the water table, whichever was deeper. Soil samples were collected from surface soils (0 to 2 feet BGS), from immediately above the air-groundwater interface (smear zone), and from the bottom of the boring. Boring advancement, soil sampling, soil classification, soil screening and field quality control measures were completed in accordance with the procedures described in the SAP. Boring logs were prepared for each boring and are presented in Appendix D.

Soil samples were collected from each boring for the LNAPL observation wells as part of the LNAPL monitoring network expansion described below in Section 2.5.1.

Samples were collected from the soil borings for laboratory determination of either the “standard” set of soil analytes, as shown below:

- Standard soil analytes:
  - BTEX measured by USEPA Method 8021B,
  - PAHs determined by USEPA Method 8270SIM, and
  - sulfolane analyzed by USEPA modified Method 8270D with isotopic dilution.
- COPC analytes:
  - select PAHs by USEPA Method 8270 PAH SIM,

- select metals by USEPA Method SW6020,
- sulfolane by USEPA Method SW8270D M with isotopic dilution,
- total cyanide by USEPA Method SW9013/SW9014,
- DRO and RRO by Alaska Methods AK102/103,
- GRO by Alaska Method AK101,
- select SVOCs by USEPA Method SW8270D,
- select VOCs by USEPA Method SW8260B, and
- isopropanol and propylene glycol by USEPA Method SW8015B.

Due to an error, none of the soil-boring samples were submitted for analysis of isopropanol and propylene glycol. Selection of COPCs is discussed in Section 2.2.

2.4.4.3 Downgradient Surface Soil Investigation

To assess potential sulfolane sorption to surface soils irrigated with groundwater containing dissolved-phase sulfolane, FHRA conducted sampling of garden soils within the offsite downgradient plume area. Sampling was completed on October 20 and 22, 2011 as proposed in the SCWP Addendum (ARCADIS, 2011b). While additional sampling from greenhouses was completed, no deviations from the proposed scope of work were noted by field staff.

The two properties chosen for sampling are shown on Figure 15. Prior to sampling, the two private properties were reviewed with ADEC. One outdoor garden and one indoor greenhouse were located on each of these properties. These properties were selected based on the reported historical irrigation of garden plots with sulfolane-impacted groundwater prior to the 2011 growing season; each location used sulfolane-free water during the 2011 growing season. Prior to collecting samples, the property owners were consulted to verify that additional topsoil had not been added since irrigation with sulfolane-impacted groundwater was discontinued and the ADEC was consulted to confirm sampling locations. In addition, surface soil sampling was completed upon receiving access to the selected properties under terms acceptable to FHRA.

To collect soil that is less exposed to environmental processes, the top 3 inches of soil was cleared from each sampling location prior to sampling. Two samples were collected per garden (one from each outdoor garden and one from each indoor greenhouse) from soil within the interval from 3 to 9 inches BGS. This interval was also inferred to be within the root zone for garden plants. The top 3 inches of soil was cleared by hand with a clean hand trowel or equivalent and decontaminated before the start of sampling and between sample locations. Samples were collected using a new stainless steel spoon and submitted to SGS in Anchorage, Alaska, to be analyzed for the following:

- Sulfolane by USEPA modified Method 8270D with isotope dilution and
- Total organic carbon (TOC) by USEPA Method 9060A

Results of the downgradient surface soil investigation are presented in Section 3.6.2.3.

2.5 Characterize NAPL

The SCWP and SCWP Addendum identified data needs in the understanding of NAPL characteristics and occurrence, and proposed tasks to further characterize the nature and extent of NAPL impacts present at the site (Barr, 2010b, ARCADIS, 2011b). Results are being used to confirm the stability of the LNAPL plume, monitor the effectiveness of the interim removal actions, and monitor for ongoing or new releases. As these are long-term goals, several of the proposed tasks are ongoing and will continue as IRAP implementation continues and the Onsite FS is completed. LNAPL investigation activities completed at the site will further refine the LCM and will estimate LNAPL recoverability and establish remedial goals for addressing LNAPL onsite.

2.5.1 LNAPL Monitoring Network Expansion

As proposed in the SCWP, four observation wells were installed to address data needs in the understanding of LNAPL occurrence in areas downgradient of CUs #1 and #2, downgradient of containment areas CA4 and CA6, and downgradient of the former truck-loading area.

The wells were installed during Phase 2, with wells O-1 through O-3 installed on September 23, 2010, and O-4 installed on September 16, 2010 (Figure 16). The wells were installed by Homestead following the drilling and soil sampling techniques described in Section 2.3.1. Well construction details are provided in Table 3. Smear zone chemical profiling completed in conjunction with the installation of the O-wells is described below in Section 2.5.4.

As groundwater elevation and LNAPL occurrence data have been gathered, it became apparent that additional LNAPL monitoring locations were warranted. LNAPL was observed in observation well O-2, therefore, additional delineation was needed. Groundwater elevation data demonstrated that several of the wells in the LNAPL monitoring network had flooded screens, rendering them unsuitable for LNAPL monitoring. Several wells in the LNAPL monitoring network were damaged and required decommissioning. The SCWP Addendum proposed expanding the LNAPL well network to address these issues and delineate the lateral extent of the mobile LNAPL. Seventeen LNAPL wells were installed between September 13 and October 15, 2011 at the locations proposed in the SCWP Addendum.

Drilling, soil sampling, soil classification, soil screening, well installation and development were completed using the methods described in Section 2.3.1 and in accordance with the procedures described in the SAP. Most of the wells were constructed of 2-inch-diameter PVC riser pipe and machine-slotted well screens, but one well (O-10) was constructed of 4-inch diameter pipe for potential use as an LNAPL recovery well. The 10-foot-long well screens were set to span the water table, with the bottoms set at least five feet BWT (approximately 15 feet BGS). Well construction details are provided in Table 3. Boring logs are presented in Appendix D.

Initial LNAPL gauging data from these wells indicated the need for additional monitoring locations, as discussed in Section 3.9. Additional wells were installed downgradient of wells O-11 and O-13 (O-24, O-25, O-26 and O-27) and to the east of wells O-7 and O-9 (O-21 and O-22) (Figure 16).

2.5.2 LNAPL Gauging

As proposed in the SCWP, FHRA has initiated a program to monitor LNAPL using an onsite network of monitoring wells, observation wells, and recovery wells screened across the water table. The apparent LNAPL thicknesses were measured in accordance with the SAP. The current LNAPL monitoring network is shown on Figure 16. Locations and monitoring frequency are shown in Table 8.

2.5.2.1 Fourth Quarter 2010 and First Quarter 2011

Twenty-eight wells were to be checked monthly and 21 were to be checked quarterly. The actual number of wells at which LNAPL measurements were completed was as follows:

4th Quarter of 2010	**Monthly Measurements**			**Quarterly Measurements**
	October 2010	November 2010	December 2010	
	19 of 28 wells	3 of 28 wells	0 of 28 wells	10 of 21 wells

1st Quarter of 2011	**Monthly Quarterly Measurements**			**Quarterly Measurements**
	January 2011	February 2011	March 2011	
	0 of 28 wells	4 of 28 wells	16 of 32 wells	5 of 21 wells

As previously discussed, field work during the fourth quarter of 2010 and the first quarter of 2011 was affected by the onset of extreme winter conditions. Due to a lack of favorable conditions, as prescribed in the revised SAP, a priority was placed on monitoring well sampling over LNAPL thickness measurements.

2.5.2.2 Second and Third Quarters 2011

By April of 2011, four new wells (MW-176A, MW-178A, MW-179A, and MW-180A) had been added to the quarterly LNAPL-gauging schedule. Also, five wells (R-19, S-33, S-35, S-37, and R-20), were unavailable for gauging because they were frost-jacked, destroyed, or damaged. This left a total of 48 wells available for quarterly monitoring, and 25 wells for monthly monitoring. In May of 2011, four observation wells (O-1, O-2, O-3, and O-4) were added to the LNAPL-gauging network to be checked monthly, bringing to 29 the total number of wells to be gauged monthly.

The numbers of wells where LNAPL measurements were completed are as follows:

2nd Quarter of 2011	**Quarterly Measurements**	**Monthly Measurements**	
	April 2011	May 2011	June 2011
	37 of 48 wells	24 of 29 wells	28 of 29 wells

Of the 48 wells available in April, 11 wells were frozen and could not be checked for LNAPL. In May, 24 wells could be gauged, four were frozen, and two (MW-116 and MW-138) were inaccessible due to the shut-down at the refinery that month; one quarterly well (R-32) was also gauged that month. In June, all but one of the 29 wells could be gauged; MW-138 could not be gauged due obstructed access.

By July, two more wells (MW-187 and MW-188) were added to the quarterly LNAPL-gauging network, bringing the quarterly total of wells to be gauged to 50. In September, six wells were decommissioned and removed from the LNAPL-gauging list, bringing the monthly total to 23 wells.

3rd Quarter of 2011	**Quarterly Measurements**	**Monthly Measurements**	
	July 2011	August 2011	September 2011
	49 of 50 wells	29 of 29 wells	23 of 23 wells

In July, 49 of the 50 wells were checked for LNAPL; MW-188 was frozen. In August, each of the 29 LNAPL-gauging wells was checked, and each of the 23 available wells was checked in September.

2.5.2.3 Fourth Quarter 2011

Further review of the well-screen depths listed in the September 2011 SCWP Addendum demonstrated wells MW-115, MW-116, and MW-135 (slated for monthly gauging) were screened too deeply to be suitable for LNAPL gauging, so they were removed from the LNAPL-gauging network. In late September, nine more observation wells (O-5 through O-13) were added to the LNAPL network, with another eight wells (O-14 through O-21) added by mid-October. This brought the number of wells available for quarterly LNAPL gauging to 61, and the number available for monthly monitoring to 35. Seven more wells (O-22, and O-24 through O-29) were installed and added to the network in November, bringing to 68 the number of quarterly wells available for gauging, and to 42 the number of wells for monthly LNAPL-gauging.

4th Quarter of 2011	**Quarterly Measurements**	**Monthly Measurements**	
	October 2011	November 2011	December 2011
	61 of 61 wells	0 of 42 wells	35 of 42 wells

All of the 61 available LNAPL wells were checked in October. In November, no wells were checked due to extreme cold weather (in accordance with the SAP). In December, 35 of the 42 available wells were checked; three wells (MW-138, O-14, and O-21) were not sampled because an NPR operator would not allow access, two wells (O-9 and S-22) could not be opened due to ice, one well (S-32) could not be located, and one well (R-35R) was not measured due to active product recovery.

One more observation well (O-23) was added in mid-December, leaving a total of 69 quarterly and 43 monthly LNAPL-gauging wells. Well O-23 was added after gauging was completed in December, so it was not included in the December round of LNAPL gauging.

2.5.3 Bail-down Testing

Bail-down testing is being completed to provide an estimate of LNAPL recoverability. After completion of initial bail-down testing in the first quarter of 2011, FHRA initiated a program of semiannual bail-down testing during the second and fourth quarters to characterize LNAPL recoverability and to identify any seasonal fluctuations in recoverability at the site. Bail-down testing field notes are provided in Appendix M. Results of the bail-down testing are presented in Section 3.7.3.

2.5.3.1 First Quarter 2011

SWI attempted to complete LNAPL bail-down tests at four wells on March 17 and 18, 2011:

- S-21, near Containment Area CA5;

- S-33, near Containment Area CA6;
- S-51, near the former truck-loading rack; and
- MW-138 near CU #2.

S-33 could not be located, possibly due to being buried in snow (Appendix M); therefore, nearby well S-44 was tested in its place. S-21, S-51, and MW-138 are 2-inch diameter wells, while S-44 is a 4-inch diameter well. The wells are shown on Figure 16.

The bail-down tests followed the procedures presented in Section 3.3.3.3 of the 2010 Revised SAP (Appendix M of the SCWP). The field team used a Solinst Model #122 oil/water interface probe to measure the depth to LNAPL and depth to water, and then calculated the thickness of LNAPL in the well. This information was then used to calculate the quantity of LNAPL to be removed from the well during the bail-down phase of the test as prescribed by the method.

A peristaltic pump was used to remove LNAPL from the wells, with the tubing intake set near the surface of the LNAPL layer to avoid removing water. The field team used the interface probe to measure LNAPL thickness during bail-down pumping to determine when the LNAPL layer was removed from the well casing (i.e., LNAPL thickness not measureable using the interface probe). Once the calculated volume of LNAPL had been removed and the accumulated LNAPL in the well casing had been removed, the pump was shut off and LNAPL recovery gauging began. Well S-44 was an exception; less than half the calculated volume of NAPL was removed because of slow recharge.

Product recovery monitoring consisted of measuring depth to LNAPL and depth to water from the designated measuring point at the top of the well casing. Measurements were generally taken at one- to two-minute intervals for the first five minutes, two- to five-minute intervals from five to fifteen minutes, and five- to fifteen-minute intervals from fifteen minutes to the end of each test. The measurements and times of the readings were recorded on the field logs (Appendix M). The tests were concluded when the field personnel determined that LNAPL thickness had stabilized, in accordance with the procedure (maximum 0.03-foot change over previous measurement).

At well S-21, approximately 0.2 gallons of LNAPL were removed, and then the pump was shut off to allow additional LNAPL to flow into the well casing. Pumping was resumed until a cumulative

0.4 gallons were removed. Approximately 0.6 gallons of water were removed from the well in addition to the LNAPL.

Approximately 0.7 gallons of LNAPL were removed from well S-44 before the pump was turned off to allow additional NAPL to flow into the well casing. Pumping was resumed, but the test was stopped when it became apparent that LNAPL recovery was very slow and more water was being removed from the well than desirable. The test procedure states less than one gallon of water should be removed from the well; however, 1.2 gallons of water were removed with a cumulative 0.8 gallons of LNAPL. This was less than one-half the target volume.

At S-51, approximately 0.7 gallons of LNAPL were pumped from the well. The pump was then turned off to allow additional LNAPL to flow into the well casing. Pumping was then resumed until a cumulative 1.5 gallons were removed. Approximately 0.3 gallons of water were removed from the well in addition to the LNAPL.

At well MW-138, 0.6 gallons of LNAPL, or three times the target volume, were removed, along with 0.3 gallons of water. The extra volume of LNAPL removed during bail-down is attributed to the LNAPL rapidly recharging into the well during the bail-down process.

2.5.3.2 Second Quarter 2011

SWI attempted to complete LNAPL bail-down tests at 23 wells in May 2011, but testing was only completed successfully on eight wells: MW-115, O-2, S-20, S-21, S-22, S-39, S-51 and S-52. These were the only wells that were not frozen and had LNAPL present during the reporting period.

Final LNAPL thickness measurements were obtained after a recovery period of 30 to 35 minutes. The final LNAPL thicknesses at O-2, S-21 and S-20 were approximately 56, 42 and 5.9 percent of their initial apparent LNAPL thickness, respectively. The final thickness at S-52 (the only 4-inch-diameter well tested) was 4.8 percent of the initial thickness. Well S-39 was tested twice during the May 2011 event and testing produced similar results; the final LNAPL thicknesses were 3.5 and 1.4 percent of the initial apparent LNAPL thickness. The results qualitatively indicate LNAPL recoverability is greatest in O-2 and S-21. However, the minimal thicknesses present in these wells suggest that the recoverable volume near those wells may be minimal. Bail-down testing field notes are provided in Appendix M.

Results of bail-down testing are discussed in Section 3.7.3.

2.5.3.3 Third Quarter 2011

Bail-down testing was not performed in the third quarter since it was to be performed semiannually in 2011, during the second and fourth quarters.

2.5.3.4 Fourth Quarter 2011

Bail-down testing during fourth quarter 2011 was completed in October 2011 in 10 monitoring wells in which LNAPL was observed (MW-138, O-9, O-11, O-13, O-19, S-20, S-22, S-50, S-51 and S-52 (Figure 16). Static depth to water and LNAPL were measured and recorded prior to initiating each test. LNAPL was removed using a dedicated bailer for each well. After removal, the rate of LNAPL recovery into the well was recorded by measuring depth to LNAPL and depth to water at logarithmic to linear time intervals (more frequent data collection early in the test, with reduced frequency as the tests progressed).

Bail-down tests at monitoring wells MW-138, O-9 and O-11 and Test 1 at S-50 were not analyzed due to either poor LNAPL recovery into the well, inability to line-fit data to any of the three analysis methods in the API Tool or minimal LNAPL drawdown during test initiation. Bail-down testing data was analyzed using the API Tool and results are discussed in Section 3.7.5.2.

2.5.4 Smear Zone Chemical Profiling

As proposed in the SCWP, chemical profiling of the smear zone was completed during the installation of the new observation wells as part of LNAPL characterization. The smear zone is the layer of impacted soil above and below the water table, caused by the smearing of contaminants into the soil as the water table fluctuates up and down. The profiling identifies which LNAPL constituents are present in the soil.

As described in Section 2.3.1, during installation of wells O-1 through O-4 (O-wells), soil samples were collected only from the bottom of the borings or at intervals with PID measurements greater than 20 ppm. Additional soil borings (O-borings) were placed immediately adjacent to the O-wells on October 19 and 20, 2010, in order to obtain the necessary composite soil samples for the profiling. Soil samples were collected continuously, both above and below the water table, as specified by the SCWP. The soil samples from the two intervals above the water table and two intervals below the water table were used for the composite sample from each boring, as proposed in the SCWP. These composite samples were analyzed for sulfolane, GRO, DRO, VOCs, and SVOCs. The results of these analyses are discussed in Section 3.7.2. Laboratory analytical reports are included in Appendix N.

2.5.5 LNAPL Sampling and Analysis

LNAPL samples were collected and analyzed in order to obtain physical characteristics of the LNAPL, such as specific gravity, color, and viscosity. Analyses were also completed to determine LNAPL constituents and obtain "fingerprint" data. The resulting data are being used to address data needs in the LNAPL conceptual model and are being used, or will be used, to evaluate potential sources, evaluate LNAPL as a source of dissolved-phase contaminants, and are feeding into the LNAPL mobility assessment. Specific gravity data are used to calculate corrected groundwater elevations in wells with LNAPL.

LNAPL samples were collected from a total of four wells from three areas of NPR on December 3 and 6, 2010. In accordance with the SCWP, samples of LNAPL were collected from:

- Well MW-138 in the CU #2 area;
- S-21 near containment area CA5A;
- S-33 near CA6; and
- S-51 near the former truck-loading rack.

Additional LNAPL samples were collected from five wells in order to further characterize LNAPL as follows:

- R-33 and MW-115 near CU #1 and #2;
- R-32 and S-22 near containment areas CA5A and CA5B; and
- S-39 near CA4.

The well locations are shown on Figure 16.

Prior to sampling, the depth of LNAPL in the well was gauged using an oil-water interface probe. Samples were then collected using a peristaltic pump. Only the amount of tubing needed to skim the LNAPL from the groundwater surface was deployed in order to avoid capturing groundwater. Samples were collected into the appropriate laboratory-provided sampling containers and submitted to SGS for determination of:

- Specific gravity by ASTM International (ASTM) Method D-1298;

- Sulfolane content by USEPA Method 1625B; and
- VOC content by USEPA Method 8260B.

The samples were also analyzed by Alaska Methods AK102/103 (equivalent to USEPA Method 8015B), to obtain a hydrocarbon "fingerprint," as proposed in Section 6.6.3.1 of the SCWP.

The SCWP indicates USEPA Method 8270D would be used to analyze sulfolane; however, since the completion of the December 2010 LNAPL sampling, the laboratory, in consultation with Environmental Standards, Inc. (ESI), developed an additional standard operating procedure (SOP) that outlines the method for analyzing sulfolane in LNAPL. Therefore, USEPA Method 1625B was used to complete subsequent sulfolane analyses. On April 18, 2011, sampling was repeated at MW-138, S-51, and R32, and analyses were completed in accordance with the additional SOP.

The specific gravity method is also different than the method stated in the SCWP; Method ASTM D-1298 was used to analyze the specific gravity of LNAPL due to the method available at the SGS reference laboratory, Wyoming Analytical of Golden, Colorado.

The LNAPL samples were also submitted for analysis of color by ASTM D-1500 and viscosity by ASTM D-445 in order to further characterize the LNAPL constituents. Results of these analyses are discussed in Section 3.7.2. Laboratory reports are provided in Appendix N.

2.5.6 LNAPL Mobility Assessment

2.5.6.1 LNAPL Fluid Sample Collection

LNAPL and groundwater samples were collected and analyzed to provide site-specific fluid physical properties for incorporation into the LNAPL assessment of mobility and recoverability. Multiple LNAPL samples were collected from the site monitoring wells to determine the density, viscosity and interfacial tensions (air/water, air/LNAPL, and water/LNAPL) of the LNAPLs present to supplement the sampling described in Section 2.5.5.

From September 30 to October 7, 2011, LNAPL and groundwater samples were collected from nine wells at the site including MW-138, O-13, R-21, R-40, S-20, S-22, S-50, S-51 and S-52. LNAPL that accumulates in wells is subject to losses related to constituent volatilization that may affect the fluid properties of the LNAPL. Therefore, LNAPL present in the well at the time of sampling was purged to ensure that the sample was representative of LNAPL in the formation. Each sample consisted of approximately 0.5 liter of LNAPL and 0.5 liter of groundwater. Samples were collected by bailer or peristaltic pump and LNAPL and groundwater were placed into separate containers prior to being shipped to Core Laboratories for analysis. The fluid physical properties testing program is described in detail in Section 2.5.6.6.1.

2.5.6.2 Changes to the Proposed LNAPL Core Collection Field Methods

Changes to the LNAPL fluid sampling program were instituted due to the lack of sufficient volume of LNAPL to support laboratory analysis in several of the proposed wells. LNAPL was not collected from MW-115, O-2, S-21, and S-33 due to insufficient LNAPL volume at the time of sampling. Additional samples were collected from wells R-21 and R-40 as substitutes for wells O-2 and S-33. Also, O-13 was added to the sampling plan after installation.

2.5.6.3 LNAPL Soil Core Collection Field Methods

The objective of LNAPL soil core collection is to obtain samples that are representative of the in-situ conditions that affect LNAPL mobility. LNAPL soil core sample collection locations were selected to target the most impacted areas within the LNAPL footprint, based on LNAPL accumulation in wells and supporting data from previous investigations. Samples were collected near the groundwater table, where the LNAPL saturation is typically the highest, and across the full smear zone. The LNAPL soil cores were collected using undisturbed soil sampling techniques to retain the in-situ soil pore structure and fluids to facilitate representative laboratory evaluation of soil capillarity and petrophysical properties.

LNAPL soil coring was conducted between September 28 and October 6, 2011. Eight locations were selected for soil core collection. Soil borings were advanced via hollow stem auger drill rig and logged to determine the extent of the smear zone at each location prior to soil core collection. The smear zone extent was determined by reviewing the boring logs for elevated PID readings and observations of petroleum odor and staining.

A hollow-stem auger rig with a 2-foot-long and three-inch diameter split spoon sampler outfitted with Lexan™ liners was used to collect the undisturbed LNAPL soil cores. The 2-foot cores were packed vertically and frozen using dry ice and shipped with fresh dry ice to Core Laboratories for soil core photography and petrophysical analyses.

The LNAPL soil core locations and the associated soil borings are shown on Figure 6 and are paired as follows:

Soil Boring	LNAPL Core
SB-109	ASB-01
SB-180	ASB-02
SB-130	ASB-03
SB-165	ASB-04
SB-134	ASB-05
SB-115	ASB-06
SB-123	ASB-07
SB-117	ASB-08

Undisturbed LNAPL soil cores were generally collected from to 5 to 13 feet BGS in 2-foot intervals. This interval was sufficient to capture the LNAPL impacted (smear) zone based on the review of the associated boring logs. The soil petrophysical testing program is described in detail in Section 2.5.6.6.2.

2.5.6.4 Changes to the LNAPL Soil Core Collection Field Methods

Several minor changes were made to the scope of work proposed in the SCWP Addendum (ARCADIS, 2011b). These changes did not affect the quality of the data collected. The changes incorporated include:

- The soil cores were originally proposed for advancement using a direct-push drill rig. The direct-push drill rigs available were not large enough to push the core liners into the soil without excessive disturbance of the soil pore space. A hollow-stem auger rig with a larger hammer (requiring fewer strikes to advance the soil core) was subsequently used to advance the borings.

- Prior to initiating work, a health and safety policy of hand clearing the borings to 5 feet BGS was established to prevent striking subsurface improvements. The undisturbed soil core interval changed from 4 to 12 feet BGS, as proposed in the SCWP Addendum, to 5 to 13 feet BGS due to this policy. This interval adjustment fully captured the LNAPL smear zone at each boring location based on the review of the associated boring logs. Soil borings ASB-01 and ASB-08 were advanced to 12 and 11 feet BGS, respectively.

- The soil cores were originally proposed to be collected in acetate liners. However, Lexan™ liners were used instead because acetate liners were not available locally.

2.5.6.5 Natural Source Zone Depletion Sampling

Natural Source Zone Depletion (NSZD) refers to processes that naturally reduce LNAPL mass in the subsurface through time. Groundwater samples were collected at wells MW-105, MW-105A, MW-

109, MW-116, MW-176A, MW-176B, MW-180A and MW-180B as proposed in the SCWP Addendum for laboratory analysis of biogeochemical parameters. The samples were submitted to SGS Laboratories of Anchorage, Alaska for analysis. The results are presented in Section 3.7.4.

An evaluation of LNAPL depletion rate by NSZD processes was completed following the protocols outlined in the *Technology Overview for Evaluating Natural Source Zone Depletion at Sites with LNAPL* (Interstate Technology & Regulatory Council [ITRC] 2009b). The complete methodology and evaluation are described in detail in Appendix O.

2.5.6.6 Laboratory Testing

This section describes data collected from site activities to support the LNAPL assessment including LNAPL mobility, NSZD, and LNAPL recoverability assessments.

2.5.6.6.1 LNAPL Physical Properties

LNAPL samples were collected from nine monitoring wells in September and October 2011 and sent to Core Laboratories of Bakersfield, California for analysis of density, viscosity, and three interfacial tension pairs. A brief description of each test and the pertinent information generated from the tests follow.

- LNAPL Density – ASTM D1481: This test provides basic information on the density of the LNAPL which is compared to that of water and used when modeling the distribution and mobility of the LNAPL.

- LNAPL Viscosity – ASTM D445: This test assesses fluid viscosity at a controlled temperature representative of groundwater temperature. LNAPL is typically more viscous than groundwater and LNAPL viscosity is used to translate hydraulic conductivity to LNAPL conductivity.

- Interfacial Tension – ASTM D971: Interfacial tension between air-water, air-LNAPL and water-LNAPL fluids is assessed with this test. This information is used as input for the LNAPL modeling to determine the distribution and mobility of the LNAPL in the subsurface.

All fluid properties tests were performed at 1 °C, which is representative of the average annual groundwater temperature at the site. Results from laboratory testing are summarized in Appendix O.

2.5.6.6.2 Soil Petrophysical Properties

The process for determining laboratory analysis of undisturbed soil cores is iterative. First, the petrophysical laboratory photographs the frozen cores using natural and ultraviolet light. The natural light photographs show the soil structure. The ultraviolet photographs show LNAPL distribution in the soil cores because polyaromatic compounds in hydrocarbon products fluoresce within the visible light spectrum when exposed to ultraviolet light. Brighter fluorescence generally indicates higher LNAPL saturation zones. ARCADIS reviewed the core photographs along-side the associated soil boring logs and used these data to select core segments for testing based on the soil structure observations and visual degree of LNAPL impact. Petrophysical tests were designated to the most LNAPL-impacted portions of the cores. Summary descriptions of the petrophysical tests performed follow.

- Free Product Mobility – Water Drive Method (FPM-WD), proprietary method by Core Laboratories and API RP40 – This method forces water though the subsample to displace free LNAPL. This test provides porosity, field LNAPL saturation, and residual LNAPL saturation under saturated conditions, which is expected to be greater than residual saturation under unsaturated conditions. The test is conducted at hydraulic gradients that far exceed typical site conditions; hence, values for residual LNAPL saturation measured using this method will be conservative as compared to field residual saturation.

- Free Product Mobility – Centrifuge Method (FPM-C), Methods API RP 40 and ASTM D425M, Dean-Stark centrifugal method – This method utilizes centrifugal force to displace free LNAPL and water in a subsample of the soil core with air, which provides the minimum residual saturation that could be expected in the subsurface under unsaturated conditions. This test additionally provides several LNAPL mobility modeling input parameters including irreducible water saturation, initial LNAPL saturation, and porosity. The subsample used for this test is collected from the portion of the core that has the highest LNAPL saturation per visual inspection of the core photographs.

- Air-Water Capillary Pressure Drainage (AWCD), Method ASTM D6836, centrifugal method – This method generates a Soil Water Characteristic Curve by measuring the amount of water extracted from a water saturated sample under increasing amounts of negative pressure. The results of this test provide the necessary data to calculate the capillarity curve van Genuchten fitting parameters. The subsample used for this test is the same sample from FPM-C or FPM-WD.

- Laser Particle Size Analysis (LPSA), Method ASTM D422 – This test provides a standard grain size distribution of the LNAPL impacted soil. It is intended to better understand the geology of the site and to determine how results of the above mentioned tests will translate to other portions of the site. This subsample is tested from soil of other tests, specifically FPM-C or FPM-WD for this project as noted for AWCD.

Soil samples were used from FPM-C and FPM-WD for AWCD and LPSA testing. Soil samples were inspected prior to AWCD testing to ensure the integrity and pore structure of the plug was not compromised. AWCD and LPSA tests were completed on soil samples where field saturations exceeded residual saturations or on the FPM-C sample if residual saturation was not exceeded. Results from laboratory testing are summarized in Appendix O.

2.5.7 LNAPL Forensic Evaluation

FHRA completed a forensic evaluation to determine the nature of NAPL in several monitoring wells at the site. In addition, the evaluation was completed to identify the relative age of the NAPLs present and to determine if mixing has occurred between different product types, if possible.

2.5.7.1 Materials and Methods

Fifteen samples were obtained for chemical analysis to support this evaluation. Ten samples were obtained from monitoring or recovery wells on site (NAPL samples). Five additional samples of refined product were provided by the NPR laboratory staff (product samples). The product samples include an 87-octane regular unleaded gasoline (gasoline-R), premium unleaded gasoline (gasoline-P), petroleum naphtha (naphtha), Jet A (also identified as a No. 1 diesel fuel or kerosene, but identified in this report as Jet A), and No. 2 diesel fuel (diesel).

Samples were analyzed by Friedman & Bruya, Inc., a forensic laboratory located in Seattle, Washington. All samples were analyzed for C8-C24 hydrocarbons by gas chromatography with a flame ionization detector (GC/FID) to produce chromatograms for “fingerprint” comparison purposes. Note that these chromatograms cover DRO, but do not include the lighter C4 to C8 compounds that are more typical of GRO hydrocarbons. PIANO analysis was also conducted on all samples using gas chromatography with mass spectrometry (GC/MS). PIANO analysis is a detailed evaluation of 149 compounds in the C3 to C15 range. Compounds include paraffins (normal alkanes [e.g., hexane, octane]), isoparaffins (branched or isoalkanes [e.g., isooctane]), aromatics (e.g., benzene, toluene), naphthenes (cyclo-alkanes [e.g., cyclohexane]) and olefins (alkenes [e.g., 1-

pentene]). In addition to these petroleum hydrocarbons, the PIANO analysis included 11 oxygenated compounds such as ethanol and methyl tert-butyl ether (MTBE).

Graphic and visual evaluation was the primary means of interpreting the fingerprint and PIANO data. Two types of graphic information were evaluated: GC/flame ionization detector (FID) fingerprints and carbon number PIANO profiles. Fingerprint evaluation is the most basic form of interpreting NAPL and product results. NAPL fingerprints were visually compared against product fingerprints to provide a “first-cut” classification of samples for compounds in the C8 to C24 range. A normal alkane standard was provided by the laboratory to help identify the general carbon range of product and NAPL samples. PIANO profiles were calculated for each sample for C3 to C15 petroleum hydrocarbon classes. These profiles allow for interpretation of the distribution of different PIANO classes within each carbon range.

A multivariate correlation analysis was completed for all samples as a crude means of statistically comparing the samples. Ratio analysis was completed for paraffins vs. isoparaffins (P:I Ratio) and aromatics vs. naphthenes (A:N Ratio) for each carbon range where data was available from the PIANO analysis. These ratios can be used to interpret the effect of age or relative weathering in many forensic analyses (Kaplan et al. 1997; Morrison 2000; Zorzetti et al. 2011). A multivariate least-squares regression analysis was completed to estimate the relative proportion of primary refined petroleum fuels present in the NAPL samples (i.e., comingled plumes from different sources). Initial calculations included all three source fuel mixtures; however, only two sources were included if coefficients were determined to not be statistically significant at the $\alpha=0.05$ confidence level and the regression was recalculated with fewer parameters. Given the uncertainties associated with age and weathering of the NAPL samples, the mixing evaluation is qualitative rather than a well-defined quantitative estimate.

2.5.8 LNAPL Recovery from Remediation Systems

In accordance with the IRAP, during 2011 FHRA installed and operated LNAPL recovery systems at R-20R, R-32, R-33, R-35R, R-40, S-50, and O-2 (shown on Figure 17). A dedicated product recovery pump was previously installed in R-21; however, following installation of the new inner well screen (as described in Section 2.3.1.8.3), the product recovery pump was no longer able to fit in R-21. Upon the onset of winter conditions in November, the product recovery system in S-50 (which was planned for seasonal operation) was moved to R-21. The systems currently operating in R-21, R-35R, and R-40 are considered dual-phase recovery systems as they also allow for groundwater recovery.

In addition to the LNAPL recovery systems installed as part of the IRAP, FHRA continues to operate a LNAPL recovery system at MW-138 and performs manual product recovery at R-39 with a hand-held portable product recovery pump. Seasonal operation due to well freezing is planned for the LNAPL recovery systems at S-50 (as previously noted), O-2, R-32, and R-33.

In periods when the flow of LNAPL into the recovery well exceeds the removal by the LNAPL recovery system, FHRA has experienced capture by the groundwater recovery system which is removed by a coalescer prior to the air strippers. During periods of excessive LNAPL recovery, FHRA has observed an increase in dissolved-phase concentrations in the air stripper effluent (as further discussed in Section 5.1). As a result, FHRA has temporarily reduced the groundwater recovery rate at R-21, R-39, and R-40 to reduce the volume of LNAPL recovery by the groundwater recover pumps and is developing methods to increase LNAPL recovery by the intended LNAPL pumps and thus allow higher groundwater recovery rates. The methods developed include installation of a stilling well within the recovery wells to allow unencumbered operation of the skimmer pump floating intake device. Additionally, FHRA has installed different floats with increased buoyancy on the skimmer pump intake as the original floats were positioning the product intake too close to the water interface, which resulted in excess water capture.

The recovered LNAPL from all of these systems is accumulated in product storage tanks and periodically recycled within a refinery process unit. A summary of the LNAPL recovery results is provided in Section 5.1.

Upon installation of additional LNAPL observation wells, LNAPL was found to be present in wells O-7, O-9, O-10, O-11, O-13, and O-19, as described in Section 3.9. Based on the location of O-11 and O-13, FHRA is performing manual recovery at these wells (as temperature conditions allow) and monitoring LNAPL recovery (see Section 2.5.3.4 for bail down testing results). Manual product recovery is being completed with a portable product recovery pump, vacuum truck, and absorbent materials.

2.5.9 DNAPL Assessment

As stated in the SCWP, a 150-gallon release of sulfolane occurred in July 2002 at Tank 194 near CU #1 (Figure 3). Pure sulfolane is denser than water, with a specific gravity of 1.261, raising concerns regarding the potential for the formation of a dense nonaqueous phase liquid (DNAPL). According to a website maintained by the United States Geological Survey (USGS) Toxic Substances Hydrology Program (http://toxics.usgs.gov/definitions/dnapl_def.html), a DNAPL is defined as a liquid denser than water that does not dissolve or mix easily in water (i.e., it is immiscible). Given that sulfolane is miscible with water, a persistent DNAPL layer is not expected to be present. To determine the need for additional investigation regarding potential DNAPL, the SCWP proposed evaluating trends in dissolved-phase sulfolane data from existing and new monitoring wells.

As described in Section 2.3.1, eleven deep monitoring wells (i.e., screen depths greater than 45 feet BWT) were installed in 2010 in an area that is downgradient from the CUs and sulfolane storage Tank 194. These wells were the closet sub-water table monitoring locations available at that time, and included:

- Wells MW-174A, MW-176B, MW-178B, MW-179B, and MW-180B; installed to depths of approximately 37 to 40 feet BWT; and
- Wells MW-174B, MW-175, MW-176C, MW-178C, MW-179C, and MW-180C; installed to depths of approximately 76 to 80 feet BWT.

Well locations are shown on Figure 18. The wells were installed and constructed as described in Section 2.3.1. Exact construction details for these wells are presented in Table 3. Groundwater samples collected from these wells provide information regarding groundwater quality and the possible presence of a DNAPL sulfolane layer. Soils sampled from the deep borings were classified as described in Section 2.3.1 to characterize geology and determine if low-permeability layers may be present, since potential DNAPL would accumulate on these layers.

Another five existing deep monitoring wells are located downgradient from those listed above, and samples from these wells provide additional information about the vertical distribution of sulfolane downgradient of a potential DNAPL layer. These five wells include:

- MW-101, installed to a depth of approximately 48 feet BWT;
- Wells MW-102 and MW-154A, installed to depths of approximately 52 and 62 feet BWT, respectively; and
- Wells MW-144B and MW154B installed to depths of approximately 77 and 88 feet BWT, respectively.

These wells' locations are also shown on Figure 18, and their construction details are provided in Table 3.

Groundwater samples were collected from these sixteen wells during 2010 and/or 2011, and analyzed to determine sulfolane concentrations and to determine if an additional investigation regarding potential DNAPL is necessary. Results are discussed in Section 3.7.6. Laboratory analytical reports are in Appendix L.

2.6 Characterize Groundwater Impacts

Characterization of the dissolved-phase plumes is being completed by collecting and analyzing groundwater sampling from existing and new monitoring wells. Depending on the well location, groundwater samples are analyzed for BTEX, sulfolane, and/or natural attenuation parameters.

Evaluation of the resulting data for trends and responses to groundwater elevation fluctuations has started and will be continued as more data are collected. Evaluation of data has also begun with respect to potential natural attenuation of sulfolane

Groundwater data are being used as a tool to monitor the effectiveness of the IRAP, and will continue to be used to monitoring future corrective actions.

The process to identify additional COPCs in groundwater was discussed in Section 2.2 and the results are presented in Section 3.2. Groundwater samples from a select group of wells were analyzed for some COPCs in the third quarter of 2011; the final list of COPCs was not developed until after the third quarter groundwater event was completed.

2.6.1 BTEX

BTEX analytes are used as the primary indicators of petroleum-related impacts to groundwater onsite.

2.6.1.1 Monitoring Network Revision

The SCWP proposed expanding the BTEX monitoring network to include the following monitoring and observation wells: S-19, S-20, S-23, S-41, and S-44 to provide additional onsite plume definition, and MW-153A and MW-153B to monitoring groundwater near the downgradient property boundary. The SCR proposed adding wells MW-176A, MW-179A, and MW-180A to the network.

During the summer of 2011, four wells in the BTEX network (S-19, S-20, S-23, and S-41) were observed to be damaged beyond repair. Therefore, the SCWP Addendum (ARCADIS, 2011b) proposed decommissioning the four wells and replacing them as follows:

Well	Status	Replacement	Status
S-19	decommissioned	MW-196	Installed October 2011
S-20	To be decommissioned	none	Not applicable
S-23	To be decommissioned	none	Not applicable
S-41	To be decommissioned	O-16	Installed October 2011

As shown above, S-19 has been decommissioned, while the other three have not due to the onset of winter conditions (see Table 5 for additional details). Well locations are shown on Figure 19. The remaining wells were to be decommissioned in 2012. Well decommissions completed in 2012 will be described in the SCRA-2012.

Additional new wells (O-17 and O-18) were installed immediately west of CA2 and CA3, as proposed in the SCWP Addendum (Figure 19). The wells were installed as described in Section 2.3.1 and in accordance with the SAP.

Two additional wells were added to the BTEX monitoring network following their installation during the summer and autumn of 2011. These were well MW-192A, which was installed in August at the south-westernmost corner of the NPR property, and well MW-196, installed in October at the center of the southern NPR property boundary to replace S-19. These wells are scheduled to be sampled annually. The wells were installed as described in Section 2.3.1 and in accordance with the SAP.

2.6.1.2 Sampling

As proposed in the SCWP, sampling and analyses of groundwater samples for BTEX and 1,2,4-TMB were conducted at a subset of onsite wells screened at or near the water table. Wells were scheduled for sampling on a semiannual (second and fourth quarter of the year) or annual (second quarter) basis. The BTEX and 1,2,4-TMB monitoring network, as proposed in the SCWP Addendum is shown on Figure 19. In an email dated August 4, 2011, ADEC approved discontinuation of additional sampling for 1,2,4-TMB, based on data that had been collected to date. 1,2,4-TMB analysis was inadvertently continued through fourth quarter 2011, but were to be discontinued in first quarter 2012.

2.6.1.2.1 Fourth Quarter 2010

During the fourth quarter of 2010, a transition began from the former monitoring plan (Table 5 of the SCWP) to the plan proposed in SCWP Table 9. Groundwater samples were collected from the onsite network generally according to the sampling schedule presented in SCWP Table 5. As a result, several wells listed in SCWP Table 9 were not sampled, including MW-116, MW-133, MW-148A, MW-148B, MW-149A, MW-149B, MW-153A, MW-153B, S-23, and S-41. Wells MW-115, S-20, and S-44 were not sampled due to the presence of LNAPL. The fourth quarter sampling was completed in October and November. Wells MW-106, MW-134, and MW-141 were not sampled during the fourth quarter, but were sampled in September 2010. Samples were collected in accordance with the SAP. Field sampling sheets are provided in Appendix P. Groundwater samples were submitted to SGS for BTEX analysis by USEPA Method 8260B. No analyses for 1,2,4-TMB were completed. Laboratory reports are included in Appendix L. The results are presented in Section 3.8.1.

2.6.1.2.2 First Quarter 2011

Although the revised monitoring plan proposed no sampling during the first quarter of 2011, samples were collected in February from wells MW-106, MW-109, MW-110, MW-111, MW-113, MW-124, MW-125, MW-126, MW-132, MW-133, MW-135, MW-139, MW-140, MW-141, MW-144A, and MW-145 due to a miscommunication. They were sampled again during the second quarter to maintain consistency with the SCWP schedule.

The first quarter 2011 groundwater sampling was conducted in accordance with the methods and procedures described in the SAP. Field sampling sheets are provided in Appendix P. Groundwater samples were submitted to SGS for BTEX and 1,2,4-TMB analysis by USEPA Method 8260B. Laboratory reports are included in Appendix L. The results are discussed in Section 3.8.1.

2.6.1.2.3 Second Quarter 2011

Groundwater sampling was completed to the extent practical in the second quarter of 2011, according to the procedures summarized in the SAP. Twelve wells were not sampled because they were frozen (MW-110, MW-134, MW-135, MW-136, MW-179A, MW-180A, and S-19) or because of the presence of LNAPL (MW-115, MW-138, MW-1786A, S-20, and S-44). Laboratory reports are included in Appendix L. The results are discussed in Section 3.8.1.

2.6.1.2.4 Third Quarter 2011

Although BTEX and 1,2,4-TMB sampling is generally not planned for third quarter, groundwater samples from several wells were analyzed for BTEX and 1,2,4-TMB as part of the COPCs in groundwater evaluation described below in Section 2.6.3.

2.6.1.2.5 Fourth Quarter 2011

Groundwater sampling was completed in the fourth quarter of 2011, according to the procedures summarized in the SAP. Six wells were not sampled because of the presence of LNAPL (MW-115, MW-134, MW-136, MW-138, MW-1786A, and S-44). Laboratory reports are included in Appendix L. The results are discussed in Section 3.8.1.

2.6.2 Sulfolane

As proposed in the SCWP and SCWP Addendum, analyses of groundwater samples for sulfolane are conducted at monitoring wells completed at multiple depths within the suprapermafrost aquifer. Section 2.6.2.1 below discusses the well depth groupings established to monitoring discrete vertical zones in the aquifer. Expansion of the sulfolane monitoring network to address horizontal and vertical data needs is discussed in Section 2.6.2.2. Groundwater sampling is discussed in section 2.6.2.3, 2.6.2.4, and 2.6.2.5.

Wells are scheduled for sampling on quarterly, semiannual (second and fourth quarter of the year) or annual (second quarter) basis.

2.6.2.1 Well Depth Groupings

The SCWP divided the sulfolane monitoring network into vertical zones with respect to the water table as follows:

- water table wells,
- wells screened 10 to 55 feet BWT,
- wells screened 55 to 90 feet BWT, and
- wells screened 90 to 160 feet BWT.

Depths below the ground surface were not chosen for the reason that the ground surface is not flat. Although the study area has little relief, enough exists to make this approach unusable. Elevation with respect to mean sea level was not chosen due to the fact that the water table drops nearly twenty feet from the southeast to northwest across the study. For example, a well grouping in the 460-470 ft MSL range would be 25 to 30 feet BWT at the upgradient end of the plume, and screened across the water table near the downgradient end of the plume. Therefore, groupings were selected based on depth of the screen top BWT. Since the water table fluctuates, the screens are compared to the minimum water table level.

The water table group consists of wells screened across the water table. The water table wells group includes wells screened within ten feet of the water table to account for water table fluctuations. The deeper groupings were devised as the sulfolane plume delineation program progressed during 2009 and 2010 and several factors became evident:

- Sulfolane was present at depth (i.e., below the water table) in the aquifer,
- Stratigraphic confining layers were not present in the saturated zone, and
- Permafrost was present within the study area.

Since sulfolane was present at depth, FHRA began constructing well nests, consisting of a water table well and a deeper well installed at the top of permafrost. Since permafrost was often encountered within 40 to 60 feet of the ground surface, many of these deeper wells were constructed in this depth interval. As installation progressed, a "natural" grouping of wells emerged in areas where permafrost was relatively shallow. In addition, it appeared that many private wells were installed in this zone; therefore, it was desirable to obtain representative samples from a zone that was being used as a potable water supply.

As additional nests were installed, permafrost was encountered at deeper intervals and wells would be installed near the permafrost. Another natural grouping emerged as several deeper wells were installed near permafrost at depths of approximately 90 feet. Shallower "in-fill" wells would be installed adjacent to the deep well and also near the 50-foot depth interval and at the water table to create a well nest. The deepest grouping includes wells installed more than 90 feet BWT. To date, more than 250 onsite and offsite wells have been installed and the site conceptual model has been refined. If additional monitoring wells are required, well screen depths will be targeted based on the enhanced understanding of the transport of sulfolane.

2.6.2.2 Monitoring Network Expansion Sequence

As noted above, the sulfolane monitoring network has been expanded to fill data needs, using both new monitoring wells and existing wells that were previously not used for sulfolane monitoring. The new monitoring wells were installed in six phases as described above in Section 2.3.1.2. Wells installed during Phases 1 through 6 are shown on Figure 20 and construction details are shown in Table 3.

2.6.2.2.1 Phase 1

The primary goal during installation of the Phase 1 wells was to define the downgradient edge of the sulfolane plume. Phase 1 also included wells installed to define the edge of the plume at depth. The wells were installed moving northwest (downgradient) from NPR in a step-wise approach, with successive bands of monitoring wells installed following receipt of sulfolane results from previously installed wells. Final well locations were influenced by utility locations and access issues, both in the physical sense (e.g., could a well location be reasonably accessed by sampling technicians; did permafrost prevent the use of the location), and with consideration of property ownership (i.e., was the desired well location on public property).

Initial Phase 1 wells were constructed to delineate the plume at the water table. Deeper wells were installed adjacent to the water table wells to delineate the vertical extent of the plume. If permafrost was encountered, a well was usually set just above the permafrost.

The sequence of well installation was as follows:

- Water table wells MW-150A, MW-151A, and MW-152A, and deeper wells (10-55 ft BWT) MW-150B, MW-151B and MW-152B were installed along North Pole High School Boulevard, and MW-153A was installed near the northern property boundary from October 2 through 7, 2009.

- Water table wells MW-155A through MW-160A were installed in the Ford Subdivision between November 11 and 13, 2009, following the detection of sulfolane in groundwater samples collected from wells located along North Pole High School Boulevard.

- Water table wells MW-161A through MW-164A were installed along an east-west line approximately 2,000 to 5,000 feet downgradient of the Ford Subdivision between November 25 and December 10, 2009, following sulfolane detections at MW-155A, MW-156A, MW-157A, MW-158A, and MW-159A.

- Water table wells MW-165A through MW-168A were installed further downgradient, along an arc stretching from Richardson Highway to Badger Road from January 7 through January 18, 2010, following sulfolane detections at MW-161, MW-162A, MW-163A, and MW-164A.

- After sulfolane was reported in groundwater samples from wells MW-161A, MW-162A, MW-163, and MW-164, additional water table wells were installed to better define the edges of the plume from February 25 to March 24, 2010, including MW-169A, MW-170A, MW-171A, and MW-172A.

The wells were placed at locations suitable for creating nests of multiple wells at various depths, if determined necessary for vertical plume delineation. Deeper wells with depths ranging from 25 feet to 145 feet BWT were installed adjacent to the shallow wells (Figure 20) as follows:

- from February 17 to March 27, 2010, deeper wells MW-151C, MW-156B, MW-166B, MW-167B, MW-171B, and MW-172B (10 to 55 feet BWT); MW-160B (55 to 90 feet BWT); and MW-170B and MW-170C (90 to 160 feet BWT) were installed to further characterize the center and define the edges of the plume at depth.

- MW-154A and MW-154B (both 55 to 90 feet BWT), were installed at NPR near existing shallow well MW-139 on October 5, 2009, and February 20, 2010, respectively, to delineate the plume at depth onsite.

- A shallow and deep well were installed along the northeastern property boundary to monitor water quality between NPR and The City's water supply wells. MW-173A (water table) was installed on March 31, 2010 and MW-173B (90 to 160 feet BWT) was installed on March 30, 2010.

- Well MW-153B (10 to 55 feet BWT) was installed adjacent to MW-153A on April 20, 2010, to define the western edge of the plume at depth near the northern property boundary.

MW-153B was the last Phase 1 well installed prior to preparation of the SCWP. During evaluation of the data from the Phase 1 wells, data needs were identified with respect to the dissolved-phase sulfolane plume. Therefore, the SCWP proposed the installation of additional monitoring wells.

2.6.2.2.2 Phase 2

The additional wells proposed in the SCWP were installed during Phase 2, which occurred from September 9, to November 24, 2010. Seventeen onsite and 17 offsite sulfolane delineation wells were installed during Phase 2. The wells were installed at the general locations and depths proposed in the SCWP, as well as some additional locations. As was the case during Phase 1, wells were installed to address data needs in understanding of the plume at the water table, and deeper wells were installed to further define both the horizontal and vertical extent of the plume below the water table. The water table wells include wells MW-181A, MW-182A, MW-183A, MW-185A, MW-186A, and MW-187 (Figure 20). The deeper wells include MW-155B, MW-158B, MW-161B, MW-163B, MW-164B, MW-165B, MW-169B, MW-170D, MW-181B, MW-184, MW-185B, MW-186B and MW-188 (10 to 55 feet BWT); and MW-144B, MW-175 MW-177 and MW-186C (55 to 90 feet BWT) (Figure 20).

MW-188 was a well originally proposed in the SCWP to be southwest of MW-166A/B; however, due to access issues, the location was moved northwest. Multiple attempts were made to install the well on Benn Lane; however, permafrost was encountered at the ground surface and the borings were advanced 10 feet into the permafrost without finding the lower limit. Therefore, the location was moved further to the northwest and MW-188 was installed on Luckie's Lane November 24, 2010 (Figure 20).

MW-175 was originally proposed in the SCWP to be near existing well MW-130. Due to access issues, MW-175 was installed approximately 250 feet east of this location.

In addition to the wells proposed in the SCWP, FHRA installed three additional onsite well nests to better define the horizontal and vertical extent of the onsite plume downgradient of CUs #1 and #2 and Lagoon C. Wells installed include MW-178A/B/C, MW-179A/B/C, and MW-180A/B/C (Figure 20). The three A wells are screened across the water table. The three B wells (10 to 55 feet BWT) and three C wells (55 to 90 feet BWT) are deeper.

2.6.2.2.3 Phase 3

Phase 3 of the well-installation effort was designed to fill vertical and horizontal gaps in the well network installed during Phases 1 and 2 during 2010. Seventeen wells were installed both onsite and offsite, some to the top of permafrost, from August 12 through September 1, 2011. Wells installed to the top of permafrost at existing well nests included MW-164C, MW-169C, MW-179D, MW-182B, and MW-183B. Six additional well nests were also installed to fill horizontal gaps between previously installed wells. New well nests were installed adjacent to the Tanana River at MW-193A/B and MW-191A/B, and upgradient from NPR at MW-192A/B. New well nests were also installed at the apparent limits of the plume boundary at MW-190A/B, MW-189A/B, and MW-194A/B (Figure 20).

Included in Phase 3 were wells MW-189A, MW-190A, MW-191A, MW-192A, MW-193A, an MW-194A (water table); MW164C, MW-169C, MW-182B, MW-183B, MW189B, MW-190B, MW-191B, MW-192B, MW-193B, and MW-194B (10 to 55 feet BWT); and MW-179D (90 to 160 feet BWT) (Figure 20).

A deeper well in the 55 to 90 feet BWT zone was planned at the MW-161 well nest; however permafrost was encountered at a depth of 54 feet so no well was installed.

MW-164C was intended to be installed in the 55 to 90 feet BWT zone; however permafrost was encountered at a depth of 63 feet BGS, so the well was installed to a total depth of 62.4 feet (approximately 55 feet BWT).

MW-169C was intended to be installed in the 55 to 90 feet BWT zone; however permafrost was encountered at a depth of approximately 62 feet BWT. During installation, the well was inadvertently pulled up, and the installed depth was approximately 53 feet BWT (59.9 feet BGS).

2.6.2.2.4 Phase 4

Phase 4 of well-installation effort continued filling vertical gaps in the network, focusing on installing wells along the centerline and northwest edge of the sulfolane plume, and attempting to delineate permafrost in the area. Nine wells were installed at existing well locations both onsite and offsite from September 26 through October 12, 2011, with the goal of setting the bottom of the wells at the top of permafrost or 150 feet BGS (approximately 140 to 145 feet BWT), whichever was encountered first.

Wells MW-148C and MW-148D were installed at an existing well nest along the access road immediately north of NPR; MW-148C was installed to from 50 to 55 feet BGS (approximately 40 to 50 feet BWT) to provide information at that depth interval at that location, and well MW-148D was installed to 151 feet BGS (approximately 145 feet BWT) because its boring contacted permafrost at 151.5 feet BGS. Wells MW-152C, MW-159B/C, and MW-157B were installed along the apparent centerline of the plume at locations in the subdivision north of NPR. Permafrost was found at well MW-152C at 67.5 feet BGS (approximately 60 feet BWT), at MW-159C at about 72.5 feet BGS (approximately 65 feet BWT), and at MW-157B at 30.1 feet BGS (approximately 23 feet BWT) (Figure 20).

Well MW-181C was installed at well nest MW-181A/B at the northwest edge of the plume, and was set at 150 feet BGS (approximately 140 feet BWT) because permafrost was not encountered at that location. Wells MW-168B and MW-185C were installed south and southwest of MW-181C, respectively (Figure 20); the boring for MW-168B contacted permafrost at 52.5 feet BGS (approximately 41 feet BWT), and the boring for MW-185C encountered permafrost at 121 feet BGS (approximately 113 feet BWT).

Included in Phase 4 were wells MW148C, MW-152C, MW-157B, MW-159B, and MW-168B (10 to 55 feet BWT); MW-159C (55 to 90 feet BWT); and MW-148D, MW-181C, and MW-185C (90 to 160 feet BWT) (Figure 20).

MW-152C was intended to be installed in the 55 to 90 feet BWT zone: however permafrost was encountered at a depth of 67.4 feet BGS (approximately 58 feet BWT), so the well was installed with its screen set from 60.1 to 64.6 feet BGS (approximately 53 to 57.5 BWT).

2.6.2.2.5 Phase 5

Phase 5 entailed installing six well nests northwest of the truck-loading area on the refinery property, along a transect perpendicular to the long axis of the sulfolane plume. The purpose of these VPT wells is to assess the vertical distribution of sulfolane from the water table to permafrost or 150 feet BGS (approximately 140 to 145 feet BWT), whichever was encountered first. Each nest consisted of one continuous multichannel tubing (CMT) well installed to 50 or 60 feet BGS (40 to 45 or 50 to 55 feet BWT), with channels installed at 10-foot depth intervals; one well installed to the top of the permafrost layer (or 140 to 145 feet BWT), with a 5-foot screen set at the base; one well with a 5-foot screen installed to 10 feet below the bottom of the CMT well (about 40 to 55 feet BWT); and one well with a 5-foot screen installed to 20 feet below the bottom of the CMT well. Eighteen nested wells, plus six CMT wells were installed at the site from early October through early November 2011. Details regarding the VPT wells were described in Section 2.3.1.7.

2.6.2.2.6 Phase 6

Phase 6 involved installing wells on NPR property to identify the depth of permafrost at seven on-site locations. One well (MW-197B; Figure 20) was installed October 16, 2011. The remaining wells (MW-186D, MW-195B, MW-198, MW-199, MW-300, and MW-307; Figure 20) were installed between December 2 and December 10, 2011. None of these borings encountered clearly identifiable permafrost, but the boring for MW-186D did not penetrate deeper than approximately 137 feet BGS (129 feet BWT) because it encountered a very dense gravel layer that prevented the drill auger from turning; MW-186D was therefore installed to that depth. The other Phase 6 wells were installed to depths of about 150 feet BGS (140 to 145 feet BWT).

2.6.2.2.7 Addition of Existing Wells

As noted previously, the sulfolane monitoring network was expanded by using existing wells that were previously not used for sulfolane monitoring. The SCWP proposed adding existing wells S-19, S-38, S-39, S-40, S-51, and MW-105A to the water table sulfolane monitoring network (Figure 20). Wells S-19 and MW-105A were proposed to monitor groundwater upgradient (south) of the CUs. Wells S-38, S-39, S-40, and S-51 were added to monitor the effects of recovery wells R-35, R-40, R-39, and R-21, respectively.

The SCWP also noted that several existing onsite wells screened between 10 and 55 feet BWT are located downgradient of the tank farms and process areas. Wells in these areas include MW-101, MW-104, MW-127, MW-129, MW-147B, and MW-148B; therefore, these wells were added to the monitoring network. MW-105 was added as an upgradient monitoring location.

2.6.2.2.8 Other Revisions

During the summer of 2011, six wells in the sulfolane network (S-19, S-20, S-38, S-40, S-41, and MW-144B) were observed to be damaged beyond repair. Therefore, the SCWP Addendum (ARCADIS, 2011b) proposed decommissioning these wells and replacing them as follows:

Well	Status	Replacement	Status
S-19	decommissioned	MW-196	Installed October 2011
S-20	To be decommissioned	none	Not applicable
S-38	To be decommissioned	O-19	Installed October 2011
S-40	To be decommissioned	O-3	Installed Sept. 2010
S-41	To be decommissioned	O-16	Installed October 2011
MW-144B	decommissioned	MW-144Br	Installed October 2011

As shown above, S-19 and MW-144B have been decommissioned, while the other four have not due to the onset of winter conditions (see Table 5 for additional details). Well locations are shown on Figure 20.

2.6.2.3 Sampling

Monitoring well sampling for sulfolane was conducted in accordance with the SAP. Field sampling sheets are provided in Appendix P. Groundwater samples were submitted to SGS for sulfolane analysis by USEPA Method 8270D in accordance with the SAP. In an email dated May 17, 2011, ADEC approved an updated laboratory method for the analysis of sulfolane in groundwater. The new method, Modified Method 1625B with isotope dilution was used for groundwater sample analysis beginning in third quarter 2011. Laboratory reports are included in Appendix L. The results are discussed in Section 3.8.2.

2.6.2.3.1 Water Table Network

The water table wells from the sulfolane monitoring well network shown in on Figure 20. As was the case with the BTEX sampling network, the fourth quarter 2010 marked a transition from the former sulfolane monitoring plan (Table 5 of the SCWP) to the revised monitoring plan (Table 10 of the SCWP). Groundwater samples were collected generally according to the sampling schedule presented in Table 5 of the SCWP. Several of the proposed wells were not sampled, including MW-104, S-40 and S-41. Wells MW-115, MW-138, R-21, S-20, S-21, S-38, S-39 and S-51 were not sampled due to the presence of LNAPL. Wells MW-106, MW-129, and MW-134, and MW-141 were not sampled during the fourth quarter, but were sampled during the third quarter of 2010. Most of the fourth quarter 2010 sampling was completed in October or November. Due to cold weather restrictions, in accordance with the SAP, very few wells were sampled during December of 2010.

The SCWP's SAP includes a provision for not collecting samples during periods of extreme cold weather, defined as ambient temperatures or chill factors colder than -5°F.

During the first quarter of 2011, monitoring wells were sampled as weather permitted between early January and late March. During the first quarter, out of 49 work days available for sampling, 26 days were warm enough to sample. The first quarter groundwater sampling period was ended March 11th to afford enough time for the laboratory analyses to be returned and subjected to quality assurance review for inclusion in May SC Report. Most of the wells scheduled for quarterly sampling were successfully sampled during the first quarter of 2011. Wells S-38, MW-166A, and MW-179A could not be sampled because they were frozen. Wells S-39, S-40, S-51, and MW-176A were not sampled because LNAPL was present in the wells. Well MW-159 was inaccessible and could not be sampled because it was buried under a large snow berm. Well MW-160A was destroyed by a road grader in the summer of 2010. At the February 2011 TPT Meeting, ADEC agreed that replacement of MW-160A was not necessary. Well MW-182 was not sampled because the monument was filled with frozen soil. Despite being scheduled for semiannual sampling, wells MW-106, MW-109, MW-110, MW-111, MW-113, MW-130, MW-132, MW-144A and MW-145 were sampled during the first quarter due to a miscommunication.

Most of the second quarter 2011 groundwater sampling for sulfolane was completed in April, with a few samples collected in May and June of 2011. Most of the wells scheduled for sampling in the second quarter were successfully sampled with the following exceptions:

- Water table wells S-19, S-38, MW-134, MW-150A, MW-152A, MW-156A, MW-158A, MW-162A, MW-165A, MW-166A, MW-168A, MW-178A, MW-179A, MW-180A, MW-183, and MW-185A were frozen and could not be sampled;
- LNAPL was present in wells S-20, S-21, S-39, S-40, S-51, MW-115, MW-138, and MW-176A, and the wells were not sampled; and
- Wells MW-182 was damaged and could not be sampled.

Most of the third quarter 2011 groundwater sampling for sulfolane was completed in August, with a few samples collected in July and September of 2011. Most of the wells scheduled for sampling in the third quarter were successfully sampled with the following exceptions:

- Wells MW-166A, MW-168A, and MW-188 were frozen and could not be sampled.

- LNAPL was present in wells S-38, S-39, S-40, S-51, MW-176A, and MW-186A, and the wells were not sampled.

Most of the fourth quarter 2011 groundwater sampling for sulfolane was completed in October, with a few samples collected in November of 2011. Most of the wells scheduled for sampling in the fourth quarter were successfully sampled with the following exceptions:

- LNAPL was present in wells R-21, S-21, S-39, S-44, S-51, MW-115, MW-134, MW-136, MW-138, MW-176A, and MW-186A and the wells were not sampled;
- Wells S-38, S-40, S-20, S-19, and MW-160A are damaged and could not be sampled.

S-19 has been decommissioned. S-38, S-40, S-20, and MW-160A were to be decommissioned in 2012 as described in Section 2.3.1.8 when conditions allow. Well decommissions completed in 2012 will be described in the SCRA-2012.

2.6.2.3.2 10 to 55 Feet BWT Zone

All of the wells in this monitoring zone that are sampled for sulfolane are shown on Figure 20. The results are discussed in Section 3.8.2.

During the fourth quarter of 2010, all intermediate-depth wells scheduled for quarterly sampling were sampled during October or November. New wells were sampled during October and November, but very few were sampled during December due to cold weather, in accordance with the SAP.

During the first quarter of 2011, most of the wells in this monitoring zone that are scheduled for quarterly sampling were successfully sampled. Wells MW-151C, MW-153A, MW-166B, and MW-179B could not be sampled because they were frozen. Wells MW-152A and MW-152B were inaccessible and could not be sampled because they were buried under large snow berms. Despite being scheduled for semiannual sampling, wells MW-104 and MW-129 were sampled during the first quarter due to a miscommunication.

Most of the second quarter groundwater sampling for sulfolane was completed in April, with a few samples collected in May and June of 2011. Most of the wells scheduled for sampling in the second quarter were successfully sampled with the following exceptions:

- Wells MW-151C, MW-152B, MW-156B, MW-162B, MW-166B, MW-176B, MW-178B, MW-179B, MW-180B, MW-185B, and MW-188 were frozen and could not be sampled.

- Well MW-169B was in disrepair and could not be sampled.

Most of the third quarter 2011 groundwater sampling for sulfolane was completed in August, with a few samples collected in July and September of 2011. Most of the wells scheduled for sampling in the third quarter were successfully sampled with the following exceptions:

- Well MW-166B was frozen and could not be sampled.
- A visible sheen was observed in monitoring well MW-176B, which is likely due to LNAPL entering the screen as it was lowered into place during well installation activities. The well was to be cleaned and redeveloped prior to the first quarter 2012 sampling event.
- Well MW-169B was in disrepair and could not be sampled.

Most of the fourth quarter 2011 groundwater sampling for sulfolane was completed in October, with a few samples collected in November of 2011. Most of the wells scheduled for sampling in the fourth quarter were successfully sampled with the following exceptions:

- A visible sheen was observed in monitoring well MW-176B, which is likely due to LNAPL entering the screen as it was lowered into place during well installation activities. Prior to the fourth quarter 2012 sampling event, the well was inspected and no sheen was observed. The interior wall of the well riser pipe was then swabbed with absorbent material. Sampling was completed in the fourth quarter and the well will continue to be monitored for LNAPL. Results of the cleaning and subsequent sampling will be reported in the *Fourth Quarter 2012 Groundwater Monitoring Report*.
- Wells MW-169B, and S-41 were damaged and could not be sampled.

MW-169B and S-41 were to be decommissioned in 2012 as described in Section 2.3.1.8, as the weather allows. Since MW-169C is screened in the same monitoring zone, MW-169B will not be replaced. Well decommissions completed in 2012 will be described in the SCRA-2012.

2.6.2.3.3 55 to 90 Feet BWT

The wells in this monitoring zone that are sampled for sulfolane are shown on Figure 20. The results are discussed in Section 3.8.2.

New wells were sampled during October and November 2010, but very few were sampled during December due to cold weather, in accordance with the SAP.

Most of these wells were sampled between early January and late March 2011, during the first quarter of 2011. Wells MW-176C, MW-177, MW-178C, and MW-179C could not be sampled during the first quarter of 2011 because they were frozen. MW-154B and MW-160B were not sampled due to time constraints imposed by cold weather and the end of the first quarter of 2011.

Most of the second quarter 2011 groundwater sampling for sulfolane was completed in April, with a few samples collected in May and June of 2011. Most of the wells in this monitoring zone scheduled for sampling in the second quarter were successfully sampled with the following exceptions: wells MW-176C, MW-177, MW-178C, and MW-179C were frozen and could not be sampled.

Most of the third quarter 2011 groundwater sampling for sulfolane was completed in August, with a few samples collected in July and September of 2011. All of the wells in this monitoring zone were successfully sampled in the third quarter.

Most of the fourth quarter 2011 groundwater sampling for sulfolane was completed in October, with a few samples collected in November of 2011. All of the wells in this monitoring zone were successfully sampled in the fourth quarter.

2.6.2.3.4 90 to 160 Feet BWT

The wells in this monitoring zone that are sampled for sulfolane are shown on Figure 20. The results are discussed in Section 3.8.2. The three wells were sampled during the first quarter of 2011, between early January and late March 2011. Second quarter samples were collected in April, third quarter samples were collected in August and September, and fourth quarter samples were collected in October.

All of the wells in this monitoring zone were successfully sampled in the second, third, and fourth quarters of 2011.

2.6.2.4 Vertical Profiling Transect and Mass Flux

At ADEC’s request, a transect of VPT wells was installed approximately perpendicular to the groundwater flow direction and center line of the plume as shown on Figure 8. Initial groundwater sampling at the VPT wells occurred in the fourth quarter of 2011 and the results are discussed in Section 3.8.2.

2.6.2.4.1 Hydraulic Conductivity Distribution at the VPT

Hydraulic conductivity is an input parameter for the calculation of mass flux and mass discharge. Thus, an interpretation of the spatial distribution of hydraulic conductivity at the VPT transect was developed based on the lithologic descriptions presented in boring logs from monitoring wells along the transect, as well as the results of single well pumping tests (SWPT) conducted at monitoring wells within 480 feet of the VPT transect (MW-101, MW-101A, MW-143, MW-139, MW-154A, MW-154B, MW-127, MW-131, MW-102). SWPT methods and results are presented in sections 2.3.4.4 and 3.5.1.2, and summarized in Table 12. A lithologic cross section (Figure 21) was developed from data presented in boring logs from SWPT monitoring wells and VPT monitoring wells MW-301 through MW-306 (Appendix D).

For purposes of this evaluation, each lithologic description observed in monitoring wells along the transect was categorized into one of four soil "zones" as follows:

1. Zone A – gravel and sandy gravel with minor or trace silt
2. Zone B – gravelly sand
3. Zone C – fine-grained sand
4. Zone D – silt and silty fine-grained sand

A constant hydraulic conductivity value was assigned to each of these zone designations. While there is likely variability in hydraulic conductivity within each zone designation, the limited resolution in lithologic descriptions presented in boring logs does not allow for a more detailed interpretation of this variability.

Estimates of the hydraulic conductivity for the four defined lithologic zones were derived by the following process:

1. Hydraulic conductivity of different soil types was measured in the field at nine monitoring wells within 480 feet of the VPT (MW-101, MW-101A, MW-143, MW-139, MW-154A, MW-154B, MW-127, MW-131, MW-102), screened in multiple soil types and depth horizons within the suprapermafrost zone using the SWPT method (section 2.3.4.4). The measured hydraulic conductivity values ranged between approximately 50 feet/day and 10,700 feet/day and averaged 311 feet/day (geometric mean). SWPT measurements for wells near the VPT transect are presented in Table 13.

2. A lithologic grid of different soil types was developed for the VPT cross section based on soil descriptions provided in geologic logs (Figure 21). Each grid cell was categorized as zone A, B, C or D based on the soil descriptions presented above. Each grid cell was assigned a top and bottom elevation based on the geologic logs (Table 13).

3. Each grid cell was assigned a hydraulic conductivity value corresponding to the predominant soil type within the grid cell based on lithologic descriptions. All grid cells within the same lithologic zone (A, B, C, or D) were assigned the same hydraulic conductivity value for computational purposes. The hydraulic conductivity values for each zone were adjusted within reasonable published literature value ranges (section 3.5.1) until the average hydraulic conductivity for the entire grid was consistent with the average measured hydraulic conductivity value (geometric mean) (Table 13).

4. The final hydraulic conductivity value used for computational purposes are listed in Table 13 and are as follows:

    - Zone A – gravel and sandy gravel with minor or trace silt; Estimated K = 700 feet/day

    - Zone B – gravelly sand; Estimated K = 300 feet/day

    - Zone C – fine-grained sand; Estimated K = 75 feet/day

    - Zone D – silt and silty fine-grained sand; Estimated K = 10 feet/day

2.6.2.4.2 Mass Flux and Mass Discharge Estimates

Mass flux and mass discharge measure the strength of a source or plume at a given time and location. Mass flux is a per-area rate measurement, with units of mass per unit time per unit area (e.g., grams per day per square foot [g/day/ft^2]). Mass discharge is an integrated mass flux term, over an area such as a plume cross-sectional transect, in units of mass per time (e.g., grams per day [g/day])Newell et al. 2011, ITRC 2010).

Mass flux and mass discharge can be used for the following applications:

- Further develop the site conceptual model,

- Develop remedial selection and design,

- Evaluate effectiveness of the groundwater extraction system, and
- Evaluate effectiveness of natural attenuation processes.

The transect method was selected to calculate mass flux and mass discharge for the approximate vertical plane defined by the VPT well clusters MW-301 through MW-306. This method is commonly used with direct measurements and is standard industry practice (Farhat et al. 2006).

Specifically, mass discharge at the VPT was estimated by:

1. Defining a vertical plane perpendicular to groundwater flow,
2. Discretizing that plane into a mass flux grid based on an interpreted hydraulic conductivity distribution (section 2.6.2.4.1) and on established sampling intervals,
3. Estimating mass flux through each grid cell,
4. Summing mass flux estimates for each cell to derive an estimate of the total or integrated mass flux (mass discharge) through the defined cross-sectional area of the plume.

2.6.2.4.3 Methods

Six VPT well clusters (MW-301 through MW-306), located approximately 1,900 feet from the potential source area and approximately 700 feet from the groundwater extraction system, were installed to establish a vertical sampling plane through the sulfolane-impacted suprapermafrost groundwater plume.

FHRA used the Mass Flux Toolkit (Toolkit) developed by GSI Environmental for the Department of Defense Environmental Security Technology Certification Program (Farhat et al. 2006) to calculate the mass discharge (grams/day) across the transect defined by the VPT well clusters (Figures 8 and 21).

