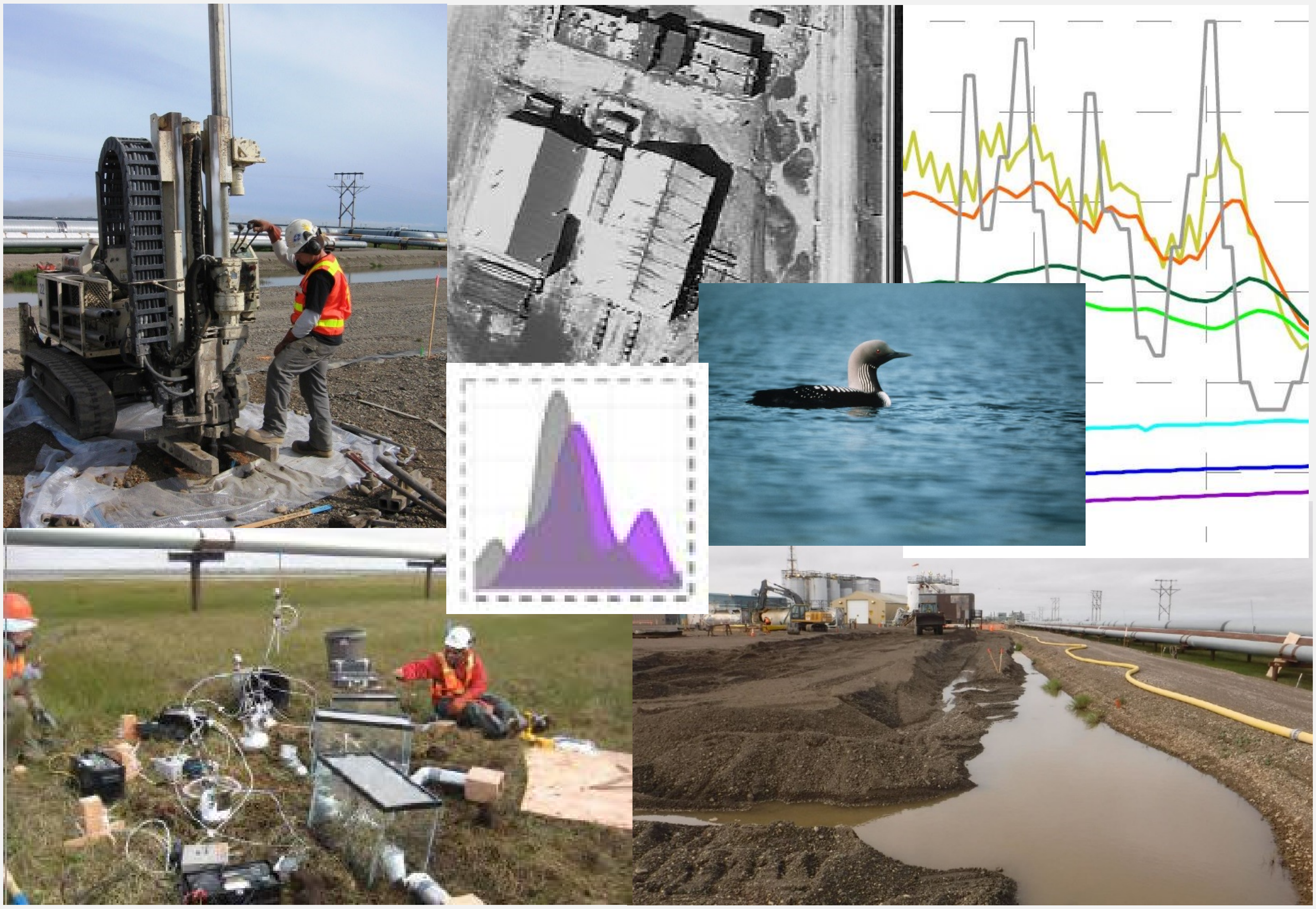

Prepared for:

Hilcorp North Slope, LLC

Former Tuboscope Site

Comprehensive RFI Report

Administrative Order on Consent

EPA Docket No. RCRA-10-99-0179

EPA Docket No. RCRA-10-2007-0222

13 May 2022

Project No.: 0563556

The business of sustainability

Signature Page

13 May 2022

Former Tuboscope Site

Comprehensive RFI Report

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CONTENTS

List of Tables

Tables (In Text)

Tables (Following Text)

List of Figures

Acronyms and Abbreviations

Name	**Description**
°C	degree Celsius
°F	degree Fahrenheit
µg/L	microgram per liter
1,1,1-TCA	1,1,1-trichloroethane
1,1-DCA	1,1-dicholoroethane
1,2-DCA	1,2-dichloroethane
3&4-methylphenol	sum of the concentrations of 3-methylphenol and 4-methylphenol
AAC	Alaska Administrative Code
ADEC	Alaska Department of Environmental Conservation
ADNR	Alaska Department of Natural Resources
AL	Action Level
amsl	above mean sea level
ASTM	American Society for Testing and Materials
AWQS	Alaska Water Quality Standards
bgs	below ground surface
BNP	bimetallic (iron and palladium) nanoscale particle
BOC	Base Operations Center
BPRM	BP Remediation Management
BPXA	BP Exploration (Alaska) Inc.
BTEX	benzene, toluene, ethylbenzene, and total xylenes
BTV	background threshold values
CEC	cation exchange capacity
CIC	Corrosion Inhibitor Chemical
CID	Contained-In Determination
CL	cleanup level
cm/sec	centimeter per second
COI	constituent of interest
COPC	constituent of potential concern
COPEC	constituent of potential ecological concern
CSM	conceptual site model
DO	dissolved oxygen
DQO	data quality objective
DRO	Diesel Range Organics
EDGE	EQuIS Data Gathering Engine
EOA	Eastern Operating Area

ERM	ERM Alaska, Inc.
foc	fraction organic carbon
FS-WI	Field Sampling Work Instruction
ft	foot
g/kg	grams per kilogram
HNS	Hilcorp North Slope, LLC
i.e.	id est [Latin: that is (to say); in other words]
IDW	investigation derived waste
IM	Interim Measure
Kd	soil-water partition coefficient
K_{OC}	soil organic carbon partition coefficient
LiDAR	Light Detection and Ranging
LNAPL	light, nonaqueous-phase liquid
MCL	maximum contaminant level
MDL	method detection limit
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mV	millivolts
NAD	North American Datum
NAVD	North American Vertical Datum
OASIS	OASIS Environmental, Inc.
ORP	oxidation-reduction potential
p-isopropyltoluene	para-isopropyltoluene
Pace	Pace Analytical Services, LLC
PAH	poly-cyclic aromatic hydrocarbon
PBU	Prudhoe Bay Unit
pH	hydrogen potential
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
QQ	quantile-quantile
RCRA	Resource Conservation and Recovery Act
RFA	RCRA Facility Assessment
RFI	RCRA Facility Investigation
RO-COPC	RCRA Order Constituent of Potential Concern
SVOC	semi-volatile organic compound
SESA	system evaluation site assessments
SIM	select ion monitoring

SL	Screening Level
SLR	SLR International Corporation
SM	matrix code for mineral soil
SO	matrix code for pad material / gravel
SPGW	suprapermafrost groundwater
SWMU	Solid Waste Management Unit
TAH	total aromatic hydrocarbons
TAqH	total aqueous hydrocarbons
TCE	trichloroethene
TN	matrix code for tundra soil
TOC	total organic carbon
TTLA	Tanker Truck Loading Area
URS	URS, Greiner, and Woodward-Clyde
USCS	Unified Soil Classification System
USEPA	United States Environmental Protection Agency
VOC	volatile organic compound
YSI	YSI® 556 field instrument
WG	matrix code for suprapermafrost groundwater
WS	matrix code for surface water
WX	matrix code for pad porewater

GLOSSARY

The glossary presents terms defined by the Resource Conservation and Recovery Act (RCRA) Order and Alaska Department of Environmental Conservation (ADEC) regulation used by consultants supporting BP Exploration (Alaska) Inc. (BPXA) projects.

Action Level (Tier II): A risk-based chemical concentration based on Prudhoe Bay Unit (PBU)-wide exposure assumptions (SLR 2016).

Active-Layer Water: Water in the active-layer interval present between the ground surface and the permafrost during the summer seasonal thaw.

Background Threshold Values (BTV): Include a threshold point estimate of the natural concentration of a metal and is often used in screening evaluations of background conditions (USEPA 2015). Site concentrations below the BTV are considered representative of natural background conditions, and values above the BTV may be above background. Prudhoe Bay Facility background metal concentrations defined in the B*ackground Metal Concentrations in Soil, Prudhoe Bay Facility, Alaska* (SLR 2019a), and the *Surface Water Background RCRA Facility Investigation Report* (SLR 2018). The procedures for estimating BTVs and evaluating background conditions were described in the *Background Metals in Small Surface Water Bodies RCRA Facility Investigation Report, Addendum 1-Data Evaluation Plan, Prudhoe Bay Facility, Alaska* (SLR 2015b).

Constituents of Interest (COI): Constituents identified for the purpose of performing specific phases of work including RCRA Facility Investigations (RFI), Interim Measures (IM), Corrective Measures Study (CMS), and Corrective Measures Implementation (CMI).

Constituents of Potential Concern (COPC): May include: (1) COI that are detected during an investigation that warrant further assessment; and (2) Constituents that are potentially site-related and whose data are of sufficient quality for use in a risk assessment (USEPA 2012). COPCs identified in this report will be advanced to a Corrective Measures Study as Contaminants of Concern.

Constituents of Potential Ecological Concern: Constituents of potential concern that exceed established ecological screening or action levels and that will be quantitatively evaluated when performing a baseline ecological risk assessment (SLR 2016).

Corrective Measure: Any United States Environmental Protection Agency- (USEPA) selected measures or actions to control, prevent, or mitigate the release or potential release of hazardous wastes and/or hazardous constituents in the environment at or from the Site (PBU) (USEPA 2007).

Corrective Measures Implementation: Those activities necessary to initiate, complete, monitor, and maintain the remedies USEPA has selected or may select to protect human health and/or the environment from the release or potential release of hazardous waste and/or hazardous constituents into the environment from the Site (PBU) (USEPA 2007).

Corrective Measures Study: The investigation and evaluation of potential remedies that will protect human health and/or the environment from the release or potential release of hazardous waste and/or hazardous constituents into the environment at or from the Site (PBU) (USEPA 2007).

Data Quality Objectives (DQO): Quantitative and qualitative statements designed to ensure that data of known and appropriate quality are obtained for their intended use(s) (USEPA 2000a, 2006a, and 2007).

Evaluation Criteria: The criteria used for evaluating data in this RFI report. The criteria consist of RCRA Tier II Action Levels and, if Tier II levels are not available or applicable, a combination of Tier I Screening Levels, Alaska Water Quality Standards (AWQS), ADEC Method 2 soil cleanup levels, ADEC Table C groundwater cleanup levels, and background levels.

Exceptional Site: Solid Waste Management Units (SWMU) or AOCs where non-traditional oil and gas exploration and production operations or releases have occurred.

Facility: An abbreviated reference to the Prudhoe Bay facility operated by Hilcorp North Slope, LLC (HNS).

Hazardous Constituents: RCRA regulations define hazardous constituents based on the list of chemicals in 40 Code of Federal Regulation (CFR) 261, Appendix VIII, or the groundwater monitoring list chemicals in 40 CFR 264, Appendix IX.

Hazardous Substances: ADEC regulations define hazardous substances with established soil and water cleanup levels in Title 18 of the Alaska Administrative Code, Chapter 75 (18 AAC 75) Tables B1, B2, and C (ADEC 2018). Alaska Statute AS 46.03.826 defines a hazardous substance as an element or compound which, when it enters the atmosphere or in or upon the water or surface or subsurface land of the state, presents an imminent and substantial danger to the public health or welfare, including but not limited to fish, animals, vegetation, or any part of the natural habitat in which they are found (ADEC 2018).

Hydrologically Connected Groundwater and Surface Water: ADEC guidance found in *Technical Memorandum 01-005, Regulatory Approach to Managing Contamination in Hydrologically Connected Groundwater and Surface Water* (ADEC 2011), identifies hydrologically connected groundwater as a groundwater that is in contact with a surface water or is in close proximity to a surface water so that there is mixing of the groundwater and surface water in the hyporheic zone. For the purposes of this project, pad porewater monitoring wells located within 50 feet of a surface water body are considered to be “closely connected hydrologically” to surface water.

Interim Measures (IM): Those actions initiated in advance of implementation of final Corrective Measures to control or abate immediate threats to human health and/or the environment and to prevent or minimize the potential release or spread of hazardous waste and/or hazardous constituents into the environment at or from Solid Waste Management Units (SWMUs) or Areas of Concern (AOCs) throughout the implementation of the PBU RCRA Order, while long-term Corrective Measures alternatives are evaluated (USEPA 2007).

Method Detection Limit (MDL): Statistically derived expressions of theoretical detection capability, which are based on standard deviation of replicate spiked samples taken through all steps of an analytical procedure with 99 percent confidence that the analyte concentration is greater than zero. MDLs are based on a discrete set of measurements, and in the data reporting process samples collected from the PBU are reported to an MDL adjusted for sample-specific parameters such as sample weight/volume, percent solids, or dilution (Environmental Standards, Inc. 2017).

Off-Pad: Refers to areas that are not located atop or contained within a gravel pad or berm.

On-Pad: Refers to areas located atop or contained within a gravel pad or berm.

Pad Porewater: Suprapermafrost groundwater that exists within the man-made gravel pads that support the Site activities. The pad porewater zone is typically less than 2 feet in thickness. For purposes of interpreting the PBU RCRA Order, USEPA regulation, and guidance for Work under the PBU RCRA Order, pad porewater shall be treated as groundwater. Pad porewater may have the potential to migrate to surface water, but it is not a direct source of drinking water.

PBU RCRA Order: Administrative Order on Consent RCRA-10-2007-0222, issued 3 October 2007.

Permafrost: A layer of soil or bedrock that has been at or below the freezing point of water (zero degrees Celsius [°C]) continuously for 2 or more years. On Alaska’s North Slope, this includes perpetually frozen soil and or strata extending from a depth of about 36 inches below ground surface (bgs) to about 2,000 feet bgs (USEPA 2007).

Permafrost Elevation: The measured elevation above mean sea level at the top of the subsurface permafrost interval during the summer thaw season as measured at specific time intervals.

Project Group: A Project Group from the Project Group List required under Attachment D (PBU RCRA Order), Scope of Work for Site-Wide Project Work Plan. These Project Groups are SWMUs and AOCs from the list in Attachment C that have been organized into manageable groups (USEPA 2007).

Prudhoe Bay facility: The contiguous land, and structures, other appurtenances, and improvements on the land in the area depicted in Attachment A of the PBU RCRA Order. This area contains the SWMUs and AOCs investigated under the PBU RCRA Order. The defined area of the facility does not include 6 square miles of the Eastern Operating Area (EOA) of the PBU that are not under control of HNS (USEPA 2007).

Prudhoe Bay Unit (PBU): Describes the oil field, oil field operations, and oil field ownership. Synonymous with Prudhoe Bay oil field, Prudhoe Bay field, or Prudhoe Bay facility.

RCRA Facility Investigation (RFI): Any required investigation and characterization of hazardous wastes and/or hazardous constituents and the nature and extent including, but not limited to, the direction, rate, movement, and concentration of those hazardous wastes and/or hazardous constituents that have been, or are likely to be, released into the environment at or from the Site (USEPA 2007).

RCRA Order Constituents of Potential Concern (RO-COPC): Any hazardous constituents known or suspected to be used, stored, or produced in significant quantities within the PBU as well as any breakdown products of these constituents that are also hazardous for which screening levels have been (or will be) developed (USEPA 2007).

Receptors: Those humans, animals, or plants and their habitats that are or may be affected by releases of hazardous wastes and/or hazardous constituents to the environment at or from the Site (USEPA 2007).

Release: Any spilling, leaking, pouring, emitting, emptying, discharging, injecting, pumping, escaping, leaching, dumping, or disposing of hazardous wastes (including hazardous constituents) into the environment (including the abandonment or discarding of barrels, containers, and other closed receptacles containing hazardous wastes or hazardous constituents) (USEPA 1989a).

Reporting Limit (RL): The lowest amount of analyte in a sample that can be reliably measured and reported under specific analytical conditions (i.e., the lower limit of quantitation) (Environmental Standards, Inc. 2017).

Screening Level (Tier I): The site screening levels based on USEPA-accepted risk-based sources and developed in consideration of both human health and ecological receptors. Tier I SLs represent the lowest available health-based levels identified from a variety of regulatory sources and as such represent generic, conservative Tier I Screening Levels (SLR 2016).

Site: That portion of the physical area of the Prudhoe Bay facility shown in Attachment A of the Order (USEPA 2007). This defined area does not include 6 square miles of the Eastern Operating Area of the PBU that are not under the control of HNS.

Solid Waste Management Unit (SWMU): Any discernible unit at which solid wastes have been placed at any time, irrespective of whether the unit was intended for the management of solid or hazardous wastes, including those areas of, or at, the facility where solid waste has been treated, stored, disposed of, managed, or released (USEPA 2007).

Suprapermafrost Groundwater (SPGW): Water in the active layer above permafrost. For this document, active-layer water is considered suprapermafrost groundwater at locations off, or away from, man-made gravel pads and roads.

Surface Water: Open water present at the ground surface. Surface water features include lakes, ponds, thermokarst troughs filled with water, streams, and rivers.

Total Aqueous Hydrocarbons (TAqH): TAqH are defined in the Alaska Water Quality Standards (Title 18 of the Alaska Administrative Code, Chapter 70 [18 AAC 70]) (ADEC 2020) as the collective dissolved and water-accommodated monoaromatic and poly-cyclic aromatic hydrocarbons that are persistent in the water column. TAqH does not include floating surface oil or grease. TAqH is calculated as the sum of total aromatic hydrocarbons (TAH) plus the following poly-cyclic aromatic hydrocarbons listed in USEPA Method 610 (laboratory analytical method): acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, and pyrene.

Total Aromatic Hydrocarbons (TAH): TAH are defined in the Alaska Water Quality Standards (18 AAC 70) (ADEC 2020) as the sum of the following volatile monoaromatic hydrocarbon compounds: benzene, ethylbenzene, toluene, and the xylene isomers, more commonly referred to as BTEX.

Work Plan: The detailed plans prepared by Respondent to satisfy the requirements of the Order and any corresponding Scope of Work (USEPA 2007).

EXECUTIVE SUMMARY

The former Tuboscope site Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) was conducted in response to Administrative Order on Consent for Corrective Action under Section 3008(h) of RCRA for the Prudhoe Bay Facility (United States Environmental Protection Agency [USEPA] Docket No. RCRA-10-2007-0222) (hereinafter, “PBU RCRA Order”). The objectives of the RFI, as stated in the PBU RCRA Order, “are to characterize the environmental conditions of the Site and to determine the nature and extent of the release(s) or potential release(s).” Investigative activities conducted between 2008 and 2018 have characterized environmental conditions at the former Tuboscope site, assessed releases, and determined the nature and extent of impacts to environmental media. The RFI was conducted separately from the Interim Measure (IM) requirements of the Administrative Order on Consent (USEPA Docket No. RCRA-10-99-0179, hereinafter, “Tuboscope Order”).

The former Tuboscope site is located on the North Slope of Alaska, within the Prudhoe Bay Unit (PBU). The former Tuboscope building was used for inspection and refurbishment of tubular pipes used in oil well construction. Pipe cleaning operations occurred within the former shop building. Solvents were used to remove pipe dope, which contained lead and other metals, from the threaded pipes. The shop had an unlined gravel floor, which would not have contained any solvent releases. Additionally, a 5,000-gallon aboveground tank was present at the building and used to store diesel fuel. The AMF Tuboscope Company ceased operations at this site in 1982, when a fire destroyed the building. Solvents and diesel fuel were released to the gravel pad during pipe cleaning operations and/or during the fire. The Tuboscope shop building was not rebuilt after the fire.

A drilling mud plant was temporarily located adjacent to the then-operating Tuboscope building for approximately 3 years in the early 1980s. While present, drilling mud boxes containing dry formulation solids were stored outside near the drilling mud plant building. These dry formulation materials were moved into the plant building as needed, mixed with drilling mud formulation fluids, and transported to nearby drill pads where they were used during oil and gas well drilling operations.

Building on the results of previous investigations, the RFI was an extensive investigation that characterized the nature and extent of contamination. The RFI was initiated in accordance with the *RCRA Facility Investigation Work Plan, Former Tuboscope Site* (OASIS 2009a). Constituents of interest (COI) that were the focus of the RFI were identified based on spill records, site history, and historical laboratory data. These constituents include volatile and semi-volatile organic compounds, petroleum hydrocarbons, and select metals.

The investigation was conducted with the active involvement of and input from USEPA and Alaska Department of Environmental Conservation (ADEC). As the investigation progressed, detailed interim reports were provided including the 2008–2011, the 2012, and the 2013 RFI Interim Summary Reports (OASIS 2012b, ERM 2014a, and ERM 2014b). To address data gaps identified by the Agencies, work plan addenda and amendments were issued (OASIS 2012a, OASIS 2012c, and ERM 2013c). All data gaps identified by the Agencies have been addressed.

The RFI database was developed through the collection of environmental media samples, including:

- 222 surface soil samples
- 281 subsurface soil samples
- 207 pad porewater samples
- 56 suprapermafrost groundwater (SPGW) samples
- 186 surface water samples

The RFI dataset includes approximately 91,000 analytical results documenting concentrations of constituents in environmental media.

Naturally occurring surface soil in the off-pad area is highly organic peat, which forms patterned ground due to cryogenic processes. The area is underlain by permafrost including areas of massive ground ice, ice lenses, and ice-rich soil. An aquifer is not present. During the thaw season, SPGW and surface water tend to flow through ice wedges between permafrost polygons. The Base Operations Center (BOC) pad and adjacent roads were constructed by placing a thick layer of gravel on top of the native tundra surface.

The North Slope is an arid region. The rate of potential evapotranspiration exceeds the available water from precipitation. A minimal amount of water percolates through pad gravel and is available to mobilize constituents. Lack of water, highly organic tundra soil, and long periods of freezing temperatures serve to limit the rate of contamination migration.

Over time, hydrology at the former Tuboscope site has changed. Changes have been a result of construction of roads (initially between 1968 and 1971), construction of the BOC pad (1976 to 1977), installation of a culvert that connected a drainage ditch to the surrounding tundra, isolation of the drainage ditch and closure of the culvert (1983), installation of a curtain liner (1988), pumping of water from the drainage ditch as part of IMs (1997 to 2016), and backfill of the drainage ditch (2018). The RFI was completed in 2018 with the collection of surface and subsurface soil samples from beneath the former drainage ditch treatment system prior to its decommissioning.

SPGW flow is generally toward the northeast near the former Tuboscope building location. However, following periods of snow melt or precipitation, SPGW may temporarily flow from near the former building location to the southwest.

The conceptual site model (CSM) for the former Tuboscope site provides current and reasonably anticipated exposure scenarios and identifies exposure pathways as potentially complete or incomplete. Analytical data were compared to Evaluation Criteria protective of unrestricted land use including hypothetical future resident subsistence users and a variety of ecological receptors that are present on the North Slope. As appropriate, data have also been screened based on criteria for ADEC-only constituents. Analytical results for surface water and SPGW closely connected hydrologically to surface water have been compared to Alaska Water Quality Standards (AWQS). The reasonably anticipated future land use of the former Tuboscope site is continued use for oil and gas development. After the end of field life, the reasonably anticipated future land use will be non-residential subsistence land use.

This report documents several releases of hazardous wastes and hazardous constituents at the site, resulting in the following constituents being released into the environment:

- Solvents (including 1,1,1-trichloroethane [1,1,1-TCA], USEPA hazardous waste No. F001), 1,4-dioxane (a stabilizer for the solvents), and metals associated with the removal of pipe dope (lead, copper, and possibly zinc)
- Petroleum hydrocarbons released in spills of diesel fuel
- Barium and other metals associated with the operation of a drilling mud plant that was previously at the former Tuboscope site

Figure ES-1 summarizes the extent of 1,4-dioxane contamination in soil and water. Figures ES-2 and ES-3 show similar information for chlorinated solvent and petroleum hydrocarbons, respectively.

The RFI dataset also includes evidence of other releases that occurred near the former Tuboscope site but are unrelated to the site. These nearby releases can be addressed under ADEC Contaminated Sites Program regulations. RFI results indicate that COIs have been delineated both laterally and vertically to the Evaluation Criteria. Constituents of potential concern (COPC) have been identified for each environmental media.

Elevated concentrations of metal constituents appear to result from four sources. Some are naturally occurring, some are due to imported gravel, some are due to releases of hazardous constituents, and some are due to localized changes in geochemistry caused by biodegradation of organic compounds. The extent of impacts varies by metal constituent and with each constituent’s fate and transport properties.

Petroleum hydrocarbons released into the environment are biodegrading through both aerobic and anaerobic processes. Anaerobic conditions are supportive of reductive dechlorination of chlorinated solvents, which is occurring and released chlorinated solvents are attenuating naturally. Low temperatures reduce rates of biodegradation. Volatilization is a significant fate and transport for many of the constituents.

The information reviewed and data gathered in support of the RFI justify conclusions as they relate to the nature and extent of releases that have occurred at the former Tuboscope site. Data collected in support of this RFI is of adequate technical quality to identify, develop, and implement appropriate corrective measures to protect human health and the environment.

Constituents of Potential Concern that have been detected above screening levels due to releases at the former Tuboscope site and have been forwarded to the Corrective Measures Study.

1. TUBOSCOPE BACKGROUND

This comprehensive report presents the findings of the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) performed at the former Tuboscope site Solid Waste Management Unit (SWMU). The RFI was conducted in response to the RCRA Section 3008(h) Administrative Order on Consent [USEPA Docket No. RCRA-10-2007-0222] (hereinafter, “PBU RCRA Order”), for corrective action within the Prudhoe Bay Unit (PBU) that has been executed between the United States Environmental Protection Agency (USEPA) and BP Exploration (Alaska) Inc. (BPXA). In 2020, Hilcorp Energy Company, LLC completed the purchase of BPXA, which is now being operated as Hilcorp North Slope, LLC (HNS). RFI activities were initiated in 2008 and completed in 2018.

The former Tuboscope site is located on the Base Operations Center (BOC) pad within the Prudhoe Bay facility. Figure 1 shows the project location relative to the other production pads and infrastructure in the PBU, while Figure 2 shows the former Tuboscope site setting. The former Tuboscope site is legally described, under the public land surveying system, as being in the southwest quarter of Section 19 of Township 11 North, Range 14 East of the Umiat Meridian in the North Slope Borough of Alaska.

An accidental chemical release was reported at the former Tuboscope site in 1982, when a fire destroyed a building used for solvent-cleaning of drill pipe. Since that time, several investigations have been performed to assess the nature and extent of the chemicals released both as the result of the fire and the cleaning operations. Under the authority of RCRA, an Administrative Order on Consent from the USEPA, Docket No. RCRA-10-99-0179, (hereinafter, “Tuboscope Order”) was executed in 1999. The Tuboscope Order required the development and implementation of Interim Measures (IM) to control or abate threats to human health and/or environment and to prevent or minimize the spread of hazardous constituents from the accidental release. The initial IM Work Plan was approved in 1999 (URS 1999) and was implemented at the former Tuboscope site. IMs implemented at the former Tuboscope site include:

1. The drainage ditch adjacent to the former Tuboscope building location was isolated in 1983 for the collection of contaminated water.
2. A curtain liner was installed in the GC3 Pipeline Access Road east of the drainage ditch in 1988 to prevent off-pad migration of 1,1,1-trichloroethane (1,1,1-TCA).
3. The seasonal removal and treatment of water from the drainage ditch as detailed in the 1999 IM Work Plan (URS 1999) was implemented to capture, stabilize, and reduce the areal extent of the aqueous chlorinated compound plumes.

In 2007, USEPA issued the PBU RCRA Order that included the former Tuboscope site as a SWMU. Paragraph 58 of the PBU RCRA Order required submittal of an update to the IM Work Plan and included provisions to terminate the Tuboscope Order upon USEPA approval of the updated IM Work Plan. The final version of the *Interim Measures Work Plan Former Tuboscope Site* was issued in 2009 (OASIS 2009b) and was submitted USEPA on 10 April 2009. The work plan states: “Interim measures and monitoring at this site will continue under the existing Tuboscope Order until approval by EPA of this revised Interim Measures Work Plan, at which time the Tuboscope Order will be terminated and work continued under the Prudhoe Bay RCRA Order (RCRA-10-2007-0222).” BP Remediation Management (BPRM) submitted an IM work plan for the former Tuboscope site (ERM 2015a) in July 2015, which was approved by USEPA (USEPA 2015), thus satisfying the PBU Order requirement allowing termination of the Tuboscope Order. BPXA again requested termination of the Tuboscope Order in a letter to USEPA dated 31 March 2016. USEPA responded in a letter dated 25 August 2016 stating that the Tuboscope Order would be terminated once acceptable financial assurance is in place under the PBU Order (USEPA 2016), but that in the interim the other Tuboscope Order work requirements would be waived. As of June 2021, USEPA had not yet terminated the Tuboscope Order, pending acceptance of financial assurance documentation for the PBU RCRA Order.

Where applicable, selected data collected prior to and following completion of the RFI has been incorporated in this report. Data collected at the former Tuboscope site in 2015 and 2016 under the IM Termination Pilot Study (ERM 2016b; ERM 2017b) has been incorporated into this report where applicable to delineate the nature and extent of site contamination and define migration pathways to human and ecological receptors. Soil data collected in 2018 during the IM drainage ditch decommissioning project is also included in the dataset as specifically requested by USEPA in 2019.

Oasis Environmental, Inc. (OASIS) performed RFI activities at the former Tuboscope site from 2008 to 2011; ERM Alaska, Inc., (ERM), formerly OASIS, performed RFI activities from 2012 through 2018. ERM also performed the 2015 and 2016 IM Termination Pilot Study. All efforts were executed under the direction of BPRM on behalf of BPXA.

Based on the PBU RCRA Order, the *RCRA Facility Investigation Work Plan, Former Tuboscope Site* (OASIS 2009a), and the subsequent addenda and amendments (OASIS 2012a; OASIS 2012c; ERM 2013c) the following overall objectives were identified:

- Identify and characterize releases of hazardous constituents[1] identified within the area of investigation.
- Define the nature and extent of these releases at or from the area of investigation.
- Characterize potential pathways for hazardous constituent migration.
- Identify actual or potential human and ecological receptors.
- Support the development of an area-of-investigation-specific risk assessment.
- Support the development of alternatives for RCRA Corrective Measures.

Project objectives for each phase of the investigation addressed specific components of the overall objectives for the RFI. Phase-specific investigation objectives are discussed in Section 6.2.

This report adheres to the specifications detailed in the PBU RCRA Order, with two exceptions. The PBU RCRA Order states certain figures are to use a scale of 1 inch equals 50 feet or other such scale approved by USEPA. Due to the size of the former Tuboscope site and the data density in the central portion of the site, a pair of figures have been provided to summarize analytical results for select constituents and to allow figures to be printed on 11-inch by 17-inch paper. The entire data distribution has been shown at a scale of 1 inch equals 180 feet. To allow legible labels to be applied to the higher data density in the central portion of the site, the second figure zooms into this area and uses a scale of 1 inch equals 37.5 feet. The PBU RCRA Order also states that “the concentrations of each constituent shall be clearly visible.” Given the large size of the dataset, labeling the concentration of each constituent would result in figures that would be very difficult to read and understand. Instead, colored symbols were used to indicate whether results exceeded evaluation criteria, and symbol sizes were used to indicate relative constituent concentrations.

The following appendices have been included with this report to provide detailed data and information:

A. Historical Aerial Photographs

B. Curtain Liner As Built Drawings

C. Photographic Log

D. Habitat Map

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[1] RCRA hazardous constituents (hazardous constituents) are listed in 40 Code of Federal Regulations (CFR) 261, Appendix VIII and 40 CFR 264, Appendix IX.

E. Soil Boring and Monitoring Well Logs
F. Geotechnical Reports
G. Thermistor Data and Interpreted Thaw Elevations
H. Pressure Transducer Data
I. Conceptual Site Model
J. Field Notes and Sample Forms
K. TTLA Design and Construction Drawings
L. Comprehensive Laboratory Analytical Data Tables
M. Laboratory Data
N. Statistical Analysis of Background Concentrations
O. Environmental Standards Inc. Validation Reports
P. Data Usability Review
Q. Updated Tier I Screening Levels and Tier II Action Levels

1.1 Historical Activities

The 1968 aerial photograph depicts the undeveloped tundra setting where the BOC pad was constructed. See Appendix A for all historical aerial photographs discussed herein. The road that would become the GC3 Pipeline Access Road first appears in the 1971 aerial photograph. Construction of the BOC pad is first visible in the 1977 aerial photograph. At the time, a strip of land between the pad and the road remained undeveloped tundra. Subsequent aerial photographs show water filling this area over time and the tundra surface in this strip of land sinking. Based on previous documents, this strip of land is referred to as a drainage ditch.

By the time of the 1978 aerial photograph, the eastern portion of the Tuboscope building was constructed, and a large aboveground storage tank is visible just to the north of the building. By the 1981 aerial photograph, construction of the western portion of the building had been completed.

The AMF Tuboscope Company conducted operations at this site from 1978 until 18 February 1982, when a fire destroyed the building. Prior to the fire, this former Tuboscope building was used for inspection and refurbishment of new and used threaded well piping. Pipe cleaning operations occurred within the Tuboscope building. The chlorinated solvent, 1,1,1-TCA, was used to remove lead-containing pipe dope from the threaded pipes. Pipe dope is any thread lubricant or thread sealing compound that is used to make a pipe thread joint leak proof and pressure tight. Pipe dope used in the oil and gas industry at that time may have contained 15 percent copper and 7 percent lead; zinc may also have been present (Jones & Stokes 1990). It is likely that spent solvents were released during pipe cleaning and/or during the fire. A description of the release is provided in Section 1.2, Release Description, below. The Tuboscope shop building was not rebuilt after the fire.

A drilling mud plant was relocated adjacent to the then-operating Tuboscope building in 1981 (IT Alaska, Inc. 2001a). The location of the former drilling mud plant, just north of the former Tuboscope building, is shown on Figure 2. The drilling mud plant is visible on the 1983 aerial photograph of the site, but not on the 1984 aerial photograph.

Over time, gravel addition began to prevent possible north-south flow through the ditch to the east of the Bulk Chemical Building (1981 through 1987 aerial photographs). The 2001 and 2002 aerial photographs show gravel being placed for the first time near the GC3 Pipeline expansion loop, cutting off the drainage ditch to the south.

Due to hazardous constituent releases stemming from the fire at the former Tuboscope building, USEPA issued the Tuboscope Order in 1999 requiring IMs to prevent constituents from migrating to the adjacent tundra northeast of the former Tuboscope building (URS 1999). A summary of the IM activities is provided in Section 1.3, Interim Measures Activities, below.

A large material storage yard, the Material Storage Warehouse, and the Corrosion Inhibitor Chemical (CIC) Storage Facility are in the vicinity of the former Tuboscope building. Two secondary containment areas are present on the north and south sides of the CIC Tanker Truck Loading Areas (TTLA). They are both north of the former Tuboscope building and drilling mud plant locations, shown on Figure 2.

Hazardous constituent releases were discovered at the southern TTLA secondary containment system. The lined area is a 90-foot by 75-foot containment where liquids are transferred between stationary tanks at the CIC Storage Facility and tanker transport trucks. The containment area is less than 200 feet north of the former Tuboscope site in the vicinity of the former drilling mud plant and was investigated in support of design and construction of the TTLA (OASIS 2012d).

The northern TTLA is located on the BOC pad, but outside the area impacted by releases from the former Tuboscope building. The area is a lined 100-foot by 130-foot containment where liquids are transferred between stationary tanks at the CIC Storage Facility and tanker transport trucks. The containment area is on the north side of the CIC Storage Facility, more than 400 feet north of the former Tuboscope building and was investigated prior to construction of the TTLA (OASIS 2010a).

The Material Storage Warehouse is located on the BOC pad, approximately 400 feet west north-west of the former Tuboscope building. A vehicle bull rail is on the southern side of the warehouse building providing electrical outlets to deliver power to engine and equipment heaters needed for winter operations. Light trucks and other personnel are parked in this area. Incidental diesel leaks from light trucks have occurred in this area, which is within the area of investigation but not associated with the SWMU.

1.2 Release Description

A review of historical information for the former Tuboscope site identified documented releases and potential release concerns (OASIS 2008b). Releases were identified based on historical knowledge, the outcome of IM and RFI activities, and analytical results. A fire occurred at the former Tuboscope shop used for pipe cleaning operations resulting in hazardous constituent releases. Released constituents include lead, diesel hydrocarbons, and volatile organic compounds (VOC) including the solvent 1,1,1-TCA, its degradation by-products, and 1,4-dioxane.

The former Tuboscope building had an unlined gravel floor that would not have contained any liquid releases during the fire or during routine operations. In addition, firefighting water aided the transport of released chemicals across the site. Per conversations with BPXA’s greater Prudhoe Bay Waste Coordinator (Vic Ferris), who assisted during firefighting activities at the Tuboscope building, the fire occurred in the middle of the night on 18 February 1982. Strong winds fanned the flames and carried the firefighting water away from the building. BPXA has confirmed firefighting foam was not used to fight the former Tuboscope building fire. However, the fire released 1,1,1-TCA cleaning solvent containing lead and other metals from tubular pipe cleaning. The fire also released diesel fuel from an aboveground storage tank. A review of weather data from the National Oceanic and Atmospheric Administration for the Barrow airport on that day indicates that the low temperature was -43 degrees Fahrenheit (°F). At this temperature, it is likely that water used to fight the fire froze onsite. When this water melted, it would have flowed to the northeast to the former drainage ditch, and then through a culvert on the eastern edge of the pad that ran from the ditch beneath the GC3 Pipeline Access Road and discharged to the adjacent tundra. Impacted water created a secondary source area at the northeast end of the culvert (near sample location ST-52).

A 5,000-gallon aboveground storage tank supplied diesel fuel for the shop building generator. According to the Alaska Department of Environmental Conservation (ADEC) Contaminated Sites Database, a 1,000-gallon diesel release reportedly occurred at the former Tuboscope building on 14 January 1981 (ADEC 2019a). A separate 20-gallon discharge of diesel fuel was reported to ADEC on 27 January 1983 (ADEC 2019a) from the BOC pad drilling mud plant. Additional small diesel fuel releases are recorded in the ADEC Contaminated Sites Database with insufficient information to specifically identify the location of the spills. Little information is available in the ADEC records regarding containment or cleanup actions completed to address the diesel fuel releases.

A drilling mud plant was located immediately to the north of the former Tuboscope building for a few years in the early 1980s. Measured concentrations of barium in surface soil indicate a spatial pattern is present where the former drilling mud plant was located. Pad grading and maintenance performed in the area have redistributed drilling mud formulation materials. Surface soil samples collected from the tundra indicate wind likely transported the dry drilling mud formulation materials (or impacted pad materials) off-pad to the northeast. Samples collected from the former IM drainage ditch indicate winter snow plowing and spring meltwater flow across the pad surface may also have resulted in transport of drilling mud formulation materials.

Table 1.2-1: Documented Hazardous Constituent Releases

Release	Hazardous Constituent	Comments
Former Tuboscope building fire	1,1,1-TCA [a]	The chlorinated solvent, 1,1,1-TCA, was used to remove lead-containing pipe dope from the threaded pipes.
	Lead, copper, and possibly zinc	Pipe dope containing lead, copper, and possibly zinc was associated with routine activities conducted at the former Tuboscope building.
Diesel fuel storage tank/system releases	VOCs (primarily BTEX), SVOCs (primarily PAHs), and Diesel Range Organics (DRO)	Diesel fuel was used to power the former shop building generator.
Former drilling mud plant operations	Barium and other metals	Barium (in the form of barium sulfate) is the primary component in formulation of drilling muds used on the North Slope.

[a] Includes 1,1,1-TCA degradation products (1,1-dichloroethane and chloroethane) and 1,4-dioxane
BTEX: benzene, toluene, ethylbenzene, and total xylenes
PAHs: poly-cyclic aromatic hydrocarbons
VOCs: volatile organic compounds
SVOCs: semi-volatile organic compounds

In addition to the documented releases summarized in Table 1.2-1, RFI data indicate several unassociated releases of hazardous constituents may have occurred, either at or near the former Tuboscope site. Table 1.2-2 summarizes these releases.

Table 1.2-2: Potential and Nearby Releases

Release	Comments	Potential Tuboscope Release	Nearby Release
Diesel hydrocarbon releases in the vicinity of the CIC Storage Facility southern TTLA and former drilling mud plant	Diesel Range Organics (DRO) concentrations measured in soil near and beneath the southern CIC Storage Facility TTLA suggest a small, localized diesel fuel release occurred in this area. Impacted soil was excavated and removed during construction.		X
Barium release at the northern TTLA	Localized barium impacts were documented during pre-construction sampling at the northern TTLA (ERM 2013a). These impacts are separate from releases that occurred at the former drilling mud plant.		X
Diesel hydrocarbon releases at the Material Storage Warehouse bull rail	Hydrocarbon constituents are present in soil and water samples collected at the location of monitoring well MW-26 in the western portion of the southern bull rail at the Material Storage Warehouse. These impacts are localized and separate from releases that occurred at the former Tuboscope building or drilling mud plant.		X
3&4-Methylphenol release(s)	3-Methylphenol and 4-methylphenol (3&4-methylphenol) are present in pad porewater in multiple locations. Plumes with concentrations above the lowest Tier II Action Level are present at two locations. One plume is in the vicinity of the former Tuboscope building; the second plume is to the southeast in the GC3 Pipeline Access Road. The road impacts are separate from the impacts near the former Tuboscope building. The source of the 3&4-methlyphenol impacts is unknown.	X	X

Barium impacts were discovered in surface soil during pre-construction sampling of the northern TTLA at the CIC Storage Facility. These impacts do not originate from, and are not in contact with, releases from historical operations at the former Tuboscope building. Any future action related to these impacts will be performed outside PBU RCRA Order requirements and will be addressed separately under ADEC Contaminated Sites Program regulations.

A small petroleum hydrocarbon release was discovered during the RFI at the southern light vehicle parking area and bull rail at the Material Storage Warehouse. This release does not originate from, and is not in contact with, releases from historical operations at the former Tuboscope building. Any subsequent monitoring or future corrective action related to this release will be performed outside PBU RCRA Order requirements and will be addressed separately under ADEC Contaminated Sites Program regulations.

Based on the location of the 3&4-methylphenol plume at the former Tuboscope building location, it may be related to historical site activities. The plume of 3&4-methylphenol at the GC3 Pipeline Access Road is separate and may be unrelated to the plume present at the former Tuboscope building.

Once released into the environment, organic constituents may biodegrade. This process consumes electron acceptors and can result in localized changes to the geochemistry. Where such changes have mobilized metals, they have been described as secondary releases.

Figures provided with this report show the spatial extent of select RFI constituents of potential concern (COPC). COPCs are present in pad gravel, pad porewater, tundra soil, tundra suprapermafrost groundwater (SPGW), and surface water in area of investigation.

