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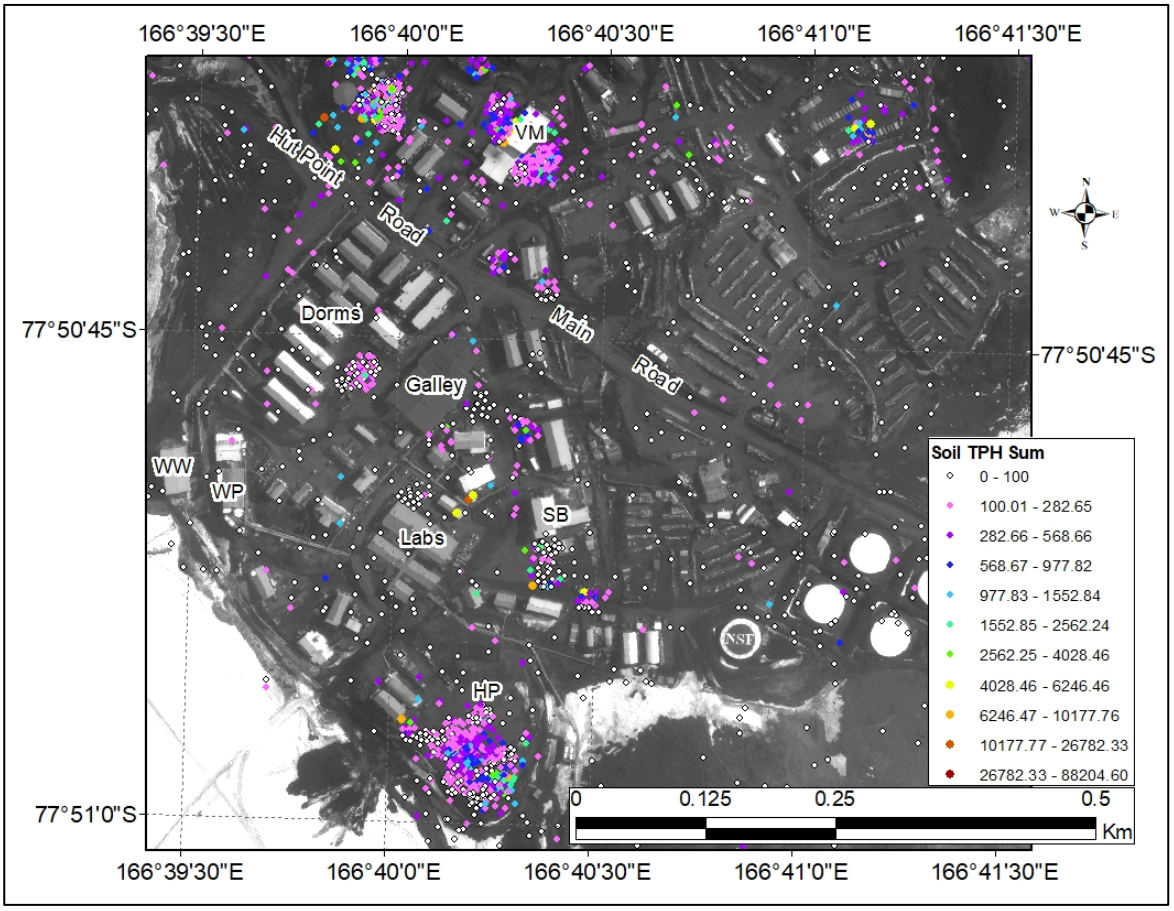
Assessment for Soil Reuse Standards at McMurdo Station

Rosa T. Affleck, Amanda J. Barker, Anita K. Meyer, and Jay L. Clausen

May 2020



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Rosa T. Affleck, Amanda J. Barker, and Jay L. Clausen

U.S. Army Engineer Research and Development Center (ERDC)
Cold Regions Research and Engineering Laboratory (CRREL)
72 Lyme Road
Hanover, NH 03755-1290

Anita K. Meyer

Environmental and Munitions Center of Expertise
U.S. Army Corps of Engineers (USACE)
Omaha, NE 68102

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Abstract

The soils at McMurdo Station in Antarctica contain hydrocarbons derived from accidental fuel spills and industrial development. The current practice for contaminated soils is to remove any material with concentrations greater than 100 mg/kg of total petroleum hydrocarbons (TPH) and to transport them to the United States for disposal. Any soils that contain concentrations of TPH less than 100 mg/kg can be reused on-site. While this is the current standard practice, there remains little evidence to verify that 100 mg/kg is an appropriate reuse standard. Moreover, the current practice is based on the guidelines for cleanup values in California (the port of entry where the soils are currently shipped for treatment and disposal), which has few environmental similarities with Antarctica.

In the present study, we investigate current regulations for cleanup and soil reuse in U.S. states, Canadian territories, and other countries with cold climates. We also discuss case studies from Arctic and Antarctic regions where soil has been reused after treatment. Additionally, we present a site conceptual model for risk assessment based on known site information and recommend future focus areas for addressing hydrocarbon-contaminated soils at McMurdo Station.

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Preface

This study was conducted for the National Science Foundation (NSF), Office of Polar Programs (OPP), Antarctic Infrastructure and Logistics Program (AIL), under Project EP-ANT-19-93, "Assessment for Soil Reuse Standards at McMurdo Station." The technical monitor was Ms. Margaret Knuth, Operations Manager, NSF-OPP-AIL, U.S. Antarctic Program; she also provided logistical guidance and technical supervision.

The work was performed by the Force Projection and Sustainment Branch (CEERD-RRH) and the Biogeochemical Sciences Branch (CEERD-RRN) of the Research and Engineering Division (CEERD-RR), U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL), and the Environmental and Munitions Center of Expertise, U.S. Army Corps of Engineers. At the time of publication, Mr. Justin Putnam was Acting Chief, CEERD-RRH; Dr. Gina Ralph was Acting Chief, CEERD-RRN; and Mr. J. D. Horne was Chief, CEERD-RR. The Deputy Director of ERDC-CRREL was Mr. David B. Ringelberg, and the Director was Dr. Joseph L. Corriveau.

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Acronyms and Abbreviations

ADEC	Alaska Department of Environmental Conservation
BTEX	Benzene, Toluene, Ethylbenzene and Xylenes
CA	California
CEE	Comprehensive Environmental Evaluation
CRREL	U.S. Army Cold Regions Research and Engineering Laboratory
DRO	Diesel-Range Organics
EAL	Environmental Action Level
EPA	Environmental Protection Agency
EPOLAR	Engineering for Polar Operations, Logistics, and Research
ERDC	Engineer Research and Development Center
ESL	Environmental Screening Level
GRO	Gasoline-Range Organics
HAVE	Hot Air Vapor Extraction
HP	Helo Pad
ITC F1	Information Technology and Communications First Footer
MassDEP	Massachusetts Department of Environmental Protection
MTBE	Methyl Tert-Butyl Ether
NA	Not Applicable
NARL	Naval Arctic Research Laboratory
NAVFAC	Naval Facilities Engineering Command
NCS	Nonhazardous Contaminated Soil
NEPM	National Environment Protection Measure

NHDES	New Hampshire Department of Environmental Services
NL	No Assigned Limit
NOCS	Nonhazardous Oil-Contaminated Soil
NSF	National Science Foundation
PHIS	Petroleum Hydrocarbon–Impacted Soil
RC	Reportable Concentration
RRO	Residual-Range Organics
RSL	Regional Screening Level
SB	Science Support Building
SVOC	Semi-Volatile Organic Compound
TPH	Total Petroleum Hydrocarbons
USACE	U.S. Army Corps of Engineers
USAP	United States Antarctic Program
VM	Vehicle Maintenance Facility
VT DEC	Vermont Department of Environmental Conservation
WP	Water Treatment Plant
WW	Wastewater Treatment Plant

1 Introduction

1.1 Background

McMurdo Station* is a research facility and logistics hub of the National Science Foundation's (NSF) United States Antarctic Program (USAP) and is located on an outcrop of barren volcanic rock on the southern tip of Ross Island, Antarctica. Science support activities at the Station have created some degree of landscape or terrain disturbance and environmental alteration (Snape et al. 2003; Klein et al. 2008; Tin et al. 2009; Kennicutt et al. 2010; Raymond and Snape 2017). Significant landscape disturbance occurred in the late 1950s and continued in the 1970s as construction activities accommodated expansion. Accidental spills and chemical contamination from leaking fuel and materials brought to the Station have caused adverse environmental alterations. Some of these ground contaminants that have accumulated are likely from a variety of products, such as oil-based paints, lubricants, grease, cleaners, and fuels. The fuel types used at the Station, which are designed with low freezing points, include aviation fuels (AN8, JP-5, and JP-8) and gasoline for some vehicles (Haehnel et al. 2017). For example, AN8 is not a standard commercial product but has a designed freezing point of −58°C, making it suitable for use in electric generators, boilers, heavy machinery, and other equipment.

Because of the slow biological degradation of the legacy pollutants within polar environments, the contaminants persist, frozen in place, and accumulate, lasting indefinitely. Contaminants related to the above disturbances (hydrocarbons and metals) were specifically found to be elevated in runoff during the snowmelt period (Affleck et al. 2014). Kennicutt et al. (2010) and Klein et al. (2008, 2012) collected and analyzed several hundred soil samples over nine years to monitor the extent of the environmental impact of the various contaminants. These contaminants were from localized spills in active operational areas at the Station. They found hydrocarbon levels in soils were high in areas where accidental spills occurred and in areas or pads where day-to-day activities (i.e., vehicle parking, heavy equipment loading and unloading, fueling loading, etc.) take place. Kennicutt et al. (2010) and Klein et al. (2008, 2012) describe that, from

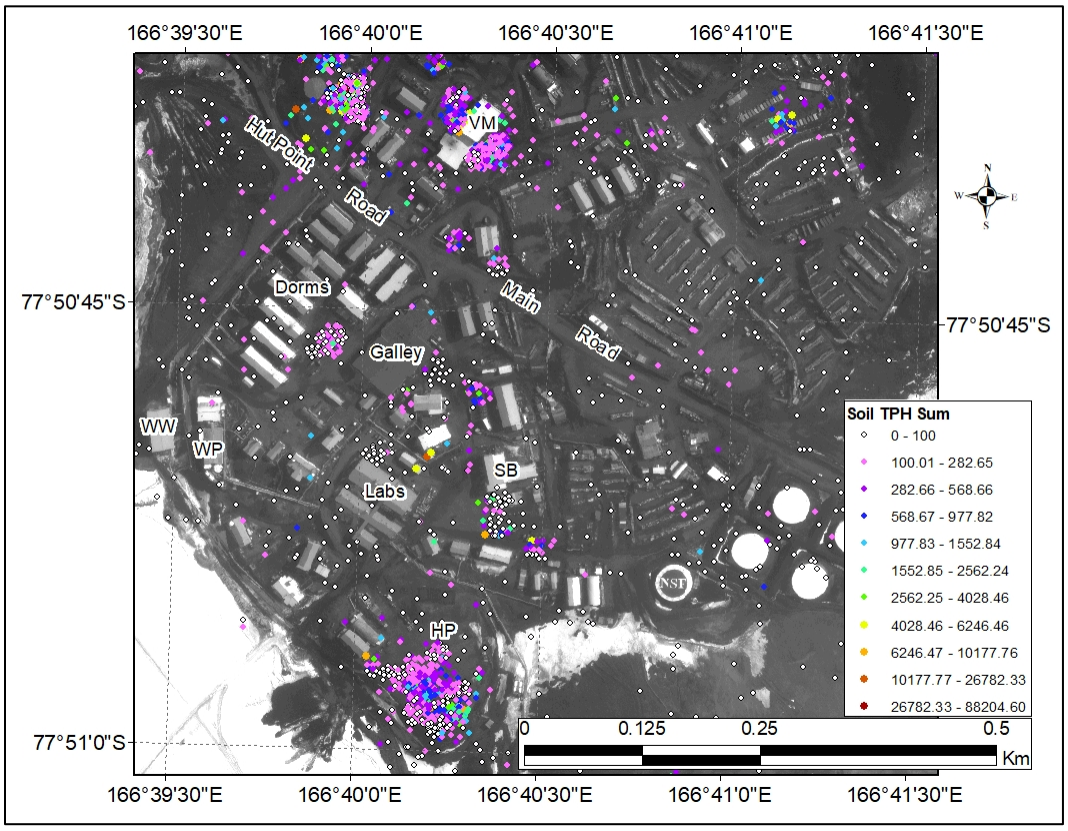
* Often referred to as simply "the Station"

1992 to 2004, up to 10,000 L of localized fuel spills occurred in the northeast areas of Hut Point and Main Road; and 25,000 L of fuel was spilled near the Helo Pad. These localized areas are where the soils with elevated total petroleum hydrocarbons (TPH) concentrations are located (Figure 1). The TPH concentrations in surficial soils at the Station are dispersed in patches of 0.032 to 88,200 mg/kg with the highest concentration found in parking spaces, previous refueling stations, the vehicle maintenance facility, and the Helo Pad area (Kennicutt et al. 2010; Klein et al. 2008, 2012). A total of 12.2% of the 3.1 km^2 area of the Station (assuming that an area within 100 m of a sampling location is contaminated) is expected to have TPH soil concentrations of 100 mg/kg or greater (Klein et al. 2012).