The total mass flux value was calculated across the transect using the following calculation (Farhat et al. 2006):

$$\omega = \sum_{i=1}^{i=n} C_i q_i A_i$$

where:

ω= Mass discharge - integrated mass flux across the transect (g/day)

C_i = Sulfolane concentration at mass flux grid cell i (g/L)
q_i = Specific discharge (Darcy velocity) through mass flux grid cell i (feet per day [ft/day])
A_i = Area of mass flux grid cell i (square feet)

The specific discharge (q_i) can be calculated using:

$$q_i = K \times i$$

where:
K = hydraulic conductivity of mass flux grid cell i (ft/day)
i = hydraulic gradient (foot per foot [ft/ft])

The VPT plane was subdivided into a mass flux grid based on locations of the VPT well clusters, the interpreted hydraulic conductivity distribution (section 2.6.2.4.1), and sulfolane sampling intervals. The Toolkit mass flux grid is included as Appendix R, along with Toolkit input parameters and results. The following is a brief description of the boundaries of, and divisions within, this grid:

- The top of the mass flux grid was defined based on an average water table depth of 9 feet BGS.
- Mass flux grid cell boundaries were defined by the Toolkit based on the locations of VPT well clusters MW-301 through MW-306, with the column width defined by points at one-half of the distance between well clusters.
- At VPT wells MW-301 and MW-306 the distance to the northeastern and southwestern endpoints of the mass flux grid were set equal at one-half of the distance to adjacent monitoring wells MW-302 and MW-305, respectively.
- Grid cells were further subdivided based on sulfolane sampling intervals, i.e., if there were multiple intake intervals where sulfolane concentrations were measured in a single hydraulic conductivity zone, then a grid boundary was placed at one-half the distance between intake intervals.
- The base of the mass flux grid was defined for each individual column and corresponds with the bottom of the deepest screen interval at each well, or a confirmed depth to permafrost, as indicated in boring logs.

Due to the operational limitations of the Toolkit, some resolution of the hydraulic conductivity distribution was lost when inputting the distribution into the Toolkit. However, this loss of resolution likely caused only a small variation in the total flux calculated. An estimated hydraulic conductivity was assigned to each grid cell, based on the zone designation of the grid cell. The hydraulic gradient (I) was selected as the midpoint between the measured range 0.0007 to 0.0028 ft/ft across the site in each groundwater monitoring zone (I=0.001 ft/ft). This gradient estimate is consistent with historical observations and modeling results.

Sulfolane concentrations were assigned to each mass flux grid cell as follows:

- Sulfolane concentration data used in this calculation were collected in November 2011 at each sampling interval within the transect wells (section 3.8.2).
- Observations of sulfolane concentrations observed at intake intervals were applied across the entire grid cell in which they are contained.
- Sulfolane concentrations below the limit of quantitation (LOQ) were input as one-half the LOQ (e.g., <6.2 µg/L was input as 3.1 µg/L).
- If sulfolane was not sampled within a grid cell defined by the Toolkit, then the average of the concentrations in the grid cells above and below was applied.

Results of the mass flux calculation are presented in Section 3.8.2.7.

2.6.2.5 Private Wells

A door-to-door survey was conducted in search areas located downgradient of NPR in order to identify private water supply wells. Search areas 1 through 7b are shown on Figure 22. Offsite site characterization activities began in 2009. Since that time, permanent buildings within the search areas were visited and residents were surveyed to determine the presence of wells on the properties. If a well was identified, information regarding well construction details and water usage was requested. If a drinking-water well was present on a property, permission to collect a groundwater sample for sulfolane analysis was requested. The overall search area was expanded until water sample results were nondetect for sulfolane.

Following development of the sulfolane isotope dilution analytical method, FHRA resampled wells with nondetect sulfolane results within and near the sulfolane-impacted area. Based on the results of the resampling event, search areas 7a and 7b were added during the fourth quarter 2011 (Figure 22). In addition, during the fourth quarter 2011, FHRA attempted to contact homes within the search areas that were previously not sampled or unable to be contacted.

As of December 31, 2011, a total of 868 properties were visited within the search areas, and 592 wells found (some properties have multiple wells). Between November 11, 2009, and December 31, 2011, a total of 518 wells within the search areas were sampled. In addition, FHRA was contacted (by either a landowner or a real estate agent) with requests for testing wells located outside the search areas, resulting in the collection of an additional 109 private well samples during this time period. Sampling locations are shown on Figure 22.

Residential water samples were collected upstream of water-treatment systems where possible. In the event a pre-treatment sampling port was not available, water samples were obtained from a faucet at a sink. Prior to sampling, the water was allowed to run until temperature, pH and conductivity stabilized. Samples were collected directly into laboratory-provided sample containers. Samples were stored in an insulated cooler containing sufficient "gel ice" to maintain temperatures within the acceptable range (0 °C to 6 °C). Samples were then delivered to the SGS sample-receiving office in Fairbanks, Alaska. In cases where the sample-receiving office was closed, the samples were stored in a refrigerator at SWI and maintained within the acceptable temperature range.

Seventy-four properties were identified with wells from which samples were not collected for the following reasons:

- the wells were unused, dry or frozen (37 wells);
- the resident refused to participate in the sampling program (18 wells); and/or
- the well is used solely for summer activities, including irrigation (19 wells).

In addition, in some cases, wells solely used for irrigation were not sampled. Irrigation well sampling did not occur in 2012. Sampling will be considered as part of the offsite related activities anticipated to be performed in 2013.

The private well sampling results are discussed in Section 3.8.2. Copies of laboratory reports were provided to the well owner. Residential laboratory reports and the associated ADEC data review checklist are presented in Appendix L.

2.6.3 Contaminants of Potential Concern in Groundwater

Groundwater COPCs for the site were sampled during the third and fourth quarters of 2011). Selection of COPCs is discussed above in Section 2.2. The monitoring wells proposed for additional COPC analysis are presented on Figure 23 and include: MW-110, MW-113, MW-125, MW-127, MW-133, MW-135, MW-138, MW-141, MW-148A, MW-149A, MW-153A, MW-176A, and S-20.

In an email dated August 5, 2011, ADEC approved the proposed list of COPC wells and requested FHRA to include a water table well MW-139 downgradient of the rail-car loading rack, and two deeper wells MW-174B and MW-176B near the source area.

Groundwater samples were collected according to the SAP (SWI, ARCADIS, 2011) and submitted to SGS for the analyses summarized in Table 14.

COPC analysis was initiated during the third quarter reporting period; however, the complete analytical list presented in Table 14 had not yet been finalized. PAHs were not analyzed during third quarter sampling, but were included in the fourth quarter sampling event. In addition, isopropanol and propylene glycol were analyzed during third quarter, but not analyzed during fourth quarter sampling. However, these two COPCs were to be included during the first quarter 2012 groundwater monitoring event to determine if they are present in the selected wells at the site.

Third quarter groundwater samples were collected in August 2011. Monitoring wells MW-135, MW-138, MW-176A and S-20 were not sampled during the third quarter event. Monitoring wells MW-135, MW-138 and MW-176A were not sampled due to the presence of measurable LNAPL thicknesses at each well. S-20 was identified to be decommissioned and was not sampled during the third or fourth quarter sampling events.

Groundwater samples were collected during the fourth quarter in October 2011. Monitoring wells MW-138, MW-174B, MW-176A, MW-176B and S-20 were not sampled during the fourth quarter event. Monitoring wells MW-138 and MW-176A were not sampled due to the presence of measurable LNAPL thicknesses at each well. A visible sheen was observed in monitoring well MW-176B, which is likely due to cross-contamination during well installation activities. The well was to be cleaned and redeveloped prior to the first quarter 2012 sampling event. In addition, monitoring well MW-174B was inadvertently omitted from the COPC sampling. These wells were to be included for COPC sampling during the first quarter 2012 groundwater sampling event. As stated above, S-20 is scheduled to be decommissioned and therefore was not sampled for COPC analysis.

Results of sampling groundwater for COPCs are discussed in Section 3.8.3.

2.6.4 Natural Attenuation Evaluation

An Offsite FS will be completed to evaluate potential remedies, including monitored natural attenuation (MNA), to address sulfolane-impacted groundwater occurring beyond the limits of NPR. The SCWP proposed collecting groundwater samples from several offsite monitoring wells and analyzing the samples for parameters that will, over time, provide the information necessary to evaluate the potential for natural attenuation of dissolved sulfolane.

2.6.4.1 Potential MNA Mechanisms

Potential mechanisms that may be applicable to natural attenuation of sulfolane include:

- Biodegradation (aerobic or anaerobic),
- Abiotic reactions, and
- Dilution

Published literature for sulfolane fate in aquifer systems suggests the observation of sulfolane biodegradation under primarily aerobic conditions. Some anaerobic biodegradation has been documented under manganese and nitrate reducing conditions, but this has been sporadically observed.

The daughter products of in situ sulfolane biodegradation have not been well documented, although aerobic mineralization of sulfolane to sulfate and carbon dioxide via the reaction below has been observed in laboratory cultures (Greene et al, 2000):

$$C_4H_8O_2S + 6.5O_2 \rightarrow 4CO_2 + 3H_2O + 2H^+ + SO_4^{2-}$$

Sampling and analysis conducted by FHR in conjunction with operation and maintenance of the onsite sulfolane remediation system has demonstrated rapid removal of sulfolane associated with backwash solids from the multimedia filters. The backwash solids are primarily comprised of iron and manganese oxides precipitated from the recovered groundwater. In support of onsite feasibility study activities, jar tests have been conducted with the backwash solids from the remediation system. These jar tests suggest that the removal mechanism may not require warmer-than-ambient groundwater temperatures or higher-than-ambient concentrations of dissolved oxygen. Sulfolane removal observed in these jar tests coincided with simultaneous oxidation of ferrous iron from the groundwater and reduction of manganese from the backwash solids. While additional work is underway to understand this mechanism, the mechanism may involve the participation of sulfolane in an abiotic redox reaction at the surface of the iron/manganese oxide.

2.6.4.2 Selection of MNA Parameters

Based on the mechanisms described above, the following MNA parameters were selected to evaluate the potential for dilution, biological degradation, or abiotic reactions that may attenuate sulfolane in situ:

- Dissolved oxygen – necessary for aerobic sulfolane biodegradation.
- pH – Aerobic biodegradation may produce acidity – a decrease in pH accompanying declining sulfolane concentrations may suggest aerobic biodegradation. Both biological and abiotic reactions may also be pH-dependent.
- Specific conductivity – Indicator of groundwater salinity – may be used as a tracer to evaluate potential dilution.
- Temperature – Temperature may affect the degree of biological sulfolane degradation.
- Total Alkalinity – As the groundwater has significant buffering capacity, acidity generated from aerobic sulfolane degradation may not cause a decrease in pH, but may result in a change in alkalinity.
- Sulfate –One of the possible daughter products of aerobic sulfolane biodegradation, and also a possible electron acceptor for anaerobic sulfolane degradation.
- Sulfide – Indicator of sulfate reduction - potential anaerobic pathway for sulfolane degradation.
- Nitrate – Possible electron acceptor for anaerobic sulfolane degradation.
- Total Kjeldahl nitrogen – Necessary nutrient for biological activity – evaluate potential nutrient limitations for sulfolane biodegradation.
- Total Phosphorus - Necessary nutrient for biological activity – evaluate potential nutrient limitations for sulfolane biodegradation.
- Ferrous/Ferric Iron – Potential redox couple associated with either biological (anaerobic) or abiotic sulfolane degradation.

- Manganese (II)/Manganese (IV) – Potential redox couple associated with either biological (anaerobic) or abiotic sulfolane degradation.

2.6.4.3 Quarterly Groundwater Analyses

To assess whether microbially-mediated natural attenuation of sulfolane may be occurring within the plume, concentrations of various parameters were measured to check for changes attributable to sulfolane biodegradation. Such changes may include decreases in concentrations of terminal electron acceptors, or increases in concentrations of biodegradation byproducts that coincide with decreases in sulfolane concentration.

As MNA is a remedial alternative that is under consideration for offsite sulfolane impacts, the sampling plan presented in the SCWP focused on collection of data from the following areas:

- Uncontaminated sidegradient monitoring wells;
- Wells located at different distances along the dominant groundwater flow path within the limits of the sulfolane plume, but outside the limits of the hydrocarbon plume; and
- Wells just outside the sulfolane plume.

The SCWP included 30 monitoring wells along the groundwater flow path and at the edge of the sulfolane plume to be sampled for MNA parameters, incorporating shallow and deeper wells to provide information regarding biodegradation activity with depth. The wells and rationales for sampling them are shown in Table 15; locations are shown on Figure 24. Subsequent to the SCWP, MW-160A was destroyed, and therefore, has been removed from the MNA network.

During the first quarter of 2011, groundwater samples were collected for MNA parameters between February 10 and March 9, 2011. All but six of the wells listed in Table 15 were sampled. Wells MW-152A, MW-152B, and MW-159 were inaccessible because they were buried under large snow berms. MW-160A was destroyed by a road grader in the summer of 2010, and wells MW-166A and MW-166B were frozen.

Groundwater samples for MNA Parameters were collected during the second quarter between April 6 and May 25, 2011. All but twelve of the wells listed in Table 15 were sampled. Wells MW-152A, MW-152B, MW-156A, MW-156B, MW-158A, MW-162A, MW-162B, MW-165A, MW-166A, MW-166B and MW-168 were frozen and MW-160A was previously destroyed.

Groundwater samples for MNA Parameters were collected during the third quarter between August 4 and 18, 2011. All but four of the wells listed in Table 15 were sampled. Wells MW-166A, MW-166B and MW-168 were frozen and MW-160A was previously destroyed.

During the fourth quarter of 2011, sampling of groundwater for MNA Parameters occurred from October 3 through November 4, 2011. All wells listed in Table 15 were sampled except the destroyed well MW-160A. Additionally, wells MW-105, MW-105A, MW-109, MW-110, MW-116, MW-180A, MW-180B, and MW-182A were sampled as part of other site characterization activities including the natural source zone depletion evaluation, subsurface microbiological characterization and the compound stable isotope analysis as described in Sections 2.5.6.5, 2.6.4.5 and 2.6.4.6, respectively.

At each well sampled, the wells were first purged in accordance with the SAP. Following purging, field-based measurements were taken, and samples were collected for laboratory analysis by the USEPA or Standard Methods for the Examination of Water and Wastewater, 20th Edition (SM20) methods shown in Table 15.

Samples collected for measurement of natural-attenuation parameters were submitted to SGS for analysis. SGS utilized the methods listed above in Section 2.6.4.2 for TOC, alkalinity, and sulfate in accordance with Table 5 of the SCWP SAP. Additional natural attenuation parameters not specifically included in the SCWP were measured by SGS or using field-based methods. Total phosphorus, total Kjeldahl nitrogen total hardness, and nitrate/nitrite were determined using the methods listed in Table 15. Laboratory analytical reports are presented in Appendix L.

Field-based measurements of dissolved oxygen, conductivity, temperature, and pH were performed using a YSI ProPlus multiprobe, calibrated according to the manufacturer’s instructions. Total and reduced iron, total and reduced manganese, and sulfide were measured using Hach Co. reagents and a DR/2010 field spectrophotometer following the manufacturer’s protocols, with a few exceptions. Hach Co. reagents were not available for the iron measurements when the samples from wells MW-151A/B, MW-157, MW-162A/B, MW-163A, MW-164A, MW-165A, MW-167A/B, and MW-168 were collected; those samples were submitted to SGS for total iron analysis by USEPA Method 200.8, and dissolved iron analysis (in 0.45-µm field-filtered samples) by the same method. Oxidized iron species are determined by the difference between total and reduced iron in the Hach Co. measurements, or between total and dissolved iron in the laboratory measurements.

Reduced manganese was determined using Hach Co. reagents and a modification of the protocol for total manganese analysis. The Hach Co. manganese analysis employs the “PAN method,” which is capable of detecting low levels of manganese. In this method, an ascorbic acid reagent is added to the sample initially to reduce all oxidized forms of manganese to divalent manganese. After adding an alkaline-cyanide reagent to mask potential interferences, the PAN Indicator is then added to combine with the divalent manganese to form an orange-colored complex that is measured colorimetrically. Reduced manganese was measured in the samples by omitting the addition of ascorbic acid, which allowed measurement of the reduced manganese present in the sample prior to adding the reducing agent. Oxidized manganese is then determined by the difference between total and reduced manganese.

Results of the natural attenuation evaluation are presented in Section 3.10.

2.6.4.4 Isotherm Analyses

The decision to include isotherm analysis in the SCWP was driven by the better-than-expected performance of activated carbon adsorption as a treatment alternative for sulfolane-impacted water during treatment studies performed for IRAP and Point-of-Entry (POE) applications (see Section 5.0). The team believed it was important to verify the partitioning coefficient for sulfolane at the site to allow its comparison to published values. Such a comparison would confirm that sulfolane adsorption/desorption, as it relates to both natural attenuation progress monitoring, as well as fate and transport of sulfolane at the site, occurs to the extent originally anticipated based on published information.

FHRA will continue the practice of integrating information into its analysis that is obtained from other activities (e.g., POE bench and pilot testing) to inform and focus data collection plans in support of the feasibility study for remediation at the site. As POE pilot testing proceeds, and as pilot testing of the activated carbon system is conducted, a significant portion of the sampling and analysis associated with these efforts will focus on evaluation of biologically-mediated sulfolane degradation occurring in conjunction with these systems. The information learned from these activities will be used to help interpret data from ongoing MNA sampling, and to focus/augment data collection activities in support of the feasibility study.

The objective for isotherm testing outlined in the SCWP was to evaluate the possible amount of adsorbed sulfolane within the plume that may desorb during remediation/natural attenuation and affect the observed trends in sulfolane concentration by establishing site-specific distribution coefficients. To achieve this objective, a protocol was developed in consultation with ADEC and

Dr. David Barnes (University of Alaska-Fairbanks) to evaluate the possible adsorption of sulfolane to aquifer material

As summarized in the SCWP, the protocol was originally developed as a desorption isotherm test, and consisted of:

- Collection of a sediment sample from a zone within the sulfolane plume, but outside the zone of LNAPL occurrence;
- Quantification of sulfolane within the sediment material;
- Equilibrating unimpacted (sulfolane-free) groundwater with the sediment in different water: sediment ratios;
- Measuring the resulting aqueous sulfolane concentrations; and
- Computing distribution coefficients from the data.

During development of the protocol, the team concluded that the analytical method for quantification of sulfolane in the aquifer sediment lacked the necessary sensitivity to support computation of distribution coefficients from the data. The approach was therefore modified to an adsorption isotherm test, in which a known amount of sulfolane (500 ppb) was spiked into clean groundwater, and then equilibrated with different amounts of aquifer sediment.

With respect to the original objective of the isotherm test described in the SCWP, modifying the protocol from a desorption test to an adsorption test carries the inherent assumption that adsorption of sulfolane to the aquifer sediment is fully reversible. Therefore, when using the results of the test to evaluate the amount of sulfolane that may potentially desorb during natural attenuation of the dissolved-phase sulfolane plume, it is important to note that the indicated amount may be conservatively high, as the adsorption process may not be completely reversible. Subsurface soil for the testing was collected from the boring for well MW-186C, installed on October 15, 2010. Continuous split-spoon samples were collected from the boring starting at 50 feet BGS to a depth of 64.5 feet. The spoon was generally advanced about two feet per sample (actual sample intervals were 50 to 52 feet, 53 to 55 feet, 55 to 57 feet, 57 to 59 feet, 59 to 60.5 feet, 60.5 to 62 feet, and 62.5 to 64.5 feet BGS). Additional split-spoon samples were collected from 70 to 72 feet, 80 to 82 feet, and 90 to 92 feet BGS. The aquifer material was placed into a new, clean five-gallon bucket with a lid and kept cool (0 °C to 6 °C) until it was delivered to SGS for the testing. (The sample from 100 to

101.5 feet BGS in this boring was collected as an analytical sample for SGS; the sulfolane concentration result for this sample was less than the limit of quantitation of 0.613 mg/kg.)

Twenty liters of sulfolane-free groundwater from NPR was collected from MW-173A and provided to SGS for use in the testing. The testing procedure was conducted in 12 half-gallon (1,900 mL) glass wide-mouth Mason jars with lids, into which were placed aquifer material and sulfolane-spiked groundwater from NPR. A description of the testing protocol is provided below.

A 10-liter composite of aquifer sediment was prepared, and the free water was drained from it using paint filters or cheesecloth. From the composite, three subsamples were collected for determination of sediment-phase sulfolane concentration, bulk density, TOC content, and moisture content. Aliquots of the remaining composited aquifer sediment were placed into the jars as outlined in the table below. Twenty liters of groundwater were spiked with 10 milligrams of sulfolane, and the remaining jar volumes were filled with sulfolane-spiked groundwater, leaving minimal headspace; the volume of water added to each jar was recorded.

Jar ID	1, 2, 3	4, 5, 6	7, 8, 9	10, 11, 12
Sediment Volume	900	750	500	250
Water Volume	Balance (about 1200 mL)	Balance (about 1350 mL)	Balance (about 1600 mL)	Balance (about 1850 mL)

Once the sorption-testing jars were prepared, they were treated in the following manner:

- Shake the jars by hand for 90 seconds, then store at 2 °C to 6 °C.
- After 24 hours, filter the contents of Jars 1, 4, 7, and 10 through a 0.45-micron filter and analyze for sulfolane. Shake the remaining jars by hand for 90 seconds, and place back in cool storage.
- After 48 hours, filter the contents of Jars 2, 5, 8, and 11 through a 0.45-micron filter and analyze for sulfolane. Shake the remaining jars by hand for 90 seconds, and place back in cool storage.
- After 72 hours, filter the contents of Jars 3, 6, 9, and 12 through a 0.45-micron filter and analyze for sulfolane.

The data resulting from this testing, summarized in Section 3.10.2, included:

- Sulfolane and organic carbon concentrations measured on the triplicate sediment samples
- Bulk density (grams/mL) of the drained sediment
- Moisture content of the drained sediment
- Volume of water added to each test jar
- Sulfolane concentrations at the specified equilibration times for each jar

These data were used to estimate a distribution coefficient (K_d, K_{oc}) for sulfolane in NPR aquifer material. The distribution coefficient can be used to estimate the amount of sulfolane adsorbed to the aquifer material at a given groundwater concentration, and can be compared to published values to evaluate the degree of adsorption relative to that observed at other sites.

2.6.4.5 Subsurface Microbiological Characterization

In the SCWP Addendum, FHRA proposed characterization of the microbiological communities in the subsurface of the site to better understand the biodegradation potential of sulfolane in groundwater. Due to the low groundwater temperatures of 0 to 2 °C and the previously untested behavior of sulfolane in an environment of this nature, FHRA proposed to complete the characterization work in two phases.

2.6.4.5.1 Bio-Trap Field Pilot Study

As proposed in the SCWP Addendum (ARCADIS 2011b), FHRA initiated implementation of Phase 1 of the Subsurface Microbiological Characterization study. Phase 1 includes a Bio-Trap® Field Pilot Study, Bio-Trap Seeding Study and the Bio-Trap Desorption Study to determine the feasibility of implementing Phase 2 of the proposed Subsurface Microbiological Characterization, which involves deployment of Carbon-13- (^{13}C-) labeled sulfolane seeded Bio-Traps.

Bio-Traps are passive in-situ samplers that contain Bio-Sep® beads, which provide a large surface area for microbes to attach to, thereby allowing the formation of biofilms. In natural systems, greater densities of microbes will generally be found attached to a surface rather than floating freely in groundwater; therefore, this method of sampling provides more accurate characterization of microbes in situ than characterization of microbial communities present in a groundwater sample. Bio-Traps can be left in situ for periods of several weeks to several months, allowing colonization of the beads, which provide a media for biofilm formation. Once removed from groundwater, microbial deoxyribonucleic acid can be extracted from the beads for further analysis using either phospholipid fatty acid analysis (PLFA) or quantitative polymerase chain reaction (qPCR). The PFLA method provides a big-picture bacterial "fingerprint" of the broad communities present within the groundwater, but does not quantify microorganisms or provide species-level information. It can be used to compare the differences between bacterial communities present in different parts of a contaminant plume. Conversely, qPCR can provide quantitative numbers of species or groups of organisms within a sample, but does not provide information on the overall community structure or fingerprint. This can be used to assess the health and growth of targeted organisms. Both methods represent conditions within the aquifer, but differ by the scale at which they perform this assessment. For example, PLFA results are reported as fractions of the community spread out among six broad structural groups of organisms (monoenoic, terminally branched saturated, branched monoenoic, mid-chain branched saturated, normal saturated, and polyenoic). Each of these groups has a general classification associated with them. The moneonic structural group, for example, is abundant in Proteobacteria which is a phylum comprising more than 1,500 different species of bacteria. Conversely, qPCR can report the number of a specific species of bacteria (e.g. 1 of the 1,500 difference species within the proteobacteria phylum).

Bio-Traps can be baited with ^{13}C-labeled compounds to assess contaminant biodegradation. Because the natural abundance of ^{13}C in the environment is very low, ^{13}C-labeled compounds provide a unique tracer for the transport and transformation of ^{13}C that originated in the ^{13}C-compounds Sulfolane is used as a carbon substrate when being consumed by microbes. During biodegradation, some of the ^{13}C present in the ^{13}C-labeled sulfolane will be incorporated into the cellular wall structure, thereby enriching the cell wall with ^{13}C. PLFA analysis can evaluate for the presence of ^{13}C, which (if detected) is a direct line of evidence that the sulfolane is being consumed as a carbon substrate and is therefore undergoing biodegradation. If the ^{13}C-labeled compound is completely mineralized by bacteria, it will be transformed to ^{13}C carbon dioxide. If methanogens play a role in the biological degradation of sulfolane, ^{13}C-enriched methane may also be generated. Both the carbon dioxide and methane gas becomes trapped within the beads, which can be extracted and measured in an analytical laboratory for the presence of ^{13}C. Therefore, the presence of either ^{13}C carbon dioxide or ^{13}C methane in this study provides another definitive signature of sulfolane biodegradation.

2.6.4.5.2 Methods

On September 21, 2011, FHRA deployed three unbaited Bio-Traps within the screened interval of well MW-130 (Figure 25) to assess the ability and rate of the native microbial community to colonize the Bio-Trap Bio-Sep beads at low groundwater temperatures (generally less than 4 °C). The Bio-Traps were installed one on top of the other, with individual lines extending to the top of the well for subsequent individual recovery by field staff. Well MW-130 was chosen for Bio-Trap deployment because it had a relatively high concentration of sulfolane (335 µg/L) during the second quarter 2011, with no detections of BTEX.

Following deployment, the Bio-Traps were collected from well MW-130 on October 19, 2011 (28 days), December 14, 2011 (83 days) and February 7, 2012 (139 days) and shipped on ice to Microbial Insights of Rockford, Tennessee under proper chain-of-custody procedures. The proposed deployment period for each Bio-Trap was originally scheduled for 30, 60 and 90 days to determine the feasibility and optimum incubation period for the Phase 2 ^{13}C-Labeled Sulfolane Field Study. This schedule was modified based on the results of the first Bio-Trap, which successfully showed the growth of a variety of organisms after 28 days, but at lower than desired cell densities. The schedule for retrieving the second and third Bio-Traps was therefore modified to collect the Bio-Traps later than previously scheduled (increased to 80 and 140 days) to allow for additional biomass growth.

The first two Bio-Traps (28 and 83 days) were analyzed for analysis for qPCR of methanogens, total bacteria and iron/sulfate reducers, and concentrations of PLFA. The last Bio-Trap (139 days) was analyzed for PLFA only. During analysis, real-time PCR used oligonucleotides that are designed to target specific genes or organisms of interest. In order to target methanogenic organisms, the alpha subunit of the methyl co-enzyme M reductase gene was used. For iron and sulfate reducing bacteria, the 16S of the deltaproteobacterial organisms in this group was targeted as an indicator.

Results of the Bio-Trap Field Pilot Study are presented in Section 3.10.3.1.

2.6.4.5.3 Bio-Trap Seeding Study

As part of Phase 1 of the Subsurface Microbiological Characterization proposed in the SCWP Addendum (ARCADIS, 2011b), Microbial Insights completed a sulfolane loading study to determine the feasibility of loading sulfolane to Bio-Trap Bio-Sep beads. This portion of Phase 1 was undertaken to determine if sulfolane loading to Bio-Sep beads is possible and the best method for loading. The seeding method developed during this phase would be used for seeding ^{13}C-labeled sulfolane to Bio-Sep beads during Phase 2 to hopefully provide a definitive signature of sulfolane biodegradation.

2.6.4.5.4 Methods

Microbial Insights prepared two solutions of sulfolane in water at concentrations of 250 and 1,000 mg/L. Bio-Sep beads were then actively mixed in each of the two solutions for 48 hours and the concentration of sulfolane sorbed to the beads was measured. Microbial Insights extracted sulfolane sorbed to the beads seeded in the 1,000 mg/L sulfolane solution. Three solvents were used: water, methanol and methylene chloride. Also, a second extraction was completed with methylene chloride to determine the effectiveness of a second extraction using that method. For this portion of the project, sulfolane analyses were conducted at Microbial Insights using a gas chromatograph/mass spectrometer.

Results of the Bio-Trap Seeding Study are presented in Section 3.10.3.2.

2.6.4.5.5 Bio-Trap Desorption Study

To assess the feasibility of installation of Bio-Traps seeded with sulfolane into groundwater for Phase 2 of the Subsurface Microbiological Characterization, FHRA studied desorption of sulfolane from Bio-Trap Bio-Sep beads. This study evaluated the magnitude of sulfolane losses due to desorption during a timeframe consistent with the deployment of Bio-Traps in the field. It is not uncommon for a Bio-Trap to experience some desorption of the baited compound; results from this study characterize the potential for desorption.

2.6.4.5.6 Methods

Groundwater from well MW-105, located upgradient of the plume and unimpacted by COPCs, was shipped to Microbial Insights and subsequently sterilized. A Bio-Trap baited with sulfolane was placed in the groundwater sample and stored in the laboratory at 1 °C to mimic field conditions for 60 days. One sulfolane sample was collected from the sterilized groundwater before installation of the Bio-Trap and additional samples were collected 15, 30, and 60 days after installation.

Results of the Bio-Trap Desorption Study are presented in Section 3.10.3.3.

2.6.4.6 Biodegradation Stable Isotope Evaluation

As proposed in the SCWP Addendum (ARCADIS, 2011b), a stable isotope evaluation was conducted to assess potential biodegradation of sulfolane in groundwater at the site.

Monitoring of MNA parameters aimed at demonstrating biodegradation of sulfolane in groundwater at the site has not indicated a definitive biodegradation process in the aquifer. Due to the relatively low concentrations of sulfolane and associated low concentrations of biodegradation geochemical indicators, more traditional methods of identifying in-situ biodegradation may not be sufficiently sensitive to detect these processes in the aquifer surrounding NPR.

To complete this evaluation, FHRA proposed a compound-specific stable isotope analysis to assess in-situ biodegradation of sulfolane in site groundwater to augment standard geochemical parameter monitoring and provide more direct evidence of biodegradation. Sampling was proposed in a phased manner to evaluate the efficacy of the method at the site. Phase 1 sampling was completed and the data are presented below.

2.6.4.6.1 Technical Background

Elements including oxygen, carbon (C) and sulfur have naturally occurring, variable ratios of stable isotopes and are distributed throughout the biosphere. Isotopes of an element have the same number of protons and electrons, but a different number of neutrons, resulting in differing masses for the different isotopes. For example, carbon is found most abundantly as ^{12}C (light isotope) and is stable with six protons and six neutrons. ^{13}C (heavy isotope), with six protons and seven neutrons, is also a naturally occurring isotope of carbon but is much less common (1.1 percent of carbon).

Stable isotopes are measured as the ratio of the heavy to the light isotope (e.g., $^{13}C/^{12}C$). Results for the stable carbon isotopic composition of sulfolane are reported using delta notation ($\delta^{13}C$). Delta notation is used to indicate the stable isotope ratio relative the international standard Pee Dee Belemnite (PDB). Variations of isotopic ratios are typically small and are reported in units of parts per thousand or per mil (‰).

Differences in masses between isotopes of an element result in slightly different reaction rates in biological, chemical, and physical processes. These slight differences in reaction rates result in subtle, but measurable, shifts in stable isotopic composition between phases or between reactant and product. Isotopic shifts, also known as “fractionation,” can be used to track degradation of organic COPCs. For example, stable carbon isotopes have been successfully employed to demonstrate natural and enhanced biological degradation of chlorinated solvents in groundwater (Hunkeler et al. 1999, Song et al. 2002, Kirtland et al. 2003). Measurement of the stable carbon isotopic composition of sulfolane was proposed to assess natural attenuation through biodegradation of sulfolane in groundwater at and downgradient from NPR.

2.6.4.6.2 Phase 1 – Field Methods

Groundwater samples were collected from nine wells in conjunction with the fourth quarter 2011 groundwater monitoring event. The wells selected represent a range of sulfolane concentrations and distances from source areas in groundwater at the site: MW-110, MW-127, MW-142, MW-148B, MW-161B, MW-164A, MW-171A, MW-180A, and MW-182. These wells are shown on Figure 26. The monitoring well network was selected to evaluate potential shifts in carbon-isotope ratios caused by biodegradation downgradient from source areas at the site. In addition, a bulk sulfolane solvent sample collected from the sulfolane extraction unit was submitted for analysis to establish a baseline carbon isotope ratio for sulfolane currently in use at the facility.

Samples were submitted to the University of Oklahoma Organic Geochemistry/Stable Isotope Laboratories (University of Oklahoma) for stable carbon isotope analysis by gas chromatography – isotope ratio mass spectrometry (GC-IRMS).

2.6.4.6.3 Phase 1 – Laboratory Analytical Methods

FHRA and the University of Oklahoma are not aware of previous sulfolane isotope studies. Thus, this stable carbon isotope evaluation required the University of Oklahoma to develop a new analytical method to analyze sulfolane isotopic composition.

During laboratory analysis, sulfolane was thermally converted to carbon dioxide as a surrogate for IRMS determination of carbon isotope ratios. Preliminary analytical runs of a bulk sulfolane standard by GC-IRMS were successful. However, initially the results could only be sustained during short runs and performance quality declined over longer series of sample injections to the GC-IRMS required for this type of analysis.

Analysis of the complete sample set for longer sample runs resulted in excessive fluctuations of $\delta^{13}C$ measurements, which produced poor duplicate precision and an uncertainty that was too high to provide meaningful results. The University of Oklahoma reported that that this was due to inadequate GC-IRMS reactor performance and the use of dichloromethane (DCM) for extraction. To improve the performance of the reactor and extraction, the following operating protocols were modified:

- The IRMS temperature was increased (from 940°C to 1100°C) to assure adequate sulfolane combustibility.
- The reactor in the GC-IRMS was refurbished with fresh nickel and platinum reactor wires to assure adequate combustion performance.
- The sample was cryofocused on liquid nitrogen to sharpen the solvent peak for shorter residence on the GC column and the splitless injection time was shortened to reduce the amount of DCM loaded into the column, reducing interference.

The University of Oklahoma reanalyzed samples with splitless injection-GC-IRMS according to the above-mentioned protocols and was able to achieve quantifiable and duplicated results.

Only five of the nine groundwater samples collected were analyzed successfully. Despite historical detections of sulfolane in groundwater samples collected at wells MW-171A and MW-180A, sulfolane concentrations were not detected in groundwater samples collected from these monitoring wells for stable carbon isotopic analysis. Thus, samples from these wells were not analyzed. Groundwater samples collected from monitoring wells MW-161A and MW-164A were extracted and analyzed for sulfolane stable carbon isotope composition, however sulfolane was not detected in these samples during isotopic analysis, potentially indicating that sulfolane mass was significantly lost during the extraction and solvent removal process. Results are presented in Section 3.10.4.

Furthermore, additional MNA groundwater samples were collected and submitted to SGS for analysis for the following geochemical parameters: total phosphorus, total Kjeldahl nitrogen, carbonate alkalinity, bicarbonate alkalinity, hardness as calcium carbonate, sulfate and nitrate-N by the methods described in Section 3.10.4.

2.6.5 Data Evaluation

The SCWP proposed to evaluate groundwater analytical data in order to identify trends. Trend data assist in the evaluation of plume migration, stability, remediation effectiveness, and the correlation of data to water table fluctuations. A preliminary analysis of the temporal variability in sulfolane and BTEX groundwater concentrations in the area of NPR was undertaken using a statistical analysis of historical groundwater data and visual inspection of the concentration graphs (Appendix S).

As stated in Section 6.7.1.3 of the SCWP, Monitoring and Remediation Optimization System (MAROS) software developed by the Air Force Center for Engineering and the Environment (AFCEE) was to be used to evaluate concentration trends with the program's Mann-Kendall testmodule. However, MAROS is unable to handle data sets with greater than 40 results. Since many of the wells have data from greater than 40 sampling events, SWI developed a computer program capable of performing the Mann-Kendall test and calculating the data set's coefficient of variation (COV) to assess temporal trends when the number of observations is greater than 40.

The MAROS evaluation of concentration trends depends on the result of a Mann-Kendall trend analysis, coupled with the COV. A statistically significant increasing or decreasing trend will be identified by the Mann-Kendall analysis if the probability of a false-negative assessment is less than 5 percent (i.e., $p < 0.05$); MAROS refers to this condition as a "confidence in trend" above 95 percent.

MAROS purports to discriminate between “no trend” and a “stable” contaminant concentration by evaluating the COV of a given well’s data set. The COV is defined as the ratio of a data set’s standard deviation to its mean. COV values less than or near 1 indicate the data form a relatively close group about the mean value; values larger than 1 indicate the data exhibit a greater degree of scatter about the mean. The MAROS decision matrix is tabulated below:

Mann-Kendall Statistic	Confidence In Trend	Concentration Trend
S > 0	> 95 percent	Increasing
S > 0	90 to 95 percent	Probably Increasing
S > 0	< 90 percent	No Trend
S ≤ 0	< 90 percent and COV ≥ 1	No Trend
S ≤ 0	< 90 percent and COV < 1	Stable
S < 0	90 to 95 percent	Probably Decreasing
S < 0	> 95 percent	Decreasing

The MAROS trend evaluation results for the wells in the NPR monitoring network are presented in Sections 3.8.1.6 and 3.8.2.7. Only those wells with greater than three sampling events (the minimum for any statistical test) were considered. In addition, only sulfolane results from 2006 through the fourth quarter of 2011 were used to be able to compare data with similar detection limits; BTEX analytical results from 1987 and later were used for the trend assessments.

The standard practice in this test is to assign a single value to all nondetect results, as long as it is below the lowest detection limit. For these statistical analyses, nondetect results were represented numerically by a value equal to the lowest analytical detection limit for each well’s data set, rather than a value equal to one-half of the practical quantitation limit as stated in the SCWP. This approach was used to be consistent with standard practice, and to avoid erroneous identification of trends related to variations in the PQLs. It is important to note that this statistical analysis is limited to the database utilized and is subject to the limitations that are inherent in conducting this type of analysis at this time. The test does not consider or interpret other site conditions such as seasonal fluctuations and monitoring well functions.

To assess whether seasonal concentration fluctuations may be masking increasing trends, the concentration graphs (Appendix S) were visually inspected. Those wells exhibiting “Decreasing” or “Increasing” trends appear to be unaffected by seasonal variations. Those wells exhibiting “No Trend” or “Stable” trends have the greatest potential to have been affected by seasonal fluctuations. The data available for these wells were insufficient to conduct a seasonal Kendall test (minimum of three years required). Seasonal variations in sulfolane and BTEX continue to be evaluated, and may be included in trend assessments in those cases where seasonal influences could mask long-term trends.

These factors will continue to be evaluated by the project team and, as such, data evaluation will continue as data are gathered, and statistical analyses will be completed on an annual basis.

2.7 Evaluation of Subpermafrost Sulfolane Results

Sulfolane has been detected in groundwater samples collected from several residential wells believed to be completed below permafrost; however, it is unknown whether these data are truly representative of the subpermafrost aquifer for the following reasons:

- Due to construction methods and potential use of heat tracing to maintain flow in the wells, it is possible the permafrost around these wells has thawed, allowing for cross-contamination and pumping from the shallow suprapermafrost aquifer.
- It is also possible that the shallow portions of the subpermafrost wells' casings are compromised, allowing shallow sulfolane-impacted water to enter the wells.
- It is possible that some private wells may have been modified subsequent to installation, and therefore, the depths listed on the logs may not be the intervals from which water is currently being pumped.

Because drilling through the permafrost in an attempt to reach regions beneath permafrost zones is not currently desirable and because the geochemistry is believed to vary between the suprapermafrost and subpermafrost aquifers, the SCWP proposed using geochemical means to evaluate the deep private well data. Specifically, the SCWP proposed collecting groundwater samples from the subpermafrost residential wells and analyzing the samples for geochemical parameters. The results would be compared to data from known deep and shallow well data to determine if the residential wells in question are potentially drawing water and contaminants from the suprapermafrost aquifer.

Three areas were identified where residential wells yielded samples containing sulfolane, and where available information suggested these wells were constructed in the subpermafrost aquifer (Figure 27). Groundwater samples were collected from these subpermafrost residential wells for field and laboratory analysis as proposed in the SCWP. Samples were also collected for comparison purposes from suprapermafrost monitoring wells near the residential wells, and in other areas; samples were collected on March 4, and March 9 through 12, 2011. Table 16 lists the wells sampled and the well screen depths. The depths of permafrost BGS are based on well installation logs for the residences and monitoring wells, or anecdotal information from residents and, as such, may not be completely reliable. Since water table elevation information was not available for the residential wells, the permafrost depths have not been converted to feet BWT.

Temperature, conductivity, pH, dissolved oxygen, and oxidation/reduction potential were measured using a field meter at the time of sample collection. Water quality parameters were measured using a flow-through cell. In addition, total and reduced iron and manganese were measured in the field using a Hach Co. DR/2010 meter and reagents. Other analytes were determined by SGS and included: sulfolane, ammonia, phosphate, TOC, alkalinity, pH, sulfate, chloride, nitrate, nitrite, fluoride, sodium, potassium, calcium, magnesium, antimony, arsenic, barium, chromium, copper, beryllium, cadmium, mercury, nickel, selenium, silver, thallium, and zinc. Results of the analysis are discussed in Section 3.11. Laboratory reports are presented in Appendix L.

Subsequent to this geochemistry evaluation, FHRA submitted *Deep Private Well Groundwater Monitoring Plan* (ARCADIS, 2012a) in order to evaluate flow paths that convey sulfolane to deep private wells. The tasks described in the plan will be initiated once access issues are resolved, and results will be presented in a future submittal.

2.8 Surface Water Assessment

2.8.1 Gravel Pit and Surface Water Sampling and Analysis

On August 11, 2010, surface water samples were collected from the north and south gravel pits (Figure 28), as proposed in the SCWP. The SCWP also indicated FHRA would complete gravel pit sampling at an additional downgradient location, immediately south of monitoring well nest MW-160. However, due to concerns regarding contamination from nearby surface use impacting water quality in the gravel, thereby impacting ability to collect samples representative of groundwater entering the pit, the pit was not sampled.

An additional surface water sample was collected from Badger Slough, north of the extension of Garnet Drive on October 10, 2010 (Figure 28).

The gravel pit samples were collected by dipping a clean sample jar attached to a pole in the water approximately 10 feet from the shoreline. The slough sample was collected by using a disposable bailer and filling the required analytical sample jars. Each of the samples was recovered from within eight inches of the water's surface, in accordance with the SAP. The samples were submitted to SGS for analysis of sulfolane by USEPA Method SW8270D. Results are discussed in Section 3.12. Laboratory reports are provided in Appendix L.

2.8.2 Pore-Water Investigation

In the SCWP Addendum FHRA proposed to complete pore-water sampling at five surface water features at or downgradient of the site (ARCADIS, 2011b). While sulfolane has not been previously detected in surface water samples (Barr 2011a), pore-water monitoring refines the CSM by further defining the potential for sulfolane to impact surface water bodies via surface water/groundwater exchange. Due to complications with property access, several of the proposed piezometer locations have been changed with input from ADEC. The piezometer locations are shown on Figure 29.

Four of the originally-proposed sample locations were chosen based on their proximity to the estimated location of the sulfolane plume. As of the submittal date of this report, FHRA has been unable to obtain access to the gravel pits located on the Bradley Airfield property. A single off-site piezometer was installed and pore-water was sampled at the HC Construction Pit (Pore-5, near the intersection of Badger Road and Peridot Road) and one on-site piezometer was installed near the north gravel pit (Pore-1). One additional sampling location (Pore-6, HC Construction Pit) was added at ADEC's request. However, due to a communication issue in the field, Pore-6 was not installed, and access is no longer available. The HC Construction Pit was expanded in 2011 and gravel is being actively mined from the pit.

To ensure that no residual impacts are present in soil in the HC Construction Pit, one soil sample was collected from the piezometer bore hole from the screened interval of the piezometer (approximately 3 to 4 feet BWT). One additional soil sample was collected from soils excavated from the active gravel pit.

In March 2012, FHRA obtained access to install two additional piezometers (Pore-3 and Pore-4) near the two shallow gravel pits northwest of MW-161 (Figure 29). These two shallow pits northwest of MW-161 were installed in lieu of the previously proposed Bradley Airfield locations. These locations were installed in accordance with the documents noted above; because they are not active gravel pits, and because gravel is not known to be transported away from this location for other uses, soil sampling was not conducted.

Property access was denied at the Rosson's gravel pit, proposed Pore-2 site south of offsite monitoring well MW-160. Results from the pore-water investigation are presented in Section 3.12.2.

2.9 Monitor Effectiveness of IRAP Corrective Measures

During 2011, samples for laboratory analysis were collected on a monthly basis from the groundwater treatment system discharge in accordance with Wastewater Disposal Permit 2005-DB0012. Additional samples were collected to gauge performance of the treatment system at the combined air stripper influent and active air stripper effluents. Results of this monitoring are presented and discussed in Section 5.1. All samples were collected and analyzed in accordance with the SAP.

Additional monitoring was conducted upon installation of the GAC system, which was installed in June in accordance with the IRAP to provide sulfolane removal from the recovered groundwater (as discussed in Section 5.1). A sampling plan for monitoring the GAC system performance was submitted to ADEC on May 20, 2011 (Page, 2011). This plan was followed, with a minor deviation, through treatment of 30,000,000 gallons of groundwater and the results are presented in Section 5.1. The monitoring plan included sampling at the Gallery Pond Effluent, lead GAC vessel (A) effluent, and lag GAC vessels (B, C, and D) based on predicted breakthrough. The monitoring plan was deviated as breakthrough was not observed in Vessel A so the collection of lag vessel samples was reduced. Analysis specified in the monitoring plan included sulfolane; BTEX; 1,2,4-TMB; pH; alkalinity; and dissolved iron. During execution of the monitoring plan, FHRA elected to sample at additional locations, such as the Sand Filter influent, and included additional analysis (total iron, TOC, and total suspended solids) to assist in the evaluation of the GAC system performance and potential sulfolane degradation mechanisms.

The monitoring plan (Page, 2011) submitted to ADEC deviated from the SCWP and IRAP by not including TAqH analysis, as this analysis was not necessary to evaluate the effectiveness of sulfolane removal by the GAC system. Upon completion of the monitoring plan which was for the first 30,000,000 gallons, FHRA has continued with twice-monthly performance monitoring of the GAC system.

Upon operation of the GAC system, ADEC approved (via a letter from William Smyth dated May 23, 2011) a 4-month monitoring period (which expired on September 30, 2011) to evaluate performance of the GAC system prior to establishing a discharge limit for sulfolane. At the conclusion of this period, FHRA requested an extension of this monitoring period to continue evaluation of the GAC system performance. ADEC has provided an extension of the monitoring period (Smyth, 2011) until a new permit is issued.

In accordance with the requirements of the Wastewater Disposal Permit, samples were collected from MW-106 and MW-141 in April 2011 and October 2011 (semiannually) with analysis for BTEX and TAH. The results of this monitoring are also presented in Section 5.1.

As described in Section 2.3.4.3, FHRA completed a recovery well pumping test to evaluate capture of the system following implementation of the IRAP improvements. Results of the capture zone testing are discussed in Sections 3.5.1 and 5.1.1.1.

3.0 Results and Findings

This section presents the results of the site characterization activities described in Section 2.0, as proposed in the SCWP and SCWP Addendum, for tasks completed through the fourth quarter of 2011. This includes research into potential sources and release mechanism; an update of the COPCs; additional characterization of the onsite and offsite physical setting; delineation and characterization of LNAPL, soil impacts, and groundwater impacts; and an update of the CSM.

As previously stated and as discussed in the Site Characterization Subgroup meetings, due to the compressed schedule, several tasks are ongoing. This includes horizontal and vertical groundwater gradient evaluation, seasonal trend evaluations, the subsurface microbiological characterization, and the biodegradation stable isotope evaluations. In addition, FHRA will continue to discuss plans to further characterize onsite soil impacts, and suprapermafrost and subpermafrost groundwater impacts with ADEC.

Results of these tasks will be presented to the extent practical in future submittals. FHRA will also continue to participate in the Site Characterization Subgroup and TPT meetings and use these opportunities to present results and discuss future work.

This report includes groundwater monitoring data that has been presented thus far in the quarterly monitoring reports. Also presented are results of the laboratory drain investigation and a summary of the sump investigation results previously submitted to ADEC.

3.1 Sources and Release Mechanisms

As stated in Section 2.1, sources and release mechanisms were identified to understand potential impact locations (potential contaminants are discussed in Section 3.2) and determine if release mechanisms are still actively contributing contaminants to the environment. The task was completed with the consideration of process knowledge and facility documentation and operating history. Efforts were focused on petroleum-related issues in general, and sulfolane–related issues in particular.

The results of recent efforts to further define sources and release mechanisms will be presented in a future submittal.

3.1.1 Potential Sources of Contamination

Potential sources of contamination include those locations at which products and chemicals were used, stored, or transported within NPR. This includes ASTs; USTs; product distribution systems including the truck-loading racks and railcar-loading areas; the process areas including CUs #1, #2, and #3 and the extraction unit (EU); the wastewater system, including the wastewater lagoons, sumps and drain systems; drum storage areas; waste piles; and septic systems. Of these areas, sulfolane was thought to be present or potentially present in the sulfolane storage tank (Tank 194); Tanks 192, 195, and 196; the railcar and new truck-loading rack, the EU, and the wastewater lagoons, sumps and drain systems. Further evaluation of each area is discussed below.

3.1.1.1 Sulfolane Storage and Use

The "sulfolane process" was added to NPR in 1985. Sulfolane solvent has been received at the site via railcar and tanker trucks and is off-loaded to Tank 194. As stated in Section 1.5, NPR currently uses Sulfolane W, which is a mixture of 3 percent water, a small amount of monoethylamine, and sulfolane (which is a solid at room temperature). The sulfolane solution is stored in Tank 194. Tank 194 is located adjacent to the rail spur, between Lagoon A and CU #1 (Figure 3). Sulfolane is delivered from Tank 194 to the EU (Figure 3) via aboveground piping. Sulfolane is used in the EU to extract aromatics in the process of making gasoline from crude stock.

The sulfolane process is a liquid-liquid extraction process that is completed after the crude undergoes desalting, atmospheric distillation, and vacuum distillation. Crude oil is separated into gas, naphtha, light distillates, gas oil, and reduced crude in the atmospheric distillation units. The naphtha and light distillate are sent to the EU (Figure 3) to produce high octane gasoline blend stock.

As indicated in the EU process flow diagram (Appendix C), sulfolane is initially mixed with the naphtha and light distillates in the EU to extract the aromatics. The aromatic-laden sulfolane is sent to an extract stripper, then to the solvent recovery column to remove the aromatics; the sulfolane is recirculated in the EU and reused in the extraction process. After the aromatics are removed, the residual feedstock (raffinate) is sent to a wash tower to remove residual sulfolane.

Gasoline is the only fuel currently and historically produced in the EU using the sulfolane process. Table 1 lists the sulfolane content in gasoline produced at NPR from 1992 through 2009 (prior data are no longer available). In the past, #1 fuel oil, jet fuel, military jet fuel (JP4), and kerosene were produced using naphtha raffinate, which may have contained sulfolane due to "carryover."

Currently, potential carryover is thought to be reduced due to lower throughput, better management practices, and improved equipment in the EU wash tower.

Currently, on rare occasions, sulfolane may enter other fuels, due to two simultaneous events. The first event is a process known as recirculation, in which the feed from the Trans-Alaska pipeline is shut down, requiring NPR to recirculate products into the crude tank and through the process units to keep the units at their optimal operating temperature. The second required simultaneous event would be an "upset" in the EU, which would result in product with sulfolane entering recirculation. While rare, this event has happened at NPR. The amount of sulfolane introduced is likely to be very small and will become diluted during recirculation. Historically, upsets would result in sulfolane concentrations upwards of 800 ppm in gasoline, as shown in Table 1.

During turnaround maintenance events, sulfolane from the EU is pumped into the sulfolane storage tank via above-ground piping (Tank 194) and railcars positioned at the south end of the rail spur adjacent to Tank 194 (Figure 3). FHRA currently seals off sumps S-02/04-2 and S-04-6 from their underground piping to prevent sulfolane from entering the wastewater system, although this was not the case historically. Temporary hard piping is installed and routed to the sulfolane transfer line and frac tanks. The rail spur containment pans drain to the rail sump, which is also piped to a frac tank.

The EU wash water is then pumped out of the EU directly to the frac tanks through the temporary hard piping. Residual water from piping and associated equipment is drained to S-04-6 and S-02/04-2 and routed to the frac tanks. As stated above, FHRA currently seals off these sumps from their underground piping during turnaround events.

Historically, a variety of methods were used to flush the units, however, FHRA currently uses deionized water. The water is pumped into frac tanks for later use as make-up water. This water is tested for sulfolane content, COD, conductivity and pH. Water is used to test the unit for leaks. A corrosion inhibiter and acid are injected into the water. After the acid circulation is complete, the acid is neutralized as it is pumped to the frac tanks. Water is used to rinse acid from the unit; the rinse water is sent to the frac tanks. Water with soda ash is added to neutralize the system; this water is also pumped to a frac tank. After washing is complete, wash waters contained in the frac tanks are pumped into the EU wash towers and associated equipment. Sulfolane is then off loaded from the rail cars and pumped back into the EU.

FHRA has a discrete department at NPR that is dedicated to ensuring that all equipment within the process units, including the EU is inspected at regular intervals. Vessels and piping are scheduled for inspection based upon several factors, including the type of equipment, the type of operation it performs, its manner of construction, the chemical and physical environment in which it operates, and other considerations. All of the process equipment in the EU is located above ground, so any leaks that may be caused by integrity problems can be readily identified and addressed. In addition, the entire unit is constructed within a secondary containment structure.

During the 2011 soil investigation, borings were placed around Tank 194 and the EU, and along the pipe racks between Tank 194 and the EU as shown in Figure 6. The soil investigation was described in Section 2.4.4; Results are presented in Section 3.6.2.2.

3.1.1.2 Product Storage Tanks

Petroleum products are stored in ASTs located in the central portion of the site (Figure 3). The ASTs are all constructed within bermed and lined containment areas.

In particular, historical records indicate Tanks 508 and 509 (the bolted tanks) leaked, as did their containment area, indicating that they were likely sources of releases to groundwater at the site. Tanks 508 and 509 were 10,000-barrel bolted steel, repurposed military tanks located near the south end of containment area CA5 (Figure 3). These tanks were used to store hydrocarbon product until 1986, at which point they were decommissioned. The tanks were then available for use as extra storage and treatment capacity for wastewater when Lagoon B was full, as discussed below in Section 3.1.1.6. Aerial photographs indicate these tanks were removed sometime between 1993 and 1995.

These tanks have been reported in several facility records to have leaked fuel products. The containment area around Tanks 508 and 509, although lined, was reported to have leaked due to holes punctured in the liner during construction. LNAPL is present in the subsurface under the tank farm area, directly to the north of the former location of these tanks, as described in Section 3.7. It does not appear that Tanks 508 and 509 would have been material sources of sulfolane to groundwater because a majority of the releases from these tanks predated sulfolane use at the site and refinery personnel have indicated that liners may have been installed into the bolted tanks prior to their use in wastewater treatment activities. No information is available regarding the type of liner used, nor integrity testing of the liners.

Analysis of LNAPL samples collected from wells located in this area has been completed and the data, specifically from recovery well R-32, confirm that sulfolane is not present in the LNAPL in this area. These results are discussed further in Section 3.7.2.

Soil borings SB-134, SB-158, and ASB-05; and observation well O-10 were placed near the former locations of Tanks 508 and 509 to investigate the soils in this area (Figure 6). Additional borings were placed throughout accessible areas of the tank farms and along the pipe racks as shown on Figure 6. Since the containment areas are lined, it was not possible to place borings within them. The soil investigation was described in Section 2.4.4; results are presented in Section 3.6.2.2.

3.1.1.3 Underground Storage Tanks

Five USTs are currently located at the site (Figure 30) for the purpose of providing heating oil for the occupied buildings at NPR as follows:

- 1,000-gallon steel heating oil tank at the Administration Building
- 4,000-gallon steel heating oil tank at the Maintenance Building
- 1,500-gallon steel heating oil tank at the Warehouse/Operations Building
- 1,000-gallon steel heating oil tank at the Security Building
- 1,000-gallon steel heating oil tank at the Laboratory Building

All USTs and their associated piping undergo annual leak and tightness testing and are protected from corrosion by deep bed anode systems. Sulfolane is not used to produce heating oil; therefore, the current USTs are not a potential source of sulfolane to the environment.

A single record indicates Williams operated two gasoline USTs from 1981 until they were removed in 1989. Both USTs were 1,500-gallons in size and were used to store gasoline. No additional information is available regarding the location of these former USTs, leak and tightness testing, or potential releases, and the reference may have erroneously indicated the tanks were at NPR, not a service station in the area. Since these USTS were in service after the sulfolane use began in 1985, sulfolane may have been present in the gasoline stored in these USTs. Since the USTs' former locations are unknown, it was not possible to target them during the soil investigation; however, the USTs are not listed as the location of any of the gasoline releases in Table 2. In addition, the extensive groundwater monitoring network will likely characterize potential impacts related to both the current and former USTs.

3.1.1.4 Product Distribution Systems

3.1.1.4.1 Railcar-Loading Area

The railcar-loading area is located in the northwest portion of the refinery (Figure 3). Historical spills to soil in the railcar-loading area have been reported in numerous documents and spill records. Spills to the soil were reportedly more common prior to 1985 due to the limited catchment basins at the railcar-loading rack that were not as long or as wide as the railcars, and would have allowed spilled product to escape to soils. The original catchment basins for the railcar-loading area were initially modified during the refinery expansion in 1985 to cover the entire length of the railcars. The spill containment system at the railcar-loading area was once again modified to be wider than the railcars in 1996. Currently, the railcar-loading area is configured with catchment pans between and along the sides of the rails.

While petroleum impacts are present in this area (see Section 3.6.1), sulfolane impacts are not expected. Railcars that were historically used to deliver sulfolane were offloaded at the southern portion of the rail spur, near Tank 194. Sulfolane use at NPR began after the refinery expansion that included the expansion of the catchment basins at the rail rack. Fuel products that are loaded into railcars at the rail rack that had come in contact with the sulfolane extraction process could have potentially contained residual sulfolane due to “carryover.” However, the “carryover” sulfolane concentration in any spills of fuel products to soil at the site would be nominal when compared to the concentrations of sulfolane measured in wastewater.

As noted below in Section 3.1.1.6.2, railcars have been used to store sulfolane-containing fluids during turnaround maintenance events. During these events, the railcars are positioned at the same location that sulfolane was historically offloaded from railcars, at the far south end of the rail spur adjacent to Tank 194 (Figure 3), not at the railcar-loading rack.

Soil borings SB-114 and SB-116 were installed adjacent to the railcar loading rack as part of the 2011 soil investigation (Figure 6). Four soil samples were collected during the installation of SB-114, and two soil samples were collected during the installation of SB-116. These samples were submitted for analysis of COCs, including sulfolane. Results of the soil investigation are discussed in Section 3.6.2.2.

3.1.1.4.2 Truck-Loading Racks

The former truck-loading rack was located just east of the railcar-loading area adjacent to CA4 (Figure 3). It was constructed on a concrete pad; however, it is not known if there was containment for the concrete pad area. The former truck-loading rack was decommissioned as part of the 1985 refinery expansion prior to the inception of sulfolane use at NPR. At that time, a new truck-loading rack was constructed at the north end of the refinery (Figure 3). Sampling of soil for sulfolane was not completed prior to, or during decommissioning of the former truck-loading rack since sulfolane use at NPR did not occur until after the former truck rack was decommissioned.

Analysis of LNAPL collected from an observation well located near the former truck-loading rack (S-51) is discussed in Section 3.7.2. Results indicate sulfolane is not present in the LNAPL in this area.

The new truck-loading rack is the only truck-loading rack that has been in operation at NPR since sulfolane use began. It was built on a concrete pad with a containment curb around the outside of the pad, and the entire area slopes toward a sump containment system.

Several soil borings and observation wells were placed in this area as shown on Figure 6. Results of the soil investigation are discussed in Section 3.6.2.2.

3.1.1.5 Process Area

The process area consists of CU #1, CU #2, CU # 3, and the Extraction Unit, which are located in the southern portion of the site, south of the tank farms (Figure 3). Of the process areas, sulfolane is used in the EU, which is adjacent to CU #2. Further description of the process area, with respect to sulfolane in wastewater and sumps, is discussed below. Releases are described in Section 3.1.2.

As shown on Figure 6, numerous soil borings were placed within and adjacent to the process area. Results of the soil investigation are discussed in Section 3.6.2.2.

3.1.1.6 Wastewater System

The site is currently configured with three lagoons (Lagoons A, B, and C; Figure 3). Lagoons A and C are currently in operation for storage and treatment of wastewater. Lagoon B, which was decommissioned in 2006 and never used by FHRA, was the only wastewater lagoon onsite between 1977 and 1987. Lagoons A and C were built in October 1987 and September 1989, respectively.

Prior to October 1987, some wastewater was sent from Tank 192 to CU #1 for evaporation; the remainder was then sent to Lagoon B. Tank 192 was installed during construction of the refinery in 1977, at the west end of CU #1 (Figure 3). The tank was used to collect material, including storm water runoff from the oily water sewer system. Tank 192 separated the hydrocarbon and water fractions; hydrocarbons were returned to the refining process and wastewater was sent to treatment or vaporization. Before October 1987, what is now known as Lagoon B was the only lagoon in the wastewater treatment system.

Once Lagoon A was constructed in October 1987, Lagoon B received aerated wastewater from Lagoon A through September 1989, when Lagoon C was constructed. Wastewater in Lagoon A was aerated for ~18.5 days (summer operations), after which the wastewater was sent to Lagoon B, where it would reside for ~28.5 days (summer operations). The effluent from Lagoon B would then drain to Sump-909A, and from there it was pumped to the city sewer.

In 1998, the wastewater treatment system was upgraded to handle the additional water that would be introduced to the system with the construction of CU #3. The upgrade consisted of the installation of additional air strippers, the CTX-40T box unit (CTX boxes) and piping to accommodate parallel flow between the CTX system and air strippers, as well as repair of corroded piping between Lagoon B and the city sewer system. The exact location of the piping section that was corroded is unknown, although it generally ran eastward from Lagoon B. As shown on Figure 6, numerous soil borings have been placed in the area east of Lagoon B. Results of the soil investigation are presented in Section 3.6.2.2.

Sulfolane from the EU can enter the wastewater system through general maintenance activities, during turnarounds, or from relief valves that drain into the sumps. Historical records reflect that sulfolane has been measured in wastewater at the refinery and has been found and monitored in many portions of the wastewater system. Therefore, releases of wastewater to the subsurface may have included sulfolane.

As noted previously, Tanks 508 and 509 (i.e., the Bolted Tanks) were also used for the storage and treatment of wastewater after they were taken out of service for product storage in 1986. Reportedly, the Bolted Tanks were used when Lagoon B was full and the refinery required storage of additional out-of-spec (e.g., >250 ppm sulfolane, biological oxygen demand/chemical oxygen demand [BOD/COD]) wastewater before treatment. Liners were installed into the bolted tanks prior to their use in wastewater treatment activities; however, they were not installed to the top of the tanks and were observed to leak wastewater. No information is available regarding the type of liner used, nor integrity testing of the liners.

Tanks 195 and 196 were constructed in 2003 and are currently used as buffer tanks for potentially out-of-spec wastewater (> 250 ppm sulfolane). Wastewater is placed into Tank 195, then Tank 196. Samples are collected from the tanks as necessary (as they fill) and analyzed for sulfolane. Samples are also collected from Tank 192 generally daily, Monday through Friday. If the Tank 195 and Tank 196 sulfolane concentrations exceed 250 ppm, then wastewater is metered into the system using predetermined pumping rates (based on the measured concentrations) to ensure adequate dilution of the sulfolane prior to flowing to Tank 192. If the concentrations are less than 250 ppm, then the wastewater is placed directly into Tank 192.

Historical wastewater records indicate sulfolane in wastewater has been measured at levels exceeding 1,000 ppm (97,000 ppm was measured wastewater added to Lagoon B in 1993). An average daily sulfolane concentration of approximately 2,000 ppm has been calculated using 2010 and 2011 data from Tanks 192, 195, and 196. Concentrations are believed to have varied significantly as wastewater management practices have improved.

General process knowledge indicates that sulfolane-containing wastewater has been introduced to Sump 02/04-2, and historical data indicates the presence of sulfolane in Lagoon B, Sump 908, and Tank 192, and more recently in Tanks 195 and 196. Additional discussion of Sump 02/04-2 follows in Section 3.1.1.6.2.

3.1.1.6.1 Wastewater Lagoons

Records for Lagoons A and C indicate both lagoons were constructed as a double-lined system with leak detection. Lagoon A records from 1988, 1991, 1996, and 1997 indicate there were integrity issues with the liner system in this lagoon. Records for Lagoon C indicate there had been liner integrity issues prior to 2000 in this lagoon. The records are unclear as to whether significant releases were associated with the liner integrity issues. General process knowledge and data from Tank 192 indicates the possibility that sulfolane may have been included in wastewater stored in Lagoons A and C. The original primary and secondary liners of Lagoon A are still in place. The primary liner of Lagoon A was last inspected in 2006, and found to be in good condition. Lagoon C's primary liner was replaced with two liners in 2010 above the original secondary liner, which is still in place. Operator rounds are conducted daily for the liners.

Historical records indicate there have been liner integrity problems with Lagoon B that have resulted in sulfolane releases that have impacted groundwater, as indicated by data collected from adjacent groundwater monitoring well MW-110. Lagoon B was reported to have been removed from active service and replaced by Lagoon C in September 1989. However, aerial photographs indicate liquid was still present in Lagoon B soon after Lagoon C was introduced to the wastewater treatment system in 1990 and 1991. The wastewater held in Lagoon B was pumped into Lagoon C starting on May 22, 1991, continuing throughout the month.

Closure operations for Lagoon B began in 1990 but were not completed until July 1991, at which time the liner was removed. A closure certification report was provided to the USEPA. Photos taken during inspection of the lagoon showed holes in the liner.

After closure operations were completed at Lagoon B in 1991, the liner was replaced and use of the lagoon was reserved for out-of-spec (i.e., >250 ppm sulfolane or BOD/COD) wastewater until 2003. FHRA emptied the lagoon in 2006 and replaced the liner. Records and aerial photographs indicate water resided in Lagoon B throughout much of that time period.

Records indicate holes in the lagoon were initially identified in 1986 and again in 1990 and 1991. When FHRA emptied the lagoon in 2006, additional holes and tears were found. Historical records indicate high-sulfolane concentration wastewater was stored in Lagoon B prior to 2003, and groundwater data collected from MW-110 indicate Lagoon B is a source of sulfolane to groundwater due to historical operations.

Soil borings were placed around the lagoons as shown in Figure 6. Results of the soil investigation are discussed in Section 3.6.2.2. Additional borings placed at Lagoon B during 2012 will be discussed in the 2012 SCRA.

3.1.1.6.2 Sump and Drain Systems

The facility's oily water sewer system collects water from the process areas, tank farms, skid runoff, laboratory, truck rack and railcar-loading area catchment basins, the sump and drain system, and the equipment-loading area.

The sumps, constructed as part of the original refinery, were made of concrete. Because containment issues were observed in the concrete sumps, the sumps were lined with steel during the 1984-1986 timeframe. Additional sumps were constructed on an as-needed basis as additional facilities were added to the refinery (Appendix J). The sumps and drains are underground structures at the site, and there is a potential for leaks from the sumps and drains to the subsurface under the site.

In 2009 and 2010, FHRA undertook a comprehensive evaluation of the integrity of the oily water sewer system (the sump and drain systems) at the refinery. The results of this investigation were reported to the Alaska ADEC by FHRA in a letter dated December 8, 2010 (Appendix J). Integrity issues were identified for five of the 42 refinery sump systems. These five sumps were potential sources of releases to the subsurface. However, three of the five sumps found to have integrity issues would not have come in contact with sulfolane during operation, and all of the five sumps were repaired by FHRA. Also, the inner shell of Sump 02/04-2, which would have been the recipient of material containing sulfolane, was not found to have integrity issues during this inspection; however, it was discovered that a 1997 repair of the sump did not provide for a weld around a pipe penetration in the shell. The drain lines from CU #2 into the sump were found to have integrity issues.

FHRA issued a separate report on July 21, 2010 relating to integrity issues identified with the laboratory drain system (Appendix J). The results of investigations completed at specific sumps are discussed further in Section 3.6.4.

Evidence of Historical Releases from Sump 02/04-2

Sump 02/04-2 is located between CU #2 and the EU (Figure 3) and acts as a collection point for both units, connected to both by a drain piping system. It has been also used to collect residual draindown and wash water during EU turnarounds (maintenance events).

Turnarounds for the EU required de-inventorying of process tanks within the unit by transferring sulfolane-containing fluids to tanks or railcars positioned at the south end of the rail spur adjacent to Lagoon B. After the process tanks were de-inventoried, the residual material and the wash water were allowed to gravity-drain to sump 02/04-2. EU turnarounds occurred every year or every other year from 1985 (when the unit was constructed) until 2003, then again in 2006, 2010, and a limited turnaround in 2011.

Sump 02/04-2 appears to have been a source of sulfolane to groundwater, based on sump and piping integrity records and the groundwater chemistry from downgradient monitoring well MW-138. Integrity issues were identified during a November 3, 1997 inspection that found that the bottom of the sump had corroded through. On November 10, 1997, the operator at the time installed a new steel liner in the sump and coated the sump with polyurethane foam. The sump was inspected again in 1998 and 1999 to assess performance of the coating.

In May 2009, Sump 02/04-2 and piping leading to the sump were inspected. The inspection revealed that a gasket for a nozzle in the sump had deteriorated and that no back-weld had been completed during the 1997 repair. Tightness testing was completed on the piping that leads from CU#2 and the EU into the sump. The line from the EU passed the test; however, the drain line leading from CU #2 into Sump 02/04-2 failed the test. The drain leading from CU#2 to Sump 02/04-2 was removed from service and isolated from the sump by installing a blind flange in the sump (Appendix J).

During the onsite soil investigation described in Section 2.4.4.2, soil borings SB-166, SB-173, SB-174, and ASB-02; and an observation well were placed in the area surrounding sump 02/04-2 and its associated piping to investigate potential impacts. Results of the soil investigation are presented in Section 3.6.2.2.

Sump 908

Sump 908 is located southwest of the current gallery pond (Figure 14) and receives wastewater from the salt drier, which removes water from hydrocarbon products. Wastewater produced from this process has been reported historically to have high sulfolane concentrations (e.g., 35,000 to 55,000 ppm in 2000).

Sump 908 was found to have pitting and complete failure in the steel walls, base, and piping to the sump during an inspection in 1997. In response to the findings of the inspection, Sump 908 was lined with steel and coated with a polymer on October 17, 1997.

An inspection report from September 26, 2006, indicates that minimal corrosion was found in the sump. No instances of through corrosion were identified, and no polymer liner was indicated.

A July 6, 2010 inspection report indicates that a polymer coating in the sump had failed. Heavy corrosion and pitting were identified during the visual inspection, which identified pin-size holes in various areas on the floor and shell. The suggested remedy was to recoat and repair the shell and floor of the sump. Soon after the inspection, the shell and the floor were replaced with new plates.

Sulfolane concentrations in wastewater collected in Sump 908 would have been higher in the past, when sulfolane carryover was higher in gasoline (Table 1). Therefore, Sump 908 would have been a larger contributor of sulfolane to groundwater in the early-to-mid 1990s, when the sump was found to be corroded during inspection and when carryover in gasoline was high (Table 1), compared to the sump's contribution of sulfolane to groundwater in 2010, when the sump was once again found to be corroded.

Soil boring SB-160 was installed near sump 908 as part of the 2011 soil investigation (Figure 6) and four soil samples were collected during the installation. These samples were submitted for analysis of COPCs, including sulfolane. Results of the soil investigation are discussed in Section 3.6.2.2.

Sump 901

Previous source assessment work had indicated Sump 901 located near the east end of CU#1 (Figure 3) to be a potential source of sulfolane to groundwater. However, subsequent work indicates that a wash area located on the western end of CU #1 is the more likely source. A discussion of this analysis will be presented in a future document.

3.1.1.7 Drum Storage

Drums and portable containers are stored in the following areas (Figure 3):

- CU #1 – 400-gallon oil cleaner
- CU #2 – 400-gallon oil cleaner
- CU #3 – 3,400-gallon filming amine storage tank
- CU #3 Utility Building – 55-gallon used oil drums, 110-gallon compressor oil drums
- Effluent Building – 400-gallon filming amine storage tank; 6,000-gallon demulsifier storage tank; 450-gallon lube oil tote
- Maintenance Building – 120-gallon kerosene skid mounted storage tank
- Chemical Injection Room – 330-gallon monoethanolamine totes, 165-gallon lube oil drums, 55-gallon antifoam drums
- Warehouse Skid Curbed Containment Area – up to 21,120 gallons (motor oils, octane reference fuels, seal fluids drums and totes)
- Hazardous Waste Storage Containment Area – up to 18,040 gallons in used oil drums

The volumes listed for the drums are based on maximum number of drums that could be onsite and, therefore, may not be an accurate representation of actual volumes at a given time.

Soil boring locations (Figure 6) were selected as described in the SCWP. Results of the soil investigation are presented in Section 3.6.2.2.

3.1.1.8 Waste Piles

A contaminated soil storage skid (40’ x 20’ x 3.5’) located in the hazardous waste storage area (Figure 3) is used to store propylene glycol or non-benzene containing hydrocarbon-impacted materials. Soils are covered by polyethylene liner material after each addition prior to shipment offsite for treatment and/or disposal. Soil boring SB-143 was placed in this area during the soil investigation. Results of the soil investigation are presented in Section 3.6.2.2.