1.2.1 Source Area Description

Contamination likely originated from the source areas shown on Figure 2. These include:

- The former Tuboscope building and an adjacent 5,000-gallon aboveground fuel storage tank
- The former drilling mud plant
- The CIC Storage Facility southern TTLA where a small, localized diesel fuel release was discovered and partially removed (OASIS 2012d; OASIS 2014)

Figures ES-1, ES-2, and ES-3 summarize the extents of the chlorinated solvent, 1,4-dioxane, and petroleum hydrocarbon contamination (respectively). The subsequent sections describe the migration, secondary sources, activities that have reduced impacts, and temporal trends and plume stability.

1.2.2 Nearby Releases

Four potential releases in the area of investigation have been documented near the former Tuboscope site, but these nearby releases are not associated with the Tuboscope site (Table 1.2-2):

- Diesel hydrocarbon releases in the vicinity of the CIC Storage Facility southern TTLA and former drilling mud plant
- Barium release at the northern TTLA
- Diesel hydrocarbon releases at the Material Storage Warehouse bull rail
- 3&4-Methylphenol release to the southeast in the GC3 Pipeline Access Road

Any future investigation or corrective action for these impacts will progress separately under ADEC Contaminated Sites Program regulations. Investigation will not be pursued under the PBU RCRA Order since the impacts detected in this area are not associated with historical activities conducted at the former Tuboscope building.

Diesel Range Organics (DRO) concentrations measured in soil near and beneath the southern CIC Storage Facility TTLA suggest a small, localized diesel fuel release occurred in this area. Diesel-fuel-impacted soil was removed during construction of the TTLA secondary containment area. In contrast, diesel fuel impacts present to the east of the southern TTLA and north of the former Tuboscope building may be associated with releases from the 5,000-gallon aboveground diesel fuel tank at the former Tuboscope building.

As reported in the *2012 Interim Measures System Evaluation Site Assessment and RCRA Facility Investigation Interim Summary Report* (ERM 2014a), petroleum constituents were detected in pad porewater at the western edge of the pad, near the southern light vehicle parking area at the materials storage building (ERM 2014a). This release is not connected to the diesel release at the former Tuboscope building and may be attributed to activities associated with the road vehicle bull rail that was present at this location (ERM 2014a). Ethylbenzene concentrations in pad porewater are present above the lowest Tier II Action Levels (ALs) at this location. The extent of the ethylbenzene plume is isolated from the former Tuboscope site building and is due to a separate release.

Concentrations of 3&4-methylphenol indicate an exceedance of the lowest Tier II ALs at monitoring wells MW-56 and MW-92 in the gas-line road southeast of the former Tuboscope building. The 3&4-methylphenol plume in this area is separate from a 3&4-methylphenol plume at the former Tuboscope building. The source of 3&4-methylphenol impacts has not been identified and does not appear to be related to releases at the former Tuboscope building.

1.3 Interim Measures Activities

The Tuboscope Order required the development and implementation of IMs to control or abate threats to human health and/or environment and to prevent or minimize the spread of hazardous constituents from the accidental release. The initial IM Work Plan was approved in 1999 (URS 1999) and was implemented at the former Tuboscope site. IMs implemented by BPXA at the former Tuboscope site between 1983 and 2014 are summarized below. Details regarding these activities can be found in the following documents: *Former Tuboscope Site Interim Measures Work Plan* (URS 1999), Section 4.0 of the *2007 System Evaluation Site Assessment Work Plan* (OASIS 2007a), and the *2012 Interim Measures System Evaluation Site Assessment and RCRA Facility Investigation Interim Summary Report* (ERM 2014a).

- 1983: The drainage ditch adjacent to the source area (the former Tuboscope building) was isolated for the collection of contaminated water. The culvert between the drainage ditch and the off pad setting to the east was sealed at this time.
- 1988: The curtain liner was installed in the GC3 Pipeline Access Road to the east of the drainage ditch. The culvert between the drainage ditch and the off pad setting to the east was removed.
- 1995 to 1996: An assessment of water handling alternatives for the drainage ditch water was performed (OASIS 2007a). A granular-activated carbon treatment system was designed, installed, and ran for two days in 1996. This treatment system was designed to remove 1,1,1-TCA from water captured in the former drainage ditch (Figure 2) prior to disposal via a permitted underground injection well.
- 1997: A one-time only Contained-In Determination (CID), meaning the contaminated media could be considered to no longer contain hazardous waste, was received from USEPA (USEPA 1997). The treatment system extracted and treated 10,000 gallons of water from the drainage ditch. The water was disposed of at the Pad 3 Class I injection well.
- 1998: The IM Work Plan (URS 1999) was submitted to USEPA. A one-time only CID was received from USEPA (USEPA 1998) for disposal of water extracted from the drainage ditch and treated during 1998.
- 1999: The Tuboscope Order was finalized. USEPA approved the IM Work Plan and issued a new CID (USEPA 1999a; USEPA 1999b).
- 2000: USEPA approved the revised IM Work Plan (URS 1999) and revised the CID (USEPA 2000b).
- 2000 to 2001: The water extraction and treatment system IM was operated for both thaw seasons. A total of 92,400 gallons of water were extracted from the drainage ditch, treated, and disposed of (URS 2000; IT Alaska 2001b).
- 2002: System evaluation site assessments (SESA) were scheduled to occur once every 5 years. The first SESA was performed in accordance with Section 5.7 of the approved *Former Tuboscope Site Interim Measures Work Plan* (URS 1999) to assess the effectiveness of the IM. Results showed that the IM had been effective at reducing the areal extent of the 1,1,1-TCA plume, as well as at preventing the migration of 1,1,1-TCA to the off-pad setting (OASIS 2002). Concentrations of 1,1,1-TCA; 1,1-dichloroethane (1,1-DCA); lead; and DRO in near-surface soil samples collected during the 2002 SESA indicated that while contaminants released in the fire are present in surface soil at the former Tuboscope site they had not completely mobilized to the subsurface (OASIS 2002). No modifications to the IM were recommended. A total of 89,334 gallons of water were extracted from the drainage ditch, treated, and disposed of at the Pad 3 Class I injection well in 2002 (OASIS and E2 Solutions 2002).

- 2003 to 2006: The water extraction and treatment system IM was operated during each thaw season in 2003, 2004, 2005, and 2006. A total of 599,340 gallons of water were extracted from the drainage ditch, treated, and disposed of at the Pad 3 Class I injection well during this 4-year period.
- 2007: The second SESA was performed. Sampling efforts were combined with supplemental sampling performed to further evaluate the use of bimetallic (iron and palladium) nanoscale particles (BNP) to remediate 1,1,1-TCA (OASIS 2007b). The combined assessment results indicated that the aqueous chlorinated solvent plumes were stable or reduced in size since the 2002 assessment, suggesting that the water extraction and treatment system IM had been operating as designed (OASIS 2008c). A total of 90,762 gallons of water were extracted from the drainage ditch, treated, and disposed of at the Pad 3 Class I injection well in 2007 (OASIS and E2 Solutions 2007).
- 2008 to 2011: The water extraction and treatment system IM was operated during each thaw season in 2008, 2009, 2010, and 2011. A total of 477,330 gallons of water were extracted from the drainage ditch, treated, and disposed of at the Pad 3 Class I injection well during this 4-year period (OASIS 2008e; OASIS 2009c; OASIS 2010b; OASIS 2011).
- 2012: Data for the 2012 SESA was collected in conjunction with a sampling event performed as part of the RFI and focused on evaluating the continued effectiveness of the IM. The results of the 2012 SESA indicated that the concentrations of the chlorinated constituents had generally decreased since 2007 (ERM 2014a). A comparison of the areal extent of 1,1,1-TCA dissolved in the water in 2012 to the areal extent in 2007 shows that the dissolved plume for 1,1,1-TCA appeared to be stable and did not extend far beyond the edge of the pad (ERM 2014a). A total of 151,704 gallons of water were extracted from the drainage ditch, treated, and disposed of at the Pad 3 Class I injection well (OASIS 2012f).
- 2013 to 2014: The water extraction and treatment system IM was operated during the 2013 and 2014 thaw seasons. A total of 363,342 gallons of water were extracted from the drainage ditch, treated, and disposed of at the Pad 3 Class I injection well during this 2-year period (ERM 2013b; ERM 2014c). The *Final Former Tuboscope Site Interim Measure Water Treatment System Operations and Maintenance Manual* was issued in 2013 (OASIS 2013).
- 2015 to 2016: An IM Termination Pilot Study was conducted in 2015 and 2016 to evaluate site conditions under a simulated IM termination scenario to determine if, or under what conditions, the water extraction and treatment IM could be terminated. The simulated IM termination scenario was accomplished by maintaining the water level in the drainage ditch to mimic site conditions that would occur if the drainage ditch were backfilled. Water elevation and temperature data collected in 2015 show that simulated termination did not alter pad porewater flow direction or thaw depth (ERM 2016b; ERM 2016c). Analytical results from samples collected in 2015 and 2016 show that with a few exceptions, concentrations of primary constituents of interest (COI), 1,1,1-TCA, 1,1-DCA, chloroethane, 1,4-dioxane, and lead, did not change. Rebound of COI concentrations in monitoring wells immediately downgradient of the source area was not observed (ERM 2016b; ERM 2017a).
- 2018: IM Drainage Ditch Decommissioning: The 2015 and 2016 IM Termination Pilot Study determined extraction and treatment of water from the drainage ditch no longer supported its intended purpose. Following USEPA termination of the IM requirement for the former Tuboscope site and USEPA approval, the drainage ditch was backfilled in the summer of 2018, eliminating the need to manage accumulated precipitation and pad porewater in the drainage ditch (ERM 2019a). At the request of the USEPA, three surface soil samples and three subsurface soil samples were collected from the bottom of the ditch prior to its being backfilled. Results of these soil samples are included in the dataset used for this report and in the *2018 IM Measures Annual Operations and Drainage Ditch Decommissioning Report* (ERM 2019a).

- 2019: IM Drainage Ditch Decommissioning Water Monitoring: USEPA approval of IM decommissioning included a requirement for the collection of pad porewater and surface water samples. The 2019 results showed increased concentrations for several key COIs (1,1,1-TCA, 1,1-DCA, chloroethane, and DRO) in comparison to recent data generated in 2012, 2015, and 2016 at multiple locations (ERM 2020a). When the drainage ditch was backfilled in 2018, the additional weight appears to have compressed underlying tundra soil, forcing excess water (and constituents) out and up. ERM hypothesized that the 2019 results showed increased concentrations in some locations due to discharge of water from the tundra soil and due to temporary changes in pad porewater flow direction.
- 2020: IM Drainage Ditch Decommissioning Water Monitoring: Based on the increased COI concentrations measured in 2019, additional pad porewater and surface water monitoring was conducted in 2020 (ERM 2020b).

1.4 Applicable Regulations

1.4.1 RCRA Background

In 1976, RCRA was created as the first amendment to the Solid Waste Disposal Act. The 1984 Hazardous and Solid Waste Amendments expanded the scope and requirements of RCRA. The 1984 Hazardous and Solid Waste Amendment extended corrective action authority at treatment, storage, and disposal facilities to all waste management at units that received solid or hazardous waste at any time. RCRA provides USEPA with the authority to require investigation and remediation of these releases at RCRA facilities.

The corrective action program is an important part of RCRA, but it is largely not codified in regulation. Most of the actual or potential requirements are addressed in a 1996 Advance Notice of Proposed Rulemaking (61 Federal Register 19432) (USEPA 1996), and previously proposed rules (55 Federal Register 30798) (USEPA 1990a) that were never formally approved. These are used as guidance; specific requirements may be established through a RCRA permit, voluntary agreement, order, or administrative or judicial action.

1.4.2 Applicability of RCRA to the Former Tuboscope Site

The former Tuboscope site is part of the Prudhoe Bay Western Operating Area and was operated by the AMF Tuboscope Company for inspection and refurbishment of new and used threaded well piping. Operations were conducted from 1978 until 18 February 1982, when a fire destroyed the building. On 18 February 1982, Sections 3004 and 3005 of RCRA became applicable to the former Tuboscope site, requiring that a permit be obtained.

The Tuboscope Order was issued on 6 August 1999 to BPXA as the operator of the Prudhoe Bay facility under Section 3008(h) of RCRA, which allows USEPA to take enforcement action to require corrective action at an interim status hazardous waste treatment, storage, and disposal facility. The Tuboscope Order is a negotiated settlement between USEPA and BPXA. Similarly, the PBU RCRA Order was issued to BPXA as the operator of the Prudhoe Bay facility under Section 3008(h) of RCRA and is considered a consent order because it represents a negotiated settlement between USEPA and BPXA. The PBU RCRA Order is incorporated by reference into the RCRA permit for the PBU Hazardous Waste Process Facility. Hilcorp Energy Company, LLC acquired BPXA on 1 July 2020 and became the operator of the PBU as HNS. The RFI was performed at the former Tuboscope site in accordance with the PBU RCRA Order.

In accordance with both the Tuboscope Order and the PBU RCRA Order, the former Tuboscope site has been identified as a SWMU. A SWMU is any discernable unit at which solid wastes have been placed at any time, irrespective of whether the unit was intended for the management of solid or hazardous waste. The PBU RCRA Order lists the former Tuboscope site as SWMU 4.1 (Tuboscope), the only SWMU in Project Group IV. The Order defines an Area of Concern (AOC) as “any area of the Site where a release to the environment of hazardous waste or hazardous constituents has occurred, is suspected to have occurred, or may occur, regardless of the frequency or duration of the release.” The former Tuboscope site has elements of both a SWMU and an AOC but in this document, the former Tuboscope site is simply referred to as a SWMU to be consistent with the terminology used in the Tuboscope and PBU RCRA Orders.

1.4.3 Status of RCRA Corrective Action at the Former Tuboscope Site

The first element of the corrective action process is the initial site assessment, which is referred to as a RCRA Facility Assessment (RFA). The RFA compiles existing information on environmental conditions at a given SWMU or Area of Concern, including information on actual or potential releases. This data is used to determine areas of potential concern. The RFA for the Western Operating Area was completed in December 1989 and the former Tuboscope site was identified as SWMU #72 (USEPA. 1990b). Documented releases of 1,1,1-TCA and #2 diesel oil were listed in the RFA. Data from groundwater and surface water monitoring conducted in 2019 and 2020 is discussed in Section 6.2.1.9 but became available after the comprehensive RFI data set was finalized and has not been included in the tables or figures for this report. The 2019 and 2020 data will be considered in development of the corrective measures study (CMS) for the former Tuboscope site.

Under the PBU RCRA Order, site characterization is accomplished under an RFI. The RFI is used to assess the nature and extent of contamination from releases identified during the RFA. USEPA emphasizes that remedial investigations should be tailored to the specific conditions and circumstances at the SWMU or Area of Concern and focus on the units, releases, and exposure pathways of concern (61 Federal Register 19432). Attachment E of the PBU RCRA Order details requirements for RFI work plans and reports. Data collected in support of the RFI meets PBU RCRA Order requirements and project data quality objectives (DQO) and are suitable for assessing the appropriateness of corrective measures to protect human health and the environment. Over the 9 years when RFI samples were collected, data completeness ranged from 98.5 to 100 percent.

The RFI at the former Tuboscope site began in 2008 and continued through 2018. Additional information collected during IM activities after 2013 has also been included in the RFI. Specifically, at the request of USEPA, results for soil samples collected in 2018 during the IM water treatment system decommissioning have been included. Results for groundwater and surface water monitoring conducted in 2019 and 2020 are not part of the RFI dataset and have not been included in the tables or figures. An overview of results for these two monitoring events is presented in Section 6.2.1.9. These data will be considered during the CMS.

IM are short-term actions to control ongoing risks while the investigation is underway or before a final remedy is selected. IM implemented by BPXA at the former Tuboscope site under the 1999 IM Work Plan (URS 1999) included isolation of the drainage ditch east of the former Tuboscope building location (source area), the previously installed vertical curtain liner in the GC3 Pipeline Access Road, and seasonal removal and treatment of water captured in the drainage ditch. USEPA approved a revised CID in 2015 (USEPA 2015) and, per the requirements of the 2015 CID, water treatment was no longer necessary unless the CID criteria were exceeded. Treatment of water captured in the former Tuboscope site drainage ditch ceased in 2014. The drainage ditch was decommissioned in 2018 (ERM 2019a) leaving only the curtain liner IM at the former Tuboscope site. The curtain liner reduces flow, although some pad porewater flows over the top of the curtain liner.

1.4.4 Evaluation Criteria and Constituents of Interest

Data in this report were assessed using the Evaluation Criteria described in this section. Paragraph 52 and Attachment D of the PBU RCRA Order require the establishment of Site screening levels. Specifically, the PBU RCRA Order states: “The proposed Site screening levels shall be based on EPA accepted risk-based sources and shall be developed in consideration of both human health and ecological receptors together with the unique environmental characteristics of the North Slope.”

In accordance with the first part of this definition, Tier I Screening Levels (SL) were developed based on USEPA-accepted risk-based sources that represent the lowest available risk-based concentrations identified from a variety of regulatory sources. All analytical results were compared to lowest Tier I SLs in frequency of detection tables and the comprehensive analytical data tables in Appendix L.

Tier II ALs were developed to account for the “unique environmental characteristics of the North Slope.” Analytical results were compared to lowest Tier II ALs in frequency of detection tables and analytical data tables, results figures, and text descriptions. The most recent Tier I SLs and Tier II ALs have been used to prepare this Comprehensive RFI Report. These criteria are:

- Defined in the *Site-Wide Conceptual Model and Screening Levels Report* (SLR 2016)
- Updated in the 2019 *RCRA Annual Report, Prudhoe Bay Facility, Alaska* (Hobbit Environmental Consulting Corp. 2020)
- Updated in Appendix Q of this report

Tables presented in the Appendix Q update are comprehensive in that they include all changes proposed to date, as well as values for which no changes have been proposed. As of May 2022, the updates have not been approved by USEPA.

In addition to Tier I SLs and Tier II ALs, the following Evaluation Criteria were used as necessary:

- Naturally occurring background concentrations as represented by PBU-wide background threshold values (BTV) (SLR 2018; SLR 2019a)
- Alaska Water Quality Standards (AWQS) (ADEC 2008; ADEC 2020)
- State of Alaska cleanup levels (CL) for ADEC-regulated hazardous substances not regulated by USEPA (ADEC 2018) as detailed in Section 1.4.4.3

Table 1 provides a legend for data tables (including comprehensive data tables located in Appendix L) and details the sources of values for used for Evaluation Criteria. Quantitative values for Evaluation Criteria are presented in Table 2. These tables follow the text.

1.4.4.1 Constituents of Interest

The RFI performed at the former Tuboscope site produced approximately 91,000 individual constituent analytical results for environmental media within the approximately 23-acre area where impacts are potentially present from SWMU-specific releases. Historical activities at the former Tuboscope site have resulted in impacts with several hazardous constituents reported at concentrations elevated above applicable Evaluation Criteria.

The former Tuboscope site has been identified as an “Exceptional Site” (ERM 2016a). It is not considered a typical upstream oil and gas exploration or production facility; therefore, COIs identified for the former Tuboscope site (listed in Table 2) include additional, atypical chemicals not common to other investigations that will be performed within the Prudhoe Bay facility. The COIs were defined as investigation analytes in the *RCRA Facility Investigation Work Plan, Former Tuboscope Site* (OASIS

2009a) and the subsequent addenda and amendments (OASIS 2012a; OASIS 2012c; ERM 2013c). These COIs were selected based on the following:

- Historical operations and releases at the former Tuboscope building and the nearby former drilling mud plant
- Prudhoe Bay facility-specific information sources (materials used, stored, or produced in significant quantities in the Prudhoe Bay facility, historical hazardous waste management, historical spills and releases, and validated laboratory analytical results)
- Constituents presented in the *Regulated Constituents of Potential Concern Report* (ERM 2016a)
- Site history from the Comprehensive Standard Laboratory Analyte List presented in Table 3-7 of the *Regulated Constituents of Potential Concern Report* (ERM 2016a) and Table B4-1 in the *Quality Assurance Project Plan* (QAPP) *for Administrative Order for Corrective Action under Section 3008(h) of the RCRA – BPXA's Prudhoe Bay Facility* (herein after referred to as the "Site-wide QAPP") (Environmental Standards 2008, 2013, 2014, 2017)

Due to gaps in site history, analytical testing has been performed to include the complete laboratory analytical method lists. COIs include a wide spectrum of VOCs, semi-volatile organic compounds (SVOC), poly-cyclic aromatic hydrocarbons (PAH), and metals applicable to an investigation of this Exceptional Site. Constituents were analyzed as per approved work plans. For each phase of the RFI, the latest version of the *Site-Wide Conceptual Site Model and Screening Levels* report identified the Tier I SLs and Tier II ALs used for that phase (SLR 2008, 2011, 2012, 2013a, 2015a, 2016). These reports were used to define the DQOs for each subsequent phase of the RFI.

Additional evaluation against ADEC-only CLs for hazardous substances not regulated by RCRA and against AWQS is included to inform future decision making by ADEC under its regulatory programs (see Section 1.4.4.3).

1.4.4.2 Screening Levels and Action Levels

As required by the PBU RCRA Order, concentrations of COIs are initially compared to screening levels. USEPA has approved the use of tiered screening levels. The term "lowest Tier I SL" refers to the lower of a constituent's respective human health and ecological values.

As detailed in the *Site-Wide Conceptual Model and Screening Levels Report*, Tier I SLs are based on protection of human health and ecological receptors. Tier I SLs are generic, conservative values based on human health and ecological receptors. Tier I SLs are based on USEPA-accepted risk-based sources that represent the lowest available risk-based concentrations identified from a variety of regulatory sources, including USEPA, the ADEC, the National Oceanic and Atmospheric Administration, the states of Oregon and Washington, and Oak Ridge National Laboratory. Some Tier I SLs may not be solely risk-based; Tier I SLs do not reflect conditions in the PBU. Typically, the human health Tier I SL is a regulatory standard (e.g., maximum contaminant level) or a risk-based value adjusted to a target hazard quotient of 0.1 and/or to an excess lifetime cancer risk of $1x10^{-6}$ based on conservative, generic exposure assumptions (SLR 2016). Tier I SLs were initially developed for soil and water for the list of PBU RCRA Order Constituents of Potential Concern (RO-COPC) defined in the *Regulated Constituents of Potential Concern Report* (ERM 2016a), but the list has been expanded to include values for additional constituents.

Where Tier I SLs are proposed in Appendix Q, COI concentrations in soil, SPGW, and surface water have been compared to these levels to assess whether hazardous constituents could pose an unacceptable human health or ecological threat. All COIs are also subjected to Tier II evaluation. The process for developing Tier I SLs and Tier II ALs is described in detail in the 2016 *Site-Wide Conceptual Model and*

Screening Levels Report and remains unchanged in the *2019 RCRA Annual Report* and in Appendix Q except as noted.

Development of Tier II human health ALs relies on the availability of relevant toxicity data. Development of Tier II ecological ALs relies on the availability of relevant studies for ecological receptors. Table 1.4-3 details selection of Tier II ALs based on whether human health Tier II ALs, ecological Tier II ALs, both, or neither are available. In this document, the selected values are referred to as lowest Tier II ALs.

Table 1.4-3: Selection of Tier II Action Levels

Human health Tier II AL	Available	Available	Not available	Not available
Ecological Tier II AL	Available	Not available	Available	Not available
Selected Tier II AL	Use lower of human health and ecological Tier II AL	Use lower of human health Tier II AL and the ecological Tier I SL (unless an attempt was made to develop the ecological Tier II AL but there was insufficient data)	Use lower of ecological Tier II AL and the human health Tier I SL (unless an attempt was made to develop the human health Tier II AL but there was insufficient data)	Default to lowest Tier I SL

Tier II ALs consider both human health and ecological risk. Like Tier I SLs for human health, Tier II ALs for human health are conservative as they target a hazard quotient of 0.1 and an excess lifetime cancer risk of $1x10^{-6}$ (SLR 2016). The lowest Tier II human health ALs for soil and water are based on the most sensitive of the following:

- Industrial worker
- Current non-resident subsistence user
- Potential future resident subsistence user

Tier II ALs for each of these human health receptors considers oral, dermal, and inhalation exposure; the non-resident subsistence user also included biota ingestion.

The lowest Tier II ecological values for soil are based on protecting the most sensitive of the following terrestrial indicator species:

- Mammals
  - Arctic shrew
  - Brown lemming
  - Least weasel
- Birds
  - Willow ptarmigan
  - Snow goose
  - Lapland longspur
  - Snowy owl

- Plants

The lowest Tier II ecological values for waters are based on protecting the most sensitive of the following aquatic receptors:

- Arctic loon
- Algae
- Zooplankton
- Fish

The lowest Tier II AL is the value protective of the most sensitive of the above-listed receptors, regardless of the presence of a pathway of exposure.

As documented in Appendix C of the *Site-Wide Conceptual Model and Screening Levels Report* (SLR 2016), an extensive literature review was conducted to identify available toxicological data applicable to each ecological receptor listed in the Site-wide CSM for a broad range of constituents. Ecological Tier II ALs were not developed for constituents for which no relevant toxicity studies could be identified. Ecological Tier II ALs for such constituents are listed as NA (not available) in Table 23 of Appendix Q, indicating that it was not possible to develop an ecological Tier II AL because the required ecological toxicity data was not available. Although Tier I ecological screening levels are updated regularly, the literature review of ecological toxicity data had not been repeated for annual updates to Tier II ALs, including those published in the *2019 RCRA Annual Report* (Hobbit Environmental Consulting Corp. 2020). In contrast to the *Site-Wide Conceptual Model and Screening Levels Report*, the *2019 RCRA Annual Report* does not assess the possibility of developing ecological Tier II ALs for constituents added since 2016. Specifically, for several constituents the Tier II AL was the human health-based Tier II AL and the availability of data required to develop an ecological Tier II AL had not been assessed since 2016. To help ensure the adequacy of the Tier I SLs and Tier II ALs, the following checks were made:

- For COIs without a Tier I SL, Tier II AL, or ADEC-only cleanup level, frequency of detection data was tabulated and reviewed. The determination of whether to develop additional Tier I SLs was based on the standard established by USEPA in *Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual*, Section 5.9.3: Evaluate Frequency of Detection (USEPA 1989b). Based on this review, no additional Tier I SLs are required.
- COIs without an ecologically-based Tier II AL and that have a Tier I SL based on protection of ecological receptors that is lower than the Tier II AL based on protection of human health were reviewed to help ensure adequate protection of ecological receptors.
    - In the case of constituents for which both the Tier I ecological SL and the Tier II human health AL remain unchanged from the USEPA-approved *Revised Site-Wide Conceptual Site Model and Screening Levels Report* (SLR 2016), those Evaluation Criteria have been used.
    - Additional Evaluation Criteria were not developed for constituents with no analytical results above the ecological Tier I SL in either the Tuboscope comprehensive RFI dataset or the Sand Dunes Landfill comprehensive RFI dataset.
    - Where sufficient data is available, ecological Tier II ALs were developed for the following constituents because 1) their current Evaluation Criteria were not approved by USEPA as part of the *Revised Site-Wide Conceptual Site Model and Screening Levels Report* (SLR 2016), 2) they are present in either the Tuboscope comprehensive RFI dataset or the Sand Dunes Landfill comprehensive RFI dataset (or both), and 3) measured concentrations exceed Tier I SLs: 1,1-dichloroethane, 1,1,2,2-tetrachloroethane, and isopropylbenzene in soil and water. See Appendix Q for details.

- Manganese is on the “Core List of Additional Regulated COPCs” presented in the *Regulated Constituents of Potential Concern Report* (ERM 2016a). ADEC cleanup levels for manganese in soil and groundwater were subsequently published in September 2018. For manganese in soil and water, Tier I human health SLs, Tier II human health ALs, and Tier II ecological ALs have been developed, as detailed in Appendix Q.
- For total chromium in soil, a Tier I human health SL, Tier II human health AL, and Tier II ecological AL were developed (Appendix Q). New Tier II hexavalent chromium ALs were also developed for various avian receptors and were used to develop total chromium ALs for birds.
- Ecological Tier II ALs were developed for 1,4-dioxane (Appendix Q).

For the following constituents in soil, an ecological Tier II AL is not available, and the ecological Tier I SL has been substituted:

- Benzo(k)fluoranthene
- Chrysene
- Dibenz(a,h)anthracene
- Dibenzofuran
- 1,1,2,2-Tetrachloroethane
- 1,1-Dichloroethane
- 1,4-Dichlorobenzene
- Isopropylbenzene
- Styrene
- Trichlorofluoromethane

For styrene and 2-methylphenol in water, an ecological Tier II AL is not available, and the ecological Tier I SL has been substituted. For lead in water, a human health Tier II AL is not available and the human health Tier I SL has been substituted.

Development of additional Tier I SLs and Tier II ALs is detailed in Appendix Q, which is being provided for USEPA approval.

1.4.4.3 State of Alaska Requirements

In addition to the RCRA corrective action requirements specified in the PBU RCRA Order, State of Alaska regulations have been evaluated for potential applicability at the former Tuboscope site. This evaluation included the ADEC Contaminated Sites Program and Water Quality Program. An overview of the applicable ADEC requirements is provided below.

18 AAC 75 – ADEC-Only Cleanup Levels

ADEC Contaminated Sites Program regulations are defined in 18 Alaska Administrative Code (AAC) 75, *Oil and Other Hazardous Substances Pollution Control* (ADEC 2018). The ADEC Contaminated Sites Program maintains a database of contaminated sites located in the state. The database lists the former Tuboscope site under File Number 300.38.094, Hazard ID 1176, and the Site Name Hilcorp NS Tuboscope, Inc. Lease Tract (BPX).

The *Regulated Constituents of Potential Concern Report* (ERM 2016a) included a core list of additional ADEC-regulated COPCs. That list included the following constituents for which Tier I SLs and Tier II ALs have been assigned: n-propylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, 1-methylnaphthalene, chromium (III), chromium (VI), and manganese.

Soil and groundwater CLs promulgated in 18 AAC 75 have been used as Evaluation Criteria only for ADEC-only constituents. Specifically, analytical results for DRO, bromobenzene, n-butylbenzene, sec-butylbenzene, tert-butylbenzene, methyl-tert-butyl ether, cyclohexane, and hexane have been compared to 18 AAC 75 CLs (ADEC 2018). For these COIs, results for soil samples have been compared to human health CLs for soil in the arctic zone, and results for SPGW and pad porewater samples have been compared to the groundwater human health CL.

ADEC procedures require that contaminants at a site do not exceed cumulative risk thresholds for carcinogenic and noncarcinogenic compounds, accounting for exposure to multiple contaminants across multiple pathways. To determine which ADEC-only constituents are considered COPCs, maximum detected analytical results have been compared to 1/10th of their 18 AAC 75 CLs (ADEC 2018).

18 AAC 70 – Alaska Water Quality Standards

The State of Alaska has established AWQS based on protected water use classes and subclasses. Examples of protected water uses include agricultural water supply and contact water recreation. In Alaska, waterbodies are, by default, protected for all water use classes and subclasses listed in 18 AAC 70.020. Unless ADEC has reclassified a water body in accordance with 18 AAC 70.220 or 18 AAC 70.235, the applicable standard is the lowest of the values established for each of the protected water uses. AWQS are detailed in *18 AAC 70: Water Quality Standards*, which adopts the *Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances* (ADEC 2008) by reference. ADEC regulations at 18 AAC 75.345 (f) require that “Groundwater that is closely connected hydrologically to nearby surface water may not cause a violation of the water quality standards in 18 AAC 70 for surface water or sediment.”

Table 2 presents applicable quantitative AWQS requirements for VOCs, SVOCs, metals, petroleum hydrocarbons, and other organic and inorganic parameters. For some metals, AWQS published in *Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances* distinguish between dissolved and total values. To screen metals concentrations, if the ADEC Manual does not specify whether an AWQS is based on a dissolved or total concentration, both dissolved and total constituent concentrations measured in surface water and SPGW closely connected hydrologically to surface water are compared to AWQS. For antimony, barium, iron, manganese, mercury, and vanadium, the AWQS does not distinguish between the total and dissolved form of the metal and both dissolved and total values have been compared to the AWQS.

Hardness-dependent AWQS are applicable to dissolved cadmium, chromium (III), dissolved copper, dissolved lead, dissolved nickel, and dissolved zinc (ADEC 2008). For these metals, the AWQS has been calculated based on the hardness of the water in each individual sample; for samples without associated hardness data, the default hardness value of 100 milligrams per liter (mg/L) was assumed.

The "Core List of Additional ADEC-Regulated COPCs," as outlined in the *Regulated Constituents of Potential Concern Report* (ERM 2016) includes pH, which is only regulated under AWQS in surface water. Although pH is amongst the water quality parameters, it is not a COI and no analytical samples were collected for pH. No acids or bases were disposed of at the former Tuboscope site, and pH results have not been evaluated against the AWQS.

1.4.4.4 Background Threshold Values

An evaluation process involving multiple steps for distinguishing naturally occurring (i.e., background) concentrations of metals from those influenced by a release has been defined and is discussed in Section

6.2.6. The assessment is limited to select metals that may be naturally occurring or may be associated with a release. Determination of whether the concentration of a metal is naturally occurring or due to a release is made based on multiple lines of evidence. One line of evidence used is comparison to PBU-wide background threshold values (BTV) (SLR 2018; SLR 2019a).

BTVs for select metals in soil and surface water are presented in Table 2. These values are based on samples collected from across the Prudhoe Bay facility. BTVs were calculated based on the 95 percent upper tolerance limit of the 90th percentile concentrations based on background data available for soil across the Prudhoe Bay facility (SLR 2019a), and for surface water from small and medium/large size lakes within the Prudhoe Bay facility (SLR 2018). Two types of BTVs are available for soil. The first is applicable to mineral soil (SM) and pad material/gravel (SO); the second is applicable to tundra soil (TN). There are no BTVs for pad porewater or SPGW; therefore, concentrations of metals in pad porewater and SPGW are compared to BTVs calculated for surface water (SLR 2018).

Because BTVs are not available for pad gravel and pad porewater, analytical results for COIs in pad gravel and pad porewater have been compared to results for un-impacted gravel and SPGW from the Put 23 mine site that was presented in the draft *Consolidated Background Report, Prudhoe Bay Facility* (SLR 2013b). The draft *Consolidated Background Report* has not been approved by USEPA, and Put 23 results were used for comparison purposes as one of multiple lines of evidence.

1.5 Land Ownership and Management

The State of Alaska owns the land where the former Tuboscope site is located. This land is leased to HNS as part of the Prudhoe Bay facility and is managed by the Alaska Department of Natural Resources (ADNR) Division of Mining, Land, and Water. At lease termination, the land is required to be returned in a condition satisfactory to the ADNR Commissioner. The North Slope Borough has zoned the BOC pad, where the former Tuboscope site is located, and the surrounding area for resource development (North Slope Borough 2005). The purpose of the resource development district is to accommodate large-scale resource extraction.

1.6 Stakeholders

In addition to ADNR, the current land user, regulatory agencies, and other stakeholders may have an interest in the results of the RFI and in any corrective measures required at the former Tuboscope site. These stakeholders are described below.

1.6.1 Current Lease Holder

The area of the Prudhoe Bay facility that includes the former Tuboscope site is currently leased from the State of Alaska to HNS and is operated as part of an active oil and gas facility. There are no other current land users at the former Tuboscope site. Oil and gas production and related activities within the Prudhoe Bay facility are expected to continue for another 40 years.

1.6.2 Regulatory Agencies

Regulatory agencies involved in the corrective action process at the former Tuboscope site include the USEPA and the ADEC. The USEPA provides regulatory oversight for both the Tuboscope Order and the PBU RCRA Order. The former Tuboscope site is subject to ADEC's Contaminated Sites Program regulations. The former Tuboscope site is listed in the ADEC Contaminated Sites Program database under Contaminated Sites File No. 300.38.094.

1.6.3 Other Stakeholders

The Prudhoe Bay facility is located within the North Slope Borough and the village of Nuiqsut is the closest inhabited community, approximately 62 miles west of the Prudhoe Bay facility. The only other nearby communities include the villages of Utqiagvik (formerly Barrow) and Kaktovik (on Barter Island, approximately 100 miles away). Many people in these communities live a subsistence lifestyle. The Prudhoe Bay facility is not accessible by road from these villages and their subsistence lifestyle activities are limited within the Prudhoe Bay facility to a relatively thin corridor along the Beaufort Sea coast. The former Tuboscope site is not currently used for subsistence purposes and subsistence use is not expected at the former Tuboscope site during the life of the field.

2. ENVIRONMENTAL SETTING

This section of the report provides a summary of the environmental setting for the former Tuboscope site. Important considerations regarding the former Tuboscope site environmental setting include the following:

- Cryogenic, aeolian, and fluvial process dominate off-pad tundra topography and geomorphology.
- A groundwater aquifer is not present.
- The hydrologic cycle (and thus potential constituent fate and transport) is subject to the unique effects of the periglacial and arid environment.

The former Tuboscope site lies within the area described by ADEC regulations as the arctic zone. The arctic zone includes all areas north of latitude 68 degrees north (18 AAC 75.990(4)). Landforms in this area were created by cryogenic action and the hydrologic cycle is significantly different from more temperate climates. This has a direct impact on both constituent fate and transport and on potential exposure pathways. According to the ADEC *Technical Memorandum: Establishing Arctic Zone Cleanup Levels*, continuous permafrost beneath the ground surface acts as a barrier for contaminant migration to groundwater and neither pad porewater nor SPGW are normally considered a reasonably expected potential source of drinking water (ADEC 2019c).

The former Tuboscope site lies within the Beaufort Coastal Plain Ecoregion. Massive subsurface ice is widespread throughout the area, appearing as vertical wedges, films, lenses, pore-fillings, and segregated masses. The dominant surface soil in the Beaufort Coastal Plain consists of several feet of ice-rich organic silt overlaying coarse sands and gravels (Alyeska Pipeline Services Company 2007).

The North Slope is characterized by networks of polygonal ground features (thermokarst) created by freeze and thaw cycles impacting the active layer. Numerous thermokarst lakes (thaw lakes) have also been formed by cryogenic processes. Shallow thaw bulbs may be present beneath active river channels and lakes at depths greater than 6 feet (Kreig and Reger 1982). The Beaufort Coastal Plain Ecoregion is underlain by thick, continuous permafrost, with an average temperature of less than 19 °F (Brown et al. 1997; Ferrians 1965). The permafrost is 670 to 2,150 feet thick in most areas (Péwé 1975).

The former Tuboscope site is located on the BOC pad. The area of investigation consists of an on-pad area and an off-pad area. The on-pad area exists where gravel pads have been constructed on the tundra, Undisturbed native tundra is present in the off-pad area.

2.1 Physiography and Topography

A review of historical aerial photography from 1968 (prior to initial pad construction) through 2010 identified pre-pad construction features that could potentially influence constituent transport, as well as historical operations that could have contributed to COI impacts from non-natural sources. The collection of aerial photographs is provided as Appendix A. As shown on the 1968 aerial photograph, prior to pad construction, the natural site topography was an uneven surface characterized by thermokarst polygons and small surface water body features. The BOC pad now covers some of these features.

Topography is particularly important to a SWMU that is underlain by permafrost. The top of the permafrost is largely a function of topography and surface cover. Raised ground surface elevations, such as caused by the construction of roads and pads, can raise the top of permafrost. In turn, the elevated top of permafrost can control the flow direction of SPGW and pad porewater. When a linear feature, such as a gravel road, raises the top of permafrost higher than the elevation of surrounding surface and subsurface water, it forms a flow divide. As shown on the 1971, 1973, and 1974 aerial photographs in Appendix A, once a road was constructed through the area, water began to accumulate on the southwest side of the road.

Light Detection and Ranging (LiDAR) data collected in 2014 provides the most current topographic relief survey of the former Tuboscope site. The topography at the former Tuboscope site is generally flat. The native ground surface elevation tends to be slightly higher to the southwest of the pad than it is to the northeast.

Based on the LiDAR data, the highest surface feature is the road that runs to the west of the BOC pad (Figures 13 through 16). Depressions in the pad are present at the secondary containment areas north and south of the Bulk Chemical Building. With the exceptions of backfilling the drainage ditch (2018) and routine grading and maintenance of the BOC pad surface during the thaw season, there have been no recent changes to the surface topography at the former Tuboscope site.

2.2 Infrastructure and Human Influences

Historical and current human influences, including onsite operations, structures, and conditions, may affect the hydrogeology and migration of constituents in or from the former Tuboscope site. Current knowledge of structures and activities affecting surface and subsurface water flow are described below and depicted on Figure 2:

- The gravel pad is currently used as a materials storage yard where materials are stored on racks and timbers above the pad surface. To maintain access, crews plow snow from the pad. There is limited space for snow disposal, and historically, some snow was plowed into the former drainage ditch for storage.
- A former drainage ditch was used to capture impacted pad porewater as part of USEPA-approved IMs between 1997 and 2018 (ERM 2019a). Snow meltwater, precipitation in the form of rain, and pad porewater accumulated in the former drainage ditch during the summer thaw season each year. Historically, extraction and any necessary treatment of accumulated water from the former drainage ditch began in June and concluded in September. Water was removed from the former drainage ditch to prevent it from overtopping the GC3 Pipeline Access Road.
- An access road (GC3 Pipeline Access Road) is present on the northeast side of the gravel pad to provide access to pipelines that run to gathering center GC3.
- In 1988, as part of the former IMs, a curtain liner was installed in the GC3 Pipeline Access Road to help contain impacted pad porewater. The curtain liner was not removed when the drainage ditch IM was decommissioned in 2018.
- Polyvinyl chloride slotted piping and a high-density polyethylene vertical liner were installed beneath the former Tuboscope building location as part of the BNP treatment technology pilot study.
- A drilling mud plant was present on the north side of the former Tuboscope building for only a few years in the early 1980s. It was used to prepare barite-based drilling muds for oil and gas well drilling operations.
- Chemicals are stored in aboveground tanks with secondary containment at the CIC Storage Facility. Shallow lined excavations provide secondary containment measures beneath two separate TTLAs present to the north and south.
- The Materials Storage Warehouse is used to store a wide variety of materials and supplies that must be protected from the elements. This building has a slab on grade foundation.

2.3 Habitat

A habitat survey was completed by SLR in 2011 to characterize ecological conditions across Tuboscope. The survey included the creation of a habitat map that indicates the types of habitats present. The map has been included as Appendix D. Habitat categories were based on the *Geobotanical Atlas of the Prudhoe Bay Region, Alaska* (Walker et al. 1980). The following 11 habitat categories were characterized within and immediately surrounding the former Tuboscope site:

- Active BOC pad
- Wet tundra
- Surface water bodies
- Wet meadows
- Wet tundra/wet meadows
- Wet tundra with high-centered polygons and dry tundra
- Moist/dry tundra
- Dry tundra
- Water bodies with emergent vegetation
- Moist tundra with high-centered polygons and dry tundra
- Disturbed areas

2.4 Climate

The Kőppen climate classification for the Prudhoe Bay facility is Group E: polar and alpine climates and Type: ET tundra climate. The climate is characterized by persistent wind, low-ambient temperatures, and minimal amounts of precipitation. Precipitation levels in the Prudhoe Bay facility are comparable to those found in deserts around the world. The Arctic Coastal Plain's environmental and climatic conditions are the result of the far northern location, where surface and subsurface conditions are frozen 8 to 9 months each year. The region is characterized by a short growing season, continuous permafrost beneath the land surface, and low summer temperatures that are exacerbated by frequent coastal fog and mist.

The overall annual precipitation of the region is very low. From 2007 to 2015, Prudhoe Bay had an average annual precipitation from snow and rain of just 3.053 inches (Western Regional Climate Center 2016). The average annual rainfall from 2007 to 2015 was 2.334 inches, with the remainder of the precipitation falling as snow or sleet.