Samples recently collected from a soil pile during the 2018–2019 season spill (sample named "Soil Pile") and in the ground at the first footer location of Information Technology and Communications (sample named "ITC F1") by the Science Support Building (Figure 1) showed TPH numbers (C10–C36 carbon ranges) of 4900 and 14,000 mg/kg, respectively. However, TPH results for the less than 2 mm fraction from the same samples were 1250 ± 90 and 3500 ± 300 mg/kg, respectively (Beal et al. 2020). This indicates that samples from a more recent spill compared to legacy contaminated soils contained relatively high TPH concentrations. To complicate matters, analysis of these samples by gas chromatography–flame ionization detection indicated differing sources of hydrocarbon; the contaminants in ITC F1 samples are mainly from jet fuels or kerosene while those in the Soil Pile are from a combination of jet fuels, kerosene, and hydraulic fluid (Beal et al. 2020). Gas chromatography–mass spectrometry analysis from these two samples (Appendix A) indicated low concentrations of 2-methylnapthalene and N-nitrosodipenylamine for Soil Pile while ITC F1 had low concentrations of naphthalene, 2-methylnapthalene, dibenzofuran, fluorine, and an estimated presence of phenanthrene and bis(2-ethylhexyl)phthalate. The latter was likely a laboratory cross-contaminant. The Soil Pile material appeared to be more highly weathered than the ITC F1 sample although both were significantly weathered. The low semi-volatile organic compound (SVOC) concentrations of specific analytes supports this position given the much higher TPH measurement values. The results from these two samples suggest that the remaining compounds in the soil as TPH are not likely to be dissolvable or available for biological uptake and thus are relatively immobile.

The USAP's current practice for remediating fuel-contaminated soils at the Station prescribes treatment of soil until measured TPH concentrations are decreased to 100 mg/kg at which point the soil is considered clean enough for reuse (Antarctic Support Contract 2018; Klein et al. 2012). Sampling assessments by Kennicutt et al. (2010) and Klein et al. (2008, 2012) at the Station used a threshold of 30 mg/kg to represent a significant concentration of TPH in soil. This value represents approximately three times the method detection limit (Chiang et al. 1997; Klein et al 2012). In addition, Klein et al (2012) indicated that this threshold value is a conservative action level.

Figure 1. Total petroleum hydrocarbons (TPH) in surficial soils at McMurdo Station. HP is the Helo Pad, SB is the Science Support Building, VM is the Vehicle Maintenance Facility, WP is the Water Treatment Plant, and WW is the Wastewater Treatment Plant. (Data from Kennicutt et al. 2010; Klein et al. 2008, 2012.)



Precautionary measures, such as mitigating the impacts from common sources and preventing or minimizing spills or other accidental releases, are currently in place at the Station (NSF 2019). NSF (2019) indicates that removal or disposal of legacy contamination that has been frozen in place may cause greater impact than leaving the materials in place. However,

under certain situation and depending on the site conditions, legacy contaminated materials (in soil, snow, or ice) and any recent contaminations (fuel spill or hazardous materials) if identified should be tested to determine whether removal or on-site cleanup is a must. If required, the contaminated materials would be extracted, removed, and shipped from the continent. Currently, any material at the Station with concentrations greater than 100 parts per million (ppm; ppm and mg/kg are used interchangeably in this report) of TPH are transported to the United States for disposal, and any soils that contain concentrations of TPH less than 100 mg/kg are reused on-site (Antarctic Support Contract 2018; Klein et al. 2012). This value is based on State of California guidelines for soil cleanup values because that is where shipped soils arrive at after leaving the Station.

Because the environmental and climatic conditions at the Station are not similar to those in the State of California, evaluation of reuse or cleanup standards based on polar and cold regions is needed to identify appropriate options. For this study, we compare the cleanup and soil reuse guidelines of other states and countries located in cold climates, which may be more appropriate for the Station's environment than California's are. We also present a Station site conceptual model for understanding soil reuse and describe the implications to the environment, human health, and future construction activities.

1.1.1 Climate

The climate at McMurdo Station resembles a desert environment, having very little precipitation. Based on the climate record from 1973 to 2008, the Station receives an average annual total of 174 mm of precipitation (Affleck et al. 2012). Because the climatic condition at the Station is extremely cold, most of the precipitation is in the form of snow, even at the height of the austral summer months (November, December, and January). The lowest and highest recorded temperatures at the Station are –49.1°C and 13.3°C, respectively, and the annual mean is –17°C. The air temperatures rarely rise above freezing, even in the austral summer. Typically, the daily temperatures were below 0°C, but often rose above 0°C for a portion of the day.

Winds at the Station are strongest during winter months (Hoffman 1979), but high winds are common in the summer months (Affleck et al. 2012; Adlam et al. 2010). The mean and the maximum wind speeds from the

data collected in January 2010 were 3.9 and 13.3 m/s, respectively (Affleck et al. 2012). These wind events generally last from 1 to 5 days, approximately. Wind direction was primarily between 70° and 100° (true north), and the relative humidity was about 72% in December and 69.8% in January (Affleck et al. 2012). Winds often result in airborne dust conditions (Seman and Affleck 2012) and snow drifting. Because the distribution of the annual snowfall is highly dependent on winds, exposed land areas are essentially snow-free most of the year (Hoffman 1979), including some localized areas with elevated contaminants.

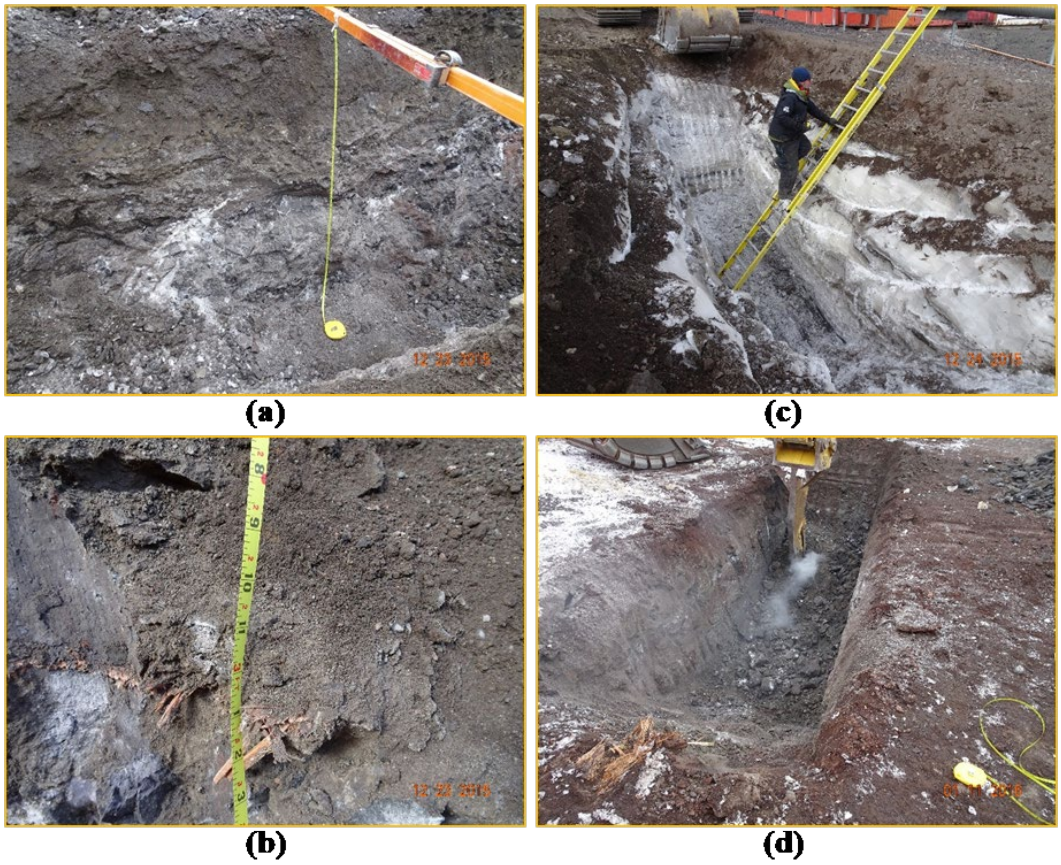
1.1.2 Geology and subsurface conditions

The predominant geologic features at the Station are characterized as basaltic and pyroclastic flows interbedded with widespread tills. The general description of the surface geology of the Station consists of varying amounts of scoria and basalt fragments in an ice matrix with fractured basalt bedrock. These fractured rocks and boulders are classified as (olivine-augite) basalts (Cole et al. 1971; Hoffman 1979), which can vary from compact (dense gray rock) to vesicular basalts (rocks with tiny holes). Some rocks have a reddish color owing to oxidation of iron minerals and are differentiated as felsitic scoria. Compact rocks from much harder crystalline flows are found at deeper depths and at various locations. The fine-grained materials exist due to the physical and natural (thermal and cryogenical) changes with time. The presence of ice-cemented permafrost within Ross Island is common (Balks et al. 2013; Affleck et al. 2017, 2014, 2012). The presence of reddish material is common throughout the Station and is composed of a sand and gravel mixture (Crockett 1998). The exposed land area at the Station has very limited or no organic content.

Flat fill platforms are common across the Station, which are mostly mechanically leveled ground. Figure 2 shows near-surface ground conditions from soil pits dug during a geotechnical investigation in 2015 (Affleck et al. 2017). These platforms are used as pads, outdoor storage locations, and access areas. In some cases, the fill materials used on the pads contained contaminated materials, debris (i.e., wood chips and plastic materials), and other pollutants (Figure 2c). Other places at the Station were built on top of a man-made deposit of snow or on a natural deposit of ice as shown in Figure 2c. Additionally, Figure 2d shows the presence of reddish fill material near the surface and ice-cemented fractured rocks and boulders below. Hydrocarbon odor in the soil was encountered while digging down to 3 m in the ice-cemented layer (Figure 2d). This area was mapped with

TPHs in excess of 500 ppm but below 1000 ppm of contamination at the soil surface (Kennicutt et al. 2010; and Klein et al. 2012).

Figure 2. Near-surface ground conditions from soil pits (Affleck et al. 2017) showing (*a*) geologically ice-cemented soil, (*b*) mechanically buried debris, (*c*) buried massive ice, and (*d*) reddish fill on the soil surface and fractured rocks with ice lenses.



The active layer (i.e., layer of ground that thaws in the summer months) varies in depth from 0.1 to 0.3 m below the surface. At the bottom of the active layer, the ice-cemented layer transitions to a permafrost layer with the average temperatures at 1.22 m below the surface measured at −5.6°C to −26.1°C for January and September, respectively. These soil temperatures reflect the seasonal trend of the area; however, diurnal temperature extremes occur in surface soils in the summer months. Thawing in the active layer occurs early in December, and the active layer deepens as the summer progresses (Affleck et al. 2012, 2017). During the summer months, liquid water appears at the interface between the permafrost table and the active layer (just above the frozen layer or right below the permafrost table). Thus, lateral and subsurface movement of moisture from

melted ice or snowmelt accumulate and flow in the subsurface (i.e., the active layer) above and along the impermeable frozen soil layer (Affleck et al. 2012, 2017).

1.1.3 Hydrology

The watershed terrain is composed of high ridges and sloping hills of barren volcanic rock, frozen soil with permafrost, and perennial snow and ice fields (Affleck et al. 2012). The general area within the Station is covered by snow that accumulates over the austral winter and typically either ablates or blows away during the austral summer, exposing the dark, unvegetated ground surface. A significant portion of the heat that causes snowmelt originates from the snow-free portion of the watershed. The hydrology is dominated by snowmelt and glacier ice as little if any liquid precipitation occurs. The major flow paths at the Station are well defined, with earthen ditches that cross under roads via culverts (Affleck et al. 2014). Ditches are relatively deeper than other natural flow paths. Some of the natural runoff flow paths change over time due to erosion, which depends on the intensity of the snowmelt runoff. A study done by Affleck et al. (2014) showed flow discharge during the austral summer ranges from 74 to 4239 m^3/day, indicating runoff does occur at the Station. Consideration for the hydrological flow paths established at the site is important for understanding soil reuse standards and guidelines. Other than the seasonal melting and surface flow during the austral summer, it is important to note that the general area does not have a typical natural aquifer for groundwater because the ground is perennially frozen.

1.1.4 Environmental protection protocols for McMurdo Station

The governing environmental structure for Antarctica is complex, requiring agreement and input from a variety of sovereign entities. Since 1959, Antarctica has been governed by the Antarctic Treaty, which was originally signed by 12 parties and now has a total of 54. While the majority of the Antarctic Treaty is simple, actually implementing and enforcing protocols remain complex. Additionally, any remediation or site reclamation tasks are difficult given the remote location and cost-intensive effort required for any site activities (Raymond and Snape 2017). In 1998, the Protocol on Environmental Protection to the Antarctic Treaty (i.e., the Madrid Protocol) was ratified and designated key annexes to protect the environmental quality of the continent (Secretariat of the Antarctic Treaty 1991a, 1991b). Annex I assesses environmental impact, Annex II speaks to conservation

of Antarctic flora and fauna, Annex III centers on waste disposal and waste management, Annex V details the area for protection and management, and Annex VI focuses on the liabilities arising from environmental emergencies. While the Madrid Protocol was a significant step toward suggestions for contamination cleanup and soil reuse, there were and still remains no concrete action levels for environmental quality and remediation (Poland et al. 2003; Raymond and Snape 2017). Thus, the Protocol does not have explicit guidelines for contaminant action levels, and each party does its own assessment as to contamination levels for reuse or transport off continent. The overall guideline is that cleanup is noncompulsory or disadvantageous if the removal processes create greater adverse impacts than leaving contaminated soil in situ (Secretariat of the Antarctic Treaty 1991a, 1991b; McWatters et al. 2016).