On occasion, excavated contaminated soils have been stored in the open area northeast of the laboratory (Figure 30) on visqueen until they are profiled. These waste piles are covered to eliminate potential leaching of contaminants to the ground due to precipitation. Once the soil has been sampled, it is placed in roll-off boxes until characterization is completed and the soils are then sent offsite for treatment and/or disposal. Soil boring SB-179 was placed in this area during the soil investigation. Results of the soil investigation are presented in Section 3.6.2.2.

3.1.1.9 Septic Systems

FHRA records indicate septic leach fields receive domestic wastewater from the firehouse, the laboratory, the distribution building, and the current truck rack. A fifth drain field that received domestic wastewater from the construction office was abandoned (Figure 30). Domestic wastewater does not come into contact with sulfolane; therefore, sulfolane is not anticipated to be present in the septic drain fields.

Results of the soil investigation completed at the laboratory (Section 3.6.3) indicate sulfolane was not present above the laboratory reporting levels in the soils beneath the laboratory.

3.1.2 Spill Events and Releases

The spill summary is presented in Table 2. Spill records from NPR do not reflect all of the material historically spilled, as evidenced in reports from the 1980s that indicate the recovery of substantially more product than had been documented as releases. Spill records also do not reflect releases that may have occurred from below-grade structures, particularly including the oily water sewer system, sumps, and lagoons. As stated previously, FHRA is not in a position to verify the completeness or accuracy of records that were maintained prior to their ownership of NPR.

3.1.2.1 Volume Released

The MAPCO 90-Day Response (1989) indicated that 92 spills were reported between 1977 and 1987, resulting in more than 160,000 gallons leaked or spilled at the site. However, it was also represented in the same report that 275,000 gallons of product were recovered; suggesting that considerably more product had been recovered than was reportedly spilled.

A total of 3,096 documented spills have been reviewed from 1977 to 2010. From those records; 2,863 of the spills included volume estimates. The total volume of the documented spills was ~281,964 gallons.

3.1.2.2 Release Locations

Records reflect spills in numerous locations throughout the site (Table 2). These locations include the process areas (CUs #1, #2, #3, and the EU), the area of the lagoons, product storage areas (e.g., tank farms), the railcar-loading rack area, and the current and former truck-loading rack areas (Figure 3).

3.1.2.3 Spill Response Remediation Performed

The spill records reflect that, in many cases, efforts were made to recover at least a portion of the material that had been spilled. During the winter, remediation efforts typically involved allowing the material to freeze, at which point it was collected and disposed of. During the warmer months, spills onto soil or gravel were generally excavated. Sorbent pads were commonly used if the spill was on an impermeable surface. Material that was released to skids was often washed to a sump and allowed to enter the oily water system. As described previously, in 2009 and 2010, FHRA undertook a comprehensive evaluation of the integrity of the oily water sewer system.

3.1.2.4 Confirmation Sampling

A majority of the spill records do not reflect that confirmation sampling was completed to verify the adequacy of remediation efforts. Due to the presence of historically-spilled petroleum hydrocarbon already present in the soil, confirmation sampling may not have been completed in many instances because of perceived difficulty of distinguishing current spills from historic spills.

3.1.2.5 Summary

Due to the large number of historical releases and the lack of information regarding specific cleanup actions and soil sampling, a data need existed regarding soil quality. As described in Section 2.4.4, an extensive onsite soil investigation was performed in 2011. Results are of the investigation are presented in Section 3.6.2.2.

3.1.3 Potential for Ongoing Release

The potential for ongoing releases is mitigated by FHRA through its integrity and inspection program and its active awareness program. In addition, ongoing groundwater monitoring provides additional data regarding potential ongoing releases.

3.1.3.1 FHRA Programs

FHRA has taken a two-pronged approach for the prevention of future releases at NPR. The first is through prevention of spills and leaks, and the second is through mitigation of a leak before it causes a significant environmental impact. The preventative strategy is completed through the mechanical integrity programs for storage tanks, sumps, ponds, and underground piping from certified inspectors, as well as more frequent inspections by operators. The mitigation strategy is completed through a very active awareness of leak potentials and quick responsiveness to spills. More details are listed below.

3.1.3.1.1 Mechanical Integrity and Inspection Program

The mechanical integrity and inspection program spans four major areas for the mitigation of future contaminant releases which include tanks (feed and storage), wastewater sumps, wastewater lagoons, and piping.

- Tanks: All storage tanks are inspected on a rotation consistent with API 653. Inspection results and repairs are documented in the Equipment Files.

- Wastewater Sumps: FHRA has 42 sumps that were all inspected in 2009 or 2010, as described previously. Inspection records and repairs are documented in the Equipment Files. Future inspection frequencies have been set based on a risk assessment of service, historic corrosion, and past repairs. As part of the sump inspections FHRA has tested the underground piping feeding the sump systems. Any lines that were suspect for leakage have been removed from service. FHRA is evaluating alternatives for repairing, replacing, or leaving out of service the affected piping. Results of the investigation completed to address suspect sumps and piping are discussed in Section 3.6.4. A soil investigation has been completed as described in Section 2.4.4 and results are presented in Section 3.6.2.2.

- Wastewater Lagoons: The wastewater system has two lagoons (A and C) which each have two liners with leak detection between the primary and secondary liners. The primary liner is installed on the surface of the ground. The secondary liners are externally inspected each spring and operator rounds are conducted daily. The manufacturer’s end of life for the liners is typically in the range of 15 to 20 years, but the inspections determine the extent of patch repairs or replacement. A third lagoon (B) is out of service, as discussed previously.

- Piping: The piping mechanical integrity program involves a methodical routine of thickness testing and tracking in a database. Corrosion rates are tracked and retirement dates are projected. FHRA proactively repairs or replaces piping prior to retirement dates.

As stated in Section 3.1.1.1, FHRA has a discrete Department at the refinery that is dedicated to assuring that all equipment within the process units, including the EU is inspected at regular intervals. Vessels and piping are scheduled for inspection based upon several factors, including the type of equipment, the type of operation it performs, its manner of construction, the chemical and physical environment in which it operates, and other considerations. All of the process equipment in the EU is located above ground, so any leaks that may be caused by integrity problems can be readily identified and addressed. In addition, the entire unit is constructed within a secondary containment structure.

Whenever an inspection indicates that the frequency and/or procedure for the inspection of any particular piece of equipment or system should be modified, the Mechanical Integrity Department evaluates and implements changes to the applicable inspection protocols.

3.1.3.1.2 Active Awareness Program

NPR has very stringent protocols and expectations regarding the mitigation, awareness, reporting, and responses to releases. The operating personnel have an ongoing active awareness through routine surveillance rounds to locate spills before they become an impact or attempt to minimize the release by early detection. Supervisor Incident Reports (SIRs) are used to document any plant spills (no matter how minor) as they occur, usually by operating and maintenance personnel. The SIR is submitted to the Refinery Shift Superintendent and investigations and applicable cleanup activities are initiated immediately.

In addition, the supervisory and management personnel conduct multiple audits throughout each month regarding safety, environmental cleanliness, and housekeeping for each unit. These audits have a report structure and are logged, and both are used to provide information back to operations.

3.1.3.1.3 Summary

FHRA prevents spills by the use of the mechanical integrity and inspection programs. The refinery personnel are engaged in spill prevention and providing rapid cleanup response to spills.

3.1.3.2 Groundwater Monitoring

Data from the comprehensive LNAPL monitoring network are another tool that has been employed for the purpose of monitoring for ongoing releases, since most of the observation wells are located in areas of product production, distribution, or storage. LNAPL occurrence and forensic data are presented in Section 3.7.

Data from monitoring dissolved-phase contaminants in groundwater are also used as a line of evidence in the evaluation of potential ongoing releases. Results and trends are discussed in Sections 3.8.1.6 and 3.8.2.7. Preliminary evaluation suggests stable or decreasing trends in the sulfolane and BTEX at most locations. Monitoring of LNAPL and dissolved-phase constituents will continue.

It should be noted that the current groundwater pump and treat system is located downgradient of most of the potential sources of significant releases (i.e., product storage tanks and process areas) and that the system is actively capturing a significant volume of LNAPL and dissolved-phase contaminants, as described in Section 5.1. Evaluation of the capture zone is currently underway and additional remedial alternatives will be evaluated during the Onsite FS.

3.1.4 Potential Offsite Sulfolane Sources

Site summaries from the ADEC contaminated sites website and from SWI's project files are presented in Table 17 and shown on Figure 31. To date, the higher priority has been placed on delineating the offsite plume rather than identifying other potential offsite sources; therefore, evaluation of the sites with respect to the offsite plume has not been completed. As offsite sulfolane data are gathered, potential anomalies will be compared to known contaminated sites to evaluate those sites as sources; however, as described in Section 3.1.1.4.1, "carryover" of sulfolane into fuel products is not believed to be a significant source of contamination.

3.2 Chemicals of Potential Concern

COPCs have been identified from a list of potential constituents of interest (COIs), such as those that were likely used or spilled at the site. COPCs for each dataset were carried through the HHRA process.

Preliminary lists of COIs and COPCs in soil and groundwater at the site were presented in the Site Characterization and First Quarter 2011 Groundwater Monitoring Report (Barr 2011a). The lists were revised in the SCWP Addendum (ARCADIS, 2011b) based on the ADEC (2011a) Comment Matrix on the site characterization report and were described in the HHRA.

The list of COIs was developed according to the following process:

1. FHRA compiled a list of spills based on staff interviews, refinery records and a review of spill records retained by ADEC (Table 2).
2. The list of spills was refined by eliminating:
    a. Spills less than 10 gallons.
    b. Spills that were reportedly contained.
    c. Spills that were remediated and had confirmation sampling.

For many spills on the list, the material spilled was specific to one ingredient (e.g., propylene glycol) or was a material with obvious and limited ingredients (e.g., kerosene). However the names of other materials reportedly spilled did not list the individual ingredients (e.g., oily water). Refinery specialists such as chemists, wastewater experts and production leads were consulted to apply operational knowledge of the refinery to determine the ingredients that made up this set of material. By this process, the list of spills was then distilled down to the "ingredients" or the primary constituents that make up the material spilled. This ingredient list was also compared to constituents that had been included in laboratory analyses of facility wastewater. The resulting ingredient list was then used to make up a list of COIs for the site. The COI list also included chemicals that were analyzed during previous site characterization studies, regardless of whether they were detected above the practical quantitation limit (PQL). The list of COIs for the site is shown in Table 18. All constituents on the ingredient list were included on the COI list. If a chemical was previously detected at the site and/or was included in the "ingredient list," it was considered a COI.

Table 18 indicates if a chemical was previously analyzed in soil or groundwater samples collected at the site, and if it was detected above the PQL. Table 18 also indicates if a chemical was included in the "Ingredient" list; the last four columns of the table summarize whether toxicity data are available from the USEPA's Integrated Risk Information System ([IRIS]; USEPA 2011b). Table 19 lists the COPCs identified in soil and groundwater based on ADEC (2011c) COPC selection guidance applied to the COIs identified in Table 18. Maximum detected concentrations and/or the laboratory reporting limits of COIs in soil and groundwater were compared with ADEC screening levels corresponding to a 1 x 10^{-6} target excess lifetime cancer risk (ELCR) and 0.1 target hazard quotient, as shown in Table 19. COI soil concentrations were compared with ADEC screening levels protective of potential migration to groundwater based on a zone with less than 40 inches of annual precipitation, direct-contact exposures and outdoor inhalation (ADEC 2008a Table B-1 of 18 AAC 75, Method Two). If ADEC soil screening levels were unavailable, then COI concentrations in soil were compared with USEPA Regional Screening Levels ([RSLs]; USEPA 2011d), adjusted to a target ELCR of 1 x 10^{-6}, (if necessary) and a hazard quotient equal to 0.1, for the applicable exposure pathway. Soil screening levels for GRO, DRO and RRO were from ADEC (2008a) Table B-2 Method Two. COI groundwater concentrations were compared with ADEC groundwater screening levels (ADEC 2008a; Table C). If ADEC groundwater screening levels were unavailable, then COI concentrations were compared with USEPA RSLs (USEPA 2011d) based on tap water ingestion.

The higher of either the maximum COI concentration detected above the laboratory reporting limit or maximum detection limit was compared with the selected ADEC screening levels. The selected soil screening levels were based on the lesser of the migration to groundwater, 1/10 the direct contact or 1/10 the outdoor air screening levels. COIs with concentrations exceeding the selected soil screening level were identified as COPCs.

The preliminary COPCs identified at the site, as presented in Table 19, are COIs that were detected in site media and exceeded ADEC screening levels. COIs not detected in site media but that had practical quantitation limits exceeding ADEC screening levels, and COIs identified by the refinery as "ingredients" that could have been released, are considered COPCs. Arsenic in groundwater was eliminated as a COPC based on published background concentrations for the area of the site (USGS, 2001). Arsenic was the only metal eliminated during the initial COPC screening as a potential COPC in groundwater based on a background concentration screen. No other metal COIs were eliminated from the list of COPCs based on background concentrations during the initial screening. Additional COPC screening, in accordance with the ADEC Risk Assessment Procedures Manual (ADEC 2011c) was conducted upon review of soil and groundwater data collected in 2011. Table 19 shows COPCs retained after an initial screening conducted in anticipation of the HHRA in September 2011, as well as COPCs retained after the subsequent screening conducted after evaluation of the data collected in 2011. In accordance with ADEC (2011c) guidance, Table 19 is provided in Microsoft® Excel format on the DVD that accompanies this submittal. Additional soil and groundwater COPC screening will be conducted using analytical data collected during the 2012 field season.

3.3 Geology

NPR and the surrounding North Pole area are located on the Tanana River flood plain, a relatively flat-lying alluvial plain situated between the Tanana and Chena Rivers (Figure 1). The elevation of the flood plain is between 400 and 630 feet MSL and the surface slopes downward to the northwest approximately 1 to 10 feet per mile.

The Tanana River is a glacially-fed braided river that drains the northern Alaska Range; it exhibits an anastomosing pattern of channels separated by bars and islands. The Chena River is a meandering tributary to the Tanana, discharging into the Tanana near Fairbanks.

The geology of the area is dominated by a thick sequence of unconsolidated alluvial deposits. Depth to bedrock in the area of NPR is estimated at 500 to 600 feet BGS (Péwé, 1982). An injection well on the GVEA property adjacent to NPR (Figure 3) was drilled to a depth of 450 feet and did not encounter bedrock; no borings placed during site characterization have encountered bedrock. Bedrock crops out as low relief hills on the flanks of the Tanana River valley to the northwest, north, northeast, and east. A more detailed review of regional geology is provided in Section 2.2 of Appendix Q.

Using information from boring logs (Appendix D), and private wells, several cross sections have been prepared to show the stratigraphy in the upper 150 feet of the alluvial deposits. Eight cross sections have been prepared through NPR and the area downgradient of the site (Figure 32) to show the onsite and offsite geology; the cross sections are shown on Figures 33 through 40. Permafrost data from private wells continue to be integrated into the conceptual model. The cross sections have been annotated with the most recent dissolved-phase sulfolane data.

Up to two feet of organic soils can be found at the surface of undeveloped portions of the NPR property and surrounding area. As properties are developed, the surficial organic soils are often removed during construction and replaced with sand and gravel fill derived from local sources. As shown on the cross sections, fill is present at a few onsite and offsite locations at depths of up to 6 feet BGS.

Interbedded discontinuous layers of silt, fine sandy silt, and silty fine sand, with occasional peat lenses predominate the upper 10 to 15 feet of the unconsolidated sequence. The colors of these deposits varied considerably from black to brown to gray, occasionally exhibiting gray and brown mottling near the water table. These soils are believed to have been deposited in sloughs and meander-cutoff channels, and as overbank flood deposits. Historical topographic maps and aerial photographs predating NPR construction show a slough and meander loop in the vicinity of the current truck-loading area and silty deposits were encountered during construction of the current truck-loading rack. Peat was encountered at the MW-170 well nest from approximately 8 to 12 feet

BGS and 20 to 21 feet BGS and in several 2011 soil borings (SB-108, SB-111, SB-125, and SB-141) at depths ranging from 2.1 to 10.5 feet BGS. As is the case with the organic soils, the silty layers are often excavated and replaced with sand and gravel fill during site development.

The GPR survey described in Section 2.3.2.2 was performed in an effort to identify the depth of the contact between the surficial silt/sand deposits and the underlying coarse sand and gravel deposits. A map showing the interpreted depth of this contact is included in Appendix F. Also included in Appendix F is a map showing the approximate boundary of the contact between the fine-grained silts and the coarse-grained sands and gravels at the water table. The results of the GPR survey indicate the contact between the silt/sand and gravel deposits at the refinery ranged from 4 feet to 10 feet BGS. Depth contours indicate the deepest contact occurs in the area north of the lagoons and south of R-42.

Soil descriptions from the 2010 and 2011 field activities have been integrated with soil descriptions from historical monitoring well boring logs to map the distribution of fine-grained soil at NPR. Fine-grained soils were encountered in 97 of the 114 shallow soil borings. The distribution of silt encountered in onsite soil borings is presented in Figure 41. The silt/fine sand ranged in thickness from less than one foot to approximately 14 feet; the contact between the silt/sand and gravel deposits ranged from 1 foot to 15 feet BGS. The silt/fine sand extends below the water table in the southwestern corner of the refinery near the lagoons and the area around the truck rack.

A comparison of the GPR results to soil descriptions from the soil borings indicates some consistency, however, due to high noise-to-signal ratio and the distance between the lines, there are some discrepancies in depths at which the finer-grained units were identified. The presence of finer-grained materials is an important consideration when evaluating potential remedial alternatives for the site. Direct observation of soil types, rather than the GPR results, will be the primary data used during future planning for a site remedy.

Coarse-grained alluvial sands and gravels are present below the surficial silt/sand deposits (Figures 33 through 40). These deposits are predominantly sandy gravels and gravelly sands, with occasional discontinuous lenses of sand, silt, and rare thin lenses of peat. The gravel is fine to coarse and the sands are commonly fine- to medium-grained with a relatively low fraction of coarse sand. Color varied from brown to gray, although, as grain size increased, colors became dominated by the lithology of the clasts. The upper surface of these coarse-grained alluvial deposits is typically encountered within 10 to 15 feet of the ground surface. The deposits likely extend to the upper bedrock surface. Denser zones within the coarse-grained alluvial deposits have been encountered at depths of about 130 to 140 feet BGS during the installation of several deep wells, including the new City water supply wells, wells along the VPT transect, and deeper wells within NPR. The dense zones slowed auger advancement during drilling; at the city well site, the dense zones did not yield water. The lateral and vertical continuity of these zones is not known.

3.4 Permafrost

The study area is described as being within the discontinuous permafrost zone (Williams 1970) and Ferrians (1965) noted that the Tanana Valley area is "generally underlain by numerous isolated masses of permafrost." Additional background information regarding permafrost is presented in Appendix Q.

Permafrost has been observed in the subsurface in both onsite and offsite areas. It has been encountered during the installation of monitoring wells and has been noted in the logs of residential wells. Its upper surface appears to be irregular and its thickness is not well defined. Groundwater flow pathways, if any, between the suprapermafrost and subpermafrost aquifers have not been identified.

3.4.1 Areas of Occurrence

Permafrost was encountered in thirty-three of the monitoring well borings and was reportedly encountered in private well borings installed in the vicinity of NPR. It should be noted that these private wells were installed between 1978 and 2010, and the permafrost conditions may have changed since the wells were installed. Table 20 presents the description of permafrost encountered in the monitoring well borings; Table 21 presents the permafrost information compiled from private well logs.

3.4.2 Depth and Thickness

Top-of-permafrost depths ranged from near the ground surface to approximately 151.5 feet BGS (27 to 143 feet BWT) in the monitoring well borings. None of the monitoring well borings placed since October 2009 were advanced through the permafrost.

Private well logs from unverified sources have reported that the top of permafrost encountered ranged from the one foot to 65 feet BGS. Water table elevation data are unavailable for the private wells; therefore, the permafrost depth below the water table has not been calculated at these locations. The bottom of permafrost ranged from 14 to 245 feet BGS. The thickness of permafrost layer was reported to range from five feet to 242 feet.

Figure 42 provides a graphical representation of the depth to permafrost in the area downgradient of NPR. It appears that permafrost was encountered in wells at shallower depths in areas farther northwest of the refinery, especially in the area along Peridot Street between Richardson Highway and Badger Road. The upper surface of the permafrost appears to be deepest at NPR, and also at well borings placed near Badger Slough. A linear depression in the upper surface of the permafrost appears to extend northwest from NPR, generally following Old Richardson Highway and the Alaska Railroad, two of the older property developments in the area. This information suggests that land surface development may influence the topography of permafrost in the area.

The approximate top of permafrost is also shown on the cross sections (Figures 33 through 40). The cross sections illustrate the irregular nature of the upper permafrost, particularly onsite near the boundary between the developed and undeveloped areas west of the railroad tracks and north of the gravel pits (Figure 36). Cross Section II-II' (Figure 34) shows the apparent linear depression in the upper permafrost surface that was encountered at MW-170 and appear to trend in a northwesterly direction.

Permafrost is not noted in the log for the 450-foot deep GVEA injection well, located immediately south of NPR (Figure 3). Permafrost was also not encountered within 150 feet of the ground surface at monitoring well MW-173B, located along the northeast property boundary (Figure 42). Subsequent drilling encountered permafrost onsite at MW-154C (102 feet BGS), MW-179D (140.5 feet BGS), and along the VPT (Figure 42). Additional deep well borings drilled at NPR in the fourth quarter of 2011 did not encounter permafrost; including 6 wells drilled to approximately 150 feet BGS (MW-195B, MW-197B, MW-198, MW-199. MW-300, and MW-307); and one well drilled to approximately 135 feet BGS (MW-186D) (Figure 42). Lack of permafrost observations during drilling does not necessarily mean it is absent at these locations.

Permafrost thicknesses from private well logs are shown on Figure 43. The thickest measurements were reported between Old Richardson Highway and Badger Road, west of Peridot Street.

Figure 44 shows a three-dimensional representation of permafrost in the study area, constructed as part of the groundwater model described in Section 4.0, using information from monitoring well and private well logs. The blue and green colors indicate areas of shallower permafrost occurrence, while the orange and red colors indicate areas of deeper permafrost occurrence. The red color along the western edge of the study area corresponds with the location of the Tanana River. Permafrost is also deep (>100 feet BGS) along Badger Slough. An apparently continuous area of shallow permafrost is located near the downgradient end of the sulfolane plume, extending to the northwest.

3.4.3 Classification

The permafrost generally lacked visible ice and ranged from poorly- to well-bonded, with the exception of the MW-155B where visible ice was noted between sand grains. The descriptions of permafrost encountered during installation of the well borings are shown in Table 20.

The drillers that installed the private wells did not classify the permafrost beyond noting that subsurface materials were “frozen.”

3.5 Hydrogeology

Key hydrogeologic concepts include an understanding of sources and sinks of groundwater, the general distribution of conductive aquifer materials beneath the site and in the area, and the general distribution of permafrost and its influence on groundwater flow. For purposes of this discussion, “the site” is NPR property (Figure 2). Offsite includes areas in the vicinity of the site. Monitoring wells installed by FHRA beyond the limits of NPR are considered offsite.

Precipitation on portions of the Tanana basin at elevations less than 1,000 feet MSL is estimated to be 8 x 10^6 acre·ft/yr (Anderson, 1970). Actual evapotranspiration over the same area is estimated to be 6.3 x 10^6 acre·ft/yr (Anderson, 1970). The balance of the precipitation is believed to recharge the shallow water table, and then discharge to rivers within the basin. This portion of the basin has an area of approximately 12,000 mi^2. Therefore, the annual average rate of precipitation infiltration is approximately 2.7 inches per year (in/yr). This cycling of recharge to the area rivers occurs above the permafrost. Lakes and swamps in the basin act as sinks for groundwater when they are unfrozen (Appendix Q).

Reaches of the Tanana River, Chena and Little Chena Rivers, and the Badger Slough (also known as Chena Slough) are located in the area. The Little Chena River and Badger Slough are tributaries to the Chena River, which is a tributary to the Tanana River. For the purposes of constructing the groundwater model (Section 4.0), discharge and stage data for the Chena River, Little Chena River, and Tanana River were obtained from the USGS water data web site, as described in Appendix Q and summarized below:

River	Mean Annual Discharge (cfs)
Tanana River	20,546
Chena River	814 to ~1,300 cfs (increasing in the downstream direction)
Little Chena River	205 cfs

A key characteristic of rivers in the region is their large seasonal variation in flow and stage due primarily to spring snow melt. For example, the Tanana and Chena rivers have spring flows that can be four to six times their October flows, with annual changes in stage of 6 to 10 ft (USGS, 2011). This seasonal fluctuation influences groundwater flow, as discussed in Section 3.5.3.

Two flood-control structures have been built in the study area, the Moose Creek Dam on the Chena River approximately two miles upstream of NPR, and a levee along the northern side of the Tanana extending from the Moose Creek Dam to Fairbanks (Figure 1-1 in Appendix Q). The floodgates on Moose Creek Dam are only used during high flow to ensure that the Chena flow through Fairbanks is controlled at a maximum of 12,000 cfs. If the Chena flow is sufficiently high at the dam, water will flow to the Tanana along a constructed sill. Between 1979 and the summer of 1993, the dam was only used during eight periods of high flow, and the sill was only used once (Glass et al. 1996).

3.5.1 Aquifer Characteristics

The aquifer beneath the alluvial plain between the Tanana and Chena Rivers was deposited by a high-energy, braided stream system (Nakanishi and Lilly, 1998, p. 4). The aquifer consists of a complex system of alternating lenses of sand, gravel, and silt (Cederstrom, 1963, p. 17). The lenses are not known to be thick (typically less than 20 feet thick) and individual units cannot be traced for great distances in the subsurface (Cederstrom, 1963, p. 17; Nakanishi and Lilly, 1998, p. 4).

The aquifer beneath the alluvial plain between the Tanana and Chena Rivers generally consists of highly-transmissive sands and gravels under water table conditions (Cederstrom, 1963, p. 1; Glass, Lilly, and Meyer, 1996, p. 5). The Tanana River has a drainage area of approximately 20,000 square miles upstream of Fairbanks (Glass, Lilly, and Meyer, 1996, p. 5). In the vicinity of NPR, this aquifer is reportedly greater than 600 feet thick (at least 616 feet near Moose Creek Dam: Glass, Lilly, and Meyer, 1996, p. 5); however, the deepest known well in the vicinity of NPR is the GVEA injection well, which is 450 feet deep and did not reach bedrock. This well is located at the GVEA substation along the southern NPR property boundary (Figure 3).

Downey and Sinton (1990) estimated the hydraulic conductivity (K) of the alluvial aquifer near the Fairbanks North Star Borough to be 1,000 ft/day. Reported hydraulic conductivities of the aquifer materials in the region range from 8 to 2,400 ft/day (Nakanishi and Lilly, 1998, p. 6). These data are primarily from relatively shallow wells. However, the GVEA injection well, which is perforated from 412 to 432 feet BGS, had a specific capacity of approximately 80 gpm per foot of drawdown (gpm/ft); indicating relatively permeable materials were penetrated at that depth (Appendix D).

A study in 1987 (SWI, 1987) concluded that hydraulic conductivity of the sand and gravel ranged from 100 to 1,000 ft/day based on grain size analyses of samples taken from NPR. Aquifer testing at NPR in 2009 indicated a range of hydraulic conductivity values from 130 to 580 ft/day, based on an estimated saturated thickness of 590 feet and pumping of wells penetrating the upper 15 feet of the aquifer (Barr, 2010b). As described in section 3.5.1.1 below, based on the timing of NPR property development, the proximity of the Tanana River, and the lack of permafrost encountered in the GVEA injection well these estimates were developed with an understanding that no permafrost was present beneath developed areas of the refinery. As noted in Section 3.4, subsequent investigations have encountered permafrost beneath the refinery and work is ongoing to determine its depth and extent. Using the current estimated representative saturated thickness of the suprapermafrost aquifer of 150 feet (see Section 3.5.1.1.1), the 2009 aquifer testing results indicate a hydraulic conductivity range of approximately 500 to 2,300 ft/day.

Hydraulic conductivity estimated based on grain-size analyses for samples of aquifer material sampled during well installation range over 4 orders of magnitude, from 1.1 to 14,000 ft/day (Table 22). However, as shown below and on Table 22, results for nearly 75% of the samples fall between 1.8 ft/day to 574 ft/day and approximately 97% are less than 1,000 ft/day. The three lowest values were reported for samples collected from the shallow silty layers located near the water table (Table 22).

Hydraulic conductivity range	Number of samples	Percentage of samples
1.0 to 9.9 ft/day	5	4.6%
10 to 99 ft/day	81	74.3%
100 to 999 ft/day	20	18.3%
1,000 to 9,999 ft/day	2	1.8%
>10,000 ft/day	1	0.9%

These data do not show an apparent trend with depth (Figure 45).

A soil sample from 10 to 12 feet BGS at MW-306-CMT was analyzed for effective porosity by ASTM D425, density by API RP 40, hydraulic conductivity by ASTM D5084, and moisture content. The analytical results for the sample are summarized in Table 23 and the laboratory report is in Appendix E. The resulting hydraulic conductivity for this sample is 8.61E-05 cm/s or 0.244 ft/day, which is very low relative to most measurements and estimates for the site and given the material description (sandy gravel with small amounts of silt), and suggests that either the silt content in the sample was relatively high or the sample was not fully saturated at the time of the testing.

Aquifer testing of the new North Pole water supply wells in July 2010 indicated a hydraulic conductivity ranging from approximately 700 to 1,100 ft/day based on pumping of wells screened from approximately 120 to 150 feet BWT (Barr, 2010c & Barr, 2010d). Aquifer testing of the recovery well system after installation of well R-42 in August 2011 indicated hydraulic conductivity ranging from approximately 1,000 to 1,500 ft/day (see Sections 2.3.4.3 and 3.5.1.1). The primary difference between the August 2011 testing and the 2009 testing was the understanding of the depth of permafrost beneath the refinery, which reduces the saturated thickness of the aquifer (see Section 3.5.1.1.1).

Excluding an outlier (Table 12) single-well pumping tests yielded an estimated range of hydraulic conductivity values from 50 to 720 ft/day, with a geometric mean of 200 ft/day. Detailed descriptions of these efforts are presented in Section 3.5.1.2.

These aquifer characteristics are consistent with results from other sites in the North Pole area, and historical literature. Slug test data collected in 1993 from the Arctic Surplus Salvage Yard site on Badger Road (8 miles northwest of NPR) yielded hydraulic conductivities ranging from 12 ft/day (silty sand, silt with sand, and gravel, 1.5 feet to 15 feet BGS) to 65 ft/day (gravelly sand, 50 feet to 60 feet BGS), and flow velocities up to 1.3 ft/day. A 1995 recovery well optimization study pump test at NPR found variability in aquifer characteristics over small distances (i.e., tens of feet) based on differences in measured drawdown in wells at similar distances from a pumped well (SWI, 1995). The 1995 testing consisted of a step-drawdown test of well R-34. The well was pumped at rates of 50, 100, 150 and 170 gpm for 6 hours at each rate. Quantitative analysis of the 1995 data is not possible because the rate was not constant and drawdowns were calculated only at the end of each step. The steps were not long enough to allow application of the Jacob method for distance-drawdown analysis.

In summary, the estimated range of hydraulic conductivity based on all applied methods is 1.1 to 14,000 ft/day (see Section 3.5.1.4). Based on groundwater flow modeling described in Appendix Q and the recovery system aquifer testing described in Section 3.5.1.1, a representative hydraulic conductivity value for the aquifer in the vicinity of the extraction well system is approximately 1,250 ft/day. The USGS reported the following range of hydraulic conductivities for various soil types (USGS, 1978):

Material	Hydraulic Conductivity (ft/day)
Silty Sand	0.01
Gravelly Sand	10
Sandy Gravel	100
Medium Gravel	10,000

In the SC/CAP, the hydraulic gradient was estimated at 5.5 feet per mile and the groundwater velocity was calculated to be approximately 1.3 ft/day (SWI, 2002). Based on an assumed effective porosity of 0.25, a representative seepage velocity of 1.7 ft/day is estimated for the suprapermafrost aquifer (see Section 2.5.4 of Appendix Q). Glass, Lilly, and Meyer (1996, p. 1) report a slope on the water table of 4 feet per mile. As data continue to be gathered, work will continue to refine the estimate of groundwater velocity for the site.

3.5.1.1 2011 Recovery Well Pumping Test

Results of the aquifer testing described in Section 2.3.4.3 are presented here. In summary, the aquifer testing consisted of turning off all five extraction wells within approximately 4 minutes of each other on August 30, 2011, then turning them back on approximately 24 hours later. The timing of the pump shutdowns, startups, and average pumping rates before and after the shutdown period is summarized in Table 24.

Water level data were collected both manually and with two types of data loggers. Water levels were recorded during the observation period associated with aquifer testing. The earliest manual measurements were recorded on August 19, 2011. Groundwater levels were declining during the aquifer testing period. The rate of fall from August 29th to the period of the actual testing was greater than that observed from approximately August 29th to September 2nd. The rate of fall for the aquifer testing period was estimated based on analysis of several hydrographs to be approximately 0.0556 ft/day. This rate of water level drop was subtracted from the measured/calculated water levels to produce a "detrended" hydrograph for each well during period of the testing. Responses to variations of the pumping rates were calculated using the detrended data.

3.5.1.1.1 Aquifer thickness estimate

Compared with previous aquifer test analyses at the refinery, the greatest change in the conceptual model is that permafrost has been encountered in newer wells closer to the extraction well system than previously thought given the timing of development of the refinery, its proximity to the Tanana River, and lack of permafrost in the GVEA well log. Permafrost depth data continue to be collected.

A representative value for the saturated thickness of the suprapermafrost aquifer of 150 feet was used in the aquifer test analyses, compared with a value of 590 feet used previously. In other words, the current analyses apply to the suprapermafrost aquifer. As described in Section 7.3.5, additional deep onsite monitoring wells are planned, which should provide additional information regarding permafrost depth and aquifer thickness.

The representative saturated thickness estimate of 150 feet is based on comparison of depth to permafrost in the vicinity of the extraction system. For example, in VPT area north of the extraction wells, the top of permafrost ranges from 70 feet below ground surface to greater 150 feet (see Figure 36). None of the 150-foot deep borings in the central portion of the refinery encountered permafrost (from areas southwest of the extraction well array to areas northeast of the extraction wells, see Figure 35). Figure 33 shows that northwest of the extraction wells, the top of permafrost decreases from depths of 59 to 110 feet below ground surface (see wells MW-153B, MW-301-70, and MW-302-110) to greater than 150 feet below ground surface near the recovery wells (see wells MW-199 and MW-307). Likewise, Figure 34 shows that in a section passing through the extraction well array, the top of permafrost ranges from 102 to 151.5 feet below ground surface

3.5.1.1.2 Aquifer Boundary Evaluation

Aquifer boundaries near the extraction system that might have influenced the aquifer test include the possibility of induced recharge from the Tanana River and the influence of permafrost. Calculations indicate that, given the low specific yield of the formation, the influence of the Tanana River might have affected the data. However, a boundary was tested using AQTESOLV and no appreciable deviation in the type curves for the solution resulted (Figure 15 of Appendix T). In addition, no indication of a recharge boundary caused by infiltration from the river was apparent in the aquifer test data.

Likewise, no indication of a barrier boundary was apparent in the aquifer test data. Such a response would be expected if a large mass of shallow permafrost is located close to the extraction system.

3.5.1.1.3 Analyses Performed

Analyses of the combined recovery and pumping phases were performed as follows. The recovery period was simulated in AQTESOLV using negative pumping rates. In other words the recovery following system shut-down was simulated as injection, applying the principle of superposition (Kruseman and deRidder, 1991). This produces negative displacements during the recovery phase, so the analyses have to be shown with linear axes, whereas log-log plots are typical for pumping tests. The pumping period was simulated by entering a rate equal to the difference between the pumping rate prior to the testing and the rate after the pumps were turned back on. Well R-21 was turned on at a substantially higher rate than it was pumped prior to shut down. Otherwise the rates were similar before and after the shutdown (Table 24).

Data from the MW-186 nest were analyzed first. Wells MW-186B and MW-186C are substantially deeper than the other wells that were monitored. In order to retain the information these deeper wells provide regarding vertical anisotropy (the ratio of vertical hydraulic conductivity to radial hydraulic conductivity), data from each of the shallower wells in which water levels showed a substantial response to the aquifer testing were combined with the data from MW-186B and MW-186C and analyzed. Use of composite plots of drawdown observed at more than one location and inclusion of effects of partial penetration is the recommended practice (Moench, 1994). Analyses are summarized in Table 25. The figure numbers for the corresponding AQTESOLV analyses in Appendix T are indicated.

The recovery phase did not reach a steady state before the pumps were restarted. Consequently, the drawdown estimates would need to be corrected for the additional rise in water level that would have occurred due to the pump shutdown as projected through the pumping period if they are to be used in an analysis by themselves. This correction was calculated for wells MW-186A, B, and C and the pumping phase data analyzed (see Figure 14 of Appendix T). The aquifer parameters calculated in this analysis are very comparable to those from the combined recovery/pumping data.

3.5.1.1.4 Discussion

The storage coefficient was insensitive in these analyses, typically reaching its lower bound, but not appreciably affecting the data if it were placed at any value in the allowed range of 1.5×10^{-5} to 1.5×10^{-3}. Some of the analyses produced storage coefficients at the upper bound allowed in the analyses. The elastic response to the testing is apparently so rapid and so small in magnitude that it could not be measured.

The specific yield values are relatively low, which may reflect the heterogeneity of the aquifer system (Moench, 1994) and the influence of silty and sandy material within the gravel deposits at the water table (e.g., see Pool and Eychaner, 1995).

Based on the current estimate of saturated thickness of the suprapermafrost aquifer, the estimated hydraulic conductivity in the vicinity of the recovery well system ranges from 310 to 450 m/day (1,000 to 1,500 ft/day), with a geometric mean value of 400 m/day (1,300 ft/day).

3.5.1.2 Single-well Pumping Test Results

Transmissivity and hydraulic conductivity values estimated from the single-well pumping tests are summarized in Table 12. The AQTESOLV well test analysis summaries are included in Appendix H. Hydraulic conductivities are calculated from the transmissivity and well screen length for each well and ranged from approximately 50 to 10,700 ft/day. The hydraulic conductivity of 10,700 ft/day at well MW-154A was nearly two orders of magnitude relative to the other measurements. The geometric mean of the hydraulic conductivities measured at the site, excluding well MW-154A, is approximately 200 ft/day while the standard deviation of the dataset is approximately 180 ft/day.

The transmissivity and hydraulic conductivity values derived from the short-duration testing suggest significant heterogeneity exists within the geologic formation around the test wells, as indicated by the nearly three order-of-magnitude range in values estimated. Variation in the test results can be due in part to differences in well efficiency, varying degrees that the wells are screened across the aquifer, the relatively short test duration, and heterogeneity in aquifer geology and aquifer hydraulic properties. For these reasons the transmissivity and hydraulic conductivity values should be considered as indicating relative differences in aquifer properties across the area tested rather than as absolute values of these aquifer parameters. Due to its longer duration and use of observation wells, the aquifer transmissivity and hydraulic conductivity values derived from the 2011 recovery well pumping test (Section 3.5.1.1) are more representative of the aquifer parameters in the vicinity of the recovery wells.

3.5.1.3 Single-Well Tracer Testing Results

After tracer was introduced, tracer washout was monitored and evaluated to estimate well-specific groundwater flux at a local scale. Using these estimates, flow variability can be evaluated and mapped across a site. These estimates of groundwater flux are reliable because they are a direct measurement of washout as it occurs in the well. Direct estimates of groundwater flux on a well by well basis may be different than the overall groundwater flux observed across the site due to localized variations in permeability, also known as heterogeneity. Theoretically groundwater flux and hydraulic conductivity are related through Darcy's Law in which flux is equal to hydraulic conductivity multiplied by hydraulic gradient. However, in order for this relationship to yield accurate results at sites, the actual hydraulic gradient through a test well must be known. Since hydraulic gradients are estimated for the site using head measurements obtained at wells that may be tens to hundreds of feet apart, it is not uncommon to observe some amount of variability when attempting to relate the two quantities.

Darcy flux is defined as the volume of groundwater flowing through a unit area of saturated soil per unit time while groundwater velocity indicates the amount of time it takes a hypothetical particle of water to traverse a given distance and may be estimated using a form of Darcy's Law which equates groundwater velocity to hydraulic conductivity times hydraulic gradient divided by mobile porosity (Freeze and Cherry, 1979). Groundwater velocity calculations based on hydraulic head and conductivity measurements essentially provide an average of site conditions, whereas direct point measurement of groundwater flux is sensitive to heterogeneities at a smaller scale.

The results indicate that, at many locations, 90% of the washout occurred within the first day of monitoring (i.e. MW-101A and MW-139); however, there were several wells (i.e. MW-144A, MW-145 and MW-150A) that showed slower washout and required more than 2 days to demonstrate 90% washout. Calculated groundwater flux estimates based on observed washout indicate the groundwater flux through the aquifer ranges from 0.008 to 0.57 ft/day. The results of the tracer washout evaluation are presented in Table 26. Appendix U shows normalized tracer decay as a function of time for all wells investigated.

Closer evaluation of the data obtained for MW-101, MW-131, MW-154A and MW-154B, suggested that the water column in the well may not have been adequately mixed, therefore, a range of groundwater flux values have been estimated for these locations. MW-101, MW-154A and MW-154B had long water columns (greater than 60 feet), which would have contributed to uneven mixing. Although the water column in MW-131 (14 feet) was not as long as that observed at MW-154A and MW-154B, uneven mixing was observed. The range of values presented is based on groundwater flux calculated using the entire water column compared to the groundwater flux calculated based on only the saturated screen interval.

The range in groundwater flux estimated from the single well tracer tests reflects the heterogeneity observed during drilling, based on grain size distribution differences in soil samples. Boring logs at the tested wells confirm variability in the lithology, which ranges from fine sands to sandy gravels. Correlation of lithology and groundwater flux estimates indicate the lowest estimates of groundwater flux at MW-144A, MW-145 and MW-150A correspond with the finer-grained materials (fine sand, silty fine sand) while the highest groundwater flux estimates (MW-101A, MW-131, and MW-139) correspond to the wells with coarser-grained materials in the screen interval (sand, sandy gravel).

Correlation of groundwater flux and hydraulic conductivity estimates from the single well pumping tests (Figure 46) indicate there is a larger range in hydraulic conductivity than there is in groundwater flux at the site. Hydraulic conductivities measured at the site using the single well pumping test method generally ranged approximately two orders of magnitude across the tested wells while groundwater flux generally varied approximately 1.5 orders of magnitude. As a result, the hydraulic gradients estimated from the SWTT data and measured hydraulic conductivity values also varied by one to two orders of magnitude. This is not unexpected, and is indicative of localized variability in the hydraulic gradient between monitoring wells that may not be evident on a site-wide scale using other methods. Using the SWTT data, the geometric mean of the estimated hydraulic gradient at individual wells ranged from of 0.0004 to 0.0013, which brackets the measured site-wide hydraulic gradient of 0.001. It is worth noting that the calculation of groundwater flux at the vertical profiling transect (Section 3.8.2.7) was based on a constant assumed hydraulic gradient of 0.001, this is on the higher end of the calculated range for individual wells, and would result in groundwater flux estimates that are higher than those observed using the SWTT method.

Groundwater velocity was not calculated for the site because field measurement of the mobile (effective) porosity proposed as part of the large tracer test has not been completed yet. Groundwater velocity calculations based on the tracer test data will be presented to ADEC in the 2012 SCRA. FHRA recommends removing testing on wells MW-113, MW-125, MW-186A, and S-39 from the planned scope of work because a sufficient amount of data has been collected to evaluate subsurface heterogeneity to support feasibility analyses of potential remedial technologies and remedial alternatives. These data include the 17 single well tracer tests, single well pump tests and more detailed geologic logging during installation of the VPT wells.

3.5.1.4 Summary of Hydraulic Conductivity Estimates and Applications

The hydraulic conductivity of saturated materials within the suprapermafrost aquifer has been estimated using numerous techniques as described in the preceding subsections of this report. As would be expected of an aquifer formed in a braided stream environment of deposition, and as documented in the literature regarding the region cited above, the hydraulic conductivity estimates range over orders of magnitude. Site-specific hydraulic conductivity estimates range from 1.1 to 14,000 ft/day and are summarized as follows:

- Estimates based on grain size analyses range from 1.1 to 14,000 ft/day with three of the 109 values exceeding 1,000 ft/day;

- Estimates based on 2009 testing of the recovery well system using a saturated thickness of 150 feet range from 500 to 2,300 ft/day;

- Estimates based on the single-well pumping tests range from 50 to 10,700 ft/day;
- Estimates based on 2010 aquifer testing of the new City of North Pole wells range from 700 to 1,100 ft/day;
- Estimates based on 2011 testing of the recovery well system ranged from 1,000 to 1,500 ft/day based on an estimated saturated thickness of 150 feet; and
- Estimates based on the single-well tracer tests range from 9 to 670 ft/day.

The variability of hydraulic conductivity in the subsurface is critical in the evaluation of many aspects of the site characterization and evaluation of potential remedial alternatives because the degree and pattern of heterogeneity at a site dictates the feasibility and effectiveness of remedial technologies. To the extent possible, site-specific data have been utilized in all aspects of the site characterization as summarized below. This is in recognition of the high degree of variation in hydraulic conductivity observed both horizontally and vertically in the aquifer.

- Mass flux estimate at the VPT. Data from aquifer tests within and near the VPT were used in this estimate (see Section 2.6.2.4)
- Groundwater capture evaluation. Aquifer testing results and available geologic and water level information as of the end of the third quarter of 2011 were used in calibrating the groundwater flow model and in evaluating the extent of capture of the groundwater extraction system (see Section 5.1.1.1 and Appendix Q).
- LNAPL mobility. Modifications to the relative permeability of the aquifer materials with respect to LNAPL and LNAPL transmissivity were estimated using site-specific testing (see Section 7.5.2)

The density of available data for the groundwater flow model, which covers approximately 250 square miles, varies widely with location due to the nature of the investigation and locations of wells installed by others. The available data have been incorporated to the extent possible (see Appendix Q). As noted above, the version of the groundwater flow model presented in this report was based on data collected through the end of the third quarter of 2011. Horizontal hydraulic conductivity values in the groundwater flow model range from 0.028 ft/day to 1530 ft/day (see Table 5 of Appendix Q). Figures showing the spatial distribution of hydraulic conductivities are included as Figures 4-3a, 4-

3b, 4-3c, and 4-3d of Appendix Q. The lowest values in the model represent the silty units found at or near the water table.

3.5.2 Potentiometric Surface Elevation

The water table at NPR and offsite is shallow, typically occurring within 15 feet of the ground surface. Gravel pits excavated below the water table on the western portion of the site have filled with groundwater. The water table typically occurs within the alluvial sand and gravel although, in some cases, it may occur in the silty slough deposits.

Fourth quarter 2011 groundwater elevation data are shown in Table 27; historical data are provided in Appendix V. Onsite the elevation of the water table varied from approximately 480 feet MSL to 490 feet MSL, decreasing from southeast to northwest. Offsite, the water table elevation varied from approximately 460 to 485 feet MSL, and decreases in elevation to the northwest, mimicking the gradually decreasing elevation of the ground surface (Figure 47). The elevation of the potentiometric surface associated with deeper portions of the aquifer, as indicated by wells completed in the 15 to 55 feet BWT interval is similar to the water table, as shown on Table 27.

The water table is known to fluctuate in elevation; historical data indicate it may fluctuate up to nine feet at some locations (SWI, 2002). This is consistent with values reported by Glass, Lilly, and Meyer (1996, p. 13). Hydrographs for well MW-138 (Figure 48) and R-20 (Figure 49) show that the water table has fluctuated up to four feet since 2007. The groundwater elevation typically decreases during winter and early spring, with the lowest elevations occurring from late March through May. Elevations appear to increase during June and July, peaking during late July or August. Elevations then typically decrease through the remainder of the year (Figures 48 and 49). These variations are similar to those observed at three shallow wells maintained by the United States Geological Survey (USGS) as part of its Active Groundwater Level Network as shown as Appendix W. Water levels in these wells have been observed to fluctuate from 3 to 4 feet in the period of record 2001 to 2011.

Data from wells with pressure transducers and data loggers also confirm this pattern of fluctuation. The data from the MW-151 and MW-186 well nests as shown on the hydrographs in Appendix X indicate increasing groundwater elevations in December 2010, followed by decreasing elevations though March 2011. Water levels rose after mid-April, and then fluctuated until early September, after which they have consistently fallen. Groundwater elevations at the MW-170 nest (Appendix X) increased during December 2010, decreased during January and February 2011, increased during early March, and were stable in later March. Since that time, the water levels in the MW-170 nest have followed similar trends to those in the MW-186 nest. Water levels in the MW-162 nest (Appendix X) vary in a manner similar to the MW-170 nest, although the relative difference between the peak elevations in well MW-162A are less than those in the MW-170 nest. Hydrographs from onsite observation wells, while not measured as frequently, show a similar pattern (Appendix X).

Groundwater level fluctuations have been noted that do not coincide with the period of elevated discharge of the Tanana River. A rise and fall in water levels was noted in late April to early May 2011 in many of the wells. This event may have been caused by ice on the Tanana River creating backwater conditions (Meyer, 2012). This event has not been observed every year in the USGS wells southeast of NPR. A similar rise in groundwater levels that is unrelated to the Tanana River discharge occurs in the early winter (Appendix X). This event may also be caused by ice on the Tanana River creating backwater conditions. See Appendix W for additional details.

During October 2011, the tops of the well risers were resurveyed to determine the degree to which frost heaving had changed the elevations of these measuring points. The hydrographs shown in Appendix X show the offsets created by the change in the measurement datum in these wells. Evaluations of the influence of frost heaving and evaluation of data collected since October 2011 are on-going.

3.5.3 Flow Direction and Horizontal Hydraulic Gradient

Beyond the zones of influence of the NPR groundwater recovery system, groundwater flow directions are controlled by recharge from the Tanana River to the aquifer and discharge from the aquifer to the Chena River, as described by Glass, Lilly, and Meyer (1996, p. 39). Variations in river stage over time are believed to be the primary cause of variations in flow direction through the aquifer between the rivers (for example, see Lilly, et al., 1996 and Nakanishi and Lilly, 1998, p. 4). Based on data from USGS water table wells, the flow direction varies up to 19° from a north-northwesterly direction to a few degrees east of north (Appendix W). The flow direction trends to the north-northwest in spring and more northerly in the summer and fall (Glass, Lilly, and Meyer, 1996).

Data from the three USGS wells closest to NPR indicate a slope on the water table ranging from 4.5 to 6.5 feet per mile. These wells are located near the Tanana River, southeast of NPR (see Figure 50). Data from the USGS Active Groundwater Level Network wells were included in Appendix W.

Flow directions are being monitored in the suprapermafrost aquifer at NPR, and north and west of NPR. Data loggers have been deployed in seventeen wells and are programmed to record water levels on a daily to hourly basis. The direction and magnitude of the hydraulic gradient in the aquifer can be estimated using groups of three wells completed at similar depths and arranged in a triangular pattern. Plots of the water level data and flow direction for ten combinations of the wells completed in the upper 10 feet of the suprapermafrost aquifer are shown on figures in Appendix Y. Excluding the likely outliers discussed in Appendix Y, the calculated flow directions show similar ranges (up to 25.7 degrees) to those from the USGS wells southeast of the refinery (described in Appendix W). The differences between the rose diagrams shown on Figures 2a and 2b of Appendix Y suggest that frost jacking of well casings and periodic changes to the well casing elevations may require that the flow variation data be considered only in groups between surveys. Handling the data in this way will still provide an estimate of the variability in flow direction, although some uncertainty may exist as to the actual direction of flow. This was the only group of wells for which flow direction could be calculated before and after the resurvey. As described in Appendix Y, a standard operating procedure is being developed to handle frost jacking and other issues related to the data logger program. Errors associated with the water level estimates from the data logger program will be estimated and the influence of those errors on the estimates of flow directions and horizontal hydraulic gradients will be evaluated in the future.

Horizontal hydraulic gradients were also calculated between the groups of wells. The gradients tend to be greatest in the summer when the Tanana River stage is highest and recharge from the river to the alluvial aquifer is greatest. The calculated horizontal hydraulic gradient for the period of record ranged from 0.0007 to 0.0028 (3.7 to 15 feet per mile). An apparent offset in the calculated horizontal hydraulic gradient between wells MW-111, MW-113, and MW-186A occurred when the casing elevations were corrected for frost jacking on October 6, 2011 (see Figure 3 of Appendix Y). This was the only group of wells for which horizontal hydraulic gradient could be calculated before and after the resurvey.

3.5.3.1 Third Quarter 2009

Groundwater elevation data from a period of high water table conditions during August 2009 were plotted on a site map and contoured (Figure 47). The map shows that the water table occurs at an elevation between 484 and 489 ft MSL. The contours indicate the shallow groundwater flows in a north-northwesterly direction. The map also depicts localized depressions in the water table in the vicinity of the active recovery wells R-21, R35, R-39, and R-40.

3.5.3.2 First Quarter 2011

Figure 51 shows a map of groundwater elevations measured manually in onsite and offsite water table wells on March 25, 2011. Figure 52 shows a map of groundwater elevations collected automatically using the transducers and data loggers in onsite and offsite water table wells on March 11, 2011. This date was chosen as it offered the most complete data set from the various wells with transducers. However, data were not available from MW-113 (gap in measurements between January 19 and March 15, 2011), MW-150A (no data were available until June 2011), and MW-158A (was not functioning). Both maps present data collected during a period of seasonally low water table elevations. Flow directions are more northwesterly at these times than during the period of higher water levels shown on Figure 52, which is consistent with the regional information described above.

The horizontal gradient in deeper portions of the aquifer, as indicated by wells completed in the 15 to 55 feet BWT zone, also appears to be in a northwesterly direction (Figure 53).

3.5.3.3 Second Quarter 2011

An onsite groundwater elevation contour map is shown on Figure 54 based on groundwater elevations measured in June 2011. As seen on Figure 54, a depression in the groundwater contour is present across NPR in the area of the active recovery wells. New recovery well R-42 was installed to expand the groundwater capture zone to the west, as described in the IRAP (Barr 2010b).

3.5.3.4 Third Quarter 2011

During the third quarter of 2011 reporting period, groundwater appeared to flow to the northwest, which is consistent with historical groundwater data. Potentiometric maps are included for three monitoring zones: water table, 10 to 55 feet BWT, and 55 to 90 feet BWT (Figures 55 through 59). Evaluation indicates a northerly flow direction onsite at the water table (Figure 55), and in the 55 to 90 foot zone (Figure 59) while a northwesterly direction is indicated onsite for the 10 to 55 foot zone (Figure 57).

3.5.3.5 Fourth Quarter 2011

During the fourth quarter of 2011, the groundwater gradient indicated flow to the northwest, which is consistent with historical groundwater data. Potentiometric maps are included for three monitoring zones: water table, 10 to 55 feet BWT, and 55 to 90 feet BWT (Figures 60 through 64). Onsite groundwater gradients of 0.004 ft/ft, 0.007 ft/ft, and 0.008 ft/ft were calculated for the water table, the 10 to 55 foot’ BWT, and 55 to 90 foot BWT groundwater zones, respectively. Offsite groundwater gradients of 0.006 ft/ft and 0.005 ft/ft were calculated for the water table and 10 to 55 foot BWT groundwater zones, respectively. Groundwater gradients observed during the reporting period are consistent with historical groundwater gradients.

3.5.4 Vertical Gradients

As noted above in Section 3.5.2, hydrographs have been prepared using data collected from automated loggers installed in well nests, including onsite nest MW-186, and offsite nests MW-150, MW-151, MW-162, and MW-170 (Appendix X).

Vertical hydraulic gradients as measured within well nests were calculated for wells monitored with data loggers and using synoptic rounds of manual water level measurements (see Appendix Y). By convention, negative vertical hydraulic gradients indicate an increasing hydraulic head with depth in the aquifer and suggest movement of water from deeper in the formation toward the shallower portion of the formation. The MW-162 well nest (permafrost at approximately 60 feet BWT) exhibited a consistent downward (positive) vertical hydraulic gradient (Appendix Y Figure 33). The MW-170 well nest (permafrost at approximately 125 feet BWT) exhibited a consistent upward (negative) vertical hydraulic gradient between MW-170A and MW-170C (Appendix Y Figure 34). Well MW-170A has a lower hydraulic head than any other well in the nest (see Table Y-1). Well nest MW-150 (permafrost estimated at approximately 60 feet BWT) exhibited vertical hydraulic gradients that varied from positive in the summer to negative in the winter (Appendix Y Figure 31). The vertical hydraulic gradients in the MW-151 well nest were consistently upward (negative) from MW-151C to the shallower wells and varied from positive to negative between MW-151A and MW-151B (Appendix Y Figure 32). The vertical hydraulic gradients in the MW-186 well nest (no permafrost encountered at 127 feet BWT) were nearly all negative between all combinations due to the influence of the recovery well system (Appendix Y Figure 35).

Vertical hydraulic gradients calculated between the shallowest and deepest wells in well nests measured on or about 4/12/2011 and 7/14/2011 are plotted on Appendix Y Figures 36 and 37, respectively. Vertical gradients were primarily downward on 4/12/2011 (6 downward, 3 neutral, 2 upward). Vertical gradients were primarily upward on 7/14/2011 (9 downward, 0 neutral, 22 upward).

The magnitudes of the estimated vertical hydraulic gradients were affected by the effects of frost jacking, but none of the directions of the gradient changed following the resurvey in October 2011. As described in Appendix Y, a standard operating procedure is being developed to handle frost jacking and other issues related to the data logger program. Errors associated with the water level estimates from the data logger program will be estimated and the influence of those errors on the estimates of vertical hydraulic gradients will be evaluated in the future.

3.5.5 Permafrost Influences

Previous investigations indicate permafrost may be absent beneath the Tanana River, Chena River, and Chena Slough (Appendix Q). Discontinuity in the permafrost beneath the Tanana River was shown conceptually on Figure 13 of the SCWP (Appendix Z). This is a critical factor in the hydrogeologic conceptual model because, as described above, these rivers are the primary sources and sinks for water in the aquifer.

As noted in the SCWP, the permafrost between the rivers is believed to be discontinuous. Residential wells logs in the North Pole area indicate maximum depths of permafrost ranging from 90 feet to 230 feet BGS. Many of the smaller-capacity water supply wells in the North Pole area and the new monitoring wells installed by NPR are completed above the top of the permafrost, in what is termed the suprapermafrost aquifer. Total depths of these wells range from less than 40 to 150.5 feet BGS. These shallow wells have been installed in the suprapermafrost aquifer because this aquifer does not completely freeze seasonally as it does in areas where the bottom of the suprapermafrost aquifer is closer to the surface and seasonal frost penetrates the aquifer.

Unfrozen aquifer material below the permafrost is termed the subpermafrost aquifer (e.g., Williams, 1970). Geochemistry measurements were collected from shallow and deep wells, as described in Section 2.7, and is discussed in Section 3.10.

Many authors indicate permafrost is essentially impermeable (e.g., see Williams, 1970, pp. 1 and 24; Sloan and van Everdingen, 1988, p. 264). Bolton (2006, p. 49) indicates that permafrost forms an aquiclude at the base of the suprapermafrost aquifer. In other words, permafrost does not transmit significant quantities of water under ordinary hydraulic gradients. Others discuss processes that can lead to fracturing in the upper meter or so of permafrost and diffusion of contaminants in unfrozen water within permafrost at rates of centimeters per year, typically in areas in which the top of the permafrost is subject to greater seasonal temperature variations than in the North Pole area (see Biggar, 2004 and McCarthy, Walker, and Vigoren, 2004).

Permafrost will modify localized groundwater flow and contaminant transport in the Tanana River Valley. As discussed by Carlson and Barnes (2011), permafrost creates low-permeability zones that create converging and diverging groundwater flow paths in response to its distribution. Contaminants migrating in groundwater influenced by permafrost will also be expected to show more variable concentration patterns in response to the divergent and convergent groundwater flow patterns. In the vicinity of the sulfolane plume undulations in the permafrost surface and the reduction in the aquifer thickness would also result in increased flow velocities from south to north.

In the offsite study area, groundwater, and therefore sulfolane, may be migrating up and over the shallow permafrost areas noted in Figures 42 and 44. The broadening of the plume appears to correspond with the area of shallow permafrost.

Although sulfolane has been detected in additional subpermafrost private wells, the mechanism by which it has entered these wells has not been determined. Performance of further studies, such as a tracer-test to evaluate private well casing seal integrity, has been suggested by ADEC. This evaluation will be considered as part of the offsite related activities anticipated to be performed in 2013.

3.6 Soil Impacts

Evidence of soil impacts has been observed onsite at NPR historically, during the laboratory drain investigation, during the sump investigation, and during the 2011 onsite soil investigation. The 2011 soil investigation data are fully validated; soil impacts are evaluated below.

Results from offsite sampling indicate no soil impacts.

3.6.1 Historical Results

Historical analytical data (Appendix I) from the four soil borings and four monitoring wells installed in 2001 (Figure 14) indicated that ADEC soil cleanup levels (SCLs) were exceeded as follows:

- Benzene at B-1, B-2, B-4, MW-135, and MW-139;
- Toluene at MW-135;
- Ethylbenzene at B-1, B-4 and MW-135;
- Xylenes at B-1 and MW-135;
- Naphthalene at B-1; and
- GRO and DRO at B-1, B-4, and MW-135

Arsenic was also reported to exceed SCLs at all locations; however, the concentrations are consistent with natural background levels in the region (USCOE, 1994). Arsenic is discussed further in Section 3.6.2.2.3.

Since the samples were collected within the range of water table fluctuations, it is unknown if the impacts were due to a release near the boring, or from impacts that had migrated in groundwater. The soil impacts were not delineated horizontally or vertically (Appendix I).

Analytical data for samples collected in 2004 from the railcar-loading area indicate surficial soils (<1 foot BGS) collected at twelve of the fifteen sampling locations contained RRO at concentrations that exceed the SCL. Deeper soil samples collected at each of these twelve locations were reported to contain RRO; however, the concentrations were below the SCL. DRO concentrations in thirteen of the fifteen samples exceeded the SCL. At eight of these locations, the deeper sample also contained DRO at a concentration exceeding the SCL. No further work was completed to determine the depth of the DRO impacts (Appendix I).

3.6.2 Site Characterization

3.6.2.1 Well Bore Samples

As stated in Section 2.4.4, soil samples were selected for laboratory analysis from the well screen intervals of several well borings installed in 2010. Soil samples exhibiting evidence of impacts were collected from onsite well borings.

No soil samples collected from offsite well borings were reported to contain sulfolane (Table 28). Resulting analytical data from the onsite well borings indicated that ADEC SCLs were exceeded as follows:

- BTEX, 2-methylnaphthalene, GRO, and DRO in a soil sample collected near the water table at MW-175;
- Benzene, xylenes, 2-methylnaphthalene, GRO, and DRO in a sample collected from 5.0 to 6.5 feet BGS at MW-176C;
- Benzene, 2-methylnaphthalene, and DRO in a sample collected near the water table MW-178C;
- Benzene in a sample collected near the water table MW-180C;

- Benzene, ethylbenzene, and 2-methylnaphthalene in a sample collected near the water table MW-186C;
- BTEX; 1,2,4-TMB; 1,3,5-TMB; n-butylbenzene; n-propylbenzene; sec-butylbenzene; naphthalene; 2-methylnaphthalene; dibenzofuran; GRO; and DRO in samples collected near the water table (7.5-11.5 feet BGS) at O-2; and
- Benzene in a sample collected from below the water table (15-16.5 feet BGS) at O-2.

At MW-175, MW-176C, MW-178C, MW-180C, and MW-186C, the depths of the impacted zones exceeding SCLs are unknown since no additional samples were collected, or the next analytical sample was at least 75 feet below the impacted sample. The horizontal extent of the impacted zones was not delineated at that time.

At O-2, results from the deeper sample (14-15.5' BGS) indicated most of the compounds exceeding SCLs were confined to the interval near the water table. The horizontal extent of the impacted zone was not delineated at that time.

Sulfolane was reported in soil samples collected near or below the water table at O-1 and O-2 (Table 28). Analysis of soil samples collected in 2011 indicates significant interference with sulfolane results when hydrocarbons are present. A revised method for sample extraction and sulfolane analysis has been developed. ESI reviewed the 2010 sulfolane soil results and determined that one had been estimated high due to hydrocarbon interferences; at ESI's request SGS reissued the laboratory report for these samples. Sample O-1 (15-16.5) did not change in the reissued laboratory report.

3.6.2.2 Onsite Soil Investigation

Samples obtained from borings and monitoring wells for the 2011 soil investigation were submitted to SGS for analysis of the standard and COPC analyte lists. A total of 83 soil borings, 24 observation wells (wells O-5 through O-29) and seven monitoring wells (MW-144B, MW-192A, MW-192B, MW-195, MW-196, MW197B, and MW-307) yielded 301 soil samples. These included 103 surface soil samples (0 feet to 2 feet BGS). Soil data were fully validated and results are presented in subsequent sections and summarized in Tables 29 through 35 for BTEX, sulfolane and other COPCs including petroleum hydrocarbons, VOCs, SVOCs, PAHs and metals. Results for sulfolane and benzene were categorized into four sample depth zones and borings with data in the four zones are on

Figures 65 through 68: surface soil (0 to 2 feet BGS), unsaturated soil (2 to 7 feet BGS), smear zone (7 to 10 feet BGS) and saturated soil (10 to 18 feet BGS).

For the data evaluation presented below, the 7 to 10 foot BGS soil zone is considered to be the smear zone. Sample depths that spanned two designated soil zones were categorized based on the bottom depth (e.g., a sample depth of 6.5 to 7.5 feet BGS was assigned to the 7 to 10 foot BGS zone). The remaining COPC results were not depicted on figures due to the limited number of detections and/or co-location with benzene detections. Validated soil data are evaluated below.

3.6.2.2.1 Benzene, Toluene, Ethylbenzene and Total Xylene Concentrations in Soil

Concentrations of BTEX exceeded their corresponding migration-to-groundwater (MTG) SCL (ADEC 2006) in 79 soil samples collected during 2011. Exceedances for each constituent are listed below:

- Benzene exceeded its MTG SCL of 0.025 mg/kg in 79 soil samples, ranging in concentration from 0.0277 mg/kg (O-27 [10.3 to 11 feet BGS]) to 36.3 mg/kg (SB-174 [7.5 to 9.5 feet BGS]).
- Toluene exceeded its MTG SCL of 6.5 mg/kg in 22 soil samples, ranging in concentration from 7.84 mg/kg (O-21 [6 to 8 feet BGS]) to 300 mg/kg (SB-174 [5.5 to 7.2 feet BGS]).
- Ethylbenzene exceeded its MTG SCL of 6.9 mg/kg in 35 soil samples, ranging in concentration from 8.32 mg/kg (MW-197B [15 feet BGS]) to 98.3 mg/kg (O-21 [6 to 8 feet BGS]).
- Total xylenes exceeded its MTG SCL of 63 mg/kg in 27 soil samples, ranging in concentration from 64.1 mg/kg (O-9 [6 to 8 feet BGS]) to 706 mg/kg (SB-180 [5.5 to 7.2 feet BGS]).

Because exceedances of toluene, ethylbenzene and total xylenes in soil correlate with exceedances of benzene, the distribution of benzene in soil at NPR is further discussed below and depicted on Figures 65 through 68. Data are provided in Table 29.

Surface Soil – 0 to 2 feet BGS

Benzene exceeded the MTG SCL in nine soil samples within the 0 to 2 foot BGS soil zone. Benzene concentrations exceeding the MTG SCL (0.025 mg/kg) ranged from 0.231JH mg/kg (SB-114; flagged by the laboratory as estimated) to 0.597 mg/kg (SB-128) in soil samples from borings O-21, SB-114, SB-128, SB-143, SB-146, SB-158, SB-160, SB-174 and SB-180. Soil analytical results for the 0 to 2 foot BGS soil zone are depicted on Figure 65.

Unsaturated Soil – 2 to 7 feet BGS

Benzene exceeded the MTG SCL in 17 soil samples within the 2 to 7 foot BGS soil zone. Benzene concentrations exceeding the MTG SCL (0.025 mg/kg) ranged from 0.0288 mg/kg (SB-143) to 30.9 mg/kg (SB-146) in soil samples from borings O-21, SB-110, SB-113, SB-114, SB-117, SB-122, SB-128, SB-134, SB-143, SB-146, SB-150, SB-151, SB-155, SB-160, SB-165 and SB-173. Soil analytical results for the 2 to 7 foot BGS soil zone are depicted on Figure 66.

Smear Zone – 7 to 10 feet BGS

Benzene exceeded the MTG SCL in 30 soil samples within the 7 to 10 foot BGS soil zone. Benzene concentrations exceeding the MTG SCL (0.025 mg/kg) ranged from 0.0938J mg/kg (O-7; flagged by the laboratory as estimated) to 36.3 mg/kg (SB-174) in soil samples from borings O-7, O-9, O-10, O-11, O-13, O-19, O-21, O-27, SB-109, SB-110, SB-111, SB-112, SB-114, SB-115, SB-120, SB-122, SB-123, SB-126, SB-130, SB-150, SB-151, SB-156, SB-158, SB-160, SB-165, SB-168, SB-173, SB-174, SB-175 and SB-180. Soil analytical results for the 7 to 10 foot BGS soil zone are depicted on Figure 67.

Saturated Soil – 10 to 18 feet BGS

Benzene exceeded the MTG SCL in 20 soil samples within the 10 to 18 foot BGS soil zone. Benzene concentrations exceeding the MTG SCL (0.025 mg/kg) ranged from 0.0277 mg/kg (O-27) to 2.27 mg/kg (MW-197B) in soil samples from borings MW-197B, O-11, O-13, O-20, O-21, O-27, O-29, SB-115, SB-117, SB-124, SB-126, SB-130, SB-134, SB-146, SB-150, SB-151, SB-156, SB-165 and SB-180. Soil analytical results for the 10 to 18 foot BGS soil zone are depicted on Figure 68.

Four samples were collected from the total depths of wells O-11, MW-144B, MW-192B and MW-197B. The sample collected from MW-197B at 50 to 52 feet BGS exhibited a concentration of benzene (0.390 mg/kg) exceeding the MTG SCL of 0.025 mg/kg. Benzene was not detected in soil samples from the three remaining wells.

3.6.2.2.2 Sulfolane Concentrations in Soil

Sulfolane exceeded its interim estimated screening level of 0.073 mg/kg, derived by ADEC from the interim goal for drinking water that was in effect for 2011, in 30 soil samples collected during 2011. The distribution of sulfolane in soil at NPR is further discussed below and depicted on Figures 69 through 72. Data are provided in Table 30.

Surface Soil – 0 to 2 feet BGS

Sulfolane was detected in three soil samples, but did not exceed the estimated screening level in any soil sample within the 0 to 2 foot BGS soil zone. Soil analytical results for the 0 to 2 foot BGS soil zone are depicted on Figure 69.

Unsaturated Soil – 2 to 7 feet BGS

Sulfolane exceeded the interim estimated screening level (0.073 mg/kg) in seven soil samples within the 2 to 7 foot BGS soil zone. Sulfolane exceedances ranged from 0.0772 mg/kg (SB-141) to 18.4 mg/kg (SB-143) in soil samples from borings O-6, SB-118, SB-141, SB-143, SB-144, SB-160 and SB-175. Soil analytical results for the 2 to 7 foot BGS soil zone are depicted on Figure 70.

Smear Zone – 7 to 10 feet BGS

Sulfolane exceeded the interim estimated screening level (0.073 mg/kg) in nine soil samples within the 7 to 10 foot BGS soil zone. Sulfolane exceedances ranged from 0.0751J mg/kg (SB-174; flagged by the laboratory as estimated) to 1.43J mg/kg (SB-175; flagged by the laboratory as estimated) in soil samples from borings O-28, SB-115, SB-158, SB-160, SB-173, SB-174, SB-175 and SB-180. Soil analytical results for the 7 to 10 foot BGS soil zone are depicted on Figure 71.

Saturated Soil – 10 to 18 feet BGS

Sulfolane exceeded the interim estimated screening level (0.073 mg/kg) in 14 soil samples within the 10 to 18 foot BGS soil zone. Sulfolane exceedances ranged from 0.0759 mg/kg (SB-120) to 2.75 mg/kg (SB-180) in soil samples from borings O-19, O-20, SB-109, SB-112, SB-113, SB-114, SB-117, SB-120, SB-122, SB-131, SB-134, SB-146, SB-158 and SB-180. Soil analytical results for the 10 to 18 foot BGS soil zone are depicted on Figure 72.

The laboratory was not able to determine if sulfolane was present in 37 soil samples due to interference from hydrocarbons. Samples with interference are denoted with an “R” in Table 30 and depicted with gray symbols on Figures 69 through 72.

3.6.2.2.3 Arsenic Concentrations in Soil

Arsenic concentrations at NPR were evaluated using the 95% Upper Confidence Limit of the Mean (95%UCL). The 95%UCL is a number that provides a 95% level of confidence that the true mean (average) concentration of the population of samples is below that value. In other words, the 95% UCL is the value that when calculated for a random data set equals or exceeds the true mean 95% of the time. Calculating a 95%UCL depends on the distribution of the dataset and variability in the data. Distribution testing and 95%UCL calculations were performed for the arsenic in soil data set using USEPA ProUCL software (Version 4.1; USEPA 2007) and implemented according to the recommendations provided in the associated technical documentation (USEPA 2006, 2007, 2011). ProUCL statistics are provided as Appendix AA. For the arsenic in soil data set that includes 70 samples (n=70) with a minimum concentration of 1.62 mg/kg and a maximum concentration of 17.6 mg/kg, the mean concentration (arithmetic average) was 5.5 mg/kg. Because the data were not normally distributed, as is common with environmental data sets, nonparametric tests were used to identify the 95%UCL of 7.3 mg/kg.