3. GEOLOGIC DATA

This discussion of Tuboscope geology focuses on factors that impact constituent fate and transport.

3.1 Soil Boring Logs and Well Completion Logs

Between 2008 and 2018, 138 soil borings were installed at 108 discrete locations across the former Tuboscope site. This includes 17 boreholes associated with the southern TTLA. Thirteen strings of thermistors were installed at the former Tuboscope site. Soil boring logs are provided in Appendix E. Designations for the boreholes changed over time; Table E-1 provides the associated location identifiers, proposed boring numbers (as listed in the various work plans), borehole numbers, and monitoring well numbers. Monitoring wells were constructed in 47 boreholes completed during the RFI. Monitoring well locations are shown on Figures 3 and 4. The locations of soil borings are shown on Figure 5. Associated monitoring well construction logs and thermistor logs are also included in Appendix E. Photograph 9 of Appendix C depicts soil boring installation.

3.2 Cross Sections

Figure 6 provides a conceptual cross section, useful in understanding the interaction of geology (Section 3.3) and water flow (Section 4) beneath and surrounding the former Tuboscope site. Water flow directly impacts constituent fate and transport, which is discussed in Section 4.6. In addition to site lithology, the conceptual cross section shows the top of permafrost and the top of active layer water. Also shown is the location and impact of the former drainage ditch and the impact of 2018 drainage ditch decommissioning.

Figure 7 shows the location of two cross sections and associated monitoring wells and surface water samples. Each cross section depicts soil boring locations, subsurface geology, monitoring well and thermistor locations, maximum seasonal thaw (permafrost elevations), and SPGW depths.

Cross section A-A’ runs from southwest to northeast and is shown on Figure 8. Conditions shown are prior to the drainage ditch being backfilled. The cross section extends from the BOC pad, across the drainage ditch, and into the tundra. Gravel used in pad construction extends from the ground surface to an underlying and pre-existing layer of peat. Off the pad to the northeast, the peat extends to the ground surface. Beneath the peat layer, ice lenses are present in some areas and native mineral soil (primarily sandy silt or silty sand) is present in other areas. A zone of massive ground ice and ice-rich soil is present on the southwest side of the cross section. The elevation of the ground surface, the top of pad porewater, and the permafrost table all tend to be highest beneath the BOC pad (at monitoring wells MW-24 and MW-33) and decrease toward the drainage ditch.

Figure 9 displays cross section B-B’, which runs from northwest to southeast. The cross section runs beneath the BOC pad and runs parallel to the former drainage ditch. The cross section clearly shows the following (from ground surface down): gravel pad, tundra soil, and native mineral soil. The following sections detail the properties of each of these materials.

3.3 Geologic Description

The geology of the Prudhoe Bay facility is described in the *Site-Wide Project Work Plan – Part 1: Site-Wide Background Report, Prudhoe Bay Facility* (OASIS 2008a). The terrain of the Prudhoe Bay area is referred to as a “flat thaw-lakes plain,” which is generally characterized as mostly flat and wet with numerous thaw lakes, polygon-patterned ground, and non-patterned ground (Walker et al. 1980; Walker 1985).

The former Tuboscope site is in the Arctic Coastal Plain, a treeless, poorly drained, periglacial environment underlain by permafrost (Appendix C, Photograph 2). The geology at the former Tuboscope site has been evaluated as part of the ongoing RFI. Soil characteristics were identified in general accordance with standards established by the Unified Soil Classification System (USCS), as described in American Society for Testing and Materials (ASTM) Method D2487-11; *Standard Practice for Classification of Soils for Engineering Purposes* (ASTM 2011). Procedures detailed in the ASTM Method D2488-09a, *Standard Practice for Description and Identification of Soils* (Visual-Manual Procedure; ASTM 2009) were referenced while describing soil types encountered during the field investigation. Frozen soil was described in accordance with the guidance found in ASTM D4083-89 (2007) *Standard Practice for Description of Frozen Soils* (ASTM 2007). Soil samples were assigned one of three matrix codes: TN for tundra, SM for mineral soil, or SO for pad material/gravel. Site-specific details are presented below.

3.3.1 Off-pad Surface Geology

The ground surface in off-pad areas to the east and west of the former Tuboscope site is predominantly tundra mat, and near-surface soil is predominately classified as peat (PT). Based on the ERM field geologists' descriptions, this soil is:

- Dense and dark brown
- 90 percent to almost 100 percent organic material
- 0 percent to 10 percent silt
- Wet or frozen
- Well sorted

The mean total organic carbon (TOC) content for tundra soil was 109,000 milligrams per kilogram (mg/kg). The peat layer ranges from 0.5 to 7 feet thick.

As with most of the Arctic Coastal Plain, the peat tends to be hydric (wet) because of shallow permafrost and seasonal flooding. Saturation and high organic content frequently results in anaerobic conditions and favors the growth of wetland vegetation. Anaerobic conditions and low temperatures impede decomposition of organic material, resulting in the accumulation of plant material as peat or muck. Muck soil is defined by the U.S. Department of Agriculture National Resources Conservation Service as sapric organic soil (soil in which virtually all the organic material has undergone sufficient decomposition to prevent the identification of plant parts) that is waterlogged.

As documented in the 1968 aerial photograph taken prior to the development of the BOC pad, the area consisted of polygon-patterned ground, with high-centered polygons divided by ice wedges (Appendix A). A few slightly higher areas are also visible (tan color). During winter, extreme heat loss from this layer causes surface soil to contract, which results in formation of ice wedges. This type of ground surface only tends to occur when the following factors are present: poorly drained tundra, continuous permafrost, arid conditions with little snow to insulate the ground surface, and soil that is regularly cooled to at least -15 to -20 degrees Celsius (°C) (Conley 2019).

Ice wedges begin to propagate at depth and extend vertically to the ground surface. Once initial cracks have formed, water may accumulate in the cracks. When that water subsequently freezes and expands, the cracks expand. Where this extreme freeze and thaw cycle has repeated itself for many years, individual ice wedges interconnect and result in patterned ground.

While the 1968 aerial photograph shows water-filled ice wedges, subsequent aerial photographs presented in Appendix A show several tundra ponds that range in size. Construction of the BOC pad and associated roads altered impeded water flow pathways and the thermal regime. On the North Slope, ponded water fills in low areas formed when massive ice in the subsurface thaws. The water decreases the albedo of the surface resulting in additional heat capture and melting. As the underlying massive ice or ice lenses thaw, the land surface slumps.

3.3.2 Geology of Constructed Pad and Roads

Based on soil samples collected during the RFI, the BOC pad and adjacent roads were constructed of sandy gravel (GW) or gravelly sand (SW). Typically, the pad gravel is:

- Dense
- Dry
- Grayish brown
- Poorly sorted
- 10 to 40 percent coarse-grained, subrounded gravel
- 20 to 35 percent fine-grained, subrounded gravel
- 35 to 60 percent fine- to coarse-grained sand

The mean TOC content for samples of pad gravel was 2,670 mg/kg. In most areas, the gravel pad is 5 to 7 feet thick. Appendix F includes dry density, porosity, and pH data and a particle size distribution for a sample of pad material collected between the ground surface and 3 feet below ground surface (bgs) (Laboratory Number. 1904).

As shown in Figure 6, the BOC pad and nearby roads appear to have been constructed directly on top of the native tundra surface. If the peat was thawed during or after construction, this tends to compact the peat, reducing its hydraulic conductivity.

The gravel serves to insulate the underlying ground and protect it from thaw. This may result in a localized mound in the permafrost layer, altering the flow path for SPGW/pad porewater. Where a road or pad is constructed high enough, this effect can raise the top of permafrost higher than surrounding surface water and suprapermafrost groundwater, preventing water flow beneath the road or pad. To maintain the surface elevation, additional gravel is added to the pads and roads over time.

3.3.3 Native Mineral Soil

Native mineral soil is present beneath pad and tundra mat. This soil is generally well-graded, light gray, sandy silt (ML) or sand (SP). Layers of gravel and sandy gravel (GW), gravelly sand (SW), and silty sand (SM) were also encountered. These soil types were generally saturated or frozen. The following are typical of the ERM field geologists' soil descriptions presented on the boring logs (Appendix E):

- Sandy silt (ML): medium dense; olive-gray; with 90 percent silt and 10 percent fine-grained sand; well sorted
- Sand (SP): medium dense; olive-gray; 90 to 100 percent fine-grained sand with 0 to 10 percent silt, coarse-grained sand, or subangular gravel; well sorted
- Gravel with sand (GW); brown; 30 percent fine gravel; 25 percent coarse gravel; 25 percent coarse sand; 20 percent fine to medium sand
- Gravelly sand (SW); olive-gray; 60 percent fine to medium sand; 30 percent fine, subangular gravel; 10 percent coarse sand
- Silty sand (SM): medium dense; olive-gray; 80 percent fine-grained sand with 20 percent silt; well sorted

The mean TOC content of native mineral soil was 19,300 mg/kg.

3.3.4 Ice Lenses and Ice-Rich Soil

Ice-rich soil, ice lenses, and areas of massive ground ice are present below the active layer. In contrast to the ice wedges described above, ice lenses and areas of massive ground ice tend to be horizontal features. Soil moisture is drawn to the freezing front (the interface between pad porewater and pore ice) due to a gradient in soil moisture tension that is established as the water freezes and forms part of the growing ice lattice. This process can force the soil particles apart to produce what are termed ice lenses. An example of massive ground ice was encountered in soil boring SB-84, beginning at 6.3 feet bgs and extending at least 10 feet bgs.

4. HYDROLOGY AND HYDROGEOLOGY DATA

The hydrologic study was designed to assess groundwater flow across the former Tuboscope site to better understand potential migration pathways for constituents. The following subsections summarize study activities and provide the findings of the hydrological study, which was conducted between 2009 and 2013. The hydrology study occurred before the drainage ditch was backfilled; IM water withdrawal occurred during each summer while the study was occurring.

Hydrology and hydrogeology at the former Tuboscope site were evaluated over the course of the RFI. The information presented below focuses on flow of pad porewater, SPGW, and surface water and on how water movement can impact constituent fate and transport. Key conclusions are as follows:

- An aquifer is not present.
- Frozen soil serves as a lower confining layer and can also limit the potential horizontal flow direction of water in the subsurface.
- Constituents dissolved in SPGW can become frozen in place.
- The water flowing beneath the site and in nearby surface water bodies is limited in quantity and duration.
- The former drainage ditch depressed the top of permafrost, creating a zone where soil would thaw each summer, but out of which suprapermafrost could not flow.
- In the surrounding tundra, flow is generally limited to ice wedges, in late summer when they are thawed.

Information presented in this section begins with consideration of site-specific factors that impact the movement of water at the former Tuboscope site (Section 4.1). Thermistor data was used to assess permafrost elevations (Section 4.2). Pressure transducer data was combined with surface elevations for water in monitoring wells and surface water bodies to develop a piezometric surface (Section 4.3). The hydraulic conductivity of pad material and tundra soil is considered in Section 4.4. Taken together, permafrost elevations, piezometric head, and hydraulic conductivity control the flow of water in the subsurface. The flow of pad porewater and SPGW is limited because of the arid climate and low hydraulic gradient. Assessment of SPGW and pad porewater flow directions is presented in Section 4.5. Section 4.6 assesses physical-chemical properties related to constituent fate and transport. Monitoring well and surface water sampling locations are depicted on Figures 3 and 4. Thermistor and pressure transducer data are in Appendices G and H, respectively.

4.1 Overview and Site-Specific Considerations

Migration of pad porewater from the source area was the predominant focus of the hydrology study during the RFI. Section 6.2.5 details data collection activities associated with the hydrologic study.

Review of historical aerial photographs indicates that the GC3 Pipeline Access Road was constructed between 1968 and 1971 (Appendix A). In contrast to the 1968 photograph, the 1971, 1973, and 1974 aerial photographs show surface water accumulating to the west of the road, but not to the east. This suggests that prior to construction of the BOC pad, surface water in the area flowed from southwest to northeast and that the naturally occurring gradient runs roughly perpendicular to the road in that direction. As described below, pad and road construction can elevate the permafrost table, reducing or preventing flow of water in the subsurface.

Pad porewater and SPGW movement is limited because of the arid climate, cold temperatures, and minimal hydraulic gradient. Prudhoe Bay receives approximately 3.053 inches of total precipitation from snow and rain each year (Western Regional Climate Center 2016). A significant portion of water added by precipitation is lost due to evapotranspiration. Based on data from Imnavait (located on the upper Kuparak River), the nearest site at which pan evaporation data is collected, potential evapotranspiration ranged from 6.6 inches to 9.6 inches annually between 2000 and 2008 (Kane et al. 2009). Because the rate of potential evapotranspiration exceeds the available water from precipitation, the volume of water added to pad porewater and SPGW each year is limited.

The cold climate results in surface water and soil near the ground surface being frozen 8 to 9 months each year. Deeper soil remains continuously frozen (permafrost). Subsurface flow of liquid water is only possible at temperatures near or above the freezing point. These conditions only exist for a short time each year, generally during July through the early part of September, which further limits subsurface water flow. The flat terrain of the Arctic Coastal Plain only allows for low hydraulic gradients.

Several activities at the former Tuboscope site impact hydrology. The 3.053 inches of total annual precipitation includes approximately 2.334 inches of rain, with the remainder of the precipitation falling as snow or sleet. Snow is regularly plowed from the BOC pad and nearby roads. This minimizes water from snow melt on the pad and roads and increases snow melt in the surrounding areas. The primary available areas for snow disposal are the two impoundment ponds to the southwest. Likewise, winds redistribute accumulated snow and concentrate it on the lee side of roads, buildings, and other prominent features and in low areas.

During the 2015 IM Termination Pilot Study, ERM observed that aside from snow melt water, precipitation is the greatest contributor of water to the drainage ditch. The drainage ditch did not recharge readily during the 2015 thaw season after the initial over-pumping to remove snow meltwater in May (ERM 2016b). ERM observed that the water level in the drainage ditch did not rise significantly until August when the precipitation increased.

Two lined, secondary containment areas are present on the north and south sides of the TTLA, north of the former Tuboscope building. The northern TTLA liner was installed in 2010; the southern TTLA liner was installed in 2012. As with the CIC Storage Facility, Bulk Chemical Building, and other nearby structures, the liners prevent infiltration of water into the subsurface.

IMs implemented by BPXA at the former Tuboscope site have also had a significant impact on site hydrology:

- 1983: The drainage ditch adjacent to the source area was isolated for the collection of contaminated water. The culvert between the drainage ditch and the off pad setting to the east was sealed at this time.
- 1988: A curtain liner was installed in the GC3 Pipeline Access Road to the east of the drainage ditch. The culvert between the drainage ditch and the off pad setting to the east was removed.
- 1997 to 1998: Water was extracted from the drainage ditch.
- 2000 to 2017: Water was extracted from the drainage ditch.
- 2018: The IM drainage ditch was decommissioned.
- 2019: Approximately 3 to 4 feet of gravel were added to the GC3 Pipeline Access Road.

4.2 Soil Temperatures, Permafrost, and Thermistor Data

The vertical depth at the top of the seasonal permafrost thaw elevation (freeze-thaw interface) during the hydrology study period from 2009 to 2013 was determined by subtracting the interpolated thaw depth from the surveyed ground surface elevation (relative to mean sea level [amsl]) at each thermistor location.

Elevation data for the top of each thermistor string locations were obtained from a contracted surveyor, F. Robert Bell and Associates.

Thermistors were installed between 2009 and 2012, and data loggers collected subsurface temperature data until 2013. The resulting soil temperature data was used to better understand the permafrost depths and how frozen soil impacts site hydrology.

Table G-1 (Appendix G) provides a summary of the construction details for each thermistor string. Elevations at the upper boundary of the permafrost (permafrost table) are presented in Table G-2 (Appendix G). Figure 10 presents September 2013 permafrost elevation data. Thermistor data is discussed in detail in the 2008 to 2011, 2012, and 2013 RFI interim summary reports (OASIS 2012b; ERM 2014a, ERM 2014b).

Factors impacting soil temperatures and the depth of frozen soil (including permafrost) include albedo, the insulating properties of snow and vegetation, and the flow of water. Seasonal maximum thaw depths typically range from approximately 5 to 6.25 feet bgs beneath the BOC pad in a typical year (ERM 2014b), or up to 7.5 feet bgs in a warm year. Data collected during the RFI and the 2015 IM Termination Pilot Study (ERM 2016b) show that the maximum thaw depth is influenced by several factors, including: the duration of the thaw season, the heat transfer properties of native material/peaty soil, the location of buildings and other aboveground structures, the presence of subsurface infrastructure, and the presence of the drainage ditch and vehicle traffic.

Across the North Slope, and in tundra areas surrounding the BOC pad, snow accumulates and tends to insulate the underlying soil throughout the winter. This insulation minimizes the radiation of heat from the soil and minimizes the ability of extremely cold air temperatures to penetrate the ground. In contrast, snow is cleared from the BOC pad. This allows soil heat to radiate out during cold weather and results in far lower winter temperatures in upper portions of the subsurface.

As the year progresses, and the sun begins to rise above the horizon, the high albedo of the snow cover reflects the sun’s rays and minimizes heat gain in tundra soil. Without the snow, the darker pad materials begin to gain heat more quickly when the sun shines. During the summer, tundra vegetation insulates the underlying soil and minimizes heat penetration. Pad material, lacking such insulation, gains heat more quickly. When combined, these properties result in far greater changes in temperature of pad material and deeper thaw depths, when compared to tundra soil. However, the surface elevation of the pad material is higher than the surrounding tundra, and the elevation of the top of permafrost tends to be higher beneath roads and pads than beneath the surrounding tundra.

Both pad gravel and tundra soil thaw from the ground surface down. The seasonal maximum thaw depths for each year occurred between the end of August and the beginning of September. In contrast, re-freeze of the active layer is driven by subfreezing temperatures at both the ground surface and in the underlying permafrost. Re-freeze of the active layer occurs simultaneously from top and bottom and occurs much more rapidly than thaw.

Gravel pads at thickness of 4 to 6 feet, such the pad present at the former Tuboscope site, can insulate and reduce heat transfer from the surface to the underlying permafrost regime (UAF 2015). The effects of albedo and the insulating properties of snow and vegetation are demonstrated by thermistor data from thermistor T-66, which is in undisturbed tundra east of the BOC pad, and thermistor T-33, which is in pad material. At 3 feet bgs, tundra soil reached a winter minimum temperature of 9.75 °F. In contrast, pad material at the same depth reached a minimum temperature of -20.66 °F, 30 degrees colder. The summer maximum temperature at thermistor T-66 was 31.01 °F. The summer maximum temperature at thermistor T-33 was 48.94 °F. The thaw depth beneath the pad (at T-33) extended to 7.5 feet bgs. In contrast, thaw only reached to under 2 feet bgs at T-66. Detailed thermistor data has not been presented in this report but is available upon request. This comparison is presented for illustration purposes only; the date ranges for available data from T-33 and T-66 are different.

In contrast to gravel pads, surface waters located above the permafrost can cause the permafrost to thin or disappear entirely from the area (UAF 2015). Surface water bodies are present along the western side of the pad in the form of two impoundment areas split by a roadway running from the BOC/Stores pad to the Spine Road and along the eastern side of the pad in the form of two drainage ditches, located between the BOC/Stores pad and the GC3 access road and various smaller seasonal water bodies resulting predominantly from annual permafrost thawing. The presence of the surface water bodies in these areas likely contributes to deepening top of permafrost elevations at thermistors locations near the edges of the pad, in the drainage ditch, and outlying tundra areas.

The former Tuboscope site is at approximately 70.3 degrees north latitude. Even during the summer solstice, sunlight strikes the site at a low angle, no more than 43.2 degrees. Because of this low angle, buildings, aboveground pipelines, and stored material cast long shadows, reducing the solar insolation received by nearby soil.

Figure 10 shows the elevation of permafrost beneath the BOC pad at approximately its seasonal minimum (data from 6 to 9 September 2013). Although the contours in the figure have been smoothed, the cryogenic processes associated with thermokarst environments may result in localized depressions where heat associated with water flow is focused. The highest permafrost elevations are just over 32.5 feet above mean sea level (amsl). Beneath the central portions of the pad (monitoring locations 11, 16, 24, 34, 35, and 84), the elevation of permafrost tends to be as much as 1.5 feet higher than near the edges (for instance monitoring point 39) and as much as 3.5 feet higher than it was near the former drainage ditch and pipeline access road (monitoring points 22, 89, and 91). The presence of surface water in the ditch both decreased albedo and directly added heat, resulting in a lower permafrost table.

4.3 Piezometric Surface

Pad porewater, suprapermafrost, and surface water elevation and flow data were collected through both manual gauging and continuous data collection using installed pressure transducers at a total of 50 on-pad monitoring wells, 133 surface water, and 87 SPGW monitoring locations. SPGW elevations data collection began in 2011 and surface water elevation data collection began in 2012. Pad porewater, surface water and SPGW elevations are generally at their respective seasonal maximums at the end of the thaw season, typically occurring between the end of August and beginning of September.

The piezometric surface for surface water, pad porewater, and SPGW was developed using the following data sources:

- Surveyed elevations of surface water
- Measured depths of pad porewater and SPGW in monitoring wells
- Pressure transducer water depth data
- Surveyed elevations of measuring points on monitoring wells

For more detailed data, refer to the 2008 to 2011, the 2012, and the 2013 RFI interim summary reports for a detailed discussion of the former Tuboscope site hydrology study (OASIS 2012b; ERM 2014a, ERM 2014b). The most complete datasets were developed in 2013 and 2015.

4.3.1 2013 Data

Data displayed on Figures 11 and 12 are intended to approximate maximum thaw in September. As shown on Figure 11, the highest head measurements were at the two impoundment ponds between the

BOC pad and Spine Road, and southwest of Spine Road. The lowest heads were in the tundra, east of the former Tuboscope site.

Figure 12 shows the elevation of water in the drainage ditch as approximately 33.3 feet amsl (at ST-63). The available data suggest that the top of the curtain liner is approximately 31.5 feet amsl, and the pad porewater surface is approximately 1.8 feet above the top of the curtain liner (Figure 8). Higher water elevations to the northwest (near the CIC Storage Facility and Bulk Chemical Building) correspond to deeper permafrost elevations in that area (Figure 10), suggesting that increased flow of pad porewater around the curtain liner is providing sufficient heat to depress the permafrost table.

The elevation of surface water in the two impoundments to the southwest is approximately 35 feet amsl (Figure 11). This is higher than the top of permafrost (Figure 10), suggesting that (at maximum thaw) water could migrate from the impoundments, under the BOC pad, and to the tundra to the northeast.

4.3.2 2015 Data

The piezometric surface based on 15 July, 29 July, 12 August, and 25 August 2015 data is shown on Figures 13 through 16. These figures also show the ground surface elevation based on LiDAR data.

As with data from 2013 and the other years of monitoring, the piezometric head is higher to the southwest of the BOC pad, decreases across the pad, and is lower to the northeast. The elevation of surface water in the impoundment pond to the west ranged from 33.96 feet amsl to 34.11 feet amsl. This is higher than the permafrost elevations beneath the BOC pad at maximum thaw (approximately 32.5 feet amsl), suggesting that permafrost will limit, but not prevent, migration of water beneath the BOC pad.

Also of interest is the elevation of Spine Road (approximately 42 feet amsl). Spine Road is the larger road located approximately 1000 feet southwest of the former Tuboscope site. This elevation compares to the BOC pad, which has an elevation of approximately 39 feet amsl. Because the permafrost table tends to follow the ground surface elevation in pads and roads, the available data suggests that the permafrost table beneath Spine Road may be up to 3 feet higher than it is beneath the BOC pad. This higher elevation minimizes or prevents water flow beneath the road, which in turn minimizes pad porewater flow beneath the former Tuboscope site.

4.4 Hydraulic Conductivity

As shown on Figures 8 and 9, pad porewater flows through gravel and (potentially compacted) tundra material beneath the gravel. SPGW flows in areas of native tundra, primarily through thawed ice wedges.

Appendix F provides particle size distribution testing data (sieve analysis results) generated per ASTM D422. Pad material is composed primarily of poorly sorted gravel and sand with a considerable portion of interstitial fine material. The hydraulic conductivity for gravel pad material can vary considerably depending on the degree of compaction. Published hydraulic conductivity data for silty gravel / silty sandy gravel ranges from 0.000000164 feet per second to 0.0000164 feet per second (StructX 2020). Due to the freeze thaw cycles reducing the compaction of pad material over time, actual hydraulic conductivity is likely higher. Rates of contaminant migration at other North Slope sites suggests that effective hydraulic conductivity at the former Tuboscope site is likely between 0.0005 feet per second and 0.05 feet per second. Based on an assumed hydraulic gradient of 0.005 feet per foot (see Section 4.5 for source data), a Darcy's velocity ranging between 0.0036 feet per day and 0.36 feet per day was calculated. Assuming an effective porosity of 0.185 (from StructX 2020 for gravel/silty sandy gravel), a seepage velocity of between 0.02 feet per day and 2 feet per day was estimated. These values represent the maximum flow velocity at the top of pad porewater (where it is thawed for a longer period each year); flow just above permafrost is essentially stagnant in most years.

The hydraulic conductivity of peat has been reported as 10^{-3} to 10^{-2} cm/sec (Bear 1972). However, the properties of peat are highly site-specific due to the varying degree of peat decomposition, void volume fraction, and amount of compression. Unlike mineral soil, peat is compressible (Wong et al. 2009). As ice wedges grow, they compress soil inside of the polygons, increasing soil density and decreasing the hydraulic conductivity of the material. The ice wedges are expected to thaw before the surrounding tundra because of heat transported by water flow. During the short portion of each year when surface soil is thawed, the matrix has relatively high hydraulic conductivity in the ice wedges and very low hydraulic conductivity within the permafrost polygons. Water flow is generally limited to the ice wedges and soil in close vicinity to the ice wedges.

As can be seen on Figures 3 and 4, essentially all SPGW monitoring wells are in or immediately adjacent to surface water features. Monitoring wells installed inside of permafrost polygons are not expected to produce sufficient water for sample collection. As shown in the data for thermistor T-66, the maximum thickness of the active layer below undisturbed tundra is approximately 2 feet bgs.

4.5 Suprapermafrost Groundwater, Pad Porewater, and Surface Water Flow

As detailed in Section 4.1, the level of evapotranspiration at the former Tuboscope site is close to the amount of water provided by precipitation. This limits the flow of liquid water.

The water-saturated interval in on-pad wells is typically no more than a few feet thick during the thaw season (June through August), with maximum thaw occurring in early August through early September. Off-pad, surface water is present for 2 to 3 months of the year in thermoskarst features and low areas in the tundra where the melted SPGW collects. Based on field observations, the water-saturated interval off-pad is typically no more than a few feet thick. SPGW is only present in quantities sufficient for sampling at the end of the thaw season. Most of the surface water bodies at the former Tuboscope site freeze completely during the winter months. The exception is Big Lake (Figure 1), which serves as the drinking water source for the BOC pad and surrounding facilities.

The current understanding of hydrology at the former Tuboscope site is as follows:

- The predominant pad porewater flow direction is toward the northeast. The pad porewater gradient has variously been calculated as 0.0049 feet per foot (2012 data), 0.0053 feet per foot (2013 data), and 0.0051 feet per foot (2015 data) (ERM 2016b). The 2012 and 2013 data represent extraction from the drainage ditch. During 2015, the drainage ditch was over pumped early in the thaw season during the IM pilot study; as a result, the water level in the drainage ditch was below the pad porewater level for most of the thaw season.
- A slight (and intermittent) pad porewater divide was present at the former Tuboscope site during 2015, running northwest to southeast in the vicinity of monitoring wells MW-24, MW-31, and MW-35. During the times of higher precipitation events, the divide becomes more apparent showing pad porewater flow toward the west on the western side of the pad (Figures 13 to 16). This westward gradient is a function of precipitation driving water level rise faster in soil (where the water only occupies the void volume) than in the surface water bodies. The westward gradient was localized and did not extend beneath the location of the former Tuboscope building. The available data indicate that water cannot migrate west of Spine Road (ERM 2015b).
- Spine Road traverses the Prudhoe Bay facility and provides a partial hydraulic barrier subsurface water flow due to thermal (insulating) properties of the gravel. The elevated permafrost table (caused by the road) minimizes or prohibits westward water flow toward the Big Lake drinking water source (ERM 2014d). The elevation of the surface of the road is approximately 42 feet amsl. Assuming a thaw depth of approximately 5 to 7.5 feet bgs (based on thermistor data from the BOC pad), the seasonal minimum permafrost thaw elevation is believed to be between 34.5 and 37 feet amsl.

Based on data from late August in 2015, SPGW elevations near the impoundments just to the east ranged from 34.76 to 36.16 feet amsl. Several surface water and SPGW samples have been collected from various locations west of Spine Road to verify that impacted water is not impacting Big Lake. Analytical samples were collected from the following surface water and SPGW sample locations (Figures 3 and 4) in 2011 and 2012: ST-108, ST-109, ST-111, SPGW-108a, SPGW-109a, SPGW-110a, and SPGW-111a. These sample locations are west of Spine Road and between 0.12 and 0.22 mile east-southeast of the former Tuboscope site. Analytical results from these sample locations show that SPGW and surface water are not impacted west of Spine Road by constituents associated with the former Tuboscope site.

- SPGW and surface water in the vicinity of the curtain liner (at monitoring wells MW-19, MW-22, and MW-37 and surface water sampling location ST-53) has been measured at elevations between 32.52 and 33.36 feet amsl, which is above the top of the curtain liner (approximate elevation of 31.5 feet amsl). In contrast to Spine Road (the top of which is approximately 42 feet amsl), the GC3 Pipeline Access Road was a much lower structure (surface elevation was approximately 35.5 feet amsl before additional material was added in 2019). This suggests that a significant permafrost mound is not present beneath the GC3 Pipeline Access Road and that neither the curtain liner nor the road are complete barriers to the flow of water or migration of constituents at the height of the thaw season.
- Changes in the thaw depth throughout the thaw season generally follow the surface topography.

Hydrologic assessment information collected at the former Tuboscope site during the RFI and the 2015 IM Termination Pilot Study suggests that pad porewater flow is predominantly to the east-northeast from the former Tuboscope building source area on-pad to the tundra off-pad (ERM 2014a; ERM 2014b). Minimal westward flow has been observed in the on-pad area, and often coincides with high precipitation events; this flow is not significant.

Surface flow or runoff could have potentially transported constituents on the pad surface to the surrounding tundra. Over time, gravel has been added as part of routine maintenance and this transport process likely became insignificant at the former Tuboscope site. During the warmer months, precipitation is low, and surface sheet flow is not significant. During winter, workers remove snow from the BOC pad, and as a result, significant surface flow across the pad and into the tundra during spring thaw is not expected. For the released constituents contained within or beneath the pad material, most of the transport would be through pad porewater/SPGW to the surrounding tundra.

Thaw bulbs can occur at the foot of pads and around ponds where the soil temperature is slightly elevated relative to the surrounding area due to the presence of the pad or pond itself. Thaw bulbs increase the depth of the seasonal active layer, potentially resulting in increased water and constituent movement in SPGW and pad porewater. While this phenomenon may have been important be important beneath the former drainage ditch, in the tundra such mechanisms are likely insignificant away from rivers and lakes.

4.6 Constituent Fate and Transport

Constituent fate refers to the expected final state that a constituent will achieve following release to the environment. Transport refers to mechanisms that move constituents away from the source area. The fate and transport of constituents detected in the environmental media (i.e., surface soil, subsurface soil, surface water, pad porewater, and SPGW) were qualitatively evaluated during the RFI. The goal of this evaluation was to understand if COIs in surface and subsurface soil can impact surface water because of contaminant transport via pad porewater and SPGW and if COIs in surface soil can directly impact surface water as a result of surface runoff and erosion.

Information provided in the section below was used to develop a conceptual site model (CSM) for the former Tuboscope site. The CSM includes pertinent details regarding releases and site-specific transport mechanisms that influence constituent migration. Section 5 presents the CSM.

4.6.1 Sources and Extent of Known Contamination

Documented and potential historical releases at the former Tuboscope site are detailed above in Section 1.2. Released compounds may include:

- 1,1,1-TCA and lead
- Diesel fuel and fuel-related compounds, including VOCs (primarily BTEX), SVOCs (primarily PAHs), and DRO
- Barium and other metals
- 3&4-Methylphenol

Inorganic constituents are present in soil above lowest Tier II ALs and in water media above lowest Tier II ALs and AWQS. These inorganics include metals and chloride, which occur naturally within the Prudhoe Bay facility.

4.6.2 Fate and Transport Mechanisms

The primary fate and transport mechanisms for constituents at the Tuboscope source area include the following:

- Dissolution from pad gravel and underlying pad porewater
- Migration from pad porewater through SPGW to surface water
- Advection and diffusion in pad porewater, SPGW, and surface water
- Biodegradation of organic chemicals
- Freeze and thaw processes, which slow migration and biodegradation

Each of these mechanisms tends to decrease constituent concentrations over time. However, these attenuations are not at continuous rates and are influenced by the annual freeze and thaw cycle. Additional fate and transport mechanisms may include:

- Surface runoff/overland flow
- Volatilization of some constituents from soil and water
- Wind erosion and deposition

4.6.3 Physical-Chemical Properties Related to Transport

The physical-chemical properties of the constituents present at the former Tuboscope site strongly influence their fate and transport. These properties dictate environmental partitioning and constituent mobility. These properties also affect the chemical behavior of the constituents and their susceptibility to degradation induced by physical and biological agents.

Table 3 presents a summary of the primary physical-chemical properties that can affect constituent fate and transport. For organic constituents, the properties that influence fate and transport of organic constituents in the environment are:

- Soil organic carbon partition coefficient (K_{OC})

- Water solubility (S)
- Henry's law constant (H)
- Vapor pressure

The fate and transport of inorganic constituents is discussed later in this section.

Table 3 summarizes the fate and transport properties with a qualitative assessment of SPGW migration potential. Constituents in soil have the potential to migrate due to dissolution and the movement of water. The mobility of a constituent is strongly influenced by the constituent's tendency to partition between the solid and aqueous phases, which is largely a function of the constituent's solubility and its affinity for adsorption. Volatilization (as measured by Henry's law constant vapor pressure) can also affect the distribution of a constituent in the environment due to the constituent's partitioning between soil, water, and air.

K_{OC} provides a measure of the extent of constituent partitioning between organic carbon in the soil matrix and water at equilibrium. The higher the K_{OC} (measured in liters per kilogram), the more likely a constituent is to bind to soil than to remain in water. Table 4.6.3-1 describes potential constituent mobility based on K_{OC}.

Table 4.6.3-1: Mobility Classification Based on K_{OC}

K_{OC} (L/kg)	Log K_{OC} (L/kg)	Potential Mobility Class
<10	<1	Highly mobile
10-100	1-2	Mobile
100-1,000	2-3	Moderately mobile
1,000-10,000	3-4	Slightly mobile
10,000-100,000	4-5	Hardly mobile
>100,000	>5	Immobile

Notes:
EPA-712-C-08-020 lists any compound with a K_{OC} of over 5,000 liters per kilogram (L/kg) as immobile.

Sources: USEPA 2010; USEPA 2006b; FAO 2000

Actual mobility is a function of both the K_{OC} of the constituent and the organic carbon content of the soil. The soil-water partition coefficient (Kd) is related to the soil organic partition coefficient (K_{OC}) and the fraction organic carbon (foc, as measured by TOC) by the following relationship.

$$Kd = K_{OC} * foc$$

The median TOC and foc concentrations for 337 soil samples collected at Tuboscope are as follows:

- Pad gravel (SO) – TOC = 2,670 mg/kg – foc = 0.00267 grams per gram
- Mineral soil (SM) – TOC = 19,300 mg/kg – foc = 0.0193 grams per gram
- Tundra soil (TN) – TOC = 109,000 mg/kg – foc = 0.109 grams per gram

For comparison, the State of Alaska uses a standard default value of 0.001 grams per gram for foc to determine soil CLs (ADEC 2017b) and this standard default value served as a basis for calculating Tier II ALs (SLR 2016). The higher organic content of Tuboscope soil in general, and tundra soil in particular, results in reduced mobility for organic constituents as compared to the standard default values.

Water solubility describes the amount of a constituent that will dissolve in water, and thus is a primary determinant of potential transport of a constituent in the environment. Higher water solubility tends to result in increased mobility in the environment. Partitioning processes (such as adsorption, desorption, and dissolution) occur as equilibrium is established in the subsurface. These processes allow for phase transitions (e.g., constituents adsorbed to soil can become dissolved in water), which results in intermedia transfer over time. After dissolution, dispersion (diffusion and advection) can transport constituents dissolved in pad porewater or in SPGW.

Constituents with low affinity for organic carbon (low K_{OC}) and high solubility tend to be highly mobile in the environment (Table 3). Examples include 1,1,1-TCA, BTEX compounds, trichloroethene (TCE), and 1,4-dioxane. Constituents such as 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, and most PAHs tend to have low to very low mobility.

Table 4.6.3-2: Water Solubility of Constituents

Solubility (mg/L)	Solubility Description
<10	Low water solubility
10-1,000	Moderate water solubility
>1,000	High water solubility

Source: Ney 1995

When pad porewater or SPGW is in direct communication with surface water, dispersion may transport dissolved constituents from the subsurface to surface water. Constituents may also be transported to saturated soil through SPGW. However, due to limited flow, waterborne transport of constituents from pads to off-pad surface water appears to be a slow and relatively minor transport process.

Henry's law constant provides a measure of the potential for dissolved constituents to partition into the vapor phase. The higher the constant, the more likely a constituent is to volatilize than to remain in the water. Vapor pressure is a measure of a constituent's tendency to transfer to the vapor phase. Constituents with high Henry's law constants and high vapor pressures readily volatilize. Examples include 1,1,1-TCA and benzene (Table 3). PAH compounds, such as 3&4-methylphenol, have very low tendency to volatilize.

Table 4.6.3-3: Volatility from Water and Moist Soil Based on Henry's Law Constant

Henry's Law Constant (atm m^3/mol)	Volatility from Water and Moist Soil
$<3\times10^{-7}$	Non-volatile
3×10^{-7} to 10^{-5}	Low volatility
10^{-5} to 10^{-3}	Moderate volatility
$>10^{-3}$	High volatility

Source: Fetter 2001
atm m^3/mol = atmosphere cubic meters per mole

Table 4.6.3-4: Volatility from Dry, Non-Absorbing Surfaces Based on Vapor Pressure

Vapor Pressure (mmHg)	Volatility from Dry, Non-Absorbing Surfaces
$<1\text{x}10^{-6}$	Very low potential for volatility
10^{-6} to $3.9\text{X}10^{-5}$	Low volatility
$>3.9\text{X}10^{-5}$	Intermediate to high volatility

Sources: USEPA 2010; USEPA 2008a
mmHg = millimeters mercury

A partitioning process for some constituents defined as volatile is volatilization from soil or water to indoor and outdoor air. However, the need to protect the underlying permafrost to maintain building stability limits available construction techniques. Most operational buildings in the Prudhoe Bay facility are constructed atop piles that provide several feet of separation from the ground surface, and constituent transport to indoor air is therefore expected to be minimal for these structures. In contrast, structures such as vehicle maintenance shops generally require slab on grade construction to be economical. Such structures may rely on thermosyphons to prevent permafrost thaw. Several structures are constructed directly atop the BOC pad; therefore, volatile constituents may be transported to indoor air in such buildings. Freezing temperatures throughout much of the year likely reduce volatilization from pad material and pad porewater. Volatilization to outdoor air may also occur, although this process is not likely to contribute any appreciable receptor exposure due to dispersion and mixing at the surface/air interface.

Table 3 also presents the physical-chemical properties of the inorganic constituents. The properties presented are molecular weight, water solubility, and Kd. Inorganic constituents may exist in multiple oxidation states (for example ferric iron and ferrous iron) and may occur as coordination complexes. This variability results in metal mobility varying greatly based on the current and past local geochemistry.

Kd is defined as the ratio of constituent concentration associated with the soil matrix to the constituent concentration in surrounding water when the system is in equilibrium. The higher the Kd value is, the more readily the species is sorbed to the soil surface. For porous flow in saturated moisture conditions, the Kd value can be used to compute the retardation factor (Rf) of the constituent defined as:

$$\text{Rf} = 1 + (p_b/n_e)\ \text{Kd}$$

Where p_b = porous media bulk density and n_e = effective porosity of the media at saturation.

The Rf is a bulk property that describes the overall migration of the constituent species with respect to the water and can be thought of as a constituent front moving somewhere behind the water front, retarded by the various chemical interactions. If none of a particular species was retarded, then the Rf equals 1 and the constituent travels along with the water at the groundwater flow rate.

In addition to the physical-chemical properties discussed above, hydrocarbon releases frequently occur in the form of light, nonaqueous-phase liquid (LNAPL). This term refers to an organic compound that is immiscible with and lighter than water. When an LNAPL is released to the subsurface, it can migrate downward under the force of gravity and laterally at the water table. Releases of diesel fuel at and near the former Tuboscope site are presumed to have occurred in the form of LNAPL. The unique fate and transport properties of LNAPLs have been described extensively in documents published by the Interstate Technology & Regulatory Council. Because only residual LNAPL is currently present, LNAPL fate and transport properties will not be detailed here.

The processes controlling mobility of metals generally include redox reactions, adsorption-desorption reactions, and precipitation-dissolution reactions. The factors that most strongly influence these processes in water include redox state, hydrogen potential (pH), iron concentrations, and soil organic matter. The mineral hydrous ferric oxide (FeOOH) is a dominant sorbent for many inorganics in natural environments, due to its common presence on soil particles, high surface area, and amphoteric properties. The effects of iron adsorption can be dynamic. Variations in the redox potential can lead to the precipitation or dissolution of hydrous ferric oxide from the aquifer matrix. Generally, dissolved iron will precipitate as hydrous ferric oxide in the presence of oxygen in the aquifer, resulting in depletion of dissolved metals from the SPGW as the metals adsorb to the hydrous ferric oxide surface. Conversely, if reduced SPGW conditions are present, the hydrous ferric oxide may be dissolved, and adsorbed metals released to SPGW.

At the former Tuboscope site, subsurface water tends to be reducing (Table 4). Pad porewater has an average dissolved oxygen of 2.4 mg/L, redox potential of -10.4 millivolts (mV), and pH of 6.8. SPGW has an average dissolved oxygen of 2.0 mg/L, redox potential of -11.2 mV, and pH of 6.5. Upon discharge to surface water, oxygen rapidly enters the water. The surface water field measurements indicate an average dissolved oxygen concentration of 7.9 mg/L, redox potential of 33.9, mV and pH of 7.2. This suggests that some metals present in subsurface water may rapidly oxidize and settle out when discharged to surface water.

Wind erosion can lead to short-term suspension and transport of surface particulates in the atmosphere, followed by deposition to soil. However, due to the climate on the North Slope, soil is often frozen or covered with snow or ice, reducing the potential for this transport mechanism to result in substantial movement of constituent mass.

Suspension of surface particulates due to wind erosion can also result in fugitive dust in outdoor air, which may be inhaled by outdoor receptors. In most cases, this is not expected to result in significant constituent exposures, but it may be a transport mechanism near roads and in areas where dust generation is significant on a regular basis.