However, NSF follows the requirement under the U.S. Antarctic Conservation Act of 1978, which includes regulations for implementing the Protocol. Section 671.12 of the act states, "Each unauthorized release of waste in Antarctic shall be cleaned up by the person responsible for the release" (NSF 1995). Also, there is the Antarctic Committee for Environmental Protection (2014) *Clean-Up Manual* guidance, which says, "A risk assessment should be undertaken for all cleanup options being considered, with a focus on ensuring that greater adverse environmental impact does not occur as a result of the cleanup process." These environmental protocols as well as the *Guidelines for Environmental Assessment in Antarctica* (Secretariat of the Antarctic Treaty 2016) are the basis for generating the in-depth environmental impact assessment (e.g., Comprehensive Environmental Evaluation, or CEE) for the infrastructure development and modernization at the Station (NSF 2019). The CEE document covers the mitigation measures regarding the physical disturbance of the surrounding soils and management of contaminated soils during site preparation, construction, and operation of the existing facilities. While the CEE provides guidance to ensure environmentally sound approaches to minimize impacts, its highlighted suggestions for contamination cleanup are general without specification for soil reuse. Typically, the materials need to be tested to quantify the level of contamination, which is then used to determine if material can be reused or removed, packaged, and handled as hazardous waste. Thus, NSF requested an assessment and recommendation of suitable soil reuse value for the Station environment.

1.1.5 Terminology

In general, TPH encompasses many different types of compounds, all organic-based carbon chains or rings with varying chain lengths, including gasoline-range organics (GRO), diesel-range organics (DRO), and residual-range organics (RRO). For example, GRO represents the shorter carbon ranges, whereas DRO represents the longer carbon chains. The number of carbons that make up different TPH fractions can vary in name and chain-length range between different states, countries, and regulators. In addition, TPH is often further subdivided into aliphatic and aromatic components (aliphatic meaning straight chain and aromatic meaning the presence of one or more cyclic, planar structures). For risk assessment studies, TPH serves as a first-order assessment of potential contamination, but usually full site-specific risk assessment studies requires greater information on chemical speciation.

There are two distinctions for regulating contaminated sites from a governance level. *Cleanup levels* are generally used to distinguish materials that require no action if concentrations are less than or equal to that cleanup level. *Action levels* are prescribed for materials where some action is required if concentrations are greater than or equal to that action level. Cleanup and action levels are based on a variety of risk parameters, depending on the type of contaminant. For carcinogenic contaminants, the cleanup levels are often set to protect people from the risk of developing cancer in the future (risk based). For some contaminants, the cleanup levels are based on fate and transport modeling (risk of transport to ground or surface water). Lastly, *reuse* is defined as the remediated soil level or appropriate level of contaminated soil to be used in fill material without potential environmental and human health risks if used in an appropriate setting and manner. Soil reuse levels are usually site dependent.

1.2 Objective

Current practices at McMurdo Station are to excavate and remove as hazardous waste soil containing greater than 100 mg/kg of TPH and to transport it to the United States via cargo vessel for disposal. Excavated soil containing less than 100 mg/kg TPH may be reused on-site as fill materials. However, this 100 mg/kg TPH standard is based on the State of California standard for soil contaminated with petroleum products. This value was adopted by the Station since soils are shipped to California for disposal or treatment.

The purpose of this report is to review current standards and practices for reuse of soils affected by TPH and to assess how recycling contaminated or remediated soils may impact current practices at the Station. The extreme environmental conditions present at the Station may impact soil-water partitioning for TPH, and comparing the soil reuse values with other cold regions of the United States and relevant countries is important for determining and providing appropriate site-specific reuse levels.

1.3 Approach

This introductory chapter is followed by the methods used in the study. Then, the chapter 3 discusses the current regulations for cleanup and soil reuse values in countries, U.S. states, and Canadian territories where the climate is cold and snow often accumulates. In the subsequent sections, we present case studies from Arctic and Antarctic regions where soil has been reused after treatment. Additionally, we present a site conceptual model for risk assessment based on known site information and recommend future focus areas. The last sections summarize our findings and provide recommendations for soil reuse.

2 Methods

For this assessment, we chose to select a few states and countries based on average yearly temperatures that receive an established snowpack throughout the winter on an annual basis or can be characterized by freeze–thaw cycles transitioning from winter to spring to summer. In the United States, we reviewed published soil reuse and petroleum-based action levels for Alaska, California, Colorado, Maine, Massachusetts, Minnesota, New Hampshire, North Dakota, Vermont, Washington, and Wyoming. We also investigated current standards and practices used by Sweden, Canada (Alberta), Australia, and New Zealand because these countries deal with cleanup processes in cold regions. Additionally, if the governing entity had not published specific soil-reuse values, we evaluated cleanup-level values for TPH. Cleanup levels used in the document are current published values and are considered best-use practices by the governing entity or result from the country or state government's direct guidance levels.

For determining the protective levels and risk assessment for reuse, we reviewed available analytical data for petroleum in the soils at the Station. To assign soil reuse values for the site conceptual model, we assumed that any excavated soils would remain at the surface and be available for direct contact. This study also assumed that the majority of fuels used and released at the Station are middle distillates and DRO. This assumption is based on data from Kennicutt et al. (2010), Klein et al. (2012), and Beal et al. (2020).

3 Existing Guidelines

3.1 The United States

3.1.1 Alaska

Alaska separates soil cleanup levels based on location zones, including Arctic and non-Arctic. It also separates TPH into three carbon-range categories of GRO (C6–C10), DRO (C10–C25), and RRO (C25–C36), as shown in Table 1. The Arctic zone assumes that migration to groundwater is more limited than the non-Arctic zone, and cleanup values reflect the limited base flow in this region.

Table 1. Established cleanup levels for soil hydrocarbon constituents in the Arctic zone for the State of Alaska from the Alaska Department of Environmental Conservation (ADEC 2017).

Hydrocarbon Range	Ingestion (mg/kg)	Inhalation (mg/kg)	Maximum Allowable Concentrations (mg/kg)
GRO C6–C10	1400	1400	1400
DRO C10–C25	12500	12500	12500
RRO C25–C36	13700	22000	22000

The Alaska Department of Environmental Conservation (ADEC) also further separates cleanup values based on whether the soil is located above or below 1 m. In general, ADEC outlines maximum allowable soil concentrations of GRO, DRO, and RRO of 1400, 12,500, and 22,000 mg/kg, respectively. ADEC also provides further guidance for site-specific situations.

3.1.2 California

Currently at the Station, excavated soil containing 100 mg/kg TPH or less may be reused on-site as fill material, and soils containing greater than 100 mg/kg TPH are shipped to California for disposal or treatment to meet cleanup requirements. The California Regional Water Quality Control Board (referred to as the CA Water Board) published in 2006 a guidance for on-site reuse of petroleum hydrocarbon–impacted soil (PHIS) based on the overall threats or risks to human and environmental health and water quality (CA Water Board 2006). PHIS is defined as soil impacted with gasoline (C6–C12) or middle distillates (C9–C25), including diesel, kerosene, and jet fuel, collectively referred to as *diesel*. However, the CA Water Board guidance does not address reuse of soils impacted with heavier petroleum products (e.g., fuel oil Nos. 4, 5, and 6; lubricating oils; motor oil;

etc.) or any other contaminants. The CA Water Board guidance emphasizes that the soil must be sampled and tested according to a two-tiered evaluation approach to determine if soil is suitable for reuse. Table 2 provides the regulatory limits applicable to the reuse of PHIS. The CA Water Board guidance for soil concentration limits are based on the lowest Environmental Screening Levels (ESLs) to protect (1) human health via drinking water consumption, (2) human health via direct contact, (3) human health via indoor air exposure, or (4) nuisance concerns. Additional assumptions include residential land use, groundwater as a source of drinking water, and shallow soils (< 3 m). Soil concentration limits for TPH as gasoline and diesel are based on gross contamination ceiling (i.e., nuisance) limits. Soil concentration limits for BTEX (Benzene, Toluene, Ethylbenzene and Xylenes) and MTBE (methyl tert-butyl ether) are based on a generalized leaching model and protect groundwater as a potential source of drinking water. Soil concentration limits for naphthalene aim to protect human health from indoor air exposure.

In 2007, the CA Water Board published for TPH soils ESLs based on the impacts to human health. These ESLs aim to protect against direct exposure, vapor intrusion into buildings, and environmental impacts such as leaching and terrestrial biota (CA Water Board 2007). The ESLs for TPH soils are categorized according to soil depths and land use (Table 3). Further information is in CA Water Board (2007).

Table 2. The California Regional Water Quality Control Board concentration limits for gasoline and diesel.

Chemical	Tier 1		Tier 2
	Soil Concentration Limits[a] (mg/kg)	Not-to-Exceed Limits[b] (mg/kg)	Leachate Concentration Limits[c] (µg/L)
TPH Gasoline (C2–C12)	100	400	100
TPH Diesel (C9–C25)	100	400	100
Gasoline/Diesel (Benzene)	0.044	0.18	1.0

[a] Soil concentration limits may be compared to the 95% upper confidence limit of the mean calculated from the samples data for each constituent.

[b] Soil not-to-exceed limits must be compared to individual stockpile sample results for each constituent. Soil not-to-exceed limits are based on the second-lowest ESL.

[c] The leachate concentration limits for all constituents are based on the lowest groundwater screening level that is protective of nuisance odors or human health (via drinking water or indoor air impacts).

Table 3. California TPH environmental screening levels (ESL) for soils use. Groundwater is not a current or potential source of drinking water.

Analytes	Shallow Soil[a] (mg/kg)		Deep Soil[b] (mg/kg)	
	Residential Land Use	Commercial Land Use	Residential Land Use	Commercial Land Use
TPH (gasolines)	100	450	4200	4200
TPH (middle distillates)	100	150	150	150
TPH (residual fuels[c])	410	2500	5000	5000

[a] Shallow soils are soils less than or equal to 3 m below ground surface.

[b] Deep soils are soils greater than 3 m below ground surface.

[c] Residual fuels include heavy petroleum products, such as No. 6 fuel oil, lubricating oils, oil and grease, waste oils, and asphalts.

3.1.3 Colorado

The Colorado Department of Public Health and Environment has stipulations for on-site and off-site soil reuse for petroleum-impacted soils. For on-site reuse, they stipulate that soil may be used in place or elsewhere on the same property if the cleanup target levels are met (i.e., <500 mg/kg for TPH). For off-site reuse, Colorado stipulates that reuse allowances are case specific, and the users are given the burden of proving and demonstrating that reuse would not cause any adverse risks to human health or to the environment (Colorado Department of Natural Resources 2020).

3.1.4 Maine

The guidance from the Maine Department of Environmental Protection specifies reuse of contaminated material based on the purpose or application. If the material is to be used as construction fill or a building material, the reuse guidance is subjected to the solid waste rules (Maine Department of Environmental Protection 2018), shown in Table 4. The soil waste rules are based on the acceptable risk levels.

Table 4. The stipulations used by the Maine Department of Environmental Protection for acceptable risk levels broken down by chemical constituent.

Chemical	Waste Concentration (mg/kg) Dry Weight
C11–C22 Aromatics	230
C19–C36 Aliphatics	10000
C5–C8 Aliphatics	700
C9–C10 Aromatics	37.5
C9–C12 Aliphatics	1350
C9–C18 Aliphatics	1350

3.1.5 Massachusetts

The Massachusetts Department of Environmental Protection (MassDEP) does not have TPH standards specifically for soil reuse. However, MassDEP provides soil standards for different conditions and stipulates that soils containing concentrations of oil or hazardous material greater than the reportable concentrations (RCs) should not be reused. For soil contamination below RCs, the MassDEP requirements are divided into two categories: RCS1 and RCS2. RCS1 applies to locations with the highest potential for exposure, such as residences, playgrounds, and schools, and to locations within the boundaries of a groundwater resource area. RCS2 applies to all other locations. The MassDEP limits for TPH include 1000 mg/kg for RCS1 and 3000 mg/kg for RCS2 conditions. Further information can be found online at http://eeaonline.eea.state.ma.us/DEP/MOMHL/hazmat.aspx (MassDEP 2018).

3.1.6 Minnesota

The Minnesota Pollution Control Agency outlines criteria for using petroleum-impacted soil and soil containing less than 100 mg/kg GRO and DRO. The criteria are based on the Minnesota Pollution Control Agency's most conservative risk-based values and states that any soil with less than 100 mg/kg GRO and DRO may be used as fill materials. They also suggest that the site history should be taken into account when considering DRO contamination because some soils may contain DRO concentrations not related to a history of petroleum use, which changes the risk-based criteria that should be applied to the site (Minnesota Pollution Control Agency 2012).

3.1.7 New Hampshire

The New Hampshire Department of Environmental Services (NHDES) provides standards for all nonhazardous oil-contaminated soil (NOCS) and nonhazardous contaminated soil (NCS). NOCS and NCS address soils containing regulated contaminants but are not considered hazardous wastes. NHDES uses soil remediation criteria to determine the guidance for contaminated soil disposal and reuse. The soil remediation criteria for TPH are 10,000 mg/kg. However, NHDES emphasized that, in lieu of the soil standards, the responsible party may develop site-specific soil remediation standards by evaluating the risk to human health and the environment by using the methods described by ASTM (2015). Further information can be found in New Hampshire Department of Environmental Services (2019).