An evaluation of background metals concentrations was conducted by the U.S. Army Corps of Engineers (USACE) at Fort Wainwright, Alaska, located approximately 11 miles from the site. The USACE (1994) study concluded that background arsenic concentrations in the Fort Wainwright area were 8 ± 6 mg/kg south of the Chena River and 11 ± 6 mg/kg north of the Chena River. The USACE study also reported the mean for the State of Alaska as 17.3 mg/kg (USACE 1994). The NPR site-specific 95%UCL soil arsenic concentration of 7.3 mg/kg is less than half the Alaska mean (17.3 mg/kg) and less than the North Chena mean concentration (11 mg/kg) and South Chena mean concentration (8 mg/kg). These results indicate arsenic concentrations in soil at NPR are representative of background concentrations. Arsenic concentrations are summarized in Table 30 and are plotted against the mean concentrations near the Chena River and the State of Alaska mean values (Figure 73). NPR soil samples had arsenic concentrations that were detected within the background range for arsenic with the exception of one soil sample that slightly exceeded the Alaska mean of 17.3 mg/kg, at a concentration of 17.6 mg/kg (SB-101 [0 to 2 feet BGS]). This soil sample is located at the north property boundary and is likely related to fill material used for constructing the adjacent access road.

Arsenic concentrations were plotted against concentrations of other metals detected in NPR soil samples (Figure 74). The strong correlation ($R2 > 0.70$) of arsenic with copper, iron, nickel, and zinc (metals that are commonly present in soil minerals) indicate arsenic likely is naturally occurring. These correlations between arsenic and other common soil metals are significant at a 99% confidence level ($p<0.01$) and are consistent with the 95%UCL results, indicating that arsenic is present at background concentrations and is not a result of refinery activities. Additionally, soil arsenic concentrations were plotted against soil benzene concentrations (Figure 75). As shown, there is no correlation between soil arsenic and benzene concentrations indicating that detected concentrations of arsenic in soil are not co-located with petroleum impacts and are not a result of current or historical operations at NPR.

3.6.2.2.4 Other Contaminant of Potential Concern Concentrations in Soil

Other COPC concentrations in soil exceeded MTG cleanup levels in 99 samples. Tables 31 through 35 present the soil sample data for other COPCs evaluated in soil samples. Other COPCs include petroleum hydrocarbons, VOCs, SVOCs, PAHs and metals. Propylene glycol and isopropanol were inadvertently excluded from analyses in the COPC borings. Soil analytical results exhibiting concentrations exceeding their respective MTG SCL are summarized below.

Petroleum Hydrocarbons

Petroleum hydrocarbons GRO and DRO exceeded their respective MTG SCLs in nine soil samples collected during 2011 (Table 32). Exceedances for each constituent are listed below:

- GRO exceeded its MTG SCL of 300 mg/kg in eight soil samples, ranging in concentration from 314JH mg/kg (SB-175 [7 to 9 feet BGS]; flagged by the laboratory as estimated) to 1,520JH mg/kg (SB-151 [6.7 to 8.4 feet BGS]; flagged by the laboratory as estimated).

- DRO exceeded its MTG SCL of 250 mg/kg in nine soil samples, ranging in concentration from 252 mg/kg (MW-197B [15 feet BGS]) to 18,800 mg/kg (SB-160 [6.4 to 8.4 feet BGS]).

Volatile Organic Compounds

VOCs that exceeded their respective MTG SCLs include 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, cyclohexane, methylene chloride and n-hexane (Table 33). Twelve soil samples collected during 2011 exceeded one or more of the aforementioned VOCs. All VOC exceedances, with the exception of the seven exceedances of methylene chloride, correspond with benzene exceedances. Exceedances for each constituent are listed below:

- 1,2,4-Trimethylbenzene exceeded its MTG SCL of 23 mg/kg in four soil samples, ranging in concentration from 24.2 mg/kg (SB-160 [4.5 to 6.4 feet BGS]) to 61.3 mg/kg (SB-160 [6.4 to 8.4 feet BGS]).

- 1,3,5-Trimethylbenzene exceeded its MTG SCL of 23 mg/kg in soil sample SB-160 [6.4 to 8.4 feet BGS] at a concentration of 25.6 mg/kg.

- Cyclohexane exceeded its MTG SCL of 13 mg/kg in three soil samples ranging in concentrations from 17.2JH mg/kg (SB-123 [6.0-8.0 ft BGS]; flagged by the laboratory as estimated) to 44.9 mg/kg (SB-160 [6.4-8.4 ft BGS]).

- Methylene chloride exceeded its MTG SCL of 0.016 mg/kg in seven soil samples, ranging in concentration from 0.0282J mg/kg (SB-129 [7.5 to 8.7 feet BGS]; flagged by the laboratory as estimated) to 0.188JH mg/kg (SB-123 [3.5 to 5.2 feet BGS]; flagged by the laboratory as estimated).

- n-Hexane exceeded its MTG SCL of 6.2 mg/kg in three soil samples, ranging in concentration from 11.6 mg/kg (SB-160 [6.4 to 8.4 feet BGS]) to 13.0JH mg/kg (SB-123 [6 to 8 feet BGS]; flagged by the laboratory as estimated).

Semivolatile Organic Compounds

SVOCs, excluding PAHs, were not detected above MTG SCLs in any of the 66 COPC soil samples collected. Soil analytical data for SVOCs are summarized in Table 34.

Polynuclear Aromatic Hydrocarbons

PAHs that exceeded their respective MTG SCLs include 1-methylnaphthalene, 2-methylnaphthalene and naphthalene (Table 35). Thirty-five soil samples collected during 2011 exceeded one or more of the aforementioned PAHs. Thirty-four of the 35 soil samples with PAH exceedances correspond with benzene exceedances. Exceedances for each constituent are listed below:

- 1-Methylnaphthalene exceeded its MTG SCL of 6.2 mg/kg in 31 soil samples, ranging in concentration from 6.36 mg/kg (SB-117 [5 to 7 feet BGS]) to 88.5 mg/kg (O-21 [4 to 6 feet BGS]).

- 2-Methylnaphthalene exceeded its MTG SCL of 6.1 mg/kg in 35 soil samples, ranging in concentration from 6.43 mg/kg (SB-155 [5 to 6.3 feet BGS]) to 104 mg/kg (O-21 [4 to 6 feet BGS]).

- Naphthalene exceeded its MTG SCL of 20 mg/kg in five soil samples, ranging in concentration from 20.1JH mg/kg (O-11 [8 to 10 feet BGS]; flagged by the laboratory as estimated) to 57.6 mg/kg (O-21 [4 to 6 feet BGS]).

Metals

Metals that exceeded their respective MTG SCLs include total chromium, iron and nickel (Table 31). Each of the 65 soil samples collected during 2011 and analyzed for metals exceeded MTG SCLs for one or more of the aforementioned metals. Exceedances for each constituent are listed below:

- Total chromium exceeded its MTG SCL of 25 mg/kg in four soil samples, ranging in concentration from 31 mg/kg (SB-118 [2 to 3.7 feet BGS] and SB-140 [3 to 5 feet BGS]) to 50.9 mg/kg (SB-157 [0 to 2 feet BGS]).

- Iron exceeded its MTG SCL of 640 mg/kg in each of the 65 soil samples, ranging in concentration from 6,930 mg/kg (SB-151 [16 to 17.8 feet BGS]) to 29,000 mg/kg (SB-101 [0 to 2 feet BGS]).

- Nickel exceeded its MTG SCL of 8.6 mg/kg in 64 soil samples, ranging in concentration from 8.88 mg/kg (SB-129 [5.5 to 7.5 feet BGS]) to 38 mg/kg (SB-118 [2 to 3.7 feet BGS]).

Because iron and nickel concentrations are distributed across the site, exceedances are likely attributable to background concentrations for the area. Additionally, total chromium exceedances are unrelated to petroleum hydrocarbon impacts at NPR and likely attributable to background concentrations for the area (Alaska mean = 114 mg/kg; USACE 1994). As presented on Figure 76, there is no correlation between soil total chromium and benzene concentrations indicating that detected concentrations of total chromium in soil are not co-located with petroleum impacts and are not a result of current or historical operations at NPR.

Soil results from 2010 and 2011 sampling events are further evaluated in Section 3.6.5.

3.6.2.3 Downgradient Surface Soil Investigation

Sulfolane was not detected in any garden surface soil sample. TOC was detected in soil samples at concentrations ranging from 1.8 to 23.1%. Surface soil analytical results are summarized in Table 36.

3.6.3 Laboratory Drain Investigation

Soil sample analytical results from soil borings SBLAB-1 through SBLAB-5 were compared to the ADEC SCLs for migration to groundwater in the under 40-inch zone.

Soil samples collected from soil boring SBLAB-4 from 1.6 to 1.8 feet BGS and 3.8 to 4.0 feet BGS contained concentrations of DRO above the SCL of 250 milligrams per kilogram (mg/kg) with concentrations of 5,650 mg/kg (5,440 mg/kg in the duplicate sample) and 260 mg/kg, respectively. In addition, the soil sample collected from soil boring SBLAB-4 at 1.6 to 1.8 feet BGS contained a concentration of 1-methylnaphthalene above the SCL of 6.1 mg/kg with a concentration of 16.6 mg/kg (18.3 mg/kg in the duplicate sample).

Soil samples collected from soil boring SBLAB-1 from 3 to 3.2 feet BGS and 5.2 to 5.4 feet BGS contained concentrations of arsenic above the SCL of 3.9 mg/kg with concentrations of 4.92 mg/kg and 4.13 mg/kg, respectively. However, these concentrations are below naturally-occurring background concentrations in the area of NPR.

With the exceptions noted above, concentrations of the analyzed parameters were below the respective laboratory detection limit or SCL. Soil sample analytical results are summarized in Table 37. Soil sample analytical laboratory reports are included in Appendix L.

3.6.4 Sump Investigation

With the exception of DRO, concentrations of the analyzed parameters were below their respective SCLs in the soil sample collected at the Asphalt Sump. DRO was reported to be present at a concentration (2400 mg/kg) that exceeds the SCL (Appendix J).

The reported concentrations of DRO in the soil samples collected near the floor drain and the cleanout fitting associated with the Blend Building Sump exceeded the SCL. The concentrations of methylnaphthalenes exceed their respective SCLs in the sample collected near the cleanout fitting. Sulfolane was reported in the sample collected from beneath the floor drain. The impacted areas are located beneath a floor slab and are, therefore, protected from precipitation and potential leaching (Appendix J).

The reported concentrations of DRO, benzene, and the methylnaphthalenes in the base of excavation sample from the Tank Farm Truck Kero Sump exceeded their respective SCLs. The concentrations of GRO, DRO, and BTEX reported in the excavated soil samples were reported to exceed their respective SCLs. The impacted area is located beneath an indoor floor slab and is, therefore, protected from precipitation and potential leaching (Appendix J).

The 2009-2010 Sump Investigation is further described in FHRA's December 8, 2010 report to ADEC (Appendix J). The sump investigation was conducted pursuant to a March 16, 2011 work plan and under the direction of Brian Jackson of the ADEC Spill Prevention and Response Unit.

3.6.5 Onsite Soil Investigation Summary

Samples obtained from borings, observation wells and monitoring wells during the 2010 and 2011 soil investigations were submitted to SGS for analysis of the COPC analyte lists. Eighty-three soil borings, 28 observation wells and 31 monitoring wells yielded 358 soil samples. Laboratory analysis of soil samples collected during the 2010 and 2011 sampling events indicated the following COPCs exceeding applicable ADEC standards:

- BTEX: 86 soil samples
- Sulfolane: 33 soil samples
- Other COPCs: 104 soil samples

Other COPCs exceeding applicable ADEC standards include petroleum hydrocarbons (GRO and DRO), VOCs (1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, cyclohexane, methylene chloride and n-hexane), PAHs (1-methylnaphthalene, 2-methylnaphthalene and naphthalene), and metals (arsenic, total chromium, iron and nickel). All petroleum hydrocarbons, VOC and PAH exceedances correlate with samples exceeding the MTG SCL for benzene, with the following exceptions:

- one sample exceeding the MTG SCL for DRO
- seven samples exceeding the MTG SCL level for methylene chloride
- one sample exceeding the MTG SCL for 1-methylnaphthalene and 2-methylnaphthalene.

This suggests that benzene is a useful surrogate for tracking petroleum hydrocarbon contamination at NPR.

Sulfolane results were compared to the interim estimated screening level of 0.073 mg/kg, derived by ADEC from the interim goal for drinking water that was in effect for 2011. Benzene and sulfolane represent the majority of COPC exceedances in both soil and groundwater. Therefore, concentrations of benzene and sulfolane in soil were categorized into four main zones: surface soil (0 to 2 feet BGS), vadose or unsaturated soil (2 to 7 feet BGS), smear zone (7 to 10 feet BGS) and saturated soil (10 to 18 feet BGS). Results for each zone are presented on Figures 65 through 72. Sample points are color-coded to represent ranges of concentrations for each constituent to observe the distribution of exceedances at the site.

With the exception of limited soil impacts located near the fire training area, west of the railcar and truck-loading racks and metals exceedances, related to background conditions as discussed above, impacted soils correlate with process areas or areas of known releases as described in Section 3.1.2.2, including process areas (CU #1, CU #2, CU #3 and the EU), the area of the lagoons, product storage areas (e.g., tank farms), the railcar-loading rack area, and the current and former truck-loading rack areas (Figure 3). The distribution of exceedances in each soil zone is described below.

3.6.5.1 Surface Soil

Sulfolane concentrations did not exceed MTG screening levels in any surface soil sample (Figure 69).

Benzene exceedances were limited to seven general areas: CU #1, CU # 2, east of fire training area, east of containment area (CA) 1, south of CA 5A, east of CA 5B and the former truck loading rack (Figure 65). The majority of benzene impacts to surface soil are located within areas of measureable LNAPL and the dissolved BTEX plume. One exceedance (SB-143) is located outside the LNAPL and dissolved BTEX footprints, near the fire training area.

3.6.5.2 Unsaturated Soil (Vadose) Zone

Sulfolane exceedances were limited to the following general areas: the EU, east of fire training area, east of CA 1, northeast of Lagoon B and the former truck-loading rack (Figure 70). With the exception of impacts near the fire training area, impacts in the unsaturated soil zone are located within the footprint of the dissolved sulfolane plume described in Section 3.8.2.

Benzene exceedances were limited to nine general areas: CU #1, CU # 2, east of the fire training area, east of CA 1, northeast of CA 4, southeast of CA 5A, east of CA 5B, the former truck-loading rack and the current truck-loading rack (Figure 67). The majority of benzene impacts to unsaturated soil are located within areas of measureable LNAPL and the dissolved BTEX plume described in Section 3.8.1.

3.6.5.3 Smear Zone

Sulfolane exceedances were limited to six general areas: the EU, CU #1, east of Lagoon A, east of CA 1, south of CA 5A and northeast of CA 6 (Figure 71). Soil impacts within the smear zone correlate with groundwater concentrations within the sulfolane plume at the water table described in Section 3.8.2.

Benzene exceedances were detected in the following areas: CU #1, CU # 2, east of CA 1, south of CA 4, south of CA 5A, north and southeast of CA 5B, northeast and west of CA 6, south of CA 7, west of CA 8, the former truck-loading rack and the current truck-loading rack (Figure 67). Benzene impacts in the smear zone are located within areas of monitoring wells with measureable LNAPL and the dissolved BTEX plume described in Sections 3.7.1 and 3.8.1, respectively.

3.6.5.4 Saturated Soil Zone

Sulfolane exceedances were limited to seven general areas: CU #1, CU # 2, the exchanger wash skid area, south of CA 5A, CA 4, the former truck-loading rack and the current truck-loading rack (Figure 68). Soil impacts within the saturated soil zone correlate with groundwater concentrations within the core of the sulfolane plume at the water table described in Section 3.8.2.

Benzene exceedances were limited to eight general areas: CU #1, CU # 2, southwest of CA 5A, north of CA 5B, north and west of CA 6, north of CA 8, the former truck-loading rack and the current truck-loading rack (Figure 68). The majority of benzene impacts to saturated soil are located within areas of measureable LNAPL and the dissolved BTEX plume described in Sections 3.7.1 and 3.8.1, respectively. One exceedance (O-29) is located outside the LNAPL and dissolved BTEX footprints, near the north side of CA 8. One benzene exceedance was also detected in the soil sample collected from the bottom of boring MW-197B, which is located west of CA 6, indicating that impacted soils are present as deep as 52 feet BGS, which are likely related to benzene impacted groundwater.

3.6.5.5 Metals

As stated in Sections 3.6.2.2.3 and 3.6.2.2.4, the majority of arsenic and chromium exceedances are located outside of process areas and are likely attributed to background concentrations for the area (USACE 1994). The maximum arsenic detection of 17.6 mg/kg (SB-101 [0 to 2 feet BGS]) is located at the northern property boundary and is likely related to fill material used to construct the adjacent access road (Figure 65). The maximum total chromium exceedance of 50.9 mg/kg (SB-157 [0 to 2 feet BGS]) is located west of CA 8. As shown on Figures 75 and 76, exceedances of arsenic and total chromium at the site do not correlate with soil samples exhibiting exceedances of benzene or sulfolane and are therefore unrelated to petroleum hydrocarbon impacts.

3.7 NAPL

NAPL evaluation is an important component of Site Characterization, as LNAPL can continue to act as a source of dissolved-phase contaminants and, as such, LNAPL is a primary target of ongoing and future corrective action. Data collection is ongoing and the following sections provide a summary of LNAPL data collected thus far during site characterization. Trends in LNAPL occurrence may be used to determine if a release is ongoing, and will be a tool used to evaluate the effectiveness of cleanup actions. The activities completed thus far are being used to refine LCM and to estimate LNAPL recoverability and establish remedial goals for addressing LNAPL.

While DNAPL is not expected to be present due to the miscibility of sulfolane, data have been collected from deep monitoring wells to determine if an additional investigation regarding potential DNAPL is necessary.

3.7.1 LNAPL Distribution

LNAPL accumulations or sheens have been observed in 32 observation and monitoring wells since 2006 (Table 1 in Appendix O). Wells in which LNAPL accumulations have historically been observed are presented on Figure 77. Quarterly summaries are presented on Figures 78 through 82.

LNAPL thickness data from the fourth quarter of 2011 have been plotted on Figure 82. As shown on the figure, LNAPL was observed in wells located in the tank farms, near CU1 and CU2, the former truck loading rack, and the current truck loading rack. Many of the new observation wells were installed to provide better definition of LNAPL occurrence. As shown on Figure 82, a "halo" of wells with no LNAPL has been established around the LNAPL plume. Future LNAPL monitoring is discussed in Section 7.5.

Hydrographs were prepared for 17 monitoring wells at the site that have been observed to have recurrent LNAPL observations. The hydrographs show potentiometric groundwater surface elevations and LNAPL thicknesses (i.e., hydrographs) versus time (Figures 3A through 3D in Appendix O). The hydrographs also show the monitoring well screened interval where available. The hydrograph for observation well S-52 is presented as depth to water and depth to LNAPL since top-of-casing survey data are not available. Two wells, R-34 and S-50, have had recovery systems down-well, but extended nonrecovery periods made data from these wells appropriate for hydrograph generation.

Common unconfined aquifer behavior is demonstrated by most of the hydrographs on Figures 3A through 3D in Appendix O. In an unconfined aquifer system, an inverse relationship between the groundwater potentiometric surface elevation and LNAPL thickness observations is expected, e.g. LNAPL thickness decreases as groundwater levels increase. Hydrographs for wells O-2, S-22, S-44, S-20, S-50, S-51, R-34, R-4, R-14, and R-14A show this characteristic relationship between groundwater elevation and LNAPL thickness clearly. Hydrographs for monitoring wells S-21 and MW-186A do not present patterns that are characteristic of an unconfined aquifer. The inconsistent relationship between groundwater and LNAPL at these two wells may be due to the influence of nearby recovery systems (i.e., dual phase extraction wells, skimmer wells, vacuum truck operations). A vacuum truck is used to perform targeted LNAPL removal at recovery well R-18, located less than

50 feet from monitoring well S-21 as shown on Figure 1 in Appendix O. Groundwater and LNAPL are recovered with a dual-phase extraction system at recovery well R-21, located less than 100 feet from monitoring well MW-186A.

Wells MW-115, S-37, S-38, and S-39 have corrected groundwater elevations that are at or above the elevation of the top of well screening. In S-37 and S-39, LNAPL accumulations in the wells are present only when corrected groundwater elevation is below the top of well screening, which is anticipated. LNAPL accumulates in the wells at MW-115 and S-38 when corrected groundwater elevation is above the screened interval, which indicates there may be either an additional force being applied to the LNAPL in these areas or damage to the well casing above the well screen that is allowing LNAPL to enter the well at higher groundwater elevations.

The historical maximum LNAPL thickness measured in observation and monitoring wells (not recovery wells) at NPR was 3.72 feet in MW-176A in October 2011. LNAPL sheen was observed for the first time or after a long period of no LNAPL accumulations in monitoring wells S-32, S-40, S-43, and MW-176B. It is likely the increased LNAPL thicknesses and new observations were related to the historically low groundwater elevation observed in October 2011. The screened interval of 45.56 to 50.06 ft BGS Monitoring Well MW-176B is much deeper than the subsurface zone where LNAPL is known to occur, and therefore, the LNAPL sheen at MW-176B in particular requires further observation to confirm or invalidate. The LNAPL may have entered the screen as it was lowered into position during installation, and has remained trapped in the well since that time.

The LNAPL smear zone is generally approximately 3 feet thick and generally occurs from 7 to 10 feet BGS. The minimum top of smear zone is 5.5 ft BGS and the maximum bottom of smear zone is 13.2 ft BGS. The maximum smear zone thickness is 4.5 feet at the Site.

3.7.2 LNAPL Properties

The following sections describe the both the physical and chemical nature of LNAPL at NPR, based on the analyses of samples collected from various locations across the site. Also included are the results of a forensic investigation, which was conducted to identify the relative age of the LNAPLs present and to determine if mixing has occurred between different product types, if possible.

3.7.2.1 Physical Properties

LNAPL and groundwater samples were collected from the following nine monitoring wells in September and October 2011: MW-138, O-13, R-21, R-40, S-20, S-22, S-50, S-51, and S-52. Section

2.5.6.1 and 2.5.6.6 provide detail on fluid sample collection methods and fluid laboratory analysis methods. The fluid physical properties are summarized in Table 38.

Viscosity values measured at 1° C ranged from 1.77 to 5.04 centipoise (cP) with most values being approximately 2 cP. The LNAPL sampled from S-50 and S-52 was more viscous than elsewhere at the Site with viscosity values of 3.53 and 5.04 cP, respectively. LNAPL density was consistently approximately 0.82 grams per cubic centimeter (g/cm^3), except LNAPL sampled from S-50 and S-52 was denser with values of 0.8421 and 0.8520 g/cm^3, respectively. LNAPL-groundwater interfacial tension ranged from 16.8 to 25.7 dyne/cm, with interfacial tension of LNAPL sampled at O-13 being the highest value.

3.7.2.2 Chemical Properties

3.7.2.2.1 Smear Zone Soils

Prior to completion of the 2011 soil investigation, a preliminary evaluation of smear zone LNAPL was completed in 2010. These sampling results are included in Table 39. In the vicinity of well O-1, sulfolane and benzene were detected in the soil samples taken from below 12 feet BGS (near the water table). The remaining LNAPL constituents were not detected in the vicinity of well O-1. Thus, smear zone LNAPL is not apparent in the vicinity of well O-1.

In the 7.5 to 9 feet BGS sample from O-2, sulfolane content is unknown since this result was rejected; however, other NAPL constituents were detected in this sample. NAPL constituents, but not sulfolane, were detected below the water table at depths greater than 10 feet BGS. Thus, smear zone NAPL is apparent in the vicinity of well O-2, primarily from a depth of 7.5 feet BGS to 11.5 feet BGS. In the vicinity of wells O-3 and O-4, no NAPL constituents were detected above or below the water table, suggesting that smear zone NAPL is not present in the vicinity of O-3 or O-4.

3.7.2.2.2 LNAPL Composition

Results for composition sampling of mobile LNAPL are summarized in Table 40. Also shown in Table 40 are the concentrations of LNAPL constituents expressed as mole fractions. Equilibrium aqueous concentrations corresponding to the calculated LNAPL mole fractions were also computed and are listed in Table 40. It can be seen from Table 40 that the LNAPL with greatest potential to contribute benzene, ortho-xylene, and 1,2,4-TMB to groundwater is in the vicinity of MW-138. The LNAPL with greatest potential to contribute toluene to groundwater is in the vicinity of S-39. The LNAPL with greatest potential to contribute ethylbenzene and para/meta xylene to groundwater is in the vicinity of S-33. The LNAPL sample from MW-138 near the EU contained 573 µg/kg sulfolane, whereas sulfolane was below reporting limits in the other LNAPL samples collected near CU#1, the tanks farms, and the former truck-loading rack.

In summary, the LNAPL composition data indicate sulfolane has not been detected in any of the LNAPL samples collected from CU#1, the tank farms, or the former truck-loading rack areas of NPR. These areas include the majority of wells at which LNAPL has occurred (Figure 77).

3.7.2.2.3 LNAPL Forensics

NAPL samples were collected from 10 locations as shown on Figure 1 in Appendix O. Chromatograms (i.e., fingerprints) for the five product samples are provided in Appendix O and serve as the basis for interpreting the NAPL chromatograms. Side-by-side comparisons of chromatograms (with normal alkane markers) and PIANO profiles for product samples are provided on Figure 3 of Appendix O.

Both of the gasoline samples (gasoline-R and gasoline-P) have similar fingerprints in the C8 to C24 range, with the last peak (right-most peak and heaviest hydrocarbon) being on the order of C9 to C10. The PIANO profiles show higher relative proportions of paraffins and naphthenes in the gasoline-R sample compared to the gasoline-P sample, reflecting the difference in grade. The naphtha sample shows a similar distribution to gasoline, although it is slightly heavier and contains a greater proportion of paraffins and naphthenes, and lower proportion of aromatics than gasoline. Jet A is characterized by a broader range of hydrocarbons (C6 to C18) than gasoline (C4 to C10) and is dominated by paraffins and aromatics. Note that for Jet A, the individual peaks that rise above the hump of the unresolved complex mixture (UCM) are predominantly paraffins ranging from C8 to C15. Diesel fuel is characterized by a carbon range from C12 to C22, with aromatics and paraffins being the dominant classes detected in the PIANO analysis (note that isoparaffins are not measured above the C10 range). It is also noted that the PIANO analysis only extends to C15, whereas this constitutes less than one-half of the relative weight percentage of diesel fuel. However, the PIANO range that is covered for diesel is sufficient to make relevant comparisons to the NAPL samples recovered from the site.

Chromatograms for NAPL samples are shown on Figure 4 of Appendix O, and side-by-side comparisons of chromatograms (with normal alkane markers) and PIANO profiles for NAPL samples are provided on Figures 5, 6 and 7 of Appendix O.

NAPL sample results can be broadly segregated into three groups:

- Jet A-dominated fingerprints (from north to south, samples O-11, O-13, R-14A, O-2, O-9 and S-22),
- Naphtha-dominated fingerprints (samples R-39 and O-7), and
- Mixture of Jet A and naphtha fingerprints (samples S21 and R-40).

Sample S-22 has the most similar composition to the Jet A product sample based on comparison of fingerprints, PIANO plots and PIANO regression analysis. These samples have a broad UCM hump ranging from C10 to C18, with multiple discrete peaks rising above the UCM that primarily consist of paraffins. Multiple peaks are also present in the C7 to C10 range with compounds that are predominantly paraffins, isoparaffins and aromatics. The relative contribution of Jet A in these samples ranges from approximately 58 to 93%, with naphtha contributing approximately 7 to 42%. There is evidence that sample O-13 contains approximately 13% from a gasoline source based on the relative contribution from benzene and isopentane, as well as the overall general compositional constituents.

Two samples (R-39 and O-7) are predominantly composed of naphtha-like compounds, as shown on Figure 6 of Appendix O. These samples predominantly comprise a fairly narrow range of hydrocarbons in the C6 to C9 range, consisting primarily of paraffins, isoparaffins and naphthenes. Fairly low concentrations of C10 to C15 paraffins are also present in these samples, suggesting a fairly minor contribution of Jet A in these samples. Regression analysis of the PIANO data indicates that these samples consist of approximately 78 to 81% naphtha, with Jet A comprising the balance.

Two samples (S-21 and R-40) appear to be mixtures of naphtha and Jet A, and/or gasoline. Fingerprints for these samples have distributions that emphasize the presence of lighter hydrocarbons in the C7 to C10 range that is characteristic of naphtha, with a low UCM and low (yet distinct) peaks in the C10 to C18 range that is indicative of Jet A. The PIANO analysis for sample S-21 is dominated by paraffins, isoparaffins and naphthenes in the C6 to C9 range that is consistent with Naphtha as a primary source for the light hydrocarbons. On the other hand, sample R-40 includes lighter hydrocarbons down to the C4 range and overall has a greater proportion of aromatic hydrocarbons that is consistent with a gasoline component. The PIANO analysis of sample O-13 from the Jet A-dominated sample set also contains lighter C4 and C5 hydrocarbons and a higher proportion of aromatics, which suggests a gasoline component in this sample. Regression analysis of samples S-21 and R-40 consist of 47 to 51% Jet A. The remaining proportion of sample S-21 consists of naphtha, whereas the remaining portion of sample R-40 is a balance of gasoline and naphtha.

The blending of Jet A, naphtha and gasoline in all samples is supported by the regression analysis of PIANO data shown on Figure 8 of Appendix O. Most NAPL samples have a fairly good correlation with each other, with the exception of R-39 and O-7. The dominant association between NAPL samples and product is with Jet A; however, samples R-39 and O-7 have good correlations with naphtha. Figure 9 of Appendix O shows the crude estimated composition of each sample based on multivariate regression analysis of PIANO data. Diesel fuel does not appear to be a source of hydrocarbons in these samples. This conclusion is based on both fingerprint interpretation and PIANO analysis data. Fingerprints do not show the presence of petroleum hydrocarbons in the C18 to C22 range that are characteristic of diesel, and the UCM in the NAPL samples is not consistent with the UCM distribution that is typical for fresh or weathered diesel. With the exception of samples O-13 and R-40, there is limited evidence that gasoline is a significant contributor to the NAPL samples. This is based on the overall distribution of hydrocarbons (i.e., lack of dominant C4, C5 and C6 compounds) and relatively low proportion of aromatics in the NAPL samples in the C6 to C9 range.

Weathering of the samples was evaluated based on the overall carbon range distribution and on the P:I and A:N ratios. In general, lighter hydrocarbons (i.e., low carbon number) will be lost more rapidly than heavier compounds. In samples that are derived from a single refined petroleum source, paraffins and aromatics will weather (i.e., evaporate or biodegrade) more rapidly than the corresponding isoparaffins and naphthenes having the same carbon number. Therefore, the P:I and A:N ratios will decrease as weathering proceeds and it is possible to estimate the relative degree of weathering based on comparing these ratios for NAPL samples to product samples.

This fairly straight forward evaluation is complicated for these NAPL samples because of the mixing between different refined petroleum hydrocarbon sources. Figure 10 of Appendix O shows the distribution of P:I and A:N ratios by carbon number. The relative contribution of paraffins, isoparaffins, aromatics and naphthenes in these samples reflects the sources. The majority of the light paraffins and isoparaffins (<C8) are derived from naphtha, whereas the heavier equivalent compounds are derived from Jet A. The P:I ratio plot shows that the ratios tend to be less than the naphtha source line for C5, C6 and C7 hydrocarbons and less than the Jet A line for C8, C9 and C10 hydrocarbons. The majority of the aromatic compounds are derived from Jet A with some contribution for gasoline in two samples, whereas the majority of the naphthenes are derived from the naphtha source. This makes interpretation of the A:N ratios somewhat problematic because the two classes of compounds are derived from different product sources. However, the majority of the A:N ratios are well below the line for Jet A.

The rates of weathering in these samples obtained from Alaska may be different than samples from more temperate climates in the lower 49 states. Low in-situ temperatures would decrease biological activity, which would degrade petroleum hydrocarbon compounds and reduce the rates of volatilization and partitioning from NAPL to groundwater. Given these constraints, the overall distribution of P:I and A:N ratios provides evidence that weathering has occurred for these compounds relative to the naphtha and Jet A sources.

Forensics Conclusions

The following conclusions are based on the evaluation of chromatograms and PIANO data, using graphic and statistical methods:

- The 10 NAPL samples can be broadly segregated into three categories: samples dominated by Jet A (samples O-11, O-13, R-14A, O-2, O-9 and S-22), naphtha-like samples(R-39 and O-7) and a mixture of Jet A and naphtha fingerprints (samples S21 and R-40).

- Two samples (O-13 and R-40) show some evidence of a gasoline contribution based on the overall distribution of PIANO compounds and the presence of specific hydrocarbons, including benzene and isopentane.

- In general, Jet A is the most prevalent refined hydrocarbon source in the NAPL, contributing approximately 47 to 93% to the mixture in most samples.

- Naphtha is the primary refined hydrocarbon source in two samples and makes up 78 to 81% of the mixture.

- There is no compelling evidence that diesel fuel is present in any of the NAPL samples based on the lack of heavier compounds in the chromatograms.

Each of the samples collected are considered to have undergone some degree of weathering and are not considered to be fresh product or to represent a recent release. This conclusion is based on the loss of low carbon number compounds (C4 and C5) in all NAPL samples relative to fresh naphtha, and P:I and A:N ratios that are lower than the corresponding values for fresh naphtha and Jet A samples. Given climatic factors that would reduce biological activity and volatilization potential, as well as the complex chemistry of the petroleum sources, the relative decreases of the P:I and A:N ratios is consistent with slow changes over an extended period of time.

3.7.3 LNAPL Mobility

3.7.3.1 Field and Residual LNAPL Saturations

At a site with LNAPL impacts, the relative saturations of three fluids, air, LNAPL, and groundwater, must be considered when evaluating fluid mobility. Of primary interest is the mobility of the LNAPL and the related fluid saturations where LNAPL is mobile or immobile. LNAPL is mobile where there is continuity between LNAPL-filled soil pores that allows for lateral or vertical LNAPL movement. The LNAPL saturation at which LNAPL is discontinuous to the extent that it cannot flow is termed residual saturation. As defined by the ITRC, LNAPL saturations at or below residual saturation are not mobile (ITRC, 2009a).

Laboratory analysis of pore fluid saturations in site soil cores provides data on the field (initial) and residual LNAPL saturations. The fluid saturations are reported as the percentage of the soil porosity that is filled by the fluid. The field LNAPL saturation value represents the LNAPL saturation at static in situ conditions. When field saturation equals residual saturation, the LNAPL is immobile. If field LNAPL saturation in a soil core is greater than the residual LNAPL saturation, then LNAPL is mobile at the pore-scale. Hydraulic gradient, aquifer permeability, and LNAPL viscosity are a few factors that influence whether the LNAPL above residual saturation is capable of migrating.

Field and residual LNAPL saturation was assessed through the petrophysical laboratory analyses Free Product Mobility – Centrifugal Method (FPM-C) and Free Product Mobility – Water Driven Method (FPM-WD) on eight undisturbed soil cores collected from the Site. FPM-WD testing was performed at six soil core locations and FPM-C testing was performed at all eight soil core locations. FPM-C testing provides a more conservative saturation result, as compared to that of FPM-WD testing, for the purposes of determining whether LNAPL is mobile. The saturation results of the FPM-C test provide an indication of the potential for vertical LNAPL movement during unsaturated conditions (e.g., groundwater table drawdown) and FPM-WD provide an indication of mobility under saturated conditions.

Section 2.5.6 describes in detail data collection and analytical methods.

Field and residual LNAPL saturation were first evaluated for data quality by calculating and inspecting total initial pore saturation data. Total pore saturation is the initial water saturation added to the field LNAPL saturation, which are provided in the FPM-C and FPM-WD test reports. The initial total pore saturation was low, which reduces confidence in the data and indicates fluid loss during sample retrieval from the bore hole. The lower than anticipated saturations are due to the coarse-grained soils at the Site and not a function of field collection methods. The data is still useful data for drawing overall and relative conclusions on LNAPL mobility and recoverability.

Field and residual LNAPL saturations were then compared to one another to make an immobile or mobile determination, which is based on whether field LNAPL saturation is at or exceeds, respectively, the residual LNAPL saturation at each sample depth.

Table 3 and Figure 4 in Appendix O show the results of the laboratory saturation results for FPM-C and FPM-WD testing. Field saturations from FPM-WD tests were above residual saturation at ASB-02 and ASB-05, indicating LNAPL is mobile as defined by the ITRC (2009a) under saturated conditions. Field saturations exceeded residual saturations for FPM-C testing in ASB-04, ASB-07 and ASB-08, indicating LNAPL is mobile at the pore-scale in near these soil core locations during unsaturated conditions.

FPM-C and FPM-WD testing results for ASB-01 and FPM-C testing results for ASB-03 and ASB-06 show that LNAPL at these three soil core locations is at residual LNAPL saturation, indicating LNAPL is immobile at the pore-scale. However, the suspected fluid loss during soil collection reduces the confidence in this immobile LNAPL determination.

The mobile and immobile findings as a result of this analysis can inform decision-making of where to prioritize LNAPL recovery efforts.

3.7.3.2 LNAPL Pore Velocity

There is potential for LNAPL movement in the subsurface at the pore-scale wherever field LNAPL saturations exceed residual saturation. LNAPL pore velocity was calculated at locations where residual saturation was exceeded to determine the degree of mobility. ASTM International’s E2531-06e1 Standard Guide for Development of Conceptual Site Models and Remediation Strategies for Light Non-Aqueous Phase Liquids (2006) suggests that an LNAPL mobility of less than 1×10^{-6} cm/s is indicative that LNAPL in the formation is functionally immobile. When mobility exceeds this criterion, it is an indication that LNAPL may be mobile at the pore-scale and capable of moving vertically or laterally within the formation.

LNAPL pore velocity is calculated using Darcy’s Law, which relates fluid flow to the permeability of the aquifer, the fluid properties, the applied head, and the fluid-filled porosity. In the case of multiphase flow, the presence of more than one fluid within the porous media results in equivalent permeability reductions for each of the fluids in the system. For a two-phase LNAPL and groundwater system the relative permeability of the fluids has a direct relationship to the saturation of the respective fluids, i.e. as the saturation of LNAPL increases the relative permeability of the LNAPL increases.

Two methods were used to determine a site-specific LNAPL relative permeability that could be used to calculate pore velocity. The first method uses petrophysical data on fluid saturation and capillary properties to calculate LNAPL relative permeability using a series of equations developed by the American Petroleum Institute (API). The second method employs field testing of LNAPL recharge within monitoring wells to jointly measure LNAPL hydraulic conductivity and LNAPL relative permeability. Both methods use Darcy's Law of fluid flow to calculate pore velocity. Section 2.1.3 in Appendix O provides detailed methodology including equations of how to calculate LNAPL pore velocity under these two methods.

Sections 3.1, 3.2, 3.3 and 3.6 with Tables 2, 3, 4 and 7 in Appendix O provide all data utilized in the pore velocity calculations and an explanation of processing these data for use in the velocity calculations.

All input parameters were assessed for good data quality prior to being used as variables in the series of calculations that determine pore velocity provided in Section 2.1.3 in Appendix O. Calculated pore velocities under both methods were summarized and compared to the ASTM functional-immobility criterion.

LNAPL pore velocities are provided on Figure 5 in Appendix O. The LNAPL pore velocities calculated at sample depths where field saturation exceeded residual saturation using a calculated LNAPL relative permeability ranged from 2.34×10^{-5} to 8.07×10^{-4} cm/s. LNAPL velocities were also calculated using a field-derived LNAPL relative permeability from bail-down testing and ranged from 2.69×10^{-5} to 3.48×10^{-4} cm/s. The field-derived velocities correlate well to the velocities calculated using API equations, field-verifying the modeled conditions. All LNAPL pore velocities exceed the ASTM functional-immobility criterion.

The pore velocities calculated provided a quantitative indicator of the degree of mobility across the Site and can be used to inform decision-making of where to prioritize LNAPL recovery efforts.

3.7.3.3 LNAPL Pore-Entry Pressures

Lateral LNAPL migration into an unimpacted aquifer matrix that is saturated with groundwater requires displacement of that groundwater. In most aquifer systems, water is the wetting fluid (preferentially coating soil particles) and LNAPL is the nonwetting fluid. The amount of force that is required for LNAPL to displace groundwater is known as the nonwetting, or LNAPL, pore-entry pressure. API provides guidance on using the Brooks and Corey capillary pressure model to calculate the LNAPL pore-entry pressure. The Brooks and Corey model assumes that some minimum force is required for nonwetting fluid migration into water-saturated soil where no nonwetting fluid is present.

LNAPL pore-entry pressure can be calculated directly from laboratory capillarity data. However, LNAPL pore-entry pressure as displacement head (pressure data in cm of water) was calculated as critical LNAPL thickness, a more easily measured and comparable indicator than head pressure. The critical LNAPL thickness in a well that may facilitate lateral movement of LNAPL into water-wet soil is related to LNAPL displacement head pressure through a density correction using fluid physical properties. Section 2.1.4 in Appendix O provides detailed methodology including an equation of how to calculate LNAPL pore-entry pressure.

Capillary data were generated from analysis of undisturbed soil cores collected in October 2011 and analyzed at a specialized petrophysical laboratory. Fluid physical properties resulting from analysis of LNAPL and groundwater samples collected in September and October 2011 were used in these calculations and are presented in Section 3.7.2. Sections 3.2, and 3.3 with Tables 2 and 8 in Appendix O further report on the data utilized in the LNAPL pore-entry pressure calculations.

Critical LNAPL thicknesses were compared to recent LNAPL thicknesses observed in monitoring wells closest to the eight soil core locations to determine if the potential for migration exists, which would be indicated by recent observed LNAPL thicknesses exceeding critical LNAPL thicknesses.

Table 8 in Appendix O presents the critical LNAPL thicknesses required for lateral LNAPL migration into saturated soils at the eight soil core locations. The critical head pressure required for plume expansion expressed in LNAPL thickness ranges from 0.32 to 1.32 feet. LNAPL thicknesses measured in October 2011 and in the recent past at monitoring wells near all eight soil borings were above the critical LNAPL thicknesses, indicating the potential for LNAPL plume expansion.

LNAPL thicknesses compared to the pore-entry critical LNAPL thicknesses are representative of the interior of the LNAPL plume and LNAPL head pressure at the fringes of the plume is much less. Therefore, the migration potential findings of this analysis are conservative. LNAPL migration can be confirmed by observing fluid levels in sentry wells (wells installed downgradient of LNAPL impacts).

3.7.3.4 Dissolved-Phase Plume Stability

Statistical trending of dissolved-phase constituent concentrations at locations where separate-phase LNAPL is not observed in the well can be used to assess the dissolved-phase plume stability. Stable or decreasing groundwater concentrations of dissolved LNAPL compounds indicate the LNAPL plume is stable or decreasing in size.

The BTEX compounds were used for the plume stability evaluation based on available groundwater sampling data.

Groundwater sampling data from 45 monitoring wells at NPR were used for the dissolved-phase plume stability analysis and served as input data for MAROS. Additional detail on groundwater concentration data preparation is provided in Section 3.4 of Appendix O.

AFCEE created MAROS, which includes tools for nonparametric statistical concentration trend analyses using the Mann Kendall statistical test. Groundwater concentrations of indicator constituents, selected based on LNAPL fluid type or available historical analytical data for a site, are analyzed in MAROS to determine the stability of the groundwater plume. The groundwater constituents used in this assessment were BTEX. The results of the Mann-Kendall statistical analysis utilizing MAROS provide groundwater trends from which conclusions on dissolved-phase plume stability can be drawn.

Dissolved-phase trends are summarized on Figure 6 in Appendix O and a comprehensive explanation of results formatting in Figure 6 is provided in Section 4.1.5 in Appendix O. Data were not analyzed for 13 monitoring wells due to an insufficient number of detections from which to draw trend results with confidence. Groundwater samples from 21 monitoring wells had nondetection results for BTEX during the sampling period analyzed. The Mann-Kendall statistical analysis was performed on groundwater sampling data from 11 monitoring wells with sufficient data above detection limits.

Data from monitoring wells MW-125, MW-135, and MW-136 show increasing and probably increasing trends located near recovery well R-39 in the northeast area of LNAPL impact at the Site. However, there are two monitoring wells (MW-124 and MW-137) with decreasing trends immediately stepped out from these increasing trends, indicating that the influence of the LNAPL plume on dissolved-phase in this area is not significant and the LNAPL plume is likely stable in the area of R-39.

Groundwater samples collected at monitoring well MW-132 showed an increasing trend. However, the current data set of LNAPL accumulations of 1.34 to 1.87 feet in October 2011 for O-9, the nearest observation well to MW-132, is too limited to determine if the increasing trend at MW-132 is a result of plume migration.

Mann-Kendall results were stable and decreasing, respectively, for monitoring wells MW-110 and MW-116, located side- and up-gradient of the LNAPL impact area at the Site. The only downgradient monitoring well (MW-139) that was statistically-analyzed showed stable and probably decreasing trends.

These results, along with the significant number of nondetections of BTEX in monitoring wells located downgradient of LNAPL impacts, indicate the dissolved-phase BTEX plume is stable, which indicates the LNAPL plume is also likely stable.

3.7.4 Natural Source Zone Depletion

NSZD is a combination of natural processes that reduce the mass of LNAPL in the subsurface over time. Petroleum LNAPLs are complex fluids comprised of hundreds of compounds. NSZD occurs when LNAPL constituents partition from the bulk LNAPL fluid to the aqueous phase via dissolution or to the gaseous phase via volatilization. In turn, the dissolved or volatilized LNAPL constituents can be biologically degraded by microbial activity. A detailed account of the processes involved in NSZD is provided in Section 2.2 of Appendix O.

A qualitative NSZD assessment describes the extent of the plume and determines the likely processes occurring. Specific rates of dissolution, volatilization and biodegradation are calculated in a quantitative NSZD assessment. This assessment includes both qualitative and quantitative aspects.

Dissolved-phase concentration data for petroleum hydrocarbon constituents and natural attenuation parameters were the primary inputs to the NSZD.

Section 3.5 in Appendix O summarizes the data utilized in the NSZD calculations and an explanation of processing these data.

3.7.4.1 Qualitative Assessment of Natural Source Zone Depletion

Biodegradation and dissolution of the submerged portion of the LNAPL can be assessed by comparing the chemical composition of groundwater upgradient of the source zone, with groundwater immediately downgradient. Moving from upgradient to downgradient, if biodegradation is occurring, then a decrease in the concentrations of electron acceptors and a corresponding increase in the concentrations of biodegradation transformation products should be observed. The average natural attenuation parameters (oxygen, nitrate, sulfate, dissolved iron, dissolved manganese, and methane) are presented in Table 6 in Appendix O. A comparison of the upgradient and source zone/downgradient data illustrate:

- Sulfate decreases from 38 mg/L at the upgradient monitoring location to an average of 2.4 mg/L in the source zone monitoring locations.
- Dissolved iron increases from 1.66 mg/L at the upgradient monitoring location to an average of 18.2 mg/L in the source zone monitoring locations.
- Dissolve manganese increases from 0.355 mg/L at the upgradient monitoring location to 1.6 mg/L in the source zone monitoring location.
- The methane concentration increased from 0.0796 mg/L at the upgradient location to 3.6 mg/L at in the source zone monitoring locations.

The above spatial comparison of upgradient and source zone/downgradient natural attenuation parameters shows a clear decreasing trend in electron acceptors and an increasing trend in biodegradation transformation products, which indicates biodegradation of LNAPL is occurring. Oxygen and nitrate are detected in the aquifer at nominal levels, indicating oxygen and nitrate are not readily available as electron acceptors.

The assessment of LNAPL NSZD indicates source zone depletion is occurring through a combination of dissolution and biodegradation in the saturated zone. Also, it is likely that the source zone is being depleted through volatilization and biodegradation in the unsaturated zone. The total mass loss due to NSZD is estimated to be up to 2,650 gallons per year as described in the following sections.

3.7.4.2 Quantitative Estimate of Natural Source Zone Depletion

The extent of the LNAPL source zone was determined from historical observations of LNAPL at NPR. The NSZD assessment assumes a LNAPL source plume with a total area of 765,000 square feet, estimated based on the spatial distribution of monitoring wells with historical LNAPL accumulations (Figure 77). The LNAPL plume is present in sand to very fine gravel. The cross-sectional area of the saturated zone affected with LNAPL, perpendicular to the groundwater flow direction, was estimated to calculate groundwater flux through the site. The width of LNAPL affected groundwater is estimated at 850 ft based on the historical observations of LNAPL in S-51 and S-50 on the west side of the site and S-32 and O-7 on the east side of the site. The saturated LNAPL source zone (i.e., thickness of dissolved-phase-affected groundwater in the LNAPL footprint) is estimated to be 10 feet thick, based on monitoring well fluid level gauging data and observed concentrations in shallow monitoring wells. For example, in May 2011, dissolved-phase affected groundwater was detected at MW-125. Monitoring well MW-124 has a screened interval from 20.0 to 24.5 feet BGS and the measured depth to water on that day was 12.5 feet BGS indicating dissolved-phase impacts exist at least to 20.0 feet BGS, which is 7.5 feet into the water table. On average, the measured depth to LNAPL is 8 ft BGS, based on monitoring well fluid level gauging data. Parameters utilized in the analysis are presented in Table 9 in Appendix O.

3.7.4.2.1 Estimate of Source Zone Mass Depletion by Dissolution to Groundwater in the Saturated Zone

Mass loss of the LNAPL source occurs via dissolution of hydrocarbons into water as groundwater moves through the subsurface and comes into contact with hydrocarbon affected soils within the saturated zone. The flux of groundwater exiting the LNAPL source area and the rate of dissolution of hydrocarbons into water controls the mass loss. Based on the hydraulic conductivity, site groundwater gradient, and cross-sectional area of the impacted groundwater, approximately 59 cubic meters (m^3) of groundwater is exiting the source area per day. The average dissolved-phase concentration of petroleum compounds in the downgradient wells were 13.1 mg/L.

Using Equation 11 and the plume parameters given in Table 9 in Appendix O the mass depletion rate of the source zone as a result of dissolution is estimated to be between 1,300 and 2,000 kg TPH/year, or between 420 and 640 gallons/year.

3.7.4.2.2 Estimate of Source Zone Mass Depletion Rate by Biodegradation in the Saturated Zone

Mass loss of the LNAPL source via biodegradation of hydrocarbons is controlled by the groundwater flux into the LNAPL source zone, as discussed above, and the availability of electron acceptors in groundwater or the aquifer matrix. The assimilative capacity of the aquifer is 1.1×10^{-2} kg-TPH/m^3 H_2O, which comprises of approximately 60% sulfate reduction, 34% methanogenesis, 6% iron reduction and less than 1% manganese reduction.

Using Equation 12 and the plume parameters given in Table 9 in Appendix O the mass depletion rate due to biodegradation in the saturated zone is estimated to be between 1,100 and 1,700 kg TPH/year, or between 360 and 560 gallons/year.

3.7.4.2.3 Estimate of Source Zone Mass Depletion Rate by Volatilization and Biodegradation in the Unsaturated Zone

Source zone depletion through volatilization and biodegradation is determined by the rate of oxygen consumption in the subsurface and the surface area of the LNAPL footprint. Representative vadose zone NSZD rates were calculated using an assumption that oxygen is being consumed within the vadose zone and that the oxygen concentration is atmospheric at ground level and zero at the potentiometric surface. This assessment uses the distance over which oxygen is depleted to determine the rate of degradation of hydrocarbons. The impervious surface at the Site limits the rate of oxygen diffusion to the LNAPL source, limiting the rate of hydrocarbon degradation. The presence of low moisture content sand and very fine gravel in the subsurface at NPR may enhance vapor-phase migration of volatilized petroleum hydrocarbon constituents.

Using Equation 13 and the plume parameters given in Table 9 in Appendix O, a mass depletion rate in the unsaturated zone is estimated to be 4,600 kg TPH/year, or 1,450 gallons/year. This estimated mass loss rate is a hypothetical evaluation based on assumptions of oxygen consumption in the subsurface.

3.7.5 LNAPL Recoverability

3.7.5.1 Fraction of Recoverable LNAPL

Fractions of recoverable LNAPL were calculated at the eight soil boring locations using site-specific LNAPL field and residual saturations derived from the undisturbed soil core petrophysical testing. These fractions are expressed as percent recoverable LNAPL and are presented on Figure 4 in Appendix O.

Sections 4.1.2 and 4.3.1 in Appendix O provides all data utilized in the fraction of recoverable LNAPL calculations and an explanation of processing these data.

In homogeneous settings, LNAPL thickness in a well provides an indication of LNAPL saturation in the adjacent formation. Mobile, and therefore theoretically recoverable, LNAPL is present when field LNAPL saturation exceeds residual saturation. Residual saturation was not exceeded at soil boring locations ASB-01, ASB-03, and ASB-06, which indicates there is a negligible proportion of the total LNAPL in the subsurface that is recoverable.

The fractions of recoverable LNAPL ranging from 1.1% to 31.6% were calculated at the remaining five soil core locations. ASB-02 and ASB 04 have calculated recoverable LNAPL fractions of 6.0% and 5.5%, respectively. A LNAPL thickness of 0.93 foot has recently been observed in MW-138 near

ASB-02 and less than 0.5 foot of LNAPL thickness has been observed recently in MW-115 near ASB-04. The fractions of recoverable LNAPL seem low compared to the LNAPL thicknesses accumulating in nearby monitoring wells. However, the geology of sand to very fine gravel may provide sufficient storage volume and ease of LNAPL flow that accumulations greater than expected would appear in monitoring wells.

The recoverable fraction of 1.1% at ASB-08 is not well-supported by the accumulation of 2.33 and 2.16 feet of LNAPL thicknesses in neighboring monitoring wells S-50 and S-51. However, the saturation value of 0.094 at ASB-08 is one of the highest for the Site. Also, the LNAPL thickness in S-52 is less than 0.5 foot. These conflicting results suggest aquifer matrix heterogeneity in the vicinity of ASB-08.

The fractions of recoverable LNAPL calculated at ASB-05 and ASB-07 located in the plume interior were 27.9% and 31.6%, respectively. Nearby monitoring well thicknesses and productive nearby LNAPL recovery systems support this finding of recoverable LNAPL in the vicinities of ASB-05 and ASB-07.

3.7.5.2 Field LNAPL Recoverability

LNAPL transmissivity calculated from analyzing bail-down test data can be utilized to quantitatively characterize the LNAPL bulk transport conditions onsite and characterize LNAPL recoverability. Field LNAPL recoverability is characterized through short-term duration LNAPL stress testing, also called LNAPL bail-down testing.

A LNAPL bail-down 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 LNAPL saturation, permeability of the surrounding formation to LNAPL, physical properties of the LNAPL (density, viscosity, interfacial tension between LNAPL and water), and the magnitude of the initial hydraulic gradient toward the well developed during LNAPL removal.

Sections 2.3.2 and 3.6 in Appendix O provide all data utilized in the bail-down test analysis and an explanation of processing these data.

Transmissivity values for each method varied across the Site as follows:

- Bouwer and Rice: 1.4 to 15 square feet per day (ft^2/day),
- Cooper & Jacob / Jacob & Lohman: 1.8 to 18 ft^2/day, and

- Cooper, Bredehoeft & Papadopulos: 2.1 to 10 ft^2/day.

The transmissivity calculated for each well with the API Tool utilizing each method are shown in Table 7 in Appendix O.

The bail-down test from monitoring well MW-138 could not be analyzed quantitatively because the LNAPL transmissivity exceeded the water transmissivity at this location. However, the test results suggest that LNAPL is highly recoverable at that location. Monitoring wells O-11 and S-52 had poor recovery during the tests indicating that the wells were not in a state of equilibrium during test initiation. However, the shape of the response curves is indicative of formation response and can be used to quantitatively evaluate transmissivity. The poor recovery of LNAPL observed at O-11 and S-52 indicate low transmissivity, thus areas of poor LNAPL recovery.

Monitoring wells O-9, O-19 and Test 1 of S-50 lacked sufficient LNAPL drawdown during the test, but again a qualitative conclusion is determined based on the shape of the response curve. All three monitoring well tests were run for a short period of time (less than 60 minutes) with almost 100% LNAPL recovery, indicating high transmissivity in these areas.

LNAPL recovery using hydraulic methods yields negligible LNAPL when the LNAPL transmissivity is less than 0.1 to 0.8 ft^2/day (ITRC, 2009a). The calculated transmissivities using all three methodologies are above this transmissivity criterion range by one to two orders of magnitude. The field recoverability testing indicates LNAPL recovery via hydraulic methods may produce sufficient LNAPL to cause a beneficial reduction in overall LNAPL mass from the interior of the LNAPL plume around locations O-13, S-20, S-22, S-50 and S-51. However, additional field testing is necessary to correlate bail-down testing rates to recovery system rates.

3.7.6 DNAPL Assessment

Sulfolane by definition would not be expected to be present as DNAPL because of its miscibility with water. Nonetheless, deep monitoring wells downgradient of Tank 194 were analyzed for sulfolane as part of the DNAPL assessment. Results for well nests MW-174, MW-176, MW-178, and MW-179 (Table 41 and Appendix S) show the samples collected from the deepest well at each location had the lowest concentration at that nest (all four deep wells were nondetect for sulfolane). If sulfolane DNAPL were theoretically possible, which it is not, and had it been present, sulfolane would likely have been detected in the deep well samples, with potentially higher concentrations than the shallow wells.

3.8 Groundwater Impacts

Groundwater impacts have been, and continue to be, characterized through the analysis of groundwater samples collected from onsite and offsite monitoring wells. This section includes results of analyses completed on onsite well samples (COPCs) and offsite well samples (sulfolane) following submittal of the SCWP through the third quarter of 2011. Fourth quarter 2011 Sulfolane and BTEX data are presented in Tables 41 and 42, respectively; historical data are provided in Appendix S. Results for other COPCs are in Tables 43, 44, 45 and 46.

3.8.1 BTEX

Monitoring of BTEX concentrations in groundwater is used to track petroleum impacts. The results are presented below by quarter, from the fourth quarter of 2010 through the fourth quarter of 2011. The vertical distribution of benzene is then discussed, followed by a summary of the statistical data evaluation.

3.8.1.1 Fourth Quarter 2010

Benzene was detected above the ADEC cleanup level of 5 µg/L in wells MW-110 (183 µg/L), MW-125 (771 µg/L), MW-132 (56 µg/L), MW-135 (3,580 µg/L), MW-137 (7.89 µg/L), and MW-139 (67.8 µg/L) (Appendix S).

Reported toluene concentrations in samples from two wells, MW-135 (2,150 µg/L) and MW-136 (2,050 µg/L) exceeded ADEC groundwater ADEC cleanup level of 1,000 µg/L.

None of the fourth quarter 2010 ethylbenzene or xylenes results were reported to exceed ADEC groundwater screening criteria of 700 µg/L and 10,000 µg/L, respectively (Appendix S).

Fourth quarter 2010 benzene concentrations were plotted on Figure 83 to show the extent of the dissolved-phase benzene plume. For locations at which multiple sampling events were completed during the quarter, the results were averaged. Due to the range of concentrations measured across the site, a logarithmic contour interval is used on the maps. The 100-µg/L isopleth is drawn around those wells in which LNAPL was present during the quarter.

The data indicate the BTEX plume is present beneath the tanks farms and crude units #1 and #2, extending north under the current truck-loading rack and west beneath lagoons B and C, which is consistent with first quarter 2011 data. The extent of the BTEX plume is shown as an isopleth of 5 µg/L on Figure 83, which equals the ADEC groundwater cleanup level for benzene.

All wells with toluene, ethylbenzene, and xylenes detections are located within the benzene plume.

3.8.1.2 First Quarter 2011

Benzene was detected above the ADEC cleanup level of 5 µg/L in wells MW-110 (44.3 µg/L), MW-135 (1,070 µg/L), and MW-139 (49.2 µg/L) in the first quarter of 2011 (Appendix S).

None of the first quarter 2011 toluene, ethylbenzene, or xylenes concentrations were reported to exceed ADEC groundwater screening criteria of 1,000 µg/L; 700 µg/L; and 10,000 µg/L, respectively (Appendix S), however, as described in Section 2.6.1, one of the wells that exceeded the xylenes criteria in the fourth quarter of 2010 (MW-136) was not sampled.

First quarter 2011 benzene data were plotted on Figure 84 to show the extent of the dissolved-phase benzene plume. Due to the range of concentrations measured across the site, a logarithmic contour interval is used on the maps.

The data indicate the BTEX plume is present beneath the tanks farms and crude units #1 and #2, extending north under the current truck-loading rack and west beneath lagoons B and C, which is consistent with first quarter 2011 data. The extent of the BTEX plume is shown as an isopleth of 5 µg/L on Figure 84, which equals the ADEC groundwater cleanup level for benzene.

All wells with positive toluene, ethylbenzene, and xylenes results are located within the benzene plume.

3.8.1.3 Second Quarter 2011

During the second quarter of 2011, benzene was detected above the ADEC cleanup level of 5 µg/L in wells MW-116 (6,000 µg/L), MW-125 (519 µg/L) and MW-139 (43.7 µg/L). Benzene results that were flagged with lab qualifiers from wells S-41 (1,240 µg/L), MW-124 (1.20 µg/L) and MW-109 (0.430 µg/L) were not used in this analysis (Appendix S).

Toluene, ethylbenzene, and total xylenes were not detected above the ADEC cleanup level in any onsite sample (Appendix S) however, as described in Section 2.6.1, neither of the wells that exceeded the xylenes criteria in the fourth quarter of 2010 (MW-135 and MW-136) were sampled.

The data indicate the BTEX plume is present beneath the tanks farms and crude units #1 and #2, extending north under the current truck-loading rack and west beneath lagoons B and C, which is consistent with first quarter 2011 data. The extent of the BTEX plume is shown as an isopleth of 5 µg/L on Figure 85, which equals the ADEC groundwater cleanup level for benzene.

3.8.1.4 Third Quarter 2011

During the third quarter of 2011, benzene was detected above the ADEC cleanup level of 5 µg/L in wells MW-110 (128 µg/L), MW-125 (559 J µg/L) and MW-139 (145 µg/L). The benzene concentration for well MW-125 was flagged by the laboratory as estimated.

Toluene, ethylbenzene and total xylenes were not detected above the ADEC cleanup level in any onsite sample however, neither of the wells that exceeded the xylenes criteria in the fourth quarter of 2010 (MW-135 and MW-136) were sampled as they are not part of the COPC sampling network.

The data indicate the BTEX plume is present beneath the tank farms and crude units #1 and #2, extending north under the current truck-loading rack and west beneath lagoons B and C. An increase in the benzene concentration from the previous six reporting periods was observed in well MW-139; however, the reported concentration is similar to historical data prior to 2010. Well MW-139 is located west of the rail lines in the northern portion of the site. Historical data were used to support delineation of the western plume boundary. The inferred extent of the BTEX plume is shown as an isopleth of 5 µg/L on Figure 86, which equals the ADEC groundwater cleanup level for benzene. The 5 µg/L footprints observed during the reporting period are similar to historical footprints.

3.8.1.5 Fourth Quarter 2011

During the fourth quarter of 2011, benzene was detected above the ADEC cleanup level of 5 µg/L in samples collected from monitoring wells MW-110 (104 µg/L; duplicate sample 111 µg/L), MW-116 (7,470 µg/L), MW-125 (406 µg/L), MW-135 (2,430 µg/L) and MW-139 (46.8 µg/L; duplicate sample 47.5 µg/L). Benzene was also detected above the ADEC cleanup level of 5 µg/L in samples collected from observation wells O-3 (6.34 µg/L), O-5 (9.22 µg/L), O-16 (5.10 µg/L), O-20 (1,420 µg/L), and O-21 (2,100 µg/L).

Toluene was detected above the ADEC cleanup level of 1,000 µg/L in the sample collected from monitoring well MW-135 (6,080 µg/L).

Ethylbenzene and total xylenes were not detected above the ADEC cleanup level in any onsite sample.

The data indicate the BTEX plume is located at or near the water table and is present beneath the tank farms and crude units #1 and #2, extending north under the current truck-loading rack and west beneath lagoons B and C. Data from the new observation wells have served to constrain the boundaries of the plume, particularly along the leading edge and the western edge of the plume.

Historical data from MW-109 were used to support delineation of the plume boundary. The inferred extent of the BTEX plume is shown as an isopleth of 5 µg/L on Figure 87, which is equivalent to the ADEC groundwater cleanup level for benzene. The 5 µg/L footprint shown on Figure 87 is smaller than those from previous quarters due to data from the new observation wells.

An increase in the benzene concentration to 145 µg/L was detected in groundwater from well MW-139 during third quarter 2011, however, the reported concentration for fourth quarter decreased to 47.5 µg/L (duplicate sample). A statistical analysis of trends at well MW-139 indicated an overall decreasing benzene trend, (see Section 3.8.1.8 below), however, once available, an additional evaluation of seasonal groundwater trends at well MW-139 is recommended.

3.8.1.6 Summary

Figures 83 through 87 show that the benzene plume is confined to the developed portion of the NPR property, and does not extend to the property boundary or beyond. The 2010 and 2011 5-µg/L footprints appear to be similar to the footprint in 2002 as shown on Figure 17 of the SCWP (Appendix Z), indicating a stable plume.

All wells with toluene, ethylbenzene, and xylenes detections are located within the footprint of the benzene plume. Further, on review of the historical BTEX data, in all cases where the benzene concentration in a groundwater sample is below its groundwater-cleanup level, no other BTEX analyte exceeds its groundwater-cleanup level. This indicates benzene is the analyte most suitable for monitoring petroleum impacts in groundwater.

3.8.1.8 BTEX Data Evaluation

As stated in Section 2.6.5, a statistical and graphical evaluation of groundwater analytical data trends is being used to evaluate plume migration and stability, evaluate cleanup action effectiveness, and identify relationships between dissolved-phase concentrations and groundwater elevations and flow directions. Data from forty-six wells were reviewed, some of which had up to 178 sampling events. Results of the trend analyses are presented Appendix S and discussed below.

3.8.1.8.1 Nondetects, Decreasing, or Stable Trends

As shown in Appendix S, nondetects, and decreasing, probably decreasing, or stable trends were identified at most wells in the BTEX network. This includes wells within the plume, such as MW-115, MW-116, MW-124, and MW-137, and also wells located near the edge of the plume, such as MW-109, MW-111, MW-113, MW-126, MW-127, MW-132, MW-134, MW-139, MW-140, MW-142, and MW-145 (Figure 19).

3.8.1.8.2 Increasing Trends

The statistical analysis indicated increasing trends for one or more BTEX analytes at wells MW-110, MW-125, MW-135, and MW-136.

At MW-110, an increasing trend was indicated for xylenes, with no trends indicated for benzene, toluene, and ethylbenzene. MW-110 is located between Lagoons B and C (Figure 19). A visual inspection of the MW-110 concentration graph (Appendix S) indicated BTEX concentrations increased from about September 1998 through the third quarter of 2003, then decreased to pre-1998 concentrations during the first quarter of 2004. This concentration pattern led to the "no trend" evaluation for benzene, ethylbenzene, and toluene. The "increasing" trend for xylenes also appears to be related to this BTEX concentration peak through 2004. Xylenes reached a maximum concentration of 1000 µg/L in 1999, and have not exceeded 200 µg/L since October 2008. Since 2008, concentrations have followed a pattern of increasing in the second and third quarters, followed by a period of decreasing in the fourth and first quarters, a trend that may correspond with water table fluctuations. Sufficient water elevation data have not been gathered to correlate this seasonal pattern of concentration changes with water table fluctuations at this location. Since 2008, each successive annual peak has decreased in magnitude, indicating a downward trend in concentrations from that time.

Results of the statistical analysis indicated xylenes concentrations are increasing at MW-125, with benzene and toluene concentrations decreasing or probably decreasing; ethylbenzene concentrations exhibit no trend at this location. MW-125 is located north of containment area CA6 (Figure 19). The MW-125 concentration graph shows the potentially increasing trend in xylenes from 2006 through 2009, with decreased concentrations in 2010 and 2011 (Appendix S). The xylenes groundwater-cleanup level is 10,000 µg/L; the fourth quarter 2011 groundwater sample from MW-125 contained xylenes at a concentration of 752 µg/L.

At MW-135 and MW-136, increasing trends were indicated for toluene, ethylbenzene, and xylenes. For benzene, no trend was identified at MW-135 and a stable trend was indicated at MW-136. These wells are located just north of the tank farms near the northern edge of the plume (Figure 19). A visual inspection of the concentration graphs (Appendix S) indicated that BTEX concentrations peaked in the third quarter of 2008 at both wells, and have generally decreased with minor, likely seasonal, fluctuations since. The concentration trends recognized by the Mann-Kendall test identify the concentration increases at these locations through 2008 compared to analyte levels from 2002 through 2006; however, the analyte concentration decreases since 2008 are not captured in this long-term trend assessment. Insufficient water elevation data are available to correlate with the concentration data at this location.

At MW-139, a probably increasing trend was indicated for ethylbenzene, while decreasing trends were found for benzene and xylenes; no trend was indicated for toluene. MW-139 is located west of the truck-loading area (Figure 19). Xylenes concentrations have fluctuated substantially since 2002, ranging from 27 µg/L to 192 µg/L (below the ethylbenzene cleanup level of 700 µg/L) (Appendix S). Correlation of water table fluctuations with constituent concentrations is not yet possible due to a lack of groundwater elevation data.

The statistical analysis also indicated a probably increasing trend for benzene at MW-143. MW-143 is located beyond the northwestern tip of the plume (Figure 19). Benzene was not detected at MW-143 from May 2006 through October 2008, or from October 2009 to the present. A small benzene peak of 2.21 µg/L was noted during first and second quarters of 2009 (Appendix S). Insufficient water elevation data are available to correlate with concentration data at this location. The long-term concentration trend attributed to this location by the Mann-Kendall test reflects the relatively higher benzene concentration (below the cleanup level) observed from January through September 2009 compared to the earlier sample concentrations below the benzene detection limit.

In summary, the long-term increasing trends identified at wells MW-110, MW-125, MW-135, and MW-136 by the MAROS evaluation generally reflect relatively high analyte concentrations that reached peak levels that were followed by lower concentrations. A trend is commonly defined as “the general or prevailing tendency.” This statistical evaluation assessed long-term trends based on data sets with a long history (20 years at MW-110 and MW-125, and 10 years at MW-135 and MW-136). Visual inspections of concentration graphs for these wells indicate shorter-term decreasing or stable trends from their peak values that are not captured by the MAROS evaluation.

3.8.1.8.3 No Trend

At several wells (i.e., MW-101, MW-101A, MW-102, MW-105, MW-105A, MW-129, and MW-144A) no trends were identified for at least three analytes. As their concentration graphs show (Appendix S), these wells are typically are nondetect for BTEX, with only occasional nonconsecutive detections; therefore, concentrations do not appear to be increasing at these locations.

The statistical analysis also indicated no trend for benzene at MW-143. Well MW-143 is located beyond the northwestern edge of the plume (Figure 87). Benzene was not detected at MW-143 from May 2006 through October 2008, or from October 2009 to the present. A small benzene peak of 2.21

µg/L was noted during first and second quarters of 2009 (Appendix S). The other BTEX analytes have not been detected in samples from this well. Insufficient water elevation data are available to correlate with benzene concentration data at this location. The long-term concentration trend attributed to this location by the Mann-Kendall test reflects the relatively higher benzene concentration (below the cleanup level) observed from January through September 2009 compared to the earlier sample concentrations below the benzene detection limit. The trend from October 2009 to the present is not increasing since benzene and the other analytes were not detected at the well.

3.8.2 Sulfolane

Sulfolane has been detected in groundwater samples collected from both onsite and offsite wells, and from various depths within the aquifer. Maps have been prepared to show the sulfolane concentrations measured in groundwater samples collected from the fourth quarter of 2010 through the fourth quarter of 2011 (Figures 88 through 106). All of the monitoring wells are located in the suprapermafrost portion of the aquifer. For sampling events that predate the use of the isotope dilution method, the extent of the sulfolane plume is shown as an isopleth of 25 µg/L, which was the ADEC interim groundwater cleanup level for sulfolane applicable in 2011. A 10 µg/L isopleth is used for sampling events during which all analyses were completed using the isotope dilution method. Due to the range of concentrations measured across the plume, isopleths of 10 µg/L (when possible), 25 µg/L, 100 µg/L, and 1,000 µg/L are shown on the figures. Analytical data from the fourth quarter of 2011 are presented in Table 41; historical data are provided in Appendix S.

Since dissolved-phase sulfolane has been detected at various depths in the aquifer, the following discussion follows the monitoring zone depth intervals described in Section 2.6.2.1: water table, 10 to 55 feet BWT, 55 to 90 feet BWT, and 90 to 160 feet BWT.

Monitoring well results are discussed in sections 3.8.2.1 through 3.8.2.5, and shown on corresponding Figures 88 through 107. Results from private well sampling, and how those results correlate with monitoring well results are presented in Section 3.8.2.6, and shown on corresponding Figures 108 through 112.

3.8.2.1 Fourth Quarter 2010

Data from the fourth quarter of 2010 predate the use of the isotope dilution method; therefore, a 25 µg/L isopleth is used to illustrate the plume boundary on the corresponding figures.

3.8.2.1.1 Water Table

Figure 88 shows the sulfolane plume was present at the water table under CUs #1 and #2 and the tank farms, extending north-northwesterly (downgradient) offsite from NPR during the fourth quarter of 2010.

The extent of the plume exceeding the interim cleanup level at the water table during the fourth quarter of 2010, shown as the 25 µg/L isopleth, is defined by results less than 25 µg/L at wells MW-109, MW-116, MW-124, MW-132, MW-141, MW-144A, MW-145, MW-146A, MW-147A, MW-149A, MW-155A, MW-159, MW-165A, MW-166A, MW-167A, MW-168, MW-169A, MW-170A, MW-171A, MW-172A, MW-173A, MW-180A, MW-181A, MW-182, MW-185A, and MW-187. The highest concentrations were reported at onsite wells MW-110 (1390 µg/L) near Lagoon B and MW-176A (2050 µg/L) downgradient of CU #2 (Figure 88). The highest offsite concentrations were reported at wells MW-151A (106 µg/L), MW-156A (121 µg/L), and MW-158A (118 µg/L). All three wells are located in an area bounded by North Pole High School Boulevard, Homestead Road, Perimeter Road, and Holiday Drive (Figure 88).