Naturally occurring bacteria in soil and water degrade petroleum hydrocarbons over time. Biodegradation rates are determined by several factors including nutrient levels, oxygen levels, and temperature. Smaller, lighter petroleum hydrocarbons (such as benzene) tend to biodegrade more rapidly than larger, more complex hydrocarbons (such as PAHs with five or six benzene rings). Because biodegradation affects the fate of a constituent and is not a transport mechanism, it is not depicted in the Tuboscope SWMU-specific CSM diagrams (Appendix I). Biodegradation reduces the mass of petroleum hydrocarbons over time. Biodegradation of petroleum hydrocarbons and other organic matter tends to create anaerobic conditions that can be conducive to reductive dechlorination of chlorinated solvents.

5. CONCEPTUAL SITE MODEL

If a baseline risk assessment is conducted the CSM for the former Tuboscope site provides current and reasonably anticipated exposure scenarios and identifies exposure pathways as potentially complete or incomplete. In addition to the current/future industrial worker and potential future non-resident subsistence user shown on the human health CSM diagram (Figure I-1 of Appendix I), for purposes of this Comprehensive RFI Report, analytical results were compared to lowest Tier II ALs, which incorporate a hypothetical future resident subsistence user.

Both the human health CSM diagram and the ecological CSM diagram (Figure I-2 of Appendix I) differentiate between on-pad (developed areas) and off-pad (undeveloped areas) receptors. The on-pad area is defined as the area where gravel pads and roads exist (Figure 2). The off-pad exposure area refers to the undeveloped environment where gravel pad and roads are not present.

In this RFI, screening is conducted using the lowest of Tier I SL and the lowest Tier II AL, which are protective of nearly all the human health and ecological exposure pathways and receptors shown Figures I-1 and I-2 of Appendix I.

6. INVESTIGATION SUMMARY

6.1 Previous Investigations

Historical site investigation and other relevant activities completed at the former Tuboscope site between 1982 and 2007 are summarized below. Details regarding these investigations and other pre-RFI site activities can be found in the following documents: *Former Tuboscope Site Interim Measures Work Plan* (URS 1999), *RCRA Facility Investigation Work Plan, Former Tuboscope Site, Revision 1* (OASIS 2009a), and Section 4.0 of the *2007 System Evaluation Site Assessment Work Plan* (OASIS 2007a).

- February 1982: Documented release of 1,1,1-TCA at the former Tuboscope building.
- September 1982 to July 1983: The Standard Oil Company's Research and Development Center (Standard Oil R&D Group) performed an investigation of the former Tuboscope site on behalf of Standard Alaska Production Company (Note: BPXA was formerly known as the Standard Alaska Production Company). Samples of pad gravel and pad porewater were collected during this investigation. 1,1,1-TCA, 1,1-DCA, 1,1-dichloroethylene, and toluene were detected in pad porewater at low concentrations (Standard Oil R&D Group 1984a). It was estimated that 180,000 cubic feet of pad gravel had a 1,1,1-TCA concentration of 1 microgram per gram (or 1 mg/kg) or greater (Standard Oil R&D Group 1984a). The culvert between the drainage ditch and the off pad setting to the east was sealed during the summer of 1983.
- August 1984: The Standard Oil R&D Group performed a follow-on investigation to the 1982/1983 investigation to assess how effectively the 1,1,1-TCA release is contained within the pad. Concentrations of 1,1,1-TCA in the source area and the drainage ditch water were like or higher than those observed during the 1982/1983 investigation and seepage of pad porewater from the source area into the drainage ditch was observed (Standard Oil R&D Group 1984b).
- October 1985: The Standard Oil R&D Group conducted surface water sampling to assess concentrations of 1,1,1-TCA in the drainage ditch and in a surface water body off-pad to the east of the former Tuboscope site. The detected concentrations of 1,1,1-TCA in the drainage ditch water were similar to or higher than those measured during previous investigations (Standard Oil R&D Group 1986).
- August 1986: The Standard Oil R&D Group conducted a study to define the areal extent of 1,1,1-TCA contamination and to determine if contaminants were migrating away from the source area. The highest concentrations of 1,1,1-TCA were detected in pad porewater in the source area and in the drainage ditch water. 1,1,1-TCA was also detected in surface water off-pad to the east of the former Tuboscope site, in the vicinity of the outfall of the former culvert (Figure 2) and current sample location ST-52 (Standard Oil R&D Group 1987a). The results of this study showed that, except for the off-pad area near the culvert outfall, the 1,1,1-TCA contamination was contained mostly within the pad porewater and the drainage ditch water.
- August 1987: The Standard Oil R&D Group installed soil borings at the former Tuboscope site to define the horizontal and vertical extent of contamination. The data collected showed that the active-layer zone contained the largest mass of 1,1,1-TCA and had the highest 1,1,1-TCA concentrations (Standard Oil R&D Group 1987b). This study also confirmed the presence of diesel fuel contamination and mapped the diesel plume. The curtain liner was installed the following year.
- 2004: ERM conducted a field study to select optimal locations for performing a bimetallic (iron and palladium) nanoscale particle (BNP) technology pilot test at the former Tuboscope site. The BNP technology pilot test was designed to test the effectiveness of the technology at remediating 1,1,1-TCA in an arctic environment.

- 2006: On behalf of BPXA, OASIS conducted the BNP technology pilot test beneath the former Tuboscope building location. Testing was done by both physically mixing the BNP slurry with shallow soil and by injecting the slurry into the active-layer water via well points. 1,1,1-TCA concentrations in soil and water were measured before the start of the test and periodically after BNP application. Results showed a 90 percent reduction in the concentration of 1,1,1-TCA in soil in the area where the slurry was physically mixed (OASIS 2007b).
- 2007: OASIS collected soil and water samples from select locations at the former Tuboscope site to determine the long-term effectiveness of the BNP technology at reducing the concentrations of 1,1,1-TCA. Analytical results showed that concentrations of 1,1,1-TCA in soil continued to decline 1 year following the BNP technology pilot test (OASIS 2008f). While the concentrations of 1,1,1-TCA in water were lower than the pre-test concentrations, they had not continued to decline over the 1-year period (OASIS 2008f).

6.2 Summary of RFI Activities

Investigation activities conducted between 2008 and 2018 have characterized the environmental conditions at the former Tuboscope site and the nature and extent of released hazardous constituents. Data collected in support of this RFI is of adequate technical quality to identify, develop, and implement appropriate corrective measures to protect human health and the environment. Additional investigation and data collection is unlikely to improve knowledge needed for selection of corrective measures at the former Tuboscope site.

In 2008, BPXA issued the *RCRA Facility Investigation Work Plan, Former Tuboscope Site* (OASIS 2008d) in compliance with the PBU RCRA Order. The primary objective established in this work plan was to determine whether hazardous constituents are present in surface and subsurface soil, surface water, and SPGW due to releases resulting from historical activities conducted at the former Tuboscope site. Investigation activities designed to satisfy RFI objectives included characterizing the geology, stratigraphy, and hydrogeology of the area of investigation and defining the nature and extent of contamination in affected media along with the source of any potential contamination. RFI activities were to gather data of adequate technical quality to identify, develop, and implement appropriate corrective measures required to protect human health and the environment. The RFI work plan was amended in response to comments provided by USEPA following agency review, and a final version of the RFI work plan was issued (OASIS 2009a).

Table 7.2.1 lists the work plan and report for each phase of the RFI.

Table 7.2-1: Work Plan and Report for Each Phase of the RFI

Year	Work Plan	Report
2008	*RCRA Facility Investigation Work Plan, Former Tuboscope Site* (OASIS 2008d)	*RCRA Facility Investigation Interim Summary Report, Former Tuboscope Site, Administrative Order on Consent, EPA Docket No. RCRA-10-99-0179* (OASIS 2012b)
2009	*RCRA Facility Investigation Work Plan, Former Tuboscope Site, Revision 1* (OASIS 2009a)	
2012	*Phase 2 RCRA Facility Investigation Work Plan Addendum, Former Tuboscope Site* (OASIS 2012a)	*2012 Interim Measures System Evaluation Site Assessment and RCRA Facility Investigation Interim Summary Report, Former Tuboscope Site* (ERM 2014a)
2012	*Work Plan, Phase 3 RCRA Facility Investigation, Former Tuboscope Site* (OASIS 2012c)	
2013	*Former Tuboscope Site, Revised RCRA Facility Investigation Work Plan Addendum Amendment, Continuation of Hydrology Study Data Collection in 2013* (ERM 2013c)	*2013 Tuboscope RCRA Facility Investigation Interim Summary Report* (ERM 2014b)
2017	*Interim Measures Drainage Ditch Decommissioning Work Plan (2017-2018), Former Tuboscope Site, administrative Order on Consent, EPA Docket No. RCRA-10-99-0179, EPA Docket No. RCRA-10-2007-0222* (ERM 2017a)	*Former Tuboscope Site, 2018 Interim Measures Annual Operations and Drainage Ditch Decommissioning Report* (ERM 2019a)

Select photographs collected throughout the investigation are presented in the attached photographic log (Appendix C). Soil boring logs and monitoring well construction logs are presented in Appendix E. Copies of the field notebooks and sample forms for all phases of the RFI are presented in Appendix J.

6.2.1 Timeline of Investigation Activities

The following subsections summarize annual project objectives and investigation activities at the former Tuboscope site by year. Investigation was primarily performed in support of the RFI. The former Tuboscope site RFI was performed in phases between 2008 and 2013, with one exception. A limited soil sampling effort was performed during an IM drainage ditch decommissioning event in 2018. The analytical results from the 2018 soil samples collected below the bottom of the former drainage ditch have been incorporated within the RFI for data completeness.

6.2.1.1 Between 2008 and 2011

The RFI field investigation activities from 2008 through 2011 were performed as described in the original (Phase 1) work plan (OASIS 2008d), the revised (Phase 2) RFI work plan (OASIS 2009a), and its addendum (OASIS 2012a). The primary objective was to determine the extent of hazardous constituents present in surface and subsurface soil, surface water, pad porewater, and SPGW due to releases resulting from historical activities at the former Tuboscope site. RFI activities included collection of data to identify, develop, and implement appropriate corrective measures to protect human health and the environment.

Investigation activities completed from 2008 through 2011 include:

- Physically verifying the presence of the curtain liner (Photograph 4, Appendix C)
- Advancing 51 soil borings using direct push techniques for soil sample collection and lithology evaluation (Photographs 5 and 9, Appendix C)
- Installing thermistor strings with data loggers in 11 soil borings

- Constructing 42 pad porewater monitoring wells on-pad
- Constructing 39 horizontal SPGW monitoring wells (Photograph 6, Appendix C)
- Collecting and analyzing a total of:
  - 383 pad gravel samples
  - 56 tundra mat peat samples beneath the gravel pad
  - 51 native mineral soil samples beneath the gravel pad
  - 7 samples consisting of peat and mineral soil from two off-pad soil borings
  - 30 off-pad tundra surface soil samples
  - 174 pad porewater samples
  - 22 off-pad SPGW samples
  - 85 off-pad surface water samples
- Surveying the surface sample, monitoring well, and thermistor locations for geographic location coordinates and elevations
- Measuring depths to water and depths to bottom (to determine frost line, where the bottom of the well is deeper than the frost line) in the monitoring wells prior to each water sampling event

The locations of the sampling points for the RFI are shown on Figures 3, 4, and 5.

6.2.1.2 2008

Phase 1 of the RFI began in 2008 and included initial investigation to define the vertical and lateral extent of many constituents relative to the then-proposed lowest Tier I SL and Tier II AL concentrations (OASIS 2008d). The data collected improved the understanding of vertical and horizontal constituent distributions. The 1,4-dioxane plume remained poorly defined with results showing it had migrating across the former Tuboscope site through various water migration pathways. Therefore, a second phase of work was needed to fill data gaps identified based on the Phase 1 results. Water media data collection was to be expanded to include additional parameters for the assessment of natural attenuation. The results of this phase of the investigation are described in detail in the former Tuboscope site 2012 *RCRA Facility Interim Summary Report* (OASIS 2012b).

6.2.1.3 2009

Phase 2 of the RFI began in 2009 and included an evaluation of site hydrology and migration pathways for the movement of 1,4-dioxane from the pad to off-pad surface water sampling points. The activities targeted locations where 1,4-dioxane was reported in water samples collected in 2008. Four subsurface temperature monitoring points (thermistor strings equipped with automatic data loggers) were installed, and two existing thermocouple strings (previously installed in 2006 to support the BNP pilot study) were retrofitted with automatic data loggers.

Surface water monitoring was performed during the thaw season in July, August, and September. The work plan proposed measuring the surface water flow rates and directions; however, the surface water flow rates were not measurable using field instruments as they were extremely low, or stagnant (OASIS 2009a). Because of this, the hydrology study design and methodologies were re-evaluated and revised and presented in the Phase 2 RFI Work Plan Addendum (OASIS 2012a). Additional monitoring points were added to better evaluate localized flow direction changes during the thaw season. These additional points provided data to evaluate anthropogenic influences, such IM removal of water from the drainage ditch to control migration of 1,1,1-TCA (OASIS 2012b).

A geophysical survey was performed in May 2011 around the former Tuboscope building location. Soil borings were advanced during the thaw season to characterize the vertical extent of constituents. As part of the implementation of the revised hydrology study, eight additional pad porewater monitoring wells were installed, eight additional temperature monitoring points were installed, and one of the damaged temperature monitoring points (T64) was replaced. Horizontal SPGW wells were installed off-pad in 2011.

6.2.1.4 2010

Phase 2 of the RFI continued in 2010 and included limited data collection from subsurface temperature monitoring points in support of the hydrology study, and sample collection in support of 1,4-dioxane biodegradation studies. Thermistor string data logger downloads were attempted in 2010, with limited success. Pad surface grading and maintenance destroyed two of the four temperature monitoring points that had been installed in 2009. Snow removal operations destroyed the data logger of a third thermistor string. Only a temperature monitoring point constructed off-pad remained intact.

6.2.1.5 2011

Phase 2 continued in 2011 with completion of a comprehensive water sampling event to continue constituent delineation using the then-proposed lowest Tier I SLs and Tier II ALs. Activities performed in 2011 delineated the majority of the 1,1,1-TCA plume and degradation product plumes, except for the southeast extent of chloroethane along the GC3 Pipeline Access Road. However, the 1,4-dioxane plume was not fully delineated during this phase of the investigation. Diesel (DRO) impacts were delineated in pad porewater in the vicinity of the former Tuboscope building and the former drilling mud plant. Lead was found to be distributed widely across the area of investigation, and elevated concentrations were measured in samples from off-pad suprapermafrost wells believed to represent background conditions. Barium was present across the area of investigation, but at concentrations below the lowest proposed lowest Tier II AL.

Phase 1 and Phase 2 RFI environmental activities and results (performed between 2008 and 2011) are discussed in detail in the *RCRA Facility Investigation Interim Summary Report, Former Tuboscope Site* (OASIS 2012b).

6.2.1.6 2012

Phase 3 of the RFI began in 2012 and included continuation of the hydrology study. Work focused on gathering depth of thaw and water elevation data from pad porewater, SPGW, and surface water between late June and mid-September (between the thaw season and freeze-up). Goals of the hydrology study included determining the bottom of the active layer or the seasonal top of permafrost elevation, determination of hydrologic flow patterns within the former Tuboscope site area of investigation, and monitoring for seasonal effects including variation in the start and end of the thaw season to determine the months of significant hydrologic flow (OASIS 2012c).

Additionally, constituent impacts to soil and water impact were assessed to further delineate the extent of on- and off-pad contamination. The area-of-investigation-wide water sampling event was performed to verify the delineation COIs and to delineate the extent of 1,4-dioxane in the water. Investigation activities completed in 2012 include collecting and analyzing a total of:

- 10 surface soil samples from on-pad locations to evaluate the extent of drilling mud impacts to the gravel surface material
- 71 off-pad surface water samples

- 37 pad porewater samples
- 31 off-pad SPGW samples

Data collected as part of the RFI hydrology study in 2011 and 2012 indicate that the water elevations were heavily influenced by precipitation events. The groundwater flow is generally toward the northeast near the former Tuboscope building location. However, at the western edge of the pad, limited southwestward flow was observed.

The results of the analytical data collected in 2012 for the RFI, in consideration with the larger set of data collected for the RFI in 2011, indicated that delineation to the Tier II ALs, considered most appropriate for the former Tuboscope site (SWMU-specific Tier II ALs), had been completed for the COIs.

Phase 3 activities conducted in 2012 are described in detail in the *2012 Interim Measures System Evaluation Site Assessment and RCRA Facility Investigation Interim Summary Report* (ERM 2014a).

In addition, water samples were collected during the RFI in 2012 to support ongoing research regarding the feasibility of 1,4-dioxane biodegradation being performed by Rice University. A total of 11 pad porewater monitoring wells (MW-11, MW-12, MW-19, MW-22, MW-24, MW-26, MW-32, MW-33, MW-34, MW-98, and MW-201R) were sampled. Pad porewater was provided to Rice University in support of their research.

6.2.1.7 2013

Activities conducted in 2013 focused on gathering additional hydrology data within the former Tuboscope site area of investigation, with consideration for surface topography changes stemming from the 2012 construction of a recessed secondary containment area at the southern TTLA at the CIC Storage Facility. Routine maintenance was performed on temperature data loggers installed at the former Tuboscope site. Manual monitoring of water levels and frost line elevations was performed in September 2013. RFI activities conducted in 2013 are detailed in the *2013 Tuboscope RCRA Facility Investigation Interim Summary Report* (ERM 2014b).

6.2.1.8 2018

IM drainage ditch decommissioning activities performed in 2018 focused on backfilling of the former drainage ditch used for pad porewater and precipitation containment and recovery. At the request of USEPA, soil samples were collected from three locations at two shallow depth intervals below the bottom of the drainage ditch. The soil samples were collected to fill a spatial data gap and were analyzed for COIs. 2018 IM decommissioning activities are described in detail in the *2018 Interim Measures Annual Operations and Drainage Ditch Decommissioning Report* (ERM 2019a).

6.2.1.9 2019 and 2020

In 2019 and 2020, groundwater and surface water monitoring were conducted with a goal of assessing impacts to the concentrations of key COIs in pad porewater and surface water due to backfilling of the drainage ditch in 2018 (ERM 2019b, 2020c). Data from these two monitoring events became available after the comprehensive RFI data set was finalized and has not been included in the tables or figures for this report. That data will be considered in development of the CMS for the former Tuboscope site.

Pad porewater and surface water elevation data confirm that the overall pad porewater flow direction remains toward the northeast, unchanged by backfill. Backfilling the drainage ditch has raised the top permafrost. Concentrations of some constituents are higher beneath the former drainage ditch than they are anywhere else at the former Tuboscope site. The available data indicate that this soil is now permafrost, immobilizing the constituents present.

The available data also indicate that constituent concentrations are decreasing over time through biodegradation, advection, dispersion, and other natural processes. Generally, constituent concentrations in water at the former Tuboscope site either show no discernable trend or are decreasing. However, laboratory analytical results for some pad porewater and surface water samples collected in 2019 and 2020 were higher than would be expected based on comparison with historical data. The area of statistically significant increased concentrations is limited to the area near the former drainage ditch. It is believed that the backfill material compacted underlying organic tundra and mobilized some constituents. Excess pad porewater present in the drainage ditch, following backfilling in 2018, resulted in temporary changes in pad porewater flow characteristics and increased saturation of soils formerly present in the vadose zone resulting in an increase in constituent concentrations. The 2019 and 2020 results do not change the constituents of potential concern to be assessed in the CMS.

6.2.2 Supplemental Investigations

Additional investigation activities conducted at or near the former Tuboscope site after the initiation of the RFI in 2008 are described below.

6.2.2.1 Phytoremediation Study

OASIS performed treatability studies in 2009 to evaluate the potential removal of 1,4-dioxane from off-pad surface water and near-surface soil (Photographs 12 and 13 in Appendix C). The treatability studies included the evaluation of two passive off-pad in situ remedial alternatives: reduction of 1,4-dioxane concentrations through phytoremediation and biodegradation processes. The tundra environment surrounding the pad provides conditions that might allow both phytoremediation and microbial degradation of 1,4-dioxane and other COIs to occur.

Results from the study showed 1,4-dioxane was present in plant tissue and surface water samples at the study locations, confirming 1,4-dioxane was transported laterally through surface water or SPGW and is taken up by vegetation. Air samples collected from the test plots suggest that transpiration of 1,4-dioxane may be occurring by the plant species chosen for the study. Transpiration rates observed during the study were very low, indicating a phytoremediation approach for corrective measures would not provide a viable short-term remedy. The methods and results of this study are described in detail in the 2010 report titled *Phytoremediation Study Results, Former Tuboscope Site* (OASIS 2010c).

6.2.2.2 Assessments of Tank Truck Loading Areas – CIC Storage Facility

The CIC Storage Facility has two separate TTLAs where secondary containment areas were constructed in the existing gravel pads on the north and south sides of the facility. Construction entailed excavation of a shallow surface depression, where a liner and catchment basin were installed.

Northern TTLA

In 2010, seven soil borings were advanced to support the construction of the northern TTLA secondary containment system for the Bulk Chemical Building and the CIC Storage Facility. Samples were analyzed to support hazardous waste characterization and analytes included the former Tuboscope site RFI COIs. Results of the investigation determined that soil excavated from within the gravel pad during construction of the TTLA would not be hazardous waste, and that impacts stemming from historical operations at the former Tuboscope site were not present. Activities and results of this investigation are described in detail in the 2010 document *Final Report for Tuboscope Due Diligence Sampling at BOC T-44-0413 TTLA* (OASIS 2010a). Analytical results from soil removed during the northern TTLA construction event have been excluded from the RFI dataset.

Southern TTLA

In 2012, site investigation activities were performed on the south side of the CIC Storage Facility to support construction of a secondary containment area for a second TTLA. This work was performed separately from the RFI, but the data collected during this investigation was used to support the RFI. Chlorinated solvents (1,1,1-TCA and 1,1-DCA) and diesel hydrocarbons were present in samples collected from multiple soil borings completed in this area. Soil in the central portion of the proposed excavation was impacted by 1,1-DCA and soil in the southern portion of the proposed excavation area was impacted by both 1,1,1-TCA and 1,1-DCA. A localized diesel release (DRO concentration greater than 2,000 mg/kg) was identified within the pre-construction area of investigation. Investigation results supported design of the secondary containment area excavation. Results were used to develop a *Materials Management and Excavation Plan* (OASIS 2012e) for segregation, sampling, and management of the excavated soil removed from the gravel pad surface during construction. Associated site investigation activities and results are described in detail in the *2012 Corrosion Inspection and Chemical Storage Facility Tanker Truck Loading Area Pre-Construction Site Investigation* report (OASIS 2012d). Analytical results from soil removed during construction have been excluded from the RFI dataset.

6.2.2.3 Curtain Liner IM Assessment

As part of the 2012 IM SESA, and in conjunction with an area-of-investigation-wide water sampling event performed as part of the RFI, the integrity, location, and depth of the vertical curtain liner and the effectiveness of the drainage ditch were assessed. This assessment included collecting analytical data from 23 pad porewater monitoring wells, 19 surface water sample locations, and 7 SPGW monitoring wells co-located with surface water sample locations.

The 2012 investigation of the curtain liner determined that the liner was generally effective at limiting the migration of 1,1,1-TCA and other chlorinated compounds to the off-pad setting. However, the data gathered during the RFI hydrology study, and during the liner assessment, suggested that pad porewater is largely diverted by the curtain liner, and that pad porewater may over-top the liner during a portion of the thaw season allowing constituent migration through the GC3 Pipeline Access Road. The results of the 2012 SESA and the curtain liner IM assessment are detailed in the *2012 Interim Measures System Evaluation Site Assessment and RCRA Facility Investigation Interim Summary Report* (ERM 2014a). The curtain liner slows pad porewater flow, but some pad porewater flows over the top of the curtain liner.

6.2.3 Sampling and Analysis

Surface and subsurface soil samples, pad porewater samples, surface water samples, and SPGW samples were collected during various phases of the RFI to characterize the nature and extent of contamination at the former Tuboscope site. All sampling activities were performed by ADEC-qualified samplers, in accordance with the *RCRA Facility Investigation Work Plan, Former Tuboscope Site* (OASIS 2008d) and subsequent work plan addenda (OASIS 2009a, OASIS 2012a, OASIS 2012c; ERM 2013c, ERM 2017). Work plan variances are defined in the phase-specific interim summary reports. The following subsections summarize field activities performed over the course of the RFI.

6.2.3.1 Surface Soil Sampling

Surface soil samples were collected over 12 discrete sampling events between 2008 and 2012. To characterize potential site contaminants in surface soil at the former Tuboscope site, a total of 179 pad gravel soil samples at 90 locations, 11 mineral soil samples at 11 locations, and 32 tundra surface soil samples at 32 locations were collected during the RFI. Table 7 lists the location identification numbers, sample identification numbers, beginning and end depth, date of sample collection, and analytical methods for each sample by year. Figure 5 shows the locations of surface soil samples. Analytical results are summarized in the frequency of detection table for soil (Table 5), detected results are presented in Table 11-b, and the complete dataset is tabulated and included in Appendix L.

Applicable Photograph:
Photograph 8, Appendix C
Applicable Figures:
Figure 5 and figures showing results
Data Tables:
Tables 5, 7, 11-a, and 11-b
Applicable Appendices:
Appendices L and M

Under Alaska regulation 18 AAC 75.990(127), surface soil is defined as soil that extends no more than 2 feet below the surface. Subsurface soil is defined at 18 AAC 75.990(123) as soil that is more than 2 feet below the surface. Several soil samples were collected across an interval that includes both definitions, for instance some samples were collected from 1.5 to 3 feet bgs. To accommodate those samples, and due to limitations in the database, Table 11-b includes results for all samples with an end depth at or less than 3 feet bgs. Associated analytical results are shown on surface soil figures.

6.2.3.2 Subsurface Soil Sampling

Subsurface soil samples were collected over six discrete sampling events in 2008, 2009, 2011, 2012, and 2018. To characterize potential site contaminants in subsurface soil at the former Tuboscope site, a total of 134 pad gravel soil samples at 102 locations, 73 mineral soil samples at 37 locations, and 74 tundra samples at 47 locations were collected during the RFI. Table 7 lists the location identification numbers, sample identification numbers, beginning and end depth, date of sample collection, and analytical methods for each sample by year. Figure 5 shows the locations of all surface soil samples. Table 5 summarizes analytical results, detected results are presented in Table 11-c, and the complete dataset is tabulated and included in Appendix L. Analytical results for deeper soil samples with starting collection depths no more than 6 feet bgs are shown on active-layer soil figures, which do not depict results for permanently frozen soil.[2] Depths for samples collected from material beneath the drainage ditch before it was backfilled (location identifiers SD-6, SS-150, SS-151, SS-152, TM-53, SB-63, SB-150, and SB-151) have been adjusted to account for the backfill material. For select metals only, stacked box figures are provided to show the distribution of soil concentrations by depth, including concentrations of permanently frozen soil.

Applicable Photographs:
Photographs 5 and 9, Appendix C
Applicable Figures:
Figure 5 and figures showing results
Data Tables:
Tables 5, 7, and 11-c
Applicable Appendices:
Appendices E, L, and M

Soil borings were advanced using a GeoProbe® hydraulic percussion rig and soil cores were collected using MacroCore® technology. Each 5-foot-long sample barrel was equipped with a disposable plastic sleeve to contain the sample core from each drive. Cores were labeled with the appropriate location ID and depth prior to storage at temperatures at or below freezing. Processing of cores included field

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[2] Figures showing analytical results for soil samples were developed as follows: Surface soil figures show samples collected with start depths between the ground surface and 2 ft bgs. Active layer figures show samples collected with start depths at depths greater than 2 ft bgs but less than 6 ft bgs. Deep soil figures show samples collected at depths of 6 ft bgs and greater; this soil is permafrost.

screening using a photoionization detector, collecting analytical samples, and characterizing soil lithology. Figure 5 presents soil boring locations; boring logs are presented in Appendix E.

6.2.3.3 Pad Porewater Sampling

Applicable Photograph:

Photograph 10, Appendix C

Applicable Figures:

Figures 3, 4, and figures showing results by constituent

Data Tables:

Tables 6-a, 6-b, 12-a, and 12-b

Applicable Appendices:

Appendices J, L, and M

Pad porewater samples were collected over 11 discrete sampling events in 2008, 2010, 2011, 2012, 2015, and 2016. To characterize contamination at the former Tuboscope site, a total of 207 pad porewater samples were collected at 41 monitoring wells during the RFI.

Table 8 lists the location identification numbers, sample identification numbers, sample date, matrix code (WX = pad porewater), analytical methods for each sample, and whether water quality parameters were collected. Figures 3 and 4 shows the locations of all pad porewater monitoring wells sampled. Tables 6-b and 6-c summarize analytical results, detected results are presented in Tables 12-a, 12-b, and 12-c, and the complete analytical dataset is tabulated and included in Appendix L.

Monitoring wells were sampled to characterize pad porewater at the former Tuboscope site. Analytical results were used to determine where constituents exceeded Tier I SLs, lowest Tier II ALs, applicable ADEC-only CLs, or AWQS (for wells closely connected hydrologically to surface water). Pad porewater analytical data also provides insight to potential migration of contamination via pad porewater. The presence or absence of pad porewater was used to evaluate seasonal thaw effects on subsurface transport. Samples were collected during the period when seasonal thaw was at its maximum depth.

Following monitoring well development, pad porewater monitoring was conducted using low flow methods, which include measuring the depth to pad porewater, purging the well, monitoring and stabilizing field parameters, and collecting samples for laboratory analysis. Total well depth and depth-to-water was measured using an interface probe to determine the elevation of the top of pad porewater and to assess whether unacceptable levels of drawdown were occurring during purging. Interface probe results were also used to screen for separate phase hydrocarbons. Appendix J contains groundwater sampling forms that document this data.

Low flow sampling methodology was used for pad porewater monitoring and sample collection. This method involved purging the well at flow rates low enough to prevent well drawdown from exceeding 0.3 feet during purging and sampling. Monitoring wells were purged and sampled with a peristaltic pump.

Water quality parameters were measured during purging using an YSI® 556 multi-parameter and a flow-through cell. In addition to the depth-to-water, the following water quality readings were recorded on the groundwater sampling forms once every 3 to 5 minutes:

- pH (standard units)
- Dissolved oxygen (in mg/L)
- Conductivity (in milliSiemens per centimeter)
- Temperature (in °C)
- Oxidation-reduction potential (ORP) (in mV)
- Color
- Turbidity (qualitative: clear, low, moderate, or high)

Stabilization parameters were established in the RFI work plan and its various addenda and amendments. Purging continued until stabilization parameters were attained as evidenced by three consecutive readings within established ranges. The required stabilization parameters varied somewhat over the nine span of pad porewater monitoring based upon changes established by work plan addenda and amendments. The following ranges were in effect during the 2011 monitoring event and are typical of those used during subsequent monitoring events:

- pH stable to within 0.1 pH units
- Dissolved oxygen stable to within 10 percent for values greater than 0.5 mg/L (if three consecutive dissolved oxygen values were less than 0.5 mg/L, dissolved oxygen was considered stabilized)
- Conductivity stable to within 5 percent
- Temperature stable to within 0.5 °C

Once purging was complete, the flow-through cell was disconnected and pad porewater samples were collected. The flow rate during sampling remained the same as the purging flow rate. If a well purged dry before samples had been collected, the field team returned to the well within 24 hours to attempt sample collection.

6.2.3.4 Suprapermafrost Groundwater Sampling

Off-pad SPGW samples were collected over three discrete sampling events in 2011, 2012, and 2015. To characterize SPGW contamination off the BOC pad, a total of 56 SPGW samples were collected from 29 tundra monitoring wells during the RFI. SPGW sampling protocols were consistent with the protocols used to collect pad porewater (Section 6.2.3.3). All off-pad SPGW monitoring wells are closely connected to surface water.

Table 8 lists the location identification numbers, sample identification numbers, sample date, matrix code (WG = SPGW collected off the pad), analytical methods for each sample, and whether water quality parameters were collected. Figured 3 and 4 shows the locations of all SPGW monitoring wells sampled. Table 6-b summarizes analytical results, detected results are presented in Tables 12-a and 12-c, and the complete analytical dataset is tabulated and included in Appendix L.

Applicable Figures:

Figures 3, 4, and figures showing results by constituent

Data Tables:

Tables 6-b, 8, 12-a, and 12-c

Applicable Appendices:

Appendices J and L

Monitoring wells were sampled to characterize SPGW at the former Tuboscope site. Analytical results were used to determine where constituents exceeded Tier I SLs, lowest Tier II ALs, applicable ADEC-only CLs, or AWQS. SPGW analytical data also provides insight to potential migration of contamination via SPGW. The presence (or lack thereof) of SPGW was used to evaluate seasonal thaw effects on subsurface transport. Samples were collected during the period when seasonal thaw was at its maximum depth.

6.2.3.5 Surface Water Sampling

Surface water samples were collected over seven discrete sampling events in 2008, 2009, 2010, 2011, 2012, 2015, and 2016. To characterize surface water impacts, a total of 186 surface water samples were collected at 72 surface water sampling locations during the RFI. Table 8 lists the location identification numbers, sample identification numbers, sample date, matrix code (WS = surface water), analytical methods for each sample, and whether water quality parameters were collected.

Figures 3 and 4 shows surface water sample locations. Table 6-a summarizes analytical results, detected results are presented in Tables 13-a

Applicable Photograph:

Photograph 11, Appendix C

Applicable Figures:

Figures 3, 4, and figures showing results by constituent

Data Tables:

Tables 6-a, 8, 13-a, and 13-b

Applicable Appendices:

and 13-b, and the complete analytical dataset is tabulated and included in Appendix L.

Water quality parameters were measured at each surface water location using an YSI® 556 multi-parameter meter. These values, in addition to the presence of odor or sheen, were recorded on surface water sampling worksheets included in Appendix J. Analytical samples were collected using a peristaltic pump after water quality parameters were measured and recorded. Analytical samples for VOC analysis were collected first, followed by the remaining sample analytes. All sample containers were immediately placed in a cooler with frozen gel ice.

6.2.3.6 Quality Control Samples

The requirements for the collection and analysis of quality assurance/quality control (QA/QC) samples were consistent with the Site-wide QAPP (Environmental Standards 2008, 2013, 2014, and 2017), except for waste characterization samples.

6.2.4 Surveying

A licensed surveyor from F. Robert Bell and Associates surveyed locations and elevations of soil borings, monitoring wells, surface water samples, and thermistors. Geospatial information collected includes geographical coordinates, top-of-casing elevations, and ground surface elevations. Monitoring well top-of-casing elevations were surveyed on multiple occasions (generally at least once per groundwater monitoring event) to assess changes associated with frost jacking and/or subsidence.

Surveyed features and recorded measurements were collected relative to the northing and easting coordinates under the state plane coordinate system (Alaska State Plane Zone 4) and North American Datum, 1927. Elevations were surveyed based on the BP vertical datum, which was mean lower-low water elevation established at the tidal gauge at the seawater treatment plant/West Dock. The elevation of the tidal gauge was historically determined using level loop survey techniques based on benchmarks located in Fairbanks.

The PBU RCRA Order requires that new wells be surveyed using the National Geodetic Vertical Datum, 1929, or updated to North American Vertical Datum of 1988 (NAVD88). NAVD88 consists of a leveling network affixed to a single origin point. A geoid model is used; however, according to ADNR's Division of Geologic and Geophysical Surveys, the model provides a good but not perfect approximation, particularly in many parts of Alaska (ADNR 2020a). Elevations for all survey data have been converted to NAVD88 using a single conversion factor established for the area using National Oceanic and Atmospheric Administration's VDatum Tool and ADNR's tidal conversion tool (ADNR 2020b). This survey approach has been used to meet the terms of the PBU RCRA Order while still allowing newly collected elevation data to tie to historical survey data.

6.2.5 Hydrologic Study

The Tuboscope hydrology study was conducted in support of the RFI from 2008 through 2013. Activities associated with the Tuboscope hydrology study during these years included:

- Surveying monitoring well, surface water sample, and thermistor casing locations, so that changes from frost heave or sloughing can be included in active-layer water elevation data
- Installing ground temperature monitoring thermistors to determine the annual maximum thaw depth of permafrost
- Downloading, storing, and evaluating thermistor data from programmed data loggers
- Manually gauging pad porewater, surface water, and SPGW elevations during the summer thaw seasons

- Deploying pressure transducers during the 2012 summer thaw season at 50 pad porewater, surface water, and SPGW locations
- Downloading, storing, and evaluating 2012 pressure transducers data from programmed data loggers

A summary of data collection activities in support of the hydrological study is provided in the following subsections. The former Tuboscope site hydrology study is detailed in the 2008 to 2011, the 2012, and the 2013 Tuboscope RFI interim summary reports (OASIS 2012b; ERM 2014a, ERM 2014b).

6.2.5.1 Thermistor Data Collection

Subsurface soil temperature was monitored using thermistor string data loggers within the defined area of investigation between the years of 2009 and 2013. A total of 17 thermistor strings were installed and configured with data loggers to collect temperature data (Appendix G, Table G-1). Thermistors collected temperature data from fall freeze-up through the following spring thaw. Data collection began when soil temperatures rose above 20 °F. Readings were collected every 12 hours until soil temperatures dropped below 20 °F. Maintenance activities, including replacing batteries and desiccant, verifying functionality of the thermistors, and downloading recorded data, were performed on the thermistor string data loggers each summer (Photograph 7 in Appendix C).

Temperature data was used to evaluate permafrost conditions and seasonal thaw depths at the former Tuboscope site. Figure 10 presents 2013 top of permafrost elevations at the approximate time of the maximum thaw.

Ground thawing within the area of investigation typically occurred from early to mid-July through the end of September. Appendix G includes graphs of thermistor temperature data recorded for 2012 and 2015. Graphs for 2012 show the elevation of the top of SPGW, the elevation of the top of frozen soil, and the saturated thickness. Graphs for 2015 show soil temperatures recorded at various sensor depths (typically the sensor depths were 3, 4, 5, 6, 7, 8, 9, and 10 feet bgs), the inferred thaw depth, and the daily average temperature recorded at Deadhorse, Alaska. Data gaps on several of the graphs resulted from damaged thermistor data loggers, failed batteries, and inoperable data loggers due to the harsh arctic setting.

6.2.5.2 Water Elevation and Active Layer Thickness Data Collection

Depth to SPGW and total depth were measured and recorded at each monitoring well location from 2008 to 2013 using an interface probe. Surface water elevations in the former drainage ditch and in select surface water bodies were also measured. The reference point elevation of each monitoring location was surveyed. Depth to pad SPGW and top of surface water elevation measurements were recorded to enable the calculation of water level elevations relative to the vertical datum.

In addition to manual water level elevation data collection, pressure transducers with automatic data loggers were installed in 26 monitoring wells and 12 surface water bodies in 2012 to collect temporal water level elevation data to understand hydrologic changes that occur during the summer thaw season. Appendix H presents graphs showing precipitation data over time and corresponding changes in the elevation of the top of SPGW.

6.2.5.3 Hydraulic Properties Data Collection

For each of the approximately 91 discrete soil boring locations advanced using a direct push drill rig, samples were collected using a 1.5-inch diameter MacroCore and the Rig Geologist logged descriptions of soil samples (Appendix E). Hydraulic properties for site soils were determined based on the Project Geologists' assessment of soil samples and on the geotechnical reports included as Appendix F. This data supported the assessment of hydraulic conductivity presented in Section 4.4.

6.2.6 Description of Process Used to Assess Background

The process used to distinguish naturally occurring constituent concentrations from impacts related to site activities relies on assessment of multiple lines of evidence, one or more of which may be used to distinguish natural conditions from those influenced by a release. For constituents that do not occur naturally, such as chlorinated hydrocarbons, a working assumption was made that the presence of the constituent is due to site activities. A straight-forward assessment was then made based on the site history and spatial pattern of each constituent to assess whether the available evidence refuted the assumption.

Metals, which are naturally occurring but could have elevated concentrations due to site activities, were subjected to a more rigorous assessment, detailed in Appendix N. Metals results that exceeded the lowest Tier II AL and either also exceed the PBU-wide BTV or for which no BTV has been assigned were subjected to the background assessment.

For detected constituents (where maximum location-specific results [for soil samples] or the most recent results [for water samples] exceeded the MDL), QQ plots were developed, and breakpoints were identified. Results below the breakpoint and results above the breakpoint but within the 95 percent prediction interval of the PBU-wide were considered not to be impacted by site activities. For pad gravel and pad porewater, the assessment considered the Put 23 background dataset. Results that were both above the breakpoint and outside of the 95 percent prediction interval of the PBU-wide or Put 23 background datasets were subject to a weight of evidence assessment based upon:

- Review of site history
- Spatial mapping
- Principal components analysis
- Development and review of geochemical ratio plots
- Visual fingerprint analysis

Based on the weight of the evidence, results were determined to be either caused by site impacts or caused by natural processes. Figure 10 summarizes these findings. Details of the approach used and results are presented in Appendix N.

6.2.7 Investigation Derived Waste Management

Investigation derived waste (IDW) associated with RFI activities included soil cuttings, plastic soil core sleeves, decontamination water, purge water, and disposable sampling equipment. IDW was managed in accordance with the RFI work plan and its various addenda and amendments (OASIS 2008d, OASIS 2009a, OASIS 2012a, OASIS 2012c; ERM 2013c), and the *Interim Measures Drainage Ditch Decommissioning Work Plan (2017-2018), Former Tuboscope Site* (ERM 2017a). BPXA handled its IDW in accordance with USEPA document, *Management of Investigation-Derived Wastes during Site Inspection* (USEPA 1991). Details are presented in the 2008 to 2010, the 2011, and 2012 interim summary reports (OASIS 2012b; ERM 2014a; ERM 2014b).

7. INVESTIGATION RESULTS

Investigation activities at the former Tuboscope site performed in support of the RFI included the collection and analysis of soil and water samples, and completion of a hydrology study. The following sections describe the investigation results.

Table 2 includes the complete list of COIs defined in the *RCRA Facility Investigation Work Plan, Former Tuboscope Site* and applicable work plan addenda and amendments (OASIS 2008d, OASIS 2009a, OASIS 2012a, OASIS 2012c; ERM 2013c), and the *Interim Measures Drainage Ditch Decommissioning Work Plan (2017-2018), Former Tuboscope Site* (ERM 2017a). The frequency of detection tables show which COIs were detected at concentrations above lowest Tier II ALs: Table 5 (soil), Table 6-a (surface water), Table 6-b (SPGW closely connected hydrologically to surface water), and Table 6-c (SPGW not closely connected hydrologically to surface water). COIs were delineated to the lowest Tier II AL, or (for metals) to concentrations consistent with background. Generally, this section does not discuss analytical results for VOCs, SVOCs, and metals in soil and water that were below lowest Tier II ALs (or below ADEC-only criteria or their respective AWQS, as appropriate). Table 10 provides a summary of the background analysis performed for the constituents. COPCs are summarized in Table 14-a (soil), Table 14-b (SPGW closely connected hydrologically to surface water), Table 14-c (surface water), and Table 14-d (SPGW not closely connected hydrologically to surface water). Table 15 summarizes assessment of constituents based on ADEC-only CLs and AWQSs.

7.1 Soil Data Overview

Between 2007 and 2018, 503 surface and subsurface soil samples were collected and analyzed as part of this RFI. Although the formal RFI for the former Tuboscope site was initiated in 2008, some soil data collected in 2007 during a SESA is also included in the RFI dataset. The 2007 data provided the basis for development of the 2008 RFI work scope to further delineate the nature and extent of contamination identified during previous investigations.