3.1.8 North Dakota

The North Dakota Department of Health, Division of Waste Management, stipulates that TPH-contaminated soil can be reused in an unregulated manner if the soil does not exceed 100 mg/kg. If the soil exceeds 100 mg/kg TPH, then the soil must be removed from the site or treated in-place until TPH concentrations are less than 100 mg/kg. Treatment in-place options in accordance with the state law include biodegradation, leaching, venting, and aeration on an impermeable material (North Dakota Department of Health 2006).

3.1.9 Vermont

The State of Vermont Agency of Natural Resources, Department of Environmental Conservation (VT DEC), specifically defines nonhazardous waste–contaminated soils as soils contaminated with hazardous materials at concentrations above the soil screening values but that are not themselves hazardous wastes (VT DEC 2019). VT DEC outlines the criteria according to U.S. Environmental Protection Agency (U.S. EPA) Regional Screening Levels (RSLs) and usage (Table 5). In addition, VT DEC summarizes (Table 6) soil screening levels for TPH and conditions when TPH testing is required as part of the investigation and remediation of contaminated properties. Their guidance requires the specific TPH analysis (GRO or DRO), depending on site use, history, and conditions. When the source of petroleum contamination is unknown or both gasoline and diesel range (or higher) compounds are suspected, the VT DEC mandates analysis for both GRO and DRO.

Table 5. Vermont TPH screening levels for soils based on the Regional Screening Levels set by the U.S. EPA.

TPH Fractions	U.S. EPA Regional Screening Levels (mg/kg)	
	Residential Soil	Industrial Soil
Aliphatic High	230,000	3,500,000
Aliphatic Low	520	2200
Aliphatic Medium	96	440
Aromatic High	2500	33,000
Aromatic Low	82	420
Aromatic Medium	110	600

Table 6. Summary of Vermont's TPH screening values as they relate to residential and industrial soils.

Soil Screening Value for TPH	GRO (C_6–C_{10})	DRO (C_{11}–C_{28})
Residential Soils	82 mg/kg	96 mg/kg
Industrial Soils	420 mg/kg	440 mg/kg

Note: Because the U.S. EPA updates its RSLs regularly, check the U.S. EPA RSL website to confirm the most updated values (https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide#toxicity%20https://hhpprtv.ornl.gov/).

3.1.10 Washington

Washington has detailed guidelines for soil reuse standards and soil cleanup levels for petroleum-impacted soil. Stipulations for soil reuse state that soil can be used for unrestricted land use if concentrations of GRO with benzene are less than 30 mg/kg, concentrations of GRO without benzene are less than 100 mg/kg, and concentrations of DRO are less than 2000 mg/kg. The regulations also stipulate that to use the GRO without benzene soil cleanup value (<100 mg/kg), the total BTEX must be less than 1% of the total mixture (Washington State Department of Ecology 2004).

3.1.11 Wyoming

The Wyoming Department of Environmental Quality (2014) set the TPH cleanup levels for DRO as any soil with concentration higher than 2300 mg/kg. Soils above this level need to be remediated; and for GRO, the Wyoming Department of Environmental Quality (2014) stipulates that cleanup levels are site specific and are determined using the average thickness of the contaminated zone and average distance from the contaminant zone to the top of the seasonally high groundwater table.

3.2 Countries

3.2.1 Australia

The Australian's National Environment Protection Measure (NEPM) Assessment of Site Contamination (Commonwealth of Australia 2013) provides investigation levels for soil and ground water. The screening levels are divided into environmental and human health risks, including human exposure pathways, ecological risks, and risk to groundwater resources. NEPM uses ecological screening levels for TPH compound ranges as well as the corresponding fractions (designated as F) categories (F1, F2, F3, and F4), which are implemented for assessing risk to terrestrial ecosystems. The corresponding hydrocarbon fractions are divided into these

ranges: F1 (C1–C10), F2 (C11–C16), F3 (C17–C34), and F4 (C34–C40). These ecological screening levels are also broadly applied to coarse- and fine-grained soils and various land uses and are applicable to the top 2 m of soil (Table 7). The NEPM designates an area of ecological significance as one where the planning provisions or land-use designation is for the primary intention of conserving and protecting the natural environment. This would include national parks, state parks, wilderness areas, and designated conservation areas. The guideline highlights that the use of investigation and screening levels as default remediation criteria may result in unnecessary remediation and increased development costs, unnecessary disturbance to the site and local environment, and potential waste of valuable landfill space.

Further information can be found in Commonwealth of Australia (2013).

Table 7. Australia's NEPM guidelines for ecological screening levels for TPH fractions in soil.

Carbon Number Ranges (Fraction Number)	Soil Texture	Areas of Ecological Significance (mg/kg)	Urban Residential/Public Open Space (mg/kg)	Commercial and Industrial (mg/kg)
C6–C10 (F1)	Coarse and Fine	125[a]	180[a]	215[a]
>C10–C16 (F2)		25[a]	120[a]	170[a]
>C16–C34 (F3)	Coarse	--	300	1700
	Fine	--	1300	2500
>C34–C40 (F4)	Coarse	--	2800	3300
	Fine	--	5600	6000

[a] Numbers indicate that the ecological screening level is of moderate reliability.

– Insufficient data is available to derive a value.

Additionally, health screening levels are established for select petroleum compounds and fractions and assess human health risk through inhalation and direct contact pathways. The health screening levels primarily for vapor intrusion apply to different soil types, depths below surface, land-use scenarios, and the characteristics of building structures. The guidelines summarized for our assessment apply to sandy materials or coarse-grained soils only (Table 8). NEPM also includes guidelines for silt- and clay-containing soils, which are not relevant to the conditions at the Station; the limits for fine-grained soils are typically higher limits than coarse-grained soils due to porosity and permeability. Moreover, NEPM establishes the health screening levels guidelines for soil vapor for limiting petroleum vapor intrusion (Table 9).

Table 8. Australia's guidelines set by the National Environment Protection Measure (NEPM) for vapor intrusion levels of a sandy soil (mg/kg).

Carbon Number Ranges	Low–High Density Residential				Commercial and Industrial			
	Surface (<1m)	1–2 m	2–4 m	4 m+	Surface (<1m)	1–2 m	2–4 m	4 m+
C6–C10 (F1)	45	70	110	200	260	370	630	NL
>C10–C16 (F2)	110	240	440	NL	NL	NL	NL	NL

NL = means no assigned limit.

Table 9. Australia's guidelines set by the National Environment Protection Measure (NEPM) for soil vapor in a given area (mg/m^3).

Carbon Number Ranges	Low–High Density Residential				Commercial and Industrial			
	Surface (<1m)	1–2 m	2–4 m	4 m+	Surface (<1m)	1–2 m	2–4 m	4 m+
C6–C10 (F1)	180	640	1300	2600	680	2800	7000	15000
>C10–C16 (F2)	130	560	1200	2400	500	2400	NL	NL

NL = means no assigned limit.

3.2.2 Canada

The classification for TPH screening levels used by the Canadian government divides hydrocarbons into four fractions: F1 (C1–C10), F2 (C11–C16), F3 (C17–C34), and F4 (C34+). These fractions each have a soil remediation guideline for a specific activity or location: natural area, agricultural use, residential/parks, commercial use, or industrial use. Guidelines are further designated for each of these areas or uses in terms of whether the soil is fine or coarse. The guidelines compiled are specifically for Alberta (Tables 10 and 11).

Table 10. Guidelines for soil remediation in Alberta, Canada, for fine soils (in mg/kg).

Carbon Number Ranges	Natural Area	Agricultural	Residential/ Park	Commercial	Industrial
C1–C10	210	210	210	320	320
C11–C16	150	150	150	260	260
C17–C34	1300	1300	1300	2500	2500
C34+	5600	5600	5600	6600	6600

Table 11. Guidelines for soil remediation in Alberta, Canada for coarse soils (in mg/kg).

Carbon Number Ranges	Natural Area	Agricultural	Residential/ Park	Commercial	Industrial
C1–C10	210	240	240	270	270
C11–C16	150	130	130	260	260
C17–C34	300	300	300	1700	1700
C34+	2800	2800	2800	3300	3300

These Alberta guidelines define fine-grained soils as having a median grain size of less than or equal to 75 μm, whereas coarse-grained soils have a median grain size greater than 75 μm. Therefore, for petroleum-contaminated soils in Alberta, sufficient data are needed for the grain size of the soil before assessing whether a soil has unacceptable TPH levels (Alberta Environment and Parks 2016).

3.2.3 New Zealand

The New Zealand Ministry of Environment classifies TPH according to the Tier 1 soil acceptance criteria, which the ministry developed for all pathways and site use considerations, including residential, commercial/industrial and agricultural. The criteria divide any hydrocarbons found in soils into three fractions based on carbon chain length (C7–C9, C10–C14, and C15–C36) and also designates soil type and depth of contaminations for the cleanup. Given the conditions at the Station (Table 12), only the cleanup for sand and sandy-silt materials would be applicable since the soils are primarily gravel or coarse-grained materials.

Further information can be found in Ministry for the Environment (1999).

Table 12. New Zealand's soil acceptance criteria for petroleum hydrocarbon constituents in sand and sandy-silt soils at various contamination depths and based on land site use.

Soil Type + Carbon Number Ranges	Depth of Contamination and Site Use								
	Surface (<1m) (mg/kg)			1-m–4m (mg/kg)			> 4m (mg/kg)		
	Res.	Com.	Agr.	Res.	Com.	Agr.	Res.	Com.	Agr.
SAND									
C7–C9	120	120	120	120	120	120	3800	12,000	3800
C10–C14	470	5000	58	560	1,900	560	650	2100	650
C15–C36	NA	NA	4000	NA	NA	NA	NA	NA	NA
SANDY SILT									
C7–C9	500	500	500	500	500	500	3800	12,000	3800
C10–C14	510	1700	58	670	2200	670	1000	3400	4900
C15–C36	NA	NA	4000	NA	NA	NA	NA	NA	NA

Res. = residential applications.

Com. = commercial applications.

Agr. = agriculture applications.

NA = not applicable situations where the hydrocarbon is not likely to be present.

3.2.4 Sweden

The Swedish Environmental Protection Agency (Swedish EPA) divides contamination into four categories: slightly serious, moderately serious, very serious, and extremely serious. Many factors determine if a specific soil falls into one of these categories, including soil type, depth to groundwater, contaminant speciation and concentration, and site history. Furthermore, the Swedish EPA breaks down TPH into the contamination level of impact according to aliphatic or aromatic classifications (Table 13).

Table 13. Swedish Environmental Protection Agency published guidelines (in mg/kg) for petroleum contamination in soils (Swedish EPA 2002, Appendix 4).

TPH Fractions and Carbon Number Ranges	Slightly serious	Moderately serious	Very serious	Extremely serious
Aliphatics >C5–C16	<100	100–300	300–1000	>1000
Aliphatics >C16–C35	<100	100–300	300–1000	>1000
Aromatics >C8–C10	<40	40–120	120–400	>400
Aromatics >C10–C35	<20	20–60	60–200	>200

4 Existing Sites of Soil Reuse Efforts

Remediated or nonhazardous contaminated soils with appropriate TPH levels can be permitted for reuse (based on the guidance described in section 3) as long as the materials pose no potential risks to the environment and to human health. Soil reuse is advantageous, especially in places where materials and resources are limited. Soils with acceptable levels of nonhazardous petroleum hydrocarbon are typically reused on the same contiguous property where they were generated (i.e., on-site). However, testing and adequate risk assessments are typically required because the appropriate soil reuse levels usually depend on site conditions. This section briefly describes existing polar sites where soil reuse has been implemented.

4.1 Antarctic

In winter 1999, a significant accidental spill during transport released approximately 10,000 L of diesel fuel near Lake Dingle, Vestfold Hills, approximately 5 km from Australia's Davis Station in Antarctica (McWatters et al. 2016). The plume seeped into granular sandy soil within the active layer and penetrated into the permafrost. Hydrocarbon concentrations in the soils ranged from 3425 up to 29,000 mg/kg. The Antarctic environment is very dry with minimal microbial communities to support hydrocarbon degradation.

Based on the site and environmental risk assessment, all soil contaminated with more than 100 mg/kg was remediated on-site using biopiles—a variety of bioremediation technologies in which excavated soils are mixed with fertilizers to remediate the contaminated soils (Australian Antarctic Division 2015). Six biopiles were successfully constructed in 2011 and 2012 to remediate the contaminated soils, and the system was the first demonstration for bioremediation of contaminated soil in Antarctica (McWatters et al. 2016). In 2015, the biopiles soil concentrations ranged from 9 to 20 mg/kg for C6–C10 (F1 range) and 390 to 720 mg/kg for C10–C16 (F2 range). Another spill incident occurred in 2015 where the plume migrated into the foundation of a building (McWatters et al. 2019); these additional contaminated soils needed to be excavated and required remediation in the biopiles. To accommodate the additional contaminated soils for remediation, an environmental and human health risk assessment was conducted for reuse of the remediated soil from biopiles; approximately 370 metric tons of the remediated soil with concentrations of 9 to

20 mg/kg for C6–C10 (F1 range) and 390 to 720 mg/kg for C10–C16 (F2 range) were approved for soil reuse as a backfill for the excavated building foundation (McWatters et al. 2016).