3.8.2.1.2 10 to 55 Feet BWT

Figure 89 indicates sulfolane was present at in the 10 to 55 feet BWT monitoring zone during the fourth quarter of 2010. Onsite, the plume was present below the tank farms, but apparently not below CU #1 or CU #2, that is, the upgradient end of the plume appears to be shifted northwest, or in the downgradient direction, compared to the plume at the water table. The plume extends north-northwesterly (downgradient) offsite from NPR, in a manner similar to the water table plume.

The extent of the plume exceeding the interim cleanup goal at a depth of 10 to 55 feet BWT (Figure 89), shown as the 25 µg/L isopleth, is defined by results less than 25 µg/L at wells MW-101, MW-102, MW-118, MW-146B, MW-147B, MW-153B, MW-155B, MW-165B, MW-166B, MW-167B, MW-169B, MW-170D, MW-171B, MW-176B, MW-179B, MW-180B, MW-181B, MW-184, and MW-185B. The highest reported concentrations were at MW-148B (316 µg/L) near the property boundary and MW-178B (237 µg/L) downgradient of CU #2. The highest offsite concentrations were reported at wells MW-158B (136 µg/L) north of North Pole High School, MW-161B (243 µg/L) west of Bradley Sky Ranch, and MW-164 B (113 µg/L), located north of Richardson Highway along Peridot Street (Figure 89).

3.8.2.1.3 55 to 90 Feet BWT

As shown on Figure 90, sulfolane has been detected in samples collected from wells screened in the 55 to 90 feet BWT monitoring zone. The figures show that a limited number of monitoring wells have been installed at this depth due to presence of shallow permafrost in the area. The upgradient end of the plume appears to be located near the former truck-loading rack, again shifted downgradient when compared to the shallow portions of the plume, and the plume extends north-northwesterly (downgradient) offsite from NPR. Shallow permafrost has been encountered in a large portion of the offsite study area (Figure 42), preventing the installation of suprapermafrost monitoring wells (Figure 90). The permafrost may be limiting lateral migration of the plume at this depth.

Results less than 25 µg/L were reported at MW-144B, MW-170B, MW-174B, MW-175, MW-176C, MW-177, MW-178C, MW-179C, and MW-180C. The highest concentration was reported at offsite well MW-160B (115 µg/L) near Old Richardson Highway and Perimeter Road (Figure 90).

3.8.2.1.4 90 to 160 Feet BWT

Figure 91 shows fourth quarter 2010 data from the three wells installed in the 90 to 160 feet BWT monitoring zone. Sulfolane has not been detected in samples collected from these wells.

3.8.2.2 First Quarter 2011

The data from the first quarter of 2011 predate the use of the isotope dilution method; therefore, a 25 µg/L isopleth is used to illustrate the plume boundary on the corresponding figures.

3.8.2.2.1 Water Table

Figure 92 indicates the sulfolane plume is present at the water table under CUs #1 and #2 and the tank farms, extending north-northwesterly (downgradient) offsite from NPR.

The plume is similar to the 4th quarter 2010 interpretations, with minor changes likely due to fluctuating concentrations. Results less than 25 µg/L were reported at MW-106, MW-109, MW-132, MW-141, MW-144A, MW-145, MW-149A, MW-155A, MW-165A, MW-167A, MW-168, MW-169A, MW-170A, MW-171A, MW-172A, MW-173A, MW-180A, MW-181A, MW-185A, and MW-187. The highest concentrations were reported at onsite well MW-130 (930 µg/L) in the tank farm, while the concentration decreased from 1390 µg/L to 233 µg/L at MW-110 (Figure 92).

3.8.2.2.2 10 to 55 Feet BWT

Figure 93 indicates sulfolane is present in the 10 to 55 feet BWT monitoring zone. The plume is similar to the 4th quarter 2010 interpretation, extending north-northwesterly (downgradient) offsite from NPR, in a manner similar to the water table plume.

The extent of the plume exceeding the interim cleanup goal during the first quarter of 2011 is shown on Figure 93. Results less than 25 µg/L were reported at MW-101, MW-104, MW-129, MW-147B, MW-153B, MW-155B, MW-165B, MW-167B, MW-169B, MW-170D, and MW-171B. The highest concentration was reported at MW-148B (501 µg/L) near the property boundary. The highest offsite concentrations were reported at wells MW-158B (102 µg/L) north of North Pole High School, MW-161B (269 µg/L) west of Bradley Sky Ranch, and MW-164 B (104 µg/L), located north of Richardson Highway along Peridot Street (Figure 93).

3.8.2.2.3 55 to 90 Feet BWT

As shown on Figure 93, sulfolane has been detected in samples collected from wells screened in the 55 to 90 feet BWT zone. The figures show that a limited number of monitoring wells had been installed at this depth due to presence of permafrost in the area. The plume shown on the figure is similar to the 4th quarter 2010 interpretation, with the upgradient end located near the former truck-loading rack, and the plume extending north-northwesterly (downgradient) offsite from NPR. As stated previously, shallow permafrost has been encountered in a large portion of the offsite study area and. the permafrost may be limiting lateral migration of the plume at this depth (Figures 90 and 94).

The extent of the plume exceeding the interim cleanup goal during the first quarter of 2011 (Figure 94), shown as the 25 µg/L isopleth, is defined by results less than 25 µg/L at wells MW-144B, MW-170B, MW-174B, and MW-180C.

3.8.2.2.4 90 to 160 Feet BWT

Figure 95 shows first quarter 2011 data from the three monitoring wells installed between 90 and 160 feet BWT. Sulfolane has not been detected in samples collected from these wells.

3.8.2.3 Second Quarter 2011

Groundwater samples collected from the sulfolane monitoring network were analyzed for sulfolane by USEPA Method 8270D and groundwater samples collected from nine wells were analyzed using the isotope dilution method (ARCADIS, 2011d). Sulfolane data were plotted on Figures 96, 97, and 98 to show the extent of the dissolved-phase sulfolane plumes in the established depth intervals monitoring zones. Since most of the analyses were completed using USEPA Method 8270D, a 25 µg/L (the ADEC interim groundwater cleanup level for sulfolane) isopleth is used to illustrate plume extent . The footprints observed during the second quarter are similar to the footprints shown on the Fourth Quarter 2010 and First Quarter 2011 plume maps described above.

3.8.2.3.1 Water Table

Sulfolane was detected above 25 µg/L (USEPA Method 8270D) in 12 onsite wells at the water table with results ranging from 32.7 µg/L (MW-131) to 1,090 µg/L (S-41) (Figure 96). The maximum sulfolane concentration detected in well S-41 is located adjacent to tank farm containment area #1 and CU #1. The extent of the plume is defined by sulfolane results less than 25 µg/L in wells MW-105A, MW-106, MW-109, MW-132, MW-141, MW-144A, MW-145 MW-149A and MW-173A (Figure 96).

Sulfolane was detected above 25 µg/L in five offsite wells screened at the water table ranging from 49.3 µg/L (MW-157) to 116 µg/L (MW-161A). The extent of the sulfolane plume presented on Figure 96 is shown as an isopleth of 25 µg/L. The extent of the plume is defined by sulfolane results less than 25 µg/L in wells MW-155A, MW-163A, MW-169A, MW-172A, MW-181A and MW-187. Wells MW-165A and MW-166A, which are located at the downgradient edge of the plume, were frozen during this reporting period.

3.8.2.3.2 10 to 55 Feet BWT

Sulfolane was detected above 25 µg/L (USEPA Method 8270D) in three onsite wells screened in the 10 to 55 feet BWT zone, with results ranging from 41.0 µg/L (MW-174A) to 205 µg/L (MW-148B). The maximum sulfolane concentration detected in well MW-148B is located at the northern site boundary. The extent of the sulfolane plume presented on Figure 97 is shown as an isopleth of 25 µg/L. The extent of the plume is defined by sulfolane results less than 25 µg/L in wells MW-101, MW-104, MW-105, MW-129 and MW-147B.

Sulfolane was detected above 25 µg/L in four offsite wells screened in the 10 to 55 feet BWT zone, with results ranging from 56.6 µg/L (MW-163B) to 167 µg/L (MW-161B). The extent of the sulfolane plume presented on Figure 97 is shown as an isopleth of 25 µg/L. The extent of the plume is defined by sulfolane results less than 25 µg/L in wells MW-153B, MW-165B and MW-181B. Wells MW-166B and MW-167B, which are located at the downgradient edge of the plume, were frozen during this reporting period.

3.8.2.3.3 55 to 90 Feet BWT

Sulfolane was not detected above 25 µg/L (USEPA Method 8270D) in any onsite well screened in the 55 to 90 feet BWT monitoring zone.

Sulfolane was detected above 25 µg/L in two offsite wells screened at 55 to 90 feet BWT, with concentrations of 103 µg/L (MW-158B) and 127 µg/L (MW-160B.) The extent of the sulfolane plume presented on Figure 98 is shown as an isopleth of 25 µg/L. The extent of the plume is defined by sulfolane results less than 25 µg/L in wells MW-144B, MW-155B, MW-174B and MW-175. Wells located at the downgradient edge of the plume were frozen during this reporting period.

3.8.2.3.4 90 to 160 Feet BWT

Sulfolane was not detected above 25 µg/L (USEPA Method 8270D) in any onsite or offsite wells installed within the 90 to 160 feet BWT zone.

3.8.2.4 Third Quarter 2011

Groundwater samples collected from 38 onsite wells and 61 offsite monitoring wells were submitted for sulfolane analysis using the isotope dilution method during the third quarter of 2011. These data are presented in Table 41. Sulfolane data are plotted on Figures 99, 100, 101, and 102 to show the extent of the dissolved-phase sulfolane plumes at the following monitoring zones: water table, 10 to 55 feet BWT, 55 to 90 feet BWT and 90 to 160 feet BWT.

Since the isotope dilution method was used in the third quarter of 2011, a 10 ug/L isopleth is shown on the corresponding figures. The plume footprints observed during the third quarter are similar to footprints described in the sections above. Historical sulfolane analytical results are included as Appendix S.

3.8.2.4.1 Water Table

Sulfolane was detected above the interim cleanup goal of 25 µg/L in 11 onsite monitoring wells at the water table, with results ranging from 25.4 µg/L (MW-179A) to 1,240 µg/L (MW-110). Sulfolane concentrations for wells MW-125, MW-139, MW-178A and MW-180A were pending further evaluation at the time of the draft RSC Report; the updated results are included in this submittal. The sulfolane concentration at MW-139 was flagged by the laboratory as estimated. The extent of the sulfolane plume presented on Figure 99 is shown as an isopleth of 10 µg/L. The maximum sulfolane concentration detected in well MW-110 is located adjacent to the northwest corner of Lagoon B. The reported concentration from MW-183 was not used in the contour, as it is substantially lower than previous results for this location and appears incongruous within the plume (Figure 99). Results from the fourth quarter results from MW-183 are consistent with historical results, which support that the third quarter results are anomalous.

Sulfolane was detected above the interim cleanup goal of 25 µg/L in 12 offsite monitoring wells screened at the water table, ranging from 26.3 µg/L (MW-194A) to 179 µg/L (MW-161A). The sulfolane concentration for well MW-162A was pending further evaluation at the time of the draft

RSC Report; the updated results are included in this submittal. Sulfolane concentrations at wells MW-169A, MW-183 and MW-187 were flagged by the laboratory as estimated. The extent of the sulfolane plume presented on Figure 99 is shown as an isopleth of 10 µg/L.

3.8.2.4.2 10 to 55 Feet BWT

Sulfolane was detected above the interim cleanup goal of 25 µg/L in three onsite wells screened in the 10 to 55 feet BWT monitoring zone, with results ranging from 33.6 µg/L (MW-186B) to 251 µg/L (MW-148B). The sulfolane concentration at MW-179B was flagged by the laboratory as estimated. The maximum sulfolane concentration detected in well MW-148B is located at the northern site boundary. The extent of the sulfolane plume presented on Figure 100 is shown as an isopleth of 10µg/L.

Sulfolane was detected above the interim cleanup goal of 25 µg/L in 14 offsite wells screened in the 10 to 55 feet BWT monitoring zone, with results ranging from 31.3 µg/L (MW-153B, duplicate sample) to 302 µg/L (MW-161B). Sulfolane concentrations at wells MW-167B, MW-185B and MW-193B were flagged by the laboratory as estimated. The extent of the sulfolane plume presented on Figure 100 is shown as an isopleth of 10 µg/L.

3.8.2.4.3 55 to 90 Feet BWT

Sulfolane was detected above the interim cleanup goal of 25 µg/L in onsite well MW-154B (29 µg/L) in the 55 to 90 feet BWT zone. The sulfolane concentration at MW-154A was flagged by the laboratory as estimated. Well MW-154B is located west of the rail lines in the northern portion of the site. The extent of the sulfolane plume at 55 to 90 feet BWT presented on Figure 101 is shown as an isopleth of 10 µg/L.

Sulfolane was detected above 25 µg/L in offsite well MW-160B (125 µg/L), which is screened in the 55 to 90 feet BWT zone. The extent of the sulfolane plume is shown on Figure 101.

3.8.2.4.4 90 to 160 Feet BWT

Sulfolane was not detected above 25 µg/L in any onsite or offsite groundwater sample collected from the 90 to 160 feet BWT zone. Sulfolane analytical results are presented on Figure 102.

3.8.2.5 Fourth Quarter 2011

Samples collected from 54 onsite monitoring wells, 14 onsite observation wells, and 72 offsite monitoring wells were submitted for sulfolane analysis using the isotope dilution method during the fourth quarter of 2011. These data are presented in Table 41. Sulfolane data collected from monitoring wells are plotted on Figures 103 through 106 to show the extent of the dissolved-phase sulfolane plumes at the following depth intervals: the water table, 10 to 55 feet BWT, 55 to 90 feet BWT and 90 to 160 feet BWT, respectively.

Forty-nine groundwater samples were collected from VPT wells and analyzed for sulfolane; results are described in Section 3.8.2.6. Data are summarized in Table 41 and presented on Figure 36. Additionally, the maximum sulfolane concentration for each groundwater zone at each well cluster location (i.e. MW-301, MW-302, etc.) is presented on Figures 103 through 106.

Since the isotope dilution method was used in the fourth quarter of 2011, a 10 µg/L isopleth is shown on the corresponding figures. The plume footprints observed during the fourth quarter 2011 are similar to footprints described in the sections above. Historical sulfolane analytical results are included as Appendix S.

3.8.2.5.1 Water Table

Sulfolane was detected above the interim cleanup goal of 25 µg/L in samples collected from 14 onsite monitoring wells screened at the water table, with results ranging from 28.2 JH µg/L (MW-116) to 1,150 µg/L (MW-110). Additionally, sulfolane was detected above the interim cleanup goal of 25 µg/L in samples collected from eight observation wells, with results ranging from 112 µg/L (O-4) to 10,400 µg/L (O-1). Sulfolane concentrations in samples collected from wells O-3, O-12 and MW-116 were flagged by the laboratory as estimated. Sulfolane concentrations in samples collected from wells O-21 and MW-116 were quantified using quantitative ion 46 per ESI direction. The estimated extent of the sulfolane plume presented on Figure 103 is shown as an isopleth of 10 µg/L. The maximum sulfolane concentration detected in observation well O-1 is located downgradient of CU #2.

Sulfolane was detected above the interim cleanup goal of 25 µg/L in samples collected from 12 offsite monitoring wells screened at the water table, ranging from 27.2 µg/L (MW-159) to 151 µg/L (MW-161A, duplicate sample). Sulfolane concentrations in samples collected at wells MW-167A, MW-168, MW-169A, MW-185A, MW-187 and MW-193A were flagged by the laboratory as estimated. The extent of the sulfolane plume presented on Figure 103 is shown as an isopleth of 10 µg/L.

3.8.2.5.2 10 to 55 Feet BWT

Sulfolane was detected above the interim cleanup goal of 25 µg/L in samples collected from six onsite wells screened in the 10 to 55 feet BWT monitoring zone, with results ranging from 35.6 µg/L

(MW-101) to 284 µg/L (MW-148B). The sulfolane concentration in the sample collected from MW-179B was flagged by the laboratory as estimated. The maximum sulfolane concentration detected at this depth was observed in the sample collected from well MW-148B, which is located at the northern site boundary. The extent of the sulfolane plume presented on Figure 104 is shown as an isopleth of 10 µg/L.

Sulfolane was detected above the interim cleanup goal of 25 µg/L in samples collected from 18 offsite wells screened in the 10 to 55 feet BWT zone, with results ranging from 33.3 µg/L (MW-153B) to 316 µg/L (MW-161B). Sulfolane concentrations in samples collected from wells MW-167B and MW-193B were flagged by the laboratory as estimated. The extent of the sulfolane plume presented on Figure 104 is shown as an isopleth of 10 µg/L.

3.8.2.5.3 55 to 90 Feet BWT

Sulfolane was detected above the interim cleanup goal of 25 µg/L in samples collected from onsite wells MW-154A (33.1 µg/L) and MW-154B (35.1 µg/L) screened in the 55 to 90 feet BWT zone. Wells MW-154A and MW-154B are located west of the rail lines in the northern portion of the site. The extent of the sulfolane plume at 55 to 90 feet BWT presented on Figure 105 is shown as an isopleth of 10 µg/L.

Sulfolane was detected above the interim cleanup goal of 25 µg/L in samples collected from offsite wells MW-159C (106 µg/L) and MW-160B (118 µg/L, duplicate sample), which are screened in the 55 to 90 feet BWT zone. The extent of the sulfolane plume is presented on Figure 105.

3.8.2.5.4 90 to 160 Feet BWT

Sulfolane was not detected above the interim cleanup goal of 25 µg/L in samples collected from any onsite or offsite groundwater sample screened in the 90 to 160 feet BWT zone during the fourth quarter 2011 event. A detectable concentration of sulfolane in the sample collected from MW-185C was flagged by the laboratory as estimated. Sulfolane analytical results are presented on Figure 106.

3.8.2.6 Vertical Profile Transect

As stated in Section 2.6.2.4, groundwater sampling was conducted at vertical profiling transect wells to evaluate vertical distribution of sulfolane concentrations. Fourth quarter 2011 sulfolane results for the VPT wells are summarized in Table 41 and shown on Figure 36. As shown on the figure, the CMT and monitoring wells have defined the sulfolane plume horizontally and vertically across the transect.

In samples collected from the MW-301 cluster, sulfolane in groundwater was detected as estimated concentrations of 3.24J µg/L at 40 feet BGS, 5.35J µg/L at 50 feet BGS and 7.02J µg/L at 60 feet BGS. Sulfolane concentrations were not detected from the 10 to 30 feet BGS interval and are not detected at the 70 feet BGS interval, which was the total depth explored at this location.

At the MW-302 well cluster, sulfolane in groundwater was detected at a maximum concentration of 76.2 µg/L in the sample collected from the 20 feet BGS interval. The sulfolane concentration decreased with depth from 63.0 µg/L in the sample collected at 30 feet BGS to 3.39J µg/L in the sample collected at 80 feet BGS. Sulfolane concentrations were not detected at the sample collected from the 110 feet BGS interval, which was the total depth explored at this location. The sample collected from MW-302-CMT-20 (screened at 19.9 to 20.1 feet BGS) was reported at 76.2 µg/L, while the sampled collected from adjacent monitoring well MW-101A (screened at 17.8 to 22.8 feet BGS) was reported at <6.2 µg/L. By design, the CMT wells draw water from a much narrower vertical zone than the traditional monitoring wells: 0.2 feet at MW-302-CMT-20 versus 5.0 feet at MW-101A. This can result in a diluting effect with the monitoring well results, which may be the case in this situation. In addition, MW-101A was sampled on October 16, 2011, while the MW-302-CMT wells were sampled on November 10, a span of twenty-five days, which may account for additional variability between the results.

In samples collected from the MW-303 well cluster, sulfolane in groundwater was detected at a maximum concentration of 123 µg/L at 20 feet BGS. Sulfolane concentrations decreased with depth from 88.5 µg/L at 30 feet BGS to 10.2 at 80 feet BGS. Sulfolane concentrations were not detected at 130 feet BGS, which was the total depth explored at MW-303. The sample collected from MW-303-CMT-9 (screened at 8.9 to 9.1 feet BGS) was reported at 4.22J µg/L, while the sampled collected from MW-303-CMT-19 (screened at 18.9 to 19.1 feet BGS) was reported at 123JH µg/L, and the sample from adjacent monitoring well MW-143 (screened at 4.7 to 19.5 feet BGS) was reported at 56.4 µg/L. While the MW-143 result does not appear to correlate well with either MW-303-CMT sample, its concentration does fall between the two, which is reasonable considering its screened interval spans the depths from which both of these CMT wells are sampled.

At the MW-304 cluster, sulfolane in groundwater was detected at a maximum concentration of 262 µg/L in the sample collected at 20 feet BGS. Sulfolane concentrations decreased with depth from 215 µg/L in the sample collected at 30 feet BGS to 6.65J in the sample collected at 80 feet BGS. Sulfolane concentrations were not detected at 125 feet BGS, which was the total depth explored in MW-304.

In samples collected from the MW-305 cluster, sulfolane in groundwater was detected at a maximum concentration of 53.8 µg/L at 30 feet BGS. Sulfolane concentrations decreased with depth from 10.9 µg/L at 40 feet BGS to 4.96J at 60 feet BGS. Sulfolane concentrations were not detected in the samples collected from 70 to 80 feet BGS. An estimated concentration of 4.45J µg/L was detected at 100 feet BGS, which was the total depth explored at this location.

At the MW-306 cluster, sulfolane was not detected at any of the groundwater samples collected to the total depth explored of 150 feet BGS.

The distribution of sulfolane concentrations across the vertical profiling transect were used to calculate mass flux across the plume as described in Section 3.8.2.7.

3.8.2.7 Mass Flux

Using the geologic data outlined in Section 2.6.2.4.2 and analytical data collected during November 2011, the toolkit estimated a total mass flux across the VPT well cluster transect of 86 g/day (0.19 lb/day). This is the first estimate of mass flux completed for the site and future measurements will be compared to this estimate.

3.8.2.7.1 Analysis of Mass Discharge

Using the toolkit site-specific data outlined in Section 2.6.2.4.2, mass discharge was estimated at approximately 86 g/day across the transect plane. Mass flux rates across the transect plane are presented on Figure 107. The zones targeting the majority of mass flux are summarized below.

VPT Well Cluster	Approximate Depth (feet BGS/feet BWT)	Mass Flux (g/day)	Approximate Percent of Total Mass Flux
MW-302	8 (Water table) to 60 / 0 to 52	16.8	19%
MW-303	22 to 35 / 13 to 26	7.39	9%
MW-304	11 (Water table) to 60 / 0 to 49	40.63	47%
MW-305	9 (Water table) to 34 / 0 to 25	9.30	11%

Each sample interval for VPT well clusters MW-301 and MW-306 indicated a low mass discharge. There may be no significant mass flux of sulfolane at the lateral edges of the plume at these locations, but is indicated in part due to the assumption outlined above that nondetectable concentrations are equal to one-half of the detection limit. Also, sample concentrations within 40 to 70 feet BGS (35 to 65 feet BWT) at MW-301 were flagged as estimated by the lab. These assumptions skew the mass discharge estimations, reducing the relative magnitude of the total contribution to flux of the zones of the transect where sulfolane was actually detected with certainty.

3.8.2.8 Private Well Results

As stated in Section 2.6.2.5, sampling of private wells has been ongoing from November 11, 2009 through December 31, 2011. Groundwater samples from 518 private wells were collected and analyzed for sulfolane. Samples collected through May 11, 2011, were analyzed for sulfolane by USEPA Method 8270D. Subsequent samples were analyzed using the isotope dilution method. The results are shown on Figures 108 and 109, regardless of well depth and sampling date.

Results from fourth quarter 2011 private well sampling are presented in Tables 47 and 48; historical data are presented in Appendix AB. Sulfolane concentrations in private wells have ranged from less than the limit of quantitation (LOQ) to 443 µg/L. During the fourth quarter of 2011, sulfolane concentrations detected in samples from private wells ranged from 13.1 to 93.1 µg/L. Concentrations of sulfolane were not detected above the laboratory LOQ in 110 samples. Seven additional sample results were flagged by the laboratory as estimated concentrations below the laboratory LOQ.

Residential locations sampled for the first time during the fourth quarter 2011 were analyzed for sulfolane using the isotope dilution method and are presented in Table 47. Sulfolane concentrations in samples collected from three locations were above the LOQ. The property owner at each of these three locations was contacted during the original survey of the respective area, however, permission was not given to collect samples at the time of the original survey for two locations and the well at the third location was recently installed.

Data analyzed using the original sulfolane analytical method and data from the resampling event conducted during the fourth quarter 2011 using the isotope dilution method are compared in Table 48.

Of the private wells that have been sampled for sulfolane, depth information has been obtained for approximately 176 locations (Table 7). Screen intervals for private wells were assumed to be relatively discrete and consistent within groundwater zones. However, the private well depth information may not be a reliable indicator of sampling depth since it is possible that some private wells may have been modified subsequent to installation, and therefore, the depths listed on the logs may not be the intervals from which water is currently being pumped. In addition, the integrity of the private well casings may have been compromised resulting in shallow water entering the well. As mentioned previously, the potential exists for migration of groundwater along the exterior of well casings that are warmed with heat tracing.

Data from the private wells have been plotted on the appropriate monitoring zone maps with fourth quarter 2011 sulfolane data from the monitoring wells, as shown on Figures 110 through 112. No private well results have been plotted on the water table plume map, since none appear to be screened at the water table. Private well data are shown regardless of sampling date.

Figure 110 shows results for private and monitoring wells installed 10 to 55 feet BWT. The estimated extent of the plume is similar to that shown on Figure 104. The 10 µg/L isopleth has been extended north in the vicinity of the intersection of Badger Road and Peridot Street around a few wells with concentrations less than 10 µg/L, in order to include a group of private wells with concentrations that exceed 10 µg/L (Figure 110).

Results for private and monitoring wells installed 55 to 90 feet BWT are shown on Figure 111. The sulfolane plume extends offsite at this depth, but shallow permafrost may be limiting its lateral migration. Sulfolane was reported in several private wells at this depth: all are located along Badger Road north of Richardson Highway (Figure 111).

Results from wells installed 90 to 160 feet BWT are shown on Figure 112. Based on available construction information, the private well samples with sulfolane appear to be installed below permafrost. Sulfolane was reported as estimated concentrations in two samples from monitoring wells screened in this zone, both of which are installed above permafrost.

Figure 113 shows the results for private wells installed at depths greater than 160 feet BWT. Based on available construction information, these wells appear to be installed in the subpermafrost aquifer; no monitoring wells are installed at this depth. At this time, the mechanism by which sulfolane entered these wells is not understood.

3.8.2.9 Sulfolane Data Evaluation

As stated in Section 2.6.5, a statistical and graphical evaluation of sulfolane concentration trends at monitoring wells is being used to evaluate plume migration and stability, to evaluate cleanup action effectiveness, and eventually identify relationships between dissolved-phase concentrations and groundwater elevations and flow directions. Sulfolane results from private well results were not evaluated because sufficient data have not been collected to evaluate a trend from most private wells.

Results from the Mann-Kendall test and MAROS evaluation of 196 wells are summarized in Appendix S. Many of the wells have been installed recently; 98 wells have not been sampled enough times to generate a sufficient data set to complete the trend analysis.

3.8.2.9.1 Nondetects, Decreasing, or Stable Trends

As shown in Appendix S, 36 locations have not yielded samples containing detectable sulfolane. The MAROS evaluation indicated sulfolane concentrations at 24 wells are decreasing or probably decreasing, and concentrations at 11 are stable (Appendix S). The wells exhibiting decreasing or stable concentrations include most of the water table wells and most of the wells screened 10 to 55 feet BWT located within the plume, from NPR northwestward through the Ford Subdivision to Homestead Drive and to the north end of Peridot Street (Figure 20). Also included are two onsite wells installed in the 55 to 90 feet BWT zone: MW-154A (screened to 75 feet BGS [65 feet BWT]) and MW-154B (screened to approximately 95 feet BGS [85 feet BWT]).

3.8.2.9.2 Increasing Trend

The MAROS evaluation indicated sulfolane concentrations are increasing or probably increasing at six wells, MW-142, MW-153B, MW-161A, MW-166A, MW-167B, and MW-187 (Appendix S). Concentration graphs for these wells are provided in Appendix S.

Well MW-142 is a water table well located onsite at NPR, just northwest of the truck-loading area (Figure 20). The MAROS evaluation indicated the sulfolane concentration is probably increasing at MW-142. Nearby water table wells located upgradient (MW-139), downgradient (MW-143), and sidegradient (MW-101A and MW-131) to MW-142 are all characterized as having decreasing trends. Visual inspection of the MW-142 concentration graph indicates the sulfolane concentrations may have generally increased from September 2007 through March 2009, but since that time they have been fluctuating between 330 µg/L and 690 µg/L. Insufficient water elevation data are available to correlate the concentration data with water table fluctuations at this location.

MW-153B is a well installed in the 10 to 55 feet BWT monitoring zone (screened to approximately 56 feet BGS or 50 feet BWT), installed to the top of the permafrost table at the City WWTP near the northern boundary of the NPR property. The MAROS evaluation identified an increasing sulfolane concentration trend there, which appears to be supported by the graphical depiction of sulfolane concentrations at that location (Appendix S). However, as with some of the other “increasing” concentration trends, this data set is characterized by periods with no detectable analyte interspersed with measurable concentrations. The addition of more data to the MW-153B sulfolane data set may result in a recharacterization of the data as “no trend” or stable.

MW-161A and MW-187 are water table wells located approximately 9,000 feet downgradient of NPR, west of the Bradley Sky Ranch (Figure 20). The MAROS evaluation indicated no other water table wells between MW-161 and the NPR property boundary have increasing trends, though the deeper well MW-153B, discussed above, is located upgradient from these locations. Correlation of water table fluctuations at these locations with constituent concentrations is not yet possible due to a lack of groundwater elevation data; groundwater monitoring at these wells will continue to allow for further evaluation of the concentration trends.

Wells MW-166A and MW-167B are located approximately 15,000 feet downgradient from NPR. MW-166A is a water table well, and MW-167B is completed to the top of permafrost in the 10 to 55 feet BWT monitoring zone (screened to 33 feet BGS or approximately 24 feet BWT). Permafrost was encountered in the MW-166 well nest at a depth of 33 feet BGS (24 feet BWT). Five sulfolane-sample results contributed to the MAROS analysis for MW-166A, three of which were nondetect. The two most recent samples at MW-166A were collected in November 2010 and October 2011; the November 2010 sample was analyzed using EPA Method 8270D, and the October 2011 sample was analyzed using EPA Method 1625B with isotopic dilution. Fourteen sulfolane samples contributed to the MAROS analysis for MW-167B, twelve of which were nondetect. These twelve samples were collected from MW-167B from March 2010 through April 2011, and analyzed by EPA Method 8270D; the two samples with sulfolane detections at this location were collected in the third and fourth quarters of 2011, and analyzed using EPA Method 1625B with isotopic dilution.

EPA Method 1625B “corrects” the sulfolane analyte concentration using recovery information for isotopically labeled sulfolane added to the analytical sample, and appears to yield somewhat higher sulfolane results than for samples analyzed by Method 8270D. The apparent increasing trend at both MW-166A and MW-167B may be partly attributable to the change in analytical methods during the later sampling episodes. As noted above, each well has yielded only two samples with detectable sulfolane, and additional sample data should provide greater confidence in the sulfolane trends at these locations.

3.8.2.9.3 No Trend

The MAROS evaluation characterized the sulfolane concentrations as having no trend at 21 wells. For some of these wells, this may be attributed to a small sample set, with varying sulfolane concentrations. Monitoring wells MW-130, MW-161B, MW-164B, MW-166B, MW-185A, and MW-185B have only yielded four to six samples thus far. MW-130 is located on the refinery property, between containment areas CA4 and CA6, and has been sampled four times, starting in 2011; concentrations there have fluctuated between 629 and 1,130 µg/L. MW-161B is installed in the 10 to 55 feet BWT monitoring zone (screened to about 50 feet BGS or 44 feet BWT), and is part of the MW-161 well nest west of the Bradley Sky Ranch; sulfolane concentrations there have fluctuated between about 170 µg/L and 320 µg/L. Well MW-164B is installed in the 10 to 55 feet BWT monitoring zone (screened to approximately 50 feet BGS or 43 feet BWT), and is part of the MW-164 well nest, located on Peridot Street, approximately 9,500 feet downgradient from NPR; both this well and water table well MW164A exhibit no sulfolane concentration trend, with concentrations ranging from 16.5 µg/L to 106 µg/L in the shallow well and from about 81 µg/L to 134 µg/L in the deeper well. Well MW-166B is located on the drainage channel, about 2.8 miles northwest of NPR; sulfolane concentrations there have ranged from 11.4 µg/L to 37.41 µg/L. Wells MW-185A and MW-185B are nested wells sampled four times, and are screened to at the water table and in the 10 to 55 feet BWT monitoring zones, respectively, at a location about 2.3 miles north of the refinery; the shallower well has yielded one sample with detectable sulfolane, and the deeper well has yielded two samples containing sulfolane. Additional data from these six wells may eventually result in their concentrations being characterized as stable.

Wells MW-106, MW-109, and MW-141 exhibit no trend, and have occasional sulfolane detections in the midst of extended periods of nondetects. These three wells are located onsite near the western edge of the plume (Figure 20).

Other wells with no sulfolane concentration trends are located mid-plume, and include MW-151C, MW-152A, MW-152B, MW-158B, MW-159A, and MW-160B, all located in the subdivision north of NPR and south of Perimeter Drive (Figure 20). Well MW-151C is installed in the 10 to 55 feet BWT monitoring zone (screened to a depth of 57 feet BGS or 51 feet BWT), and was installed just above permafrost at that location; concentrations there have ranged between 17 µg/L and 76 µg/L. Wells MW-152A and MW-152B are located about 950 feet east of MW-151C, and are installed in the water table and 10 to 55 feet BWT monitoring zones, respectively; these wells are adjacent to well MW-152C (screened from 60 to 65 feet BGS, or 52 to 57 feet BWT), which was installed above the permafrost table encountered at 67.5 feet BGS (approximately 59.5 feet BWT). MW-152C was installed in September 2011 and has not yielded enough data to assess a concentration trend. Well MW-158B was installed with its screen set from 56 to 60 feet BGS (approximately 48 to 53 feet BWT); the top of permafrost is at 65 feet BGS (approximately 57 feet BWT). MW-159A is part of a well nest that was completed at the top of permafrost at 72.5 feet BGS (approximately 694 feet BWT). MW-160B is a deeper well installed in the 55 to 90 feet BWT monitoring zone, screened to 90 feet BGS (approximately 83 feet BWT), and was also installed above permafrost, which was encountered at 91 feet BGS (84 feet BWT). The absence of any identifiable trend in the fluctuating sulfolane concentrations at these locations may be due to anomalies in the groundwater flow regime related to their proximity to permafrost.

Sulfolane data from onsite well MW-138 also exhibits no trend. This well frequently contains LNAPL, and has historical sulfolane concentrations ranging between not detectable to 11,000 µg/L.

For the other wells, the absence of a discernible trend may be due to fluctuating concentrations near the plume boundaries, such as those seen at MW-159A, near the eastern plume boundary, and at MW-169A on the Tanana River levee. Sufficient groundwater elevation data have not been collected from these wells to correlate the concentration fluctuations to water table fluctuations.

3.8.3 Other COPCs

The partial list of COPCs was analyzed during the third quarter 2011. The full list of COPCs was evaluated in fourth quarter 2011. Fourth quarter 2011 data are summarized in Tables 43, 44, 45 and 46; historical data are provide in Appendix AC. COPC groundwater concentrations were compared with ADEC groundwater screening levels (ADEC 2008; Table C).

3.8.3.1 Third Quarter 2011

A concentration of 5,120 µg/L GRO was detected above the ADEC screening level of 2,200 µg/L in the groundwater sample collected from well MW-125 (Appendix AC). Well MW-125 is located north of CA6.

Concentrations of 2,150 and 1,970 µg/L DRO were detected above the ADEC screening level of 1,500 µg/L in the groundwater samples collected from wells MW-110 and MW-139, respectively (Appendix AC). Well MW-110 is located adjacent to the northwest corner of Lagoon B and well MW-139 is located west of the rail lines in the northern portion of the site.

Iron was detected in the sample collected from monitoring well MW-110 at a concentration exceeding the applicable USEPA Regional Screening Level (RSL) of 26,000 µg/L, at a concentration of 56,900 µg/L (Appendix AC).

The remaining COPCs were not detected above ADEC groundwater screening levels or applicable RSLs during the third quarter groundwater monitoring event. Laboratory analytical reports are included in Appendix L.

3.8.3.2 Fourth Quarter 2011

Concentrations of 20,800 and 2,850 µg/L of GRO were detected above the ADEC cleanup level of 2,200 µg/L in the groundwater samples collected from wells MW-135 and MW-125, respectively (Table 43). Wells MW-125 and MW-135 are located north of containment area 6 (Figure 23).

Concentrations of 1,860 µg/L and 1,520 µg/L of DRO were detected above the ADEC cleanup level of 1,500 µg/L in the groundwater samples collected from wells MW-139 (duplicate sample) and MW-135, respectively (Table 43). Well MW-139 is located west of the rail lines in the northern portion of the site.

Concentrations ranging from 12,500 to 59,900 µg/L of iron were detected above the USEPA RSL (11,000 µg/L) in wells MW-110, MW-125, and MW-139 (Table 44). MW-110 is adjacent to the northeast corner of Lagoon B.

COPCs propylene glycol and isopropanol were inadvertently excluded during the fourth quarter 2011 monitoring but samples were analyzed for these compounds during the first quarter 2012 monitoring event. The remaining COPCs were not detected above ADEC groundwater cleanup levels or applicable RSLs during the fourth quarter 2011 monitoring event (Table 45 and 46). Laboratory analytical reports are included in Appendix L.

3.8.3.3 Summary

To date, besides sulfolane and BTEX, only the COPCs GRO, DRO, and iron have been reported above screening levels in groundwater onsite. The exceedances were reported at locations within areas of known petroleum impacts; therefore the GRO and DRO results are not unexpected. The elevated iron concentrations are likely an indirect result of the petroleum impacts. As the petroleum constituents degrade dissolved oxygen is consumed and conditions become reduced, which results in reduction of iron from Fe^{+3} (ferric iron) to Fe^{+2} (ferrous iron). Ferrous iron is more soluble than ferric iron and more iron becomes dissolved in the groundwater. Therefore, an increase in iron concentrations is often noted in areas of petroleum impacts. Since the increased iron concentrations are the result of the benzene impacts, they are not a target for remediation, although issues with iron precipitation must be taken into consideration in remedial system design as iron will likely be oxidized which will results in its precipitation.

Regarding the remaining COPCs, it is important to note that none were detected at concentrations exceeding cleanup levels in groundwater collected near the crude units, Lagoon B, the tank farms, the railcar loading rack, and the downgradient property boundary.

3.9 Response to LNAPL Accumulation in New Delineation Wells

As described in Section 2.5.1, seventeen observation wells were installed between September 13 and October 15, 2011, as proposed in the SCWP Addendum, for the purpose of gauging LNAPL onsite. On October 22, 2011 LNAPL was observed in northern observation wells O-11 and O-13 in the truck-loading rack area. LNAPL also accumulated in wells O-7 and O-9 on the eastern side of the tank farm (Figure 16). Response actions to the accumulation of LNAPL in these wells included:

- A follow-up sump inspection was completed at the truck rack and a product leak was discovered. FHRA completed a leak investigation to estimate the volume of product spilled, to determine the cause of the leak and to make necessary repairs.
- A forensics evaluation was conducted on LNAPL present in 10 wells at the site including those near the truck rack (O-2, O-11, O-13, and R-40), wells along the northern edge of the tank farm (O-2 and R-40) and wells O-7 and O-9 on the eastern side of the tank farm.
- LNAPL gauging and bail-down testing was completed on LNAPL in the wells nearest the truck rack (O-9, O-11 and O-13).
- Dissolved-phase BTEX concentration trends were evaluated in nearby monitoring wells.

The results of the leak investigation and response actions are summarized in the following sections.

3.9.1 Sump Investigation

As described elsewhere in this report, beginning in 2009 and continuing into 2010, FHRA performed a comprehensive inspection of 42 sumps to identify and repair any sumps with integrity issues. Details of the sump investigation and results were reported in a report titled, Sump Investigation Report and Investigation Closure Request, December 8, 2010. The sump identified as S-926 is associated with the Truck Rack facility and welding deficiencies were identified and repaired. The sump passed the integrity test and inlet lines passed static leak testing. No other sumps at the truck rack were identified in the inspection report. A copy of the FHRA sump investigation report can be found in Appendix J.

As a response to the observation of LNAPL in the new wells, FHRA conducted a follow-up inspection on the Truck Rack sumps. FHRA discovered missing pipe sealant material in the Truck Lane #1 sump basin on October 25, 2011. On October 27, 2011, FHRA reported a potential spill incident to ADEC from Truck Lane #1 sump basin at NPR in the Oil and Hazardous Materials Incident Final Report, per Alaska State Regulation 18 AAC 75.300(e). The report listed the date of discharge as October 25, 2011 with a total estimated volume of 540 gallons of gasoline and ultra-low sulfur diesel (ULSD) released from the Truck Lane #1 sump. FHRA determined that the sealant material connecting piping to the bottom of the catch basin in Truck Lane #1 was missing. The Truck

Lane #2 sump sealant material was noted as degrading, but had not failed. This potential failure was calculated in FHRA's total estimated volume. A copy of the report is provided in Appendix AD.

An investigation by FHRA assumed a start date of the spill as September 17, 2009 (the last known inspection date) and an end date of October 26, 2011. Operational knowledge of the sump basins stated that 1 to 2 gallons of product (gasoline and USLD) per day are routed to the Truck Lane #1 and #2 basins. The size of the missing sealant space allowed for as much as 0.7 gallon per day of loss during that time period. Based on those numbers, FHRA estimated approximately 540 gallons of total product loss due to the spill.

FHRA temporarily shut down all truck lanes and resealed all truck lane catch basins. In the future, FHRA will install a mechanical seal where the piping connects to the catch basins in all lanes. Operations personnel performed a survey on the majority of known drains at the facility to identify pipe seals of a similar design. No other similar pipe seals were found. During the fourth quarter of 2011, additional LNAPL wells were installed to delineate the extent of LNAPL north of the tank farms (Figure 16).

3.9.2 LNAPL Forensics

On October 25, 2011 free product samples were collected from select observation wells and submitted to Friedman and Bruya, a state certified laboratory in Seattle, Washington for fingerprinting analysis. An LNAPL forensic evaluation was completed to determine the nature of LNAPL present in 10 monitoring wells at the site. The results from this evaluation are presented in Section 3.7.2.2 and indicate that a minor portion of the LNAPL sampled from monitoring wells O-13 and R-40 is representative of gasoline (Figure 9 of Appendix O).

The LNAPL forensics evaluation indicates that the LNAPL near wells O-13 and R-40 is largely Jet A and naphtha. This indicates the LNAPL present is likely largely due to historical documented releases. A list of documented releases at the site is included in Table 2. In addition, the evaluation indicates that the LNAPL present in wells at the site has undergone some degree of weathering and it is not fresh.

3.9.3 LNAPL Assessment

Well O-13 was not initially included in the LNAPL Assessment proposed scope of work, but was added to the scope of work after LNAPL accumulated in the well post-installation. Bail-down testing was completed to evaluate the recoverability of LNAPL in well O-13 as described in Section 3.7.5.2 and the LNAPL Assessment (Appendix O). Bail-down testing data from wells O-7 and O-9 were not analyzed for various reasons discussed in Section 3.6 of the LNAPL Assessment in Appendix O. These gauging and bail-down testing measurements have established a baseline for this well and additional measurements and testing will be completed at these locations to measure potential changes.

3.9.4 Downgradient Well Trends

Dissolved-phase BTEX concentrations can be used to estimate LNAPL plume stability as discussed in the LNAPL Assessment presented in Appendix O. As shown on Figure 9, wells MW-126, MW-127, MW-139, MW-140, and MW-142 are downgradient of wells O-11 and O-13. Well MW-139 has stable or decreasing concentrations of benzene, ethylbenzene and total xylenes, while toluene has not been detected enough times to establish a trend. Additionally, there have been only limited detected concentrations of BTEX in wells MW-126, MW-127, MW-140, and MW-142, which are located immediately downgradient of the truck rack, since 2006 (Appendix S).

While screened below the water table, dissolved-phase concentrations trends in wells MW-132 and MW-133 are not indicative of the presence of LNAPL. No other wells are immediately downgradient of wells O-7 and O-9.

3.9.5 Additional LNAPL Delineation Well Installation

Upon observation of the LNAPL in the delineation wells, FHRA planned for installation of new observation wells to further delineate the extent of LNAPL on the property. These additional wells were installed downgradient of wells O-11 and O-13 (O-24, O-25, O-26 and O-27) and to the east of wells O-7 and O-9 (O-21 and O-22) (Figure 16). The wells will continue to be gauged on a regular basis to monitor for changes in LNAPL thicknesses and potentially evaluate trends. If sufficient LNAPL is present, bail-down testing will be completed according to the SAP (SWI, ARCADIS 2011).

As shown on Figure 82, LNAPL during the fourth quarter of 2011 was not observed in surrounding wells S-9, O-4, O-12, O-24, O-25, and O-27, defining the extent of the LNAPL in this area.

3.9.6 Conclusions

FHRA completed the following response actions to the accumulation of LNAPL in delineation wells O-7, O-9, O-11 and O-13:

- During follow-up inspections of the truck rack sumps on October 25, 2011, it was determined that there was a missing pipe sealant material at the Truck Lane #1 sump basin. A potential release was reported to ADEC on October 27, 2011 with an estimated release volume of gasoline and ULSD.

- FHRA temporarily shut down all truck lanes and resealed all truck lane catch basins.
- The majority of the known drains at the facility were inspected and no additional pipe seals of this design were found elsewhere on the facility. In the future, FHRA will install a mechanical seal where the piping connects to the catch basins in all lanes.
- A forensics evaluation of LNAPL collected from wells on the northern portion of the site indicates that a minor portion of the LNAPL in wells O-13 and R-40 is gasoline.
- The forensics evaluation also indicates that the LNAPL present in wells at the site has undergone some degree of weathering and is not fresh.
- Wells O-7, O-9, O-13 were included in LNAPL evaluation activities. The measurements taken have established baseline conditions for comparison of future measurements.
- Evaluation of dissolved-phase BTEX concentration data in downgradient wells MW-126, MW-127, MW-139 and MW-142 does not indicate migration of BTEX constituents.
- While screened below the water table, dissolved-phase concentrations trends in wells MW-132 and MW-133 are not indicative of the presence of LNAPL.
- LNAPL has not been observed in surrounding observation wells S-9, O-4, O-12, O-24, O-25, and O-27, indicating the LNAPL extent has been defined.

3.9.7 Recommendations

FHRA recommends continued gauging of LNAPL delineation wells and bail-down testing if LNAPL thicknesses are over 0.5 feet.

3.10 Natural Attenuation Evaluation Results

This section presents results thus far from the ongoing MNA evaluation and also a geochemistry evaluation. As previously stated, the natural attenuation data are being used to evaluate remedial alternatives. Also, as previously mentioned, information collected as part of ongoing onsite remediation pilot testing, as well as bench and pilot testing associated with the POE treatment systems, will be leveraged to enhance FHR's understanding of natural attenuation processes, as well as other potential remedial alternatives.

Additional discussion of sulfolane transport properties can be found Section 2.6 of Appendix Q.

3.10.1 Evaluation of Potential Attenuation Processes

The results of geochemical sampling and analysis completed during the fourth quarter of 2011 are summarized in Tables 49 and 50, and select results are shown on Figures 114 through 117. A summary of 2011 data from wells located along two transects (Figure 117) is shown on Table 51. Also included in Table 51 are the elevations of screened intervals for the wells included in the MNA sampling program. In accordance with the SCWP, the MNA evaluation will continue as additional data are generated.

While the data collected thus far are insufficient to support rigorous statistical hypothesis testing regarding temporal and spatial trends (e.g., Mann-Kendall analysis), some preliminary insight into potential MNA trends can be gained via examination of the data relative to the potential natural attenuation mechanisms (biological degradation, abiotic reactions, and dilution). Additionally, select wells were subjected to principal component analysis (PCA), and discriminant analysis using the data collected thus far. PCA is a multivariate statistical method that compares multiple parameters simultaneously based on the way in which they contribute to the overall variability in a data set. While PCA does not test statistical significance of any observed correlations, it can provide a broad overview of multiple contemporaneous parameters and reveal potential correlations whose statistical significance can be tested via other methods. Discriminant analysis seeks to separate observations into predetermined categories (in this case, wells exhibiting decreasing, increasing, or stable trends in sulfolane concentration) based on multiple parameters.

3.10.1.1 Examination of MNA Data

The following observations can be made from the data shown in Table 51 and Figures 114 through 117;

- Dissolved oxygen concentrations are generally low (<1 mg/L) in the wells, including the side gradient wells (background),
- Concentrations of iron and manganese (total and reduced) vary across the study area and with time,

- Conductivity is generally higher in the side-gradient wells than within the plume,
- Nutrient concentrations (nitrogen and phosphorus) are generally below detection limits across the study area,
- Groundwater pH is generally within the 6 to 8 range and was lowest within the plume extent,
- Alkalinity varied across the study area and with time, and was generally lowest within the plume extent,
- Sulfate concentrations are generally between 10 and 40 mg/L, and are generally lower in downgradient wells, and
- Concentrations of nitrate and sulfide are generally below detection limits across the study area.

While low concentrations of dissolved oxygen and nutrients are not generally conducive to high levels of microbial activity, the thresholds of dissolved oxygen and/or nutrients that would limit sulfolane degradation at the low concentrations of sulfolane have not been established. Data collected by FHR around the operation of the onsite remediation system suggest that sulfolane degradation may be possible under low concentrations of dissolved oxygen or nutrients. The gradients observed in iron and manganese may represent conditions under which sulfolane may be attenuated via microbial or abiotic processes. Additional work is underway to elucidate biological and abiotic sulfolane degradation pathways. This work will be included as part of the feasibility study.

3.10.1.2 Principal Component Analysis

Two groups of wells were used for PCA analysis. The groups were selected based on similarity of their screened interval elevations, as well as their proximal arrangement along downgradient transects. Transect 1 runs approximately parallel with the Tanana River, while Transect 2 runs in a more northerly direction:

- Transect 1: MW-142, MW-148A, MW-151A, MW-156A, MW-161A, and MW-165A.
- Transect 2: MW-170A, MW-157, MW-163A, MW-164A, and MW-167A.

Two PCA plots (Figures 118 and 119) were generated using the data for each set of wells (Table 51), with the exception of nitrate, nitrite, carbonate alkalinity, and hydroxide alkalinity, as these parameters did not vary, thus they did not contribute to variability of the dataset. The PCA plot is a graphical representation of the way in which each parameter (shown as a line emanating from the origin) contributes to the overall variability of the dataset. The axes of the figure are principal components of the dataset variability, and were selected such that the maximum percentage of overall data variability could be viewed on a two-dimensional plot. As with all statistical methods, the results are affected by the number of observations. As additional data are collected, the plots will be updated to provide a refined view of data trends in light of the larger data set.

Parameters whose variability is well-captured by the plot appear as long lines, while those whose variability is not well-captured by the plot appear as short lines. Parameters whose lines are oriented in the same direction correlate positively with one another, while those oriented in opposite directions correlate negatively. Parameters whose lines are orthogonal to one another do not correlate to one another.

It can be seen from Figure 118 that sulfolane concentration is negatively correlated with dissolved oxygen concentration – a trend which would be consistent with aerobic sulfolane degradation. Sulfate, the aerobic degradation product of sulfolane, does not correlate with sulfolane concentration. However, it is important to note that background sulfate concentrations in the aquifer are large relative to the amount of sulfate that would be produced via sulfolane degradation, thus changes in sulfate concentration due to sulfolane degradation may be difficult to detect. Sulfolane concentrations also correlated positively with manganese species, and negatively with hardness, alkalinity, and oxidized iron. Testing completed by FHRA around the onsite remediation system operation suggests that changes in the oxidation states of iron and manganese may correspond with sulfolane degradation.

It can be seen from Figure 119 that sulfolane concentration correlates negatively with dissolved oxygen. Sulfolane also exhibited a weak positive correlation with pH and reduced manganese. A positive correlation between sulfolane and pH would be expected for aerobic sulfolane biodegradation. As observed in the previous PCA analysis, sulfolane concentrations did not correlate with sulfate concentration. Additional detail regarding the degradation pathways involved will be required to further evaluate MNA in the offsite plume.

3.10.1.3 Discriminant Analysis

Figure 120 is a discriminant plot performed for those wells determined to exhibit increasing, decreasing, or stable trends via the Mann-Kendall analysis (Section 3.10). The discriminant factors (or categories) were assigned to each observation as follows:

- Wells that exhibited increasing or probably increasing trends via Mann-Kendall analysis
- Wells that exhibited stable trends via Mann-Kendall analysis
- Wells that exhibited decreasing or probably decreasing trends via Mann-Kendall analysis.

Discriminant analysis was then applied to the multivariate data (excluding sulfolane concentration) to group the observations into the predetermined categories. This analysis was updated from the previous version to incorporate the fourth-quarter MNA data, as well as the most current Mann-Kendall trend results for the wells.

It can be seen from Figure 120 that the parameters that most strongly discriminate wells with increasing sulfolane trends from those with stable or decreasing trends are (in order of the strength of their contribution to Discriminant Function 1 on the x-axis):

- TOC – associated with decreasing or stable trends,
- Sulfate – associated with decreasing or stable trends,
- Dissolved Oxygen – associated with decreasing or stable trends,
- Hardness and Alkalinity – Associated increasing trends,
- Reduced iron – associated with increasing trends, and
- Reduced manganese – associated with increasing trends.

Also shown on Figure 120 are the parameters that most strongly discriminate between wells with stable and decreasing sulfolane trends. These parameters are (in order of the strength of their contribution to Discriminant Function 2 on the y-axis):

- Alkalinity – associated with decreasing trends,
- Hardness – associated with stable trends,

- TOC – associated with stable trends,
- Sulfate – associated with decreasing trends
- Temperature – associated with decreasing trends
- pH – Associated with decreasing trends
- Oxidized Manganese (IV) – associated with decreasing trends
- Reduced iron (II) – associated with stable trends
- Dissolved oxygen – associated with decreasing trends

3.10.1.4 MNA Summary

While examination of the MNA data did not reveal apparent evidence of sulfolane degradation, principal component analysis revealed subtle negative trends between dissolved oxygen and sulfolane concentration that may suggest either sulfolane attenuation under mildly reducing or mixed-redox conditions. Discriminant analysis (from which the actual sulfolane concentration data was held out) corroborated the results of the PCA analysis, and further suggested sulfolane attenuation associated with softer water and less reducing conditions.

Overall, the impact of the Tanana River and other surface water sources on the geochemistry of the aquifer is not well understood. However, the results of this analysis suggest that some attenuation of offsite sulfolane may be associated with interactions between impacted groundwater and less reducing, softer surface water.

3.10.2 Evaluation of Sulfolane Adsorption – Isotherm Testing

The objective for the isotherm testing outlined in the SCWP was to evaluate the possible amount of adsorbed sulfolane within the plume that may desorb during remediation/natural attenuation and affect the observed trends in sulfolane concentration by establishing site-specific distribution coefficients. As described in Section 2.6.4.4, prior to the isotherm test, the aquifer sediment was characterized by quantifying sulfolane concentration, TOC content, and bulk density. The isotherm test was then conducted by contacting sulfolane-spiked groundwater with different amounts of aquifer sediment, and measuring the resulting aqueous sulfolane concentration after one, two, and three days of equilibration time (see Section 2.6.4.4 for details).

Characterization results for the aquifer sediment used in the test are in Table 52. It can be seen from the results that the aquifer sediment had low organic content. The results of the isotherm test are in Table 53, along with the amounts of water and sediment used in each replicate.

For the purposes of data evaluation, distribution coefficients (K_{obs}) and organic carbon partition coefficients (K_{oc}) were computed and are also listed in Table 54. The methodology for computing the distribution coefficients was as follows:

- Calculation of sulfolane mass decrease in aqueous solution (assumed equal to mass increase adsorbed to the sediment) by multiplying the decrease in sulfolane concentration by the volume of water in the jar. The highest measured sulfolane concentration (535 ppb) was assumed to be the initial aqueous sulfolane concentration for the purposes of this calculation.

- Calculation of adsorbed concentration of sulfolane on sediment (micrograms per kilogram [µg/kg]) by dividing adsorbed sulfolane mass by the mass of sediment in the jar.

- Calculation of K_{obs} by dividing the calculated adsorbed concentration (µg/kg) by the measured concentration in aqueous solution.

- Calculation of K_{oc} by dividing K_{obs} by the average TOC concentration measured in the sediment. The reporting limit was assumed for the concentration of the nondetect TOC result for the purposes of this calculation.

The resulting K_{obs} values ranged from 0 to 4×10^{-4} liters per kilogram (L/kg). The resulting K_{oc} values ranged from 0 to 13.3 L/kg. While K_{obs} values are site-specific, K_{oc} values can be compared to published data. Table 54 summarizes published K_{oc} values for sulfolane and other hydrocarbons. It can be seen from the table that the measured K_{oc} values are much lower than published values for BTEX compounds, as would be expected based on the low octanol/water partition coefficient for sulfolane. For most of the measurements, the observed K_{oc} values were similar to the value published by Shell Chemicals Europe Limited (Shell) in 1994. With the exception of the two samples described below, K_{oc} values ranged from 0 to 2.27 L/kg. The value published by Shell is 1.1 L/kg (Shell, 1994).

For two of the samples, however (those containing 500 grams [g] and 250 g of aquifer sediment at the three-day equilibration time), the observed K_{oc} values were much higher than the published value. While the reason for this phenomenon is currently unknown, the isotherm replicates were not poisoned or otherwise sterilized to inhibit microbial activity. Therefore, biological degradation cannot be ruled out as a possible explanation for the higher-than-expected sulfolane removal observed in these isotherm replicates.

The conclusion of this work is that the degree of sulfolane adsorption to aquifer sediment is anticipated to be similar to what has been published in the literature for other sites. As ongoing data collection and evaluation of monitored natural attenuation proceeds, the distribution coefficients estimated from this work will be used to estimate the mass of sulfolane adsorbed to sediment, and account for that mass when assessing MNA progress.

3.10.3 Subsurface Microbiological Characterization Results

3.10.3.1 Bio-Trap Pilot Field Study

The PLFA analysis provides both a total biomass number along with information on the community structure of a sample. It should be noted that methanogenic organisms are not captured within this analysis and are therefore not represented within these results. Total biomass was tracked via PLFA over the three different deployment periods (Figure 121). As shown, a significant difference was observed between the 28 day and 83 day deployments, while minimal differences was observed between the 83 and 139 day deployments. These data indicate that the 83 day deployment will provide adequate time for biomass to grow and little change in the biomass density occurs after 83 days of deployment.

As discussed above, the PLFA data provide a high-level community assessment that can be used to evaluate large-scale shifts within the bacterial communities. As shown on Figure 122, some changes were observed within the community fingerprint over time, with the most notable shift represented by the appearance of metal reducing organisms during the second and third sampling event. This is discussed in greater detail below.

Similar to the total biomass number from PLFA, qPCR provides information on the abundance (density) of specific organisms or groups of organisms present on the Bio-Trap beads. Benchmark values for the relative abundance of microbes are:

- 10^3 to 10^4 cells – “low”,
- 10^5 to 10^6 cells – “moderate”, and
- 10^7 to 10^8 cells – “high”.

Results of the qPCR analysis performed on the first two Bio-Traps indicated higher specific organism group densities were present following the longer deployment period (see table, below).

Bio-Trap Deployment Period	Total Bacteria count (cells/bead; qPCR)	Methanogen count (cells/bead; qPCR)	Iron and Sulfate reducing bacteria count (cells/bead; qPCR)
28 days	3.62 E+06	3.91E+06	8.27E+03
83 days	9.97E+05	1.16E+07	1.24E+06

Per the benchmark values, total bacteria concentrations were detected within the upper range of the “moderate” benchmark following both deployment periods. Methanogen counts increased from “moderate” to “high” following the 83 day deployment period.

In addition, qPCR was also performed to identify quantities of iron- and sulfate-reducing bacteria (IRB/SRB). Significant increases in biomass concentrations were observed between the two deployment periods. Analytical results following 28 days of deployment indicated a “low” concentration, with a three order of magnitude increase following 83 days of deployment putting this group into a “moderate” benchmark category. This is consistent with the PLFA data which showed increases in metal reducers following the first sampling event. qPCR and PLFA data collected at 28 days and 83 days are shown on Figure 123. The laboratory reports are included in Appendix AE.

Conclusions and recommendations of the Bio-Trap Field Study are presented in Section 7.8.3.1.

3.10.3.2 Bio-Trap Seeding Study

The Bio-Trap seeding study completed by Microbial Insights resulted in the following:

- Seeding sulfolane to Bio-Sep beads with a 250 mg/L solution results in a concentration of approximately 0.08 milligrams of sulfolane per bead (mg sulfolane/bd)
- Seeding sulfolane to Bio-Sep beads with a 1,000 mg/L solution results in a concentration of approximately 0.30 mg sulfolane/bd

Three seeding trials were completed per seeding solution strength and standard deviations were calculated using Microsoft Excel®. The average results are shown on Figure 124.

The Bio-Sep beads with a concentration of 0.30 mg sulfolane/bd were subsequently re-extracted using three solvents: water, methanol and methylene chloride; a second extraction was completed with methylene chloride to determine the effectiveness of a second extraction using that method. Concentrations measured during re-extraction of sulfolane sorbed to the Bio-Sep beads were:

- Using water as the solvent, approximately 0.003 mg sulfolane/bd was extracted
- Using methanol as the solvent, approximately 0.2 mg sulfolane/bd was extracted
- Using methylene chloride as the solvent, approximately 0.3 mg sulfolane/bd was extracted. During the second extraction of sulfolane with methylene chloride, approximately 0.003 mg sulfolane/bd was extracted.

Three re-extraction trials were completed and standard deviations were calculated using Microsoft Excel. The average results are shown on Figure 125.

Conclusions and recommendations of the Bio-Trap Seeding Study are presented in Section 7.8.3.2.

3.10.3.3 Bio-Trap Desorption Study

The Bio-Trap desorption study showed a steady decrease in sulfolane concentrations on the Bio-Trap at days 30 and 60, resulting in a significant loss of sulfolane (72%) over the 60 day study period (Figure 126). Subsequent conversations with Microbial Insights indicate there is sufficient sulfolane present after 60 days (0.082 mg/bead, or 28% of the initial mass) to implement phase 2 of the Microbiological Characterization using ^{13}C-labeled sulfolane seeded Bio-Traps. It is anticipated that approximately 0.7 grams of sulfolane may desorb off a seeded Bio-Trap into the aquifer. An Underground Injection Control authorization will be obtained from USEPA Region 10. These potential losses are insignificant relative to the mass of sulfolane present in the aquifer.

Microbial Insights has recently developed an innovative type of closable sampler to allow for analysis without significant loss of highly soluble compounds, such as sulfolane via desorption. The new sampler has a Bio-Trap inside of it, would be filled with water from a targeted monitoring well, closed, and deployed within the targeted monitoring well. Some benefits of using this sampler include the following:

- Allow a complete ^{13}C-labeled sulfolane mass balance between the water, beads and degradation products.
- Collection of geochemical data from the water inside the sampler concurrent with the Bio-Trap analysis.
- Potential for amendment with an oxygen releasing compound (that does not result in an elevated pH) to allow for evaluation of sulfolane biodegradation under aerobic conditions.

Some limitations of using this sampler are:

- The environment within the closed sampler no longer exactly represents natural conditions.
- Depletion of dissolved oxygen and other electron acceptors beyond what may occur naturally will happen in the sampler due to the closed system. This may not be a significant issue given the anoxic/anaerobic condition of the aquifer.
- The small volume of groundwater introduced to the new sampler may not provide sufficient biomass "seed" for successful microbial growth. This can be addressed by designing the samplers to hold both an unbaited Bio-Trap and ^{13}C-labeled sulfolane baited Bio-Trap. It is anticipated that the unbaited Bio-Trap would be deployed 60 to 85 days prior to installing the new samplers. At the time of new sampler deployment, the unbaited Bio-Trap (containing biomass from the aquifer) will be placed into the sampler along with the baited Bio-Trap, seeding the system with sufficient biomass representative of the aquifer environment.

The use of this sampler is discussed further in Section 7.8.3.4.

3.10.4 Biodegradation Stable Isotope Evaluation

As discussed above in Section 2.6.4.6, five of the nine samples collected were analyzed successfully. Locations of monitoring wells sampled for the sulfolane isotope analysis are presented on Figure 26. Duplicate samples were not submitted for analysis, but duplicate analyses were completed on samples from wells MW-127 and MW-148B. The average of the duplicate analyses was used for the sulfolane carbon isotope ratios reported for wells MW-127 and MW-148B. Results are summarized in Table 55.

The "Sulfolane Product 'North Pole'" sample is the sulfolane solvent sample collected from the sulfolane extraction unit and had a stable carbon isotope ratio, δ^{13}C, of -30.9‰. This value may be representative of the baseline carbon isotope ratio for sulfolane used at the facility; however historical measurements of sulfolane used at the facility are not available.

Figure 127 presents carbon isotope ratios for sulfolane versus the distance downgradient from the southern property boundary. Carbon isotope ratios in wells MW-127 (-30.2‰) and MW-142 (-30.4‰) suggest limited isotopic fractionation of sulfolane between wells MW-110 and MW-127 and MW-142. The groundwater sample δ^{13}C value for well MW-182A appears to be enriched in the heavier ^{13}C isotope (i.e., less negative) than the onsite well δ^{13}C values indicating isotopic fractionation is occurring as the distance increases downgradient. This is a potential indication sulfolane is being degraded via natural processes as it migrates with groundwater downgradient of the site.

Figure 128 presents $\delta^{13}C$ values for sulfolane versus the concentration of sulfolane detected in the sample. The $\delta^{13}C$ value for the sulfolane solvent sample collected from the sulfolane extraction unit is assumed to be the baseline stable carbon isotopic composition of sulfolane for this evaluation. Values for carbon isotope ratios for samples from each well were plotted with the sulfolane solvent value indicating isotopic fractionation is likely occurring. Results are consistent with those shown on Figure 127 likely since sulfolane concentrations decrease as the distance downgradient increases.

Well MW-148B may be an outlier on the trends shown on Figures 127 and 126. Its carbon isotope ratio is more negative than the other samples analyzed at the site. This may be due to a lower fractionation rate at this depth in the aquifer. However, additional samples from "B" zone wells will need to be collected to evaluate potential trends at that depth in the aquifer.

A stable carbon isotope fractionation factor, ε, can be estimated from the slope of the line derived from a linear regression analysis conducted for $\delta^{13}C$ values versus the log of sulfolane concentrations (Figure 128; Clark and Fritz, 1997). Since changes in sulfolane concentrations with distance may be caused by nonfractionating processes (e.g., volatilization, sorption, and dilution) in addition to degradation, the calculated fractionation factor based on results from site samples is considered to be a "site-specific" fractionation factor and may be conservatively low if compared to laboratory-derived fractionation factors. Since laboratory-derived sulfolane stable carbon isotope fractionation factors are not available at this time, the site-specific fractionation factor will be used. A preliminary assessment of the $\delta^{13}C$ data indicates that the fractionation of sulfolane stable carbon isotopes during biodegradation of sulfolane is approximately 0.3‰. While this fractionation factor is relatively small, it is expected to be sufficiently large to result in measureable shifts in the stable carbon isotopic composition of sulfolane if degradation of sulfolane is occurring in site groundwater.

MNA parameter results for the wells sampled as part of the stable carbon isotope evaluation are consistent with results detected in the larger MNA study presented in Section 3.10.1. The results for the wells included in this evaluation are summarized below:

- Nutrient concentrations (nitrogen and phosphorus) were generally below detection limits.

- Alkalinity varied across the site with a slight increase in concentrations offsite (195 to 386 mg/L) versus onsite (145 to 195 mg/L).

- Hardness as calcium carbonate varied across the site with a slight increase in concentrations offsite (210 to 412 mg/L) versus onsite (187 to 195 mg/L).

- Sulfate concentrations were consistent within the 10 to 30 mg/L range, and were generally lower in downgradient wells.

The MNA parameter data from these wells is consistent with larger site MNA data trends. Also, no additional trends in MNA parameter concentrations are present in the data collected from the wells in this stable carbon isotope evaluation.

Conclusions and recommendations of the stable isotope evaluation are presented in Section 7.8.4.

3.11 Geochemistry Evaluation

As described in Section 2.7 the objective of the geochemistry evaluation was to test the hypothesis that sulfolane impacts observed in subpermafrost private wells may be due to suprapermafrost groundwater infiltrating to the subpermafrost aquifer via well penetrations through the permafrost. Data collected for geochemical characterization of groundwater from the supra- and subpermafrost zones is in Table 56. For geochemical comparison, the samples were divided into three areas:

- Area 1 – Vicinity of the subpermafrost sulfolane-impacted well A1-1 (average sulfolane concentration: 108 µg/L).

- Area 2 – Vicinity of the subpermafrost sulfolane-impacted well A2-1 (average sulfolane concentration: 77.4 ppb µg/L).

- Area 3 – Vicinity of the subpermafrost sulfolane-impacted well A3-3 (average sulfolane concentration: 19.0 µg/L).

Stiff diagrams were created for the samples to allow comparison of the overall groundwater composition for different wells in each area. Stiff diagrams are a graphical representation of the ionic composition of a water sample. Anions are plotted to the left of the diagram, and cations are plotted to the right. The shape of the stiff diagram provides a rapid visual indication of the relative proportions of ions in the water. Waters from the same source have similar relative proportions of ions and, therefore, the stiff diagrams have similar shapes.

In Area 1, the groundwater composition of the A1-1 well was compared to suprapermafrost samples from upgradient wells MW-162A and MW-162B. It can be seen from the stiff diagrams (Figure 129) that the subpermafrost water from the A1-1 well is characterized by a higher ratio of calcium to magnesium, as well as more copper than the suprapermafrost wells.

In Area 2, the groundwater composition of the A2-1 well was compared to unimpacted subpermafrost groundwater from wells A2-4 and A2-5, as well as suprapermafrost groundwater from MW-163A, MW-163B, MW-171A, and MW-171B. It can be seen from the stiff diagrams (Figures 130 and 131) that the compositions of all three subpermafrost wells are similar to one another. In contrast, the compositions of the subpermafrost wells differ from the suprapermafrost wells in that the ratio of calcium to magnesium is higher, and that there is more copper and zinc.

In Area 3, the groundwater composition of the A3-3 well was compared to unimpacted subpermafrost groundwater from the A3-2 well, as well as suprapermafrost groundwater from MW-164A and MW-164B upgradient. It can be seen from the stiff diagrams (Figures 132 and 133) that the compositions of the two subpermafrost samples were similar to one another. The compositions of the subpermafrost wells differ from the suprapermafrost wells in that the ratio of calcium to magnesium is higher, and that there is more copper and zinc.

While some geochemical differences can be observed between sub and suprapermafrost waters, these differences are subtle. The subtlety of these differences, along with the small number of samples and the possibility that the copper and zinc observed could be related to the pump/well construction, limits the conclusions that can be drawn from the geochemical analysis. While the hypothesis tested by this work cannot be accepted based on these results, it cannot currently be rejected in favor of another, better supported hypothesis. As discussed with ADEC during the Site Characterization Subgroup meetings, additional work will be completed with the aim to provide a more conclusive explanation for the presence of sulfolane in the subpermafrost wells.

3.12 Surface Water Assessment

Potential impacts to surface water bodies located within the footprint of the sulfolane plume were characterized by collecting water samples from gravel pits and Badger Slough. Subsequently, pore-water sampling was proposed adjacent to surface-water features at and downgradient of the site. The results will refine the CSM by further defining the potential for sulfolane to impact surface water bodies via surface water/groundwater exchange.

3.12.1 Gravel Pit and Surface Water Quality

As discussed in Section 2.8.1, samples of water were collected from the North Gravel Pit, South Gravel Pit and Badger Slough (Figure 28) for laboratory analysis. The laboratory reported that sulfolane was not detected above its LOQ of 10.0 µg/L in either of the gravel pit water samples (Table 57). The laboratory reported that sulfolane was not detected above its LOQ of 10.2 µg/L in the surface water sample collected from Badger Slough (Table 57).

3.12.2 Pore-Water Investigation

As noted in Section 2.8.2, FHRA has not been able to obtain access to one of the proposed pore-water locations (Pore-2), so it will not be sampled. The onsite pore-water location (Pore-1) and three offsite pore-water locations (Pore-3 through Pore-5) have been installed and sampled.

Soil samples were collected from a stockpile and the 3 to 4-foot BGS interval at location Pore-5. Soil samples were analyzed for BTEX, sulfolane and PAH. No analytes were detected in either sample. Soil analytical results are summarized in Table 58.

Water samples collected from pore-water locations were analyzed for sulfolane. Analytical results for pore-water collected from onsite sampling location Pore-1 indicated a sulfolane concentration of 407 µg/L, which is above the interim drinking water standard of 25 µg/L. Preliminary data indicate sulfolane was detected in the samples collected from Pore-3 and Pore-4 at concentrations of 156 µg/L and 28.7 µg/L, respectively. Sulfolane was not detected in the sample from offsite location Pore-5. Note that Pore-3 and Pore-4 locations were installed in March 2012, and the gravel ponds near both locations were frozen at the time the piezometers were sampled. This suggests that the samples collected from these locations are not necessarily representative of pore-water, but are more likely groundwater samples collected near a surface water body. Analytical results for December 2011 sampling are summarized in Table 59. Results for the March 2012 sampling were tabulated and presented in the HHRA with a detailed evaluation. Sampling locations are presented on Figure 29.

3.13 Updated Conceptual Site Model

At the request of ADEC, the attached Human Health Conceptual Site Model (CSM) has been prepared for NPR. The CSM is updated as new data are collected.