Soil samples were collected from 125 soil borings and 20 surface soil locations. Soil samples collected as part of this RFI included:

- 90 primary and field duplicate mineral soil samples collected from 48 unique locations
- 33 primary and field duplicate gravel pad material samples collected from 129 unique on-pad locations
- 106 primary and field duplicate tundra samples collected from 73 unique off-pad locations

The following discussion uses only the higher concentration from each primary and duplicate pair (ADEC 2017c). Figure 5 identifies surface soil sample and soil boring locations. Table 5 presents frequency of detection information for each constituent and summarizes the number of analytical results exceeding each of the Evaluation Criteria. Analytical results with concentrations above the method detection limit (MDL) are summarized in Table 11-a (all depths), Table 11-b (surface soil), and Table 11-c (subsurface soil). These tables also include sample depth information, date, and matrix type. Appendix L presents comprehensive soil data tables and includes information on results below the MDL and rejected results.

Table 14-a shows soil COPCs, which include: 1,1,1-TCA, 1,1,2,2-tetrachloroethane, 1,1-dichloroethane, 1,2-dichloroethane, 1,2,3-trichloropropane, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, 1,4-dioxane, ethylbenzene, toluene, xylenes, naphthalene, dibenzofuran, p-isopropyltoluene, isopropylbenzene, barium, chromium, chromium III, chromium VI, copper, lead, selenium, and zinc.

7.2 Suprapermafrost Groundwater, Pad Porewater, and Surface Water Data Overview

Water sample collection activities performed during the RFI (2008 – 2016) are summarized below:

- 186 primary and field duplicate water samples were collected from 72 unique surface water locations
- 207 primary and field duplicate pad porewater samples were collected from 41 on-pad monitoring wells
- 56 primary and field duplicate SPGW samples were collected from 29 off-pad monitoring wells

Figures 3 and 4 identify surface water, pad porewater, and SPGW sample locations. Pad porewater is defined as the subset of SPGW that exists within the man-made gravel pads. Table 8 presents surface water, pad porewater, and SPGW location identifiers, sample identification numbers, year of collection, matrix code, and analytical parameters collected at each location. Analytical results for these samples are summarized in Table 6-a (surface water), Table 6-b (monitoring wells closely connected hydrologically to surface water), and Table 6-c (monitoring wells not closely connected hydrologically to surface water). The following sections focus on results that exceed evaluation criteria.

Detected analytical results for monitoring well samples are presented in the following tables: Table 12-a (monitoring wells closely connected hydrologically to surface water), Table 12-b (monitoring wells not closely connected hydrologically to surface water), and Table 12-c (hardness-dependent metals measured in monitoring wells closely connected hydrologically to surface water). Table 13-a presents detected analytical results for surface water samples. Table 13-b presents detected results for hardness-dependent metals in surface water samples. These tables present temporal results for all monitoring well and surface water samples collected during the investigation; the constituent-specific detection and Evaluation Criteria comparison summary data presented below is based on all dates, locations, and samples.

Due to the decade-long duration of the investigation, constituent delineation figures referenced in this section present only the most recent analytical results. Comprehensive data tables in Appendix L provide a comprehensive dataset of all analytical results reported for water samples collected during the field efforts (including results below the MDL, MDLs, reporting limits (RL), field QC samples, rejected data, and data qualifiers). Although some locations were sampled more than once or may have had a duplicate sample collected, only the most recent results from each location, and only the higher concentration from each primary/duplicate pair is being used in discussions of the extent of contamination below. Unless stated otherwise, values reported in the sections below are for total metals concentrations (as opposed to dissolved metals concentrations).

COPCs in water were identified based on the COI results following comparison with applicable Evaluation Criteria. Table 14-b shows COPCs for pad porewater and SPGW closely connected hydrologically to surface water, which include: 1,1,2-trichloroethane, 1,1-dichloroethane, 1,2-dichloroethane, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, 1,4-dioxane, benzene, ethylbenzene, xylenes, isopropylbenzene, naphthalene, n-propylbenzene, 2-methylnaphthalene, 2-methylphenol, 3&4-methylphenol, various PAHs, arsenic, nickel, and zinc. Table 14-c shows COPCs for surface water, which include: 1,1-dichloroethane, 1,4-dioxane, benzene, ethylbenzene, naphthalene, 2-methylnaphthalene, various PAHs, arsenic, barium, iron, nickel, and zinc. Table 14-d shows COPCs for pad porewater not closely connected hydrologically to surface water, which include: 1,1,1-TCA, 1,1,2-trichloroethane, 1,1-dichloroethane, 1,2,3-trichloropropane, 1,2-dichloroethane, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, 1,4-dioxane, chloroform, benzene, ethylbenzene, xylenes, isopropylbenzene, naphthalene, n-propylbenzene, trichloroethene, vinyl chloride, 2-methylnaphthalene, 3&4-methylphenol, various PAHs, cadmium, copper, lead, and zinc.

7.3 Chloroethanes in Soil and Water

The 1982 fire released 1,1,1-TCA. In the environment, 1,1,1-TCA may biodegrade into 1,1-DCA. Both 1,1-DCA and 1,2-DCA can be impurities found in 1,1,1-TCA. The following sections discuss each of these chloroethanes.

7.3.1 1,1,1-Trichloroethane

The distribution of 1,1,1-TCA in surface soil is shown on Figures 101-A and 101-B; data for active-layer soil is summarized on Figures 101-C and 101-D. Out of the 487 soil samples collected, 1,1,1-TCA was detected in 222 soil samples collected at 88 locations. Concentrations range from 0.00044 to 173 mg/kg with a mean concentration of 4.6 mg/kg. The 1,1,1-TCA concentration exceeded the lowest Tier II AL of 100 mg/kg in just one sample (0.2 percent of samples). Sample 07-BNPPLT-SO1063 collected at location DB-7 at 3 to 4.5 feet bgs contained 173J-H mg/kg of 1,1,1-TCA. This sample was collected beneath the former Tuboscope building location in 2007.

The distribution of 1,1,1-TCA in surface soil follows a clear pattern, with the highest concentrations present beneath and adjacent to the former Tuboscope building location. Farther from the former building location, concentrations are below the lowest Tier II AL, and results for samples collected beyond approximately 150 feet from the former building are below the detection limit. Concentrations measured in subsurface soil tend to be higher than concentrations measured in surface soil. As with results from surface soil, concentrations in subsurface soil are highest below and near to the former building location and decrease with distance from the former building location.

Out of the 219 samples collected from monitoring wells, 1,1,1-TCA was detected in 113 samples. 1,1,1-TCA concentrations exceeded the lowest Tier II AL of 790 micrograms per liter (µg/L) in 25 SPGW samples. The maximum detected concentration of 6,090 µg/L was measured in a 2008 sample collected from monitoring well MW-202, located just east of the former Tuboscope building. Of the 134 surface water samples analyzed for 1,1,1-TCA, the constituent was detected in 25 samples and none of the analytical results exceeded the AWQS or lowest Tier II AL.

The most recent analytical results from pad porewater, SPGW and surface water for 1,1,1-TCA are shown on Figures 101-E and 101-F. The concentration of 1,1,1-TCA exceeds the lowest Tier II AL in samples from source area monitoring wells MW-201 (2,370 µg/L), MW-201R (2,910 µg/L), and MW-202 (2,980 µg/L). Results for 1,1,1-TCA analysis are available for these wells from 2008 through 2015. These results suggest a steady, but slow decrease in concentrations over time.

The constituent is present in a localized volume of pad porewater at, and downgradient from, the former Tuboscope site in a discernable spatial pattern. The highest concentrations of 1,1,1-TCA in SPGW are located just east (downgradient) of the former Tuboscope building location. Analytical results decrease with distance from the building. The impacted area is proximate to and downgradient from soil boring location DB-7 where a concentration (173J-H mg/kg) of 1,1,1-TCA was measured in 2007.

Two related constituents, also chloroethanes, were detected at concentrations above the lowest Tier II AL and appear to be associated with the release(s) of 1,1,1-TCA. In 2007, 1,1,2,2-tetrachloroethane was detected in six soil samples at concentrations above the lowest Tier II AL (0.13 mg/kg). These samples were collected at the following soil boring locations: two at SB-2B and one each at DB-1B, DB-3B, DB-4B, and DB-7B. All six samples were collected within the footprint of the former Tuboscope building. The highest concentration was measured in a sample from soil boring SB-2B which had a concentration of 1.03J-S mg/kg. The extent of 1,1,2,2-tetrachloroethane in soil above its Tier II AL is shown on Figures 101-H (surface soil) and 101-I active layer soil. Concentrations of 1,1,2,2-tetrachloroethane above the Tier II AL have not been measured since 2007. Four monitoring well samples contained 1,1,2-trichloroethane at a concentration above its lowest Tier II AL. These samples were collected from monitoring wells known to be impacted by 1,1,1-TCA: MW-19 (east of the drainage ditch), MW-22 (in 2011 and 2012, west of the drainage ditch), and MW-24 (west of the former Tuboscope building). This constituent was not detected in surface water.

7.3.2 1,1-Dichloroethane

Under anaerobic conditions, reductive dechlorination can transform 1,1,1-TCA into 1,1-DCA. Out of 488 soil samples analyzed for 1,1-DCA, the constituent was detected in 181 soil samples collected at 72 locations. 1,1-DCA concentrations range from 0.00052 to 11.2 mg/kg with a mean concentration of 1.15 mg/kg. 1,1-DCA concentrations exceeded the lowest Tier II AL of 0.14 mg/kg in 105 samples (22 percent of samples).

The distribution of 1,1-DCA in surface soil is shown on Figures 102-A and 102-B; data for active-layer soil is summarized on Figures 102-C and 102-D. The highest concentrations of 1,1-DCA in soil, including results above the lowest Tier II AL, are located below where the central portion of the former Tuboscope building was located (including samples collected from soil borings SB-1, SB-2, SB-2B, SB-3, SB-3B, SB-4, and SB-4B). In surface soil, Concentrations above the lowest Tier II AL extend towards the former drainage ditch (soil boring B-22) and beyond the former drainage ditch and vertical curtain liner (soil boring B-19). For soil samples collected in the active layer the extent of concentrations above the lowest Tier II AL is larger. Concentrations above the lowest Tier II AL are present beneath the former Tuboscope building, to the east, beneath the former drainage ditch, and beyond the vertical curtain liner (one location, soil boring SB-90). The result for upgradient soil borings B-24B and SB-29 also exceeded the lowest Tier II AL. Concentrations of 1,1-DCA in soil appear to decrease with distance from the former Tuboscope building location.

Of the 219 samples collected from monitoring wells, 1,1-DCA exceeded the lowest Tier II AL (2.7 µg/L) in 101 samples. The maximum measured concentration was 1,800 µg/L. Of the 133 surface water samples collected, 1,1-DCA exceeded the lowest Tier II AL in 19 samples. The maximum measured concentration was 380 µg/L.

The distribution of 1,1-DCA in pad pore water, SPGW and surface water is shown on Figures 102-E and 102-F based on the most recent analytical results. Concentrations above the lowest Tier II AL form a discrete plume centered on the former Tuboscope building. The highest concentrations are present in the immediate vicinity of the former Tuboscope building (monitoring wells MW-201, MW-201R, and MW-202). To the northeast (downgradient), the extent of contamination widens to include the area surrounding the former drainage ditch. The concentration of 1,1-DCA also exceeds the lowest Tier II AL in two monitoring wells to the southwest of the source area (MW-16 and MW-24). Although results for surface water samples collected at locations ST-51 and ST-52 east of the former drainage ditch exceed the lowest Tier II AL, concentrations of this volatile constituent decrease rapidly once it has discharged to surface water. As a result, surface water exceedances of lowest Tier II ALs are currently limited to these locations. The mean SPGW concentration of 1,1-DCA is 213 µg/L, as compared to the mean surface water 1,1-DCA concentration of 39.6 µg/L. The 1,1-DCA concentrations of all surface water samples collected farther than approximately 60 feet from the BOC pad were below the MDL.

7.3.2.1 1,2-Dichloroethane

The constituent 1,2-DCA may have been an impurity in 1,1,1-TCA used at the former Tuboscope site; 1,2-DCA is used in some manufacturing processes that produce 1,1,1-TCA (NCBI 2020a). At the former Tuboscope site, the residual mass of 1,2-DCA is much lower than the residual mass of 1,1,1-TCA. The distribution of 1,2,-DCA in surface soil is shown on Figures 103-A and 103-B; data for active-layer soil is summarized on Figures 103-C and 103-D.

Out of the 485 soil samples collected, 1,2-DCA was detected in 11 soil samples collected at nine locations. 1,2-DCA concentrations range from 0.0018 to 4.06 mg/kg with a mean concentration of 0.376 mg/kg. 1,2-DCA concentrations exceeded the lowest Tier II AL of 0.81 mg/kg in just one sample (0.2 percent of samples). Sample 07-BNPPLT-PM5041_10/23/07_17:35 collected at soil boring DB-7B contained 4.06 mg/kg of 1,2-DCA. This sample was collected on the eastern side of the former Tuboscope building location.

Out of 159 samples collected from monitoring wells, 1,2-DCA was detected in 23 samples; all 23 detected results exceeded the lowest Tier II AL of 0.17 µg/L. Detected concentrations of 1,2-DCA in monitoring well samples range from 0.37 µg/L to 3.8 µg/L with a mean concentration of 1.7 µg/L. None of 94 surface water samples contained detectable concentrations of the constituent.

The distribution of 1,2-DCA in SPGW and surface water is shown on Figures 103-E and 103-F based on the most recent analytical results. The data show that 1,2-DCA concentrations exceed the lowest Tier II AL beneath the former Tuboscope building location and in the immediately surrounding area. As with 1,1,1-TCA and 1,1-DCA, the highest concentrations are present in the immediate vicinity of the former Tuboscope building (monitoring wells MW-201, MW-201R, and MW-202).

7.3.3 Chloroethanes Fate and Transport

Each of the chloroethanes discussed in this section is water soluble and has a low affinity for sorbing onto organic carbon in soil (Table 3). These constituents are also volatile, either from the pure phase/dry soil or when dissolved in water/located in wet soil. Most of the mass of chloroethanes remains beneath or immediately adjacent to the former Tuboscope building location. Chloroethane concentrations in soil above the lowest Tier II AL were not found at depths greater than 4.5 feet below ground surface, indicating that vertical delineation has been successful throughout the study area. The limited flow of water (precipitation and snowmelt) through vadose zone material in the BOC Pad has served to limit the mobility of these constituents. The short period each year when pad porewater is thawed further limits constituent mobility. When the SPGW discharges to surface water, the portion of each constituent that has dissolved and migrated with SPGW rapidly volatilizes.

Direct biodegradation of 1,1,1-TCA is generally limited to anaerobic environments. As detailed in Table 4, both pad porewater and SPGW at the former Tuboscope site tend to be anaerobic. Biodegradation of 1,1,1-TCA can occur through several pathways. Reductive dechlorination can sequentially transform 1,1,1-TCA into 1,1-DCA and then chloroethane and ethane. Dehydrochlorination can transform 1,1,1-TCA into 1,1-dichloroethene. Dichloroelimination can transform 1,1,1-TCA into vinyl chloride. The end products of these reactions, specifically ethane and vinyl chloride, tend to biodegrade under aerobic conditions.

At the former Tuboscope site, chloroethane was detected in 56 of 485 soil samples; all results were below the lowest Tier II AL. The distribution of chloroethane in surface soil is shown on Figures 104-A and 104-B; data for active-layer soil is summarized on Figures 104-C and 104-D. The distribution of chloroethane in SPGW and surface water is shown on Figures 104-E and 104-F based on the most recent analytical results. Chloroethane was widely detected in SPGW and surface water, with all results below the lowest Tier II AL.

Vinyl chloride was detected in one of 485 soil samples at a concentration below the lowest Tier II AL. Information regarding vinyl chloride in water is presented in Section 7.4.2.

The following factors suggest that biodegradation of 1,1,1-TCA is occurring:

- Decreasing 1,1,1-TCA concentrations over time in the most contaminated monitoring wells (MW-201R and MW-202 located just east of the former Tuboscope building)
- The presence of degradation products such as 1,1-DCA, chloroethane, and ethane

- Reducing conditions, which are conducive to anaerobic biodegradation
- Limited geographic distribution, despite the decades that have passed since the 1982 fire

1,1-DCA is also used as a feed stock in the production of 1,1,1-TCA, and its presence could be as a contaminant in the original product. However temporal data from monitoring well MW-12 (located just north of the former Tuboscope building) provides clear evidence of reductive dechlorination. In 2008, the well contained 69.2 µg/L of 1,1,1-TCA and 48.9 µg/L of chloroethane. In subsequent years, the concentration of 1,1,1-TCA continued to drop: 8.1 µg/L in 2011, 1.5 µg/L in 2012, and ND in 2015. Over the same period, the concentration of chloroethane rose and then dropped as the supply of 1,1,1-TCA was exhausted: 108 µg/L in 2011, 51.2 µg/L in 2012, and 3.8 µg/L in 2015.

Figure 101-G shows relative concentrations of 1,1,1-TCA, 1,1-DCA, 1,2-DCA, and chloroethane. The highest sums of the concentrations for these four constituents are located near the former Tuboscope building. This is also the location of the highest concentrations of 1,1,1-TCA. Two factors change with increasing distance from the building: 1) the sum of the concentrations decreases and 2) chloroethanes tend to become increasingly dechlorinated.

As discussed in Section 7.6.3, the ratio between 1,1,1-TCA and 1,4-dioxane appears to be increasing over time. This provides an additional line of evidence that 1,1,1-TCA is biodegrading (while 1,4-dioxane is more recalcitrant).

7.4 Chloroethenes

Neither trichloroethene nor vinyl chloride were detected in any soil samples at concentrations that exceed the lowest Tier II AL. However, the MDL for 22 TCE samples and for 40 vinyl chloride samples exceeded their respective soil Tier II AL. Each of these constituents was found at concentrations above the lowest Tier II AL in a handful of water samples, which are discussed in the following sections. Trichloroethene and vinyl chloride are considered COPCs in pad porewater not closely connected to surface water.

7.4.1 Trichloroethene in Water

Of 159 SPGW samples, the TCE concentration exceeded the lowest Tier II AL (0.27 µg/L) in seven samples from two pad porewater monitoring wells (MW-201 and MW-202). Both locations are monitoring wells located just east of the former Tuboscope building. These wells are not closely connected hydrologically to surface water. Detected concentrations of TCE in SPGW range from 0.47 to 1.2 µg/L with a mean concentration of 0.83 µg/L. Seven results exceeded the lowest Tier II AL. TCE was not detected in any of 94 surface water samples. No results for either surface water samples or for samples of SPGW closely connected hydrologically to surface water exceeded the AWQS (5 µg/L).

The available dataset for monitoring wells MW-201 and MW-202 contains results from 2008, 2010, 2011, and 2012. These results indicate that TCE concentrations have decreased over time. In monitoring well MW-201, concentrations have decreased from 1.2 µg/L to 0.71 µg/L. In monitoring well MW-202, concentrations have decreased from 0.94 µg/L to below the detection limit. The distribution of TCE, with the highest concentrations located just to the east of the former Tuboscope building, suggests a release at or near the building. TCE may have been an impurity in 1,1,1-TCA or may have been used separately as a solvent.

7.4.2 Vinyl Chloride in Water

Of 159 SPGW samples, the vinyl chloride concentration exceeded the lowest Tier II AL (0.018 µg/L) in 11 samples. All exceedances were from monitoring wells MW-201 and MW-202. Detected concentrations of vinyl chloride in all water media range from 0.55 to 3.5 µg/L with a mean concentration of 1.6 µg/L.

Vinyl chloride was not detected in any of 94 surface water samples. No results for surface water samples or for samples of SPGW closely connected hydrologically to surface water exceeded the AWQS.

Vinyl chloride data for monitoring wells MW-201 and MW-202 is available from sampling events that occurred during 2008, 2010, 2011, and 2012. Results indicate that vinyl chloride concentrations have decreased over time but remain above the lowest Tier II AL. In monitoring well MW-201, concentrations have decreased from 3.5 µg/L to 1.6 µg/L. In monitoring well MW-202, concentrations have decreased from 1.2 µg/L to 0.55 µg/L. Given that these monitoring wells are located just east of the former Tuboscope building, the presence of vinyl chloride suggests that it is associated with the former Tuboscope building. Vinyl chloride may be a degradation by-product of TCE, may be a degradation by-product of 1,1,1-TCA, or may have been released separately. Under anaerobic conditions, TCE can reductively dechlorinate (via cis-1,2-dichloroethene) to vinyl chloride. However, cis-1,2-dichloroethene was not detected in any of the soil or water samples.

7.5 Chloroform

7.5.1 Distribution

Chloroform was not detected in any of 486 soil samples. However, for 27 samples, the MDL exceeded the lowest Tier II AL.

Out of the 159 monitoring well samples collected, chloroform was detected in five samples at concentrations above the lowest Tier II AL of 0.22 µg/L. All lowest Tier II AL exceedances in SPGW were from monitoring wells MW-201 and MW-202. In surface water, chloroform concentrations exceeded the lowest Tier II AL in four out of 94 samples. Chloroform does not have an AWQS.

Figures 105-A and 105-B depict the most recent water analytical results for chloroform. The most recent sampling event data show that detected chloroform concentrations exceed the lowest Tier II AL in two discrete areas. Results for three monitoring wells just east of the former Tuboscope building location exceeded the standard: MW-201 (0.37J µg/L), MW-201R (0.34J µg/L), and MW-202 (0.33J µg/L). More than 500 feet north-northwest of the former Tuboscope building, the result for surface water location ST-285 (600 feet north northwest of the former Tuboscope building, 0.30J µg/L) also exceeded the lowest Tier II AL.

7.5.2 Chloroform Source, Fate, and Transport

The most common chloroform exposure for members of the general population is related less to any commercially produced form of the chemical than to chloroform generated when organic materials come in contact with chlorinated oxidants (such as bleach) (ATSDR 1997). In addition to anthropogenic sources, chloroform is a naturally occurring compound. The available data indicate that elevated concentrations of chloroform measured in monitoring wells MW-201, MW-201R, and MW-202 are related to site activities. Based on the distribution of chloroform in Tuboscope media, the concentration of chloroform measured at surface water location ST-285 is less than its Tier II AL and does not appear to be associated with the former Tuboscope site.

Based on its soil organic carbon sorption coefficient (K_{OC}), chloroform has little affinity to sorb to organic carbon in soil. Because of its low soil adsorption and high water solubility, chloroform will readily leach from soil into groundwater. In groundwater, chloroform is expected to persist. Based on its high vapor pressure, the dominant fate process for chloroform in surface waters is volatilization. Upon discharging to surface water, chloroform present in SPGW is expected to volatilize rapidly to the atmosphere (ATSDR 1997).

7.6 1,4-Dioxane

Historically, the main use of 1,4-dioxane was as a stabilizer of chlorinated solvents, primarily 1,1,1-TCA (ATSDR 2012a). Specifically, 1,1,1-TCA was generally stored and transported in aluminum containers, and reaction with aluminum degrades 1,1,1-TCA. To help minimize degradation of the 1,1,1-TCA, 1,4-dioxane was included in the product.

7.6.1 1,4-Dioxane in Soil

Out of 319 soil samples collected, 1,4-dioxane was detected in 31 soil samples collected at 22 locations. Concentrations of 1,4-dioxane range from 0.017 to 3.0 mg/kg with a mean concentration of 0.57 mg/kg. Concentrations of 1,4-dioxane exceeded the lowest Tier II AL of 2.8 mg/kg in two samples (0.6 percent of samples); the MDL for an additional eight samples exceeded the lowest Tier II AL. The analytical results exceeding the lowest Tier II AL were for samples collected from soil borings SB-151 (2.9J-P mg/kg at 7.5 to 10.5 feet bgs) and SB-155 (3.0 mg/kg at 5 to 6 feet bgs). Both borings were advanced through the backfilled drainage ditch. These samples represent soil approximately 2 to 3 feet below the bottom of the ditch before it was backfilled. The data indicate that the drainage ditch had a thaw bulb beneath it, where water could accumulate. Results for these samples represent the active layer beneath the ditch. Water in the area likely could not readily migrate out of the thaw bulb, thawed each summer, and refroze in place each winter. The data show that the 1,4-dioxane exceedances of the Tier II AL for soil are localized in the area beneath the former drainage ditch.

The distribution of 1,4-dioxane in surface soil is shown on Figures 106-A and 106-B; data for active-layer soil is summarized on Figures 106-C and 106-D. For the soil figures, data collected from samples with start depths from 2 to 6 feet bgs are in the active layer; deeper results are permafrost. The samples from soil borings SB-151 and SB-155 that are discussed in the previous paragraph are from soil that is now permafrost. (When their depths are adjusted to account for backfill, their current start depths are greater than 6 feet bgs.) Thus, the results for these two samples do not appear on figures other than Figure ES-1.

7.6.2 1,4-Dioxane in Water

Out of 244 monitoring well samples collected, 1,4-dioxane was detected in 170 samples from 46 locations. Detected concentrations of 1,4-dioxane in SPGW range from 0.7 to 810 µg/L with a mean concentration of 51.9 µg/L. All detected concentrations exceeded the lowest Tier II AL of 0.46 µg/L. 1,4-Dioxane does not have an AWQS. Out of 181 surface water samples collected, 1,4-dioxane was detected at concentrations above the lowest Tier II AL in 112 samples.

Detected 1,4-dioxane concentrations occur in all areas of the former Tuboscope site with a discernable spatial pattern. Extent has been delineated to the lowest Tier II concentration. Concentrations decrease with distance from the former Tuboscope building location. The mean 1,4-dioxane concentration for monitoring wells not closely connected hydrologically to surface water is 79 µg/L, as compared to the mean 1,4-dioxane concentration for monitoring wells closely connected hydrologically to surface water of 34.2 µg/L and to the mean surface water 1,4-dioxane concentration of 11.3 µg/L. Figures 106-E and 106-F depict analytical results for 1,4-dioxane in water samples, and show a fully defined plume with the highest concentrations located at and to the northeast of the former Tuboscope building.

7.6.3 1,4-Dioxane Fate and Transport

Based on its fate and transport properties (Table 3), 1,4-dioxane can be expected to dissolve in water and travel downgradient with SPGW and surface water with little retardation. The constituent is hydrophilic and miscible in water (USEPA 2006). Although free phase 1,4-dioxane is highly volatile, once it has dissolved in water, 1,4-dioxane tends to remain in water and limited tendency to volatilize (H = 4.88E-06 atm-m^3/mole). Its low organic carbon partitioning factor means that 1,4-dioxane binds weakly to soil and is highly mobile in SPGW. The constituent biodegrades very slowly in water and soils and is considered recalcitrant (ASTDR 2012). Its low Henry's law constant prevents it from volatilizing from the dissolved phase or from soil moisture to the vapor phase (USEPA 2006). Because of its physical and chemical properties, 1,4-dioxane plumes have been documented to measure twice the length of the associated solvent plumes and to affect an area up to six times greater (Walsom and Tunnicliffe 2002).

This constituent is presumed to have been released with 1,1,1-TCA. When 1,1,1-TCA was still marketed as a solvent (at the end of 1995, the use of 1,1,1-TCA was limited under the Montreal Protocol), the product contained approximately 3.5 percent 1,4-dioxane as a stabilizer (ATSDR 2012a). Comparison of the concentrations of the two constituents indicates much lower relative concentrations of 1,4-dioxane remain in source area soil and higher relative concentrations of 1,4-dioxane are present in downgradient SPGW and in surface water. Overall, the relative percentage of 1,4-dioxane appears to be increasing over time (from the initial 3.5 percent) as 1,1,1-TCE volatilizes and biodegrades while 1,4-dioxane is more recalcitrant (but mobile).

7.7 1,2,3-Trichloropropane

1,2,3-Trichloropropane was historically used as a solvent and extractive agent and as a cleaning and degreasing agent (ATSDR 2019). The constituent was detected in several samples of highly contaminated media. Detected concentrations of the constituent exceed lowest Tier II ALs in two soil samples and two pad porewater samples. These samples were all collected close to each other, in the most contaminated portion of the former Tuboscope site. The two soil samples were both from source area soil boring SB-201R (at 1 to 4.5 feet bgs and 2 to 4.5 feet bgs). The pad porewater samples were from monitoring well MW-201R and monitoring well MW-202 (which is nearby).

Tier II ALs for 1,2,3-trichloropropane were first proposed in 2019 *RCRA Annual Report* (Hobbit Environmental Consulting Corp. 2020); this constituent was not previously considered a concern at the former Tuboscope site. Because of possible interference from much higher concentrations of other VOCs in these samples, laboratory review of 1,2,3-trichloropropane results was requested. An analyst with Pace Analytical confirmed the presence of the constituent in the test results and indicated that its presence was not due to carry over from a previous sample analysis.

In soil, 1,2,3-trichloropropane was detected in two of 478 samples. The constituent was detected in two of 159 water samples. The MDL for 1,2,3-trichloropropane is generally higher than the lowest Tier II AL. For instance, in the Tuboscope soil dataset, the average MDL was 0.11 mg/kg, and the lowest Tier II AL is 0.017 mg/kg. For all 65 samples with results reported as non-detect, the MDL was greater than the lowest Tier II AL. Thus, the dataset does not support definitive conclusions regarding the extent of 1,2,3-trichloropropane at concentrations above the lowest Tier II AL.

Based upon an estimated soil organic carbon partition coefficient, 1,2,3-trichloropropane is expected to display high mobility in soil and has the potential to leach into groundwater (ATSDR 2019). The vapor pressure of 1,2,3-trichloropropane and the calculated Henry's law constant suggest that volatilization from either dry or moist soil to the atmosphere may be significant environmental processes. 1,2,3-Trichloropropane in surface water is expected to volatilize rapidly to the atmosphere (ATSDR 2019).

7.8 BTEX

Two discrete areas plumes of BTEX contamination in water are present on the BOC pad. A small area of contamination is present just south of the Material Storage Warehouse. A larger area is present near the former Tuboscope building, where BTEX constituents appear to have migrated to the northeast. The extent of BTEX contamination in soil at concentrations above lowest Tier II ALs is much more localized and is limited to toluene and xylenes.

7.8.1 Benzene in Water

Out of the 219 samples collected from monitoring wells, benzene was detected in 82 samples. Detected concentrations range from 0.065 µg/L to 6.4 µg/L. Benzene concentrations exceeded the lowest Tier II AL of 0.45 µg/L in 62 samples (28 percent of samples). Of the 134 surface water samples, benzene concentrations exceeded the lowest Tier II AL in three samples; no AWQS exceedances were reported. The mean detected concentration measured in monitoring wells was 1.3 µg/L; the mean detected concentration measured in surface water samples was 0.77 µg/L.

Figures 107-A and 107-B depict the most recent analytical results for water samples analyzed for benzene. Results show a localized, somewhat discontinuous plume northeast of the former Tuboscope building. Benzene exceeds the lowest Tier II AL in monitoring wells near the former Tuboscope building, on both sides of the curtain liner and in surface water sample ST-52 adjacent to the GC3 Gas Pipeline Road. Sampling location ST-52 is near a former culvert that was sealed following discovery of constituents at this location during the initial phases of site investigation in the early 1980s.

7.8.2 Toluene

7.8.2.1 Toluene in Soil

The distribution of toluene in surface soil is shown on Figures 108-A and 108-B; data for active-layer soil is summarized on Figures 108-C and 108-D. Out of the 488 soil samples collected, toluene was detected in 165 soil samples collected at 95 locations. Reported toluene concentrations range from 0.00027 mg/kg to 9.4 mg/kg with a mean concentration of 0.433 mg/kg. Toluene concentrations exceeded the lowest Tier II AL of 3.8 mg/kg in four samples (0.8 percent of samples). Toluene concentrations above the lowest Tier II AL are limited to deeper soil. Two of the samples with results above the lowest Tier II AL were in the active layer, and two were in permafrost (refrozen soil beneath the backfilled drainage ditch).

Of the two active layer samples, one was collected from each side of the vertical curtain liner. Sample SS-150 was collected from the soil at the bottom of the drainage ditch. The sample from soil boring SB-90 was collected downgradient of the curtain liner, approximately 50 feet away.

7.8.2.2 Toluene in Water

Out of 219 monitoring well samples collected, toluene was detected in 82 samples from 22 locations. Toluene concentrations did not exceed the lowest Tier II AL of 100 µg/L in any monitoring well samples. Of the 134 surface water samples collected, one result exceeded the lowest Tier II AL, and no results exceeded the AWQS. Detected concentrations of toluene in surface water range from 0.17 to 107 µg/L with a mean concentration of 9.54 µg/L. The maximum concentration was from a sample collected from surface water location ST-15 in 2015; the location was resampled in 2016 and results were below the lowest Tier II AL.

Figures 108-E and 108-F depict the most recent available analytical results for toluene in water samples and show generally higher concentrations (but concentrations below the lowest Tier II AL) to the northeast of the former Tuboscope building location.

7.8.3 Ethylbenzene in Water

Of the 219 monitoring well samples collected, 75 ethylbenzene results from 22 locations exceeded the lowest Tier II AL of 1.3 µg/L (10 percent of samples). Detected concentrations of ethylbenzene range from 0.085 µg/L to 134 µg/L with a mean concentration of 22.5 µg/L.

Out of the 134 surface water samples collected, ethylbenzene was detected at 17 samples and exceeded the lowest Tier II AL in nine samples. Detected concentrations of ethylbenzene in surface water range from 0.16 µg/L to 7.3 µg/L with a mean concentration of 1.9 µg/L. No results from any monitoring well or surface water sample exceeded the AWQS.

The most recent analytical results for ethylbenzene in water are depicted on Figures 109-A and 109-B and show a discernable spatial pattern. An ethylbenzene plume is present to the northeast of the former Tuboscope building. Ethylbenzene associated with a release the former Tuboscope building exceeds the lowest Tier II AL in 10 monitoring wells and one surface water location (ST-52 adjacent to the GC3 Gas Pipeline Road).

A separate ethylbenzene plume is also present in pad porewater monitoring well MW-26 at the southwest corner of the Material Storage Warehouse. The ethylbenzene impact at this location is from a vehicle parking area source unrelated to the diesel fuel release at the former Tuboscope building.

7.8.4 Xylene

7.8.4.1 Xylene in Soil

Out of 329 soil samples collected, total xylene was detected in 127 soil samples collected at 50 locations. Total xylene concentrations range from 0.0047 mg/kg to 203 mg/kg with a mean concentration of 10.7 mg/kg. Total xylene concentrations exceeded the lowest Tier II AL of 71 mg/kg in just one sample (0.3 percent of samples). The maximum concentration was detected in a sample collected at soil boring DB-1, beneath the former Tuboscope building location, at a depth of 4.5 to 6 feet bgs in 2007.

The distribution of xylenes in surface soil is shown on Figures 110-A and 110-B; data for active-layer soil is summarized on Figures 110-C and 110-D. Detectable concentrations below the lowest Tier II AL were found beneath the former Tuboscope building location and just to the north and northeast.

7.8.4.2 Xylene in Water

Out of the 108 monitoring well samples, total xylene was detected in 50 samples from 22 locations. Total xylene concentrations exceeded the lowest Tier II AL of 19 µg/L in 26 samples (24 percent of samples). Detectable concentrations range from 0.5 µg/L to 1,360 µg/L, with a mean concentration of 199 µg/L.

Of the 70 surface water samples analyzed for total xylenes, the constituent was detected in eight samples from four locations. Two results exceeded the lowest Tier II AL. Detectable concentrations range from 2.2 µg/L to 25.5 µg/L with a mean concentration of 12.2 µg/L.

The most recent sample results for total xylene are depicted on Figures 110-E and 110-F. Total xylenes are present at concentrations in excess of the lowest Tier II AL in a contiguous area to the north and northeast of the former Tuboscope building location. This total xylenes plume is co-located with the ethylbenzene plumes and is similar in size and shape, with only one exception. Total xylene (but not ethylbenzene) is present at a concentration in excess of the lowest Tier II AL in pad porewater monitoring well MW-100 near the former drilling mud plant and the southern TTLA at the CIC Storage Facility.

7.8.5 BTEX Fate and Transport

Each of the BTEX compounds shares a similar structure and has similar fate and transport properties. These constituents are moderately to highly soluble in water and have relatively low tendency to partition from water and sorb onto soil organic carbon. BTEX compounds readily leach into groundwater. They are volatile from hydrocarbon mixtures, from wet or dry soil, or when dissolved in water. Under aerobic conditions, BTEX compounds tend to biodegrade rapidly, but they are somewhat more recalcitrant under anaerobic conditions. In the period following a release, the primary fate and transport mechanisms for BTEX compounds tend to be (in order of importance) volatilization, migration to groundwater, continued sorption to soil, and biodegradation (ATSDR 2007a).

The available data suggest that BTEX compounds were released near the former Tuboscope building. Current conditions in pad porewater tend to range from anoxic to anaerobic (average dissolved oxygen 2.4 mg/L and average ORP -10.4 mV).[3] When mixtures of BTEX compounds are present in an anaerobic environment, there is a sequential utilization of the substrate hydrocarbons, with toluene usually being the first to be degraded, followed by the isomers of xylene in varying order (ATSDR 2007a). Benzene and ethylbenzene tend to be degraded last, if they are degraded at all. Although initial concentrations of the BTEX components vary by fuel and lowest Tier II ALs are different, this process appears to have largely played out at the former Tuboscope site, with all toluene in SPGW and surface water below the lowest Tier II AL, based on the most recent results (compare Figure 108-F to Figures 107-B, 109-B, and 110-F).

Over time, BTEX concentrations in the source area have decreased. For instance, between 2008 and 2016, the measured concentrations of each of the four BTEX constituents have decreased at monitoring well MW-202 located just east of the former Tuboscope building. Benzene decreased from 1.1 µg/L to below the MDL. The concentrations of each of the other BTEX constituents decreased between 38 and 67 percent.

Volatilization, and to a lesser extent biodegradation, tend to limit the mobility of these compounds. As these constituents migrate toward and then discharge into surface water, the rate of both biodegradation and volatilization increase with exposure to additional oxygen and air. As a result, surface water exceedances of lowest Tier II ALs are currently limited to sampling location ST-52.

7.9 n-Propylbenzene

Propylbenzene has a wide variety of uses including as a solvent, in crude oil extraction, and as a corrosion inhibitor (NCBI 2020b). n-Propylbenzene is a COPC delineated in pad porewater to an area of known releases on the pad (Figure 111-b). Results for n-propylbenzene did not exceed the lowest Tier II AL in any of 478 soil samples.

7.9.1 n-Propylbenzene in Water

Of the 159 monitoring well samples collected, n-propylbenzene was detected in 52 samples at 17 locations. Detected concentrations of n-propylbenzene in SPGW range from 0.091 µg/L to 125 µg/L with a mean concentration of 30 µg/L. Concentrations exceeded the lowest Tier II AL of 41 µg/L in 17 samples (11 percent of samples). This constituent does not have an AWQS. Out of 94 surface water samples, n-propylbenzene was detected in three samples; all results were below the lowest Tier II AL.

The most recent analytical results for n-propylbenzene in water are depicted on Figures 111-A and 111-B. n-Propylbenzene is present at concentrations above the lowest Tier II AL in an area immediately northeast of the former Tuboscope building and immediately east of the southern TTLA at the CIC Storage Facility.

7.9.2 n-Propylbenzene Fate and Transport

This VOC is relatively soluble in water. Based on its organic carbon partitioning coefficient, n-propylbenzene is expected to be moderately mobile in the subsurface. Volatilization of n-propylbenzene from moist soil surfaces and directly from water may be an important fate process given its Henry's law constant (Table 3). Volatilization from dry soil surfaces may occur based on this constituent’s vapor pressure.

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[3] Because of limited pad porewater, several monitoring wells tend to purge dry. Field parameters (such as dissolved oxygen) collected from these wells likely do not reflect the surrounding pad porewater and may artificially increase the average dissolved oxygen concentration.

Analytical results from the former Tuboscope site indicate that n-propylbenzene has had little tendency to migrate beyond its source area. Analytical results from two monitoring wells suggest concentrations are decreasing over time. At monitoring well MW-12, located just north of the former Tuboscope building, the n-propylbenzene concentration decreased from 98.1 µg/L to 30.9 µg/L between 2008 and 2012. At monitoring well MW-202, the n-propylbenzene concentration decreased from 83.4 µg/L to 56.9 µg/L during the same timeframe.

7.10 Isopropylbenzene

Isopropylbenzene is a component of diesel fuel and has a wide variety of uses including as a solvent and for engine maintenance. Out of the 214 soil samples collected, isopropylbenzene was detected in 125 samples. Concentrations range from 0.00088 mg/kg to 33.1 mg/kg, with an average concentration of 1.26 mg/kg. Isopropylbenzene concentrations exceeded lowest Tier II AL of 0.040 mg/kg in 98 samples (46 percent of samples).

Figures 112-E and 112-F show the distribution of isopropylbenzene in surface soil. Isopropylbenzene concentrations above the lowest Tier II AL are in a discrete zone beneath, downgradient of, and north of the former Tuboscope building location.

Figures 112-G and 112-H summarize data for active-layer soil. The distribution of isopropylbenzene concentrations above the lowest Tier II AL in active-layer soil is similar to that for surface soil, except that it extends further to the west and includes soil borings B-11B and B-24.

7.11 *para*-Isopropyltoluene

The constituent *para*-isopropyltoluene (*p*-isopropyltoluene) may be used as a solvent or as a heat-transfer fluid (NCBI 2020c). p-Isopropyltoluene is a COPC delineated in pad soils to an area of known releases. Its inclusion as a COPC is based on exceedances of a Tier II AL for ecological receptors which are absent in this area.

7.11.1 para-Isopropyltoluene in Soil

Out of the 479 soil samples collected, *p*-isopropyltoluene was detected in 162 soil samples collected at 64 locations. Concentrations range from 0.00078 mg/kg to 35.1 mg/kg with a mean concentration of 2.02 mg/kg. Concentrations of this constituent exceeded the lowest Tier II AL of 3.8 mg/kg in 36 samples (8 percent of samples).

The distribution of *p*-isopropyltoluene in surface soil is shown on Figures 112-A and 112-B; data for active-layer soil is summarized on Figures 112-C and 112-D. Concentrations of *p*-isopropyltoluene above the lowest Tier II AL have been detected in both surface soil and subsurface soil. The data show that the distribution of *p*-isopropyltoluene exceedances of the Tier II AL is localized in two areas. The larger area is beneath the former Tuboscope building and includes surface soil samples from soil borings SB-1, SB-2, SB-3, SB-4, SB-7B, SB-8, SB-9, and SB-10 and active-layer soil samples from soil borings SB-1, SB-2, SB-3, SB-4, DB-1, and DB-7. The smaller area is to the south of the southern TTLA and includes surface soil samples from soil borings SB-101 and 12-TTLA-5 and active-layer soil samples from soil boring 12-TTLA-1.

No exceedances of the lowest Tier II AL for *p*-isopropyltoluene were reported for any water samples.

7.11.2 para-Isopropyltoluene Fate and Transport

Due to its low water solubility, *p*-isopropyltoluene is expected to have limited mobility in the environment. The constituent is volatile from wet and dry soil and from water. These fate and transport data are supported by the distribution of the constituent at the former Tuboscope site, where the data indicate that *p*-isopropyltoluene is present at concentrations above the lowest Tier II AL only near source areas and that higher concentrations are present in subsurface soil than are present in surface soil. Except for results from soil boring 12-TTLA-1, all results above the lowest Tier II AL are from samples collected in 2007. Natural processes have continued to decrease *p*-isopropyltoluene concentrations in the ensuing years.

7.12 Trimethylbenzenes

Trimethylbenzenes are commonly present in motor vehicle fuels. These constituents tend to be more recalcitrant than other volatile petroleum hydrocarbon constituents.