As a continuation study at Davis Station, McWatters et al. (2019) designed a new vapor intrusion contaminant transport model to study potential impacts due to the 2015 fuel spill on air quality inside buildings at the Station. They specifically focused on modeling five scenarios: (1) building on the current contaminated site without any changes; (2) excavating the contaminated soil and backfill with clean soil; (3) excavating the contaminated soil and backfill with the biopile soil (further outlined in McWatters et al. 2016); (4) excavating the contaminated soil and backfill with other remediated soil; and (5) excavating the contaminated soil, backfilling with other remediated soil, and assessing the impact of a future spill. Their model also simulated two different vapor barriers.

Based on their modeling efforts, McWatters et al. (2019) found that excavating and exchanging the surface soils are ideal for air quality inside buildings; and of the two vapor barriers, the coextruded ethylene vinyl alcohol geomembrane was superior to the linear low-density polyethylene geomembrane. Their risk assessment was primarily focused on benzene, xylene, naphthalene, and 2-methylnapthalene (McWatters et al. 2019). They found that buildings at Davis Station would benefit from an air-exchange system that is maintained at 0.15/hr and that risks to building air quality specifically from contaminated groundwater were low. Finally, their study found that buildings built directly on the ground use a foam material as a base layer and that foam should be wrapped in a layer of geomembrane vapor barrier to minimize the deterioration of the foam. Thus a raised building is ideally better to mitigate risks to building air quality than building directly on a base layer.

4.2 Arctic

The Arctic region of Alaska was extensively explored for oil reserves throughout the 1900s. Currently, Prudhoe Bay Oil Field on Alaska's North Slope is the largest oil field in North America. In addition to Prudhoe Bay, the former Naval Arctic Research Laboratory (NARL) was once operated on the North Slope of Alaska just outside the town of Utqiaġvik (formerly Barrow). Over the years, the presence of these two entities has led to studies of oil contamination and migration in frozen environments and as a function of marine life and subsurface transport. In particular, the U.S.

Naval Facilities Engineering Command (NAVFAC 2018; ICRC 2004) and the Cold Regions Research and Engineering Laboratory (Bjella 2015; Bjella, Barbato, et al. 2018) have extensively studied the former NARL site to understand the continued impact of several historic oil spills.

Compared to the Antarctic, the primary geologic composition of the coastal north slope of Alaska is marine and nonmarine deposits, consisting of unconsolidated silts and sands with some clays and gravels (Black 1964) and also with shale, mudstone, and sandstone (Payne et al. 1951). In contrast, the area adjacent to the former NARL site is underlain by fine-grained, organic-rich soils with high soil moisture (McCarthy and Solin 1995). The primary ground feature in this region of the former NARL site in Alaska is permafrost with a seasonally thawed active layer that includes matrix ice, segregation ice, ice wedges, and taliks. The area hydrology is surrounded by water tracks, streams, and swamp; thus groundwater movement is relatively near the ground surface and within the permafrost layer even during winter time. In addition, the hydrology is largely controlled by the short, annual thaw season and the spring freshet.

The oil spills and recovery efforts at the former NARL site are well documented (ICRC 2004; NAVFAC 2018; Bjella 2015; Bjella, Barbato, et al. 2018; McCarthy et al. 2004). In 1978, 530,000 L of usable gasoline were recovered following a spill that December. An additional 207,000 L of fuel were recovered in 1996, approximately 78,000 L of fuel in 1997, and 340 L of fuel were recovered and collected in 1998. In 2000, 1300 L and 900 L of oil were recovered at two separate recovery collections. In August 2002, 1734 m^3 of GRO- and DRO-contaminated soil were removed and treated on-site using hot air vapor extraction (HAVE) technology. After the soil extraction and treatment, the crew placed a 0.3 m thick soil cap over the contaminated sediments in that area (Bjella, Barbato, et al. 2018). This area was specifically targeted for cleanup and soil reuse because it is adjacent to Imikpuk Lake, which at the time was the main drinking water source for the town.

Landfarming remediation (a bioremediation technology that places contaminated soils in lined beds and periodically tills to aerate the waste) was conducted by McCarthy et al. (2004) for contaminated soils at the former NARL site and used target soil concentration values for DRO and GRO of 500 and 100 mg/kg, respectively. ADEC approved these values based on a combination of site-specific risk analyses and the maximum allowable concentration for the Artic zone soils (McCarthy et al. 2004).

5 Identifying Protective Levels for TPH-Impacted Soil Reuse Based on Risk

5.1 Site assumptions

In general, chemical characterization data generated from the soils at Antarctica near McMurdo Station is limited. There are a few studies discussing TPH values and specific hydrocarbons, but the detailed speciation (type of hydrocarbon, aliphatic versus aromatic, etc.) is generally not well documented or studied. Therefore, we developed a site conceptual model to enhance understanding of site conditions in relation to human exposure and soil reuse potential.

While the population at the Station tends to be transient, September to May sees the majority of the population. Researchers and workers typically stay in dormitory-type buildings during these warmer months. Fewer researchers are present during the harsh austral winters (June to August). No children are present at the facility.

Direct contact with surface soils and ingesting soils adhered to hands are the major exposure pathway to TPH-contaminated soil at the Station. This may occur throughout the year during outdoor work activities and when traversing the site. Contaminated soil can also be tracked inside dorms and migrate indoors as airborne dust, which would then be available for direct contact and ingestion. Inhalation of contaminated dust and dermal absorption of TPH are minor exposure pathways. Exposure to soil at the Station is characteristic of industrial and commercial direct contact rather than residential exposure. Criteria for contaminant exposure protection for residential use are more stringent than for industrial and commercial uses (California, Vermont, Australia, and Canada). Common activities for residential exposure such as children playing in a yard and adults engaged in outdoor gardening in addition exposure discussed above are not situational factor at the Station. Our assessment assumes when assigning soil reuse values that postexcavation, residual soils at or below reuse values will remain or be used in a manner that would make them available for direct contact.

Exposure to subsurface soils is limited unless actively digging, but migration of volatile TPH constituents to indoor air from the subsurface (vapor intrusion) is a possibility. A detailed analysis of vapor intrusion migration

pathways is beyond the scope of this project but has been examined in at the Davis Station in Antarctica (McWatters et al. 2019).

TPH impacts to ingestible water are nonexistent. Seawater is the source of drinking water and is provided by a desalination facility at the Station. As most hydrocarbons are insoluble, surface overland flow in the summer months can result in either sediment transport of TPH-laden soil or dispersion of TPH into the water or subsequent transport to the sea. Overland migration of TPH in soils is possible either as residuals absorbed to soil grains or dissolved into flowing water (Affleck et al 2014), particularly as a function of snowmelt. However, human health exposure to surface water is likely to be limited except for individuals performing environmental monitoring. These individuals should adhere to cautionary protection measures such as wearing personal protective equipment and gloves. Otherwise, human exposure is limited to direct contact, principally by individuals working with the soil (excavation) or environmental monitoring (soil or surface water) under an industrial or commercial setting.

5.2 Risk evaluation

Available analytical data for petroleum in soils at McMurdo Station for this analysis are limited to TPH; composition of the aliphatic and aromatic fractions is not available. Given the lack of available details regarding composition of TPH and the inability to extract meaningful levels of SVOCs from the couple of samples (Appendix A) at the Station, using site history factors to assign protective levels of TPH to soils for reuse is reasonable. The Interstate Technology Regulatory Council (2018) describes a "whole product approach" for assessing petroleum risk where weighted toxicity factors are assigned to the variety of petroleum products such as gasoline, diesel, oil, etc., based on relative concentrations of aliphatic and aromatic hydrocarbons. We examined the sources cited by the Interstate Technology Regulatory Council for this approach and found the State of Hawaii's guidelines developed by the Hawaii Department of Health (2017a, 2017b) to be the most transparent and relevant for this analysis. We also examined Alaska's cleanup methods for protecting human health, safety, and welfare and the environment (ADEC 2018). Their procedures used standardized default exposure and soil parameters and account for conditions more closely aligned with the Station, as they consider Arctic conditions and polar environments.

Both states accomplish a "whole product approach" for TPH by developing risk-based values for different types of petroleum by assuming certain percentages of aliphatic and aromatic carbon chain lengths and compositions. Hawaii designates their values as environmental action levels (EALs), and Alaska refers to theirs as cleanup levels. Both use default exposure factors for residential land use and assign toxicity factors to the different petroleum types, though some of these vary between the two states. Hawaii also developed EALs for industrial and commercial land use while Alaska allows cleanup levels for that type of land use on a site-specific basis. Hawaii developed EALs for (1) gasoline range, (2) middle distillates (e.g., diesel fuel, jet fuel), and (3) residual fuels (fuel oil, oils, and asphalts). Alaska developed cleanup levels for (1) GRO, (2) DRO, and (3) RRO. Details regarding the percentages and fractions selected to represent these types of petroleum may be found in Hawaii Department of Health (2017a, 2017b) and the ADEC (2018).

While both states use risk-based approaches, they each have ceiling values for allowable levels of TPH. The Hawaii Department of Health (2017a) ceiling values are intended to protect against odors arising from TPH and from sheens on surface water that may occur from TPH in soils migrating to surface waterbodies. Given the potential for oil sheens to be present in Antarctica also, our assessment considered Hawaii's guidance to be valuable. Alaska's ceiling value appears to be the highest risk-based residential value considering all climate types in that state. Tables 14 and 15 present the protective values for different types of petroleum.

Table 14. State of Hawaii environmental action levels for petroleum-derived hydrocarbons (in mg/kg).

Petroleum Type	Industrial/Commercial	Residential
Gasoline	500	450
Middle Distillates	500	220
Residual Fuels (oils)	25,000	500

Table 15. State of Alaska Arctic zone cleanup levels for petroleum-derived hydrocarbons (in mg/kg).

Hydrocarbon Range	Residential	Maximum Allowable Concentration
GRO	1400	1400
DRO	12,500	12,500
RRO	13,700	22,000

5.3 Results

The preponderance of fuels used and presumably released at the Station generally fall into the category of middle distillates and DRO. If there is no concern for petroleum odors, the Alaska value for DRO of 12,500 mg/kg could be used as a reuse value. However, if it is likely or data suggests that gasoline has been released at a given area of the Station or across it, the GRO value of 1400 mg/kg can be selected as a recommended reuse value. If there is a concern for odors or for overland runoff of soil contamination to surface water through snowmelt processes, the Hawaii EAL of 500 mg/kg can be used as a recommended reuse value as it addresses both of these issues for gasoline and middle-distillate petroleum. Hawaii's published residential EALs would be overly conservative given the commercial and industrial land use at McMurdo Station.

This analysis did not consider migration to occupied buildings via vapor intrusion as there was limited data and as it was outside the scope of the investigation. We recommended that if TPH-contaminated soils are going to be left in place near occupied buildings or used as fill for building construction, additional studies determine the possible chemical incompatibility with building materials and potential leaching or migration during construction or excavation of soil.

6 Summary

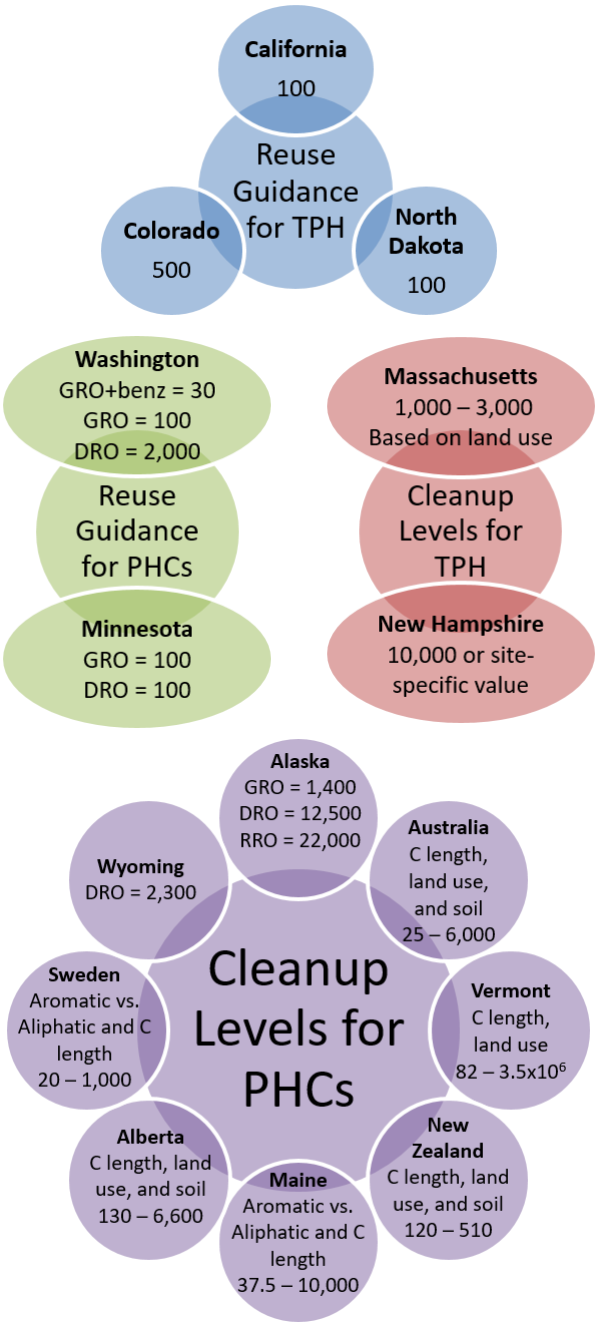
Investigating current regulations for cleanup levels and soil reuse guidance in countries, U.S. states, and Canadian territories where the climate is cold is more applicable for planning scenarios for Antarctica. The purpose of this investigation was to understand the established practices of other cold regions compared to current practice at the Station for soils affected by petroleum-derived hydrocarbons, in particular TPH. The assessment of the standards compiled here provides recommendations for potential future implementation at the Station. Figure 3 summarizes these efforts.