This CSM was developed following the DEC guidance document “Policy Guidance on Developing Conceptual Site Models” (October 2010) and the DEC Human Health Conceptual Site Model (revised 10/01/10) and the Human Health Conceptual Site Model Scoping Form (revised 10/01/10). Due to the substantial difference in COPC presence onsite (petroleum constituents, sulfolane, and other constituents associated with the refining process) versus offsite (sulfolane only), two separate CSM graphical forms have been prepared to more clearly portray and distinguish potential exposure pathways for the onsite and offsite receptors.

The basis for selection or deselection of media, exposure pathways and current/future receptors for this preliminary CSM is described below. Please refer to the attached graphical CSM scoping forms (Appendix AF).

3.13.1 Onsite Media Selection

Surface Soil: Available data indicate limited surface soil samples have been collected onsite. Therefore, all transport mechanisms were selected for further evaluation.

Subsurface Soil: Limited data indicate COPCs are present in onsite subsurface soil. Therefore, all transport mechanisms were selected for further evaluation.

Groundwater: Onsite groundwater has been impacted by COPCs. Therefore, transport mechanisms were selected for further evaluation.

Surface Water: Based on historical surface water data, the onsite surface water bodies are not known to be impacted. However, a pore-water sample collected near the eastern banks of the North Gravel Pit as shown on Figure 29 indicates sulfolane impacts are present in pore-water at that location. This exposure media was selected for further evaluation.

Sediment: Sediment data have not been evaluated; therefore, this exposure media was also selected for further evaluation.

3.13.2 Onsite Potential Receptors

Potential human receptors were identified based on current and reasonably foreseeable future land use at the site. The following potential human receptors were identified:

- Current and future commercial or industrial workers (indoor and outdoor),
- Current and future visitors and trespassers, and
- Future construction/trench workers (no current construction work is ongoing at NPR).

Onsite residents were excluded due to the industrial use of the site, and because it is reasonable to assume that the site will remain in use for industrial or commercial purposes for the foreseeable future. Subsistence harvesters and consumers were not considered as receptors because the site is secured.

3.13.3 Onsite Exposure Pathways

Three possible exposure pathways were evaluated for the receptors potentially present at the site: ingestion, dermal absorption, and inhalation.

Ingestion: Current and future commercial/industrial workers may potentially ingest some quantity of surface soil incidentally. Adults can ingest soil particles that adhere to food or their hands during normal activities. Workers involved in soil-invasive activities, such as trench/excavation workers, may also ingest subsurface soil due to contact with excavated soil and windblown particles during excavation activities.

Ingestion of groundwater is not a complete pathway at the site for most receptors; potable water is supplied from a municipal source, and, based on the industrial nature of the site, it is unlikely that a potable well would be installed at the site in the future. However, current and future construction/trench workers may ingest groundwater in excavation trenches.

Ingestion of surface water is not a complete pathway for onsite receptors. Although there are onsite gravel pits, it is unlikely that commercial or industrial workers or construction workers would be in contact with the surface water for any routine or likely maintenance activities at the site.

Ingestion of wild foods is not a complete pathway for onsite receptors.

Dermal Absorption: Onsite commercial/industrial workers and construction/trench workers may contact COPCs in surface soil during normal activities and in subsurface soil or groundwater during excavation activities.

Dermal absorption of COPCs in groundwater by current and future outdoor commercial/industrial workers while extinguishing fires is considered insignificant because fires are relatively rare and the exposure period would be relatively short. Therefore, dermal absorption from this exposure pathway was qualitatively evaluated in the site-specific risk assessment.

Dermal absorption of COPCs in surface water is not a significant pathway for onsite receptors. Although there are onsite gravel pits, it is unlikely that commercial or industrial workers or construction workers would be in contact with the surface water for any routine or likely maintenance activities at the site.

Inhalation: Inhalation exposure may include the inhalation of airborne COPCs adsorbed to particulates (fugitive dust) or as vapor (volatile emissions). Inhalation of particulates may occur when wind erodes surface soil; onsite commercial/industrial workers and construction/trench workers may be exposed to nonvolatile chemicals in surface soil via inhalation of particulates at the site. Onsite construction workers may also be exposed to COPCs via inhalation of particulates resulting from wind erosion of subsurface soils removed during soil-invasive activities.

Inhalation of volatile emissions may occur through the direct volatilization of chemicals from soil and groundwater to the atmosphere. Current and future onsite commercial/industrial workers and construction workers may be exposed to volatile chemicals in surface and/or subsurface soil and groundwater via inhalation of volatile emissions that have migrated from these media into outdoor or indoor air. Inhalation of volatile compounds in tap water is not a potentially complete pathway for onsite receptors because groundwater is not used as a potable source onsite.

3.13.4 Offsite Media Selection

Surface and Subsurface Soil: Only limited soil data have been collected offsite. However, there are no known offsite COPC sources associated with the site, and the only known dissolved-phase COPC that has migrated offsite is sulfolane. Laboratory analysis of offsite soil samples has not indicated any detectable concentrations of sulfolane in offsite surface or subsurface soil. Therefore, surface and subsurface soil, and associated transport mechanisms and exposure pathways were not selected for further evaluation.

Groundwater: Offsite groundwater has been impacted by sulfolane. Sulfolane is not volatile, and other volatile constituents are not known to be present in offsite groundwater. Also, offsite groundwater is located at a depth greater than six feet below ground surface; therefore, uptake by root systems directly from groundwater by offsite plants is unlikely. However, impacted groundwater is known to be used for irrigation of plants and vegetables, and the plant uptake of sulfolane through irrigation water has been shown to be a complete pathway. Accordingly, the transport mechanisms for groundwater selected for further evaluation include flow to private wells, surface water bodies, flow to sediment, and uptake by plants or animals.

Surface Water: Based on historical data, offsite surface water is not known to be impacted. However, pore-water samples collected adjacent to offsite surface water bodies have indicated detectable concentrations of sulfolane. Accordingly, transport mechanisms associated with offsite surface water were selected for further evaluation,

Sediment: Sediment data have not been collected. Therefore this exposure media was selected for further evaluation.

3.13.5 Offsite Potential Receptors

Potential human receptors were identified based on current and reasonably foreseeable future land use downgradient of the site. (Note that not all pathways are significant and/or potentially complete for all receptors). The following potential human receptors were identified:

- Current and future residents
- Current and future indoor and outdoor commercial or industrial workers
- Current and future recreational users
- Current and future construction/trench workers

Subsistence farmers and consumers are not identified as receptors because the site is not located in an area known for subsistence harvesting.

3.13.6 Offsite Exposure Pathways

Two possible exposure pathways were evaluated for the receptors potentially present off site: inhalation and ingestion.

Inhalation: Inhalation exposure may include the inhalation of fugitive windborne dust originating from onsite COPCs in surface soil.

Ingestion: The only known current offsite COPC is dissolved-phase sulfolane. Although dissolved-phase petroleum constituents are present onsite, the plume is undergoing ongoing active remediation, and further migration appears to be controlled. Because sulfolane is not volatile and is not readily absorbable by skin, the only exposure pathways for sulfolane evaluated for offsite receptors is ingestion.

Ingestion of groundwater (i.e., well water or groundwater accumulated in a trench excavation) is a potentially complete pathway for selected receptors.

Access to downgradient, offsite surface water bodies is minimal due to industrial land use and hazardous physical conditions, and direct contact with surface water and sediment by human receptors is limited. However, concentrations of sulfolane have been detected in pore-water samples collected adjacent to offsite surface water bodies. Therefore, ingestion of surface water during swimming was evaluated for offsite residents and recreational users.

Ingestion of wild foods is considered a complete pathway for residents. “Wild” foods are not expected to be impacted due to the depth to groundwater and lack of offsite soil impact. However, farmed or home-grown plants irrigated with water impacted by sulfolane may accumulate concentrations of this COPC.

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4.0 Groundwater Flow and Transport Modeling

A model has been developed to represent the groundwater system in the Tanana Valley (Figure 1) and to simulate the fate and transport of the sulfolane plume located in the vicinity of NPR. The primary objective of the groundwater model is to match the sulfolane plume extent and concentration distribution based on environmental data collected from NPR monitoring well network and domestic wells. The version of the groundwater flow model presented in Appendix Q of this report was based on data collected through the end of the third quarter of 2011. The development of the model followed guidance published by the Alaska Department of Environmental Conservation (ADEC 1998).

The groundwater model was constructed using a large quantity of data of many different types from both public and private sources. Nearly 3,000 unique locations were processed and incorporated into the model that include information on surface water, groundwater levels, aquifer geometry and hydraulic parameters, permafrost, climate, pumping from domestic, industrial and municipal wells, and water quality data. In order to obtain information pertaining to groundwater elevation, groundwater flow, permafrost, stratigraphy, and groundwater chemistry, 327 locations associated with the NPR were evaluated. USGS locations provided information pertaining to groundwater elevation and surface water data: 941 wells provided ~70,000 groundwater elevation measurements from both automated equipment and manual measurements, and 29 surface water stations provided more than three million data points for stage and discharge measurements. The ADNR WELTS database contains ~840 locations from which permafrost, stratigraphy, and groundwater flow were interpreted. The Fairbanks North Star Borough database provided ~410 private well logs, which were interpreted to identify permafrost within the vicinity of the City. Meteorological data from three stations within the Tanana Valley were evaluated for precipitation and temperature. Digital elevation models (DEMs), well logs, and geologic cross sections were used to incorporate ground and bedrock surfaces into the model. A variety of geographic data (e.g., geologic maps, soils, vegetation, land use, land survey, tax lots, roads, topography, and watersheds) were also evaluated.

The groundwater model has undergone a review and comment process by ADEC and it will be used as a tool for the evaluation of the following:

- guidance on data collection,
- onsite and offsite remedial action alternatives,

- onsite and offsite remediation timeframe estimates,
- plume migration forecasting, and
- assist clean-up action plan decision-making.

The groundwater model is described extensively in Appendix Q and includes the following components:

- the site conceptual model,
- modeling program selection,
- model components,
- model calibration,
- model verification,
- sensitivity analysis,
- uncertainty analysis, and
- the post-audit plan.

5.0 Status Update on Cleanup Actions

This section summarizes the current status of the onsite remediation system, evaluates operating results for 2011, and provides an update on implementation and performance monitoring of the interim corrective actions described in the IRAP. FHRA has also provided ADEC with routine updates on IRAP implementation progress throughout the year at the ongoing TPT meetings and in the quarterly groundwater monitoring reports.

In addition to the onsite remediation system evaluation in Section 5.1, Section 5.2 includes a summary of ongoing offsite efforts to determine how groundwater impacts beyond the limit of NPR will be addressed, including results of Point-of-Entry treatment system testing.

5.1 Onsite Remediation System Operation Summary

Ongoing remediation efforts at the site include groundwater recovery and treatment, and LNAPL recovery and recycling, as described in Sections 5.1.1, 5.1.2, and 5.1.3. The current components of the remediation systems are described below:

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

- Pneumatic LNAPL recovery systems are operated at on a year-round basis at R-20R, R-21, R-35R, R-40, and MW-138. Additionally, seasonal operation due to well freezing is conducted at R-32, R-33, and S-50. As noted in Section 2.5.8, FHRA also utilizes a vacuum truck or hand-held product recovery pump at other locations (e.g. R-39) if LNAPL is present and product recovery is possible. A LNAPL recovery system was previously operated at O-2; however, that system was moved to another location (S-50) due to low recovery rates. Additionally, some locations (MW-138, R-20R, R-32, R-33, and S-50) have periods during the year when sufficient LNAPL is not present for recovery and the systems are not operated.

- Recovered groundwater is treated through a prefilter for solids removal, a coalescer for LNAPL removal and four air strippers for removal of 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 GAC system for sulfolane removal.

5.1.1 Groundwater Recovery Summary

The objective of the recovery well system operation is to provide capture of the shallow dissolved-phase plume. Implementation of the corrective actions described in the IRAP included installation of one additional recovery well (R-42). Operation of the groundwater pump and treat system currently involves groundwater recovery from five recovery wells (R-21, R-35R, R-39, R-40 and R-42), as shown on Figure 17. Recovery well R-42 began operation on July 26, 2011 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 is pumped from the remediation recovery wells under water use permit LAS24907, issued by the DNR.

Implementation of the corrective actions described in the IRAP included installation of nested monitoring wells (MW-186 A/B/C) to allow for evaluation of the vertical capture of the groundwater recovery system. A capture zone test using this new well nest along with other existing wells was performed in August/September 2011 and is described in Sections 2.3.4.3 and 3.5.1.

Recovered groundwater is treated on site prior to discharge at the South Gravel Pit in accordance with wastewater disposal permit 2005-DB0012 issued by ADEC. Additional discussion of the treatment system operation and performance is provided in Section 5.1.2.

Table 60 summarizes the volume and rate of recovered groundwater in 2009 through 2011 on a monthly basis. Annual groundwater recovery totals are summarized below:

- 2009: 69,200,000 gallons;
- 2010: 107,100,000 gallons;
- 2011: 136,900,000 gallons.

As seen in the groundwater recovery totals above and in Table 60, FHRA has continued to optimize the existing remediation system to increase capture of the shallow dissolved-phase plume onsite. Additional increase in the total groundwater recovery was observed in July 2011 following operation of new recovery well R-42. The average monthly pumping rate for the remediation system in 2011 was 260 gpm, while upon operation of R-42 the system averaged 346 gpm (August through December 2011).

The pumping rates for the individual recovery wells are measured weekly and the 2011 average for each well is shown in the table below. In addition, the reporting period total and percent runtimes are presented in the table below:

Location	2011 Average Flow Rate (when active)	2011 Runtime	Percent Runtime
R-21	75 gpm	8,337 hours	95.2%
R-35R	75 gpm	5,482 hours	62.7%
R-39	81 gpm	8,514 hours	97.2%
R-40	39 gpm	8,504 hours	97.1%
R-42	102 gpm	3,771 hours	99.1% (following startup)

As discussed in Section 2.5.6, in periods when the flow of LNAPL into the recovery well exceeds the removal capacity of the LNAPL recovery system, some LNAPL is captured by the groundwater recovery system which must be pumped to a coalescer for removal prior to flow through the air strippers. During these periods of excessive LNAPL recovery, FHRA has seen an increase in dissolved-phase hydrocarbon concentrations in the air stripper effluent (as further discussed in Section 5.1.3.1). As a result, FHRA has temporarily reduced the groundwater recovery rate at R-21, R-39, and R-40 to reduce the volume of LNAPL unintentionally diverted to the groundwater recovery system. FHRA has installed a 2-inch diameter stilling well in R-21 and R-40 to promote more reliable LNAPL recovery and is evaluating additional methods to increase LNAPL recovery which will allow higher groundwater pumping rates without overloading the air strippers with increased hydrocarbon concentrations. FHRA is also planning to install replacement recovery wells at R-21, R-39, and R-40 in 2012 with a greater total depth and diameter (at R-21), which will allow a higher groundwater recovery rate while maintaining LNAPL-only recovery with a skimmer system.

Additionally, the 2011 recovery well runtimes were affected by planned and unplanned downtime events, which are further discussed in Section 5.1.4. The following is a summary of major events that had the greatest effect on runtime in 2011:

- Recovery well R-35 had a failure of the well screen in the fourth quarter of 2010 and a new recovery well (R-35R) was installed as a replacement. R-35R was started in March 2011; however, it only operated for a short period of time (63 hours) before it was shut down due to excessive amount of fine-sand recovered. In response, FHRA conducted additional redevelopment on R-35R; however, the well continued to produce fine sand. Although a sieve analysis was used to determine the appropriate screen size during well installation, the excessive production of fine sand prompted the installation of a second interior well screen with a smaller slot size to reduce the recovery of fine sand. Groundwater recovery from R-35R was resumed on May 11, 2011, and has since operated without problems.

- Tie-in of equipment upgrades installed as part of the IRAP including: new piping from R-21 (February 10, 2011), additional prefilter (initial tie-in on March 23, 2011 and final tie-in on August 15 to 19, 2011), sand filter and GAC system (May 22 to 25, 2011).

- Cleaning the well screen at R-21, R-39, and R-40. Additionally, well screen failure occurred in R-21 during cleaning on August 19, 2011. To minimize the downtime associated with installation and connection of a replacement well, a smaller (8-inch-diameter) well screen was installed within the well and the new annular space was filled with pea gravel. Upon startup of the well on August 26, 2011, no reduction in the potential groundwater recovery rate was observed.

5.1.1.1 Groundwater Capture Evaluation

As discussed in Sections 2.3.4.3 and 3.5.1.1, a recovery well pumping test was performed to evaluate the horizontal and vertical capture of the groundwater recovery system, and to provide information for updating the groundwater flow model. Utilizing the pumping test information, FHRA completed capture zone modeling of the groundwater recovery system.

The current groundwater recovery well system is capable of recovering approximately 460 to 480 gpm, dependent upon the variable backpressure of the treatment system. A total groundwater extraction rate of 460 gpm was evaluated using the calibrated regional groundwater model (Appendix Q). As noted in Section 5.1.1, the groundwater recovery rate in several locations has been temporarily reduced and FHRA is evaluating options to resume operation at the maximum pumping rates. The groundwater model utilized the following groundwater recovery rates, which are the planned pumping rates at each location:

Location	Pumping Rate (gpm)
R-21	90
R-35R	85
R-39	90
R-40	80
R-42	115

These rates were simulated under conditions representing high-stage and low-stage on the Tanana River to represent the expected annual range of groundwater flow directions and hydraulic gradients present in the vicinity of the site.

Capture provided by the recovery wells was depicted using particle tracking techniques. Particles were placed along an east-west line at model nodes located near Lagoon B and Sump No. 2 at depths approximating the water table and at approximately 20, 40 and 60 feet BGS (approximately 10-15, 30-35, and 50 to 55 feet BWT). The particles migrated advectively with the flowing groundwater and created tracking lines as shown in Figures 134 through 137 (low Tanana Stage) and Figures 138 through 141 (high Tanana stage). The particle tracking lines depict the zones in which groundwater is captured by the recovery wells, as indicated by tracking lines that converge at the wells. Particles were added to the model iteratively to depict the outer edges of groundwater capture and to delineate in greater detail areas of modeled bypass between the recovery wells for each depth interval and river stage condition. As shown in Figures 134 through 141, the recovery wells provide a high degree of capture at current pumping rates. Further details of the capture zone analysis are provided in Appendix Q.

Based on particle tracking, it appears that limited areas within the sulfolane plume are not captured by the groundwater recovery system. FHRA will evaluate alternatives to address these areas as part of the FS process.

An additional line of evidence when evaluating groundwater capture is the mapping of the groundwater elevation contours. As shown on Figure 60, a depression in the potentiometric surface was observed in the area of the groundwater recovery wells. The total flow from the groundwater recovery system was 338 gpm during this event and not at full capacity (estimated at approximately 460 to 480 gpm for the current system). As noted in Section 5.1.1, groundwater recovery has been periodically reduced due to excessive capture of LNAPL by the groundwater recovery system which was causing loading concerns on the air strippers. As discussed in Section 7.6, FHRA is also planning to install additional monitoring wells in 2012 which will allow further demonstration of the effects of the recovery wells on the groundwater elevation (i.e., radius of influence and gradients toward the recovery system). Groundwater elevation contours demonstrating capture will continue to be presented in the quarterly groundwater monitoring reports.

Sections 3.8.1.6 and 3.8.2.7 presented a statistical trend analysis of groundwater analytical data to evaluate plume migration and stability. Trend analysis of the groundwater data is another line of evidence utilized to evaluate the effectiveness of the groundwater recovery system. As previously discussed, with implementation of the IRAP improvements, FHRA initially began to increase the overall groundwater recovery rate in January 2010 (Table 60), and further increases have been seen since July 2011 following installation of R-42. The following is a review of the recent trends (through the fourth quarter of 2011) in the sulfolane concentration in the monitoring wells immediately downgradient of the recovery system (and within the sulfolane plume) as these locations will be the first to show improvement. Groundwater velocity in the area has previously been estimated to be 1.3 ft/day or 474 ft/year (SWI, 2002).

- MW-127 (Figure 142): located approximately 350 feet downgradient from the line of recovery wells. The sulfolane concentration peaked in 2008 and has seen a general decrease since then.

- MW-131 (Figure 143): located approximately 1,000 feet downgradient from the line of recovery wells. The sulfolane concentration has generally declined since monitoring began in 2006 and an additional significant decline was seen in late 2010 and 2011.

- MW-139 (Figure 144): located approximately 450 feet downgradient from the line of recovery wells. The sulfolane concentration has generally decreased since 2009.

- MW-142 (Figure 145): located approximately 620 feet downgradient from the line of recovery wells. The sulfolane concentration has generally been stable, with a general decrease in the peak concentrations measured during fluctuations since 2009. The Mann-Kendall test results for benzene and xylenes in MW-142 indicate no trend for these compounds (Appendix S).

- MW-143 (Figure 146): located approximately 800 feet downgradient from the line of recovery wells. The peak sulfolane concentrations measured in 2009, 2010, and 2011 have exhibited a decreasing trend.

The trend at the five wells indicated the groundwater sulfolane concentration downgradient of the groundwater recovery system is generally decreasing. As previously noted, it appears that limited areas within the sulfolane plume are not captured by the groundwater recovery system. FHRA will evaluate alternatives to address these areas as part of the FS process and CP.

Table 41 includes sulfolane analytical data from monitoring wells MW-186B/C, which are located near R-21 and provide an indication of the vertical contaminant distribution near the groundwater recovery system. The results for MW-186B, which is screened from 51 to 60 feet BGS, indicated a sulfolane concentration of 33.6 ug/L during third quarter monitoring and 35.8 ug/L during fourth quarter monitoring. MW-186C, which is screened from 91 to 100 feet BGS, did not have a detectable level of sulfolane during the third and fourth quarter monitoring events. The shallow well in the nest (MW-186A) was not sampled due to the presence of LNAPL.

5.1.1.2 Mass Recovery

Table 61 presents a summary of the sulfolane mass recovery during sampling events in 2011. The sampling results include the routine monthly sampling plus additional sampling completed as part of the IRAP performance monitoring. In 2011, the sulfolane mass recovery by the groundwater extraction and treatment system averaged 0.46 pounds per day (lb/day). Additionally, the mass recovery was generally higher in the second half of 2011 as the groundwater recovery rate was increased.

5.1.2 LNAPL Recovery Summary

As previously noted, in 2011 FHRA performed LNAPL recovery at R-20R, R-21, R-32, R-33, R-35R, R-39, R-40, S-50 and O-2 (Figure 17). The recovered LNAPL from these systems is accumulated in a product storage tank and periodically recycled within a refinery process unit. Additional LNAPL was recovered by the groundwater recovery system and was removed by the coalescer installed ahead of the air stripper.

A summary of the LNAPL recovery in 2011 is provided in Table 62. During this period, a total of 3,603 gallons of LNAPL was recovered. The majority of the recovery during the reporting period was from the dual-phase recovery wells (R-21, R-35R, and R-40), monitoring well O-2, and the coalescer. The well screens in dual-phase recovery wells R-21, R-39, and R-40 were cleaned in August 2011, and since that time a higher rate of LNAPL accumulation in the these wells has been noted. Evaluation of LNAPL recoverability is included in the LNAPL mobility assessment in Appendix O. As mentioned in Section 5.1.1, FHRA is planning to replace recovery wells R-21, R-39, and R-40 to allow increased groundwater capture, with subsequent increased LNAPL capture. As part of the FS process, FHRA is also evaluating additional LNAPL recovery options and potential locations. FHRA will also evaluate the need for increased treatment capacity based on the results of the Onsite FS.

Table 63 provides a summary of LNAPL recovery at the North Pole Refinery since 1986. From 1986 to current, approximately 391,000 gallons of LNAPL have been recovered. As expected, the annual product recovery volume has generally decreased as remediation has progressed, which is a line of evidence that the volume of recoverable LNAPL is decreasing.

5.1.3 Groundwater Treatment Summary

As noted in Section 5.1.1, FHRA operates groundwater recovery wells to provide capture of shallow dissolved-phase contaminants. The recovered groundwater is pumped to an onsite groundwater treatment system, which is operated to remove LNAPL and dissolved-phase contaminants. The recovered groundwater passes through a prefilter for solids removal, a coalescer for LNAPL removal and four air strippers for removal of VOCs before accumulating in the Gallery Pond. The groundwater from the Gallery Pond is then pumped through sand filters and a 4-vessel GAC system, which were added as part of the IRAP implementation. The sand filters were added to remove suspended solids and GAC vessels were added to remove organic compounds, including sulfolane. The treated groundwater is discharged to the South Gravel Pit in accordance with wastewater disposal permit 2005-DB0012, issued by ADEC. A process flow diagram of the groundwater recovery and treatment system is provided on Figure 147.

Operation of the sand filters and the GAC filter system began on June 9, 2011. Additional startup monitoring was conducted to monitor the effectiveness of sulfolane removal; results are discussed in Section 5.1.3.2.

5.1.3.1 Air Stripper Performance

The air stripper towers effectively removed the majority of dissolved-phase hydrocarbons from the recovered groundwater prior to discharge to the Gallery Pond and further treatment by the GAC filter system. Monthly monitoring was conducted and the results for 2011 are shown in Table 64.

Detectable levels of BTEX constituents were present in some samples collected at the air stripper effluents during the second half of 2011; however, the residual contaminants were removed by the GAC vessels as analytical results indicate dissolved-phase contaminant concentrations were below detection limits at the final effluent. The intermittent increase in BTEX concentrations measured in the air stripper effluents is likely the result of increased LNAPL capture in recovery well R-21. This LNAPL was recovered in the coalescer prior to the air strippers; however, it resulted in an increase in the dissolved-phase concentration in the air stripper effluent. As a result of the BTEX detections in the air stripper effluent, FHRA has increased the number of active air stripper units to reduce the flow to each unit and thus increase BTEX removal efficiency. Analytical laboratory reports are provided in Appendix AG.

5.1.3.2 Granular Activated Carbon System Performance

Operation of the sand filters and the GAC filter system began on June 9, 2011. Since that time, recovered groundwater has passed through the sand filters and the GAC filter system for sulfolane and BTEX (if present) removal prior to discharge to the South Gravel Pit. In addition to the monthly monitoring described in Section 5.1.3.1, additional monitoring was conducted to evaluate the effectiveness of the sand filters and the GAC filter system following startup. ADEC approved a 4-month monitoring period (expired September 30, 2011) to evaluate performance of the GAC filter system prior to establishing a discharge limit for sulfolane. At the conclusion of this period, FHRA requested an extension of the monitoring period to continue evaluation of GAC filter system performance. ADEC provided an extension of the monitoring period until the new permit is issued via a September 29, 2011 email from William Smyth.

A sampling plan for monitoring the GAC filter system performance was submitted to ADEC (via email) on May 20, 2011. As noted in Section 2.9, this plan was followed, with minor deviation, through treatment of 30,000,000 gallons of groundwater and the results are shown in Table 65. After treatment of 30,000,000 gallons, FHRA has continued performance monitoring at a frequency of twice monthly. Initially after startup, the GAC vessels were operated in series through Vessel A, Vessel B, Vessel C, and Vessel D. Since August 23, FHRA has modified the operating lineup due to flow restriction as a result of iron precipitation, and the system has generally been operated with Vessels A and B in series, followed by Vessels C and D in parallel. Modifications to the vessel operating sequence resulted in no change in the effluent sulfolane concentration, as described below.

As shown in Table 64, the sulfolane concentration at the Final Effluent has been below the LOQ in every monitoring event, showing significant removal of sulfolane from the recovered groundwater. During each monitoring event, the Vessel A effluent sulfolane concentration has been below the LOQ with the exception of the September 13, 2011 monitoring event (Table 65). Prior to this detection, Vessel A was the lead vessel for treatment of approximately 37.6 million gallons of groundwater and the average Vessel A inlet concentration was 76 µg/L. During the September 13, 2011 monitoring event, elevated BTEX concentrations were detected in the Vessel A inlet, which may have interfered with sulfolane removal in Vessel A. The Vessel A outlet concentration was again below the LOQ during the next monitoring event on September 29, 2011, and has remained below the LOQ for the remaining monitoring events in 2011. The final monitoring event of 2011 was conducted on December 14, and the Vessel A outlet concentration was below the LOQ following treatment of over 86,000,000 gallons of groundwater.

During the 30,000,000-gallon monitoring event (August 26, 2011), a low-level (j-flagged) concentration of sulfolane below the LOQ was reported at the Vessel B outlet. During the next monitoring event on September 13, 2011, the sulfolane concentration at the Vessel B outlet was below the LOQ. Prior to the 30,000,000-gallon monitoring event, FHRA conducted a backwash event at Vessel B, which is a potential explanation for the low-level outlet concentration reported. With Vessels C and D treating the effluent of Vessels A and B, there is no risk of sulfolane reaching the Final Effluent during a backwashing event at Vessel A or B.

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 Section 1.5.1, sulfolane is relatively nonvolatile and reduction across the air strippers and between the air stripper outlets and the GAC vessel inlet was not expected. FHRA is performing additional bench-scale testing to potentially identify the mechanism for this degradation. Bench testing results have been discussed with ADEC and will be presented in the Onsite FS. Because the sulfolane removal is observed following aeration in the air stripper, FHRA is in the process of completing an air sparging pilot test to evaluate if aeration of the aquifer will create conditions for sulfolane reduction in-situ. Mechanisms identified as a result of bench and pilot-scale testing will also inform the MNA analysis conducted as part of the Offsite FS. The results of the air sparging pilot test are being discussed with ADEC staff in the Site Characterization Subgroup meetings and will be presented in the final Onsite FS.

5.1.4 Summary of Non-routine Repairs, Changes, and Maintenance

Section 5.1.1 provided a summary of the major non-routine work which had a significant effect on the groundwater recovery system runtime. Below is a summary of repairs, changes and maintenance that were conducted during 2011. Not included in the list below are routine change-outs of the prefilter and coalescer cartridges.

- *January 1 through May 11, 2011*: Recovery well R-35 failed in the fourth quarter of 2010 and a new recovery well (R-35R) was installed as a replacement as discussed in Section 5.1.1. Groundwater recovery from R-35R was resumed on May 11, 2011, and has since operated without problems

- *January 6, 2011*: Down-hole video recorded for R-40 to assess well and screen integrity. The video did not indicate the well screen or integrity had been compromised; however, the screen had fouling associated with biological material and precipitation.

- *January 31, 2011*: Down-hole video recorded for R-21 and R-39 to assess well and screen integrity. The video for both wells did not indicate the well screen or integrity had been compromised; however, the screen had fouling associated with biological material and precipitation.

- *February 10, 2011*: Tie-in of new discharge piping from R-21 to the treatment system.

- *March 23, 2011*: Initial tie-in of a second prefilter unit prior to the coalescer.

- *May 22 to 25, 2011*: Sand filter and GAC treatment system tie-in.

- *August 15 to 19, 2011*. Well cleaning conducted at R-40, R-39 and R-21; tie-in completed on second prefilter unit; and replacement of Gallery Pond discharge pumps.

- *August 19 to 26, 2011*. New well screen installed in R-21.

- *September 7, 2011*. R-39 and R-42 were shut down for 1 hour to reduce system flow and allow belt replacement on an air stripper blower.

- *November 8, 2011*. R-35R was shut down for up to 10 hours due to failure of the groundwater pump.

5.1.5 IRAP Implementation Progress Update

FHRA has implemented interim corrective actions, as described in the IRAP, with the purpose of optimizing the existing remediation system to aggressively address, to the extent practical, LNAPL and sulfolane-contaminated groundwater on the refinery property. A summary of the interim corrective actions implemented are highlighted below:

- Installation and operation of new recovery well R-42.

- Installation and operation of a second prefilter unit to provide redundancy to improve reliability and remove a flow restriction.

- Installation of new pumps in the Gallery Pond discharge to allow a higher flow rate through the GAC vessels.
- Installation and operation of seven additional LNAPL recovery systems.
- Replaced the discharge piping from R-21 to allow groundwater recovery at a higher flow rate without transmission of solids to the treatment system. Although not described in the IRAP, new discharge piping was also installed to R-35R, R-39 and R-40 which will increase the overall reliability of the groundwater recovery system.
- Installation of a new sand filter and GAC treatment system to remove sulfolane from the recovered groundwater.

5.2 Offsite Response Actions

To address potential drinking water risks associated with offsite dissolved-phase groundwater contamination, the following mitigation activities have been completed: (1) replacement of the City of North Pole's existing municipal wells; and (2) provision of alternate water supplies to those residences and businesses whose wells have exhibited detections of sulfolane.

Also, as part of the efforts to provide a long-term residential water supply, FHRA has conducted a feasibility study for in-home treatment which indicated a POE GAC filtration system as the best technology for sulfolane removal. POE treatment refers to treatment of water at the point where it enters a residence, as opposed to treatment at a centralized facility prior to distribution to individual residences. The results of the feasibility testing and recommended system design were submitted to ADEC in the *Point-of-Entry Treatment System Feasibility Study and Design Report* (Barr, 2011). FHRA has assembled full-scale POE treatment systems and conducted additional testing to evaluate effectiveness during residential usage. The following sections include a summary of results for in-home pilot testing (Section 5.2.1) and accelerated pilot testing (Section 5.2.2).

To provide assurances to residents who utilize a POE treatment system, FHRA requested the Water Quality Association (WQA) to provide a third-party independent review as part of their Gold Seal Certification Program. WQA has completed their review of the pilot-testing results and has provided certification of the treatment system effectiveness. The WQA lists the certification under the name of the treatment system vendor working with FHRA, Richards Distributing Inc.

5.2.1 Point-of-Entry Treatment System In-Home Pilot Testing

The objective of the in-home pilot testing is to verify that the design basis used for the preliminary POE system design is adequate for use in final design and implementation. It is important to test the technology in full-scale (i.e., in an actual residence) on a variety of water sources to identify any variability in performance that may be due to reliability of the full-scale equipment or differences in feed-water quality. A description of the in-home pilot testing scope and monitoring plan was provided in the *Point-of-Entry Treatment System Feasibility Study and Design Report.* FHRA intends to submit an addendum to the POE report once pilot testing efforts have been completed to summarize the final results and recommendations. Prior to submittal of this addendum, a summary of the monitoring plan and test results is provided in this report.

FHRA is completing ongoing pilot testing in five homes that have been selected to include both higher and lower sulfolane concentrations to provide a range of anticipated water qualities. The locations of the test homes are shown on Figure 148. The treatment systems installed include a primary 2.5-cubic-foot carbon tank for sulfolane removal. Through April 2011, FHRA conducted weekly monitoring of the system influent (referred to as “Pretreatment”) and primary tank effluent (“First vessel effluent”) to validate the results found in bench-scale testing conducted as part of the feasibility study and to test with actual water usage rates. Since April, the monitoring frequency has been reduced to monthly. Each system also contains a secondary 2.5-cubic foot carbon tank, which upon breakthrough of the first vessel, is also sampled on the same frequency of the primary vessel (referred to as “Second vessel effluent”). FHRA has added a third redundant vessel to the homes in which breakthrough has occurred in the first vessel, so that the effectiveness of the second vessel can be monitored until breakthrough to evaluate series operation.

A summary of the laboratory monitoring results through 2011 are provided in Tables 66, 67, 68, 69, and 70 for the five test homes (referred to as Location A, Location B, Location C, Location D, and Location E). Laboratory reports are included in Appendix AH. As seen in the attached tables, the sulfolane influent (pretreatment) concentration varied from approximately 50 to 350 µg/L. In all five test homes, the POE system effectively removed sulfolane down to nondetectable levels in the primary carbon tank (“First vessel effluent”). During the testing, sulfolane breakthrough from the primary carbon tank was detected in three of the five homes (Locations A, B, C). In the two homes in which breakthrough was not detected, the volume of water treated by the primary tank without breakthrough exceeded 25,000 gallons (Location D), and 17,900 gallons (Location E). Due to the success of the pilot testing at Locations D and E and to reduce disturbance to the residents, the carbon has been changed out in the primary and secondary tanks, and these houses were removed from the pilot-testing monitoring program in June 2011 and May 2011, respectively.

For the houses in which breakthrough of sulfolane has been observed in the primary vessel, the measured rate of increase in the post-treatment sample has been minimal, which indicates additional useful life of the primary carbon tank even after breakthrough. The preliminary system design described in the *Point-of-Entry Treatment System Feasibility Study and Design Report* included two primary carbon tanks operated in parallel; however, based on these results FHRA is installing new systems with the tanks in series.

Through the December 2011 monthly monitoring event, detection of sulfolane in the second vessel effluent occurred at Locations B and C, although at both locations the detections have been low-level (j-flagged and less than the reporting limit). The first detection of sulfolane occurred after treatment of over 96,400 gallons at Location B and 64,600 gallons at Location C. At Location A, the two vessels in series have treated over 48,700 gallons without breakthrough in the second vessel.

Through 2011, FHRA has installed 127 POE systems in affected residences and these systems are providing drinking water without detectable levels of sulfolane to these residences. Each home with a POE system installed was sampled initially to verify successful sulfolane removal and laboratory reports are provided in Appendix AH. A summary of the QA/QC review of these laboratory reports is provided in Appendix AH-Table 1. As described in the *Point-of-Entry Treatment System Feasibility Study and Design Report,* additional sampling and system maintenance was to be conducted after 6 months of operation. FHRA has also installed a commercial POE system at a church under the regulatory oversight, and with the approval, of the ADEC Division of Environmental Health Drinking Water Program.

5.2.1.1 In-Home Pilot Testing Pre-Treatment Results

The high frequency of sampling conducted during the In-Home Pilot Testing provides a data set for evaluation of the potential variations in the pre-treatment sample (i.e. raw groundwater). Figure 149 provides a plot of the reported pretreatment sulfolane concentration versus date at the five In-Home Pilot Test locations (Figure 148). For the purposes of evaluating trends in the groundwater, sulfolane values that were qualified during the data validation process as (e.g. “biased high”) are not included in Figure 149.

As seen in Figure 149, the reported sulfolane concentration has shown some variability at each location. The highest variability occurred in Location A, which also has the highest concentration.

Although the testing was completed for approximately a full year at Locations A, B, and C, a seasonal pattern is not able to be discerned.

5.2.2 Point-of-Entry Treatment System Accelerated Pilot Testing

In addition to the in-home pilot testing, FHRA conducted two accelerated pilot tests in January to March 2011 to provide more timely information regarding sulfolane breakthrough as part of the final design process. Once again, the testing results confirmed successful sulfolane removal through a POE treatment system utilizing GAC.

The pilot tests were conducted on a full-scale system based on parallel operation with two primary 2.5-cubic-foot carbon tanks. The tests were conducted at 3 gpm through one vessel (for direct correlation of a two vessel in parallel system at 6 gpm) with different flow regimes. In the first test, the flow was constant with no downtime, while flow in the second test was a “50:50” flow scenario (20 minutes on and 20 minutes off for 16 hours, followed by eight hours of completely off). As previously mentioned, FHRA intends to submit an addendum to the *Point-of-Entry Treatment System Feasibility Study and Design Report* to summarize the results of these pilot–testing efforts; therefore, a brief summary of the results are provided in the remainder of this section.

For the first test conducted without downtime, the first detectable level of sulfolane in the primary tank effluent was after treatment of 10,739 gallons (Table 71). The influent concentration varied from 235 to 156 µg/L during the test. Laboratory reports are included in Appendix AH.

For the second test conducted with the 50:50 flow scenario, the first detectable level of sulfolane in the primary tank effluent was after treatment of 11,794 gallons (Table 72). As seen in the in-home testing, the sulfolane concentration in the post-treatment sample showed minimal increase as the testing continued. The influent concentration during this test varied from 290 to 231 µg/L.

Based on the successful sulfolane removal demonstrated in the initial pilot testing, in-home testing, and accelerated pilot testing, FHRA has proceeded with installation of the POE systems in additional residences. As mentioned above, the purpose of the additional pilot testing was to confirm the initial pilot test results and to inform the final design process. Based on the results, the design has been modified to include operation in series (versus parallel), as this has demonstrated longer carbon lifetime which will reduce the change out frequency, and thus reduce homeowner disturbances.

6.0 Quality Assurance/Quality Control

Q QA/QC procedures assist in producing data of acceptable quality and reliability. Analytical results for laboratory QC samples were reviewed and a QA assessment of the data was conducted as they were generated. The QA review procedures provided documentation of the accuracy and precision of the analytical data and confirmed that the analyses were sufficiently sensitive to detect analytes at levels below suggested action levels or regulatory standards, where such standards exist. The laboratory reports for each of the project samples for this report, including case narratives describing laboratory QA results in detail, and completed ADEC data-review checklists are included in Appendix L.

At the direction of the Chemistry Subgroup, a large number of samples submitted for sulfolane analysis in 2011 were reported by SGS with Level IV data packages. Several hundred sulfolane work orders were produced with Level IV reports, and were subjected to third-party review by ESI, Inc. (ESI), which reviewed the reports to check the analyses conformed to the Chemistry Subgroup's key elements for sulfolane analysis. All groundwater samples submitted for sulfolane analysis in the third and fourth quarters of 2011, all sulfolane soil samples, all residential-well samples in the third quarter, and about 20 percent of the residential-well samples in the fourth quarter were produced with Level IV reports. The reviews by ESI were provided to the Chemistry Subgroup and ADEC.

6.1 2010 Well Installations & Water Sample Data Quality

This section summarizes the results of the QA review of data generated during the Phase 1 monitoring-well installation and sampling tasks; these assessments were provided to FHRA as monitoring-well installation and sampling progressed during the Phase 1 tasks. This section also presents Phase 2 monitoring-well installation and sampling QA/QC assessments not previously reported. The results discussed here include only the initial sample collected from each well following installation; subsequent sampling results are not presented in this section. Data from September through December 2010 were previously reviewed and the ADEC data-review checklists were submitted to ADEC through FHRA with the 2010 monthly reports. The reader is referred to the ADEC data-review checklists presented in Appendix L for additional detail. The laboratory work orders SWI reviewed for this section are listed below.

Phase 1 water samples: 1095969, 1095975, 1096197, 1096937, 1096986, 1100933, 1100805, 1100810, 1100834, 1100852, 1100872, 1101938, and 1100900.

Phase 1 soil samples: 1100801 and 1100996

Phase 2 water samples: 1106866, 1106873, 1106876, 1106886, 1106900, 1106903, 1106910, 1106915, and 1108024.

Phase 2 soil samples: 1106717, 1106723, 1106728, 1106740, 1106753, 1106761, 1106765, 1106777, 1106791, 1106804, 1106853, 1106857, and 1106861.

6.1.1 Sample Handling

The samples were hand-delivered to SGS at their Fairbanks sample-receiving office generally within 24 hours of collection. Samples were received there at a temperature between 0 °C and 6 ºC. SGS then shipped the samples to their Anchorage laboratory to perform the requested analyses, using the methods specified on the chain-of-custody records.

SWI reviewed COC records and laboratory-receipt forms to confirm custody was not breached and samples were kept properly chilled during shipping. The sample-cooler temperature was generally within acceptable limits upon arrival at the SGS Anchorage laboratory, with a few exceptions:

Phase 1 Sample Findings:

- The temperature blank in the cooler for SGS work order 1100810 (water) was measured below the acceptable range upon arrival at -1.0 °C; ice was noted in both bottles for sample MW-169. Therefore, the result for this sample is considered to be biased low. Ice was not noted in the other water samples, and those results are not considered to be biased due to the low temperature. The initial sample from well MW-169 did not contain sulfolane at a concentration greater than the laboratory LOQ, and the low bias may have reduced a detectable concentration to a level below the LOQ.

- The cooler for SGS work order 1100805 (water) was received at the SGS office in Fairbanks within the proper temperature range, but the cooler temperature was not recorded upon its arrival at the laboratory in Anchorage. Out of an abundance of caution, the sulfolane results for samples in this work order are considered to be biased low, though they have no evidence to suggest the samples were received in a compromised condition. The affected samples were MW-151C (17.4 µg/L), its duplicate MW-251C (17.2 µg/L), MW-154B (not above the laboratory LOQ of 10.6 µg/L), MW-156B (113 µg/L), MW-160B (20.2 µg/L), and MW-162B (15.4 µg/L).

- The temperature of the temperature blank in the cooler for SGS work order 1100996 (soil) was 6.2 °C upon the cooler's receipt at the laboratory in Anchorage. The samples in this work order were soil samples 1489-021810-1511, 1489-021810-1512, 1489-021810-1513/1489-021810-2513, 1489-021710-1561, 1489-021710-1562, 1489-021610-1621, 1489-021610-1622, 1489-021610-1623, and 1489-021610-1624 from borings for MW-151C, MW-156B, and MW-162B. These samples did not contain sulfolane at concentrations above the LOQ.

- The elevated temperature (i.e., 0.2 °C above the maximum desired temperature of 6 °C) is unlikely to have affected the soil concentration of this nonvolatile analyte.

Phase 2 Water Sample Findings:

- Cooler temperatures for the Phase 2 water sample delivery groups were within the acceptable range of 2 °C to 6 °C when they were delivered to the SGS Fairbanks receiving office in eight of the nine work orders. The temperature in one work order (11068024) was below 2 °C when it was delivered to the SGS Fairbanks office. USEPA publication SW-846 allows sample temperatures between 0 °C and 6 °C, and ADEC's chemist has approved sample temperatures within this range, despite the range noted on the ADEC data-review checklist. This was communicated in an e-mail between ADEC's chemist, Earl Crapps, and SGS, dated March 25, 2011.

- The temperatures were below 2 °C in eight of the nine work orders upon arrival at the Anchorage laboratory. Ice was not documented in the samples associated with the below-range temperature blanks, and the reported sulfolane concentrations (whether above the LOQ or not) were unaffected in these samples. This situation was noted for the following Phase 2 work orders: 1106866, 1106873, 1106876, 1106886, 1106900, 1106903, 1108024, and 1106915.

- Sample *MW-180B* from work order 1106876 was extracted and analyzed outside of hold time due to laboratory error; sulfolane was not detected in this sample but is considered biased low (flagged "JL").

Phase 2 Soil Sample Findings:

- Cooler temperatures for the Phase 2 soil sample delivery groups were within the range of 2 °C to 6 °C when SWI delivered them to the Fairbanks receiving office for nine of the 13 work orders. The temperatures were below 2 °C in 12 of the 13 work orders upon arrival at the Anchorage laboratory. Ice was not documented in the associated samples and the reported sulfolane or other target analyte concentrations (whether above the LOQ or not) were unaffected in these samples. This situation was noted for the following work orders: 1106717, 1106723, 1106728, 1106753, 1106761, 1106765, 1106765, 1106777, and 1106857.

- Four coolers were delivered to the SGS Fairbanks receiving office with temperatures outside the acceptable range. Work order 1106740 was received with a temperature of 6.3 °C; samples in this work order were removed from SWI's sample storage refrigerator and packed in the cooler immediately prior to delivery to SGS so the cooler temperature was unlikely to be representative of the sample temperature. Three work orders were delivered to the SGS Fairbanks receiving office with cooler temperatures below 2 °C: 1106791, 1106804, and 1106861; as noted above, the low temperatures are unlikely to have affected the target analyte concentrations in these work orders' samples.

Other than the items noted above, there were no sample-handling anomalies identified that would adversely affect data quality for this project.

6.1.2 Analytical Sensitivity

Phase 1 Sample Findings:
The reporting limits for sulfolane analyses in water ranged from 6.2 µg/L to 11.1 µg/L in the 13 Phase 1 water-sample work orders. The sulfolane reporting limits for Phase 1 soil samples ranged from 0.559 mg/kg to 0.623 mg/kg (only sulfolane was measured in the soil samples for Phase 1).

Laboratory method blanks were analyzed in association with samples collected for this project to check for contributions to the analytical results possibly attributable to laboratory-based contamination. Sulfolane was not detected in the method blanks associated with the Phase 1 work orders.

Phase 2 Water Sample Findings:
The reported LOQs for sulfolane analyses in water ranged from 10.0 µg/L to 11.4 µg/L in the nine Phase 2 water-sample work orders. Sulfolane was not detected in the method blanks associated with these work orders.

Phase 2 Soil Sample Findings:
LOQs for various VOCs and SVOCs exceeded applicable ADEC soil-cleanup levels in each of the 13 Phase 2 soil work orders. These are typically analytes that have not been detected in project samples; however, it cannot be determined whether analytes with LOQs greater than cleanup levels may have been present in the samples at concentrations between their cleanup levels and their LOQs.

Sixty analytes had LOQs greater than their ADEC soil-cleanup levels in at least some of the soil samples. Twenty-four analytes' LOQs were greater than their soil-cleanup levels in each of the 51 soil samples; nine of these analytes (nitrobenzene; hexachloroethane; 4-chloroaniline; N-nitrosodimethylamine; 2,4-dinitrotoluene; hexachlorobutadiene; hexachlorobenzene; 3,3-dichlorobenzidine; 2,4-dinitrophenol) were identified as COPCs to be assessed in soil at the refinery based on an assessment of the materials used and/or known to have been released at the facility. Several of the 60 analytes had elevated LOQs because they were measured in samples containing hydrocarbons at levels that raised their LOQ. Therefore, the elevated LOQs should not affect site-characterization efforts regarding the distribution of petroleum. The remaining COPC analytes were assessed as part of the soil-sampling effort conducted during the autumn of 2011.

6.1.3 Accuracy

Laboratory analytical accuracy may be assessed by evaluating the analyte recoveries from continuing calibration verification (CCV), laboratory control sample (LCS), and LCS duplicate (LCSD) analyses. LCS/LCSD samples assess the accuracy of analytical procedures by checking the ability to recover analytes added to clean aqueous or solid matrices. Accuracy may also be assessed by evaluating the recovery of analyte surrogates added to project samples.

The laboratory noted no CCV failures for this project.

Phase 1 Sample Findings:
SWI reviewed the LCS/LCSD results for the Phase 1 sample work orders to assess the analytical accuracy for these samples; the LCS and LCSD recoveries were within acceptable limits (LCS and LCSD recovery limits for sulfolane were 40 percent to 120 percent), indicating the laboratory analyses were accurate. Each project sample reported here also had sulfolane-surrogate recoveries within QC goals. The laboratory data indicate the analytical results were accurate.

Phase 2 Water Sample Findings:
SWI reviewed the LCS/LCSD results for the Phase 2 water-sample work orders to assess the analytical accuracy for these samples; the LCS and LCSD recoveries were within acceptable limits, indicating laboratory results were accurate. Each project sample reported here also had sulfolane-surrogate recoveries within QC goals. The laboratory data indicate the Phase 2 water-sample analytical results were accurate.

Phase 2 Soil Sample Findings:
A number of LCS/LCSD analytes were above the laboratory QC limits for VOC and SVOC analyses. The laboratory often attributed these anomalies to sample dilution, and these analytes were not detected in the project samples.

A number of surrogate recoveries in the Phase 2 soil samples were outside the laboratory QC limits. Of these, many were surrogates for analytes not detected in the corresponding project samples. When a surrogate recovery outside QC limits corresponded to a project sample with an analyte concentration above the LOQ, SWI flagged the result “JH” (estimated, biased high) or “JL” (estimated, biased low).

6.1.4 Precision

SWI collected duplicate samples at a frequency of at least 10 percent of the samples submitted for organic compound analysis to evaluate the precision of analytical measurements, as well as the reproducibility of their sampling technique. To evaluate the precision of the data, SWI calculated the relative percent difference (RPD; difference between the sample and its field duplicate divided by the mean of the two); an RPD can be evaluated only if the results of the analyses for both duplicates are above the LOQ.

Phase 1 Sample Findings:
Laboratory analytical precision can also be evaluated by laboratory QC-sample RPD calculations using the LCS/LCSD and matrix spike/matrix spike duplicate (MS/MSD) results. The results of the LCS/LCSD and MS/MSD RPD calculations were within the laboratory’s acceptable range.

SWI collected 42 project samples and 11 field-duplicate samples (a total of 53 samples) for the Phase 1 water-sampling task between October 2009 and April 2010. Sulfolane was detected above the LOQ in five sample sets, and SWI was able to calculate RPDs; results of RPD calculations for these duplicate samples ranged from 1 percent to 28 percent and were within the data-quality objective (30 percent for water) recommended by the ADEC data-review checklist for field duplicates (Appendix L). Based on their review, the Phase 1 water data reported here are considered precise.

Phase 2 Water Sample Findings:
Laboratory analytical precision can also be evaluated by laboratory QC-sample RPD calculations using the LCS/LCSD and MS/MSD results. The results of the LCS/LCSD and MS/MSD RPD calculations were within the laboratory’s acceptable range.

SWI collected 34 project samples and four field-duplicate samples (a total of 38 samples) for the Phase 2 water-sampling task. Sulfolane was detected above the LOQ in both samples in one of these pairs; hence SWI was able to calculate RPDs. The result of RPD calculation for the duplicate sample pair was 12 percent and within the data-quality objective (30 percent for water) recommended by the ADEC data-review checklist for field duplicates (Appendix L). Based on their review, the water data reported here are considered precise.

Phase 2 Soil Sample Findings:
SWI identified QC anomalies where RPDs calculated using laboratory LCS/LCSD and MS/MSD samples were outside the laboratory QC criteria in 11 of the 13 Phase 2 soil-sample work orders. In each case, SWI noted the corresponding analytes were not detected above the LOQ in the original sample.

SWI collected 58 project samples and five field-duplicate samples (for a total of 63 samples) for the Phase 2 soil-sampling task. RPDs for analytes reported above the LOQ in project sample MW-175(7.5-9) and its field duplicate MW-175D (work order 1106777) were within acceptable limits, except GRO, o-xylene, 1,3,5-TMB, and naphthalene had RPDs greater than the ADEC data-review checklist's recommended QC target of 50 percent for soils. GRO, BTEX, sec-butylbenzene, and 4-isopropyltoluene RPDs exceeded 50 percent in project sample MW-176C (5-6.5) and its field duplicate MW-176D (work order 1106791). In project sample MW-186C (7.5-9) and field duplicate MW-186D (work order 1106853), only 2-methylnaphthalene exceeded 50 percent RPD. Project sample and field duplicate pairs 0-2(5-6.5)/0-2D and 0-2(10-11.5)/0-2DD were submitted with work order 1106861. No analytes were detected above the LOQ in sample pair 0-2(5-6.5)/0-2D. RPDs for the analytes benzene, ethylbenzene, o-xylenes, and naphthalene exceeded 50 percent in sample pair 0-2(10-11.5)/0-2DD; soil-sample heterogeneity may account for the RPDs greater than 50 percent.

6.1.5 QC Summary

By working in general accordance with the SAP, the samples SWI collected are considered to be representative of site conditions at the locations and times they were obtained. Based on their QA review, no samples were rejected as unusable due to QC failures. In general, the quality of the analytical data for this project does not appear to have been compromised by sample handling or analytical irregularities.

6.2 First Quarter 2011 Water Sample Data Quality

This section summarizes SWI's QA review of the groundwater data collected for organic analyses (i.e., sulfolane, BTEX, and 1,2,4-TMB) during the first quarter of 2011. The reader is referred to the

ADEC data-review checklists presented in Appendix L for additional detail. The SGS work orders SWI reviewed for this section are listed below: This section summarizes SWI's QA review of the groundwater data collected for organic analyses (i.e., sulfolane, BTEX, and 1,2,4-TMB) during the first quarter of 2011. The reader is referred to the ADEC data-review checklists presented in Appendix L for additional detail. The SGS work orders SWI reviewed for this section are as follows: 1118015, 1118024, 1118025, 1118026, 1118029, 1118035, 1118047, 1118060, 1118063, 1118067, 1118094, 1118095, 1118096, 1118101, 1118102, 1118118, 1118119, 1118129, 1118130, 1118132, 1118133, 1118144, 1118148, 1118149, 1118151, 1118152, 1118153, 1118154, and 1118162.

SWI reviewed the analytical results for laboratory QC samples and also conducted a QA assessment of the first quarter groundwater data as they were generated. The SGS laboratory reports for each of the first quarter groundwater samples, including case narratives describing laboratory QA results in detail, and completed ADEC data-review checklists are included in Appendix L.

6.2.1 Sample Handling

SWI typically hand-delivered samples to SGS at their Fairbanks sample-receiving office within 24 hours of collection. Samples were generally received there within the temperature specified on the ADEC data-review checklist (4.0 ± 2 ºC). SGS then shipped the samples to their Anchorage laboratory to perform the requested analysis, using the methods specified on the chain-of-custody COC records.

Several coolers arrived in Anchorage at temperatures below the range specified on the ADEC data-review checklist, but above 0 °C. Samples associated with these colder temperatures were unaffected by the deviation from the ADEC checklist's specifications.

SWI reviewed COC records and laboratory sample-receipt forms to confirm custody was not breached and samples were kept properly chilled during shipping. The sample-cooler temperature was generally within acceptable limits upon arrival at the SGS Anchorage laboratory, with the exception of some sulfolane-analysis samples in SGS work order 1118101 (samples MW-157, MW-162A, MW-162B, and MW-151B). Those samples arrived in Anchorage containing visible ice; out of an abundance of caution, these samples' sulfolane concentrations were flagged as estimates ("J") due to the ice.

Sample holding times were met for most of the samples, with the exception of samples

MW-144B (SGS work order 1118095) and MW-169B (work order 1118144). Sulfolane was not detected in either of these samples above the LOQ. The nondetect results were flagged ("UJ") as estimated due to the hold-time exceedance.

Aside from the issues noted above, no other sample-handling problems affected the organic analyte data.

6.2.2 Analytical Sensitivity

The reporting limits for sulfolane analyses in water ranged from 10.2 µg/L to 13.7 µg/L in the 29 water-sample work orders, and were below the recommended action level for infants (25 µg/L) established by the ADEC. The BTEX and 1,2,4-TMB reporting limits were all below ADEC groundwater-cleanup levels.

Laboratory method blanks were analyzed in association with samples collected for this project to check for laboratory-based contamination. Target organic analytes were not detected in the method blanks associated with the first quarter 2011 samples.

Trip blanks were carried during the sampling of volatile organic analytes, and were shipped with the samples to the laboratory for analysis. They were analyzed with the volatile organic samples to check for cross-contamination or contamination from outside sources during shipping and handling. No analytes were detected in the trip blanks.

Equipment blanks (EBs) were collected when nondedicated pumps were used to collect groundwater samples, at a frequency of one EB per 20 samples. No analytes were detected in the EBs.

6.2.3 Accuracy

Laboratory analytical accuracy for these samples was assessed by evaluating the analyte recoveries from CCV, LCS, and LCSD analyses. Accuracy was also assessed by evaluating the recovery of analyte surrogates added to project samples.

The laboratory noted no CCV failures for this project. The LCS and LCSD recoveries were within acceptable limits (LCS and LCSD recovery limits for sulfolane were 40 percent to 120 percent); indicating laboratory control results were accurate.

All but one sulfolane sample (MW-239, a duplicate of sample MW-139 in SGS work order 1118094) had surrogate recoveries within laboratory QC goals. The sulfolane surrogate in sample MW-239 was recovered below laboratory control limits, so the sulfolane result for this sample was considered biased and flagged “JL” to indicate the measured concentration was an estimate biased low. The BTEX and 1,2,4-TMB surrogates were recovered within control limits, indicating those results were accurate.

6.2.4 Precision

SWI collected duplicate samples at a frequency of at least 10 percent of the samples submitted for organic compound analysis to evaluate the precision of analytical measurements, and the reproducibility of their sampling technique. Laboratory analytical precision was also evaluated by laboratory QC-sample RPD calculations using the LCS/LCSD and MS/MSD results.

The results of the duplicate-sample analyses were generally within the acceptable range for water-sample RPDs (i.e., less than 30 percent) with some exceptions:

- The sulfolane RPD for duplicate pair MW-143/MW-243 (SGS work order 1118162) exceeded 30 percent. The associated sulfolane results were flagged “J” due to imprecision.
- The sulfolane RPD for duplicate pair MW-139/MW-239 (SGS work order 1118094) exceeded 30 percent. The associated sulfolane results were flagged “J” due to imprecision.
- The sulfolane RPD for duplicate pair MW-113/MW-213 (SGS work order 1118094) exceeded 30 percent. The associated sulfolane results were flagged “J” due to imprecision.
- The results of the LCS/LCSD RPDs were generally within laboratory control limits, with some exceptions:
- The sulfolane RPD in work order 1118026 was outside laboratory control limits, but no associated project samples contained detectable sulfolane, so the results were unaffected.
- The sulfolane RPD in work order 1118047 was outside laboratory control limits. Samples MW-150A and its duplicate MW-250A were associated with this LCS/LCSD pair, and were flagged “J” as estimates due to imprecision.
- The sulfolane RPD in work order 1118094 was outside laboratory control limits. Samples MW-139, MW-239, and MW-101 were associated with this LCS/LCSD pair, and their sulfolane results were flagged “J” as estimates due to imprecision.

- The sulfolane RPD in work order 1118095 was outside laboratory control limits. Sample MW-144B was associated with this LCS/LCSD pair, but did not contain detectable sulfolane, so its result was unaffected.

- The sulfolane RPD in work order 1118096 was outside laboratory control limits. Sample MW-141 was associated with this LCS/LCSD pair, but did not contain detectable sulfolane, so its result was unaffected.

- The sulfolane RPD in work order 1118102 was outside laboratory control limits. Samples MW-109, MW-110, MW-130, MW-149, and MW-129 were associated with this LCS/LCSD pair, but only samples MW-110 and MW-130 contained detectable sulfolane. The sulfolane results for MW-110 and MW-130 were flagged "J" as estimates due to imprecision.

- The sulfolane RPD in work order 1118149 was outside laboratory control limits, but no associated project samples contained detectable sulfolane, so the results were unaffected.

- The sulfolane RPD in work order 1118151 was outside laboratory control limits. Samples MW-148A, MW-148B, MW-156A, MW-156B, and MW-256B were associated with this LCS/LCSD pair. The sulfolane results for these samples were flagged "J" as estimates due to imprecision.

- The sulfolane RPD in work order 1118152 was outside laboratory control limits. Samples MW-153B and MW-170C were associated with this LCS/LCSD pair. Only sample MW-153B contained detectable sulfolane, and its sulfolane result was flagged "J" as an estimate due to imprecision.

- The sulfolane RPD in work order 1118153 was outside laboratory control limits. Sample MW-149A was associated with this LCS/LCSD pair, and its sulfolane concentration was flagged "J" as an estimate due to imprecision.

- The sulfolane RPD in work order 1118154 was outside laboratory control limits. Sample MW-161A was associated with this LCS/LCSD pair, and its sulfolane concentration was flagged "J" as an estimate due to imprecision.

6.2.5 QC Summary

By working in general accordance with the SAP, the first quarter 2011 groundwater samples collected for organic analysis are considered to be representative of site conditions at the locations and times they were obtained. Based on the QA review, no samples were rejected as unusable due to QC failures. Aside from the issues noted above, the quality of the analytical data for this project does not appear to have been compromised by sample handling or analytical irregularities.

6.3 Geochemical Water Sample Data Quality

This section summarizes the results of SWI's QA review of the geochemical-parameter data for MNA and differentiation of sub- and suprapermafrost groundwater. The reader is referred to the ADEC data-review checklists presented in Appendix L for additional detail. The SGS work orders SWI reviewed for this section are listed below.

MNA Geochemical Parameters: 1118101, 1118118, 1118129, 1118132, 1118148, 1118149, 1118151, 1118154, and 1118162.

Sub- and Suprapermafrost Geochemical Parameters: 1118147, 1118161, 1118167, 1118171, and 1118172

6.3.1 Sample Handling

SWI hand-delivered samples to SGS's Fairbanks sample-receiving office, where they were generally received between 2 °C and 6 °C, the temperature range specified on the ADEC data-quality review checklist; for several work orders, temperature blanks were measured below this range, but above 0 °C upon delivery in Fairbanks. SGS then transferred the samples to their Anchorage laboratory by overnight carrier, where they were generally received between 0°C and 6 °C. While multiple temperature blanks were below the ADEC checklist-specified temperature range, they were within the acceptable range of 0 °C to 6 °C specified in USEPA publication SW-846 and approved by the ADEC's chemist. The sample results are not considered to be affected by low sample-receipt temperatures, except in the cases where ice was observed in the samples. The following samples/analyses were potentially affected by the presence of ice, and the results flagged "JL" (positive results) or "UJ" (nondetects): MW-156A – data for nitrate/nitrite and alkalinity; MW-157 – data for TOC, alkalinity, total phosphorus, and total Kjeldahl nitrogen (TKN); MW-162A – data for sulfate, TOC, alkalinity, total phosphorus, TKN, total iron, and hardness; MW-162B – data for TOC, total phosphorus, and TKN; and MW-151B – data for sulfate, TOC, and alkalinity.

Other than the items noted above, there were no sample-handling anomalies identified that would adversely affect geochemical data quality.

6.3.2 Analytical Sensitivity

In multiple cases, the LOQ for total phosphorus was noted as elevated in the case narrative due to matrix interference. SGS's LOQ for total phosphorus is typically 10.0 µg/L; the elevated LOQs were generally 100 µg/L. There is no regulatory limit for total phosphorus; this parameter is reported for purposes of evaluating MNA and to differentiate between sub- and suprapermafrost groundwater. The "elevated" LOQ does not affect data quality or usability, except one cannot determine if total phosphorus was present between the typical LOQ and the elevated LOQ.

Laboratory method blanks were analyzed in association with geochemistry samples collected for this project to check for laboratory-based contamination. Analytes were not detected above LOQs in the method blanks, with one exception. Zinc was detected above the LOQ in a method blank reported in work order 1118172; however, the zinc result for the one project sample associated with this method blank was greater than 10-times the concentration detected in the method blank. In accordance with the EPA's National Functional Guidelines for Inorganic Data Review, the result should not be considered affected by the method-blank detection. However, the laboratory flagged the result "B."

No trip blanks were submitted for the MNA and sub-and suprapermafrost sample work orders addressed in this section, since no volatile analyses were requested. No equipment blanks were submitted; geochemical parameters were measured for purposes of evaluating MNA and to differentiate between sub- and suprapermafrost groundwater, not as contaminants of concern. The data are usable for the purposes for which they were obtained.

6.3.3 Accuracy

Laboratory analytical accuracy was assessed by evaluating the analyte recoveries from CCV, LCS, and LCSD analyses. There were no CCV recovery failures affecting the accuracy of geochemical data, and LCS/LCSD recoveries were within laboratory control limits for each sample and analyte.

For some analyses, the laboratory analyzed an MS and MSD in addition to the LCS, to evaluate their ability to recover analytes from matrices similar to those of project samples. MS/MSD recoveries were within laboratory control limits, with the following exceptions:

- Several MS/MSD recovery failures were noted where the original sample spiked for the MS/MSD was not from the MNA or sub- and suprapermafrost project-sample set, so the results were unaffected.

- In several work orders, MS recovery of calcium was outside laboratory control limits, but the concentration in the original sample was at least 4-fold greater than the spiked amount. If spiking levels are low relative to the native analyte concentrations, it is not appropriate to flag the result; the low MS recovery therefore did not affect the result for this analyte.

- In work order 1118118, MS recovery of TKN was below laboratory control limits. The sample spiked for this MS was MW-157, and the TKN result (not-detected above the LOQ) should be considered potentially affected by the low bias, and was flagged "UJ."

- In work order 1118167, MS recovery of sulfate was below laboratory control limits. The sample spiked for this MS was MW-162B, and the sulfate result should be considered affected by the low bias, and was flagged "JL."

Based on CCV, LCS/LCSD, and MS/MSD recovery information, the results are considered accurate for purposes of this project, with affected data flagged as described above.

6.3.4 Precision

SWI collected duplicate samples at a frequency of at least 10 percent of the project samples collected to evaluate the precision of analytical measurements, and reproducibility of the sampling procedure. Field-duplicate RPDs, where calculable, were within data-quality objectives.

Laboratory analytical precision was also evaluated by laboratory QC-sample RPD calculations using the LCS/LCSD, MS/MSD, and laboratory duplicate-sample results. LCS/LCSD and MS/MSD RPDs were within laboratory control limits. SGS reported laboratory duplicate-sample RPD failures for total phosphorus and/or TKN in a number of case narratives; in each case, the QC-sample pages of the report, as well as the electronic data deliverable (EDD), indicated an RPD within the laboratory control limits. It appears the duplicate-sample RPD failures were noted by the laboratory in error, and precision for these analyses is acceptable.

In some cases, the laboratory did not analyze duplicate samples, so there was no measure of analytical precision. However, field-duplicate RPDs indicated adequate overall precision; the geochemical results are sufficiently precise for purposes of evaluating MNA of sulfolane and differentiating between sub- and suprapermafrost groundwater.

6.3.5 QC Summary

By working in general accordance with the SAP, the geochemical samples SWI collected are considered to be representative of site conditions at the locations and times they were obtained. Based on this QA review, no samples were rejected as unusable due to QC failures. Sample results affected by sample-handling or QC anomalies are flagged as noted in the appropriate section; where multiple flags corresponded to a single result, the most conservative flag was used. In general, the quality of the analytical data for this project does not appear to have been compromised by sample handling or analytical irregularities, and is considered adequately sensitive, accurate, and precise for the purposes of assessing MNA of sulfolane and differentiating between sub- and suprapermafrost groundwater.

6.4 2010 Gravel Pit and Surface Water Samples

This section summarizes the results of the QA review of surface-water samples collected from the north and south gravel pits on NPR, and from Badger Slough. Samples were submitted to SGS for analysis of sulfolane. The SGS work orders reviewed for the 2010 surface-water sampling events are 1104995 (gravel pits) and 1106810 (Badger Slough).

Details regarding the results of the QA review are presented below.

6.4.1 Sample Handling

Samples were hand-delivered to the SGS Fairbanks receiving office and then shipped overnight via Lynden Transport to the SGS Anchorage laboratory to perform the requested analyses, using the methods specified on the chain-of-custody (COC) records.

SWI reviewed sample-receipt forms for each work order (WO) for both SGS locations and checked that samples were received in good condition and within the acceptable temperature indicated on the ADEC data review checklist (2 °C ± 4 °C). The ADEC data-review checklists contain details regarding this review. ADEC's chemist considers samples received at temperatures between 0 °C and 6 °C acceptable in the absence of ice, as specified in the Environmental Protection Agency (EPA) publication SW-846. Therefore, for the purposes of this report, temperatures between 0 °C and 6 °C were considered acceptable. Samples from the gravel pits and slough were received within the acceptable temperature range upon arrival at both SGS locations in 2010.

SWI also reviewed COC records for each work order to confirm information was complete, custody was not breached, and samples were analyzed within the acceptable holding times. COC records were complete and holding times were acceptable.

There were no sample-handling anomalies identified that would adversely affect data quality for the slough and gravel pit samples.

6.4.2 Analytical Sensitivity

Laboratory method blanks were analyzed in association with samples collected for this project to check for contributions to the analytical results possibly attributable to laboratory-based contamination. No analytes were detected above the LOQ in the method blanks associated with project samples.

6.4.3 Accuracy

Laboratory analytical accuracy may be assessed by evaluating the analyte recoveries from CCV, LCS, and LCSD analyses. LCS/LCSD samples assess the accuracy of analytical procedures by checking the laboratory's ability to recover analytes added to clean aqueous matrices. Accuracy was also assessed for the organic analyses by evaluating the recovery of analyte surrogates added to project samples.

The laboratory did not note in the case narratives any CCV failures that might affect project-sample data quality. SWI reviewed the LCS/LCSD results in the work orders associated with these samples. LCS and LCSD recoveries were within acceptable limits, indicating the results were accurate. Organic surrogate recoveries were within laboratory control limits.

Laboratory CCV, LCS/LCSD, and surrogate-recovery information indicate the analytical results were accurate.

6.4.4 Precision

Duplicate surface-water samples were not collected for this project. Laboratory analytical precision can be evaluated by laboratory QC-sample RPD calculations using the LCS/LCSD sample results. The results of RPD calculations for LCS/LCSD were within the laboratory's acceptable range. Based on the review, the surface-water data collected in 2010 are considered precise.

6.4.5 Data Quality Summary

By working in general accordance with the proposed scope of services and sampling and analysis plan, where applicable, the surface-water samples collected in 2010 are considered to be representative of site conditions at the locations and times they were obtained. Based on the QA review, no samples were rejected as unusable due to QC failures. In general, the quality of the analytical data for these surface-water samples does not appear to have been compromised by analytical irregularities.

6.5 Second Quarter 2011 Water Sample Data Quality

This section summarizes the results of the QA review of monitoring well groundwater sample data collected during the reporting period sampling event. Samples were submitted to the laboratory for analysis of sulfolane, BTEX and 1,2,4-TMB, and/or geochemical parameters (nitrate/nitrite, alkalinity, hardness, TKN, TOC and total phosphorus). The ADEC data review checklists provide additional detail and are included in Appendix L. The associated WOs are listed below.

Groundwater Monitoring Sample WO List

1118212 1118208 1118276

1118235 1118219 1118284

1118213 1118222 1118288

1118216 1118230 1118257

1118221 1118256 1118333

1118238 1118239 1118339

1118223 1118236 1118345

1118229 1118248 1118351

1118250 1118247

Details regarding the results of the QA review are presented below.

6.5.1 Sample Handling

Samples were hand delivered to the SGS Fairbanks receiving office and then shipped overnight via Lynden Transport to SGS Anchorage to perform the requested analyses, using the methods specified on the COC records. SGS reviewed sample receipt forms for each WO for both SGS locations and confirmed that samples were received in good condition and within the acceptable temperature indicated on the ADEC data review checklist (2°C ± 4°C). The ADEC data review checklists contain details regarding this review. The ADEC's chemist considers temperatures received between 0 and

6°C acceptable in the absence of ice, as specified by the USEPA Test Method SW-846. Therefore, for this report, sample temperatures between 0 and 6°C are acceptable. Samples were received within the acceptable temperature range upon arrival at both SGS locations during the reporting period sampling event, with the exception of one cooler for WO 1118221. This cooler was received with a temperature blank at 6.5°C and contained samples for analysis of sulfolane from the following wells: MW-170D, MW-184, MW-170B, MW-170A, MW-167A, MW-167B, MW-171A and MW-171B. Sulfolane was not detected in these samples; the results are flagged "UJ" to indicate the nondetect results may be attributable to a low bias due to the elevated temperature.