7.12.1 Trimethylbenzenes in Soil

7.12.1.1 1,2,4-Trimethylbenzene

Out of 475 soil samples collected, 1,2,4-trimethylbenzene was detected in 211 soil samples collected at 88 locations. Detected concentrations range from 0.00066 to 115 mg/kg with a mean concentration of 14.6 mg/kg. Concentrations of 1,2,4-trimethylbenzene exceeded its lowest Tier II AL of 47 mg/kg in 24 samples (5 percent of samples).

As shown on Figures 113-A and 113-B, 1,2,4-trimethylbenzene exceedances of the Tier II AL in surface soil are spatially distributed in a localized area beneath the former Tuboscope building and northward toward the southern TTLA. The distribution of 1,2,4-trimethylbenzene in active-layer soil is shown on Figures 113-C and 113-D. The distribution of the constituent in active-layer soil is similar to that of surface soil, but some migration to the northeast of the former Tuboscope building is evident.

7.12.1.2 1,3,5-Trimethylbenzene

Out of the 482 soil samples collected, 1,3,5-trimethylbenzene was detected in 199 soil samples collected at 80 locations. Concentrations range from 0.00053 to 62.3 mg/kg with a mean concentration of 5.7 mg/kg. Concentrations of 1,3,5-trimethylbenzene exceeded its lowest Tier II AL of 14 mg/kg in 31 samples (6 percent of samples).

In surface soil, 1,3,5-trimethylbenzene exceedances of the Tier II AL are present beneath and in the area surrounding the former Tuboscope building location (Figures 114-A and 114-B). Concentrations above the lowest Tier II AL are also present in the area south of the southern TTLA. The distribution of 1,3,5-trimethylbenzene in active-layer soil is shown on Figures 114-C and 114-D. As is the case with 1,2,4-trimethylbenzene, the distribution of 1,3,5-trimethylbenzene in active-layer soil is similar to that of surface soil, but some migration to the northeast of the former Tuboscope building is evident.

7.12.2 Trimethylbenzenes in Water

7.12.2.1 1,2,4-Trimethylbenzene

Of 159 monitoring well samples collected, 1,2,4-trimethylbenzene was detected at 75 samples collected from 23 locations. Detected concentrations of 1,2,4-trimethylbenzene in monitoring well samples range from 0.13 µg/L to 816 µg/L. 1,2,4-Trimethylbenzene concentrations exceeded the lowest Tier II AL of 3.7 µg/L in 43 samples. This constituent does not have an AWQS.

In surface water, 1,2,4-trimethylbenzene was detected in 10 of 94 samples. Detected concentrations range from 0.093 µg/L to 4.5 µg/L. Two results exceeded the lowest Tier II AL: a 2008 sample and its duplicate sample collected at location ST-52. The mean concentration of 1,2,4-trimethylbenzene measured in monitoring well samples was 117 µg/L, as compared to the mean surface water of 2.2 µg/L.

The most recent water sample results for 1,2,4-trimethylbenzene are depicted on Figures 113-E and 113-F. Concentrations above the lowest Tier II AL are present beneath the former Tuboscope building location, around the southern TTLA, and to the northeast with a discernable spatial pattern. Based on the most recent results, no surface water sample locations exceed the lowest Tier II AL for 1,2,4-trimethylbenzene. More recent data from surface water sample location ST-52 (and all other sampled surface water locations) indicate that current concentrations are below the lowest Tier II AL.

7.12.2.2 1,3,5-Trimethylbenzene

Of the 159 monitoring well samples collected, 1,3,5-trimethylbenzene was detected in 69 samples collected from 22 locations. Detected concentrations of 1,3,5-trimethylbenzene range from 0.089 µg/L to 195 µg/L. Detected concentrations exceeded the lowest Tier II AL for 1,3,5-trimethylbenzene of 3.3 µg/L in 41 samples. An AWQS has not been assigned for this constituent.

Of 94 surface water samples collected, 1,3,5-trimethylbenzene was detected in eight samples collected from two locations (ST-51 and ST-52). Detected concentrations range from 0.57 µg/L to 1.9 µg/L; all results were below the lowest Tier II AL. The mean concentration of 1,3,5-trimethylbenzene in monitoring well samples was 39.6 µg/L, as compared to the mean surface water of 1.3 µg/L.

The most recent analytical results for 1,3,5-trimethylbenzene in water samples are depicted on Figures 114-E and 114-F. The extent of contamination above the lowest Tier II AL for 1,3,5-trimethylbenzene is very similar to the extent for 1,2,4-trimethylbenzene: beneath the former Tuboscope building location, around the TTLA, and to the northeast.

7.12.3 Trimethylbenzenes Fate and Transport

K_{OC} values for 1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene indicate that these constituents have relatively low mobility in soil. Volatilization from moist and dry soil surfaces is expected to occur based on measured Henry's law constants and the vapor pressures published for these constituents. Non-volatilized trimethylbenzenes may be subject to biodegradation under aerobic conditions; however, under anaerobic conditions biodegradation appears to be minimal (NCBI 2020d). If released to water, trimethylbenzenes are expected to adsorb to soil particles based on their K_{OC} values. Volatilization from water surfaces is expected to occur based on their Henry's law constants.

The distribution of trimethylbenzene at the former Tuboscope site is in accordance with the published physical-chemical properties. In surface soil and active-layer soil, these constituents are found near their presumed source areas: the former Tuboscope building and the southern TTLA. The available data indicate that they migrated to pad porewater shortly after release. This likely occurred as part of fuel free product (LNAPL) migrating downward through the vadose zone under the influence of gravity. From there, trimethylbenzene contamination advected with the pad porewater gradient to the northeast. However, volatilization and biodegradation prevent additional migration. The data indicates that much higher concentrations are present in monitoring well samples than in surface water samples and all surface water concentrations are now below the lowest Tier II AL. This is likely due to rapid volatilization from surface water and due to higher concentrations of oxygen in surface water enhancing biodegradation. Trimethylbenzenes rapidly volatilize from surface waters; the volatilization half-life from a model river was calculated to be 3.4 hours (USEPA 1987). Results from surface water sample location ST-52 suggest that the extent of trimethylbenzene contamination may be decreasing over time.

Figure 113-G shows the relative aqueous concentrations of 1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene in pie charts. The ratio of the concentrations of the two constituents appears to remain consistent across the area where they were detected. Given their similar fate and transport properties, this suggests a similar release history.

7.13 PAHs and SVOCs

7.13.1 PAHs and SVOCs in Soil

Out of the 260 soil samples analyzed for PAHs, only dibenzofuran was reported above the applicable lowest Tier II AL. Other than dibenzofuran, except for four results for dibenz(a,h)anthracene that were below the MDL, MDLs for PAH compounds support decision making at the respective lowest Tier II ALs.

Out of the 245 soil samples analyzed for SVOCs, only a single result (for naphthalene) was reported above the applicable lowest Tier II AL. Except for 14 results for di-n-butylphthalate that were less than MDL, MDLs for SVOC compounds support decision making at their respective lowest Tier II ALs.

7.13.2 PAHs and SVOCs in Water

One hundred and fifty monitoring well samples were analyzed for PAHs. Table 8.12-1 summarizes the lowest Tier II AL, maximum detected concentration, and number of results above the lowest Tier II AL for PAHs detected in monitoring well samples. Locations mentioned in this section are presented on Figure 115.

Table 8.12-1: Summary of PAH Concentrations Measured in Monitoring Well Samples at Concentrations above their Lowest Tier II AL

PAH	Lowest Tier II AL (µg/L)	Maximum Detected Concentration (µg/L)	Number of Results above the Lowest Tier II AL
Acenaphthene	9.1	0.55	0
Anthracene	2.1	0.044	0
Benzo(a)anthracene	0.021	0.085	1
Benzo(a)pyrene	0.00037	0.05	2
Benzo(b)fluoranthene	0.0062	0.088	3
Benzo(k)fluoranthene	0.038	0.088	2
2-Chloronaphthalene	2.5	0.084	0
Chrysene	0.59	0.085	0
Dibenz(a,h)anthracene	0.00020	0.077	2
Dibenzofuran	0.081	1.3	27
Fluoranthene	1.4	0.14	0
Fluorene	7.7	1.4	0
Indeno(1,2,3-cd)pyrene	0.0016	0.087	2
2-Methylnaphthalene	2.4	95.5	23
Naphthalene	0.17	46.6	18
Phenanthrene	48	0.43	0
Pyrene	0.46	0.072	0

Because of numerous detections of naphthalenes (including 2-methylnaphthalene) and dibenzofuran at concentrations above the lowest Tier II AL, they are discussed in separate subsections below. The remaining Tier II AL exceedances occurred in three monitoring well samples.

A 2012 pad porewater sample from monitoring well MW-36 (located at the southeast corner of the drainage ditch) contained the following constituents at concentrations above their lowest Tier II AL: benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)perylene.

Monitoring well MW-37 is located directly east of the drainage ditch, upgradient from the vertical curtain liner. A 2012 sample from pad porewater monitoring well MW-37 contained the following constituents at concentrations above their lowest Tier II AL: benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, dibenz(a,h)anthracene, dibenzofuran, and indeno(1,2,3-cd)perylene, and naphthalene. Where a release of petroleum hydrocarbons occurs, it is common for several PAH compounds to exceed regulatory limits in the same sample.

Monitoring well MW-95 is in the central portion of the BOC pad. Monitoring well MW-95 contained benzo(b)fluoranthene at a concentration above its lowest Tier II AL in a 2012 sample. The presence of low concentrations of individual PAH compounds is not suggestive of a petroleum hydrocarbon release.

Table 8.12-2 summarizes the lowest Tier II AL, maximum detected concentration, and number of results above the lowest Tier II AL for PAHs measured in surface water samples.

Table 8.12-2: Summary of PAH Concentrations Measured in Surface Water Samples at Concentrations above their Lowest Tier II AL

PAH	Lowest Tier II AL (µg/L)	Maximum Detected Concentration (µg/L)	Number of Results above the Lowest Tier II AL
Acenaphthene	9.1	0.089	0
Anthracene	2.1	0.32	0
Benzo(a)anthracene	0.021	0.28	4
Benzo(a)pyrene	0.00037	0.29	7
Benzo(b)fluoranthene	0.0062	0.27	9
Benzo(k)fluoranthene	0.038	0.28	4
2-Chloronaphthalene	2.5	0.055	0
Chrysene	0.59	0.29	0
Dibenz(a,h)anthracene	0.00020	0.31	4
Dibenzofuran	0.081	0.014	0
Fluoranthene	1.4	0.3	0
Fluorene	7.7	0.2	0
Indeno(1,2,3-cd)pyrene	0.0016	0.29	6
2-Methylnaphthalene	2.4	2.8	2
Naphthalene	0.17	2.4	10
Phenanthrene	48	0.29	0
Pyrene	0.46	0.27	0

Concentrations of PAHs above lowest Tier II ALs have been detected at the following surface water locations: ST-44, ST-51, ST-52, ST-72, ST-105, ST-219, ST-285, and ST-316. Typically, detected concentrations are near the lowest Tier II AL. However, the Tier II AL is frequently less than the MDL. For instance, five samples from surface water location ST-44 have been analyzed for PAHs. In four of the samples, benzo(a)pyrene was not detected, but the MDL (which ranged from 0.020 µg/L to 0.022 µg/L) was greater than the lowest Tier II AL (0.00037 µg/L). In the fifth sample, benzo(a)pyrene was detected at a concentration (0.20J-D µg/L) above the lowest Tier II AL. At locations known to have been impacted by petroleum hydrocarbons, such as surface water sampling location ST-52, concentration of PAHs above lowest Tier II ALs, should be considered site impacts. At locations such as surface water sampling location ST-72, that are distant from the pad and do not appear to be otherwise impacted by petroleum hydrocarbons, detections of PAHs appear not to be associated with a release and are likely associated with natural concentrations or anthropogenic sources not associated with a release. In addition to releases of crude oil or petroleum products, elevated PAH concentrations can be associated with natural fires, incomplete combustion of petroleum products, and peat soil.

7.13.3 Naphthalenes

7.13.3.1 Analytical Methods that Detected Naphthalenes

Naphthalene was analyzed in soil and water samples by three separate methods: SW8260B (VOCs), SW8270C/SW8270D (SVOCs), and SW8270C SIM/SW8270D SIM (PAHs). Results from each method varied. For each sample, the highest reported result was selected for use, unless data quality or integrity issues dictated otherwise (ADEC 2017c). These selected results are captured in the project database and are shown on the tables in this report. The (generally lower) results that were not selected have not been included in the frequency of detection tables or the data tables.

The constituents 2-methylnaphthalene and dibenzofuran were analyzed in soil and water samples by two separate methods: SW8270C/SW8270D (SVOCs) and SW8270C SIM/SW8270D SIM (PAHs). Results from each method varied. The higher reported result for each sample was selected for use, unless data quality or integrity issues dictated otherwise.

7.13.3.2 Naphthalene

Naphthalene in Soil

Out of the 487 soil samples collected, naphthalene was detected in 180 samples. Naphthalene concentrations range from 0.00042 to 92.9 mg/kg. Naphthalene concentrations exceeded lowest Tier II ALs of 3.2 mg/kg in 43 samples (9 percent of samples).

Figures 116-A and 116-B show the distribution of naphthalene in surface soil. Naphthalene concentrations above the lowest Tier II AL are located beneath and near the former Tuboscope building location. The naphthalene concentration also exceeds the lowest Tier II AL at soil boring SB-101, located approximately 130 feet farther north.

Figures 116-C and 116-D summarize data for active-layer soil. Naphthalene concentrations above the lowest Tier II AL are located beneath the former Tuboscope building location and to the north at soil borings SB-12 and SB-100.

Naphthalene in Water

A total of 168 monitoring well samples were analyzed for naphthalene, which was detected in 90 samples from 42 locations. Detected concentrations of naphthalene range from 0.0083 µg/L to 225 µg/L. Naphthalene concentrations exceeded the lowest Tier II AL of 0.098 µg/L in 68 samples.

In surface water, naphthalene was detected in 39 of 137 samples. Detected concentrations range from 0.009 µg/L to 6 µg/L. The mean concentration measured in surface water (0.47 µg/L) was significantly lower than the mean concentration measured in monitoring well samples (21.5 µg/L).

Figures 116-E and 116-F depict the most recent analytical results for naphthalene in water. The constituent is present at concentrations above the lowest Tier II AL in a discrete area beneath the former Tuboscope building and to the north, east, and southwest. The highest measured concentrations (and potential source areas) are near the former Tuboscope building and to the east of the southern TTLA. One of the most recent surface water sample results (ST-52) exceeds the lowest Tier II AL.

7.13.4 2-Methylnaphthalene

Of 260 soil samples analyzed for 2-methylnaphthalene, no results exceeded the lowest Tier II AL. Of the 146 monitoring well samples analyzed for 2-methylnaphthalene, the constituent was detected in 93 samples collected from 42 locations. Concentrations range from 0.0066 µg/L to 95.5 µg/L. Measured concentrations exceeded the lowest Tier II AL of 2.4 µg/L at 41 locations.

Of the 87 surface water samples collected, 2-methylnaphthalene was detected in 29 samples from 19 locations. Concentrations range from 0.009 µg/L to 2.8 µg/L. Measured concentrations in surface water exceeded the lowest Tier II AL at two locations. The average concentration of 2-methylnaphthalene in surface water (0.35 µg/L) is far lower than the average concentration measured in monitoring well samples (11.5 µg/L).

Figures 117-A and 117-B depict the most recent analytical results for 2-methylnaphthalene in water. Concentrations exceed the lowest Tier II AL beneath the former Tuboscope building location and beneath the southern TTLA. The concentration of 2-methylnaphthalene in two monitoring wells located to the southeast of the former drainage ditch (MW-19 and MW-90) exceeds the lowest Tier II AL.

7.13.5 Dibenzofuran

Dibenzofuran can be produced by the partial oxidation of organic matter in fires. It is hypothesized that elevated concentrations of dibenzofuran at the former Tuboscope site were produced when fire destroyed the former Tuboscope building.

7.13.5.1 Dibenzofuran in Soil

Measured concentrations of dibenzofuran exceeded the lowest Tier II AL (0.0020 mg/kg) in 36 of 252 soil samples (14 percent). Detected concentrations range from 0.00046 to 0.48 mg/kg with a mean concentration of 0.056 mg/kg. Of those samples with non-detected results, 135 had MDLs above the lowest Tier II AL.

As shown on Figures 118-A and 118-B, dibenzofuran exceedances of the Tier II AL in surface soil are spatially distributed in a localized area beneath the former Tuboscope building and to the north, just beyond the location of the former drilling mud plant. The distribution of dibenzofuran in active-layer soil is shown on Figures 118-C and 118-D. The distribution of the constituent in active-layer soil is similar to that in surface soil. Given the number of non-detected results with MDLs above the lowest Tier II AL, the actual distribution of dibenzofuran in surface soil and in active-layer soil at concentrations above the lowest Tier II AL may be larger than shown on these figures.

7.13.5.2 Dibenzofuran in Water

The constituent was detected in 45 out of 146 monitoring well samples. Measured concentrations in monitoring well samples range from 0.0064 µg/L to 1.3 µg/L and exceeded the lowest Tier II AL (0.081 µg/L) in 27 samples. In 100 surface water samples, dibenzofuran was detected in four samples. Measured concentrations range from 0.009 µg/L to 0.014 µg/L. None of the results for surface water samples exceeded the lowest Tier II AL. The average concentration of dibenzofuran in surface water (0.012 µg/L) is far lower than the average concentration measured in monitoring well samples (0.31 µg/L).

Figures 118-E and 118-F depict the most recent analytical results for dibenzofuran in water. Concentrations exceed the lowest Tier II AL beneath the former Tuboscope building location and in SPGW to the north and east. The distribution of dibenzofuran at concentrations above the lowest Tier II AL is water is similar to the distribution in soil.

7.13.6 3&4-Methylphenol

3&4-Methylphenol can be used as a solvent for cleaning and degreasing. Also known as m-cresol and p-cresol, these constituents are important components of creosote, a wood preservative with antibacterial properties. A total of 245 soil samples were analyzed for 3&4-methylphenol. No results exceeded the lowest Tier II AL.

Of the 116 monitoring well samples analyzed for 3&4-methylphenol, the constituent was detected in 59 samples at 27 locations. Measured concentrations exceeded the lowest Tier II AL of 82 µg/L in 28 samples. Detected concentrations of 3&4-methylphenol in monitoring well samples range from

4.4 µg/L to 302 µg/L. Detections of 3&4-methylphenol in soil and monitoring well samples are frequently co-located with detections of phenol; all phenol results in both media are below the lowest Tier II AL.

Of the 70 surface water samples analyzed for 3&4-methylphenol, the constituent was detected in three samples. All results were below the lowest Tier II AL. Detected concentrations in monitoring well samples range from 41.1 µg/L to 69.6 µg/L. The average concentration measured in surface water (57.2 µg/L) was lower than the average concentration measured in monitoring well samples.

Figures 119-A and 119-B depict the most recent analytical results for 3&4-methylphenol in water. The data show that detected 3&4-methylphenol concentrations exceed the lowest Tier II AL in nine pad porewater monitoring wells. The constituent exceeds the lowest Tier II AL in two distinct plumes: near the former Tuboscope building and within the GC3 Pipeline Access Road. In addition to 3&4-methylphenol, groundwater samples from monitoring well MW-92 also contained 2-methylphenol at a concentration (13.4 µg/L) above its lowest Tier II AL (13 µg/L).

The mean pad porewater 3&4-methylphenol concentration is 89.2 µg/L, as compared to the SPGW 3&4-methylphenol mean concentration of 18.9 µg/L and to the mean surface water 3&4-methylphenol concentration of 57.2 µg/L. Water sample results for 3&4-methylphenol are depicted on Figures 119-A and 119-B. The most recent sample event results for 3&4-methylphenol show that concentrations exceed the lowest Tier II AL in eight pad porewater monitoring well locations representing two separate plumes. 3&4-Methylphenol is present at concentrations above the lowest Tier II AL on both the eastern and western sides of the former Tuboscope building. While the source of the 3&4-methylphenol is unknown, it is evident that this plume is well defined and centered around the former Tuboscope building. The 3&4-methylphenol impacts on the western side of the former Tuboscope building differs from the other petroleum constituent plumes, which are predominantly located east/northeast of the former Tuboscope building. A second plume is present in the GC3 Gas Pipeline Access Road located southeast from the former Tuboscope building plume and separated by numerous non-detect sample locations. This plume appears unrelated to releases from the former Tuboscope building and appears to represent a different source. 3&4-Methylphenol has been detected in perimeter SPGW wells to the far south and southwest of the BOC pad, at locations well outside the range of any impacts that may have originated from the former Tuboscope building.

7.13.7 PAH and SVOC Fate and Transport

Generally, PAH constituents with higher molecular weight tend to have lower volatility, lower solubility in water, and higher solubility in fat tissues. The vapor pressure ranges of the PAHs present indicate that these constituents do not readily volatilize into the atmosphere from dry surfaces. Based on their Henry's law constants, PAHs have limited tendency to volatilize from water or moist soil. As shown in Table 3, the PAHs have high KOC values, indicating these constituents have a strong affinity to remain bound to soil. Migration of dissolved PAHs to SPGW and surface water is not considered a primary transport pathway of concern.

PAHs are believed to have been released as part of a petroleum hydrocarbon release. As such, they would have initially migrated as an LNAPL downwards through the vadose zone until they reached pad porewater. From there, PAH constituents migrated downgradient. Once concentrations of petroleum hydrocarbons dropped below the LNAPL saturation point, PAH constituents became effectively immobile due to their low water solubility. PAHs biodegrade under aerobic conditions. However, they tend to biodegrade more slowly than lighter molecular weight fuel components.

7.14 ADEC Petroleum Hydrocarbons

7.14.1 Diesel Range Organics in Soil

Out of the 351 soil samples collected, DRO was detected in 238 samples at 115 locations. Detected values of DRO in soil range from 3.7 to 9,490 mg/kg with a mean concentration of 586 mg/kg. Results for DRO were compared to its 18 AAC 75.341 CL for soil in the arctic zone (12,500 mg/kg). All results were less than the ADEC CL.

7.14.2 Diesel Range Organics in Water

Out of the 177 monitoring well samples analyzed for DRO, the constituent was detected in 141 samples. Detected concentrations of DRO in monitoring well samples range from 13.9 µg/L to 9,620 µg/L with a mean concentration of 1,350 µg/L. DRO concentrations above the 18 AAC 75 Table C groundwater CL of 1,500 µg/L were detected in 10 monitoring wells: MW-12, MW-19, MW-22, MW-36, MW-37, MW-38, MW-201, MW-201R, MW-202, and MW-202R. These wells are located east of the former Tuboscope building, near the former drainage ditch, or east of the southern TTLA.

Out of 78 surface water samples collected, DRO was detected in 35 samples. Detected concentrations of DRO in surface water samples range from 237 µg/L to 1,270 µg/L with a mean concentration of 433 µg/L.

The most recent water sample results for DRO are depicted on Figures 120-A and 120-B. Currently, only results from monitoring wells MW-38, MW-201R, and MW-202R exceed the groundwater CL. Comparison of the extent of DRO contamination in SPGW at concentrations above lowest Tier II ALs over time indicates that the plume is decreasing in size.

7.14.3 Total Aromatic Hydrocarbons in Water

Total aromatic hydrocarbon (TAH) was calculated in accordance with ADEC “Guidelines for Treatment of Non-Detect Values, Data Reduction for Multiple Detections and Comparison of Quantitation Limits to Cleanup Values” (ADEC 2017c) by summing the analytical results for benzene, ethylbenzene, toluene, and the xylene isomers. TAH concentrations were calculated for surface water and SPGW closely connected hydrologically to surface water. Results for the most recent samples are presented on Figures 121-A and 121-B and compared to the AWQS of 10 µg/L. Calculated results for TAH currently exceed the AWQS in seven monitoring wells located along the eastern edge of the BOC pad, directly downgradient from the southern TTLA and the former Tuboscope building location: MW-18, MW-19, MW-37, MW-38, MW-89, MW-90, and MW-91. The TAH calculated for surface water samples from ST-51 and ST-52, which are in the same area, also exceed the AWQS.

A second, discrete area of contamination above the TAH AWQS is located farther north at monitoring well MW-88, located over 500 feet north northwest of the former Tuboscope building. This contamination appears to be unrelated to the former Tuboscope building. Calculated TAH results from nearby surface water samples are below the AWQS.

7.14.4 Total Aqueous Hydrocarbons in Water

Total aqueous hydrocarbon (TAqH) was calculated in accordance with ADEC “Guidelines for Treatment of Non-Detect Values, Data Reduction for Multiple Detections and Comparison of Quantitation Limits to Cleanup Values” (ADEC 2017c) by summing TAH and the analytical results for acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, and pyrene. TAqH concentrations were calculated for surface water and SPGW closely connected hydrologically to surface water. Results for the most recent samples are presented on Figures 122-A and 122-B and compared to the AWQS of 15 µg/L.

The extent of TAqH contamination is very similar to the extent for TAH. Calculated results for TAqH currently exceed the AWQS in six monitoring wells located along the eastern edge of the BOC pad, directly downgradient from the southern TTLA and the former Tuboscope building location: MW-18, MW-19, MW-38, MW-89, MW-90, and MW-91. The calculated TAqH results for surface water samples from ST-51 and ST-52 also exceed the AWQS.

The calculated TAqH concentration from the most recent sample from monitoring well MW-88 exceeds the AWQS. This contamination appears to be unrelated to the former Tuboscope building. Calculated TAqH results from nearby surface water samples are below the AWQS.

7.15 Lead

Chlorinated solvents were used to remove lead-containing pipe dope from the threaded pipes in the former Tuboscope building.

7.15.1 Soil Data

Lead was detected in 351 of 365 soil samples collected. Lead concentrations range from 1.74 mg/kg to 8,440 mg/kg with a mean concentration of 120 mg/kg. Lead concentrations exceeded the lowest Tier II AL of 50 mg/kg in 53 samples (15 percent of samples). Lead concentrations exceeded the media-specific (SM/SO) BTV concentration (9.5 mg/kg) in 77 samples and the BTV for lead in peat soil (9.3 mg/kg) in 33 samples.

Figures 123-A and 123-B present the distribution of lead in surface soil. Lead concentrations above the lowest Tier II AL are located beneath the former Tuboscope building location, where a discrete zone of higher concentrations is found. Lead above the lowest Tier II AL was also found to the southwest (at soil boring SB-34) and to the northeast at three tundra sample locations (TM-42, TM-49, and SD-1).

Figures 123-C and 123-D summarize data for lead in active-layer soil. Lead concentrations above the lowest Tier II AL are located beneath the former Tuboscope building location and to the southeast at soil boring B-22 and (former surface) soil sample location SS-152, which is now beneath backfill material in the former drainage ditch. The highest concentrations of lead in active-layer soil are generally located beneath the highest concentrations in surface soil; together they form a relatively discrete zone of contamination.

Figure 123-E summarizes deep soil results (greater than 6 feet below surface) for lead by depth order. The shallowest sample depths shown on this figure are below the surface and active-layer depth intervals depicted on other site figures and are largely representative of depth intervals beneath the active layer. Except at soil boring SB-63, which was advanced in the drainage ditch, results for lead in deep soil are below the lowest Tier II AL.

7.15.2 Water Data

7.15.2.1 Total Lead in Water

Of the 242 monitoring well samples analyzed for total lead, the constituent was detected in 173 samples. Detected concentrations of total lead in monitoring well samples range from 0.047 µg/L to 334 µg/L with a mean concentration of 8.06 µg/L. Lead concentrations exceeded the lowest Tier II AL of 15 µg/L in ten samples.

Of the 171 surface water samples analyzed for total lead, three results exceeded the lowest Tier II AL; these samples were collected at locations ST-75, ST-142, and ST-146. Detected concentrations of total lead in surface water samples range from 0.048 µg/L to 59.7 µg/L with a mean concentration of 2.28 µg/L. The one exceedance of the lowest Tier II AL occurred at location ST-75 east of the BOC pad in a 2009 sample; three more recent samples collected at this location were near or below the MDL. Likewise, the one exceedance of the lowest Tier II AL that occurred at location ST-146 (which is collected approximately 600 feet east of the BOC pad) was followed by a more recent analytical result that was below the MDL. This suggests that elevated lead concentrations can be driven by the inclusion of sediment in the surface water sample. The following results exceeded the BTV (0.10 µg/L): 157 monitoring well results and 69 surface water results.

Figures 123-F and 123-G depict the most recent water sample results for total lead. Concentrations of total lead above the lowest Tier II AL are present in four monitoring wells near the former Tuboscope building location (MW-11, MW-24, MW-100, and MW-204R). The concentration in surface water sample ST-142 (located about 160 feet east of the BOC pad) also exceeded the lowest Tier II AL.

7.15.2.2 Dissolved Lead

In contrast to total lead concentrations, the maximum detected concentration and average detected concentration of dissolved lead were much lower, 19 µg/L and 2.42 µg/L respectively. This indicates that, for the former Tuboscope site as a whole, approximately 70 percent of the measured total lead concentrations in monitoring well samples are suspended particulates and the remaining 30 percent are dissolved.

No results for dissolved lead in surface water exceeded the lowest Tier II AL. The average detected concentration (0.15 µg/L) and the maximum detected concentration (0.34 µg/L) of dissolved lead in surface water were much lower than the average and maximum total lead concentrations. Only about 7 percent of the lead in surface water is dissolved. Figures 123-H and 123-I present the most recent water sample results for dissolved lead. The most recent result for monitoring well MW-204R (19.0 µg/L exceeded the lowest Tier II AL.

ADEC has established a hardness-dependent AWQS for dissolved lead (ADEC 2008). No results exceeded the AWQS calculated for each individual sample.

7.15.3 Fate and Transport Properties and Summary of Background Assessment

Lead (Pb) has three common oxidation states, 0, +2, and +4, and the most common redox state encountered in the environment is the divalent form (ATSDR 2020). Low solubility metal compounds are formed by complexation with inorganic and organic ligands (Cl^-, CO_3^{2-}, SO_4^{2-}, PO_4^{3-}). Lead carbonate solids form above pH 6, and PbS is the most stable solid when high sulfide concentrations are present under reducing conditions. Important factors that control aqueous speciation of lead include pH and the types and concentrations of complexing ligands and major cationic constituents. Equilibrium calculations show that at pH less than 5.4, the total solubility of lead is approximately 30 µg/L in hard water and approximately 500 µg/L in soft water (ATSDR 2020).

Lead adsorbs onto soil constituent surfaces such as clay, oxides, hydroxides, and organic matter. Lead adsorption studies on bulk soil indicate that adsorption strongly correlates to pH, cation exchange capacity (CEC), redox potential, and phosphate levels. Properties that affect CEC of soil, such as organic matter content, clay content, and surface area, have a greater influence on lead adsorption than soil pH. At pH values above 6, lead adsorbed on clay surfaces or forms lead carbonate (ATSDR 2020). At the former Tuboscope site, pH measured in SPGW and surface water is generally near neutral.

In the natural environment with pH near 7 and oxidizing conditions, lead transport is expected to be retarded (log Kd of 0.7 to 5). Under most geochemical conditions, adsorption to soil and aquifer material greatly limits the mobility of lead in the subsurface environment.

Lead from pipe dope appears to have been released with chlorinated solvents released at the former Tuboscope building. As the solvents migrated into the subsurface, they appear to have carried the lead with them. Concentrations in surface soil are higher than in active-layer soil, and the highest concentrations of lead in the active-layer soil are generally located beneath the highest concentrations in surface soil. In SPGW, lead appears to have migrated laterally from the relatively discrete zone of contamination. Although historical geochemical conditions mobilized lead in the subsurface, most lead is now in the particulate form and continued migration is unlikely.

Lead concentrations above the lowest Tier II AL in tundra soil appear to be limited to near-surface soil at SD-1 (0 to 1 foot bgs), TM-42 (0.3 to 1.1 foot bgs), and TM-49 (1 to 1.5 feet bgs). The elevated lead concentration in these samples may be associated with wind-blown drilling mud components or wind-blown (impacted) pad material. Results for these samples were designated as being possibly impacted by a release and included in the site impacted dataset. A fourth sample, collected at TM-48 contained 52.5 mg/kg lead, above the lowest Tier II AL. However, this sample was collected from the BOC pad and represents pad gravel, as it contained 60 percent coarse gravel and 40 percent medium sand.

The background assessment (Appendix N) concluded that releases may have impacted total lead concentrations in gravel and in pad porewater at monitoring wells MW-11, MW-24, MW-100, and MW-204R. These monitoring wells are located northwest, west, east, and north of the former Tuboscope building, respectively. Releases have also impacted lead concentrations in three tundra samples located just east of the former Tuboscope building location: SD-1, TM-42, and TM-49. The lead concentration in one mineral soil sample (from soil boring SB-63) has been impacted; this sample was collected beneath the former drainage ditch.

7.16 Barium

Barium (in the form of barium sulfate) is the primary component in formulation of drilling muds used on the North Slope. A drilling mud plant was located directly north of the former Tuboscope building.

7.16.1 Soil Data

Barium was detected in all 261 soil samples. Barium concentrations range from 52.7 mg/kg to 4,460 mg/kg with a mean concentration of 265.5 mg/kg. Barium concentrations exceeded lowest Tier II AL (400 mg/kg) in 25 soil samples (10 percent). Barium concentrations exceeded media-specific BTV concentrations in 67 SM/SO samples and in eight tundra soil samples.

As shown on Figures 124-A and 124-B, the distribution of barium exceedances of the Tier II AL in surface soil are spatially distributed in a localized area near the former Tuboscope building location and the former location of the drilling mud plant. Concentrations above the lowest Tier II AL were also measured over a wide area that includes tundra samples (TM-40 and TM-42), the area north of the Bulk Chemical Building and CIC Storage Facility, and samples to the west and southwest of the former Tuboscope building (soil borings SB-34, SB-97, and SB-98).

In contrast to surface soil results, the distribution of barium exceedances of the Tier II AL in active-layer soil are limited to two locations: TM-53 and SS-152 (Figures 124-C and 124-D). Both samples are in the former drainage ditch. Wintertime snow plowing operations may have redistributed drilling mud components released elsewhere and resulted in these impacts.

Figure 124-E summarizes deep soil results (greater than 6 feet below surface) for barium by depth order. The shallowest sample depths shown on this figure are below the surface and active-layer depth intervals

depicted on other site figures and are largely representative of depth intervals beneath the active layer. Generally, concentrations of barium in deeper soil are below the lowest Tier II ALs.

7.16.2 Water Data

7.16.2.1 Total Barium in Water

Total barium was detected in all 182 monitoring well samples and the measured concentration exceeded the lowest Tier II AL of 360 µg/L in 100 samples. None of the detected total barium concentrations exceeded the AWQS. Total barium concentrations exceeded PBU surface water BTV concentrations in 170 samples (93 percent of samples). Detected concentrations of total barium in monitoring well samples range from 93.8 µg/L to 1,980 µg/L with a mean concentration of 504 µg/L. The mean concentration was above the BTV of 150 µg/L.

In surface water, total barium was detected in all 134 samples. Results range from 79.2 µg/L to 608 µg/L with a mean concentration of 302 µg/L. Twenty-six results exceed the lowest Tier II AL. Ninety-one percent of surface water results exceed the BTV. One result (from surface water location ST-109 located approximately 1,000 feet southwest of the former Tuboscope building) exceeds the AWQS.

Most recent water sample results for total barium are depicted on Figures 124-F and 124-G. The most recent sample event results for total barium show that concentrations exceed the lowest Tier II ALs in all areas around the former Tuboscope site. The exceedances are present primarily in pad porewater, and in SPGW and surface water located immediately adjacent to the gravel pad and roads. Barium concentrations in SPGW and surface water away from the constructed gravel pads and roads are below Tier II ALs, with a few exceptions.

Adjacent to the BOC pad, total barium concentrations in surface water are present at consistent concentrations that range from 300 to 800 µg/L. This includes locations immediately adjacent to the former IM drainage ditch. Based on this surface water data, it appears that impacts of drilling mud to gravel is the primary source of the Tier II AL exceedance in waters immediately adjacent to the roads and pads.

Farther from the pad, measured concentrations of barium in surface water tend to be much higher than SPGW concentrations in co-located monitoring wells (Table 8.14-3).

Table 8.14-3: Barium Concentrations in Co-located Monitoring Well and Surface Water Samples Located Well Away from the BOC Pad

Location	Monitoring Well Concentration (µg/L)	Surface Water Concentration (µg/L)
SPGW-108A ST-108	430	1,600
SPGW-109A ST-109	304	4,140
SPGW-111A ST-111	133	1,760
SPGW-115A ST-115	175	747
SPGW-118A ST-118	263	1,510
SPGW-126A ST-126	391 J-D	1,360

Total barium concentrations are highest in pad porewater near the former drilling mud plant and the former Tuboscope building at monitoring wells MW-24, MW-62, MW-201R, MW-202, and MW-204. Total barium concentrations are also elevated on the western side of the BOC pad in pad porewater at locations away from the former drilling mud plant and the former Tuboscope building.

7.16.2.2 Dissolved Barium

Comparison of the mean concentrations of dissolved and total barium measured in monitoring wells suggests that almost all barium is dissolved. Dissolved barium was detected in all 103 monitoring well samples and the measured concentration exceeded the lowest Tier II AL of 360 µg/L in 61 samples. None of the detected dissolved barium concentrations exceeded the AWQS. Dissolved barium concentrations exceeded PBU surface water BTV concentrations in 100 samples (97 percent of samples). Detected concentrations of dissolved barium in monitoring well samples range from 106 µg/L to 1,410 µg/L with a mean concentration of 495 µg/L.

In surface water, dissolved barium was detected in all 72 samples. Results range from 79.2 µg/L to 608 µg/L with a mean concentration of 302 µg/L. Twenty-six results exceed the lowest Tier II AL. Eighty-one percent of surface water results exceed the BTV. No results exceed the AWQS. As shown on Figures 124-H and 124-I, the distribution of dissolved barium is comparable to total barium at the former Tuboscope site.

7.16.3 Fate and Transport Properties and Summary of Background Assessment

At the Prudhoe Bay facility, barium is used in drilling fluids used in the construction of oil and gas wells. There is historical evidence of release of drilling mud, and barium is a known constituent found in drilling mud formulated and stored at the former Tuboscope site.

Barium (Ba) is also a naturally occurring component of minerals that are found in small but widely distributed amounts in the earth’s crust. Under natural conditions, barium is stable in the +2 valence state and is found primarily in the form of inorganic complexes. Conditions such as pH, ORP, CEC, and the presence of sulfate, carbonate, and metal oxides affect the partitioning of barium and its compounds in the environment. Knowledge of the specific form of barium is particularly important in understanding its solubility, fate and transport properties, and toxicity (Menzie et al. 2008). In aquatic media, barium is likely to precipitate as an insoluble salt (i.e., $BaSO_4$ or $BaCO_3$). Barium is fairly immobile in most soil systems, due to the formation of water-insoluble salts and an inability of barium to form soluble complexes with fulvic or humic acids. Barium may become more mobile in soil under acidic conditions since barium sulfate and barium carbonate become more water soluble (ATSDR 2007b).

The widespread distribution of barium in surface soil at the former Tuboscope site is likely related to the drilling mud plant formerly located on the BOC pad. The highest measured soil concentration (4,460 mg/kg at SS-101) is located near the former plant location. Higher concentrations located at soil boring SB-34, southwest of the former Tuboscope building, are suggestive of a secondary release point. Wind erosion have also scattered barium-rich drilling products to other areas.

Impacts of barium to active-layer soil appear to be minimal. Barium sulfate has low water solubility, just 3.1 mg/L water at 20 °C (ATSDR 2007b). However, this solubility limit is well above the lowest Tier II AL for water (360 µg/L). Humic and fulvic acid, which may be present in high concentrations in the peat soil that surrounds the former Tuboscope site, have not been found to increase the mobility of barium (USEPA 1984).

Barium has a relatively low mean log Kd value of 2.0 (Table 3) and would be expected to potentially have a moderate ability to migrate. Concentrations of total and dissolved barium in SPGW exceed the lowest Tier II AL beneath much of the BOC pad and beneath the tundra environment to the southwest and northeast of the former Tuboscope site.

Since the solubility of barium sulfate is low, only trace amounts of barium typically dissolve in surface water (Bodek et al. 1988; NAS 1977). At pH levels of 9.3 or below, barium sulfate may limit barium concentrations in natural waters (Bodek et al. 1988).

The background assessment presented in Appendix N concluded that elevated concentrations of barium in pad gravel and some tundra soils are due to potential releases. Except at soil boring SB-63, which was advanced through the drainage ditch, the generally deeper mineral soils do not appear to have been impacted by releases.

The background assessment concluded that concentrations of total and dissolved barium in SPGW (including pad porewater) were naturally occurring. As detailed in the QQ plots, un-impacted pad porewater at Put 23 contains barium concentrations as high as, and higher than, results from the former Tuboscope site. This conclusion was also based on evaluation of geochemical ratio plots, as described in the background assessment.

The background assessment concluded that elevated concentrations of barium in pad gravel and some surface water samples are due to potential releases. Drilling mud constituents blown off the BOC pad and impacting surface tundra soil appear to have impacted surface water. Concentrations of barium in surface water rapidly decrease to below the lowest Tier II AL as the water flows away from the pad to the northeast. As detailed in

Table 8.14-3, for co-located surface water and monitoring well samples collected farther from the BOC pad, measured concentrations of barium in surface water tend to be much higher than co-located SPGW concentrations. This provides additional evidence that transport by wind erosion plays a more important transport pathway than transport by dissolution and SPGW advection.

7.17 Antimony in Soil

Antimony is not a COI at the former Tuboscope site; however, it was erroneously included as an investigation analyte during the limited soil sampling effort performed in the bottom of the former drainage ditch in 2018.

Antimony was detected in seven of 14 soil samples collected. Antimony concentrations range from 0.15 to 0.55 mg/kg with a mean concentration of 0.3 mg/kg. Concentrations exceeded the lowest Tier II AL of 0.23 mg/kg in four samples. There are no soil media-specific BTV concentrations for antimony.

There is no known source for antimony from historical operations conducted at the former Tuboscope site. Review of the QQ plot for antimony in gravel (Appendix N) indicates that the distribution of antimony concentrations at Tuboscope and at Put 23 is very similar, with one exception. The result from surface soil sample SS-152 is significantly above the breakpoint and appears to be part of a distinct distribution. The same sample contains concentrations of barium, copper, lead, and zinc that are elevated due to historical site activities.

7.18 Arsenic

7.18.1 Soil Data

Arsenic was detected in all 261 samples collected at 139 locations. Measured arsenic concentrations range from 1.9 to 86.6 mg/kg with a mean concentration of 5.86 mg/kg. Arsenic concentrations exceeded the lowest Tier II AL of 1.5 mg/kg in all 261 samples. Arsenic concentrations exceeded media-specific BTV concentrations in 17 SM/SO samples and 10 tundra (TN) samples.

As shown on Figures 125-A and 125-B, arsenic at concentrations above the lowest Tier II AL is ubiquitous in Tuboscope soil samples. A markedly higher concentration was detected in soil from soil boring SB-34 (86.6 mg/kg) located to the southwest of the former Tuboscope building location. The next two highest concentrations were reported at TM-42 (20.1 mg/kg) and SPGW-113A (14.5 mg/kg).

Figures 125-C and 125-D summarize data for arsenic in active-layer soil. As with surface soil, all results for active-layer soil are above the lowest Tier II AL. However, the distribution of arsenic concentrations in active-layer soil appears to be uniform, with no locations containing markedly higher concentrations.