In general, 5 out of the 15 governing entities that we studied have established values for soil reuse for petroleum-contaminated soils: California, Minnesota, North Dakota, Colorado, and Washington. Of those five entities, three have established soil reuse values that are specifically for TPH: California, North Dakota, and Colorado. California and North Dakota stipulate that there be less than 100 mg/kg TPH in the soil, while Colorado mandates that the soil contain less than or equal to 500 mg/kg TPH if the soil is going to be used at the same location or property where it was generated. However, if the soil will be removed and transported to a different location for reuse, the guidelines from these states require case-by-case risk assessments. The two other governing entities that have actual established values for soil reuse for petroleum-contaminated soils, but not specifically for TPH, are Minnesota and Washington. Minnesota stipulates that soil may be reused if the concentrations of GRO and DRO are both less than 100 mg/kg. Washington's guidance addresses GRO based on whether benzene is present. If the soil contains GRO and benzene less than 30 mg/kg, then the soil may be reused. If there is no benzene present, then the soils may be reused if GRO are present in quantities less than 100 mg/kg. For DRO, Washington stipulates soils may be reused if concentrations are less than 2000 mg/kg.

The 10 remaining governing entities that we studied—Alaska, Wyoming, Sweden, Canada (Alberta), New Zealand, Maine, Massachusetts, Vermont, New Hampshire, and Australia—do not specifically outline soil reuse values but do provide cleanup values for soil affected by petroleum-derived contamination. Alaska separates its maximum allowable cleanup values in terms of carbon chain length (GRO, DRO, and RRO) and sets them at 1400, 12,500, and 22,000 mg/kg, respectively. The Alaska Department of Environmental Conservation does provide for non-Arctic areas in Alaska

lower cleanup values that are a function of groundwater presence and susceptibility. Additionally, Alaska provides more detailed cleanup values in terms of carbon chain length (C6–C36) and whether there are primarily straight carbon chains or aromatic rings present.

Figure 3. Simplified schematic summarizing the results of the soil reuse guidance from applicable governing entities in relatively cold regions. Entities are divided into four categories, depending on type of petroleum designation for cleanup. All values are in mg/kg.



Alberta (Canada), New Zealand, Sweden, Australia, Vermont, and Maine all have categorized TPH values in terms of carbon chain length, including descriptive variables such as aliphatic versus aromatic presence, soil texture (coarse versus fine-grained), soil classification (silt, sand, clay, etc.), and land-use type. Typical land-use types include natural, residential, commercial, agriculture, and industrial. Sweden seems to have the most stringent regulations (comparable to concentration limits in Australia and Washington) in that long chain aromatics in soils must be less than 20 mg/kg. Wyoming and New Hampshire are the least regulated or restrictive entities. Wyoming's only guidance is that DRO concentrations must remain lower than 2300 mg/kg in soils, and New Hampshire stipulates cleanup levels at 10,000 mg/kg for TPH in soils. On the other hand, Massachusetts only differentiates regulations of TPH in soils by land use with cleanup levels range from 1000 mg/kg for residential to 3000 mg/kg for nonresidential areas.

TPH cleanup levels developed by states and other countries have some risk-based components, but not all are applicable to the whole petroleum product. TPH cleanup levels are also relevant to reuse values as they are protective of direct contact risk; and some also consider protectiveness of other media, such as surface water. Because of the lack of detailed chemical composition of the TPH data for soils at the Station, our risk evaluation is based on published risk-based derivation transparently calculated for whole petroleum values. For areas where petroleum characteristic of DRO are present in soils and there is no for petroleum odors, the State of Alaska cleanup level of 12,500 mg/kg for DRO could be used as a reuse value and be protective of human health. For areas containing GRO petroleum, the GRO value of 1400 mg/kg can be selected as a recommended reuse value. However, if there is a concern for odors or for overland runoff of TPH to surface water through snowmelt processes, the State of Hawaii EAL of 500 mg/kg can be used as a recommended reuse value for both gasoline and middle-distillate petroleum.

7 Recommendations

We conclude our assessment with recommendations to address the soil reuse values and to reduce the potential effects of contaminants at McMurdo Station.

7.1 Recommendations for soil reuse values

Our recommended values are based only on published risk-based assessment and current regulations for cleanup levels and soil reuse guidance in selected countries and U.S. states with cold climates. Our risk-based derivation for whole petroleum reuse values include:

- If there is no concern for petroleum odors, use the Alaska reuse value for DRO of 12,500 mg/kg.
- If petroleum odors are likely and if contaminants contain gasoline, which is a common fuel used at the Station, use the GRO reuse value of 1400 mg/kg.
- If odors and migration of contaminants into overland runoff is a concern, use the Hawaii reuse value of 500 mg/kg for gasoline and middle-distillate petroleum.

Ultimately, it is up to NSF to decide the reuse values for the Station. NSF has rulemaking authority over hazardous waste and cleanup requirements at the Station under the Antarctic Conservation Act of 1978 (NSF 1995).

7.2 Recommendations for future efforts and focus areas

Site preparation for the infrastructure development and modernization at the Station would potentially excavate legacy contaminated soils that have concentration values exceeding human health and environmental protection standards. Frozen in place, contaminants persist due to slow biological degradation and accumulate or last indefinitely. Contaminants (hydrocarbons and metals) were specifically found to be elevated in various places (Kennicutt et al. 2010; and Klein et al. 2008, 2012). Contaminants, especially fuel designed with a low freezing point, would alter the physical and mechanical properties of the frozen ground. Existing hydrocarbon-contaminated fill materials needs to be examined in foundation design because of possible chemical incompatibility with building materials and potential leaching or migration during construction or excavation of soil

(Bjella, Affleck, et al. 2018). To quantify and reduce the potential effects of contaminants at McMurdo Station, we recommend the following:

- Determine the type of petroleum hydrocarbon present in the soils as a function of time, location, and land-use activity. This would provide mitigation approaches for capping or placing a thin layer of clean soil on top TPH-affected soil, especially in areas adjacent to buildings.
- Assess appropriate on-site remediation technologies. This would provide a more sustainable approach and operational cost savings than shipping and disposing of the materials in the States. With acceptable risk analysis, the remediated soils can be reused appropriately. This would reduce material harvesting on the hill slopes; gravel materials especially are finite resources at the Station.
- Examine the potential for soil-vapor partitioning of hydrocarbons and vapor intrusion in buildings as a function of (1) soil; (2) type of hydrocarbon; and (3) building type, location, and primary use. This would consider different scenarios based on current and future building construction at the Station.

These recommendations are mainly protective measures for sustainable solutions, safeguarding the environment, and the health and safety of the residents and staff at the Station.

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Appendix A: Laboratory Report

Laboratory Report

Absolute Resource associates
124 Heritage Avenue Portsmouth NH 03801

Jenifer Milam
Engineer Research & Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180

PO Number: W912HZ-15-A-0043
Job ID: 50791
Date Received: 10/16/19

Project: Order ID:1205 19J1703

Attached please find results for the analysis of the samples received on the date referenced above.

Unless otherwise noted in the attached report, the analyses performed met the requirements of Absolute Resource Associates' Quality Assurance Plan. The Standard Operating Procedures are based upon USEPA SW-846, USEPA Methods for Chemical Analysis of Water and Wastewater, Standard Methods for the Examination of Water and Wastewater and other recognized methodologies. The results contained in this report pertain only to the samples as indicated on the chain of custody.

Absolute Resource Associates maintains certification with the agencies listed below.

We appreciate the opportunity to provide laboratory services. If you have any questions regarding the enclosed report, please contact the laboratory and we will be glad to assist you.

Sincerely,
Absolute Resource Associates

(for)

Jennifer Lowe
Laboratory Manager

Date of Approval: 11/11/2019
Total number of pages: 17

Absolute Resource Associates Certifications

New Hampshire	1732	Massachusetts	M-NH902
Maine	NH903		

Project ID: Order ID:1205 19J1703

Sample Association Table

Field ID	Matrix	Date-Time Sampled	Lab#	Analysis
19J1703-01	Solid	10/16/2019 0:00	50791-001	
				Acid & Base/Neutral Extractables in solid by 8270
				TPH in solids by 8100
19J1703-02	Solid	10/16/2019 0:00	50791-002	
				Acid & Base/Neutral Extractables in solid by 8270
				TPH in solids by 8100

Project ID: Order ID:1205 19J1703
Job ID: 50791
Sample#: 50791-001
Sample ID: 19J1703-01
Matrix: Solid Percent Dry: 96.1% Results expressed on a dry weight basis.
Sampled: 10/16/19 0:00

Parameter	Result	Reporting Limit	DL	Units	Instr Dil'n Factor	Analyst	Prep Date	Prep Time	Batch	Analysis Date	Analysis Time	Reference
N-nitrosodimethylamine	U	1.0	0.090	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
pyridine	U	1.0	0.25	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
aniline	U	1.0	0.076	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
phenol	U	1.0	0.15	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
2-chlorophenol	U	2.5	0.26	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
bis(2-chloroethyl)ether	U	1.0	0.16	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
1,3-dichlorobenzene	U	1.0	0.13	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
1,4-dichlorobenzene	U	1.0	0.45	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
1,2-dichlorobenzene	U	1.0	0.19	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
benzyl alcohol	U	1.0	0.15	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
2-methylphenol	U	1.0	0.15	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
2,2'-oxybis(1-chloropropane)	U	1.0	0.095	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
hexachloroethane	U	1.0	0.13	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
N-nitroso-di-N-propylamine	U	1.0	0.083	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
4-methylphenol	U	1.0	0.18	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
nitrobenzene	U	1.0	0.15	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
isophorone	U	2.5	0.14	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
2-nitrophenol	U	1.0	0.29	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
2,4-dimethylphenol	U	1.0	0.19	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
bis(2-chloroethoxy)methane	U	1.0	0.22	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
2,4-dichlorophenol	U	2.5	0.19	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
1,2,4-trichlorobenzene	U	2.5	0.13	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
naphthalene	U	0.25	0.20	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
benzoic acid	U	25	10	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
4-chloroaniline	U	1.0	0.37	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
hexachlorobutadiene	U	1.0	0.25	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
4-chloro-3-methylphenol	U	1.0	0.097	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
2-methylnaphthalene	0.47	0.25	0.051	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
hexachlorocyclopentadiene	U	5.1	0.35	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
2,4,6-trichlorophenol	U	1.0	0.18	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
2,4,5-trichlorophenol	U	1.0	0.18	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
2-chloronaphthalene	U	2.5	0.12	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
2-nitroaniline	U	1.0	0.18	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
acenaphthylene	U	0.25	0.14	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
dimethylphthalate	U	2.5	0.14	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
2,6-dinitrotoluene	U	1.0	0.13	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
2,4-dinitrotoluene	U	1.0	0.30	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
acenaphthene	U	0.25	0.13	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
3-nitroaniline	U	1.0	0.14	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
2,4-dinitrophenol	U	25	0.66	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
dibenzofuran	U	0.25	0.23	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
4-nitrophenol	U	5.1	0.20	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E

Project ID: Order ID:1205 19J1703
Job ID: 50791
Sample#: 50791-001
Sample ID: 19J1703-01
Matrix: Solid Percent Dry: 96.1% Results expressed on a dry weight basis.
Sampled: 10/16/19 0:00

Parameter	Result	Reporting Limit	DL	Units	Instr Dil'n Factor	Analyst	Prep Date	Prep Time	Batch	Analysis Date	Analysis Time	Reference
fluorene	U	0.25	0.14	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
diethyl phthalate	U	2.5	0.20	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
4-chlorophenyl phenyl ether	U	2.5	0.16	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
4-nitroaniline	U	2.5	0.29	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
4,6-dinitro-2-methylphenol	U	10	1.2	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
azobenzene	U	1.0	0.14	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
N-nitrosodiphenylamine	0.2 J	1.0	0.17	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
4-bromophenyl phenyl ether	U	1.0	0.19	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
hexachlorobenzene	U	1.0	0.51	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
pentachlorophenol	U	5.1	0.28	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
phenanthrene	U	0.25	0.11	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
anthracene	U	0.25	0.12	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
carbazole	U	1.0	0.15	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
di-n-butylphthalate	U	2.5	0.18	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
fluoranthene	U	0.25	0.25	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
benzidine	U	15	10	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
pyrene	U	0.25	0.19	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
butyl benzyl phthalate	U	2.5	0.20	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
benzo(a)anthracene	U	0.25	0.14	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
chrysene	U	0.25	0.15	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
3,3'-dichlorobenzidine	U	15	10	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
bis(2-ethylhexyl)phthalate	U	2.5	1.0	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
di-n-octyl phthalate	U	2.5	0.71	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
benzo(b)fluoranthene	U	0.25	0.051	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
benzo(k)fluoranthene	U	0.25	0.15	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
benzo(a)pyrene	U	0.25	0.14	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
indeno(1,2,3-cd)pyrene	U	0.25	0.20	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
dibenzo(a,h)anthracene	U	0.25	0.14	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
benzo(g,h,i)perylene	U	0.25	0.051	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
Surrogate Recovery		Limits										
2-fluorophenol SUR	55	21-100		%	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
phenol-D5 SUR	59	10-102		%	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
2,4,6-tribromophenol SUR	80	10-123		%	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
nitrobenzene-D5 SUR	63	35-114		%	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
2-fluorobiphenyl SUR	74	43-116		%	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E
p-terphenyl-D14 SUR	93	33-141		%	5	CL	10/18/19	15:35	12120	11/1/19	21:04	SW3546/8270E

Note: Dilution was required due to matrix interference, causing internal standard suppression.