COC records were reviewed for each WO to confirm that information was complete, custody was not breached and samples were analyzed within the acceptable holding times. COC records were complete and holding times were acceptable, with the following exceptions:

- The laboratory exceeded the nitrate/nitrite holding time for sample MW-171A in WO 1118216; nitrate/nitrite was not detected in the sample, and the data is flagged "UJ" at the limit of detection.
- The following sample receiving/labeling discrepancies were identified:
    - The trip blank was not listed on the COC for WO 1118256, but it was received and analyzed.
    - The laboratory did not sign and date the received-by box on the second page of the COC for WO 1118239, but the first page was properly completed.
    - Sample EB-111 was only delivered with one jar and labeled "EB," but the sample name was corrected and the jar contained sufficient volume for analysis.

These discrepancies were addressed prior to reporting and the results are unaffected. No other sample handling anomalies were identified that would adversely affect data quality for this project.

6.5.2 Analytical Sensitivity

Laboratory method blanks were analyzed in association with samples collected during this reporting period to check for contributions to the analytical results, possibly attributable to laboratory-based contamination. No analytes were detected above the LOQ in the method blanks associated with the reporting period samples.

Trip blanks were submitted with groundwater samples for analysis of volatile organic compounds (benzene and 1,2,4-TMB) to check for contributions to the analytical results, possibly attributable to cross contamination during sample handling and transport. Benzene was detected at 0.420 µg/L in the trip blank for WO 1118351; benzene was likewise detected in associated samples MW-124, MW-224 (duplicate of MW-124) and MW-109. The concentration detected in the samples was less than five-fold greater than the trip blank result; therefore, these results should be considered attributable to sample contamination during sample handling or shipment, and flagged "UB" in accordance with the USEPA National Functional Guidelines for Organic Data Review. Sample contamination may be attributable to the samples being packaged with the two 1-liter sample bottles from MW-180C, a well that falls within the footprint of the benzene groundwater plume; this sample was submitted for sulfolane analysis only, and information was not available regarding the sample's benzene content.

The reported LOQs for the sulfolane analyses were below the 20 µg/L interim cleanup level in each of the WOs associated with the groundwater sampling event. Likewise, BTEX and 1,2,4-TMB LOQs were below their respective ADEC Table C groundwater cleanup levels. Geochemical parameters were not measured for regulatory purposes, but rather to assess the potential for natural attenuation. LOQs for geochemical parameters were not compared to regulatory limits, where such limits exist.

6.5.3 Accuracy

Laboratory analytical accuracy may be assessed by evaluating the analyte recoveries from CCV, LCS and LCSD analyses. LCS and LCSD samples assess the accuracy of analytical procedures by checking the laboratory's ability to recover analytes added to clean aqueous matrices. In some cases, the laboratory also spiked project samples as matrix spike (MS) and MS duplicate (MSD) samples to assess their ability to recovery analytes from a matrix similar to that of project samples.

Accuracy was also assessed for organic analyses by evaluating the recovery of analyte surrogates added to project samples. For this review, the target surrogate nitrobenzene-d6 was assessed when reviewing the USEPA Method 8270 for sulfolane, because it is the most chemically similar surrogate to sulfolane. Some of the samples collected during the reporting period were analyzed for sulfolane using USEPA Method 8270; others were analyzed using the isotope dilution method. The laboratory did not report CCV failures affecting sample data quality in the case narratives. The laboratory did note that the benzene result for sample S-41 was above the linear calibration range, and flagged the result "J" as estimated.

Surrogate recoveries were within laboratory control limits, with the exception of phenol-d6 for several project and laboratory QC samples (e.g., method blank, LCS) analyzed for sulfolane. Nitrobenzene is the surrogate that most closely corresponds to sulfolane; therefore, the phenol-d6 recovery failures did not affect sulfolane data quality or usability.

LCS and LCSD, and MS and MSD results for each of the WOs associated with the reporting period sampling event were reviewed to assess the analytical accuracy of the results. LCS and LCSD recoveries were within acceptable limits. MS and MSD recoveries were also generally within acceptable limits, with the exception of low recovery of sulfate in the MS (original sample MW-127), high recovery of TKN (original sample MW-164A) and low recovery of nitrite (original sample MW-127). Remaining MS recovery failures noted by the laboratory were for spiked samples that were not in the reporting period sample set. The sulfate result for MW-127 should be considered biased low and flagged "JL," and the nitrite result for MW-157 should be flagged "UJ" at the LOQ to indicate the nondetect result is possibly attributable to the low bias indicated by the MS recovery failure. TKN was not detected in MW-164A and the result is unaffected by the high MS recovery.

Laboratory CCV, LCS and LCSD, MS and MSD, and surrogate recovery information indicate the analytical results were accurate, with the exceptions noted above.

6.5.4 Precision

Eight field duplicate sample pairs were collected for analysis of sulfolane, four pairs for analysis of BTEX and 1,2,4-TMB, and three pairs for analysis of geochemical parameters. Results of RPD calculations for these duplicate samples were within the DQO of 30 percent, where calculable, with the following exceptions:

- RPDs exceeded the DQO for the following field duplicate pairs: MW-153A/MW-253A (for sulfolane), MW-142/MW-242 (for total phosphorus), MW-159/MW-259 (for total phosphorus) and MW-124/MW-224 (for benzene).

- The benzene results for MW-124/MW-224 are qualified as nondetect (flagged "UB") due to contamination of the trip blank. Remaining results corresponding to elevated field duplicate RPDs are considered estimated and were flagged "J."

Laboratory analytical precision can also be evaluated by laboratory QC sample RPD calculations using the LCS and LCSD, MS and MSD, or laboratory duplicate sample results. RPD calculation results for LCS and LCSD, MS and MSD, and laboratory duplicate sample pairs corresponding to the reporting period sample results were within the laboratory's acceptable range.

Based on the subsequent review, the monitoring water data associated with the reporting period sampling event are considered precise, with the exceptions noted above.

6.5.5 Data Quality Summary

Based on methods outlined in the revised SAP (SWI, ARCADIS, 2011), the samples collected are considered to be representative of site conditions at the locations and times they were obtained. Based upon the QA review, no samples were rejected as unusable due to QC failures. In general, the quality of the analytical data for this project does not appear to have been compromised by analytical irregularities, and results affected by QC anomalies are qualified with the appropriate data flags.

6.6 Third Quarter 2011 Water Sample Data Quality

This section summarizes the results of the QA review of monitoring-well sample data for the third-quarter sampling event. Samples were submitted to SGS for analysis of sulfolane; benzene, toluene, ethylbenzene, and xylenes (BTEX) and 1,2,4-trimethylbenzene; and/or geochemical parameters (nitrate/nitrite, alkalinity, hardness, TKN, TOC, and total phosphorus). Sulfolane was analyzed by the USEPA Modified Method 8270D with Isotope Dilution; this is the first groundwater event that used the modified method. In addition, samples from several monitoring wells were submitted to SGS or their subcontract laboratories for determination of the partial list of COPCs which included:

- volatile organic compounds – BTEX; 1,1-dichloroethene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; 4-isopropyltoluene (p-cymene); cyclohexane; methyl tert-butyl ether; methylene chloride; n-hexane; and n-propylbenzene;
- metals – antimony, barium, cadmium, total chromium, copper, iron, lead, and selenium;
- cyanide;
- sulfolane;
- isopropanol and propylene glycol; and
- gasoline-, diesel-, and residual-range organics.

The COPC list was finalized after the third quarter 2011 sampling event was completed. SWI also reviewed the initial water-sample sulfolane data collected from the new monitoring wells installed during the third quarter of 2011. The reader is referred to the ADEC data-review checklists for additional detail (Appendix L).

The SGS work orders reviewed for the third-quarter sampling event are listed below.

1118624
1118637
1118623
1118626
1118675
1118676
1118683
1118616
1118585
1118617
1118653
1118810
1118640
1118648
1118636
1118652
1118677
1118704
1118706
1118747
1118684
1118707
1118746
1118635

Details regarding the results of the QA review are presented below.

6.6.1 Sample Handling

Samples were hand-delivered to the SGS Fairbanks receiving office and then shipped overnight via Lynden Transport to the SGS Anchorage laboratory to perform the requested analyses, using the methods specified on the chain-of-custody (COC) records. SWI reviewed sample-receipt forms for each work order (WO) for both SGS locations and checked that samples were received in good condition and within the acceptable temperature indicated on the ADEC data review checklist (2 °C ± 4 °C). The ADEC data-review checklists contain details regarding this review. ADEC's chemist considers samples received at temperatures between 0 °C and 6 °C acceptable in the absence of ice, as specified in the Environmental Protection Agency (EPA) publication SW-846. Therefore, for the purposes of this report, temperatures between 0 °C and 6 °C are considered acceptable. Samples were received within the acceptable temperature range upon arrival at both SGS locations during the third quarter of 2011.

SWI also reviewed COC records for each work order to confirm information was complete, custody was not breached, and samples were analyzed within the acceptable holding times. COC records were complete and holding times were acceptable.

The standard holding time was met for all samples in these work orders except samples MW-162A (SGS WO # 1118637) and MW-110 (SGS WO #1118746); the samples were re-extracted outside of the hold time due to responses exceeding the calibration range. According to the SGS sulfolane-analysis standard operating procedure, Section 6.5,

> "If the response of sulfolane-d8 in the dilution is less than 10x noise, the sample is re-extracted using a smaller sample aliquot. Hold times are waived for samples re-extracted due to responses exceeding the calibration range."

The data quality was therefore unaffected for samples MW-162A and MW-110.

There were a few sample-receiving/labeling discrepancies:

- SGS work order 1118810 (sulfolane samples) – the project name and number were changed due to erroneous entry on the COC;
- SGS work order 1118640 (nitrate/nitrite samples) – sample MW-151A was added to the COC after receipt by SGS;
- SGS work order 1118677 (geochemistry samples) – revised report to reflect correct sample label MW-148B and MW-248B; the COC contained a misprint.
- SGS work order 1118677 (geochemistry samples) – TOC pH adjustments were made to samples MW-131 and MW-143 by SGS, as noted in the sample preservation line on sample-receipt form;
- SGS work order 1118707 (sulfolane samples) – sample MW-153B was not listed on the COC; however, the sample jars were clearly marked and sent to the laboratory. The laboratory contacted SWI and proceeded with the analysis of this sample. The sample was analyzed within hold time and therefore the results were unaffected by the omission.

There were no other sample-handling anomalies identified that would adversely affect data quality for this project.

6.6.2 Analytical Sensitivity

Laboratory method blanks were analyzed in association with samples collected for this project to check for contributions to the analytical results possibly attributable to laboratory-based contamination. Generally, no analytes were detected above the LOQ in the method blanks associated with project samples, with the following exceptions:

- SGS work order 1118623 - The method blank for nitrate was reported at an estimated concentration less than the LOQ at 0.0400 mg/L, so it was flagged with a “J” by the laboratory. Nitrate in samples MW-167A and MW-171B was detected above the DL and below the LOQ at 0.0520 mg/L and 0.0390 mg/L, respectively; these values are affected by the method blank, and will be flagged with a “B, U” and considered not detected at the LOQ. Sample MW-163A was detected above the LOQ but within 5 times the value of the method blank at a concentration of 0.197 mg/L and will be flagged with a “JH” to indicate a high bias due to the method blank detection.

- SGS work order 1118626 - The method blank for nitrate was reported at an estimated concentration less than the LOQ at 0.0400 mg/L, so it was flagged with a “J.” Nitrate was detected in sample MW-261A above the DL and below the LOQ at 0.0320 mg/L; this value is affected by the method blank and will be flagged with a “B, U” and considered not detected at the LOQ.

- SGS work order 1118648 - The method blank for nitrate was reported at an estimated concentration less than the LOQ at 0.0310 mg/L, so it was flagged with a “J.” Nitrate was detected above the DL and below the LOQ in samples MW-156B (0.0310 mg/L), MW-159 (0.0540 mg/L), and MW-158A (0.0490 mg/L); these values are affected by the method blank and will be flagged with a “B, U” and considered not detected at the LOQ.

- SGS work order 1118706 - The method blank for chromium yielded a result less than the LOQ, with an estimated concentration (J-flagged) of 1.34 µg/L. Sample MW-113 contained chromium at an estimated concentration below the LOQ of 1.29 µg/L (flagged “J”). Since the method blank for chromium also contained chromium at a similar concentration, the chromium result for sample MW-113 will be flagged "B, U" to denote that the chromium result in that sample is attributable to the method blank.

Trip blanks were submitted with groundwater samples for analysis of VOCs to check for contributions to the analytical results possibly attributable to cross-contamination during sample handling and transport. No VOC analytes were detected in the trip blanks. Equipment blanks were also collected to assess the possibility of contaminant carryover from sampling equipment; the equipment blanks did not contain detectable analytes.

The reported LOQs for most analytes were below the ADEC cleanup levels or interim action levels, with a few exceptions:

- The 1,1-dichloroethene reporting limits for samples MW-125, MW-225, and MW-139 (40 µg/L) were greater than the 1,1-dichloroethene groundwater-cleanup level (7 µg/L). One cannot determine whether 1,1-dichloroethene might be present in samples MW-125, MW-225, and MW-139 at concentrations greater than the groundwater-cleanup level and less than the reporting limit.

- The methylene chloride reporting limits for samples MW-125, MW-225, and MW-139 (200 µg/L) were greater than the methylene chloride groundwater-cleanup level (5 µg/L). One cannot determine whether methylene chloride might be present in samples MW-125, MW-225, and MW-139 at a concentration greater than its groundwater-cleanup level and less than the reporting limit.

- The methylene chloride reporting limit for sample MW-110 (25 µg/L) was greater than the methylene chloride groundwater-cleanup level (5 µg/L). SWI is unable to determine whether methylene chloride might be present in sample MW-110 at a concentration between its groundwater-cleanup level and the reporting limit.

Geochemical parameters are not being measured for regulatory purposes, but rather for purposes of assessing the potential for natural attenuation; SWI did not compare the LOQs for geochemical parameters to regulatory limits, where such limits exist.

6.6.3 Accuracy

The laboratory did not note in the case narratives any CCV failures that might affect project-sample data quality.

SWI reviewed the LCS/LCSD and MS/MSD results for each of the work orders associated with the third quarter sampling event to assess the analytical accuracy of the results. LCS and LCSD recoveries were within acceptable limits. The MS/MSD recoveries were also generally within acceptable limits, with the exception of a high MS sulfate recovery in work order 1118636 (sample MW-163A); the sulfate result for this sample (24.3 mg/L) is considered an estimate and will be flagged “JH” to indicate the result is biased high. The LCS recovery associated with the samples in this analytical batch was within quality control limits, indicating the results were generally accurate.

The nitrate– and nitrite–N MS was recovered below control limits in work order #1118616 (containing samples MW-164A and MW-165A), but the sample spiked was not one of the project samples; the LCS was recovered within laboratory control limits, so the sample results were unaffected and are considered accurate.

Organic surrogate recoveries were within laboratory control limits.

Laboratory CCV, LCS/LCSD, MS/MSD, and surrogate recovery information indicate the analytical results were accurate, with the exceptions noted above.

6.6.4 Precision

SWI collected 14 field-duplicate sample pairs for analysis of sulfolane from the monitoring wells sampled for the third quarter sampling event. Two field-duplicate samples were submitted for the COPC analyses, and three duplicate samples were collected for the geochemistry analyses. Results of RPD calculations for these duplicate samples were within the data-quality objective of 30 percent, where calculable, with the exception of the total phosphorus RPD for MW-161A and its duplicate MW-261A; the total phosphorus concentrations for these samples will be flagged with a “J” for imprecision, and will be considered estimates.

The results of RPD calculations for LCS/LCSD, MS/MSD, and laboratory-duplicate sample pairs corresponding to project-sample results were within the laboratory’s acceptable range.

Based on the review, the monitoring-well data collected during the third quarter of 2011 are considered precise, with the exceptions noted above.

6.6.5 Data Quality Summary

By working in general accordance with the proposed scope of services and sampling and analysis plan, where applicable, the samples collected during the third quarter of 2011 are considered to be representative of site conditions at the locations and times they were obtained. Based on the QA review, no samples were rejected as unusable due to QC failures. In general, the quality of the analytical data for this project does not appear to have been compromised by analytical irregularities, and results affected by QC anomalies are qualified with the appropriate data flags.

6.7 Fourth Quarter 2011 Water Sample Data Quality

QA/QC procedures assist in producing data of acceptable quality and reliability. SWI reviewed the analytical results for laboratory QC samples and conducted a QA assessment of the data as they were generated. The QA/QC review included documenting the accuracy and precision of the analytical data and verifying that the analyses were sufficiently sensitive to detect analytes at levels below suggested action levels or regulatory standards, where such standards exist. Laboratory reports for each of the samples collected during the fourth quarter 2011, including case narratives describing laboratory QA results, and completed ADEC data review checklists are included in Appendix L.

This section summarizes the results of the QA review of monitoring well, pore-water and residential water well sample data for the fourth quarter 2011. Monitoring well samples were submitted to SGS for analysis of sulfolane; BTEX; and/or geochemical parameters (nitrate/nitrite, alkalinity, hardness, TKN, TOC, sulfate and total phosphorus). In addition, samples from several monitoring wells were submitted to SGS or their subcontract laboratories to identify COPCs. The COPCs included:

- VOCs – BTEX; 1,1-dichloroethene; 1,2,4-TMB; 1,3,5-TMB; 4-isopropyltoluene (p-cymene); cyclohexane; methyl tert-butyl ether; methylene chloride; n-hexane; and n-propylbenzene;
- SVOCs – benzo(a)anthracene; benzo(a)pyrene; benzo(b)fluoranthene; benzo(k)fluoranthene; dibenzo(a,h)anthracene; dibenzofuran; indeno(1,2,3-c,d)pyrene; 1-methylnaphthalene; 2-methylnaphthalene; and naphthalene;
- metals – antimony, barium, cadmium, total chromium, copper, iron, lead and selenium;
- cyanide;
- sulfolane;
- GRO, DRO, and RRO.

Two reissued work orders from the third quarter sampling event were reviewed following reanalysis of sulfolane using modified chromatographic conditions. At the request of the ADEC's chemistry subgroup, SGS reanalyzed select samples. This section evaluates the reanalyzed sample results and associated laboratory QC samples; the original sample results were evaluated in the third quarter 2011 report.

SWI reviewed the initial water sample BTEX and/or sulfolane data collected during the fourth quarter 2011 from monitoring wells installed during the third and fourth quarters. SWI also reviewed pore-water and residential water well sulfolane samples collected during the fourth quarter 2011. The ADEC data review checklists provide additional details and are included in Appendix L.

The table below lists SGS work orders reviewed for the fourth quarter 2011 sampling event and revised third quarter 2011 work orders.

1118992	1119631	1119695	1119752	1119615	1118990
1119630	1119644	1119754	1118947	1119623	1119606
1119641	1119794	1119791	1118954	1119659	1119619
1119646	1119640	1118989	1118967	1119666	1119633
1119753	1119793	1119618	1118978	1119688	1119660
1119686	1119621	1119632	1118988	1119693	1119896
1119687	1119642	1119694	1118993	1118948	1118637 (Q3)
1118991	1119645	1119792	1119608	1118979	1118707 (Q3)

The table below lists SGS work orders reviewed for the new monitoring well samples.

1118971	1119662	1119707	1119783
1119601	1119668	1119748	1119806
1119661	1119690	1119755	1119808

SGS work order 1119898 was reviewed for the pore-water samples.

The table below lists SGS work orders reviewed for the residential water well samples.

1118945	1119657	1119724	1119750	1119772	1119812	1119842	1119871
1118962	1119663	1119725	1119751	1119773	1119813	1119843	1119872
1118963	1119664	1119726	1119758	1119774	1119814	1119844	1119873
1118964	1119665	1119736	1119759	1119775	1119815	1119845	1119874
1118965	1119677	1119737	1119760	1119776	1119816	1119846	1119875
1118977	1119678	1119738	1119761	1119777	1119817	1119847	1119880
1118984	1119679	1119739	1119762	1119778	1119818	1119848	1119884
1119625	1119698	1119740	1119763	1119779	1119819	1119850	1119897
1119626	1119699	1119741	1119764	1119798	1119824	1119851	1119901
1119627	1119715	1119742	1119765	1119799	1119830	1119852	
1119628	1119716	1119743	1119766	1119802	1119831	1119853	
1119637	1119717	1119744	1119767	1119804	1119832	1119858	
1119653	1119718	1119745	1119768	1119805	1119833	1119859	
1119654	1119719	1119746	1119769	1119809	1119839	1119862	
1119655	1119722	1119747	1119770	1119810	1119840	1119863	
1119656	1119723	1119749	1119771	1119811	1119841	1119864	

Results of the QA review are discussed below.

6.7.1 Sample Handling

Samples were hand delivered to the SGS Fairbanks receiving office and then shipped overnight via Lynden Transport or Alaska Airlines Goldstreak to the SGS Anchorage laboratory to perform the requested analyses, using the methods specified on the chain-of-custody (COC) records. SWI reviewed sample receipt forms for each work order for both SGS locations and verified that samples were received in good condition and within the acceptable temperature indicated on the ADEC data review checklist (2 degrees Celsius [°C] ± 4 °C). The ADEC data review checklists (Appendix L) contain details regarding this review. The ADEC's chemist considers samples received at temperatures between 0 °C and 6 °C acceptable in the absence of ice, as specified in the United States Environmental Protection Agency publication SW-846, Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. Therefore, for this review, temperatures between 0 and 6 °C are considered acceptable. Samples were received within the acceptable temperature range upon arrival at both SGS locations during the fourth quarter 2011, with the following exceptions:

- SGS work orders 1119830, 1119832 and 1119833 (residential sulfolane samples). The sample cooler associated with these work orders was hand delivered to the SGS Fairbanks receiving office where the temperature blank was measured at 1.9 °C, which is within the acceptable range between 0 and 6 °C. The samples were then shipped to the SGS Anchorage laboratory via Lynden Transport. Due to the extreme temperatures in the Alaskan interior at that time, the temperature blank was measured at -1.2 °C upon arrival, which is below the acceptable temperature range. Samples associated with the below-range temperature blank were inspected for the presence of ice within the samples. The samples associated with these work orders were found to be free of ice; therefore, it is SWI's opinion that the results were unaffected.

- SGS work order 1119831. The sample cooler associated with this work order was hand delivered to the SGS Fairbanks receiving office, where the temperature blank was measured at 1.9 °C, which is within the acceptable range of 0 and 6 °C. The sample cooler was then shipped to the SGS Anchorage laboratory via Lynden Transport. Due to the extreme temperatures in the Alaskan interior at that time, the temperature blank was measured at -1.2 °C upon arrival, which is below the acceptable temperature range. The sample associated with the below-range temperature blank was inspected for the presence of ice with the sample. One of two sample jars contained ice. The sample jar that was found to be free of ice was used for the analysis; therefore, it is SWI's opinion that the sample result is unaffected.

SWI also reviewed COC records for each work order to confirm that information was complete, custody was not breached and samples were analyzed within the acceptable holding times. COC records were complete and holding times were acceptable, with the following exceptions:

- The standard holding time was not met for sulfolane samples MW-139 and MW-239 (SGS work order 1119621) or for matrix spike (MS) and matrix spike duplicate (MSD) samples associated with work orders 1119645, 1119653, 1119654, 1119655, 1119656, 1119657, 1119660, 1119663, 1119664 and 1119665. These samples were re-extracted outside of the holding time due to responses exceeding the calibration range. According to the SGS sulfolane analysis standard operating procedure, Section 6.5, "If the response of sulfolane-d8 in the dilution is less than 10x noise, the sample is re-extracted using a smaller sample aliquot. Hold times are waived for samples re-extracted due to responses exceeding the calibration range."

  The data quality was therefore unaffected for samples MW-139 and MW-239, and for the MS and MSD samples associated with the work orders noted above.

- The standard holding time was not met for the third quarter 2011 sulfolane samples that were reanalyzed during the fourth quarter 2011 using modified chromatographic conditions (SGS work orders 1118637 and 1118707). Sulfolane results for the following third quarter samples are considered biased low and denoted with a "JL" in the tabulated data: MW-125, MW-225, MW-139, MW-239, MW-139MS, MW-139MSD, MW-162A, MW-178A and MW-278A.

- The standard holding time was met for all geochemistry samples in the fourth quarter 2011 work orders except sample MW-166A; the methane holding time was exceeded by 42 minutes. The methane result associated with MW-166A is considered biased low and is denoted with a "JL" in the tabulated data.

The standard holding time was met for all COPC and BTEX samples collected during the fourth quarter 2011.

Sample receiving/labeling discrepancies are noted below:

- SGS work order 1118947 (nitrite/nitrate samples). Sample MW-167A was absent from the COC; however, the sample jar was clearly marked and submitted to the laboratory. The sampler contacted the laboratory and directed them to proceed with analysis of the sample using the information presented on the sample jar. The sample was analyzed within the acceptable holding time; therefore, results were unaffected by the omission.

- SGS work order 1118993 (nitrate/nitrite samples) and SGS work order 1119642 (sulfolane samples). Samples MW-170A and MW-174B were listed on the associated COCs; however, the times presented were inaccurate. In both cases, the sampling team contacted the laboratory to correct the mistake. These discrepancies are noted in the associated laboratory case narratives (Appendix L). The samples were analyzed within the acceptable holding time; therefore, the results are unaffected.

- SGS work order 1119660 (sulfolane samples). The sample ID for MW-150B was entered incorrectly at login. The report was reissued with the correct sample ID.

- SGS work order 1118948 (sulfolane samples). The sample ID for MW-185A was listed as MW-158A on the COC; the sample ID was corrected following review of the sample sheets.

- SGS work order 1119640 (COPC samples). The laboratory mistakenly reported sample MW-141 as MW-114. The sample ID was corrected and the report was reissued.

- SGS work order 1119642 (sulfolane samples). Sample times for MW-113 and MW-213 were reversed on the bottles, compared to the COC. The laboratory contacted the sampling team, which directed them to reference the COC information. Samples were analyzed within the acceptable holding time; therefore, the results are unaffected.

- SGS work orders 1119640 and 1119644 (COPC samples). Samples MW-135 and MW-141 were requested for metals analysis; however, the jars were not provided to the laboratory. The sample jars were later submitted under SGS work order 1119793.

- SGS work order 1118707 (Q3 revised sulfolane samples). Sample MW-125 was unable to be reanalyzed using the modified chromatographic conditions due to a broken sample jar.

- SGS work order 1119851 (residential sulfolane sample). The laboratory notes that the time was not listed on the COC for the associated sample. The laboratory correctly referenced the time on the sample jars and analyzed the sample within the acceptable holding time; results are unaffected.

Sample ID changes for residential samples collected during the fourth quarter 2011 are addressed in the ADEC data review checklists provided in Appendix L. For the privacy of the homeowner, the names are not disclosed in this report. No other sample handling anomalies were identified that would adversely affect data quality for this project.

6.7.2 Analytical Sensitivity

Laboratory MBs were analyzed in association with samples collected for this project to check for contributions to the analytical results that may attributable to laboratory-based contamination. Generally, no analytes were detected in the MBs associated with project samples, with the following exceptions:

- SGS work order 1118947. The method blank for nitrate was reported at an estimated concentration of 0.0385 J milligrams per liter (mg/L), which is less than the limit of quantitation (LOQ), and was flagged with a "J" by the laboratory. Each project sample associated with the work order had detectable nitrate within 5 times the MB concentration; therefore, the results are considered not detected and are denoted with a "UB" in the tabulated data. Samples MW-164A, MW-167B, MW-168 and MW-182A were detected below the LOQ and are considered not detected at the LOQ (<0.100 UB mg/L); sample MW-167A was detected above the LOQ and will be considered not detected at the reported concentration (<0.116 UB mg/L).

- SGS work order 1118989. The MBs for TOC and sulfate were reported with estimated concentrations below the LOQ. No associated TOC or sulfate sample results were affected, because their concentrations were at least 5 times higher than the MB concentration. One MB for TKN was reported with an estimated concentration of 0.331 J mg/L, which is below the LOQ. Associated TKN samples MW-148A and MW-148B were reported within 5 times the MB concentration below the LOQ; therefore, the results are considered not detected and are flagged "UB" at the LOQ (<1.00 UB mg/L).

- SGS work orders 1119618, 1119632 and 1119752. The MBs for TKN were reported at an estimated concentration below the LOQ. The associated TKN results for samples MW-157, MW-158A, MW-159, MW-170A and MW-270A (work order 1119618); MW-151A and MW-151B (work order 1119632); and MW-180A (work order 1119752) were detected within a factor of five of the MB concentrations and are therefore affected. TKN results for MW-151A, MW-151B, MW-157 and MW-270A were detected below the LOQ; therefore, TKN is considered not detected at the LOQ and will be reported as <1.00 UB mg/L. TKN results for MW-158A, MW-

159, MW-170A and MW-180A were reported at or above the LOQ and will be considered not detected at the reported concentrations as <1.58 UB mg/L, <1.00 UB mg/L, <1.10 UB mg/L and <1.80 UB mg/L respectively. Results are flagged "UB" to indicate they were affected by the MB detection.

- SGS work order 1119694. The MB for TKN was reported at an estimated concentration of 0.913 J mg/L, which is below the LOQ. TOC was reported at an estimated concentration of 0.206 J mg/L. The TKN and TOC results for sample MW-180B were within a factor of five of the MB concentrations; these analytes will be considered not detected at the reported concentrations. These results will be flagged "UB" to indicate that they are considered not detected at the reported value due to a MB detection.

- SGS work order 1119792. The MBs for TKN were reported at estimated concentrations of 0.912 J mg/L and 0.419 J mg/L, which are below the LOQ. TOC was reported at an estimated concentration of 0.206 J mg/L. The TOC MB detection did not affect the TOC sample results because those results were either greater than 5 times higher than the MB, or were not detected. The TKN results for samples MW-105, MW-105A, MW-109, MW-116, MW-127, MW-131, MW-142, MW-143, MW-227 and MW-242 were within a factor of five of their associated MB concentration. Results detected below the LOQ (samples MW-105, MW-105A, MW-127, MW-131, MW-142, MW-143 and MW-227) will be considered not detected at the LOQ (<1.00 UB mg/L) and results detected at or above the LOQ (samples MW-109, MW-116 and MW-242) will be considered not detected at their reported concentrations. These results will be flagged "UB" to indicate that they are considered not detected due to a MB detection.

- SGS work order 1119794. Diesel-range organics (DROs) were detected in the MB at an estimated concentration of 0.212 J mg/L, which is below the LOQ. DRO was detected in the sample from MW-125 at an estimated concentration of 0.488 J mg/L, which is below the LOQ and within 5 times the MB concentration; therefore, the result is considered not detected at the LOQ and is denoted with a "UB."

- SGS work order 1119644. The MBs for 1-methylnaphthalene, toluene and residual-range organics (RROs) had estimated concentrations below the LOQ. Associated sample results for 1-methylnaphthalene and toluene were greater than 5 times the MB concentrations and are therefore unaffected. RRO was detected in the sample from MW-135 at an estimated concentration of

0.278 J mg/L, which is below the LOQ. The result is considered not detected at the LOQ (<0.515 UB mg/L) and is denoted with a “UB.”

- SGS work order 1119640. The MBs for 1-methylnaphthalene, toluene and RRO had detectable concentrations below the LOQ. Toluene and RRO were not detected in the associated samples and therefore the results are unaffected by the MB detection. Samples MW-139 and MW-239 had reported detections greater than 5 times the MB detection and 1-methylnaphthalene was not detected in sample MW-141; therefore, these samples are unaffected by the MB detection. Sample MW-113 had a 1-methylnaphthalene estimated concentration of 0.0231 J µg/L; this concentration is less than the MB detection and therefore is considered not detected at the LOQ and is denoted with a "UB."

- SGS work order 1118991. Naphthalene was detected in the MB at a concentration of 0.121 µg/L, which is above the LOQ. 1-methylnaphthalene and 2-methylnaphthalene were detected below the LOQ at estimated concentrations of 0.0475 J µg/L and 0.0490 J µg/L, respectively. Each analyte for the associated sample was detected above the LOQ within 5 times the MB concentrations for sample MW-148A; therefore, the results for these analytes are considered not detected at the reported concentrations and are denoted with a “UB.”

Trip blanks were submitted with groundwater samples for analysis of VOCs and GRO to check for contributions to the analytical results that may be attributable to cross-contamination during sample handling and transport. VOC analytes and GRO were not detected in the trip blanks. Equipment blanks were also collected to assess the possibility of contaminant carryover from sampling equipment; the equipment blanks did not contain detectable analytes.

The reported LODs for the regulated analytes were below ADEC cleanup levels or interim action levels. Geochemical parameters were not measured for regulatory purposes, but rather to assess the potential for natural attenuation; LODs for geochemical parameters were not compared to regulatory limits, where such limits exist.

Due to the sensitivity of the instrument and reporting of estimated (J-flagged) values below the LOQ, DRO concentrations were reported in samples MW-148A (0.313 J mg/L) and MW-149A (0.247 J mg/L) in SGS work orders 1118991 and 1119631, respectively. The case narratives (Appendix L) associated with these samples note “no petroleum distillate pattern [was] observed.” Results are based on other organic matter that eluted in the DRO range; therefore, the results will be flagged as “NPS” (no petroleum signature).

6.7.3 Accuracy

Laboratory analytical accuracy may be assessed by evaluating the analyte recoveries from CCV, (LCS and LCSD analyses. LCS/LCSD samples assess the accuracy of analytical procedures by checking the laboratory's ability to recover analytes added to clean aqueous matrices. In some cases, the laboratory also spiked samples as MS and MSD samples to assess their ability to recover analytes from a matrix similar to that of the project samples. Accuracy was also assessed for organic analytes by evaluating the recovery of analyte surrogates added to samples.

The laboratory did not note any CCV failures affecting sample data quality in the case narratives (Appendix L).

SWI reviewed the LCS/LCSD and MS/MSD results for each of the work orders associated with the fourth quarter 2011 sampling event, the initial monitoring well and pore-water samples collected during the fourth quarter 2011, and residential water well samples collected during the fourth quarter 2011 to assess the analytical accuracy of the results.

LCS and LCSD recoveries were within acceptable limits, except for SGS work orders 1118967, 1118978, 1119615 and 1119623. The LCS recoveries of nitrite were above limits for these work orders; associated samples were nondetect for nitrite and are therefore unaffected by the above-range LCS recoveries.

The MS/MSD recoveries were within acceptable limits, with the following exceptions:

- SGS work orders 1118990 and 1119791. MS or MSD recoveries of spiked samples MW-160A (work order 1118990) and MW-142 (work order 1119791) were outside laboratory limits for sulfolane. Native concentrations of sulfolane in the samples were greater than 10 times the spiked concentrations. In accordance with EM 200-1-10, Guidance for Evaluating Performance-Based Chemical Data (U.S. Army Corps of Engineers 2005), a matrix effect is inferred for an MS/MSD recovery failure only when the spiked amount is high relative to the native concentration of the analyte (specifically, at least twice the native concentration). LCS recoveries were within limits; therefore, results are unaffected by the MS failures.

- SGS work orders 1118947 and 1119794. The MS recoveries of total nitrate/nitrite (work order 1118947) and cyanide (work order 1119794) were outside laboratory limits. The spiked samples are not associated with the project; therefore, results are unaffected.

- SGS work order 1118967. The MS recovery of nitrite was above laboratory limits. The associated results were nondetect and are therefore unaffected by the above-range recovery.

- SGS work order 1119693. The case narrative (Appendix L) notes that the nitrate/nitrite MS sample was not spiked and therefore the recovery was low. The associated project sample was reanalyzed outside of the acceptable holding time and the result was confirmed. Results for samples associated with this work order that were analyzed within acceptable holding times are presented in the laboratory Report (Appendix L). The MB, duplicate and LCS results associated with this work order were within limits and therefore the results are unaffected by the MS failure.

There were no other MS/MSD failures that might affect the sample results.

Organic surrogate recoveries were within laboratory control limits, with the following exceptions:

- SGS work order 1119640. The GRO surrogate associated with samples MW-139 and MW-239 was above limits due to matrix interference. GRO results for MW-139 and MW-239 are considered biased high and are denoted with a "JH" in the tabulated data.

- SGS work order 1119808. The sulfolane-d8 surrogate associated with sample MW-303-CMT-19 was recovered below the acceptable limits. The sulfolane-d8 surrogate is used to correct the original datum by dividing the original result by the sulfolane-d8 percent recovery; therefore, a low surrogate recovery would bias the results high. The sulfolane result for the sample is considered biased high and will be flagged with a "JH."

- SGS work orders 1119690 and 1119791. The case narratives (Appendix L) associated with sample MW-116 (work order 1119791) and O-12 (work order 1119690) note that sulfolane-d8 ion ratios do not meet criteria. Therefore, the sulfolane results associated with these samples are considered estimates and are flagged with a "J."

Laboratory CCV, LCS/LCSD, MS/MSD and surrogate recovery information indicate the analytical results were accurate, with the exceptions noted above.

6.7.4 Precision

SWI collected duplicate samples at a frequency of approximately 10 percent of the overall project samples collected to evaluate the precision of analytical measurements, as well as the reproducibility of sampling techniques. To evaluate the precision of the data, SWI calculated the relative percent difference (RPD; difference between the sample and its field duplicate divided by the mean of the two); an RPD can be evaluated only if there are detectable results for both duplicates.

SWI collected 30 field duplicate sample pairs for analysis of sulfolane from the monitoring wells (initial and quarterly events), pore-water wells and residential wells sampled during the fourth quarter 2011 sampling event. One field duplicate sample was submitted for COPC analyses, four duplicate samples were collected for geochemistry analyses and four duplicate samples were collected for BTEX analyses from the monitoring wells. Results of RPD calculations for these duplicate samples were within the data quality objective of 30 percent, where calculable, with the exception of the total phosphorus RPD for MW-170A and its duplicate, MW-270A. Detectable amounts of total phosphorus were only reported for sample MW-170A, which will be flagged with a "J" for imprecision and considered an estimate.

Laboratory analytical precision can also be evaluated by laboratory QC sample RPD calculations using the LCS/LCSD, MS/MSD or laboratory duplicate sample results. The results of RPD calculations for LCS/LCSD, MS/MSD and laboratory duplicate sample pairs corresponding to project sample results were within the laboratory's acceptable range, with one exception. The TKN sample duplicate RPD associated with SGS work order 1118989 was outside control limits for sample MW-152B. The sample's TKN datum is nondetect and therefore unaffected.

Based on the review, the water-sample data collected during the fourth quarter 2011 are considered precise, with the exceptions noted above.

6.7.5 Data Quality Summary

By working in general accordance with the proposed scope of services and sampling and analysis plan, where applicable, the samples collected during the fourth quarter 2011 are considered to be representative of site conditions at the locations and times they were obtained. Based on the QA review, no samples were rejected as unusable due to QC failures. In general, the quality of the analytical data for this project does not appear to have been compromised by analytical irregularities, and results affected by QC anomalies are qualified with the appropriate data flags.

6.8 2011 Well Installations & Water Sample Data Quality

This section summarizes the results of the QA review of data for the initial water samples collected from the groundwater monitoring wells installed under Phases 3, 4 and 5 of the sulfolane-delineation effort, as well as the initial water samples collected from the newly installed LNAPL-delineation wells. Samples from each of the wells were submitted to SGS for analysis of sulfolane; samples from the LNAPL wells were also analyzed for benzene, toluene, ethylbenzene, and xylenes (BTEX). The reader is referred to the ADEC data-review checklists for additional detail (Appendix L).

The SGS work orders reviewed for the initial monitoring-well sampling events are listed below:

1119961 1118811 1119748
1119690 1119601 1119783
1119755 1118971 1119806
1118736 1119668 1119808
1118799 1119962
1118806 1119707

Details regarding the results of the QA review are presented below.

6.8.1 Sample Handling

Samples were hand-delivered to the SGS Fairbanks receiving office and then shipped overnight via Lynden Transport to the SGS Anchorage laboratory to perform the requested analyses, using the methods specified on the COC records. SWI reviewed sample-receipt forms for each WO for both SGS locations and checked that samples were received in good condition and within the acceptable temperature indicated on the ADEC data review checklist (2 °C ± 4 °C). The ADEC data-review checklists contain details regarding this review. ADEC's chemist considers samples received at temperatures between 0 °C and 6 °C acceptable in the absence of ice, as specified in the Environmental Protection Agency (EPA) publication SW-846. Therefore, for the purposes of this report, temperatures between 0 °C and 6 °C are considered acceptable. Samples were received within the acceptable temperature range upon arrival at both SGS locations.

SWI reviewed COC records for each work order to confirm information was complete, custody was not breached, and samples were analyzed within the acceptable holding times. COC records were complete and holding times were acceptable. There were no sample-handling anomalies identified that would adversely affect data quality for this project.

SWI also reviewed the case narratives for each work order to note issues identified by the analytical laboratory:

- The case narrative for work order 1119690 notes the sulfolane-d8 ion ratios for sample O-12 do not meet criteria. The sulfolane results for sample O-12 are considered to be an estimate, denoted with a "J" in the tabulated data.

- The case narrative for work order 1119806 notes sulfolane-d8 failures for the matrix spike samples. The sulfolane recoveries for the matrix spike samples were within QC limits and therefore the sample analytical results are unaffected.

- The case narrative for work order 1119808 notes a sulfolane-d8 failure for a matrix spike sample. The sulfolane recovery for the matrix spike sample was within QC limits and therefore the results are unaffected. The case narrative also notes the surrogate failure of sulfolane-d8 and nitrobenzene-d5 for sample EB-304-80; however, these surrogates were reported within the acceptable range and therefore the results are unaffected. An additional surrogate failure was reported on the case narrative, this is discussed in the accuracy (surrogates) section, below.

6.8.2 Analytical Sensitivity

Laboratory method blanks were analyzed in association with samples collected for this project to check for contributions to the analytical results possibly attributable to laboratory-based contamination. No analytes were detected above the Limits of Detection (LODs) in the method blanks associated with project samples

Trip blanks were submitted with groundwater samples from the LNAPL wells for analysis of BTEX to check for contributions to the analytical results possibly attributable to cross-contamination during sample handling and transport. No BTEX analytes were detected in the trip blanks. Equipment blanks were also collected to assess the possibility of contaminant carryover from sampling equipment; the equipment blanks did not contain detectable analytes.

The reported LODs for BTEX and sulfolane were below the ADEC cleanup levels or interim action levels.

6.8.3 Accuracy

The laboratory did not note in the case narratives any CCV failures that might affect project-sample data quality.

SWI reviewed the LCS/LCSD and MS/MSD results for the initial well samples to assess the analytical accuracy of the results. LCS and LCSD recoveries were within acceptable limits. The MS/MSD recoveries were also within acceptable limits.

Organic surrogate recoveries were within laboratory control limits. However, while not actually a surrogate analyte, the sulfolane-d8 recovery was below the acceptable limits for project sample MW-303-CMT-19. The isotopic dilution method for sulfolane quantitation corrects the sulfolane analytical result using the recovery data for the deuterated "surrogate" sulfolane. The result for this sample is considered biased high, denoted with a "JH" in the tabulated data, due to the low sulfolane-d8 recovery. Therefore the sulfolane result for sample MW-303-CMT-19 is 123 JH µg/L.

Laboratory CCV, LCS/LCSD, MS/MSD, and surrogate recovery information indicate the analytical results were accurate, with the exception noted above.

6.8.4 Precision

SWI collected 10 field-duplicate sample pairs for analysis of sulfolane from initial samples collected from the monitoring wells and LNAPL-delineation wells. BTEX duplicates were collected in association with other water sampling efforts during the third and fourth quarters. Results of RPD calculations for these duplicate samples were within the data-quality objective of 30 percent.

The results of RPD calculations for LCS/LCSD, MS/MSD, and laboratory-duplicate sample pairs corresponding to project-sample results were within the laboratory's acceptable range.

Based on the review, the monitoring-well and LNAPL-well water data are considered precise.

6.8.5 Data Quality Summary

By working in general accordance with the SCWP, the SCWP Addendum, and the SAP, the samples collected are considered to be representative of site conditions at the locations and times they were obtained. Based on the QA review, no samples were rejected as unusable due to QC failures. In general, the quality of the analytical data for this project does not appear to have been compromised by analytical irregularities, and results affected by QC anomalies are qualified with the appropriate data flags.

6.9 2011 Soil Sample Data Quality

The soil samples collected during the 2011 field season included soil obtained from monitoring wells installed under Phase 3 sulfolane-delineation activities (MW-192A and MW-192B), wells installed during Phases 5 and 6 (MW-197B and MW-307), wells installed to delineate LNAPL (MW-144B, MW-195, MW-196, O-5, O-6, O-7, O-8, O-9, O-10, O-11, O-12, O-13, O-14, O-15, O-16, O-17, O-18, O-19, O-20, O-21, O-22, O-23, O-25, O-26, O-27, O-28, and O-29), and from borings installed to characterize soil at the NPR (83 soil borings). The SGS work orders reviewed for this section include the following:

Phase 3 wells: work order 1118764. The Phase 3 well soil samples were analyzed for COPCs, including PAHs by USEPA Method 8270 SIM; select metals by USEPA Method 6020; sulfolane by USEPA Method 8270D M with isotopic dilution; cyanide by USEPA Method 9013/9014; DRO and RRO by Alaska Methods AK102/103; GRO by Alaska Method AK101; VOCs by USEPA Method 8260B; and SVOCs by USEPA Method 8270D.

Phases 5 and 6 wells: work orders 1119649 and 1119867. The Phase 5 and 6 wells' soil samples were analyzed for sulfolane, GRO, and DRO by the methods noted above, and for BTEX by USEPA Method 8021B.

LNAPL-delineation wells:

1118844
1118849
1118850
1118855
1118863
1118885
1118891
1118892
1118942
1118982
1118994
1119610
1119620
1119636
1119650
1119807
1119822
1119866

The LNAPL-delineation wells' samples were analyzed for BTEX, PAHs and sulfolane, using the methods noted above.

Soil borings:

1118846
1118856
1118861
1118862
1118875
1118877
1118878
1118896
1118899
1118900
1118904
1118905
1118917
1118923
1118924
1118929
1118934
1118955
1118956
1118959
1118960
1118970
1118980
1118981
1118995
1118996
1118997
1118998
1119603
1119604

The soil-boring samples were analyzed either for the "standard" analyte list (BTEX, PAHs and sulfolane, analyzed as noted above), or for the COPCs noted above for the Phase 3 wells.

Data-validation flags associated with this review are provided in Table 73, and the data-review checklists for the soil samples are provided in Appendix L.

6.9.1 Sample Handling

Soil samples were generally collected and handled in accordance with the SCWP addendum SAP, as appropriate for each soil-sampling project. They were kept at the proper temperatures prior to analysis, with a few exceptions. The following soil samples were received at the laboratory above the acceptable upper temperature limit (+6 °C): *O-15 (0-2)*, *O-15 (14-16)*, and *O-15 (8-10)*. The affected analyses associated with these samples were PAHs by USEPA Method 8270D SIMS, BTEX by USEPA Method 8021B, and sulfolane by USEPA Method 8270D M with isotopic dilution. No analytes were detected by these analyses in these three samples, and the results are considered biased low; they are flagged "UJ" at the LOD to indicate the analyte may not have been detected due to high temperatures. These validation flags are shown in Table 73.

Two samples (*SB-120[12.0-13.1]* for VOC analysis in work order #1118923, and duplicate sample *SD-168[3.5-5.1]* for BTEX analysis in work order #1118955) exceeded the acceptable holding time due to delayed extraction/processing, and the associated results are considered biased low. Analytes not detected in these two samples are flagged "UJ" at the LOD to indicate the analytes may not have been detected due to the extended holding time prior to extraction. Analytes that were detected are flagged "JL" at the reported concentration to indicate a low analytical bias. These validation flags are shown in Table 73.

Other holding-time exceedances occurred for several samples being analyzed for PAHs, including *SB-166(0.0-2.0)* in SGS work order 1118995; samples *DO-19 (0-2)* and *DO-21 (6-8)* in work order 1119650; samples *MW-196 (0-2), MW-196 (14-16)*, and *MW-196 (6-8)* in work order 1119610*; O-16 (0-2), O-16 (14-16)*, and *O-16 (6-8)* in work order 1118994; *O-17 (0-2), O-17 (14-16)*, and *O-17 (6-8)* in work order 1119636; and *O-19 (0-2), O-19 (14-16), O-19 (4-6), O-19 (6-8), O-21 (0-2)*, and *O-21 (6-8)* in work order 1119650. One SVOC sample (*SB-176[0.0-2.0]* in work order 1119603), and three sulfolane samples (*SB-153A[0.0-2.0]* in work order 1118929, and *MW-192A* and *MW-192B* in work order 1118764) also suffered holding-time exceedances. Analytes not detected in these samples are flagged "UJ" at the LOD to indicate the analytes may not have been detected due to the extended holding times; analytes that were detected are flagged "JL" at the reported concentration to indicate a possibly low analytical bias.

The only other sample-handling anomaly that may have affected soil-data quality occurred when the methanol field-extractant was found to have leaked from sample jars in transit. This affected six soil samples being analyzed for volatile compounds, including sample *SB-105 (5.0-6.2)* for analysis of GRO and VOCs in work order 1118856, samples *SB-119 (5.0-6.4)* and *SB-124 (5.0-6.3)* for BTEX analysis in work order 1118856, sample *O-14 (0.0-2.0)* for BTEX analysis in work order 1118942, and sample *O-9 (0-2)* for BTEX analysis in work order 1118855. Each of the volatile analytes determined in these samples is considered to be biased low. Analytes not detected in these samples are flagged "UJ" at the LOD to indicate the analytes may not have been detected due to the extended holding times, and analytes that were detected are flagged “JL” at the reported concentration to indicate a possibly low analytical bias.

Review of laboratory sample-receipt documents did not reveal other sample-handling problems that would affect the quality or usability of the data, and chains of custody were not breached. The validation flags associated with this evaluation are shown in Table 73.

6.9.2 Sensitivity

The analytical sample results were compared to the ADEC soil migration-to-groundwater cleanup levels or the ADEC sulfolane interim action level to determine whether the analyses were sufficiently sensitive to detect the analytes of interest at the required levels. Each of the soil samples collected from the LNAPL-delineation wells and the Phase 5 and 6 wells had limits of detection that were below the required cleanup or interim action level.

The samples collected from the borings for wells MW-192A and MW-192B were analyzed for COPC analytes, including VOCs and SVOCs. There were several VOC and SVOC analytes that were not detected, but whose LODs were greater than the associated soil-cleanup level. These analytes are tabulated here:

2,4-Dinitrophenol	Hexachlorobutadiene
2,4-Dinitrotoluene	Methylene chloride
2,6-Dinitrotoluene	Nitrobenzene
4-Chloroaniline	N-Nitrosodimethylamine
Bis(2-Chloroethyl)ether	N-Nitroso-di-n-propylamine
Hexachlorobenzene	Pentachlorophenol

It is not possible to determine whether these analytes might have been present in the samples at concentrations greater than the soil-cleanup level but less than the LOD.

Similarly, for the samples collected from the soil borings, 40 VOC and SVOC analytes had LODs greater than their respective soil-cleanup levels. The analytes are tabulated here:

1,1,2,2-Tetrachloroethane	3&4-Methylphenol (p&m-Cresol)	Hexachlorocyclopentadiene
1,1,2-Trichloroethane	3,3-Dichlorobenzidine	Hexachloroethane
1,1-Dichloroethene	4-Chloroaniline	Isophorone
1,2,3-Trichloropropane	Bis(2-Chloroethyl)ether	Methylene chloride
1,2-Dibromoethane	Bromodichloromethane	Methyl-t-butyl ether
1,2-Dichlorobenzene	Bromomethane	Nitrobenzene
1,2-Dichloroethane	Carbon tetrachloride	N-Nitrosodimethylamine
1,2-Dichloropropane	Chlorobenzene	N-Nitroso-di-n-propylamine
2,4,6-Trichlorophenol	cis-1,2-Dichloroethene	Pentachlorophenol

2,4-Dichlorophenol	cis-1,3-Dichloropropene	Tetrachloroethene
2,4-Dinitrophenol	Dibromochloromethane	trans-1,3-Dichloropropene
2,4-Dinitrotoluene	Hexachlorobenzene	Trichloroethene
2,6-Dinitrotoluene	Hexachlorobutadiene	Vinyl chloride
2-Chlorophenol		

There were 60 soil-boring samples potentially affected by the LODs greater than soil-cleanup levels listed above; they are tabulated here:

SB-101 (0-2)	SB-123 (11.5-13.0)	SB-162(0.0-2.0)
SB-101 (4-5)	SB-123 (3.5-5.2)	SB-162(5.5-7.1)
SB-102 (0-2)	SB-125 (0.0-2.0)	SB-164 0.0-2.0
SB-102 (5-6)	SB-125 (5.0-6.5)	SB-164 3.0-4.5
SB-103 (0-2.0)	SB-129 (0.0-2.0)	SB-167 (0.0-2.0)
SB-103 (5-6.7)	SB-129 (10.5-12.2)	SB-167 (5.0-6.2)
SB-104 (0-2.0)	SB-129 (5.5-7.5)	SB-172 (0.0-2.0)
SB-104 (5.0-6.7)	SB-129 (7.5-8.7)	SB-172 (5.0-6.5)
SB-105 (0.0-2.0)	SB-132 (0.0-2.0)	SB-175 (0.0-2.0)
SB-105 (5.0-6.2)	SB-132 (8.5-10.5)	SB-175 (10.5-12.5)
SB-108(0.0-2.0)	SB-138(0.0-2.0)	SB-175 (5.0-7.0)
SB-108(6.5-7.5)	SB-138(3.0-5.2)	SB-176(0.0-2.0)
SB-118 0.0-2.0	SB-140 (0.0-2.0)	SB-176(6.0-7.1)
SB-118 2.0-3.7	SB-140 (3.0-5.0)	SB-181 0.0-2.0
SB-120(0.0-2.0)	SB-151 (0.0-2.0)	SB-181 2.5-4.1
SB-120(12.0-13.1)	SB-151 (16.0-17.8)	SB-183(0.0-2.0)
SB-120(7.2-9.2)	SB-157 0.0-2.0	SB-183(5.0-6.1)
SB-121 (0.0-2.0)	SB-157 6.0-8.0	SD-120(7.2-9.2)
SB-121 (4.0-6.1)	SB-160(0.0-2.0)	SD-123 (3.5-5.2)
SB-123 (0.0-2.0)	SB-160(12-13.5)	SD-132 (8.5-10.5)

A detailed listing of the analytes with elevated LODs associated with these samples, and those from the borings for wells MW-192 and MW-192B, is provided in Table 74. It is not possible to determine whether those analytes with elevated LODs might have been present in the samples above at concentrations greater than the soil-cleanup level but less than the LOD.

Analytical method blanks (MBs) and instrument blanks were analyzed in association with field samples to check that no laboratory-based contamination might be affecting the sample results. Some MBs were found to contain analytes of interest to this project, and 55 samples were potentially affected. The samples and analytical methods where MB detections occurred are tabulated below:

SGS Work Order	Sample ID	Analytical Method	SGS Work Order	Sample ID	Analytical Method
1118875	SD-130(11.5-12.5)	SW8021B	1118960	SB-148 6.8-7.4	SW8021B
1118877	SB-139(0.0-2.0)	SW8021B	1118996	SB-175 (0.0-2.0)	SW8260B

SGS Work Order	Sample ID	Analytical Method
1118878	SB-132 (0.0-2.0)	SW8260B
1118900	SB-157 0.0-2.0	AK103
1118900	SB-157 6.0-8.0	AK103
1118900	SB-181 2.5-4.1	AK103
1118923	SB-120(0.0-2.0)	AK101
1118923	SB-120(12.0-13.1)	AK101
1118924	SB-126(0.0-2.0)	SW8021B
1118924	SB-127(5.0-7.0)	SW8021B
1118929	SB-117(11.0-12.0)	8270D SIMS (PAH)
1118929	SB-155(0.0-2.0)	8270D SIMS (PAH)
1118929	SB-155(12.0-13.0)	8270D SIMS (PAH)
1118934	SB-123 (0.0-2.0)	AK101
1118934	SB-123 (0.0-2.0)	SW8260B
1118934	SB-123 (11.5-13.0)	AK101
1118934	SB-123 (11.5-13.0)	SW8260B
1118934	SB-123 (3.5-5.2)	AK101
1118934	SB-123 (3.5-5.2)	SW8260B
1118934	SD-123 (3.5-5.2)	AK101
1118934	SD-123 (3.5-5.2)	SW8260B
1118955	SB-163(0.0-2.0)	SW8021B
1118955	SB-163(5.0-6.8)	SW8021B
1118955	SB-170(0.0-2.0)	SW8021B
1118956	SB-167 (0.0-2.0)	SW8260B
1118960	SB-112 10.-12.0	SW8021B
1118960	SB-134 0.0-2.0	SW8021B
1118960	SB-148 0-0-2.0	SW8021B
1118996	SB-175 (10.5-12.5)	SW8260B
1118996	SB-175 (5.0-7.0)	SW8260B
1118997	SB-150(0.0-2.0)	8270D SIMS (PAH)
1118997	SB-150(10.5-12.0)	8270D SIMS (PAH)
1118998	SB-136(0.0-2.0)	8270D SIMS (PAH)
1118998	SB-136(4.0-6.0)	8270D SIMS (PAH)
1118998	SB-145(0.0-2.0)	8270D SIMS (PAH)
1118998	SB-145(3.5-5.6)	8270D SIMS (PAH)
1118998	SB-146(0.0-2.0)	8270D SIMS (PAH)
1118764	MW-192A	AK103
1119650	DO-19 (0-2)	SW8021B
1119650	DO-21 (0-2)	SW8021B
1119610	MW-195 (14-16)	SW8021B
1119610	MW-196 (0-2)	SW8021B
1119610	MW-196 (6-8)	SW8021B
1119650	O-19 (0-2)	SW8021B
1119650	O-19 (14-16)	SW8021B
1119650	O-19 (4-6)	SW8021B
1119650	O-21 (0-2)	SW8021B
1119650	O-21 (14-16)	SW8021B
1119807	O-26 (6.1-6.8)	SW8021B
1119807	O-25 (9.7-10.3)	SW8021B
1119807	O-27 (10.3-11)	SW8021B
1119807	O-25 (8-9)	SW8021B
1119867	MW-307 (8.0-8.5)	SW8021B

If an analyte was not detected above the LOQ, and was affected by an MB detection, the result is flagged “UB” at the LOQ to indicate the analyte was not detected but may have been affected by the blank. If the analyte was detected above the LOQ at a concentration less than a factor of five times the MB, the result is also flagged “UB,” but at the analyte’s reported concentration above the LOQ. A complete list of the affected analytes and flags is provided in Table 73.

In addition to method blanks, there were some instrument-blank detections for the RRO analysis that may have affected analytical results. In work order 1118846, samples *SB-103 (5-6.7)* and *SB-104*

(5.0-6.7) were each reported to contain RRO at estimated concentrations below the LOQ. The RRO results for those samples were flagged “UB” as not detected at the LOQ.

Trip blanks were kept with the volatile-analyte samples (i.e., GRO, BTEX, and VOCs) during sampling and their shipment to the laboratory to determine if cross-contamination or contamination from an outside source may have occurred during shipment or storage. There were trip-blank detections for BTEX and VOC analytes in eight work orders, affecting 27 samples. The affected samples and their associated SGS work orders are tabulated below:

SGS Work Order	Sample ID	Analytical Method
1118923	SB-120(12.0-13.1)	SW8260B
1118955	SB-114(16-18.0)	SW8021B
1118955	SB-163(0.0-2.0)	SW8021B
1118955	SB-163(5.0-6.8)	SW8021B
1118955	SB-168(0.0-2.0)	SW8021B
1118955	SB-168(11.0-12.0)	SW8021B
1118955	SB-168(3.5-5.1)	SW8021B
1118955	SB-170(0.0-2.0)	SW8021B
1118955	SB-170(6.0-7.6)	SW8021B
1118955	SB-174(12.0-13.3)	SW8021B
1118955	SD-168(3.5-5.1)	SW8021B
1118956	SB-167 (0.0-2.0)	SW8260B
1118956	SB-167 (5.0-6.2)	SW8260B

SGS Work Order	Sample ID	Analytical Method
1118960	SB-112 10.-12.0	SW8021B
1118960	SB-148 0-0-2.0	SW8021B
1118997	SB-150(0.0-2.0)	SW8021B
1118997	SB-150(10.5-12.0)	SW8021B
1118998	SB-136(0.0-2.0)	SW8021B
1118998	SB-136(4.0-6.0)	SW8021B
1118998	SB-145(0.0-2.0)	SW8021B
1118998	SB-145(3.5-5.6)	SW8021B
1119603	SB-162(0.0-2.0)	SW8260B
1119603	SB-176(6.0-7.1)	SW8260B
1119603	SB-183(5.0-6.1)	SW8260B
1119604	SB-161(0.0-2.0)	SW8021B
1119604	SB-161(6.0-7.4)	SW8021B
1119604	SD-161(0.0-2.0)	SW8021B

As with the method and instrument blanks, if an analyte was not detected above the LOQ, and may have been affected by a trip blank detection, the result is flagged “UB” at the LOQ to indicate the analyte was not detected but may have been affected by the blank. If the analyte was detected above the LOQ within a factor of five times the trip blank concentration, the result is also flagged “UB,” but at the analyte’s reported concentration above the LOQ. A complete list of the potentially affected analytes and flags is provided in Table 73.

Other than the detection-limit issues for the VOC and SVOC analytes noted above, and the samples potentially affected by method-, instrument-, and trip-blank detections, the soil analyses appear to have been sufficiently sensitive for the purposes of the project.

6.9.3 Accuracy

The laboratory assessed the accuracy of their analytical methods through a variety of quality assurance procedures. Analytical accuracy for soil samples was assessed through analysis of laboratory control samples (LCSs) and LCS duplicates (LCSDs), which evaluate their ability to recover analytes added to a clean solid matrix. It was also assessed through analysis of matrix spikes (MSs) and MS duplicates (MSDs), which evaluate analyte recovery from matrices from the field. In addition, SGS also evaluated laboratory accuracy for each sample subjected to organic analysis by assessing the recovery of analyte surrogates added to individual project samples. Continuing calibration verification (CCV), a standard practice to verify the calibration of the instrument, also allowed the laboratory to check for analytical accuracy.

There were several samples with LCS and/or LCSD recoveries above the laboratory control limits. If the analyte was not detected in the field sample, the result was unaffected by the high LCS or LCSD recovery. If the analyte was detected, either at an estimated concentration below the LOQ or at a concentration above the LOQ, the result was flagged "JH" at the reported concentration to indicate a high analytical bias. The affected samples and work orders are tabulated below, and a complete list of the affected analytes with their associated data-validation flags is provided in Table 73.

SGS Work Order	Sample ID	Analytical Method
1118899	SB-113 11.0-12.3	Sulfolane-SW8270D M w/IsoDl Sl
1118905	SB-115 15.0-17.0	Sulfolane-SW8270D M w/IsoDl Sl
1118905	SB-115 6.0-7.3	Sulfolane-SW8270D M w/IsoDl Sl
1118934	SB-123 (6.0-8.0)	SW8260B
1118934	SB-123 (6.0-8.0)	SW8260B
1118959	SB-164 3.0-4.5	SW9013/SW9014-Cyanide
1118980	SB-138(3.0-5.2)	SW9013/SW9014-Cyanide
1118998	SB-136(4.0-6.0)	Sulfolane-SW8270D M w/IsoDl Sl
1118998	SB-146(16.0-17.0)	Sulfolane-SW8270D M w/IsoDl Sl
1119603	SB-160(0.0-2.0)	SW9013/SW9014-Cyanide
1119603	SB-183(0.0-2.0)	SW9013/SW9014-Cyanide
1119610	MW-195 (14-16)	Sulfolane-SW8270D M w/IsoDl Sl
1119610	MW-195 (6-8)	Sulfolane-SW8270D M w/IsoDl Sl
1119650	O-19 (14-16)	Sulfolane-SW8270D M w/IsoDl Sl
1119807	O-27 (9-9.5)	8270D SIMS (PAH)

Surrogate analyte recoveries were checked for each sample subjected to organic analysis. If a surrogate was recovered below laboratory control limits, the concentrations of the associated analytes in the project sample were considered to be biased low. In the case of a low surrogate recovery where the analyte was not detected in the project sample, it was considered not detected at the LOD, and flagged "UJ" to indicate a possible low bias. In the case of a high surrogate recovery where the analyte was not detected, the associated analytical result was not considered to be biased and no data-validation flag was applied. If an analyte was detected, either above or below the LOQ, and the associated surrogate was recovered above laboratory control limits, the analytical result was flagged "JH" to indicate the analyte concentration may be biased high.

Twenty-six samples in 13 work orders were possibly affected by surrogate recoveries outside laboratory-control criteria. They are listed below:

SGS Work Order	Sample ID	Analytical Method
1118862	SB-109 (7.5-8.5)	8270D SIMS (PAH)
1118862	SB-111 (4.0-6.0)	8270D SIMS (PAH)
1118896	SB-128 5.0-6.6	SW8021B
1118917	SB-129 (7.5-8.7)	AK101
1118923	SB-120(7.2-9.2)	AK101
1118923	SD-120(7.2-9.2)	AK101
1118934	SB-123 (6.0-8.0)	AK101
1118934	SB-123 (6.0-8.0)	SW8260B
1118955	SB-114(0.0-2.0)	SW8021B
1118960	SB-134 5.0-6.8	SW8021B
1118996	SB-151 (0.0-2.0)	SW8260B
1118996	SB-151 (5.0-6.7)	AK101
1118996	SB-151 (6.7-8.4)	AK101
1118996	SB-175 (7.0-9.0)	AK101
1118996	SD-151 (5.0-6.7)	AK101
1119603	SB-160(4.5-6.4)	AK101
1119603	SB-160(6.4-8.4)	AK101
1118863	DO-10 (8-10)	8270D SIMS (PAH)
1118863	O-10 (8-10)	8270D SIMS (PAH)
1118885	O-11 (10-12)	8270D SIMS (PAH)
1118885	O-11 (8-10)	8270D SIMS (PAH)
1119822	O-28 (8-9)	8270D SIMS (PAH)
1119822	O-29 (11-11.5)	8270D SIMS (PAH)
1119822	O-29 (11-11.5)	SW8021B
1119649	MW-197B(15)	AK101
1119649	MW-197B(50-52)	AK101

Eighty-two analytical results were affected by either high or low surrogate recoveries in these samples. The list of affected results and their associated data-validation flags are listed in Table 73.

CCV recoveries were above control limits for a few analyses, affecting results in the four samples listed below:

SGS Work Order	Sample ID	Analytical Method
1118956	SB-167 (5.0-6.2)	SW8260B
1118998	SB-145 (0.0-2.0)	8270D SIMS (PAH)

SGS Work Order	Sample ID	Analytical Method
1118955	SB-168 (3.5-5.1)	8270D SIMS (PAH)
1118955	SB-170 (0.0-2.0)	8270D SIMS (PAH)

The CCV recoveries were each above laboratory control limits, so the affected sample results were flagged “JH” to indicate the results were potentially biased high. The list of affected results and their associated data-validation flags is presented in Table 73.

As noted above in the sample-handling section of this review, the methanol field-extractant was found to have leaked from sample jars in transit. This may have affected the accuracy of the analyses in those samples, including sample *SB-105 (5.0-6.2)* for analysis of GRO and VOCs in work order 1118856, samples *SB-119 (5.0-6.4)* and *SB-124 (5.0-6.3)* for BTEX analysis in work order 1118856, sample *O-14 (0.0-2.0)* for BTEX analysis in work order 1118942, and sample *O-9 (0-2)* for BTEX analysis in work order 1118855. Each of the volatile analytes determined in these samples is considered to be biased low. Detected analytes are flagged “JL” to indicate an estimated concentration with a low bias, and analytes not detected are flagged “UJ” as not detected due to the low bias.

Aside from the LCS/LCSD-, surrogate-, and CCV-recovery anomalies noted above, and the inaccuracy potentially related to the leaking methanol, the laboratory quality assurance data indicate the analytical results are accurate.

6.9.4 Precision

Field-duplicate samples were collected at a frequency of 10 percent of total samples to evaluate the precision of analytical measurements and the reproducibility of the sampling technique. The duplicate precision was assessed by evaluating the relative percent difference (RPD; the difference between the sample and its field-duplicate result divided by the mean of the two). RPD can be evaluated only if the results of the analyses for both the sample and its duplicate are above LOQs. RPDs greater than 50 percent were considered to indicate imprecise results. There were field-duplicate RPD failures (i.e., RPD greater than 50 percent) affecting the results in 22 project samples (nine work orders). The affected samples and analyses are listed below:

SGS Work Order	Sample ID	Analytical Method
1118923	SB-120(7.2-9.2)	SW8260B
1118929	SB-117(5.0-7.0)	SW8021B
1118955	SB-168(3.5-5.1)	8270D SIMS (PAH)
1118955	SD-168(3.5-5.1)	8270D SIMS (PAH)

SGS Work Order	Sample ID	Analytical Method
1118970	SB-149 (3.5-5.2)	SW8021B
1118996	SB-151 (5.0-6.7)	AK102
1118996	SB-151 (5.0-6.7)	AK103
1118996	SB-151 (5.0-6.7)	SW8260B
1118996	SD-151 (5.0-6.7)	AK102
1118996	SD-151 (5.0-6.7)	AK103
1118996	SD-151 (5.0-6.7)	SW8260B
1119603	SD-160(4.5-6.4)	AK101
1118863	DO-10 (8-10)	SW8021B
1118891	DO-13 (8.0-9.1)	8270D SIMS (PAH)
1118891	DO-13 (8.0-9.1)	SW8021B
1118849	DO-7 (6-8)	8270D SIMS (PAH)
1118849	DO-7 (6-8)	SW8021B
1118863	O-10 (8-10)	SW8021B
1118891	O-13 (8.0-9.1)	8270D SIMS (PAH)
1118891	O-13 (8.0-9.1)	SW8021B
1118849	O-7 (6-8)	8270D SIMS (PAH)
1118849	O-7 (6-8)	SW8021B

Field-duplicate RPD failures affected 83 sample results, and those results were flagged “J” as estimates due to sample-replicate imprecision. A complete list of the affected analytes with their associated data-validation flags is provided in Table 73.

Laboratory analytical precision can also be evaluated by RPD calculations. The laboratory MS/MSD or LCS/LCSD RPDs provide information regarding the reproducibility of their procedures and, therefore, a measure of analytical precision. Three analyte results were flagged “J” due to MS/MSD RPD failures: naphthalene in samples *SB-111 (4.0-6.0)* and *SB-111 (8-9.2)* (SGS work order 1118862) and 2-methylnaphthalene in sample *SD-123 (3.5-5.2)* (SGS work order 1118934). The other measures of analytical precision were within acceptable limits.

Other than the RPD anomalies noted above, the analytical data collected from the soil samples for this project are considered precise. The list of affected results and their associated data-validation flags is provided in Table 73.

6.9.5 Sulfolane Analysis Hydrocarbon Interference

Following the analysis of several soil samples collected for determination of sulfolane, it was discovered that petroleum hydrocarbons were interfering with the sulfolane quantitation. The hydrocarbon interference led to several of the soil-sample sulfolane results being flagged “R” (Table 73) as rejected, or unusable. Following several weeks of discussion within the Technical Project Team’s Chemistry Subgroup, a decision was made to re-extract and analyze the soil samples out of hold-time. SGS prepared an aqueous-extraction protocol to remove hydrocarbon interferences, allowing quantitation of sulfolane in soil.

Soil samples with sulfolane data rejected due to hydrocarbon interference were re-extracted using SGS's aqueous-extraction protocol if there was sufficient sample mass remaining. If the re-extracted sulfolane result was below detection, the sample result was again flagged "R." If the re-extracted sample result was detected, it was flagged "J" as an estimate due to being analyzed beyond the standard sample-holding time. The final results and data flags associated with these re-extracted samples are presented in Table 75.

6.9.6 Summary

By working in general accordance with the project SAP, the soil samples collected are considered to be representative of site conditions at the locations and times they were obtained. Aside from the issues noted above, in general, the quality of the analytical data for this project does not appear to have been compromised by any analytical irregularities.

The list of affected results and their associated data-validation flags are provided in Table 73. The laboratory reports for soil samples and the ADEC data-quality-review checklists for these reports are included in Appendix L.

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7.0 Conclusions and Recommendations

Conclusions drawn from site characterization work completed through 2011 at NPR are discussed below. Also described are FHRA's recommendations for ongoing and additional work to fill data needs, based on data collected through 2011. FHRA submitted the 2012 SCWP in May 2012 (ACRADIS, 2012c) to provide details, and to expand upon the work outlined below. Results will be presented in the SCRA-2012 to be submitted by January 25, 2013.

7.1 Potential Sources of Contamination

Potential sources of contamination include product storage tanks; USTs; railcar-loading area; the former and current truck-loading racks; the process areas; the wastewater system, including the wastewater lagoons, sumps and drain systems; drum storage areas; waste piles; and septic systems (Figure 30).

Spill records were reviewed to determine where releases had occurred, and which of the potential source areas listed above had experienced a release. A total of 3,096 documented spills have occurred from 1977 to 2010, with a total volume of approximately 282,000 gallons. Surface spills have occurred at numerous locations, including the process areas (CUs #1, #2, #3, and the EU), the wastewater lagoons, the tank farms, the railcar-loading rack area, and the current and former truck-loading rack areas (Figure 3). While files indicate cleanup actions have occurred, for many spills, facility records contain little information regarding confirmation sampling. Therefore, a soil investigation was completed to investigate potential impacts and fill data needs from previous investigations, as described below in Section 7.4). The spill records were reviewed as part of the contaminant of concern evaluation, described below in Section 7.2.

Based on a review conducted in 2011 of historical documents and other operational information, the primary contributors to sulfolane impacts to groundwater were identified to be wastewater releases from sump 02/04-2 and Lagoon B. Contributions of sulfolane to the environment from discrete surface spills, including spilled fuels, appears less significant than the subsurface wastewater releases. Analysis of LNAPL samples collected from onsite wells supports this hypothesis, as sulfolane has not been detected in any of the LNAPL samples collected from wells located near the crude units, the tank farm areas, or the former truck-loading rack. Efforts to identify other potential significant sulfolane source areas continued in 2012 and will be described in the SCRA-2012.