Figure 125-E summarizes deep soil results (greater than 6 feet below surface) for arsenic by depth order. Generally, arsenic concentrations appear to decrease with depth in permanently frozen soil.

7.18.2 Water Data

7.18.2.1 Total Arsenic in Water

Of the 184 monitoring well samples analyzed for total arsenic, all results exceeded the lowest Tier II AL of 0.011 µg/L. Detected concentrations of total arsenic range from 0.46 to 15.5 µg/L with a mean concentration of 4.09 µg/L. Almost all results (177) exceeded the BTV for arsenic in surface water (1.0 µg/L). Five results exceeded the AWQS of 10 µg/L.

Total arsenic was detected in 126 of 133 surface water samples. All detected results exceed the lowest Tier II AL. Fifty-nine results exceeded the BTV, and one result exceeded the AWQS. Detected concentrations of total arsenic in surface water range from 0.21 to 14.4 µg/L with a mean concentration of 1.35 µg/L.

The most recent water sample results for total arsenic are depicted on Figures 125-F and 125-G. Arsenic at concentrations above the lowest Tier II AL is ubiquitous in SPGW and surface water. Total arsenic concentrations are generally higher in the gravel pad environment than the off-pad tundra setting. Concentrations of total arsenic tend to be lower in surface water than they are in monitoring well samples. Otherwise, no discernable spatial pattern is evident.

7.18.2.2 Dissolved Arsenic

Out of the 105 monitoring well samples analyzed for dissolved arsenic, the constituent was detected in all samples at concentrations that exceed the lowest Tier II AL. An AWQS has not been established for dissolved arsenic. Dissolved arsenic concentrations exceeded media-specific BTV concentrations in 103 samples (98 percent of samples). For monitoring wells for the former Tuboscope site as a whole, approximately 87 percent of the detected arsenic was in the dissolved form.

Dissolved arsenic was detected in 67 of 71 surface water samples. All detected results exceed the lowest Tier II AL. Seventeen results exceeded the BTV. Detected concentrations of dissolved arsenic in surface water range from 0.18 to 3 µg/L with a mean concentration of 0.89 µg/L. In surface water, the average measured concentration of dissolved arsenic was approximately 66 percent of the total arsenic concentration.

Figures 125-H and 125-I present the most recent water sample results for dissolved arsenic. The distribution of dissolved arsenic is comparable to the distribution of total arsenic. Dissolved arsenic at concentrations above the lowest Tier II AL is ubiquitous in SPGW and surface water. Concentrations of dissolved arsenic tend to be lower in surface water than they are in monitoring well samples. Otherwise, no discernable spatial pattern is evident.

7.18.3 Fate and Transport Properties and Summary of Background Assessment

Arsenic (As) is a ubiquitous element that is detected at low concentrations in virtually all environmental matrices. At the former Tuboscope site, arsenic has been detected consistently in all media and at locations across the area of investigation.

Arsenic exhibits complex geochemistry and can be present in several oxidation states (-3, 0, +3, +5). In general, the mobility of arsenic in the environment and its toxicity vary depending on the valence state, whether it is an organic or inorganic form, and factors such as solubility and particle size. Processes controlling mobility of arsenic include redox reactions, adsorption-desorption reactions, precipitation-dissolution reactions, and biotransformation. The factors that most strongly influence these processes in water include redox state, pH, sulfide ion concentrations, iron concentrations, biota, and concentrations of organic matter (ATSDR 2007c).

Based on reported Kd values of arsenic (Table 3), it appears that sorption of arsenic on soil may be moderate with a log Kd value of 3.2 centimeters cubed per gram. The value of Kd depends strongly upon the pH of the water, the arsenic oxidation state, and the temperature. In acidic and neutral waters, arsenate is extensively adsorbed, while arsenite is relatively weakly adsorbed. (Pad porewater and SPGW at the former Tuboscope site is mildly acidic and surface water is mildly basic.) It is not unusual to have reducing conditions in a tundra environment because of the degradation of natural organic material. Under reducing conditions, arsenite is the dominant form; arsenite can adsorb or coprecipitate with metal sulfides. Arsenic that is adsorbed to iron and manganese oxides may be released under reducing conditions. In aerobic environments arsenate is the dominant form; arsenate behaves as a chelate and can precipitate when metal cations are present. Arsenate can also coprecipitate with or adsorb onto iron oxyhydroxides under acidic and moderately reducing conditions. Coprecipitates are immobile under these conditions, but arsenic mobility increases as pH increases.

The background assessment presented in Appendix N concluded:

- Concentrations of arsenic measured in gravel are naturally occurring, except for samples collected at 12-TTLA-10, 12-TTLA-13, 12-TTLA-16, 12-TTLA-17, and SB-34. Except for soil boring SB-34 (which is located approximately 350 feet southwest of the former Tuboscope building), these samples were collected at the southern TTLA for the CIC Storage Facility. These results exceed the breakpoint on the QQ plot. This assessment also considered geographic distribution and the principal components analysis (PCA).
- Concentrations of arsenic measured in mineral soil are naturally occurring, except soil boring SB-63, which is located beneath the former drainage ditch.
- Concentrations of arsenic measured in tundra soil are naturally occurring, except at soil borings SB-55 (an active layer sample collected approximately 300 feet southeast of the former Tuboscope building), SB-94 (a deep soil sample collected east of the Material Storage Warehouse), and TM-42 (a surface soil sample collected from the tundra approximately 170 feet northeast of the former Tuboscope building).
- Releases may have impacted total and dissolved arsenic concentrations in SPGW (excluding pad porewater).
- Concentrations of total and dissolved arsenic measured in pad porewater are consistent with naturally occurring concentrations.
- Releases may have impacted the concentration of total arsenic in surface water and the concentration of dissolved arsenic in surface water samples ST-40 (east of the Northern TTLA) and ST-43 (east of the former drainage ditch).

7.19 Cadmium

7.19.1 Soil Data

Cadmium was detected in 205 soil samples at 123 locations. Cadmium concentrations range from 0.047 to 1.9 mg/kg, with a mean concentration of 0.33 mg/kg. Cadmium concentrations exceeded the lowest Tier II AL of 0.92 mg/kg in four samples (2 percent of samples). Cadmium concentrations exceeded the media-specific (SM/SO) BTV concentration (0.45 mg/kg) in 21 samples and the BTV for cadmium in peat soil (0.36 mg/kg) in 32 samples.

Figures 126-A and 126-B present the distribution of cadmium in surface soil. Cadmium concentrations above the lowest Tier II AL were detected at two soil sample locations (SB-43 and SPGW-113A), which are well away from the BOC pad. These tundra location samples had moisture contents of 73 percent and 74 percent. The following metals are also above the lowest Tier II AL in these samples: arsenic, chromium, copper, mercury, and zinc. Figures 126-C and 126-D summarize data for cadmium in active-layer soil.

Figure 123-E summarizes deep soil results for cadmium by depth order. Cadmium concentrations above the lowest Tier II AL are located at two deeper soil sample locations (SB-28 advanced at the former Tuboscope building at 6.5 to 9 feet bgs and SB-94 advanced east of the Material Storage Warehouse at 9 to 9.6 feet bgs). Both soil samples were described as peat, but were mostly ice, with moisture contents of 84 percent and 93 percent. These samples also had concentrations above the Tier II AL of several other metals: arsenic, barium, chromium, copper, lead, mercury, and zinc. Deep, mucky peat may display

distinct geochemistry not related to site releases, and soil samples that are mostly water present analytical challenges with regards to both subsampling and calculating results on a dry weight basis.

7.19.2 Water Data

7.19.2.1 Total Cadmium in Water

Of the 179 monitoring well samples analyzed for total cadmium, the constituent was detected in 46 samples. Total cadmium results in monitoring well samples range from 0.024 µg/L to 0.93 µg/L, with a mean concentration of 0.12 µg/L. Cadmium concentrations exceeded the lowest Tier II AL of 0.32 µg/L in four samples. Total cadmium does not have an AWQS. The cadmium BTV was established at the detection limit; in general, detected results exceeded the BTV.

Of the 131 surface water samples analyzed for total cadmium, five results exceeded the lowest Tier II AL. Detected concentrations of total cadmium in 11 surface water samples range from 0.036 µg/L to 5.3 µg/L, with a mean concentration of 0.71 µg/L. The highest exceedances of the lowest Tier II AL occurred at location ST-47 (east of the BOC pad) in a 2009 sample and at ST-146 (approximately 600 feet east of the BOC pad) in a 2011 sample. The most recent samples collected at these locations had results below the MDL.

The most recent water sample results for total cadmium are depicted on Figures 126-F and 126-G. Concentrations of total cadmium above the lowest Tier II AL are present in three monitoring wells (MW-18, MW-32, and MW-100 located near the southern TTLA) and at three surface water locations (ST-109 [in the tundra over 1,000 feet southwest of the former Tuboscope building], ST-142 [in the tundra to the east of the BOC pad], and ST-290 [east northeast of the Material Storage Warehouse]). The monitoring well and surface water results for cadmium detected above the Tier II AL were all collected in 2012. The total cadmium concentrations at the three monitoring well locations were all below the RLs in previous sampling events. This suggests a possible temporal variation at these locations or an analytical anomaly. In 2012, soil adjacent to monitoring wells MW-18 and MW-100 was excavated and the southern TTLA horizontal liner was installed.

7.19.2.2 Dissolved Cadmium in Water

Of the 105 monitoring well samples analyzed for dissolved cadmium, the constituent was detected in five samples. Detected concentrations of dissolved cadmium in monitoring well samples range from 0.032 µg/L to 0.11 µg/L, with a mean concentration of 0.071 µg/L. Dissolved cadmium concentrations were all below the Tier II AL of 0.32 µg/L. ADEC has established a hardness-dependent AWQS for dissolved cadmium (ADEC 2008). No results exceeded the AWQS calculated for each individual sample.

Dissolved cadmium was not detected in any of the 69 surface water samples analyzed. The most recent water sample results for dissolved cadmium are depicted on Figures 126-F and 126-G. The detected concentrations of dissolved cadmium are generally comparable to the concentrations of total cadmium reported from the same sampling events.

7.19.3 Fate and Transport Properties and Summary of Background Assessment

Cadmium (Cd) exists in the +2 oxidation state in nature and forms several aqueous complexes, especially with dissolved carbonate. Its concentration may be controlled by either adsorption or precipitation processes. The extent to which cadmium is bound to soil varies greatly with type of mineral, oxidation state of the system, and presence of competing cations in solution. In the natural environment with pH near 7 and oxidizing conditions, cadmium transport is expected to be retarded (Kd of 227). However, the Kd value is pH and redox sensitive because cadmium transport is affected by aqueous complexes and precipitates involving other redox sensitive constituents (e.g., dissolved sulfide). In low redox environments, the presence of sulfide leads to increased cadmium precipitation. Under varying ambient conditions of pH, salinity, and redox potential, cadmium is considered more mobile than other metals in aquatic environments (ATSDR 2012c).

Cadmium exceeded the lowest Tier II AL at two surface soil locations (SB-43 east of the BOC pad and SPW-113A west of the Materials Storage Warehouse), two tundra soil boring locations (SB-28 and SB-94), and at three monitoring well sample locations (MW-18, MW-32, and MW-100). The two soil boring samples were deep (SB-28 at 6.5 to 9 feet bgs and SB-94 at 9.0 to 9.6 feet bgs) and well away from the BOC pad. Although the three monitoring well sample locations form a relatively contiguous area, the three surface water locations (ST-109, ST-142, and ST-290) are spread far apart. Elevated concentrations measured in soil samples and in pad porewater samples do not appear to be connected. However, cadmium results are not available from the tundra layer at monitoring wells MW-18, MW-32, or MW-100. Elevated concentrations measured in monitoring well samples and in surface water samples do not appear to be connected.

The background assessment (Appendix N) concluded that cadmium concentrations appear to be naturally occurring, except for the following:

- Tundra soil samples at soil borings SB-43 and SB-94
- Pad porewater samples collected at monitoring wells MW-18 and MW-100
- Surface water sample ST-142

The soil sample from soil boring SB-43 contained 74 percent moisture; the soil sample from soil boring SB-94 contained 84.2 percent moisture. Because constituent concentrations are reported on a dry weight basis, and because of issues with subsampling, results for soil samples containing mostly water are subject to greater uncertainty.

7.20 Chromium

Chromium, as chrome lignosulfonate, was a commonly used deflocculant in water-based drilling mud systems (ARCO 1982). It was used to maintain heavy, solids-laden drilling muds in a fluid state. A drilling mud plant was located directly north of the former Tuboscope building.

7.20.1 Soil Data

Chromium was detected in 242 out of 261 soil samples. Chromium concentrations range from 2.8 to 145 mg/kg with a mean concentration of 17.2 mg/kg. A Tier II AL for total chromium of 6.5 mg/kg has been proposed as detailed in Appendix Q. Total chromium exceeds the proposed Tier II AL in 202 of 261 samples. Chromium concentrations exceeded the media-specific (SM/SO) BTV concentration (21 mg/kg) in 27 samples and the BTV for peat soil (22 mg/kg) in 20 samples.

Chromium III results were reported or calculated when results for both total chromium and chromium VI were available. Chromium III was detected in 198 of 217 soil samples. Chromium III concentrations range from 2.6 to 145 mg/kg with a mean concentration of 13.9 mg/kg. Chromium III concentrations exceeded the lowest Tier II AL of 10 mg/kg in 127 samples (59 percent of samples).

Figures 127-A and 127-B present the distribution of chromium III in surface soil, showing that chromium III concentrations above the lowest Tier II AL are spatially distributed across the former Tuboscope site. Chromium III concentrations above the lowest Tier II AL are located beneath and just north of the former drilling mud plant location and south of the CIC Storage Facility. The highest chromium above the lowest Tier II AL was found to the southwest at soil boring SB-34, which is located almost 400 feet southwest of the former Tuboscope building. Chromium III is reported at lower concentrations (but at concentrations often above the lowest Tier II AL) to the east in tundra sample locations.

Figures 127-C and 127-D summarize data for chromium III in active-layer soil. Chromium III concentrations above the lowest Tier II AL appear to be widespread and naturally occurring, with a handful of locations where elevated concentrations may be present due to site activities.

Figure 127-E summarizes data for chromium III in deep soil. Chromium III concentrations appear to be widespread and naturally occurring, with the exception of four locations (SB-28, beneath the former Tuboscope building at 6.5 to 9 feet bgs; SB-30, approximately 100 feet south of the former Tuboscope building at 6 to 8 feet bgs; SB-94, east of the Materials Storage Warehouse at 6 to 6.9 feet bgs; SB-98, on the western edge of the BOC pad at 13 to 15 feet bgs) with concentrations greater than three times the Tier II AL.

Chromium VI was detected in 17 of 217 soil samples. Chromium VI concentrations range from 0.59 to 13.3 mg/kg with a mean concentration of 3.0 mg/kg. All detected results exceeded the lowest Tier II AL of 0.40 mg/kg. For comparison, the range of MDLs for the hexavalent chromium in soil samples is 0.33 to 362 mg/kg. The sensitivity of the analytical method for hexavalent chromium may not be adequate to determine exceedances of the lowest Tier II AL with confidence.

Figures 128-A and 128-B present the distribution of chromium VI in surface soil; Figures 128-C and 128-D summarize data for chromium VI in active-layer soil; Figure 128-E summarizes data for chromium VI in deeper soil. Detections of chromium VI at concentrations above the lowest Tier II AL in surface soil occur southeast of the former drilling mud plant at location SS-295 and at source area soil boring SB-201R. In active layer and deep soils detections above the lowest Tier II AL are localized beneath and around the former drainage ditch. Figure 128-E shows that MDLs for chromium VI were frequently above the lowest Tier II AL.

7.20.2 Water Data

7.20.2.1 Total Chromium in Water

Of 183 monitoring well samples analyzed for total chromium, the constituent was detected in 173 samples. Total chromium concentrations range from 0.14 to 17.4 µg/L with a mean concentration of 1.81 µg/L. None of the detected total chromium concentrations exceeded the lowest Tier II AL of 58 µg/L. Total chromium concentrations in monitoring well samples exceeded the surface water BTV (0.82 µg/L) in 109 samples (60 percent of samples).

Of the 128 surface water samples analyzed for total chromium, none exceeded the lowest Tier II AL. Detected concentrations of total chromium in 84 surface water samples range from 0.098 µg/L to 15.9 µg/L, with a mean concentration of 1.36 µg/L. Total chromium concentrations exceeded the BTV concentration in 23 surface water samples (23 percent of samples).

7.20.2.2 Dissolved Chromium in Water

Out of the 102 monitoring well samples analyzed for dissolved chromium, the constituent was detected in 59 samples. None of the results exceeded the lowest Tier II AL. Dissolved chromium concentrations range from 0.25 to 3.7 µg/L with a mean concentration of 0.79 µg/L. Dissolved chromium concentrations exceeded the BTV concentration (1.0 µg/L) in 12 samples (12 percent of samples).

Of 63 surface water samples analyzed for dissolved chromium, no results exceeded the lowest Tier II AL. Detected concentrations of dissolved chromium in 40 surface water samples range from 0.24 µg/L to 1.6 µg/L, with a mean concentration of 0.61 µg/L. Results for eight samples analyzed for dissolved chromium concentrations exceeded the BTV (1.0 µg/L) (13 percent of samples).

Out of 69 monitoring well samples analyzed for chromium VI, the constituent was detected in three samples. Chromium VI concentrations in monitoring wells range from 0.0044 to 0.02 µg/L with a mean concentration of 0.012 µg/L. The chromium VI concentration exceeded the lowest Tier II AL of 0.012 µg/L in one monitoring well sample (MW-20 southeast of the former drainage ditch in 2011).

Out of the 52 surface water samples analyzed for chromium VI, the constituent was detected in 10 samples. Chromium VI concentrations in surface water range from 0.0062 to 0.029 µg/L with a mean concentration of 0.016 µg/L. The chromium VI concentration exceeded the lowest Tier II AL in seven surface water samples (ST-105 in 2011, 2012 [native sample and duplicate]; ST-174, ST-218 2011; ST-222 in 2011, 2012). Chromium VI concentrations were below the BTV concentration (0.026 µg/L), except in one surface water sample (ST-105 in 2011). For comparison, the RL for the hexavalent percent chromium in water samples is 0.025 µg/L. The sensitivity of the analytical method for hexavalent chromium may not be adequate to determine exceedances of the BTV and the lowest Tier II AL with confidence. MDLs for 36 non-detect surface water samples were less than the lowest Tier II AL.

Chromium III results were reported when both total chromium and chromium VI were analyzed. Out of the 10 monitoring well samples with reported results for chromium III, the constituent was detected in two samples, at concentrations of 5.7 µg/L and 6.2 µg/L. Out of the 35 surface water samples with reported results for chromium III, the constituent was detected in one sample at a concentration of 5.9 µg/L. The chromium III concentration did not exceed the lowest Tier II AL (58 µg/L).

The most recent water sample results for chromium VI are depicted on Figures 128-F and 128-G. Concentrations of chromium VI above the lowest Tier II AL are present at four surface water locations (ST-44, ST-74, ST-222 [all located near the former drainage ditch], and ST-105 [located just west of the Material Storage Warehouse]).

7.20.3 Fate and Transport Properties

Chromium (Cr) is a naturally occurring element present in the earth's crust that exists in two valence states in the environment: trivalent (chromium III or Cr^{+3}) and hexavalent (chromium VI or Cr^{+6}). Typically, chromium III in an aqueous environment is associated with particles, while chromium VI remains in solution. Chromium III has low solubility and a strong tendency to adsorb to negatively charged soil clay particles. As a result, chromium III is generally immobile and remains close to the origin of deposition. On the other hand, chromium VI occurs in the environment as the negatively charged species chromate (CrO_4^{-2}) or dichromate ($Cr_2O_7^{-2}$), which are highly soluble and have a low affinity to adsorb on mineral surfaces. As a result, chromium VI tends to be mobile in the environment. Chromium VI will reduce to the trivalent state under strongly reducing conditions (ATSDR 2012d).

Several factors influence the adsorption behavior of chromium including the following:

- Concentrations of chromium III in soil solutions are typically controlled by dissolution/precipitation reactions; therefore, adsorption reactions are not significant.
- Increasing the pH decreases adsorption (and decreases in Kd) of chromium VI on soil.
- The redox state affects chromium adsorption. Ferrous iron associated with iron oxide/hydroxide minerals in soil can reduce chromium VI resulting in precipitation. Soil containing manganese oxides oxidize chromium III to chromium VI resulting in lower Kd values.
- The presence of competing anions (e.g., SO_4, CO_3/HCO_3, Cl, NO_3) reduce chromium VI adsorption.

The background assessment (Appendix N) concluded that potential releases are contributing to chromium concentrations in gravel. Chromium concentrations in the active-layer soils, deep soils, and waters appear to be naturally occurring, except for the following:

- Mineral soils at soil borings SB-29 (just west of the former Tuboscope building, 37.8 mg/kg) and SB-98 (western edge of the BOC pad, 59.2 mg/kg)

- Peat samples at soil borings SB-25 (south of the former Tuboscope building, 37.8 mg/kg), SB-28 (beneath the former Tuboscope building, 85.9 mg/kg), SB-94 (east of the Materials Storage Warehouse, 42.4 mg/kg, and 126 mg/kg in a deeper sample), and tundra sample TM-42 (32.8 mg/kg)

The data show that the 17 chromium VI Tier II exceedances in soil occur near the former Tuboscope building and drainage ditch:

- Surface locations SS-295 and SB-201R northeast of the former Tuboscope building
- Active-layer soil locations SS-150, SS-151, and SB-64 (near the former drainage ditch)
- Deep soil locations SB-63, SB-151, SB-152, SB-153, SB-154, and SB-155

The detections of chromium VI in water occur at surface water locations ST-105 in 2011, 2012; ST-174, ST-218 in 2011; ST-222 in 2011, 2012 and at monitoring well MW-20 in 2011. Except for ST-105, these locations are near the former drainage ditch. The surface water results suggest the possibility that chromium VI was transported from the drainage ditch to surface locations to the east.

7.21 Copper

7.21.1 Soil Data

Copper was detected in 260 samples collected at 139 locations. Copper concentrations range from 3.2 to 132 mg/kg with a mean concentration of 14.0 mg/kg. Copper concentrations exceeded the lowest Tier II AL of 37 mg/kg in six of 261 samples (2 percent of samples). Copper concentrations exceeded the media-specific (SM/SO) BTV concentration (24 mg/kg) in seven samples and the BTV for peat soil (19 mg/kg) in 25 samples. Copper concentrations appear to be widespread and naturally occurring, with a handful of locations where elevated concentrations may be present due to site activities.

Figures 129-A and 129-B present the distribution of copper in surface soil, showing that results for two surface soil samples exceed the lowest Tier II AL, and the samples were collected far apart. The highest copper results were found more than 200 feet to the southwest of the former Tuboscope building at soil boring SB-34 (132 mg/kg) and 150 feet to the east in tundra sample location TM-42 (50.9 mg/kg).

Figures 129-C and 129-D summarize data for copper in active-layer soil. The highest copper result was found in the former drainage ditch at sample location SS-152 (49.4 mg/kg) and was the only active layer sample with a result above the lowest Tier II AL.

Figure 129-E summarizes data for copper in deep soil. Copper concentrations below the Tier II AL appear to be widespread and naturally occurring. Results for three deeper samples exceeded the Tier II AL:

- SB-94 (over 400 feet northwest of former Tuboscope building, 53.0 mg/kg, 9 to 9.6 feet bgs)
- SB-63 (drainage ditch, 53.9 mg/kg, 6.5 to 8.5 feet bgs)
- SB-28 (former Tuboscope building, 74.5 mg/kg, 6.5 to 9 feet bgs)

7.21.2 Water Data

7.21.2.1 Total Copper in Water

Out of the 182 monitoring well samples analyzed for total copper, the constituent was detected in 133 samples. Detected concentrations of total copper in monitoring wells range from 0.2 to 23.7 µg/L, with a mean concentration of 2.35 µg/L. Detected total copper concentrations exceeded the lowest Tier II AL of 1.1 µg/L in 82 samples. Total copper concentrations exceeded the surface water BTV (1.2 µg/L) in 80 samples. The highest exceedances of the lowest Tier II AL occurred in 2012 at locations MW-32 (south southwest of the CIC Storage Facility, 23.7 µg/L), MW-83 (south end of the BOC pad, 11.2 µg/L), and MW-100 (near the southern TTLA, 14.6 µg/L). Results for samples collected in 2011 from monitoring wells MW-32 and MW-100 were an order of magnitude lower.

Of the 128 surface water samples analyzed for total copper, 39 results exceeded the lowest Tier II AL. Detected concentrations of total copper in 104 surface water samples range from 0.2 µg/L to 22.6 µg/L, with a mean concentration of 1.91 µg/L. Total copper concentrations in surface water exceeded the BTV in 35 samples. The highest exceedances of the lowest Tier II AL occurred at locations ST-108 (10.5 µg/L), ST-109 (22.2 µg/L), ST-142 (10.5 µg/L), and ST-290 in 2012 (11.0 µg/L); and at ST-146 (22.6 µg/L) in 2011. The sample collected at ST-146 in 2012 had a result below the Tier II AL.

The most recent water sample results for total copper are depicted on Figures 129-F and 129-G. Concentrations of total copper above the lowest Tier II AL are present in most monitoring wells and surface water locations across and surrounding the former Tuboscope site. The highest concentrations (order of magnitude above the BTV) are located on the BOC pad in monitoring wells (MW-32, MW-83, and MW-100). The highest surface water concentrations were measured southwest of the BOC pad at ST-108 and ST-109, east of the drainage ditch at ST-142, and north of the former Tuboscope building at ST-290.

7.21.2.2 Dissolved Copper in Water

Out of the 103 monitoring well samples analyzed for dissolved copper, the constituent was detected in 37 samples. Detected concentrations of dissolved copper in monitoring well samples range from 0.15 to 4.8 µg/L, with a mean concentration of 0.85 µg/L. Detected concentrations of dissolved copper exceeded the lowest Tier II AL of 1.1 µg/L in seven samples. Dissolved copper concentrations exceeded the surface water BTV (1.7 µg/L) in four samples. No results exceeded the hardness-dependent AWQS calculated for each individual sample.

Dissolved copper was detected in 41 of the 64 surface water samples analyzed. Detected concentrations of dissolved copper in surface water samples range from 0.25 to 1.9 µg/L, with a mean concentration of 0.7 µg/L. Detected concentrations of dissolved exceeded the lowest Tier II AL in nine samples. Dissolved copper concentrations exceeded the BTV in two samples. No results exceeded the hardness-dependent AWQS calculated for each individual sample.

The most recent water sample results for dissolved copper are depicted on Figures 129-H and 129-I. The detected concentrations of dissolved copper are generally less than the concentrations of total copper reported from the same sampling events. Concentrations of dissolved copper above the lowest Tier II AL are present in seven monitoring wells (MW-25, MW-37, MW-100, MW-202, MW-204, SPGW-54A, and SPGW-140A) and at six surface water locations (ST-47, ST-48, ST-105, ST-174, ST-218, and ST-222). Higher concentrations in monitoring well samples are present in a discrete area to the southeast of the former Tuboscope building. In surface water, samples collected close to the BOC pad tend to have higher concentrations of dissolved copper than samples collected farther away.

7.21.3 Fate and Transport Properties

Copper (Cu) is naturally occurring in the earth’s crust. In aerobic, sufficiently alkaline groundwater systems, $CuCO_3$ is the dominant soluble copper species. The cupric ion (Cu^{2+}) forms hydroxide complexes ($CuOH^+$ and $Cu(OH)_2$) that are also commonly present. Copper forms strong solution complexes with humic acids, where the affinity of copper for humates increases as pH increases and ionic strength decreases. In anaerobic environments, when sulfur is present, copper sulfide will form and precipitate.

Copper is strongly adsorbed by soil particles (i.e., clays, metal oxides, and organic matter). Copper binds to soil much more strongly than other divalent cations, and the distribution of copper in groundwater is less affected by pH than other metals. Adsorption of copper generally increases with increasing pH. Like other heavy metals, the movement of copper in soil is also influenced by the permeability of the soil and the amount of clay and iron oxides that are present. Copper sorbs significantly to soil organic matter. These factors tend to attenuate the mobility of copper through adsorption and cation exchange (ATSDR 2004).

The wide spatial distribution of copper in soil and particularly in SPGW at concentrations above the lowest Tier II ALs across the former Tuboscope site would suggest that it is naturally occurring since copper is generally not mobile and is strongly adsorbed to soil particles. However, the elevated copper concentrations in some soil and water samples may be associated with historical activities at Tuboscope.

The background assessment (Appendix N) concluded that potential releases of copper are present in some tundra soil, groundwater, and surface water locations. Copper concentrations in gravel and mineral soils appear to be naturally occurring, except for the following:

- Gravel from SB-34 (400 feet southwest of the former Tuboscope building) and SS-152 (below the former drainage ditch)
- Mineral soil from SB-63 (below the former drainage ditch)

Dissolved copper concentrations in water samples appear to be naturally occurring, except for the following:

- Pad porewater samples at monitoring wells MW-202 (source area well east of the former Tuboscope building) and MW-25 (approximately 160 feet south southeast of the former Tuboscope building)
- SPGW sample at monitoring well SPGW-140A, east of the BOC pad

7.22 Mercury

7.22.1 Soil Data

Mercury was detected in 169 of 261 soil samples. Mercury concentrations range from 0.0017 to 0.16 mg/kg, with a mean concentration of 0.0255 mg/kg. Mercury concentrations exceeded the lowest Tier II AL of 0.014 mg/kg in 83 samples (36 percent of samples). Mercury concentrations exceeded the media-specific (SM/SO) BTV concentration (0.040 mg/kg) in five samples and the BTV for mercury in peat soil (0.074 mg/kg) in three samples. Results for 11 samples were below the MDL, but the MDL was greater than the lowest Tier II AL, and the results do not support decision making at that concentration.

Figures 130-A and 130-B present the distribution of mercury in surface soil. Mercury concentrations greater than the lowest Tier II AL were measured in samples collected from the BOC pad area, as well as tundra locations northeast and southwest of the BOC pad. The greatest concentrations of mercury were measured in samples collected from tundra sampling locations northeast and southwest of the BOC pad.

Figures 130-C and 130-D illustrate the distribution of mercury in active-layer soil samples. Mercury concentrations greater than the lowest Tier II AL were reported for samples distributed relatively evenly beneath the BOC pad. The samples with the greatest concentrations of mercury were located along the eastern margin near the former drainage ditch, and along the western margin of the BOC pad.

Figure 130-E presents the distribution of mercury in deep soil samples. Consistent with active-layer soil samples containing the greatest concentrations of mercury, deep soil samples containing mercury at concentrations greater than the lowest Tier II AL were more common in borings located in the eastern portion of the BOC pad, near the former drainage ditch.

7.22.2 Water Data

7.22.2.1 Total Mercury in Water

Of the 103 monitoring well samples analyzed for total mercury, the constituent was detected in one sample at a concentration of 0.056 µg/L. Total mercury concentration detected in that single monitoring well sample exceeded the lowest Tier II AL of 0.024 µg/L. The detected total mercury result exceeded the total mercury BTV, which was established at the detection limit. This sample was collected from source area monitoring well MW-202.

Of the 72 surface water samples analyzed for total mercury, three samples contained detectable concentrations of total mercury. Detected concentrations of total mercury range from 0.1 µg/L to 0.12 µg/L, with a mean concentration of 0.11 µg/L. The detected concentrations of total mercury exceeded the lowest Tier II AL of 0.024 µg/L, and the AWQS of 0.05 µg/L. These three samples were collected from surface water sampling locations ST-43 (two samples collected in 2009) and ST-73; results for more recent samples collected at these locations were below the MDL.

The most recent water sample results for total mercury are depicted on Figures 130-F and 130-G. Concentrations of total mercury above the lowest Tier II AL are present in one monitoring well (MW-202), which has been impacted by a variety of constituents.

7.22.2.2 Dissolved Mercury in Water

Of the 91 monitoring well samples analyzed for dissolved mercury, the constituent was detected in 11 samples. Dissolved mercury concentrations range from 0.037 µg/L to 0.063 µg/L, with a mean concentration of 0.047 µg/L. Dissolved mercury concentrations detected in all 11 samples exceeded the lowest Tier II AL of 0.24 µg/L, and one sample contained a dissolved mercury concentration that exceeded the AWQS of 0.05 µg/L. The detected dissolved mercury results exceeded the total mercury BTV, which was established at the detection limit.

Of 67 surface water samples analyzed for dissolved mercury, one sample contained a detectable concentration of dissolved mercury. A sample collected from location ST-72 contained 0.12J µg/L of dissolved mercury. The detected concentration of dissolved mercury exceeded the lowest Tier II AL of 0.024 µg/L, and the AWQS of 0.05 µg/L. The result for a more recent sample collected from location ST-72 was below the MDL.

The most recent water sample results for dissolved mercury are presented on Figures 130-H and 130-I. Concentrations of dissolved mercury greater than the lowest Tier II AL were measured in monitoring wells that appear to be scattered across the former Tuboscope site. The samples of each of the monitoring wells shown on Figures 130-H and 130-I as exceeding the lowest Tier II AL for dissolved mercury were collected in 2011 and were also analyzed for total mercury. In all cases, the result for total mercury was below the MDL. The concentrations of dissolved mercury in a sample should not exceed the concentration of total mercury. For comparison, for both total and dissolved mercury, the MDL for these 2011 water samples was 0.037 µg/L mercury, just above the lowest Tier II AL of 0.024 µg/L. There is statistical uncertainty inherent in determining the MDL. The RL for these water samples was 0.2 µg/L mercury. Per the Site-wide QAPP, the RL generally represents the lowest concentration point of the calibration curve used for quantitation of analyte results. The 2011 results were qualified as estimated (J flag) because the results were below the RL. At these very low concentrations, small changes in the instrument's baseline can be misinterpreted as a constituent signal at concentrations well below the lowest point on the calibration curve. Since 2017, the analytical laboratory had provided a much higher MDL. All 2011 results were well below the current MDL. The sensitivity of the analytical method for mercury may not be adequate to determine exceedances of the lowest Tier II AL with confidence.

7.22.3 Fate and Transport Properties

Mercury (Hg) is a naturally occurring metal that can exist in several valence states, including +1, +2, and the elemental form, and as the organic form of methyl mercury. Mercury has a strong tendency to sorb to the organic fractions of soil, which is influenced by the organic matter content of the soil or sediment. The transport and partitioning of mercury in surface waters and soil is influenced by the particular form of the compound. It can be transformed by microbes to organic forms such as methyl mercury, which is mobile and volatile. Volatile forms of mercury typically evaporate to the atmosphere, whereas dissolved solid forms partition to particulates in the soil or water column and are transported downward in the water column to the sediments. Vaporization of methylated and elemental forms of mercury from soil and surface water is controlled by temperature, with emissions from contaminated soil being greater in warmer weather. It should be noted that mercury does not tend to leach into water. However, surface water may cause mercury in particulate form to move from soil to water, especially in soil with high humic content (ATSDR 1999).

The background assessment (Appendix N) concluded that potential releases have impacted mercury concentrations in some mineral soil, some tundra soil, and one surface water location. Concentrations of mercury at the following locations may have been impacted by site activities:

- Mineral soil from soil borings SB-63 (beneath the former drainage ditch), SPGW-144A, and SPGW-44A (both east of the former drainage ditch)
- Tundra soil from locations SB-94 (east of the Materials Storage Warehouse) and TM-42 (tundra area east of the BOC pad)
- Surface water from ST-43

7.23 Nickel

7.23.1 Soil Data

Nickel was detected in all 261 soil samples that were collected at 139 locations. Nickel concentrations range from 5.6 to 203 mg/kg, with a mean concentration of 19.3 mg/kg. Nickel concentrations exceeded the lowest Tier II AL of 90 mg/kg in two samples (less than 1 percent of samples). Nickel concentrations exceeded the media-specific SM/SO BTV concentration (32 mg/kg) in five SM/SO samples and the BTV for nickel in tundra soil (32 mg/kg) in 12 tundra samples.

Figures 131-A and 131-B present the distribution of nickel in surface soil. Nickel concentration greater than the lowest Tier II AL was measured in a single surface soil sample collected from the BOC pad area (at soil boring SB-34) at an anomalously high concentration. Except for that single sample, all remaining samples collected from the surface soils both on the BOC pad and at tundra sampling locations east and west of the BOC pad contained relatively lower and uniform concentrations of nickel. In general, surface soil samples collected from the BOC pad area contain lesser concentrations of nickel than samples collected east and west of the BOC pad.

Figures 131-C and 131-D illustrate the distribution of nickel in active-layer soil samples. The lowest Tier II AL for nickel (90 mg/kg) was not exceeded in the results for any of the active-layer soil samples. Nickel was present in most of the active-layer soil samples at concentrations less than the media specific BTV concentrations (32 mg/kg for both SM/SO and tundra soils) throughout the BOC pad area. At those locations shown on Figures 131-C and 131-D where the nickel concentration in the active-layer soil sample exceeded the media-specific BTV, the samples were tundra soil samples collected beneath the BOC pad. Only a single deep soil sample (beneath the active-layer) collected from SB-28 (tundra sample collected beneath the former Tuboscope building with nickel concentration of 100 mg/kg) contained nickel at a concentration greater than the lowest Tier II AL of 90 mg/kg.

7.23.2 Water Data

7.23.2.1 Total Nickel in Water

Total nickel was detected in all 184 monitoring well samples. Concentrations of total nickel range from 3.1 µg/L to 39.9 µg/L, with a mean concentration of 11.1 µg/L. The lowest Tier II AL for total nickel of 16 µg/L was exceeded in 29 monitoring well samples (16%). Total nickel concentrations detected in monitoring well samples exceeded the BTV for surface water of 3.6 µg/L in 177 samples (96%).

All the 131 surface water samples analyzed for total nickel contained detectable concentrations of total nickel. Detected concentrations of total nickel in those surface water samples range 0.77 µg/L to 36 µg/L, with a mean concentration of 5.57 µg/L. The detected concentrations of total nickel exceeded the lowest Tier II AL of 16 µg/L in eight samples (6%), and the BTV of 3.6 µg/L in 72 samples (55%).

The most recent water sample results for total nickel are depicted on Figures 131-E and 131-F. Total nickel is a ubiquitous constituent in both surface water and monitoring well samples. The ranges of concentration for total nickel in surface water and monitoring well sample data sets are similar. However, the mean concentration of total nickel in surface water samples (5.57 µg/L) is significantly less than the mean concentration for total nickel (11.1 µg/L) in monitoring well samples of the water in direct contact with naturally occurring materials. There is no discernable spatial pattern to the occurrence of total nickel at a concentration exceeding either the lowest Tier II AL or the relevant BTV in either the surface water or monitoring well sample data sets.

7.23.2.2 Dissolved Nickel in Water

Out of the total of 105 monitoring well samples analyzed for dissolved nickel, dissolved nickel was detected in 103 samples (98%). Detected concentrations of dissolved nickel range from 3.2 to 36 µg/L with a mean concentration of 9.73 µg/L. The MDL for dissolved nickel was less than the lowest Tier II AL in all samples and exceeded the relevant BTV in only two samples (less than 2%). Detected dissolved nickel concentrations exceeded the lowest Tier II AL of 16 µg/L in eight samples (less than 8%). No results exceeded the hardness-dependent AWQS for nickel. Dissolved nickel concentrations exceeded surface water BTV concentration in 98 monitoring well samples (less than 98%). Comparison of the mean concentration for total and dissolved nickel measured in monitoring well samples indicates that about 88 percent of nickel is dissolved.

Dissolved nickel was detected in 66 of 68 surface water samples (97%). Detected concentrations of dissolved nickel range from 0.74 µg/L to 8 µg/L, with a mean concentration of 3.4 µg/L. Dissolved nickel concentrations did not exceed the lowest Tier II AL of 16 µg/L. The dissolved nickel concentration in 29 samples (43%) exceeded the surface water BTV of 3.7 µg/L.

Figures 131-G and 131-H illustrate the distribution of dissolved nickel in surface water and monitoring wells samples. Dissolved nickel is a nearly (greater than 97%) ubiquitous constituent in surface water and monitoring well samples, with no discernible spatial distribution or pattern to the occurrence of dissolved nickel exceedances of the surface water BTV for the constituent. The detected concentration range and mean concentration for dissolved nickel in monitoring well samples of water in direct contact with naturally occurring materials were significantly greater than the statistics for the surface water samples.

7.23.3 Fate and Transport Properties and Summary of Background Assessment

Nickel (Ni) is naturally present in the Earth’s crust, with concentrations typically reported in soil ranging from 4 to 80 mg/kg. Nickel is strongly adsorbed by soil, although to a lesser degree than lead. There are many adsorbing species in soil, and many factors affect the extent to which nickel is adsorbed. As a result, the amount adsorption of nickel by soil is site specific. Soil properties such as pH, organic matter, the type and amount of clay minerals, and certain hydroxides, influence the adsorption and release of nickel by soil. Amorphous oxides of iron and manganese, and to lesser extent clay minerals, represent the most important adsorbents in soil. Nickel is suspected of forming complexes with dissolved organic compounds as the mobility of nickel increases in the presence of sewage sludge (ATSDR 2005a).

As detailed in the background assessment presented in Appendix N, nickel concentrations measured in all soil media are naturally occurring, with one exception. The greatest concentration of nickel in soil was reported for a sample of pad gravel collected at soil boring SB-34 (approximately 400 feet southwest of the former Tuboscope building, 203J-M mg/kg). The sample was collected at a depth of 1.5 to 4 feet bgs and contained elevated concentrations of barium, chromium, copper, and zinc. The specific source of these elevated metals concentrations is unknown but does not appear to be related to the former Tuboscope site.

The background assessment also concluded that total nickel concentrations measured in pad porewater were naturally occurring, except for an elevated concentration of total nickel measured in monitoring well MW-86. Monitoring well MW-86 is just downgradient from soil boring SB-34.

Elevated concentrations of total nickel were reported in both SPGW (excluding pad porewater) and surface water. Because nickel adsorbs to oxides of iron and manganese, when anaerobic conditions impact these oxides, reduced forms of iron and manganese can form and all three metals can mobilize. These anaerobic conditions can be caused by biodegradation of naturally occurring organic matter or released petroleum hydrocarbons.

The background assessment concluded that dissolved concentrations of nickel in all three water media are naturally occurring. The distribution of total and dissolved nickel in water samples did not exhibit a discernable spatial distribution.

7.24 Selenium

7.24.1 Soil Data

Selenium was detected in 201 of 266 soil samples (76%). Selenium concentrations range from 0.19 to 4.6 mg/kg, with a mean concentration of 0.76 mg/kg. Selenium concentrations exceeded the lowest Tier II AL of 0.85 mg/kg in 62 samples (23%). The MDLs for 5 non-detect samples (2% of total samples) exceeded the lowest Tier II AL for selenium. There are no media specific BTV for selenium in soils.

Figures 132-A and 132-B present the distribution of selenium in surface soil. Selenium concentrations greater than the lowest Tier II AL were measured in samples collected from the BOC pad area, primarily in the vicinity of the southern TTLA, as well as tundra locations northeast and southwest of the BOC pad. The concentrations of selenium in surface soil samples collected from tundra sampling locations northeast and southwest of the BOC pad are, in general, equivalent to or greater than selenium concentrations measured in surface soil samples collected from the BOC pad.