Project ID: Order ID:1205 19J1703
Job ID: 50791
Sample#: 50791-002
Sample ID: 19J1703-02
Matrix: Solid Percent Dry: 91.3% Results expressed on a dry weight basis.
Sampled: 10/16/19 0:00

Parameter	Result	Reporting Limit	DL	Units	Instr Dil'n Factor	Analyst	Prep Date	Prep Time	Batch	Analysis Date	Analysis Time	Reference
N-nitrosodimethylamine	U	0.22	0.019	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
pyridine	U	0.22	0.054	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
aniline	U	0.22	0.016	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
phenol	U	0.22	0.032	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
2-chlorophenol	U	0.54	0.055	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
bis(2-chloroethyl)ether	U	0.22	0.034	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
1,3-dichlorobenzene	U	0.22	0.029	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
1,4-dichlorobenzene	U	0.22	0.095	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
1,2-dichlorobenzene	U	0.22	0.040	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
benzyl alcohol	U	0.22	0.031	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
2-methylphenol	U	0.22	0.032	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
2,2'-oxybis(1-chloropropane)	U	0.22	0.020	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
hexachloroethane	U	0.22	0.029	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
N-nitroso-di-N-propylamine	U	0.22	0.018	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
4-methylphenol	U	0.22	0.039	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
nitrobenzene	U	0.22	0.031	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
isophorone	U	0.54	0.030	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
2-nitrophenol	U	0.22	0.062	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
2,4-dimethylphenol	U	0.22	0.041	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
bis(2-chloroethoxy)methane	U	0.22	0.047	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
2,4-dichlorophenol	U	0.54	0.040	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
1,2,4-trichlorobenzene	U	0.54	0.029	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
naphthalene	7.1	0.054	0.043	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
benzoic acid	U	5.4	2.2	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
4-chloroaniline	U	0.22	0.079	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
hexachlorobutadiene	U	0.22	0.054	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
4-chloro-3-methylphenol	U	0.22	0.021	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
2-methylnaphthalene	18	0.27	0.054	ug/g	5	CL	10/18/19	15:35	12120	11/1/19	20:34	SW3546/8270E
hexachlorocyclopentadiene	U	1.1	0.074	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
2,4,6-trichlorophenol	U	0.22	0.039	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
2,4,5-trichlorophenol	U	0.22	0.037	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
2-chloronaphthalene	U	0.54	0.025	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
2-nitroaniline	U	0.22	0.038	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
acenaphthylene	U	0.054	0.029	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
dimethylphthalate	U	0.54	0.031	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
2,6-dinitrotoluene	U	0.22	0.028	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
2,4-dinitrotoluene	U	0.22	0.064	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
acenaphthene	U	0.054	0.028	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
3-nitroaniline	U	0.22	0.031	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
2,4-dinitrophenol	U	5.4	0.14	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
dibenzofuran	0.18	0.054	0.049	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
4-nitrophenol	U	1.1	0.043	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E

Project ID: Order ID:1205 19J1703
Job ID: 50791
Sample#: 50791-002
Sample ID: 19J1703-02
Matrix: Solid Percent Dry: 91.3% Results expressed on a dry weight basis.
Sampled: 10/16/19 0:00

Parameter	Result	Reporting Limit	DL	Units	Instr Dil'n Factor	Analyst	Prep Date	Prep Time	Batch	Analysis Date	Analysis Time	Reference
fluorene	0.17	0.054	0.030	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
diethyl phthalate	U	0.54	0.043	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
4-chlorophenyl phenyl ether	U	0.54	0.034	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
4-nitroaniline	U	0.54	0.061	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
4,6-dinitro-2-methylphenol	U	2.2	0.25	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
azobenzene	U	0.22	0.029	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
N-nitrosodiphenylamine	U	0.22	0.037	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
4-bromophenyl phenyl ether	U	0.22	0.040	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
hexachlorobenzene	U	0.22	0.11	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
pentachlorophenol	U	1.1	0.060	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
phenanthrene	0.05 J	0.054	0.024	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
anthracene	U	0.054	0.025	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
carbazole	U	0.22	0.032	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
di-n-butylphthalate	U	0.54	0.039	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
fluoranthene	U	0.054	0.054	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
benzidine	U	3.3	2.2	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
pyrene	U	0.054	0.040	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
butyl benzyl phthalate	U	0.54	0.043	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
benzo(a)anthracene	U	0.054	0.029	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
chrysene	U	0.054	0.032	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
3,3'-dichlorobenzidine	U	3.3	2.2	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
bis(2-ethylhexyl)phthalate	0.3 J	0.54	0.21	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
di-n-octyl phthalate	U	0.54	0.15	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
benzo(b)fluoranthene	U	0.054	0.011	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
benzo(k)fluoranthene	U	0.054	0.032	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
benzo(a)pyrene	U	0.054	0.029	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
indeno(1,2,3-cd)pyrene	U	0.054	0.042	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
dibenzo(a,h)anthracene	U	0.054	0.029	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
benzo(g,h,i)perylene	U	0.054	0.011	ug/g	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
Surrogate Recovery		Limits										
2-fluorophenol SUR	63	21-100		%	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
phenol-D5 SUR	66	10-102		%	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
2,4,6-tribromophenol SUR	82	10-123		%	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
nitrobenzene-D5 SUR	89	35-114		%	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
2-fluorobiphenyl SUR	74	43-116		%	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E
p-terphenyl-D14 SUR	82	33-141		%	1	CL	10/18/19	15:35	12120	10/29/19	18:00	SW3546/8270E

Project ID: Order ID:1205 19J1703

Job ID: 50791

Sample#: 50791-001

Sample ID: 19J1703-01

Matrix: Solid Percent Dry: 96.1% Results expressed on a dry weight basis.

Sampled: 10/16/19 0:00

Parameter	Result	Reporting Limit	DL	Units	Instr Dil'n Factor	Analyst	Prep Date	Prep Time	Batch	Analysis Date	Analysis Time	Reference
TPH C10-C36	14000	970	130	ug/g	5	DBV	10/21/19	8:52	12143	10/28/19	17:27	SW3550C8015Dm
Surrogate Recovery		Limits										
2-fluorobiphenyl SUR	118	40-140		%	5	DBV	10/21/19	8:52	12143	10/28/19	17:27	SW3550C8015Dm
o-terphenyl SUR	132	40-140		%	5	DBV	10/21/19	8:52	12143	10/28/19	17:27	SW3550C8015Dm

Sample#: 50791-002

Sample ID: 19J1703-02

Matrix: Solid Percent Dry: 91.3% Results expressed on a dry weight basis.

Sampled: 10/16/19 0:00

Parameter	Result	Reporting Limit	DL	Units	Instr Dil'n Factor	Analyst	Prep Date	Prep Time	Batch	Analysis Date	Analysis Time	Reference
TPH C10-C36	4900	200	28	ug/g	1	ACA	10/21/19	8:52	12143	10/21/19	22:15	SW3550C8015Dm
Surrogate Recovery		Limits										
2-fluorobiphenyl SUR	118	40-140		%	1	ACA	10/21/19	8:52	12143	10/21/19	22:15	SW3550C8015Dm
o-terphenyl SUR	111	40-140		%	1	ACA	10/21/19	8:52	12143	10/21/19	22:15	SW3550C8015Dm

Quality Control Report

124 Heritage Avenue Unit 16
Portsmouth, NH 03801
www.absoluteresourceassociates.com

Case Narrative
Lab # 50791

Sample Receiving and Chain of Custody Discrepancies

Samples were received in acceptable condition, at 0 degrees C, on ice, and in accordance with sample handling, preservation and integrity guidelines.

Calibration

No exceptions noted.

Method Blank

No exceptions noted.

Surrogate Recoveries

No exceptions noted.

Laboratory Control Sample Results

SVOC: The LCS/D12120 did not meet the acceptance criteria for pyridine, N-nitrosodimethylamine, hexachlorocyclopentadiene, and 4,6-dinitro-2-methylphenol. Since <10% of the compounds were outside of the acceptance criteria, reanalysis is not required.

Matrix Spike/Matrix Spike Duplicate/Duplicate Results

Not requested for this project.

Other

SVOC: The following samples required a re-analysis at a dilution due to internal standard interferences caused by matrix effect: 50791-001.
Reporting Limits: Dilutions performed during the analysis are noted on the result pages.

No other exceptions noted.

Data Qualifiers

U = This compound was analyzed for, but not detected above the associated method detection limit.
J = The analytical result was below the instrument calibration range, but above the method detection limit. The reported concentration is an estimate.

GLOSSARY

%R	Percent Recovery
BLK	Blank (Method Blank, Preparation Blank)
CCB	Continuing Calibration Blank
CCV	Continuing Calibration Verification
CRM	Certified Reference Material (associated with solid Metals samples)
CRMD	Certified Reference Material Duplicate (associated with solid Metals samples)
Dil'n	Dilution
DL	Detection Limit
DUP	Duplicate
LCS	Laboratory Control Sample
LCSD	Laboratory Control Sample Duplicate
LOD	Limit of Detection
LOQ	Limit of Quantitation
MB	Methanol Blank (associated with solid VOC samples)
MLCS	Methanol Laboratory Control Sample (associated with solid VOC samples)
MLCSD	Methanol Laboratory Control Sample Duplicate (associated with solid VOC samples)
MS	Matrix Spike
MSD	Matrix Spike Duplicate
PB	Preparation Blank
QC	Quality Control
RL	Reporting Limit
RPD	Relative Percent Difference
SUR	Surrogate

- QC Report -

Method	QC ID	Parameter	Associated Sample		Result	Units	Amt Added	%R	Limits	RPD	RPD Limit
SW3546/8270E	BLK12120	pyridine		<	0.19	ug/g					
		N-nitrosodimethylamine		<	0.19	ug/g					
		aniline		<	0.19	ug/g					
		phenol		<	0.19	ug/g					
		2-chlorophenol		<	0.48	ug/g					
		bis(2-chloroethyl)ether		<	0.19	ug/g					
		1,3-dichlorobenzene		<	0.19	ug/g					
		1,4-dichlorobenzene		<	0.19	ug/g					
		1,2-dichlorobenzene		<	0.19	ug/g					
		benzyl alcohol		<	0.19	ug/g					
		2-methylphenol		<	0.19	ug/g					
		2,2'-oxybis(1-chloropropane)		<	0.19	ug/g					
		hexachloroethane		<	0.19	ug/g					
		N-nitroso-di-N-propylamine		<	0.19	ug/g					
		4-methylphenol		<	0.19	ug/g					
		nitrobenzene		<	0.19	ug/g					
		isophorone		<	0.48	ug/g					
		2-nitrophenol		<	0.19	ug/g					
		2,4-dimethylphenol		<	0.19	ug/g					
		bis(2-chloroethoxy)methane		<	0.19	ug/g					
		2,4-dichlorophenol		<	0.48	ug/g					
		1,2,4-trichlorobenzene		<	0.48	ug/g					
		naphthalene		<	0.048	ug/g					
		benzoic acid		<	4.8	ug/g					
		4-chloroaniline		<	0.19	ug/g					
		hexachlorobutadiene		<	0.19	ug/g					
		4-chloro-3-methylphenol		<	0.19	ug/g					
		2-methylnaphthalene		<	0.048	ug/g					
		hexachlorocyclopentadiene		<	0.95	ug/g					
		2,4,6-trichlorophenol		<	0.19	ug/g					
		2,4,5-trichlorophenol		<	0.19	ug/g					
		2-chloronaphthalene		<	0.48	ug/g					
		2-nitroaniline		<	0.19	ug/g					
		acenaphthylene		<	0.048	ug/g					
		dimethylphthalate		<	0.48	ug/g					
		2,6-dinitrotoluene		<	0.19	ug/g					
		2,4-dinitrotoluene		<	0.19	ug/g					
		acenaphthene		<	0.048	ug/g					
		3-nitroaniline		<	0.19	ug/g					
		2,4-dinitrophenol		<	4.8	ug/g					
		dibenzofuran		<	0.048	ug/g					
		4-nitrophenol		<	0.95	ug/g					
		fluorene		<	0.048	ug/g					
		diethyl phthalate		<	0.48	ug/g					
		4-chlorophenyl phenyl ether		<	0.48	ug/g					
		4-nitroaniline		<	0.48	ug/g					
		4,6-dinitro-2-methylphenol		<	1.9	ug/g					