The potential for ongoing releases is minimized by FHRA's mechanical integrity and inspection programs, which serve to prevent releases. The refinery personnel are engaged in spill prevention and provide rapid cleanup response to spills if they do occur. Data generated from FHRA's ongoing groundwater program including LNAPL occurrence and dissolved-phase contaminants will continue to be evaluated for changing trends that would indicate a release.

7.2 Contaminants of Concern

As described in Section 3.2, the constituents of potential concern for human health were identified in accordance with ADEC guidance (ADEC 2011c). COPCs were selected from a list of COIs known or suspected to have been used at the site. The approaches used to characterize the site were intended to identify the COPCs in environmental media associated with current and historical site operations. Sampling events were sequentially conducted based on the knowledge obtained from past sampling events. It is likely that these events identified the majority of areas with residual COPCs. While it is possible that some substances may have been omitted, the probability of those substances being important in driving risk is expected to be low. The suite of analyses that was selected represents those constituents that would most likely result from site operations and are therefore the most relevant and appropriate constituents for estimating risks and hazards. Additional soil and groundwater COPC screening was conducted based on evaluation of data collected during the recent onsite soil and groundwater investigations, and during ongoing groundwater monitoring in 2012. Results were reported in the quarterly monitoring reports. COPCs were screened in accordance with the Draft ADEC Risk Assessment Procedures Manual (November 2011) in accordance with the following steps:

1. The maximum concentration or detection limit of each constituent detected in each environmental medium was tabulated.

2. The constituent-specific human health screening level was determined for each constituent.

3. The maximum site concentration (or detection limit, as appropriate) was compared to screening level for each constituent.

4. Compounds that do not exceed the appropriate screening levels were eliminated.

5. Compounds that do not exceed DEC-approved background concentrations were also eliminated.

6. Compounds that were not eliminated as COPCs were evaluated further in the HHRA (ARCADIS 2012c).

An updated COPC table, based on historical soil data and groundwater data collected in 2010 and 2011, is included as Table 19. A more robust discussion of COPC screening is included in the HHRA (ARCADIS, 2012b).

7.3 Physical Setting

7.3.1 Geology

NPR and the area surrounding North Pole is located on the Tanana River Floodplain. The geology of the area is dominated by a thick sequence of unconsolidated alluvial deposits up to 600 feet thick. Discontinuous layers of silt, fine sandy silt, and silty fine sand, with localized peat lenses, have been encountered in the upper 15 feet of the unconsolidated sequence. Alluvial sand and gravel characterized as sandy gravels and gravelly sands, with localized, discontinuous lenses of sand, silt, and organic deposits below the uppermost silty layers.

Soil descriptions from recent and historical site investigations have been used to map the distribution of shallow fine-grained soil at NPR (Figure 41). The silt/fine sand ranged in thickness from less than one foot to approximately 14 feet; the contact between the silt/sand and the underlying sand and gravel deposits ranged from 1 foot to 15 feet BGS. The silt/fine sand extends below the water table in the southwestern corner of the refinery near the lagoons and the area around the truck rack.

7.3.2 Permafrost

The study area is within the discontinuous permafrost zone (Williams 1970), and Ferrians (1965) noted that the Tanana Valley area is “generally underlain by numerous isolated masses of permafrost.” Permafrost continues to be delineated using data from numerous locations, including monitoring wells and private wells located throughout the study area. The permafrost consists of geologic strata at or below the freezing point of water 0°C (32°F) for two or more years. Permafrost data have been used in the construction of the groundwater model.

In areas where permafrost has been encountered in the study area, top-of-permafrost depths range from near the ground surface to approximately 152 feet BGS in the monitoring well borings. Residential well logs indicate the bottom of the permafrost ranges from 14 to 245 feet BGS and that the thickness of the permafrost layer ranges from five feet to 242 feet. Northwest of NPR, it appears that the top of permafrost becomes shallower. The upper surface of the permafrost appears to be deepest near NPR, and also near Badger Slough. A linear depression in the upper surface of the permafrost appears to extend northwest from NPR. Recommendations regarding permafrost are included below in Section 7.3.5.

7.3.3 Hydrogeology

The aquifer generally consists of highly-transmissive alluvial sands and gravels. The water table in the area is shallow, typically occurring within 15 feet of the ground surface (480 to 490 feet MSL onsite and 460 to 485 feet MSL offsite), and usually within the alluvial sand and gravel, and occasionally in the silty deposits. The water table decreases in elevation from southeast to northwest, mimicking the gradually decreasing elevation of the ground surface. The water table has fluctuated vertically up to four feet since 2007. Seasonal highs typically occur following snowmelt near the end of the second quarter or early in the third quarter; while seasonal lows typically occur in the weeks leading up to spring runoff.

Groundwater flow directions are controlled by discharge from the Tanana River to the aquifer and from the aquifer to the Chena River. Seasonal variations in river stage are believed to be the primary cause of variations in flow direction. The horizontal gradients tend to be greatest in the summer when the Tanana River stage is highest and recharge from the river to the alluvial aquifer is greatest. The calculated horizontal hydraulic gradient ranges from 0.0007 to 0.0028 (3.7 to 15 feet per mile).

Data collected thus far confirm that flow direction varies seasonally. Based on data from USGS water table wells, the flow direction varies up to 19° 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. Calculated flow directions from the NPR network show similar ranges to those from the USGS.

The limited available data suggest vertical gradients were primarily downward in April 2011 and upward in July 2011. Processing of the results from the data loggers is ongoing and additional evaluation will be completed for the Feasibility Studies. Recommendations are included below in Section 7.3.5.

The hydraulic conductivity of saturated materials within the suprapermafrost aquifer has been estimated using numerous methods. As would be expected of an aquifer formed in a braided stream environment of deposition, and as documented in the literature regarding the region, the hydraulic conductivity estimates range over orders of magnitude. Site-specific hydraulic conductivity estimates range from 1.1 to 14,000 ft/day.

Hydraulic conductivity is an important parameter in the evaluation of many aspects of the site characterization and evaluation of potential remedial alternatives. To the extent possible, site-specific data have been utilized in all aspects of the site characterization as summarized below. This is in recognition of the variation in hydraulic conductivity observed both horizontally and vertically in the aquifer. Specific applications include:

- the mass flux estimate at the VPT which was based on results from aquifer tests within and near the VPT,
- groundwater capture evaluation which was based on aquifer testing results and available geologic and water level information as of the end of the third quarter of 2011 that were used in calibrating the groundwater flow model used to estimate the extent of capture of the groundwater extraction system, and
- LNAPL mobility evaluation, in which modifications to the relative permeability of the aquifer materials with respect to LNAPL and LNAPL transmissivity were estimated using site-specific testing.

The density of available data for the groundwater flow model, which covers approximately 250 square miles, varies with location due to the nature of the investigation and locations of wells installed by others. The available data (as of the end of the third quarter of 2011) have been incorporated to the extent possible. Simulated heterogeneity within the model is greatest in the areas of greatest data density. Horizontal hydraulic conductivity values in the groundwater flow model range from 0.028 ft/day to 1,530 ft/day. The lowest values in the model represent the silty units found at or near the water table.

7.3.4 Groundwater Flow and Contaminant Migration

Layers of silt and zones of permafrost both have an effect on groundwater flow and contaminant migration. The silt deposits will act as localized confining layers to inhibit the vertical migration of water and solutes. As noted above, nested monitoring wells present in the NPR area show variation in vertical gradients. Periods of downward vertical gradients may result in migration of contaminants into deeper parts of the alluvial aquifer system.

Permafrost zones will alter contaminant migration pathways due to their relatively impermeable nature. Permafrost modifies localized groundwater flow and contaminant transport in the Tanana River Valley. As discussed by Carlson and Barnes (2011), permafrost creates low-permeability zones that create converging and diverging groundwater flow paths in response to its distribution. Contaminants migrating in groundwater influenced by permafrost will also be expected to show more variable concentration patterns in response to the divergent and convergent groundwater flow patterns. In the vicinity of the sulfolane plume undulations in the permafrost surface and the reduction in the aquifer thickness would also result in increased flow velocities from south to north. In the offsite study area, groundwater, and therefore sulfolane, may be migrating up and over the shallow permafrost areas. The broadening of the offsite plume appears to correspond with the area of shallow permafrost.

7.3.5 Recommendations

As discussed in the Site Characterization Subgroup meetings, FHRA proposed to install additional monitoring wells (Phase 7) at the locations shown on Figures 150 and 151; proposed well depths are shown in Table 76. As shown on the figure many of the wells were proposed to further define the sulfolane plume onsite and offsite. As more data were gathered during 2012, additional well locations were proposed in the 2012 SCWP (ARCADIS, 2012c). Results from the installation and sampling of these wells will be presented in the *SCRA-2012*.

Additional data gathered during monitoring well installation and sampling are described below. Permafrost characterization is ongoing and it continues to be logged as it is encountered during subsurface investigations. Well borings for proposed monitoring wells will serve to further define the upper surface of the permafrost. Permafrost data from private wells will continue to be integrated into the conceptual model. Additional pressure transducers will further define groundwater flow conditions in the suprapermafrost aquifer. The data will be considered during evaluation of remedial alternatives in the Offsite FS.

Collection of groundwater level data through manual and automated means will continue as described in the SCWP Addendum and discussed during the Site Characterization Subgroup meetings. Characterization of horizontal and vertical gradients and their seasonal variations is ongoing. In addition, FHRA is proposing to expand the pressure transducer/data logger network by installing additional transducers in both existing monitoring wells and new monitoring wells. The expanded transducer network is shown on Figure 152; the network is summarized in Table 77.

As described above, subsequent to the submittal of the March 2012 *Revised Site Characterization Report* (Barr, 2012), FHRA determined that additional monitoring wells were necessary. Since several of these wells were desirable locations to monitor groundwater levels, FHRA proposed to install pressure transducers and data loggers at several of these wells in the 2012 SCWP (ARCADIS, 2012c). Data collected from these data loggers will be presented in the SCRA-2012.

A standard operating procedure is being developed to handle frost jacking and other issues related to the data logger program. Errors associated with the water level estimates from the data logger program will be estimated. The influence of those errors on the estimates of flow directions, on the horizontal hydraulic gradients, and on the vertical hydraulic gradients will be evaluated in the future. Once the data from the data loggers has been processed, a full evaluation of flow direction variation and vertical gradients will be completed.

The groundwater model will be used to simulate and predict the effects of permafrost, areas of varying hydraulic conductivity, and variations in gradients on groundwater flow and sulfolane migration. These predictions will then be used during the evaluation of remedial alternatives.

Efforts to calculate sulfolane mass flux are discussed in Section 7.6.2.1.

7.4 Soil Impacts

Soil impacts have not been detected offsite. Areas of BTEX and sulfolane-impacted soils have been identified onsite. Most of the onsite soil impacts appear to be confined to areas of known releases. Soil impacts that do not appear to correlate with the areal extent of the BTEX groundwater plume were identified in the western portion of NPR.

7.4.1 Offsite

Sulfolane was not detected in any garden surface soil samples collected as part of this assessment. This suggests that sorption of sulfolane to surface soils is not likely occurring when those soils are irrigated with groundwater containing dissolved-phase sulfolane. Furthermore, sulfolane has not been detected in any of the soil samples collected during offsite monitoring well installations in 2010, although the laboratory reporting levels were elevated (Table 28). At this time, FHRA continues to provide alternative water for irrigation of food crops, and further investigation is not warranted. Because the results for these soil samples are consistent with an expectation based on sulfolane's chemistry that it would not build up in soil after irrigation with water at the concentrations measured offsite, further evaluation of risks associated with this pathway is not necessary.

7.4.2 Onsite

With the exception of metals exceedances, the majority of impacted soils correlate with areas of known releases as described in Section 3.1.2.2, including process areas (CU #1, CU #2, CU #3 and the EU), the area of the lagoons, product storage areas (e.g., tank farms), the railcar-loading rack area, and the current and former truck-loading rack areas (Figure 3). As discussed in Section 3.6.5.5 arsenic and total chromium exceedances are attributable to background concentrations consistent with the region (USACE 1994).

Potential sources of contamination described in Section 3.1.1 were compared to soil analytical results for sulfolane and benzene. Areas where sulfolane was detected above the interim estimated screening levels in soil, as identified on the facility map included in Appendix A, are listed below:

- Process areas (SB-146, SB-174, SB-175, SB-180 and O-20)
- The area between CU #1 and storage tank #194 (O-28)
- Near the lagoons (SB-141 and SB-144)
- Tank Farm Road (SB-134)
- Williams Avenue (SB-112 and SB-113)
- Tank Farm Road (SB-160)
- South of CA 5 (SB-158 and O-10)
- CA 4 (SB-115, SB-120 and O-19)
- Railcar-loading rack (SB-114)
- Former truck-loading rack (SB-117 and SB-122)
- Current truck-loading rack (SB-109 and O-2)
- Near laboratory (O-1)
- Historic storage yard west of railcar-loading rack (SB-118 and O-6)
- Near the fire training area (SB-143)

- Exchanger wash skid area (SB-131)

Benzene soil impacts located in the historic storage yard west of the railcar-loading rack, near the exchanger wash skid area do not appear to correlate with the aerial extent of the BTEX groundwater plume. Data collected during 2012, to be reported in the SCRA–2012 indicate the majority of sulfolane impacts to soil correlate with the sulfolane plume at the water table. Additionally, sulfolane soil impacts near the railcar-loading rack, current truck-loading rack, near the laboratory and CA 4 are located in the saturated soil zone (Figure 72) and are likely the results of sulfolane-impacted groundwater at the water table.

Areas where benzene was detected above the ADEC SCL in soil are listed below:

- Process areas (MW-180C, SB-146, SB-150, SB-151, SB-165, SB-173, SB-174, SB-175, SB-180, O-20 and O-21)
- Energy Boulevard (SB-155 and SB-156)
- Williams Avenue (SB-112, SB-113 and SB-126)
- East Diesel (SB-130)
- Tank Farm Road (MW-176C, SB-134 and SB-160)
- Gasoline Alley (SB-128)
- CA 4 (MW-175 and O-19)
- CA 5 (O-10)
- CA 6 (MW-197B and SB-115)
- CA 7 (O-7)
- CA 8 (O-9 and O-29)
- Railcar-loading rack (MW-186C, SB-114 and SB-123)
- Former truck-loading rack (SB-117 and SB-122)

- Current truck-loading rack (SB-109, SB-110, SB-111, O-2, O-11 and O-13)
- Near laboratory (MW-178C)
- Fire training facility (SB-143)
- West of the current truck-loading rack (SB-124 and O-27).

The majority of hydrocarbon-related impacts to soil are located near wells with measureable LNAPL and within the estimated extent of the dissolved BTEX plume (Figure 87). Furthermore, exceedances of benzene are present across much of the developed portion of the site, particularly within the smear zone and saturated soil zones. Benzene soil impacts near the current truck-loading rack, west of the current truck-loading rack, near the laboratory, CA 6, CA 7 and CA 8 are located in the smear zone and saturated soil zone (Figures 71 and 72) and are likely the results of benzene-impacted groundwater at the water table.

In general, limited COPCs were detected in soil outside the estimated LNAPL, dissolved BTEX and dissolved sulfolane plume footprints. Other COPC impacts correlate with benzene-impacted areas at the site. Iron and nickel concentrations are likely attributable to background concentrations for the area. Arsenic and total chromium impacts to soil are not co-located with petroleum or sulfolane impacts and do not appear to be a result of current or historical operations at NPR.

7.4.3 Laboratory Drain

Laboratory analysis of the soil samples collected during the laboratory drain investigation indicated constituents of COCs exceeding the applicable ADEC standards in the soil samples collected from SBLAB-4. Boring SBLAB-4 was installed near the high-use sink in the hydrocarbons laboratory on the north end of the building. Soil samples from the 1.6 to 1.8-foot interval and the 3.8 to 4.0-foot interval exhibited concentrations of TPH-D that exceed the applicable standard of 250 mg/kg. In addition, the shallower sample (1.6 to 1.8 feet) also exhibited concentrations of 2-methylnaphthalene that exceed the standard of 6.1 mg/kg, but the concentration in the deeper sample (3.8 to 4.0 feet) was nondetectable.

Arsenic was detected in each of the eleven soil samples collected during the laboratory investigation, and was present at concentrations exceeding the applicable ADEC standard of 3.9 mg/kg in both of the samples collected from SBLAB-1 (3.0 to 3.2 feet and 5.2 to 5.4 feet). However, the concentrations detected in these samples (4.92 mg/kg and 4.13 mg/kg, respectively) do not exceed the site specific 95% UCL concentration of 7.3 mg/kg, and are within the range of expected background concentrations in the area of the site, as discussed in Section 3.6.2.2.3.

Sulfolane was not present at detectable concentrations in any of the soil samples selected for laboratory analysis. The detection limits for these samples ranged from 0.495 mg/kg to 0.525 mg/kg. During the comment resolution discussions for the RSCR (Barr, 2012), an interim estimated screening level for migration to groundwater of 0.073 mg/kg sulfolane in soil was used.

Although concentrations of TPH-D were detected above the applicable ADEC standard in the soil samples collected from one boring, the concentrations decreased with depth, and are only slightly above the cleanup standard in the deeper sample. Additional soil assessment in this area is not warranted at this time. Additional soil sampling to assess general conditions at NPR was discussed above in Section 7.4.1. Furthermore, the laboratory is located upgradient of multiple wells that are included in the quarterly groundwater monitoring program, and so installation of additional groundwater monitoring points to assess conditions around the laboratory is also not proposed at this time.

7.4.4 Recommendations

Based on the results of soil investigations at the site, FHRA recommended further investigations of the following areas:

- Area around boring SB-143 near the fire training facility (Figures 65, 66, and 70)
- Area around boring SB-131 near the exchanger wash skid (Figure 72)
- Area around borings SB-118 and O-6 west of railcar-loading rack in the historic storage yard (Figure 70)
- Area around borings SB-124 and O-27, west of the current truck-loading rack (Figure 68)

Details of the 2012 soil investigation proposed in these areas and in former Lagoon B were presented in the 2012 SCWP (ARCADIS, 2012c). Results will be presented in the SCRA-2012.

In addition, FHRA recommended removing arsenic, chromium, iron and nickel from the COPC list.

7.5 LNAPL

LNAPL investigation activities completed at the site are being used to refine the LCM and will estimate LNAPL recoverability and establish remedial goals for addressing LNAPL onsite.

LNAPL accumulations or sheens have been observed in 32 observation and monitoring wells since 2006. Common unconfined aquifer behavior (i.e., LNAPL thickness decreases as groundwater elevation increases) has been observed at most monitoring locations. Exceptions are likely due to the influence of nearby recovery systems. FHRA proposes to continue monitoring the expanded LNAPL network described in Sections 2.5.1 and 2.5.2. Bail-down testing will continue as described in the SCWP Addendum.

The LNAPL sheen at MW-176B (screened at least 38 feet below the water table) requires further observation to confirm or invalidate. The LNAPL may have entered the screen as it was lowered into position during installation, and has remained trapped in the well since that time.

The LNAPL smear zone is approximately 3 feet thick and generally occurs from 7 to 10 feet BGS. The minimum top of smear zone is 5.5 ft BGS and the maximum bottom of smear zone is 13.2 ft BGS. The maximum smear zone thickness is 4.5 feet.

7.5.1 Forensics Conclusions

The following conclusions are based on the evaluation of chromatograms and PIANO data, using graphic and statistical methods:

- The LNAPL samples can be broadly segregated into three categories: samples dominated by Jet A, naphtha-like samples, and a mixture of Jet A and naphtha.
- Two samples (O-13 and R-40) show some evidence of a gasoline contribution based on the overall distribution of PIANO compounds and the presence of specific hydrocarbons, including benzene and isopentane.
- In general, Jet A is the most prevalent refined hydrocarbon source in the NAPL, contributing approximately 47% to 93% to the mixture in most samples.
- Naphtha is the primary refined hydrocarbon source in two samples and makes up 78% to 81% of the mixture.

- There is no compelling evidence that diesel fuel is present in any of the NAPL samples based on the lack of heavier compounds in the chromatograms.

Each of the samples collected are considered to have undergone some degree of weathering and are not considered to be fresh product or to represent a recent release. This conclusion is based on the loss of low carbon number compounds in all NAPL samples relative to fresh naphtha, and P:I and A:N ratios that are lower than the corresponding values for fresh naphtha and Jet A samples. Given climatic factors that would reduce biological activity and volatilization potential, as well as the complex chemistry of the petroleum sources, the relative decreases of the P:I and A:N ratios are consistent with slow changes over an extended period of time.

7.5.2 LNAPL Mobility

LNAPL at NPR is mobile within the interior and fringe of the LNAPL plume and has the potential to migrate if LNAPL recovery ceases or hydrogeologic conditions change at the site. These findings are supported by multiple LNAPL mobility assessment lines of evidence:

- Petrophysical testing of undisturbed soil cores collected at NPR showed that field saturations exceeded residual saturations at ASB-02 and ASB-04 located in the southern area of LNAPL impacts at NPR, at ASB-05 located in the central area of LNAPL impacts, and at ASB-07 and ASB-08 located in the western area of LNAPL impacts. LNAPL is mobile in these areas, meaning LNAPL can redistribute vertically and horizontally within the existing LNAPL footprint.

- Pore velocity potentials were calculated using LNAPL relative permeability calculated from API equations at five soil core locations where field saturation exceeded residual saturation and using field-derived LNAPL relative permeability from bail-down testing performed in seven monitoring wells. All calculated pore velocities exceeded the ASTM mobility criterion of 1×10^{-6} cm/s. LNAPL mobility is significant as demonstrated by pore velocities that range from 2.34×10^{-5} to 8.07×10^{-4} cm/s and the degree to which the mobility criterion is exceeded.

- The LNAPL pore-entry pressure analysis showed current and historical observed LNAPL thicknesses exceeding the critical LNAPL thicknesses calculated. This conservative analysis indicates that there is sufficient head pressure present for there to be a potential for LNAPL migration into pristine soils at all eight soil core locations. LNAPL migration can be monitored by observing fluid levels in sentry wells (wells installed downgradient of LNAPL impacts).

- Maximum LNAPL thicknesses were observed in October 2011 because the groundwater table was at a seasonal low elevation. An LNAPL sheen was observed in October 2011 for the first time or after a long period of no LNAPL accumulations in the following wells at the fringe of known LNAPL impacts: S-32, S-43, and S-40. LNAPL was measured for the first time in monitoring well MW-176A at 3.72 feet. In several wells installed in late September through early November to further delineate the LNAPL plume, LNAPL entered the new wells consistently and with thicknesses ranging from 0.13 to 1.87 feet at wells O-7, O-9, O-10, O-11, and O-13. The new appearances are most likely due to the very low groundwater elevations at the time of the fluid level gauging.

However, while the LNAPL is mobile and has the potential to migrate, the following mobility analyses indicate the LNAPL plume is stable and not migrating:

- Dissolved-phase concentrations of BTEX had generally stable to decreasing trends, especially in monitoring wells at the plume periphery, and there are numerous wells with nondetection results downgradient of LNAPL impacts at the Site. These results indicate the dissolved-phase BTEX plume is stable, which indicates at the site-wide scale that the LNAPL plume is also likely stable.

- Petrophysical testing of undisturbed soil cores collected at the Site showed field saturations at residual saturation at ASB-01 located in the leading-edge of the plume and at ASB-03 and ABS-06 located in the eastern area of LNAPL impacts at NPR, indicating that LNAPL is immobile in these fringe areas. This observation is tempered by the suspected fluid loss during soil core collection. Further, FHRA is continuing with active LNAPL recovery as summarized in Section 7.11.2.

7.5.3 Natural Source Zone Depletion

The assessment of LNAPL NSZD indicates that source zone depletion is occurring through a combination of dissolution and biodegradation in the saturated zone. The spatial comparison of upgradient and source zone/downgradient natural attenuation parameters presented in Appendix O shows a decreasing trend in electron acceptors and an increasing trend in biodegradation transformation products, which indicates that biodegradation of LNAPL is occurring. Also, it is likely that the source zone is being depleted through volatilization and biodegradation in the unsaturated zone. The quantitative evaluation of NSZD processes completed using site-specific natural attenuation parameter and hydrogeologic data indicates an ongoing total volumetric depletion rate of up to 2,650 gallons/year.

7.5.4 LNAPL Recoverability

LNAPL is currently mobile and recoverable at the site based on the mobility and recoverability data presented above coupled with the ongoing recovery and observation of LNAPL in wells. Bail-down testing data analysis and field observations will continue to be used in tandem to evaluate LNAPL mobility and recoverability.

The recoverability assessment determined that LNAPL recovery in certain areas of the facility via hydraulic methods may produce sufficient LNAPL to cause a beneficial reduction in overall LNAPL mass. These findings were based on LNAPL transmissivity measurements completed using LNAPL bail-down testing. LNAPL recovery using hydraulic methods often yields negligible amounts of LNAPL when the LNAPL transmissivity is less than 0.1 to 0.8 ft^2/day (ITRC, 2009a). The results of bail-down tests conducted at NPR in 2011 are above this transmissivity criterion range by one to two orders of magnitude. However, additional field testing is necessary to correlate bail-down derived LNAPL transmissivity values to site-specific field determined LNAPL recoverability.

Fractions of recoverable LNAPL ranging from 1.1 to 31.6 percent were calculated for the five soil cores with field LNAPL saturations exceeding residual saturations. The high proportion of recoverable LNAPL at ASB-05 (27.9 percent) and ASB-07 (31.6 percent) located in the central and western areas, respectively, of the LNAPL impacts (Figure 6) is well-supported by productive recovery systems located near these soil core locations. Recoverable LNAPL at the lower end of this range (1.1 to 6.0 percent) in soil cores ASB-08 in the western area of LNAPL impacts and ASB-02 and ASB-04 in the southern area of LNAPL impacts do not agree with LNAPL thicknesses accumulating in nearby wells.

7.5.5 Recommendations

LNAPL monitoring and recoverability testing will continue as described in the SAP. Results will be reported in the quarterly groundwater monitoring reports. Interim response actions will continue as described in Section 5.0. Through 2011, the vertical and lateral extents of LNAPL impacts had not been fully delineated at NPR. Therefore, in the 2012 SCWP (ARCADIS, 2012c) FHRA proposed to conduct additional investigation in the vicinity of O-27 using laser-induced fluorescence/ultraviolet optical screening tool (LIF/UVOST) investigation to delineate the vertical and horizontal extent of

LNAPL impacts in that area. The results of additional LNAPL delineation completed in 2012 will be reported in the SCRA-2012.

7.6 Groundwater Impacts

Groundwater onsite has been impacted by petroleum constituents and sulfolane. Offsite groundwater has been impacted only by sulfolane.

7.6.1 BTEX

The benzene plume appears relatively well defined as an onsite plume. The benzene plume is confined to the developed portion of the NPR property, and does not extend to the property boundary or beyond. The 2010 and 2011 5-µg/L footprints appear to be similar to the footprint in 2002 as shown on Figure 17 of the SCWP, indicating a stable plume. While the benzene concentrations in samples from several wells were reported to exceed the ADEC groundwater cleanup level, toluene exceeded its respective cleanup level at only two wells in the fourth quarter of 2010; and at one well in 2011 (the second well was not sampled during 2011 as described in Section 2.6.1). All reported ethylbenzene and total xylenes concentrations were below ADEC cleanup levels. All wells with toluene, ethylbenzene, and xylenes detections are located within the footprint of the benzene plume, which indicates that benzene is the most suitable analyte for monitoring petroleum impacts in groundwater at NPR.

Statistical evaluation of data collected through 2011 indicates stable or decreasing BTEX trends at most locations, which would indicate the BTEX plume has stabilized and is not migrating.

Increasing trends were identified at wells for which concentrations have peaked, and subsequent concentrations have decreased. Visual inspections of concentration graphs for these wells indicate current decreasing or stable trends that are not captured by the MAROS evaluation. The potential relationship between BTEX concentrations and groundwater elevations has yet to be established. Work will be continuing to identify these trends.

FHRA recommended continuation of monitoring for BTEX in groundwater using the expanded network described in Section 2.6.1. In addition, FHRA proposed a “one-time” sampling of a subset of monitoring wells screened in the 10-55’ BWT zone and the 55-90’ BWT zone for BTEX. The well locations are shown on Figures 153 and 154.

As described above in Section 7.3.5, FHRA proposed additional monitoring wells in the 2012 SCWP (ARCADIS, 2012c), several of which were to be sampled for BTEX. In addition, FHRA proposed a discrete interval groundwater sampling investigation onsite to obtain additional BTEX concentration data. The results will be presented in the SCRA-2012. Once the report is submitted FHRA will discuss a path forward with ADEC.

7.6.2 Sulfolane

Numerous wells have been installed onsite and offsite to delineate the sulfolane plume horizontally and vertically. The area of impact extends approximately three miles downgradient from NPR. Onsite the impact is approximately 1,250 feet wide, however, it widens to approximately 11,000 feet offsite. Onsite, along the VPT, sulfolane has been detected at a depth of 80 feet. Offsite, sulfolane has been detected in groundwater generally at shallow depths and at the top of the permafrost at some locations. There are also a few private wells, which appear to have been installed below permafrost, that are impacted by sulfolane. The nature of contamination below the permafrost is a recognized data need that will be further investigated.

Statistical analysis of sulfolane data collected through the fourth quarter of 2011 indicates decreasing or probably decreasing trends at 24 locations, and stable concentrations at 11 locations. The wells exhibiting decreasing or stable concentration trends include most of the water table wells and most of the wells screened in the 10 to 55 feet BWT monitoring zone.

Increasing trends were indicated at 6 locations: MW-142, MW-153B, MW-161A, MW-166A, MW167B, and MW-187. Further evaluation of the MW-142 data indicates a fluctuating concentration, possibly related to groundwater elevation changes. The MW-153B sulfolane concentration graph appears to indicate an increasing concentration; however, this data set is characterized by periods with no detectable analyte interspersed with measurable concentrations.

MW-161A and MW-187 are located approximately 9,000 feet downgradient of NPR, west of the Bradley Sky Ranch. The MAROS evaluation indicated no other water table wells between these wells and the NPR property boundary have increasing trends, though the deeper well MW-153B, discussed above, is located upgradient from this location. Correlation of water table fluctuations at this location with constituent concentrations is not yet possible due to a lack of groundwater elevation data; groundwater monitoring at this well will continue to allow for further evaluation of the concentration trend.

Wells MW-166A and MW-167B are wells located approximately 15,000 feet downgradient from NPR. The most recent samples collected from these wells were analyzed using EPA Method 1625B with isotopic dilution; they were the only samples that provided positive sulfolane detections.

Previous samples analyzed using EPA Method 8270D were nondetect for sulfolane. The apparent increasing trend at both wells may be partly attributable to the change in analytical methods during the later sampling episodes, which appears to yield somewhat higher sulfolane concentrations.

The MAROS evaluation characterized the sulfolane concentrations as having no trend at 21 wells. This may be attributed to:

- small sample sets with varying concentrations,
- occasional sulfolane detections in the midst of extended periods of nondetects,
- anomalies in the groundwater flow regime related to the proximity of permafrost, or
- fluctuating concentrations near the plume boundaries.

Through 2011, sufficient groundwater elevation data had not been collected from these wells to correlate the concentration fluctuations to water table fluctuations or seasonal variations; monitoring of the sulfolane network will continue as described in the SCWP Addendum. As is appropriate to its continued work in the future, FHRA may evaluate concentration trends on an annual basis and compare them to groundwater elevation trends to the extent practical.

In addition, and as discussed during the Site Characterization subgroup meetings, FHRA proposed to install additional monitoring wells at the locations shown on Figures 150 and 151; proposed well depths are shown in Table 76. Wells located proximally to the plume will be sampled for sulfolane, while those located distally from the plume will likely serve hydrogeologic and permafrost data needs. As described above in Section 7.3.5, additional wells were proposed in the 2012 SCWP (ARCADIS, 2012c). Well installation details will be presented in the SCRA-2012. Monitoring data will be presented in the quarterly groundwater monitoring reports. In addition, FHRA proposed a discrete interval groundwater sampling investigation onsite to obtain additional sulfolane concentration data. The results will be presented in the SCRA-2012.

Sulfolane has been detected in samples collected from private wells, including several for which well depth and permafrost depth information are available. Some of these wells with sulfolane detections appear to be installed below permafrost, at depths that range from 40 to 238 feet BGS.

No offsite monitoring wells have been installed through the permafrost and the mechanism by which sulfolane has entered these private wells has not been determined. Geochemical evaluations of the groundwater from these wells suggest that the composition of sulfolane-impacted water collected from subpermafrost wells may be similar to other unimpacted subpermafrost water. However, the data are insufficient to confirm any hypotheses regarding the flow path of the sulfolane to this subpermafrost zone. FHRA submitted a work plan to evaluate deep private wells in May 2012 (ARCADIS, 2012a). FHRA will execute its plan to the extent practical once access to the desired wells is obtained. FHRA will continue to study all available information regarding these subpermafrost wells in order to determine the usability of the sulfolane data for site characterization and the viability of these wells as a monitoring network. FHRA will continue the well search process, in order to identify potential receptors, maintain a buffer of unimpacted wells around the plume, and provide additional information regarding permafrost and water quality.

At this time, FHRA continues to provide alternative water supplies to those residents with impacted wells.

7.6.2.1 Mass Flux

The mass flux of sulfolane across the vertical profile transect was calculated using a variable hydraulic conductivity, as described in Section 3.8.2.7. Using this approach, the majority of sulfolane flux (approximately 85 percent) appears to be directed through a zone extending from just below the approximate water table to approximately 60 feet BGS (approximately 54 feet BWT) across the center line of the plume (measured in monitoring wells MW-302, MW-303 and MW-304). Though mass flux below 60 feet BGS (55 feet BWT) was calculated at an order of magnitude less; mass flux across the complete transect plane will continue to be monitored and will be used to evaluate appropriate remedial technologies in the Onsite FS.

Continued quarterly sampling of VPT well clusters is recommended to monitor mass flux through time. The data will be used to monitor the effects of ongoing groundwater extraction and any additional remedial measures employed at the site.

7.6.3 Other COPCs

GRO, DRO and iron were the only COPCs other than BTEX and sulfolane detected above ADEC groundwater cleanup levels during third and fourth quarter 2011 reporting periods. The extent of dissolved-phase GRO concentrations detected above groundwater cleanup levels are associated with monitoring wells MW-125 and MW-135, which are located adjacent to Containment Area 6 near the northern edge of refinery process areas (Figure 23). The extent of DRO impacts above cleanup levels are associated with monitoring wells MW-110, MW-135 and MW-139, which extend north of

Lagoon B to the northern edge of refinery process areas and west of the rail lines in the northern portion of the site (Figure 23). The extent of iron concentrations elevated above the USEPA RSL levels is associated with monitoring well MW-110. Monitoring wells with GRO and DRO impacts above groundwater cleanup levels and iron concentrations elevated above USEPA RSLs correlate with known benzene impacts in groundwater.

None of the remaining COPCs were detected at concentrations exceeding cleanup levels in groundwater collected near the crude units, Lagoon B, the tank farms, the railcar loading rack, and the downgradient property boundary, that is, near the locations of historical releases and anticipated source zones and also downgradient of the release areas.

COPCs propylene glycol and isopropanol were inadvertently excluded during the fourth quarter 2011 monitoring but were sampled in 2012 as reported in the quarterly monitoring reports.

FHRA proposes to complete sampling for GRO, DRO, and iron at the COPC wells on an annual basis, likely during the second quarter of each year. The details of the monitoring, including locations and schedule will be proposed in the next version of the SAP.

7.7 Response to LNAPL Accumulation in New Delineation Wells

As described in Section 2.5.1, seventeen observation wells were installed between September 13 and October 15, 2011, as proposed in the SCWP Addendum, for the purpose of gauging LNAPL onsite. On October 22, 2011 LNAPL was observed in northern observation wells O-11 and O-13 in the truck-loading rack area. LNAPL also accumulated in wells O-7 and O-9 on the eastern side of the tank farm (Figure 16).

FHRA completed the following response actions to the accumulation of LNAPL in delineation wells O-7, O-9, O-11 and O-13:

- A follow-up inspection indicated a missing pipe sealant material at Truck Lane #1 sump basin and a damaged seal at the lane #2 sump. A potential release of gasoline and ULSD was reported to ADEC on October 27, 2011.
- FHRA resealed all truck lane catch basins.
- Inspection of the majority of drains at NPR identified no additional pipe seals of this design. FHRA will install a mechanical seal where the piping connects to the catch basins in all lanes of the truck-loading rack.

- The forensics evaluation of LNAPL collected from wells on the northern portion of the site indicates that a minor portion of the LNAPL in wells O-13 and R-40 is gasoline.

- The forensics evaluation also indicates that the LNAPL present in onsite wells is weathered, and therefore is associated with historical releases.

- Wells O-7, O-9, O-11, and O-13 were included in LNAPL evaluation activities. The measurements taken have established baseline conditions for comparison of future measurements.

- Evaluation of dissolved-phase BTEX concentration data in downgradient wells does not indicate migration of BTEX constituents nor does it indicate the presence of LNAPL.

The LNAPL extent appears to have been defined more accurately by the installation of new observation wells. FHRA recommends continued gauging of LNAPL delineation wells and bail-down testing if LNAPL thicknesses are over 0.5 feet.

7.8 Natural Attenuation Evaluation

7.8.1 Routine Monitoring

MNA data collected through 2011 consist of three rounds of quarterly data. Principal component and discriminant analysis conducted using this data suggest sulfolane attenuation associated with less reducing or mixed-redox conditions and, potentially, interactions of impacted groundwater with surface water inputs. These findings are consistent with FHR's ongoing work associated with elucidating the sulfolane removal mechanisms observed across the air stripper and sand filter in the onsite remediation system.

7.8.1.1 Recommendations

While the Mann-Kendall trend test can be a useful tool to evaluate sulfolane concentration trends, it is recommended that the additional MNA data collected be evaluated in aggregate with tools such as principal component analysis or discriminant analysis. The reason for this recommendation is that conditions leading to attenuation of sulfolane may not be associated with specific trends in any single MNA parameter, but rather a general biogeochemical condition indicated by patterns among multiple MNA parameters

As the MNA analysis suggested potential sulfolane attenuation under less reducing or mixed redox conditions potentially associated with interactions between impacted groundwater and surface water inputs, it is recommended that monitoring wells MW-169A/B and MW-193A/B be added to the MNA network. This will aid in characterization of inputs of dissolved oxygen and other parameters from the Tanana River.

Based on the results of the MNA analysis, it is recommended that nitrate, sulfide, TKN, and total phosphorus be removed from the MNA analyte list.

7.8.2 Isotherm Testing

Isotherm testing results indicate the degree of sulfolane adsorption to aquifer sediment is anticipated to be similar to what has been published in the literature for other sites. As ongoing data collection and evaluation of MNA proceeds, the distribution coefficients estimated from this work will be used to estimate the mass of sulfolane adsorbed to sediment, and account for that mass when assessing MNA progress.

7.8.3 Subsurface Microbiological Characterization

7.8.3.1 Bio-Trap Pilot Field Study Conclusions

The purpose of the Bio-Trap study was to assess the ability and rate of the native microbial community to colonize the Bio-Trap Bio-Sep beads at low groundwater temperatures. The results presented in Section 3.10.3 indicate the following key points:

- A variety of organisms were present on the Bio-Trap beads following 28-days of deployment, although there is a potential they are present at lower than targeted densities (dependent on the analytical method).

- Data collected following 83 days of deployment indicated a “moderate to high” amount of organisms were present which are sufficient for future testing using ^{13}C-labeled Bio-Traps.

- Methanogenic organisms were present at high quantities, providing evidence that the groundwater is reducing at MW-130.

7.8.3.2 Bio-Trap Seeding Study Conclusions

Sulfolane was successfully seeded onto the Bio-Trap Bio-Sep beads during this study. The Bio-Trap loading study resulted in the following conclusions:

- To achieve the target concentration of 0.6 to 0.7 mg sulfolane/bd, Microbial Insights will use a seeding solution of 2,500 mg/L to load sulfolane onto Bio-Sep beads.

- Methylene chloride most efficiently extracts sulfolane from the Bio-Sep beads and will be used for future extractions.

- One extraction will be sufficient to extract sulfolane from Bio-Sep beads.

7.8.3.3 Microbiological Characterization Conclusions

The conclusions from the microbiological characterization studies are:

- Microbial populations at the site are healthy, measurable, and can be characterized within a reasonable deployment time frame (83 days) using Bio-Traps.

- Sulfolane can be successfully loaded to Bio-Trap Bio-Sep beads.

- Leaching of sulfolane can occur from the Bio-Traps over a 60 day period, however, the potential mass loading is insignificant compared to the current mass of sulfolane present in the aquifer.

- Regardless of the leaching, enough residual sulfolane is present after 60 days to complete ^{13}C analysis to determine whether or not microbial uptake of the ^{13}C-labeled sulfolane has occurred. This will still achieve the objective of the Phase 2 study.

- The rate of desorption with respect to the required Bio-Trap deployment time-frame may result in less than optimal data if traditional deployment techniques are utilized.

7.8.3.4 Microbiological Characterization Recommendations

Based on the above, it is recommended that Phase 2 be initiated with the following modifications to the original scope of work proposed in the SCWP Addendum (ARCADIS 2011b):

- Remove three monitoring wells from the study that either do not have detectable concentrations of sulfolane (MW-105) or the concentrations are near the analytical detection limit (MW-158A and MW-166A). The nondetectable or low concentrations of sulfolane coupled with the cold temperatures (and associated slow biomass growth and period of adaptation), make it possible that biodegradation would not be detectable over the period of Bio-Trap deployment.

- Limit the Bio-Trap deployment period to 60 days to prevent excessive leaching of sulfolane from the Bio-Sep beads.

- Use the new innovative/closeable samplers in three wells to develop a mass balance for sulfolane degradation: two for anaerobic conditions and one amended with an oxygen release compound for aerobic conditions. Each closable sampler would be seeded with biomass grown on a Bio-Trap deployed in each well 60 to 85 days prior to deployment of the ^{13}C-labeled sulfolane seeded standard Bio-Traps.

- Accompany the new innovative/closable samplers in the wells with one ^{13}C-labeled sulfolane seeded standard Bio-Trap to evaluate biodegradation in situ, as originally proposed.

- Modify the Phase 2 Bio-Trap deployment well network to the following:

Original Wells Proposed for Phase 2 Bio-Trap Deployment	Modified Wells (Phase 2): Closed Sampler Installation	Modified Wells (Phase 2): Closed Sampler with O_2 Amendment Installation	Modified Wells (Phase 2): Standard Bio-Trap installation	Screened Interval
MW-105	MW-105 (^{12}C-labeled)	MW-105 (^{12}C-labeled)	--	--
MW-110	MW-110	MW-110	--	water table
MW-142	MW-142	--	MW-142	13-18 ft BGS
MW-148A	MW-148A	--	--	water table
MW-158A	--	--	--	--
MW-161A	MW-161A	--	MW-161A	water table
MW-166A	--	--	--	--

Monitoring well MW-110 is consistently frozen during the spring and early summer. If this well is frozen, it will be substituted with MW-130. The two closed Bio-Trap samplers installed in well MW-105 will be seeded with ^{12}C-labeled sulfolane and used as controls for the study. It is anticipated that approximately 0.7 grams of sulfolane may desorb off each seeded Bio-Trap into the aquifer. An Underground Injection Control authorization will be obtained from USEPA Region 10.

7.8.4 Biodegradation Stable Isotope Evaluation

7.8.4.1 Conclusions

While substantial method development was required to complete Phase 1, a method was developed to complete laboratory analysis of the Phase 1 samples. Analysis of the sulfolane samples indicates that fractionation of stable carbon isotopes in sulfolane potentially due to natural degradation processes is occurring at the site. An apparent shift of stable carbon isotope ratios is observed between the sampled onsite wells and the downgradient offsite well MW-182A. Preliminary calculations indicate the site-specific sulfolane stable carbon isotope fractionation factor is approximately 0.3‰ and is considered sufficiently large to demonstrate degradation of sulfolane in site groundwater despite anoxic conditions in the aquifer. Additional evaluation of the Phase I data, coupled with the Phase II data and additional research underway by UAF is needed to confirm this site-specific sulfolane stable isotope fractionation factor.

7.8.4.1 Recommendations

FHRA recommends performing Phase 2 sampling using a revised scope of groundwater sampling and analysis. Phase 2 sampling will include the wells from the Phase 1 evaluation (MW-110, MW-127, MW-142, MW-148B, MW-161A, MW-164A and MW-182A), as well as additional wells MW 130, MW-138, MW-148A, MW-152A, MW-154B, MW-156A, MW-160B, MW-161B, MW-178B, MW-183A, MW-194B, MW-304 and O-1. Additionally, treatment system samples from the remediation system influent, gallery pond influent and effluent and sand filter effluent and samples from four air sparge pilot monitoring well network were included in the Phase 2 evaluation. Wells screened at additional depth intervals were included in Phase 2 sampling to determine if there are variations in the extent of sulfolane degradation at various depths, or in the presence of other COPCs. Observation well O-1 was added to the Phase 2 well network because fourth quarter 2011 data suggest O-1 is downgradient of a source area. The complete list of wells is summarized in Table 78 and is shown on Figures 155 and 156.

The Phase 1 wells were sampled again to determine if isotopic ratios vary over time and if those changes are measureable. Wells MW-171A and MW-180A were not included in the Phase 2 evaluation because sulfolane was not detected in samples from each well during the Phase 1 evaluation. To ensure completeness of the data set, sampling of monitoring wells was completed in conjunction with quarterly groundwater monitoring and during a period when at least 15 of the 20 wells proposed were unfrozen. Results of the Phase II sampling will be presented to the ADEC under separate cover.

7.9 Surface Water Assessment

Sulfolane has not been detected in water samples collected from the onsite gravel pits and Badger Slough. However, a pore-water sample collected from a piezometer east of the North Gravel Pit has indicated detectable concentrations near the banks of the gravel pit. Laboratory results indicate water samples collected from piezometers installed near gravel pits near off-site well MW-161 have also shown detectable concentrations of sulfolane. Laboratory results from a piezometer installed to the northeast of monitoring well MW-164 did not show detectable concentrations of sulfolane. As stated previously, FHRA has been unable to obtain access to the gravel pits located on the Bradley Airfield property.

7.10 Updated CSM

This CSM was completed for petroleum constituents and other constituents associated with the petroleum refining process, including sulfolane, as the only site COPCs. Because only sulfolane has been detected offsite, two separate CSM graphical forms have been prepared to more clearly portray and distinguish potential exposure pathways for the onsite and offsite receptors. This CSM will be updated as additional data are collected.

In May 2012, a Revised Draft Final Human Health Risk Assessment (HHRA) was submitted to the ADEC (ARCADIS 2012b). All potentially completed pathways identified in this Section 7.10 were evaluated in the HHRA, under several different scenarios. The results from the risk assessment are being taken into consideration as FHRA moves forward to evaluate and plan future work related to the site.

7.10.1 Onsite

Potential current and future onsite receptors may be exposed to constituents in surface and subsurface soils by direct contact including incidental ingestion of soil, dermal contact with soil, and inhalation of constituents adhered onto dust particles that have been released by wind erosion into ambient (outdoor) air.

COPCs may leach from soil to groundwater beneath the site by percolation resulting in potential direct contact exposures to constituents in groundwater. Due to the shallow nature of groundwater at the site, construction/trench workers may be directly exposed to COPCs in groundwater that has pooled at the bottom of excavations. Therefore, a possible exposure pathway is dermal absorption of COPCs in groundwater by current and future construction workers.

Some COPCs identified for the site have the potential to volatilize from subsurface soil and/or groundwater into soil gas, outdoor air and indoor air. Potential exposure pathways at the site may include volatilization of COPCs in subsurface soil and/or groundwater to outdoor air and/or indoor air of current and future onsite occupational buildings, or air within a trench used by current and future onsite construction workers.

7.10.2 Offsite

The only known current offsite COPC is dissolved-phase sulfolane. Because sulfolane is not volatile and is not readily absorbable by skin, the only exposure route evaluated for potential offsite receptors is ingestion. Ingestion of groundwater is a potentially complete pathway for offsite receptors.

Ingestion of surface water during swimming is also a potentially complete pathway for offsite residents and recreators.

Ingestion of wild foods is not a potentially complete exposure pathway for offsite residents. Wild foods are not expected to be impacted by COPCs from the site due to the sizeable depth to groundwater and lack of offsite soil impact. However, farmed or home-grown plants irrigated with water impacted by sulfolane may accumulate concentrations of this COPC. Thus, ingestion of farmed foods is a potentially complete exposure pathway for current and future offsite residents. Results of a limited garden study, which was conducted to evaluate sulfolane uptake by home-grown plants were prepared by ADEC (2011b).

Current and future offsite adult, child and infant residents, and offsite commercial and industrial workers may also inhale wind-blown dust from the site.

7.11 Cleanup Actions

Cleanup actions have focused on implementation of the IRAP in order to maximize the effectiveness of NPR's groundwater and LNAPL recovery systems as described below. FHRA will be completing an Onsite Feasibility Study to evaluate future corrective actions. FHRA is preparing an addendum to the IRAP (Barr, 2010a), in order to describe additional corrective actions to be completed in 2013.

7.11.1 Groundwater Recovery

Optimization of the existing pump and treat remediation system resulted in an increase in captured impacted groundwater onsite from 69,200,000 gallons in 2009; 107,100,000 gallons in 2010; and 136,900,000 gallons in 2011. Additional optimization efforts completed in 2011 as part of the IRAP implementation include improvements to the recovery well discharge piping to allow operation of the recovery wells at their maximum achievable groundwater recovery rates and installation of a new recovery well (R-42) to increase horizontal and vertical capture of impacted groundwater in the western portion of the site. FHRA is also in the process of installing replacement recovery wells at R-21, R-39, and R-40 with a greater total depth and diameter (at R-21), which will allow a higher groundwater recovery rate while maintaining LNAPL recovery with a skimmer system.

7.11.1.1 Groundwater Capture Evaluation

A recovery well pumping test was performed to evaluate the horizontal and vertical capture of the groundwater recovery system and provide information for updating the groundwater flow model. Utilizing the pumping test information, FHRA completed the capture zone modeling of the groundwater recovery system utilizing the calibrated regional groundwater model.

A review of the recent trends in groundwater data was completed in the monitoring wells most immediately downgradient of the recovery system (and within the sulfolane plume) as these locations will be the first to show improvement following the IRAP improvements. The trends at the five wells indicated the sulfolane concentration downgradient of the groundwater recovery system is generally decreasing.

7.11.1.2 Mass Recovery

In 2011, the sulfolane mass recovery by the groundwater averaged 0.46 lb/day. Additionally, the mass recovery was generally higher in the second half of 2011 as the groundwater recovery rate was increased. FHRA is conducting monthly sampling at each recovery well to allow evaluation of mass recovery trends from each individual recovery well.

7.11.2 LNAPL Recovery

From 1986 through the end of 2011, approximately 391,000 gallons of LNAPL have been recovered at the North Pole refinery. Annual recovery volumes have generally decreased as remediation has progressed and the volume of recoverable LNAPL has decreased. Approximately 3,600 gallons of LNAPL was removed in 2011. Recovered LNAPL is recycled within a process unit at NPR.

As part of the IRAP, seven additional product recovery systems were installed. Currently, pneumatic LNAPL recovery systems are operated when sufficient LNAPL is present at R-20R, R-21, R-32 (seasonal operation), R-33 (seasonal operation), R-35R, R-40, MW-138, and S-50 (seasonal operation with planned year-round operation). FHRA also utilizes a hand-held product recovery pump or vacuum truck at other locations (e.g. R-39) if LNAPL is present and product recovery is considered viable. The well screens in dual-phase recovery wells R-21, R-39, and R-40 were cleaned in August 2011, and a higher LNAPL recovery rate was noted in these wells.

7.11.3 Groundwater Treatment

The recovered groundwater is pumped to a treatment system that removes LNAPL and dissolved-phase contaminants. The recovered groundwater discharges to a prefilter for solids removal, a coalescer for LNAPL removal, and air strippers for removal of VOCs before accumulating in the Gallery Pond. The recovered groundwater in the Gallery Pond is then pumped through a sand filter and GAC system, which were installed as part of the IRAP improvements to remove suspended solids and sulfolane. Since the sand filters and GAC system went online in June 2011, the sulfolane concentration at the Final Effluent has been below the LOQ in every monitoring event, showing significant removal of sulfolane from the recovered groundwater.

7.11.4 IRAP Progress and Onsite Feasibility Study

FHRA has completed interim removal actions in accordance with the IRAP to aggressively address onsite LNAPL and contaminated groundwater, and is preparing an addendum to the IRAP (Barr, 2010a), in order to describe additional corrective actions to be completed in 2013. The results of full-scale operation with the IRAP and IRAP Addendum improvements will be evaluated as part of the Onsite FS to determine if additional corrective actions are appropriate to meet the objectives of preventing unacceptable human exposure to COPCs in concentrations above their risk-based levels for particular pathways onsite, and preventing offsite migration of COPCs above their risk-based levels. The feasibility study results and additional corrective actions, if needed, will be included as part of the final remedy in the *Cleanup Plan*.

FHRA is conducting an air sparge pilot study to evaluate the removal efficiency for sulfolane in groundwater. The results of this pilot testing will be utilized to evaluate potential remedial actions in the upcoming onsite feasibility study.

FHRA also is evaluating sulfolane degradation, including a bench test conducted to better understand the sulfolane removal mechanism that has been observed across the air strippers, gallery pond, and sand filters in the onsite remediation system. Results of this evaluation and testing will be submitted as part of a future submittal.

The Onsite FS will be completed in general accordance with the USEPA CERCLA guidance.

7.11.5 Offsite Feasibility Study

Data collection is necessary to complete a feasibility study to evaluate potential alternatives with respect to the offsite plume. The Offsite FS will also be completed in general accordance with the USEPA CERCLA guidance.

One element of the feasibility study includes completion of fate and transport modeling efforts, as described in Section 4.0. The fate and transport model results, along with the updated CSM included in this report, will be useful tools for evaluating potential future offsite remedial alternatives, including MNA.

In the interim, to address potential drinking water risks associated with the offsite plume, the City's municipal wells have been replaced and alternate drinking water has been provided to residents with known impacted private wells.

FHRA has conducted a feasibility study for in-home treatment of sulfolane-impacted groundwater, which indicated that POE GAC filtration is the best technology for sulfolane removal. FHRA has assembled full-scale POE treatment systems and conducted additional testing to evaluate effectiveness during residential usage.

To provide assurances to residents who utilize a POE treatment system, FHRA enlisted WQA to provide a third-party independent review as part of their Gold Seal Certification Program. WQA has completed their review and has provided certification of the treatment system effectiveness.

7.12 Groundwater Model

The draft groundwater model was submitted to ADEC on December 19, 2011. The model is based on data collected through the end of the third quarter of 2011 and is being submitted as Appendix Q of this submittal. An updated version of the model will be discussed with ADEC at a meeting scheduled for January 9, 2013.

The model will be used to evaluate the fate and transport of the sulfolane plume. It will also be used to evaluate the effectiveness of the current groundwater pump and treat system, and it will be used during the Onsite FS to evaluate other remedial alternatives, such as enhancements to the current system.

7.13 Schedule

As discussed in the sections above, several tasks are ongoing and will continue as the Feasibility Studies are completed, following the schedule below:

Task	**Completion Date**
Draft Groundwater Model	December 19, 2011 (completed)
Draft Human Health Risk Assessment	December 30, 2011 (completed)
Draft Revised SC Report	December 31, 2011 (completed)
Final Revised SC Report	March 16, 2012 (completed)
Groundwater Model (Appendix Q)	March 16, 2012 (completed)
Draft Final Human Health Risk Assessment	April 9, 2012 (completed)
Draft Onsite Feasibility Study	April 13, 2012 (completed)
Revised Draft Final Human Health Risk Assessment	May 23, 2012 (completed)
2012 Site Characterization Work Plan	May 24, 2012 (completed)
Draft Final Onsite Feasibility Study	May 25, 2012 (completed)

Task	Completion Date
Draft Offsite Feasibility Study	August 31, 2012 (completed)
Updated Groundwater Model Meeting	January 9, 2013
Interim Removal Action Plan Addendum	January 18 2013
Site Characterization Report – 2012 Addendum	January 25, 2013
Final Onsite Feasibility Study	To be determined
Final Offsite Feasibility Study	To be determined
Draft Cleanup Plan	To be determined
Final Cleanup Plan	To be determined

7.14 Reporting

FHRA will report the results of groundwater monitoring on a quarterly basis. Each quarterly report will be submitted at the end of the month that follows the end of the preceding quarter (e.g., the second quarter report will be submitted by July 31st).

Results of the continuing site characterization tasks will be reported in the quarterly groundwater reports, the Feasibility Studies, or in separate submittals. The TPT meetings and the Site Characterization and Remediation subgroup meetings will also be used as opportunities to provide updates, propose changes to work, and discuss results.

FHRA has purchased aerial imagery that is more recent than the imagery currently used for the photobase maps in this submittal. Figure 157 more accurately depicts the current configuration of local gravel pits and has a higher resolution than the currently-used image. However, the coordinates appear to be offset as it has not matched well with CADD-type line work for the refinery. FHRA will attempt to rectify the imagery, in order to potentially use it for future figures.

References

Alaska Department of Environmental Conservation (ADEC), 2011a. Comment Matrix: Site Characterization and First Quarter 2011 Groundwater Monitoring Report; North Pole Refinery; North Pole, Alaska; May 2011.

Alaska Department of Environmental Conservation (ADEC), 2011b. Final Results of the North Pole Garden Sampling Project. January 18, 2011.

Alaska Department of Environmental Conservation (ADEC), 2011c. Risk Assessment Procedures Manual. Draft. Division of Spill Prevention and Response, Contaminated Sites Remediation Program. November, 2011.

Alaska Department of Environmental Conservation (ADEC), 2011d. Monitoring Well Guidance. Division of Spill Prevention and Response Contaminated Sites Program. November 2011.

Alaska Department of Environmental Conservation (ADEC), 2010a. Draft Field Sampling Guidance. Division of Spill Prevention and Response Contaminated Sites Program. May 2010.

Alaska Department of Environmental Conservation (ADEC), 2010b. Policy Guidance on Developing Conceptual Site Models. Division of Spill Prevention and Response, Contaminated Sites Remediation Program. October 2010.

Alaska Department of Environmental Conservation (ADEC), 2009b. Site Characterization Work Plan and Reporting Guidance for Investigation of Contaminated Sites. Division of Spill Prevention and Response, Contaminated Sites Remediation Program. September 2009.

Alaska Department of Environmental Conservation (ADEC), 2008a. 18 AAC 75, Oil and Other Hazardous Substances Pollution Control. Revised as of October 2008.

Alaska Department of Environmental Conservation (ADEC), 2008b. Cumulative Risk Guidance. June 2008.

Alaska Department of Environmental Conservation (ADEC), 1998. Guidance for Fate and Transport Modeling. Division of Spill Prevention and Response, Contaminated Sites Remediation Program. July 1998.

American Society for Testing and Materials (ASTM), 2002. D5490-93(2002) Standard Guide for Comparing Ground-Water Flow Model Simulations to Site-Specific Information. Book of Standards, Vol. 4.09

Anderson, G.S., 1970. Hydrologic reconnaissance of the Tanana basin, central Alaska. U.S. Geological Survey Hydrologic Atlas HA-319. 4 plates.

ARCADIS, 2012a. Deep Private Well Groundwater Monitoring Plan, North Pole Refinery, North Pole, Alaska, June 2012.

ARCADIS, 2012b. Revised Draft Final Human Health Risk Assessment, North Pole, Alaska, May 23, 2012.

ARCADIS, 2012c. 2012 Site Characterization Work Plan, North Pole Refinery, North Pole, Alaska, May 24, 2012.

ARCADIS, 2011a. Third Quarter 2011 Groundwater Monitoring Report, North Pole Refinery, Flint Hills Resources Alaska, LLC, November 30, 2011.

ARCADIS, 2011b. Site Characterization Work Plan Addendum, North Pole Refinery, Flint Hills Resources Alaska, LLC, November 3, 2011.

ARCADIS, 2011c. Scope of Work for Additional Site Characterization Activities, Flint Hills North Pole Refinery, North Pole, Alaska. Memo to Ann Farris of ADEC. Submitted November 1, 2011.

ARCADIS, 2011d. Second Quarter 2011 Groundwater Monitoring Report, North Pole Refinery, Flint Hills Resources Alaska, LLC, July 2011.

ARCADIS, 2011e. Laboratory Area Subsurface Investigation Work Plant, North Pole Refinery, Flint Hills Resources Alaska, LLC, March 2011.

Barr Engineering Company (Barr), 2012. Revised Site Characterization Report, North Pole Refinery, Flint Hills Resources Alaska, LLC, March 2012.

Barr Engineering Company (Barr), 2011a. Site Characterization Report and First Quarter 2011 Groundwater Monitoring, North Pole Refinery, Flint Hills Resources Alaska, LLC, May 2011.

Barr Engineering Company (Barr), 2011b. Point-of-Entry Treatment System Feasibility Study and Design Report, North Pole Refinery, Flint Hills Resources Alaska, LLC, February 2011.

Barr Engineering Company (Barr), 2010a. Interim Removal Action Plan, North Pole Refinery, Flint Hills Resources Alaska, LLC, September 2010.

Barr Engineering Company (Barr), 2010b. Site Characterization Work Plan, North Pole Refinery, Flint Hills Resources Alaska, LLC, September 2010.

Barr Engineering Company (Barr), 2010c. Technical Memorandum: Groundwater Flow Modeling for the North Pole Water Supply Evaluation July 8, 2010.

Barr Engineering Company (Barr), 2010d. Technical Memorandum: Updated Groundwater Flow Modeling for the North Pole Water Supply Evaluation, December 8, 2010.

Barr Engineering Company (Barr), 2008. Groundwater Investigation, North Pole Refinery, Flint Hills Resources - Alaska, prepared for Reiss Remediation, LLC, December 2008.

Bauer, D. and J. Frechione (Bauer & Frechione), 2006. Alaska Department of Environmental Conservation. “Approval of Corrective Action Plan”. Letter to Allen Lasater, Flint Hills Resources Alaska. January 24, 2006.

Biggar, K.W., 2004. Contaminant Behaviour and Impact in Permafrost Soils: A Review of Processes and Potential Impacts. Report Submitted to Environment Canada, NWT, Canada.

Bolton, 2006. Dynamic Modeling of the Hydrologic Processes in Areas of Discontinuous Permafrost. Unpublished Ph.D. dissertation. U. of Alaska Fairbanks. 170 p.

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.

Cederstrom D.J., P. M. Johnston, and S. Subitzky, 1953. Occurrence and Development of Ground Water in Permafrost Regions. U.S. Geological Survey Circular 275. 30 p.

Clark, I and P. Fritz, 1997. Environmental Isotopes in Hydrogeology. Lewis Publishers, Boca Raton.

Downey, J.S., Sinton, P.O. 1990. Geohydrology and ground-water geochemistry at a subarctic landfill, Fairbanks, Alaska. Water-Resources Investigations Report 90-4022. US Geological Survey.

Drost, W., D. Klotz, A. Koch, H. Moser, F. Neumaier, and W. Rauert, 1968. Point dilution methods of investigating ground water flow by means of radioisotope. Water Resources Research, 4(1), 125-146.

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

Ferrians, O.J. Jr. 1965. Permafrost map of Alaska: US Geological Survey Miscellaneous Investigations 445, 1 sheet, scale 1:2,500,000.

Flint Hills Resources Alaska LLC (FHRA), 2010. Sump Investigation Report and Investigation Closure Request, North Pole Refinery, Flint Hills Resources Alaska LLC, December 2010.

Freeze, R.A. and J. Cherry. 1979. Groundwater. Prentice-Hall, Inc.

Gaspar, E and M. Oncescu, 1972. Radioactive tracer in hydrology. Elsevier Publishing Company, Amsterdam

Gieg, L.M., E.A. Greene, D.L. Coy, and P.M. Fedorak. 1998. Diisopropanolamine biodegradation potential at sour gas plants. Ground Water Monitoring and Remediation 19(3).

Glass, R.L., Lilly, M.R., and Meyer, D.F., 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 appendixes.

Goltz, M., K. Sehjong, Y. Hyouk, and J. Park. 2007. Review of Groundwater Contaminant Mass Flux Measurement. Environ. Eng. Res., Vol. 12, No. 4, pp. 176-193, Korean Society of Environmental Engineers.

Greene, E.A., Coy, D.L., and Fedorak, P.M., 1999. Laboratory Evaluations of Factors Affecting Biodegradation of Sulfolane and Diisopropanolamine. Bioremediation Journal, Vol. 3, No. 4, p. 299-313.

Grisak, G.E.,W.F. Merritt, and D.W. Williams, 1977. A fluoride borehole dilution apparatus for groundwater velocity measurements. Can. Geotech J., 14, 554-561.

Hall, S.H., 1993. Single-well tracer tests in aquifer characterization. Ground Water Monitoring and Remediation, Spring, 118-124.

Hunkeler, D., R. Aravena, and B.J. Butler. 1999. Monitoring microbial dechlorination of tetrachloroethene (PCE) in groundwater using compound-specific stable carbon isotope ratios: microcosm and field studies. *Environmental Science and Technology*, 33(16), 2733-2738.

Interstate Technology and Regulatory Council (ITRC), 2010. Use and Measurement of Mass Flux and Mass Discharge, Interstate Technology & Regulatory Council Integrated DNAPL Site Strategy Team. August 2010.

Interstate Technology & Regulatory Council (ITRC), 2009a. Evaluating LNAPL Remedial Technologies for Achieving Project Goals, ITRC Technical/Regulatory Guidance, prepared by the Interstate Technology & Regulatory Council LNAPLs Team, December 2009.

Interstate Technology & Regulatory Council (ITRC). 2009b. Technology Overview for Evaluating Natural Source Zone Depletion at Sites with LNAPL, prepared by the Interstate Technology & Regulatory Council LNAPLs Team, April 2009.

Kaplan, I.R., Galperin, Y, Lu, S.T., Lee, R.P., 1997. Forensic Environmental Geochemistry: Differentiation of fuel-types, their sources and release time. Organic Geochemistry, V. 27, pp. 289-317.

Kirtland, B.C., C.M. Aelion, P.A. Stone, and D. Hunkeler. 2003. Isotopic and geochemical assessment of in situ biodegradation of chlorinated hydrocarbons. *Environmental Science and Technology*, 37(18) 4205-4212.

Kruseman, G.P. and N.A. de Ridder, 1991. Analysis and Evaluation of Pumping Test Data, 2nd ed. Publication 47, International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands. 377 p.

Kumar, B and R.P. Nachianppan, 2000. Estimation of alluvial aquifer parameters by a single-well dilution technique using isotopic and chemical tracers: a comparison. In Proceedings of Tracers and Modeling in Hydrogeology, IAHS Publication 262, pages 53-56.

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.

Linnell, K.A., and C.W. Kaplar, 1966. Description and Classification of Frozen Soils, Cold Regions Research and Engineering Laboratory, Hanover, NH.

Luther, S.M, M.J. Dudasa, and P.M. Fedorak, 1998. Sorption of Sulfolane and Diisopropanolamine by Soils, Clays and Aquifer Materials. Journal of Contaminant Hydrology, Vol. 32, No. 1-2, p. 159-176.

MAPCO Alaska Petroleum, Inc., (MAPI) 1989. MAPCO Alaska Petroleum, Inc. North Pole Refinery, 90-Day Response to Administrative Order on Consent USEPA Docket No. 1008-11-14-3008(h), dated April 11, 1989.

McCarthy, K., L. Walker, and L. Vigoren, 2004. Subsurface fate of spilled petroleum hydrocarbons in continuous permafrost. Cold Regions Science and Technology, Volume 38, Issue 1, p. 43-54.

McKelvie, J.R., J.E. Lindstrom, H.R. Beller, S.A. Richmond, and B. Sherwood Lollar. 2005. Analysis of anaerobic BTX biodegradation in a subarctic aquifer using isotopes and benzylsuccinates. Journal of Contaminant Hydrology 81:167-186.

Meyer, D.F., 2012. Personal communication from David Meyer of the USGS with Dave Dahlstrom of Barr Engineering. 2/21/2012.

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.

Moench, A. F., Specific yield as determined by type-curve analysis of aquifer-test data, Ground Water, 32(6), 949-957, 1994.

Moench, A.F., 1997. Flow to a Well of Finite Diameter in a Homogeneous, Anisotropic Water Table Aquifer, Water Resources Research, Vol. 33, No. 6, p. 1397-1407.

Morrison, R.D., 2000. Application of forensic techniques for age dating and source identification in environmental litigation. Journal of Environmental Forensics, V. 1, pp. 131-153.

Nakanishi, A.S., and Lilly, M.R., 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.

Newell, C., S. Farhat, D. Adamson, and B. Looney. 2011. Contaminant Plume Classification System Based on Mass Discharge. Ground Water, Vol. 49, No. 6, pp. 914-919.

Page, E. 2011. Reiss Remediation, LLC. “Subject: IRAP Sampling Schedule”. E-mail to Ann Farris Alaska Department of Environmental Conservation, May 20, 2011.

Péwé, T.L., 1982, Geologic Hazards of the Fairbanks Area, Alaska, Alaska Division of Geological and Geophysical Surveys, Special Report 15, 109 pp.

Pool, D.R., and J.H. Eychaner. 1995. Measurements of aquifer storage change and specific yield using gravity surveys. Ground Water 33, no. 3: 425–432.

Saint-Fort, R., 2006. Sulfolane Attenuation by Surface and Subsurface Soil Matrices. Journal of Environmental Science and Health, Volume 41, Part A, p. 1211 – 1231.

Shannon & Wilson, Inc. (SWI), 2011. Residential-Well Search Survey, Areas 1 through 6B, Flint Hills Resources Alaska, LLC, North Pole Refinery.

Shannon & Wilson, Inc. (SWI), 2010. Revised Sampling and Analysis Plan, Flint Hills Resources Alaska, LLC, North Pole Refinery, December 28, 2010.

Shannon & Wilson, Inc. (SWI), 2006. Results of Groundwater Monitoring for Sulfolane and Proposed Long-term Sulfolane Groundwater Monitoring Program, Flint Hills Resources Refinery, North Pole, Alaska, October 2006.

Shannon & Wilson, Inc. (SWI), 2005. Report on Well Installation, Maintenance Activities, and Data Review. Flint Hills Resources Alaska, Inc., Refinery, North Pole, Alaska, December 2005.

Shannon & Wilson, Inc. (SWI), 2002. Site Characterization and Corrective Action Plan, Williams Alaska Petroleum, Inc., North Pole Refinery, June 2002.

Shannon & Wilson, Inc. (SWI) 2001. Contaminant Characterization Study, Williams Alaska Petroleum, Inc. North Pole Refinery, North Pole Alaska. October 2001.

Shannon & Wilson, Inc. (SWI) 2000. Draft Site Characterization and Corrective Action Plan, Williams Alaska Petroleum, Inc. North Pole Refinery, North Pole Alaska. December 2000.

Shannon & Wilson, Inc. (SWI), 1995. Recovery Well Optimization Study, Mapco Refinery, North Pole,Alaska. Letter report prepared for MAPCO Alaska Petroleum, Inc. 19 p.

Shannon & Wilson, Inc. (SWI), 1987. Preliminary report on site hydrogeology, North Pole Refinery, North Pole, Alaska. February 4, 1987.

Shannon & Wilson, Inc. (SWI), ARCADIS 2011. Revised Sampling and Analysis Plan, Flint Hills Resources Alaska, LLC, North Pole Refinery, November 3, 2011.

Shell Chemicals Europe Limited (Shell) 1994. Sulfolane Data Sheet, Shell Chemicals UK Ltd.

Sloan, C.E. and R.O. van Everdingen, 1988. Region 28, Permafrost Region. In Hydrogeology. The Geological Society of North America, Boulder Colorado. 1988. p 263-270.

Smyth, W.J. 2011. Alaska Department of Environmental Conservation. “Subject: RE: Permit No. 2005-DB0012 Treatment Process Modification Extension Request”. E-mail to Loren Garner, Flint Hills Resources Alaska, LLC. September 29, 2011.

Song, D.L., M.E. Conrad, K.S. Sorenson, and L. Alvarez-Cohen. 2002. Stable carbon isotope fractionation during enhanced in situ bioremediation of trichloroethene. *Environmental Science and Technology*, 36(10), 2262-2268.

Theis, C.V., 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage, American Geophysical Union Transactions, Vol. 16, p. 519-524.

United States Army Corps of Engineers-Alaska District (USCOE), 1994. Background Data Analysis for Arsenic, Barium, Cadmium, Chromium & Lead on Fort Wainwright, Alaska. Final, March 1994.

United States Environmental Protection Agency (USEPA). 2011. Integrated Risk Information System.

United States Environmental Protection Agency. 2011. ProUCL Website. http://www.epa.gov/osp/hstl/tsc/software.htm.

United States Environmental Protection Agency (USEPA). 2010. Regional Screening Levels. Last Updated November 2010.

United States Environmental Protection Agency (USEPA). 2007. ProUCL 4.0 Technical Guide. EPA/600/R04/079. Office of Research and Development, National Exposure Research Laboratory. Environmental Sciences Division, Las Vegas, Nevada, April, 141 pp.

United States Environmental Protection Agency (USEPA). 2006. On the Computation of a 95% Upper Confidence Limit of the Unknown Population mean Based upon data Sets with Below Detection Limit Observations. EPA/600/R-06/022. Office of Research and Development, National Exposure Research Laboratory. Environmental Sciences Division, Las Vegas, Nevada, March, 141 pp.

United States Geological Survey (USGS), 2011. USGS Water Data for the United States. US Geological Survey. http://waterdata.usgs.gov/nwis/.

United States Geological Survey (USGS), 2001. Ground-Water Studies in Fairbanks, Alaska—A Better Understanding of Some of the United States' Highest Natural Arsenic Concentrations. USGS Fact Sheet FS-111-01. November 2001.

United States Geological Survey (USGS), 1978. Hydrologic Information for Land-Use Planning, Fairbanks Vicinity, Alaska. Prepared in cooperation with Fairbanks North Star Borough, U.S. Environmental Protection Agency, U.S. Army Corps of Engineers.

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.

Zorzetti, B.M., Shaver, J.M., Harynuk, J.J., 2011. Estimation of the age of a weathered mixture of volatile organic compounds. Analytica Chimica Acta, v. 694, p. 31-37.