Figures 132-C and 132-D illustrate the distribution of selenium in active-layer soil samples. Selenium concentrations greater than the lowest Tier II AL were reported for samples distributed across the BOC pad. There is no discernable spatial distribution of active-layer soil samples containing selenium at concentrations exceeding the lowest Tier II AL. Apart from a single sample collected from location 12-TTLA-6, all active-layer soil samples containing selenium at a concentration greater than the lowest Tier II AL were tundra soils (as opposed to imported gravel).

Figure 132-E presents the distribution of selenium in deep soil samples. Consistent with active-layer soil samples containing the greatest concentrations of selenium, deep soil samples containing selenium at concentrations greater than the lowest Tier II AL are distributed across the BOC pad with no discernable spatial distribution or trends regarding depth.

7.24.2 Water Data

7.24.2.1 Total Selenium in Water

Total selenium was detected in 92 of 184 monitoring well samples (50%). Detected concentrations of total selenium in monitoring well samples range from 0.095 µg/L to 7.3 µg/L with a mean concentration of 0.71 µg/L. Detected total selenium concentrations exceeded the lowest Tier II AL of 2.0 µg/L in six monitoring well samples (3%). No monitoring well samples (from wells closely connected hydrologically to surface water) contained total selenium at a concentration greater than the AQWS of 5 µg/L. The BTV for total selenium is listed as not estimated due to low detection frequency in the background data set.

Total selenium was detected in 59 of 130 surface water samples (45%). Detected concentrations of total selenium in surface water samples range from 0.094 µg/L to 5.7 µg/L, with a mean concentration of 1.2 µg/L. Detected total selenium concentrations in surface water samples exceeded the lowest Tier II AL of 2 µg/L in seven surface water samples (5%) and the AWQS of 5 µg/L in a single sample (less than 1%).

Most recent monitoring well and surface water sample results for total selenium are presented on Figures 132-F and 132-G. Most recent results do not include any concentrations greater than the lowest Tier II AL.

7.24.2.2 Dissolved Selenium in Water

Dissolved selenium was detected in 22 of 101 monitoring well samples (22%). Detected concentrations of dissolved selenium in monitoring well samples range from 0.22 µg/L to 3.9 µg/L, with a mean concentration of 1.1 µg/L. Detected dissolved selenium concentrations exceeded the lowest Tier II AL of 2.0 µg/L in three monitoring well samples (3%). An AWQS has not been established for dissolved selenium. The BTV for dissolved selenium is listed as not estimated due to low detection frequency in the background data set.

Dissolved selenium was detected in 27 of 67 surface water samples (40%). Detected concentrations of dissolved selenium in surface water samples range from 0.36 µg/L to 2.2 µg/L, with a mean concentration of 1.4 µg/L. Detected dissolved selenium concentrations in surface water samples exceed the lowest Tier II AL of 2.0 µg/L in two samples (3%).

Most recent monitoring well and surface water sample results for dissolved selenium are presented on Figures 132-H and 132-I. Results at two discrete locations exceed the lowest Tier II AL: monitoring well MW-55 (approximately 120 feet south of the former drainage ditch) and surface water sample location ST-74 (east of the former drainage ditch).

7.24.3 Fate and Transport Properties and Summary of Background Assessment

Selenium is ubiquitous in the environment, being released from both natural and anthropogenic sources (ATSDR 2003). The principal releases of selenium into the environment because of human activities result from the combustion of coal, and to a lesser extent petroleum.

Selenium (Se) exists principally in the four oxidation states of selenide Se^{-2} (-2 valence), elemental selenium Se (0 valence), selenite (+4 valence), and selenate (+6 valence). Selenite and selenate, the most oxidized selenium species, are much more soluble and bioavailable than reduced and elemental forms, Se^{-2} and Se. The movement of selenium species in groundwater systems is governed by redox reactions, which control the speciation of selenium, and adsorption processes, which retard SeO_4 and SeO_3.

Adsorption of the soluble selenium species (selenite and selenate) onto soil can be an important sink of selenium in the groundwater system. Selenite, similar in its adsorption capacity to phosphate, is strongly adsorbed onto surface sites, whereas selenate, similar in its adsorption capacity to sulfate, is weakly adsorbed. This difference in adsorption capacities of selenite and selenate means that selenate can be easily leached from the unsaturated zone, whereas selenite is resistant to leaching (ATSDR 2003).

The background assessment presented in Appendix N concluded that concentrations of selenium in gravel may have been impacted by releases. The highest concentrations in gravel appear to be in a contiguous area near and beneath the southern TTLA.

Selenium concentrations in mineral soil and tundra soil appear to be naturally occurring, except in a tundra sample collected at soil boring SB-94, which was collected east of the Materials Storage Warehouse. This deep soil sample (collected at 9 to 9.6 feet bgs) also contains elevated concentrations of arsenic, barium, cadmium, chromium, copper, and mercury.

The background assessment concluded that concentrations of total and dissolved selenium in all water media are naturally occurring, with one exception. The total selenium concentration in a sample collected from surface water sample location ST-42 in 2008 does not appear to be site related. However, a more recent sample from that location collected in 2011 did not contain a detectable concentration of selenium.

7.25 Zinc

7.25.1 Soil Data

Zinc was detected in 257 of 264 soil samples (97%). Zinc concentrations range from 11.9 to 925 mg/kg, with a mean concentration of 67.85 mg/kg. Zinc concentrations exceeded the lowest Tier II AL of 30 mg/kg in 131 samples (50%). A total of 19 soil samples (7%) contained zinc at a concentration greater than the media specific BTV for SM/SO (87 mg/kg) or tundra (130 mg/kg) soils.

Figures 133-A and 133-B present the distribution of zinc concentrations in surface soil samples. Zinc concentrations greater than the lowest Tier II AL were measured in samples collected from the BOC pad area, as well as tundra locations northeast and southwest of the BOC pad. The concentrations of zinc in surface soil samples collected from tundra sampling locations northeast and southwest of the BOC pad are, in general, equivalent to or significantly greater than zinc concentrations measured in surface soil samples collected from the BOC pad. The surface soil sample collected from SB-34 is the only sample location on the BOC pad where the surface soil contained zinc at a concentration greater than both the lowest Tier II AL and the media specific BTV criteria. With the exception SB-34, all locations where the surface soils sample contained zinc at a concentration greater than the lowest Tier II AL and the applicable BTV, are east of the BOC pad.

Figures 133-C and 133-D illustrate the distribution of zinc in active-layer soil samples. Zinc concentrations greater than the lowest Tier II AL were reported for samples distributed across the BOC pad. However, the greatest concentrations of zinc in active-layer soil samples are in samples from the western margin of the BOC pad, as well as beneath and adjacent to the former drainage ditch area on the eastern side of the pad. The only location where the concentration of the active-layer soil sample exceeded the media-specific BTV was in the southern portion of the former drainage ditch (SS-152).

Figure 133-E presents the distribution of zinc in deep soil samples. Deep soil samples with zinc at concentrations greater than the lowest Tier II AL are distributed across the BOC pad without a discernable spatial pattern. There were five locations where zinc was present in the deep soil samples at concentrations exceeding the media-specific BTV: isolated individual locations (east of the Material Storage Warehouse at soil boring SB-94 and approximately 100 feet south of the former Tuboscope Building at soil boring SB-30), a location beneath former operations buildings (SB-28), and locations beneath the former drainage ditch (SB-63 and SB-153).

7.25.2 Water Data

7.25.2.1 Total Zinc in Water

Total zinc was detected in 155 of 183 monitoring well samples (85%). Detected total zinc concentrations in monitoring well samples range from 2 µg/L to 1,210 µg/L, with a mean concentration of 64.4 µg/L. Detected concentrations of total zinc exceeded the lowest Tier II AL of 39 µg/L in 33 samples (18%). The surface water BTV (5.9 µg/L) was exceeded in 105 monitoring well samples (57%). There is no AWQS for total zinc.

Out of a total of 131 surface water samples, total zinc was detected in 101 samples (77%). Detected concentrations of total zinc in surface water samples range from 1.5 µg/L to 401 µg/L, with a mean concentration of 30.6 µg/L. The detected concentration of total zinc exceeded the lowest Tier II AL of 39 µg/L in 17 samples (13%). The surface water BTV of 5.9 µg/L for total zinc was exceeded in 70 surface water samples (53%).

Figures 133-F and 133-G present the locations where total zinc was detected in surface water and monitoring well samples. Surface water samples collected from sporadic and isolated locations both east and west of the BOC pad contained total zinc at concentrations greater than the lowest Tier II AL. At those locations where the surface water sample exceeds the lowest Tier II AL and there is a co-located monitoring well, the total zinc concentration in the surface water sample is generally much greater than the total zinc concentration in the co-located monitoring well sample. Monitoring well samples containing total zinc at concentrations greater than the lowest Tier II AL are distributed as follows: 1) a relatively coherent east-west band beneath the former Tuboscope operations area, and 2) a northwest to southeast trending band along the east side of the BOC pad encompassing the former drainage ditch and along the roadway paralleling the east side of the site.

7.25.2.2 Dissolved Zinc in Water

Dissolved zinc was detected in 87 monitoring well samples (83%) out of a total of 105 monitoring well samples. Detected concentrations of dissolved zinc range from 1.3 µg/L to 760 µg/L, with a mean concentration of 16.7 µg/L. The detected concentration of dissolved zinc exceeded the lowest Tier II AL of 39 µg/L in two monitoring well samples (2%). The surface water BTV of 6.3 µg/L for dissolved zinc was exceeded in 34 monitoring well samples (32%). No monitoring well samples contained dissolved zinc at a concentration greater than their hardness-dependent AWQS. Comparison of the mean concentrations for total and dissolved zinc indicates that approximately 26 percent of zinc in monitoring well samples is dissolved zinc.

Out of a total of 69 surface water samples, dissolved zinc was detected in 43 samples (62%). Detected concentrations of dissolved zinc in surface water samples range from 2.7 µg/L to 86.5 µg/L, with a mean concentration of 14.4 µg/L. The detected concentrations of dissolved zinc exceeded the lowest Tier II AL of 39 µg/L in four surface water samples. The media-specific BTV for dissolved zinc of 6.3 µg/L was exceeded in 26 surface water samples. No surface water samples contained dissolved zinc at a concentration greater than their hardness-dependent AWQS.

Figures 133-H and 133-I illustrate the distribution of dissolved zinc in surface water and monitoring well samples. The occurrence of dissolved zinc in surface water and monitoring well samples is consistent with the total zinc results. Dissolved zinc concentrations exceeded the lowest Tier II AL or the media-specific BTV only at locations where the total zinc concentrations also exceeded the lowest Tier II AL or media-specific BTV.

7.25.3 Fate and Transport Properties and Summary of Background Assessment

Zinc (Zn) usually occurs in the +2 oxidation state and forms complexes with several anions, amino acids, and organic acids. Zinc may precipitate as a hydroxide, carbonate, or sulfide complex. Zinc is one of the more mobile metals in surface water and groundwater because it is present as soluble compounds at neutral and acidic pH values. At higher pH values, zinc can form carbonate and hydroxide complexes, which control zinc solubility. Zinc readily precipitates under reducing conditions and may co-precipitate with hydrous oxides of iron and manganese.

Sorption of zinc to soil, including hydrous iron and manganese oxides, clay minerals, and organic matter, is the primary fate of zinc in aquatic environments. Sorption of zinc increases as pH increases and salinity decreases (ATSDR 2005b).

The background assessment presented in Appendix N concluded that concentrations of zinc measured in gravel were naturally occurring, except at soil boring SB-34 and beneath the drainage ditch at SS-152. Some concentrations of zinc measured in mineral soil and tundra soil appear to be associated with site activities. Detected concentrations of zinc exceeded the BTV in only 7% of the soil samples. However, the distribution of samples exceeding either the lowest Tier II AL or the media-specific BTV potentially are indicative of impact resulting from operations at or near the former Tuboscope facility due to the proximity of elevated results to those operations.

The background assessment presented in Appendix N concluded concentrations of zinc in SPGW (excluding pad porewater) are naturally occurring. Site activities may have impacted zinc concentrations in pad porewater and surface water. The lowest Tier II AL was exceeded in 18% of the monitoring well samples and 13% of the surface water samples. Similarly, 13% of the surface water samples contained total zinc at a concentration greater than the lowest Tier II AL and 53% of the surface water samples contained total zinc at concentrations greater than the media-specific BTV. Given that concentrations of zinc in gravel have generally not been impacted but that concentrations in pad porewater suggest that impacts have occurred suggests that these impacts may not be due to a release of zinc, but due to geochemical changes caused by site activities.

7.26 Aluminum

7.26.1 Soil Data

Aluminum was generally not tested for in soil samples as it is ubiquitous in the environment and is not an USEPA hazardous constituent. There is no BTV, Tier I SL, or Tier II AL established for aluminum in soil.

7.26.2 Water Data

Total aluminum was detected in all 76 monitoring well samples analyzed for total aluminum. The detected concentrations of total aluminum in monitoring well samples range from 12.7 µg/L to 6,740 µg/L, with a mean concentration of 475 µg/L. There is no Tier I SL or Tier II AL for total aluminum. Detected concentrations of total aluminum exceeded the surface water BTV of 43 µg/L in 58 monitoring well samples (76%). The AWQS for total aluminum of 87 µg/L was exceeded in 29 of 54 samples collected from monitoring wells closely connected hydrologically to surface water (54%).

Total aluminum was detected in 45 (73%) of 62 surface water samples analyzed for total aluminum. Detected concentrations of total aluminum in surface water samples range from 2.3 µg/L to 3,580 µg/L, with a mean concentration of 383 µg/L. Detected concentrations of total aluminum exceed the media-specific BTV for total aluminum of 43 µg/L in 24 surface water samples (39%). The AWQS for total aluminum of 87 µg/L was exceeded in 17 surface water samples (27%).

7.26.3 Fate and Transport Properties

Aluminum is the most abundant metal in the Earth's crust but is never found in its elemental state in nature. In compounds, aluminum occurs in its only oxidation state (Al^{+3}) and does not undergo oxidation-reduction reactions (ATSDR 2008). Aluminum's behavior in the environment is strongly influenced by its coordination chemistry. Aluminum partitions between solid and liquid phases by reacting and complexing with water molecules and anions, including negatively charged functional groups on humic materials and clay. Aluminum can be complexed by various ligands present in the environment (e.g., fulvic and humic acids). Mobility is controlled by pH and the ligands present. The speciation of aluminum in water is pH dependent; the solid $Al(OH)_3$ is most prevalent between pH 5.2 and 8.8. Aluminum is only sparingly soluble in water between pH 6 and 8 (ATSDR 2008).

Under reducing conditions, organic substances undergo biodegradation that initially results in production of organic acids (such as acetic, butyric, and propionic acid) and later produces substances such as fulvic and humic acids. These organic acids decrease pH and increase the potential solubility of aluminum. The fulvic- and humic-ligands may bond with and mobilize aluminum in groundwater. Aluminum levels in surface water are usually very low; however, in acidic water or water high in humic or fulvic acid content, the concentration of soluble aluminum increases due to the increased solubility of aluminum oxide (Al_2O_3) and aluminum salts.

The lesser concentrations of aluminum in the surface water samples compared to the concentrations measured in monitoring well samples are a result of the oxygenation of the surface water samples causing the aluminum to become significantly less mobile and to precipitate once it reaches the surface water system. Although aluminum is present in monitoring well and surface water samples at concentrations greater than surface water background, the available data suggest that these impacts are likely associated with changed geochemical conditions (due to biodegradation of naturally occurring organic material or petroleum hydrocarbons).

7.27 Iron

Iron is not a RCRA hazardous constituent; it is a ubiquitous, naturally occurring element; and is not considered a COI at the former Tuboscope site. As a result, a Tier I SL and a Tier II AL were not developed for iron. A BTV for iron in PBU surface water was established. The following sections compare monitoring well and surface water sample results to the AWQS and the BTV for surface water.

7.27.1 Water Data

7.27.1.1 Total Iron in Water

Iron is a ubiquitous, naturally occurring element and as such was detected in all 196 monitoring well samples analyzed for total iron. Detected concentrations of total iron in monitoring well samples range from 19.2 µg/L to 94,700 µg/L, with a mean concentration of 24,400 µg/L. The surface water BTV of 930 µg/L for total iron was exceeded in 191 monitoring well samples (97%). Detected concentrations of total iron exceeded the AWQS of 1,000 µg/L in 119 of 121 monitoring well samples collected from monitoring wells closely connected hydrologically to surface water.

Total iron was detected in 136 (99%) of 138 surface water samples. Detected concentrations of total iron in surface water samples range from 39.5 µg/L to 68,600 µg/L, with a mean concentration of 7,590 µg/L. Concentrations measured in surface water are significantly lower than concentrations measured in monitoring well samples. The surface water BTV of 930 µg/L for total iron was exceeded in 82 surface water samples (59%). Detected concentrations of total iron exceeded the AWQS of 1,000 µg/L in 79 surface water samples (57%).

7.27.1.2 Dissolved Iron in Water

Dissolved iron was detected in all 117 monitoring well samples analyzed for dissolved iron. Detected concentrations of dissolved iron range from 139 µg/L to 54,400 µg/L, with a mean concentration of 21,500 µg/L. The surface water BTV for dissolved iron of 860 µg/L was exceeded in 114 monitoring well samples (97%). Detected concentrations of dissolved iron exceeded the AWQS of 1,000 µg/L in 64 monitoring well samples (55%).

Dissolved iron was detected in 64 of 76 surface water samples analyzed for dissolved iron (84%). Detected concentrations of dissolved iron in the surface water samples range from 26.2 µg/L to 53,400 µg/L, with a mean concentration of 2,890 µg/L. Concentrations of dissolved iron measured in surface water are significantly lower than concentrations measured in monitoring well samples. The surface water BTV for dissolved iron of 860 µg/L was exceeded in 21 surface water samples (28%). The detected concentrations of dissolved iron exceeded the AWQS of 1,000 µg/L in 20 surface water samples (26%).

7.27.2 Fate and Transport Properties

Iron is redox sensitive, and its mobility in the environment is significantly influenced by redox conditions. In the oxidized form, ferric iron (Fe^{+3}) is generally insoluble. Organic substances can undergo biodegradation resulting in reducing conditions and mobilizing iron. Naturally occurring, organic substances and petroleum hydrocarbons undergo biodegradation that results in reducing conditions. Reduced iron, referred to as ferrous iron (Fe^{+2}), is soluble in water. Reducing conditions can dissolve naturally occurring iron and mobilize iron in groundwater. When geochemical conditions change because of mixing with groundwater that is more characteristic of oxidizing conditions or oxygenated surface waters, the mobilized iron will oxidize and precipitate. Because ferric iron forms complexes with a variety of other metals, if the iron is subsequently reduced to ferrous iron, these other metals may be mobilized.

The mineral hydrous ferric oxide ($FeOOH$) is a dominant sorbent for many inorganics in natural environments, due to its common presence on soil particles, high surface area, and amphoteric properties. The effects of iron adsorption can be dynamic. Variations in the redox potential can lead to the precipitation or dissolution of hydrous ferric oxide from the aquifer matrix. Generally, dissolved iron will precipitate as hydrous ferric oxide in the presence of oxygen in the aquifer, resulting in depletion of dissolved metals from the SPGW as the metals adsorb to the hydrous ferric oxide surface. Conversely, if reduced SPGW conditions are present, the hydrous ferric oxide may be dissolved, and adsorbed metals released to SPGW.

The mean concentrations for both total and dissolved iron in monitoring well samples collected at the former Tuboscope site are relatively similar, a characteristic of reducing conditions in groundwater. In contrast, the mean concentration of total iron in surface water samples at the site is less than a third of the mean for total iron in monitoring well samples. The mean dissolved iron concentration in surface water samples is approximately 13% of the mean for dissolved iron in monitoring well samples. The significant decrease in iron (both total and dissolved) in the surface water samples is a result of the oxygenation of the surface water samples causing the iron to oxidize, precipitate, and become significantly less mobile once it reaches the surface water system.

Although iron (both total and dissolved) is present in monitoring well and surface water samples at concentrations greater than background, the available data suggest that these impacts are likely to be associated with changed redox conditions (due to biodegradation of naturally occurring organic material or petroleum hydrocarbons).

7.28 Manganese

7.28.1 Soil Data

Manganese is naturally present in soil on the North Slope. It is not a RCRA hazardous constituent and was only listed as an ADEC hazardous substance following the completion of fieldwork, and as such, manganese was not identified as a COI for the investigation.

Manganese, a naturally occurring element, was detected in all 11 soil samples analyzed for the element. Manganese concentrations range from 87.9 mg/kg to 325 mg/kg with a mean concentration of 191 mg/kg. A Tier II AL for manganese in soil of 620 mg/kg has been proposed in Appendix Q. Manganese has a media-specific BTV for SM/SO soil of 520 mg/kg. Detected manganese concentrations did not exceed either the proposed Tier II AL or the media-specific BTV.

7.28.2 Water Data

7.28.2.1 Total Manganese in Water

Consistent with the fact that manganese is a naturally occurring element, total manganese was detected in all 197 monitoring well samples analyzed for total manganese. Detected concentrations of total manganese range from 77.5 µg/L to 9,600 µg/L, with a mean total manganese concentration of 2,760 µg/L. A Tier II AL for manganese in water of 23 µg/L has been proposed in Appendix Q. The proposed Tier II AL for total manganese was exceeded in all monitoring well samples. The surface water BTV for total manganese of 170 µg/L was exceeded in 195 monitoring well samples (99%). Detected concentrations of total manganese exceeded the AWQS of 50 µg/L in all 121 samples collected from monitoring wells closely connected hydrologically to surface water.

Total manganese was detected in 134 of 135 surface water samples analyzed for total manganese (99%). Detected concentrations of total manganese in surface water samples range from 6.1 µg/L to 22,400 µg/L, with a mean concentration of 1,870 µg/L. The detected concentration of total manganese in surface water samples exceeded the proposed Tier II AL of 23 µg/L in 114 samples (84%). The total manganese concentration exceeded the media-specific BTV of 170 µg/L in 76 surface water samples (56%). The detected concentration of total manganese exceeded the AWQS of 50 µg/L in 104 surface water samples (77%).

Figures 134-A and 134-B present the distribution of total manganese in surface water and monitoring well samples. As noted above, manganese is a naturally occurring element in the soils of the North Slope. It is ubiquitous in monitoring wells samples and surface water samples, except for samples collected from ponded water exposed to atmospheric oxygen.

7.28.2.2 Dissolved Manganese in Water

Similarly, dissolved manganese was detected in all 118 monitoring well samples analyzed for dissolved manganese. Detected dissolved manganese concentrations range from 27.5 µg/L to 8,390 µg/L, with a mean concentration of 2,840 µg/L. The proposed Tier II AL for dissolved manganese (23 µg/L) was exceeded in all monitoring well samples. Detected concentrations of dissolved manganese exceeded the surface water BTV of 170 µg/L in 116 monitoring well samples (98%). The AWQS for dissolved manganese of 50 µg/L was exceeded in 64 samples collected from monitoring wells closely connected hydrologically to surface water (100%).

Dissolved manganese was detected in all 73 surface water samples analyzed for dissolved manganese. Dissolved manganese concentrations measured in surface water samples range from 3.8 µg/L to 7,260 µg/L, with a mean concentration of 909 µg/L. The proposed Tier II AL of 23 µg/L for dissolved manganese was exceeded in 61 surface water samples (84%). Dissolved manganese concentrations exceeded the media-specific BTV of 170 µg/L in 42 surface water samples (58%). The AWQS for dissolved manganese of 50 µg/L was exceeded in 52 surface water samples (71%).

Figures 134-C and 134-D present the distribution of dissolved manganese in monitoring well and surface water samples. The distribution of dissolved manganese in monitoring wells and surface water is consistent with mobilization of naturally occurring manganese because of reducing conditions produced by the degradation of organics (including plant matter and hydrocarbons) in the subsurface. Reducing conditions in monitoring well samples are pervasive at the site, as indicated by the similar range and means for both the total and dissolved manganese data sets. The greater range and mean concentrations for total manganese compared to dissolved phase manganese in surface water samples demonstrates the effects of increased oxygenation, and therefore lower solubility of manganese at many surface water sampling locations.

7.28.3 Fate and Transport Properties

Manganese is redox sensitive, and its mobility in the environment is significantly influenced by redox conditions. The oxidation state of manganese in soils and sediments may be altered by microbial activity (ATSDR 2012e). Manganese in water may undergo oxidation at high pH or ORP. Under oxidizing conditions, manganese tends to be present as manganese dioxide (MnO_2), which is generally insoluble. Organic substances can undergo biodegradation resulting in reducing conditions and mobilizing manganese. Reduced manganese (Mn^{-2}) is soluble in water. Reducing conditions can dissolve naturally occurring manganese and mobilize manganese in groundwater. The manganese can remain dissolved and mobile until mixing with groundwater with greater oxidizing potential or discharging to oxygenated surface water, resulting in the precipitation of the manganese.

Manganese is used for steel production. Other uses of manganese at the former Tuboscope site are unknown.

At first glance, the distribution of manganese appears to be a result of operations on the BOC pad area—with the greatest concentrations in surface water beneath and downgradient from operations areas. However, manganese (similar to iron) is sensitive to redox conditions. Under reducing, low oxygen conditions, manganese is more soluble—dissolving from its natural state in the soils into the groundwater. The well-documented degradation of hydrocarbons beneath the BOC pad resulted in reducing conditions in the groundwater. Biodegradation of naturally occurring organic materials in the tundra soils also results in reducing conditions. Degradation of hydrocarbons, combined with the biodegradation of the naturally occurring organic materials, is likely responsible for dissolution and mobilization of manganese in the groundwater, producing the spatial distribution observed for total manganese in monitoring well and surface water samples. The greater range of concentrations for manganese in surface water is likely a result of the precipitation of manganese (resulting in greater suspended solids) in oxygenated surface waters.

8. DATA QUALITY

Analytical data generated during the RFI was managed in accordance with the version of the *Site-wide QAPP* (Environmental Standards 2008, 2013, 2014, 2017) that was in effect at the time. A comprehensive Quality Assurance Review was performed to independently verify compliance with the required analytical protocols and to determine the qualitative and quantitative reliability of the data. Pace Analytical Services and TestAmerica provided laboratory services and hardcopy reports. Environmental Standards reviewed and validated these reports. A minimum of 10 percent of the analytical data received a Level IV data validation and 100 percent received a Level IIB data review. Electronic data was not used for validation purposes. Laboratory analytical reports are included in Appendix M. All data review and validation reports produced by Environmental Standards are included in Appendix O.

ERM and Environmental Standards managed electronic analytical laboratory data using the EarthSoft® EQuIS™ data management suite. The ERM Quality Assurance Coordinator used the EQuIS™ database and the EQuIS™ Data Gathering Engine (EDGE) software to generate chain-of-custody records and labels during sample management activities. The ERM Field Team Lead was responsible for the overall coordination of field activities and quality oversight of the data collection process. The ERM Field Team Lead managed data collected in the field using the EQuIS™ database and EDGE software.

Appendix P presents the data usability review for the comprehensive RFI dataset. This includes an overview and data usability reviews for the following years of data collection: 2007, 2008, 2009, 2010, 2011, 2012, 2015, 2016, and 2018. The most up-to-date version of the *Site-wide QAPP* was used to evaluate the acceptability of the data. The DQOs established for the project were met except for limited data that was rejected. Rejected and missing results cannot be used to support the investigation or future decisions. The reason for rejection and impacted results is identified in the year-specific portions of Appendix P. Rejected and missing data did not have a significant impact on data completeness. The completeness goal of 90 percent was exceeded for all phases of the RFI. For the 9 years that samples were collected, data completeness ranged from 98.5 to 100 percent for reported sample results.

The RFI dataset is presented in Appendix L, Tables L-1 and L-7. The analytical laboratory provided results, MDLs, and reporting limits. Concentrations measured above the MDL were reported as detected. In accordance with reporting conventions, reported positive results below the sample-specific reporting limit and above the MDL (adjusted for sample volume and dilution factors) were qualified and the reported values should be considered estimates. Data was managed in accordance with ADEC *Technical Memorandum: Guidelines for Treatment of Non-Detect Values, Data Reduction for Multiple Detections and Comparison of Quantitation Limits to Cleanup Values* (ADEC 2017c).

The overall quality of analytical data collected between 2007 and 2018 is acceptable. Data quality for this RFI meets the DQOs established in the work plan and its various addenda and amendments (OASIS 2008d, OASIS 2009a, OASIS 2012a, OASIS 2012c; ERM 2013c).

9. CONCLUSIONS AND RECOMMENDATIONS

Investigation activities have characterized the environmental conditions at the former Tuboscope site and the nature of released hazardous waste and hazardous constituents. All COPCs have been identified. The extent of contamination in environmental media has been delineated.

The investigation was initiated in accordance with the *RCRA Facility Investigation Work Plan, Former Tuboscope Site* (OASIS 2009a). As the investigation progressed, detailed interim reports were provided including the 2008–2011, the 2012, and the 2013 RFI Interim Summary Reports (OASIS 2012b, ERM 2014a, and ERM 2014b). To address data gaps identified by the Agencies, work plan addenda and amendments were issued (OASIS 2012a, OASIS 2012c, and ERM 2013c). All data gaps identified by the USEPA and ADEC have been addressed.

9.1 Summary of Released Hazardous Constituents

Several releases of hazardous waste and hazardous constituents have been documented at the former Tuboscope site, resulting in the following constituents being released into the environment:

- Chlorinated solvents and metals associated with the removal of pipe dope
- Petroleum hydrocarbons released in spills of diesel fuel
- Barium and other metals associated with a drilling mud plant that was operated adjacent to the former Tuboscope site

The chlorinated solvent, 1,1,1-TCA, was used to remove lead-containing pipe dope from threaded pipes within the former Tuboscope building. The shop had an unlined gravel floor, which would not have contained any solvent releases. An accidental chemical release was reported at the former Tuboscope building in 1982, when a fire destroyed the building. 1,1,1-TCA and several other chlorinated solvents have been detected in soil and/or groundwater. These other chlorinated solvents may have been impurities in the 1,1,1-TCA, may have been used as separate solvents, or may be the result of anaerobic biodegradation. These other chlorinated solvents are 1,1,2,2-TCA, 1,1-DCA, 1,2-DCA, 1,1,2-trichloroethane, TCE, vinyl chloride, and 1,2,3-trichloropropane. A stabilizer, 1,4-dioxane, was released with the solvents.

Hazardous constituents could also have been present in the pipe dope. Pipe dope used in the oil and gas industry may have contained 15 percent copper and 7 percent lead; zinc may also be present (Jones & Stokes 1990).

Some constituents migrated to a drainage ditch adjacent to the former Tuboscope building. A culvert led from the drainage ditch to the tundra and allowed additional constituent migration. In the summer of 1983, the drainage ditch was isolated to allow collection of contaminated water. The culvert between the drainage ditch and the off pad setting to the east was sealed at that time. In 1988, a curtain liner was installed in the GC3 Pipeline Access Road east of the drainage ditch to further minimize off-pad migration of constituents. Beginning in 1997, an IM water extraction and treatment system was operated each thaw season. Operation of the IM extraction and treatment system created a localized depression in pad porewater, increasing flow toward the drainage ditch. Initially, this enhanced the flow of mobile constituents toward the drainage ditch and resulted in their extraction. As the concentrations of mobile constituents in the area decreased, this effect was reduced. In 2015 and 2016, an IM termination pilot study was conducted. The drainage ditch was backfilled in the summer of 2018.

While the ditch was present, it created a localized thaw in the underlying permafrost. Water and constituents in this zone would thaw each year but were trapped by surrounding areas where the top of permafrost was higher. As a result, they did not migrate, and a deep zone of higher constituent concentrations is present.

In addition to releases of chlorinated solvents and metals associated with the removal of pipe dope, several other releases are known to have occurred at the former Tuboscope site. Diesel fuel was used to power the former Tuboscope shop building generator. One or more release of diesel fuel and related petroleum hydrocarbons is known to have occurred at the former Tuboscope building. The RFI dataset reflects other diesel releases that occurred near the former Tuboscope site but are unrelated to the site. These include releases in the vicinity of the CIC Storage Facility southern TTLA and former drilling mud plant and at the Material Storage Warehouse bull rail.

Barium (in the form of barium sulfate) is the primary component in the formulation of drilling muds used on the North Slope. A drilling mud plant was located north of the former Tuboscope building and constituents used in the formulation and processing of drilling muds appear to have been released.

9.2 Constituents of Potential Concern

Data have been assessed based on Tier I SLs and Tier II ALs. Tier II ALs are protective of unrestricted land use including hypothetical future resident subsistence users and a variety of ecological receptors that are present on the North Slope. The reasonably anticipated future land use of the former Tuboscope site is continued use for oil and gas development. After the end of field life, the reasonably anticipated future land use will be non-residential subsistence land use. As required by USEPA, assessment of cleanup to standards protective of potential future residential subsistence land use will be considered in the CMS.

COPCs for the former Tuboscope site are presented in Table 14-a (soil), Table 14-b (SPGW closely connected hydrologically to surface water), Table 14-c (surface water), and Table 14-d (SPGW not closely connected hydrologically to surface water). Constituents for which the maximum detected concentration in a media exceeded the lowest Tier II AL were generally considered to be COPCs, unless (for metals) the distribution was determined to be representative of background. The above listed tables provide a rationale for the determination for each COI. COPCs include:

- Chlorinated solvents (1,1,1-TCA, 1,1,2,2-TCA, 1,1-DCA, 1,2-DCA, 1,1,2-trichloroethane, 1,2,3-trichloropropane, trichloroethene, and vinyl chloride)
- 1,4-Dioxane (a stabilizer used for 1,1,1-TCA)
- Petroleum hydrocarbons (BTEX compounds, PAHs, isopropylbenzene 1,2,3-trimethylbenzene, and 1,3,5-trimethylbenzene)
- Metals (arsenic, barium, cadmium, chromium, chromium [III], chromium [VI], copper, lead, nickel, selenium, and zinc)

Other COPCs include the following hydrocarbons: p-isopropyltoluene (which is used as solvent or as a heat-transfer fluid), dibenzofuran (possibly from incomplete combustion during the building fire), n-propylbenzene (which is used as a solvent, in crude oil extraction, and as a corrosion inhibitor), chloroform (from an undetermined source), 3&4-methylphenol (used a solvent for cleaning and degreasing and for wood preservation), and 2-methylphenol (collocated with and likely a manufacturing impurity of 3&4-methylphenol).

The origin of some metals impacting site media is not readily apparent. Chromium may have been used as a deflocculating agent for drilling mud. Selenium was found in samples collected near the CIC Storage Facility; some corrosion inhibitors contain selenium. Elevated concentrations of some metals could be associated with anaerobic conditions created by the biodegradation of petroleum hydrocarbon or naturally occurring organic matter.

Table 15 summarizes assessment of constituents based on ADEC-only CLs and AWQSs. ADEC-only CLs do not consider impacts to ecological receptors. Other than DRO in SPGW, no constituent concentrations exceed ADEC-only CLs. The following constituents were detected at concentrations above their respective AWQS in surface water: aluminum, arsenic, barium, benzene, benzo[a]pyrene, DRO, iron, manganese, TAH, and TAqH.

9.3 Summary of the Extent of Contamination and Constituent Fate and Transport

The nature and extent of COPCs have been determined and defined for all media. Since release, the fate and transport properties of the constituents have affected their distribution in environmental media.

A distinct source area for chlorinated solvents remains in the vicinity of the former Tuboscope building as demonstrated at soil borings SB-201 and SB-202. Concentrations of chlorinated solvents above the lowest Tier II ALs are present in the surrounding BOC pad, principally to the east of the source area. Pad porewater and SPGW are generally anaerobic. Reductive dechlorination is occurring and released chlorinated solvents are attenuating naturally. Following the fire, a secondary source area (near sample location ST-52) was created by water flowing through a culvert. The culvert was sealed in 1983. Where SPGW discharges to surface water along the northeast side of the BOC pad (for instance at surface water sample locations ST-51 and ST-52), chlorinated solvent concentrations remain above the lowest Tier II ALs. However, these volatile compounds rapidly attenuate to concentrations below the detection limit as the water travels downgradient in the thermokarst troughs.

The constituent with the largest areal distribution is 1,4-dioxane. Most of the mass of this constituent appears to have migrated out of the source area. Results for only two soil samples, both collected below the bottom of the drainage ditch, exceed the lowest Tier II AL. With the drainage ditch now backfilled, the associated soil is now permafrost. 1,4-Dioxane is mobile in the subsurface environment, but once dissolved, it has relatively low volatility. As a result, concentrations above the lowest Tier II AL have migrated into surface waters as far as 700 feet to the northeast of the source area. The lowest Tier II AL for 1,4-dioxane in water is driven by protection of human health; surface water at the former Tuboscope site is not a current or reasonably expected future source of drinking water.

Concentrations of petroleum hydrocarbons that exceed the lowest Tier II AL are present below the BOC pad. Physical-chemical properties of the petroleum hydrocarbons limit their mobility in the environment. Where sufficient oxygen is available, these constituents degrade rapidly, therefore upon discharge to more oxygenated surface water, the petroleum hydrocarbon constituents rapidly attenuate to concentrations below the lowest Tier II ALs.

Although volatile constituents are present and the Materials Storage Warehouse has a slab on grade foundation, volatile constituents are not present near the warehouse and vapor intrusion impacts are not anticipated.

Elevated concentrations of metal constituents appear to be from four sources. Some are naturally occurring, some are due to imported gravel, some are due to releases of hazardous constituents, and some are due to localized changes in geochemistry caused by biodegradation of organic compounds. The extent of impacts varies by metal constituent and with each constituent's fate and transport properties.

9.4 Recommendations

Ultimately, corrective measures for the former Tuboscope site will need to address three distinct sets of requirements: 1) RCRA corrective action requirements, 2) 18 AAC 75.360 cleanup requirements, and 3) requirements at lease termination such that the land can be returned in a condition satisfactory to the ADNR Commissioner.

As described in Attachment F of the PBU RCRA Order, phased remedies may be proposed for active, operating areas where final remedy is not warranted until that area or the facility cease to operate. Under a phased remedy approach for this active operating area, corrective measures to be considered at this time will need to be protective of the surrounding environment and of human health under the current industrial land use. Corrective measures should also be consistent with future final cleanup requirements (which may be based on a different land use scenario), to the extent possible.

Remedial options available to address contamination at the former Tuboscope site are limited. For contamination in and beneath the BOC pad, only a portion of the impacted soil is available for possible excavation or in-situ treatment because the CIC Storage Facility, Bulk Chemical Building, and the southern TTLA facilities and their associated infrastructure place physical limits on the soil that can be accessed.

High quality tundra wetlands surround the former Tuboscope site and need to be protected. Cleanup operations easily can damage the surrounding tundra environment. For remediation of constituents in the tundra environment, ADEC requires balancing of three primary objectives 1) minimizing damage to the tundra from the spilled material, 2) minimizing damage to the tundra from the response actions, and 3) minimizing the time for tundra to recover (ADEC 2010). Maintenance of healthy tundra vegetation is paramount because it is the only practical way to maintain a stable thermal regime for soil underlain by permafrost. If underlying zones of massive ice, ice lenses, or ice-rich soil melt, the ground surface will subside and the surface albedo will decrease causing further warming, melting, and permanently changing the landscape. Because of the fragile nature of the tundra environment, the State of Alaska has placed strict limits on activities conducted off gravel pads. In off-pad locations, the negative impacts of remedial action are expected to outweigh potential benefits.

ERM recommends that the CMS assess practical steps that can be taken to address environmental impacts associated with the former Tuboscope site. The CMS process outlined in the PBU RCRA Order includes the development of risk-based media cleanup standards. It may be appropriate to use receptor-specific Tier II ALs as the media cleanup standards. The COPCs listed in Table 9.4-4 (referred to as contaminants of concern in Attachment E of the PBU RCRA Order) will be advanced into the CMS for further evaluation.

Table 9.4-4: Constituents of Potential Concern Forwarded to the Corrective Measures Study

		Soil	SPGW Not Closely Connected to Surface Water	SPGW Closely Connected to Surface Water	Surface Water
VOC	1,1,1-Trichloroethane	X	X		
VOC	1,1,2-Trichloroethane		X	X	
VOC	1,1,2,2-Tetrachloroethane	X			
VOC	1,1-Dichloroethane	X	X	X	X
VOC	1,2,3-Trichloropropane	X	X		
VOC	1,2,4-Trimethylbenzene	X	X	X	
VOC	1,2-Dichloroethane	X	X	X	
VOC	1,3,5-Trimethylbenzene	X	X	X	
VOC	1,4-Dioxane	X	X	X	X
VOC	Benzene		X	X	X
VOC	Chloroform		X		
VOC	Ethylbenzene	X	X	X	X
VOC	Naphthalene	X	X	X	X
VOC	Isopropylbenzene		X	X	
VOC	p-Isopropyltoluene	X			
VOC	n-Propylbenzene		X	X	
VOC	Trichloroethene		X		
VOC	Toluene	X			
VOC	Vinyl chloride		X		
VOC	Xylenes	X	X	X	
PAH	2-Methylnaphthalene		X	X	X
PAH	Benzo(a)anthracene			X	X
PAH	Benzo(a)pyrene			X	X
PAH	Benzo(b)fluoranthene		X	X	X
PAH	Benzo(k)fluoranthene			X	X
PAH	Dibenz(a,h)anthracene			X	X
PAH	Dibenzofuran			X	
PAH	Indeno(1,2,3-cd)pyrene			X	X
PAH	Naphthalene		X	X	X
SVOC	2-Methylnaphthalene		X	X	
SVOC	3&4-Methylphenol		X	X	

		Soil	SPGW Not Closely Connected to Surface Water	SPGW Closely Connected to Surface Water	Surface Water
SVOC	Naphthalene	X		X	X
Metal[1]	Arsenic			X	X
Metal[1]	Barium	X			X
Metal[1]	Cadmium		X		
Metal[1]	Chromium	X			
Metal[1]	Chromium III	X			
Metal[1]	Chromium VI	X			
Metal[1]	Copper	X	X		X
Metal[1]	Nickel			X	X
Metal[1]	Lead	X	X		
Metal[1]	Selenium	X			
Metal[1]	Zinc	X	X	X	X

[1] *Metals were assessed separately for various soil media (gravel, mineral soil, and tundra), various water media (pad porewater and SPGW), and based on whether the metal was total or dissolved in water. These distinctions have not been brought forward to this summary table but are presented later in the document.*

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TABLES

FIGURES

Appendix A **HISTORICAL AERIAL PHOTOGRAPHS**

Appendix B CURTAIN LINER AS BUILT DRAWINGS

Appendix C PHOTOGRAPHIC LOG

Appendix D **HABITAT MAP**

Appendix E SOIL BORING AND MONITORING WELL LOGS

Appendix F GEOTECHNICAL REPORTS

Appendix G THERMISTOR DATA AND INTERPRETED THAW ELEVATIONS

Appendix H PRESSURE TRANSDUCER DATA

Appendix I CONCEPTUAL SITE MODEL

Appendix J FIELD NOTES AND SAMPLE FORMS

Appendix K TTLA DESIGN AND CONSTRUCTION DRAWINGS

Appendix L COMPREHENSIVE LABORATORY ANALYTICAL DATA TABLES

Appendix M LABORATORY DATA

Appendix N STATISTICAL ANALYSIS OF BACKGROUND CONCENTRATIONS

Appendix O ENVIRONMENTAL STANDARDS INC. VALIDATION REPORTS

Appendix P DATA USABILITY REVIEW

Appendix Q UPDATED TIER I SCREENING LEVELS AND TIER II ACTION LEVELS