Method	QC ID	Parameter	Associated Sample		Result	Units	Amt Added	%R	Limits		RPD	RPD Limit
SW3546/8270E	BLK12120	azobenzene		<	0.19	ug/g						
		N-nitrosodiphenylamine		<	0.19	ug/g						
		4-bromophenyl phenyl ether		<	0.19	ug/g						
		hexachlorobenzene		<	0.19	ug/g						
		pentachlorophenol		<	0.95	ug/g						
		phenanthrene		<	0.048	ug/g						
		anthracene		<	0.048	ug/g						
		carbazole		<	0.19	ug/g						
		di-n-butylphthalate		<	0.48	ug/g						
		fluoranthene		<	0.048	ug/g						
		benzidine		<	2.9	ug/g						
		pyrene		<	0.048	ug/g						
		butyl benzyl phthalate		<	0.48	ug/g						
		benzo(a)anthracene		<	0.048	ug/g						
		chrysene		<	0.048	ug/g						
		3,3'-dichlorobenzidine		<	2.9	ug/g						
		bis(2-ethylhexyl)phthalate		<	0.48	ug/g						
		di-n-octyl phthalate		<	0.48	ug/g						
		benzo(b)fluoranthene		<	0.048	ug/g						
		benzo(k)fluoranthene		<	0.048	ug/g						
		benzo(a)pyrene		<	0.048	ug/g						
		indeno(1,2,3-cd)pyrene		<	0.048	ug/g						
		dibenzo(a,h)anthracene		<	0.048	ug/g						
		benzo(g,h,i)perylene		<	0.048	ug/g						
		2-fluorophenol SUR			56	%			21	100		
		phenol-D5 SUR			58	%			10	102		
		2,4,6-tribromophenol SUR			67	%			10	123		
		nitrobenzene-D5 SUR			65	%			35	114		
		2-fluorobiphenyl SUR			67	%			43	116		
		p-terphenyl-D14 SUR			74	%			33	141		

Method	QC ID	Parameter	Associated Sample		Result	Units	Amt Added	%R		Limits		RPD	RPD Limit
SW3546/8270E	LCS12120	pyridine			1.1	ug/g	3.80	29	*	30	130		
		N-nitrosodimethylamine			1.4	ug/g	3.80	38	*	40	140		
		aniline			1.7	ug/g	3.80	46		40	140		
		phenol			2.1	ug/g	3.80	55		30	130		
		2-chlorophenol			2.2	ug/g	3.80	57		30	130		
		bis(2-chloroethyl)ether			2.0	ug/g	3.80	53		40	140		
		1,3-dichlorobenzene			2.0	ug/g	3.80	52		40	140		
		1,4-dichlorobenzene			2.0	ug/g	3.80	53		40	140		
		1,2-dichlorobenzene			2.1	ug/g	3.80	55		40	140		
		benzyl alcohol			2.6	ug/g	3.80	69		30	130		
		2-methylphenol			2.2	ug/g	3.80	57		30	130		
		2,2'-oxybis(1-chloropropane)			2.8	ug/g	3.80	75		40	140		
		hexachloroethane			2.0	ug/g	3.80	54		40	140		
		N-nitroso-di-N-propylamine			2.1	ug/g	3.80	56		40	140		
		4-methylphenol			2.2	ug/g	3.80	59		30	130		
		nitrobenzene			2.4	ug/g	3.80	64		40	140		
		isophorone			2.4	ug/g	3.80	63		40	140		
		2-nitrophenol			2.3	ug/g	3.80	59		30	130		
		2,4-dimethylphenol			2.4	ug/g	3.80	63		30	130		
		bis(2-chloroethoxy)methane			2.3	ug/g	3.80	61		40	140		
		2,4-dichlorophenol			2.6	ug/g	3.80	69		30	130		
		1,2,4-trichlorobenzene			2.6	ug/g	3.80	68		40	140		
		naphthalene			2.3	ug/g	3.80	61		40	140		
		benzoic acid		<	4.8	ug/g							
		4-chloroaniline			2.1	ug/g	3.80	56		40	140		
		hexachlorobutadiene			2.8	ug/g	3.80	73		40	140		
		4-chloro-3-methylphenol			2.5	ug/g	3.80	66		30	130		
		2-methylnaphthalene			2.7	ug/g	3.80	71		40	140		
		hexachlorocyclopentadiene			1.3	ug/g	3.80	35	*	40	140		
		2,4,6-trichlorophenol			2.7	ug/g	3.80	71		30	130		
		2,4,5-trichlorophenol			2.6	ug/g	3.80	70		30	130		
		2-chloronaphthalene			2.5	ug/g	3.80	64		40	140		
		2-nitroaniline			2.3	ug/g	3.80	60		40	140		
		acenaphthylene			2.5	ug/g	3.80	66		40	140		
		dimethylphthalate			2.7	ug/g	3.80	71		40	140		
		2,6-dinitrotoluene			2.8	ug/g	3.80	73		40	140		
		2,4-dinitrotoluene			2.6	ug/g	3.80	68		40	140		
		acenaphthene			2.5	ug/g	3.80	65		40	140		
		3-nitroaniline			2.3	ug/g	3.80	60		40	140		
		2,4-dinitrophenol		<	4.8	ug/g							
		dibenzofuran			2.6	ug/g	3.80	69		40	140		
		4-nitrophenol			1.9	ug/g	3.80	50		30	130		
		fluorene			2.8	ug/g	3.80	72		40	140		
		diethyl phthalate			2.6	ug/g	3.80	69		40	140		
		4-chlorophenyl phenyl ether			2.8	ug/g	3.80	74		40	140		
		4-nitroaniline			2.2	ug/g	3.80	57		40	140		
		4,6-dinitro-2-methylphenol		<	1.9	ug/g	3.80	15	*	30	130		
		azobenzene			2.4	ug/g	3.80	62		40	140		
		N-nitrosodiphenylamine			3.1	ug/g	3.80	82		40	140		

Method	QC ID	Parameter	Associated Sample		Result	Units	Amt Added	%R	Limits		RPD	RPD Limit
SW3546/8270E	LCS12120	4-bromophenyl phenyl ether			2.8	ug/g	3.80	75	40	140		
		hexachlorobenzene			3.0	ug/g	3.80	78	40	140		
		pentachlorophenol			1.8	ug/g	3.80	48	30	130		
		phenanthrene			2.7	ug/g	3.80	72	40	140		
		anthracene			2.7	ug/g	3.80	72	40	140		
		carbazole			2.6	ug/g	3.80	68	40	140		
		di-n-butylphthalate			2.6	ug/g	3.80	68	40	140		
		fluoranthene			3.0	ug/g	3.80	78	40	140		
		benzidine		<	2.9	ug/g	3.80	61	40	140		
		pyrene			2.5	ug/g	3.80	66	40	140		
		butyl benzyl phthalate			2.2	ug/g	3.80	58	40	140		
		benzo(a)anthracene			2.7	ug/g	3.80	72	40	140		
		chrysene			2.7	ug/g	3.80	71	40	140		
		3,3'-dichlorobenzidine			2.9	ug/g	3.80	76	40	140		
		bis(2-ethylhexyl)phthalate			2.5	ug/g	3.80	66	40	140		
		di-n-octyl phthalate			2.3	ug/g	3.80	60	40	140		
		benzo(b)fluoranthene			2.8	ug/g	3.80	74	40	140		
		benzo(k)fluoranthene			2.9	ug/g	3.80	77	40	140		
		benzo(a)pyrene			2.7	ug/g	3.80	71	40	140		
		indeno(1,2,3-cd)pyrene			2.8	ug/g	3.80	73	40	140		
		dibenzo(a,h)anthracene			2.6	ug/g	3.80	69	40	140		
		benzo(g,h,i)perylene			2.6	ug/g	3.80	67	40	140		
		2-fluorophenol SUR			58	%			21	100		
		phenol-D5 SUR			60	%			10	102		
		2,4,6-tribromophenol SUR			79	%			10	123		
		nitrobenzene-D5 SUR			68	%			35	114		
		2-fluorobiphenyl SUR			72	%			43	116		
		p-terphenyl-D14 SUR			72	%			33	141		

Method	QC ID	Parameter	Associated Sample		Result	Units	Amt Added	%R		Limits		RPD	RPD Limit
SW3546/8270E	LCSD12120	pyridine			0.97	ug/g	3.868	25	*	30	130	14	30
		N-nitrosodimethylamine			1.4	ug/g	3.86	36	*	40	140	5	30
		aniline			1.6	ug/g	3.86	42		40	140	10	30
		phenol			2.0	ug/g	3.86	51		30	130	7	30
		2-chlorophenol			2.0	ug/g	3.86	51		30	130	12	30
		bis(2-chloroethyl)ether			1.9	ug/g	3.86	49		40	140	8	30
		1,3-dichlorobenzene			1.8	ug/g	3.86	47		40	140	9	30
		1,4-dichlorobenzene			1.8	ug/g	3.86	48		40	140	11	30
		1,2-dichlorobenzene			1.9	ug/g	3.86	50		40	140	9	30
		benzyl alcohol			2.4	ug/g	3.86	62		30	130	10	30
		2-methylphenol			2.1	ug/g	3.86	54		30	130	6	30
		2,2'-oxybis(1-chloropropane)			2.6	ug/g	3.86	68		40	140	10	30
		hexachloroethane			1.9	ug/g	3.86	49		40	140	8	30
		N-nitroso-di-N-propylamine			2.0	ug/g	3.86	53		40	140	6	30
		4-methylphenol			2.2	ug/g	3.86	56		30	130	5	30
		nitrobenzene			2.4	ug/g	3.86	61		40	140	4	30
		isophorone			2.3	ug/g	3.86	60		40	140	4	30
		2-nitrophenol			2.1	ug/g	3.86	55		30	130	8	30
		2,4-dimethylphenol			2.4	ug/g	3.86	61		30	130	3	30
		bis(2-chloroethoxy)methane			2.3	ug/g	3.86	59		40	140	4	30
		2,4-dichlorophenol			2.6	ug/g	3.86	67		30	130	3	30
		1,2,4-trichlorobenzene			2.4	ug/g	3.86	62		40	140	9	30
		naphthalene			2.2	ug/g	3.86	57		40	140	7	30
		benzoic acid		<	4.8	ug/g							30
		4-chloroaniline			2.0	ug/g	3.86	53		40	140	7	30
		hexachlorobutadiene			2.6	ug/g	3.86	68		40	140	6	30
		4-chloro-3-methylphenol			2.5	ug/g	3.86	66		30	130	1	30
		2-methylnaphthalene			2.6	ug/g	3.86	67		40	140	5	30
		hexachlorocyclopentadiene			1.5	ug/g	3.86	38	*	40	140	10	30
		2,4,6-trichlorophenol			2.8	ug/g	3.86	73		30	130	3	30
		2,4,5-trichlorophenol			2.7	ug/g	3.86	71		30	130	2	30
		2-chloronaphthalene			2.4	ug/g	3.86	62		40	140	3	30
		2-nitroaniline			2.4	ug/g	3.86	62		40	140	2	30
		acenaphthylene			2.5	ug/g	3.86	65		40	140	1	30
		dimethylphthalate			2.8	ug/g	3.86	72		40	140	2	30
		2,6-dinitrotoluene			3.0	ug/g	3.86	76		40	140	4	30
		2,4-dinitrotoluene			2.7	ug/g	3.86	70		40	140	3	30
		acenaphthene			2.5	ug/g	3.86	64		40	140	2	30
		3-nitroaniline			2.4	ug/g	3.86	62		40	140	2	30
		2,4-dinitrophenol		<	4.8	ug/g							30
		dibenzofuran			2.6	ug/g	3.86	68		40	140	2	30
		4-nitrophenol			2.1	ug/g	3.86	55		30	130	9	30
		fluorene			2.8	ug/g	3.86	72		40	140	0	30
		diethyl phthalate			2.7	ug/g	3.86	70		40	140	2	30
		4-chlorophenyl phenyl ether			2.9	ug/g	3.86	75		40	140	1	30
		4-nitroaniline			2.3	ug/g	3.86	60		40	140	5	30
		4,6-dinitro-2-methylphenol		<	1.9	ug/g	3.86	14	*	30	130	7	30
		azobenzene			2.5	ug/g	3.86	65		40	140	4	30
		N-nitrosodiphenylamine			3.3	ug/g	3.86	86		40	140	5	30

Method	QC ID	Parameter	Associated Sample		Result	Units	Amt Added	%R	Limits		RPD	RPD Limit
SW3546/8270E	LCSD12120	4-bromophenyl phenyl ether			3.0	ug/g	3.86	79	40	140	5	30
		hexachlorobenzene			3.2	ug/g	3.86	82	40	140	5	30
		pentachlorophenol			1.8	ug/g	3.86	46	30	130	5	30
		phenanthrene			2.9	ug/g	3.86	76	40	140	5	30
		anthracene			2.9	ug/g	3.86	75	40	140	5	30
		carbazole			2.8	ug/g	3.86	71	40	140	5	30
		di-n-butylphthalate			2.7	ug/g	3.86	71	40	140	5	30
		fluoranthene			3.1	ug/g	3.86	81	40	140	4	30
		benzidine		<	2.9	ug/g	3.86	70	40	140	14	30
		pyrene			2.9	ug/g	3.86	74	40	140	11	30
		butyl benzyl phthalate			2.5	ug/g	3.86	65	40	140	10	30
		benzo(a)anthracene			2.9	ug/g	3.86	76	40	140	5	30
		chrysene			2.9	ug/g	3.86	75	40	140	6	30
		3,3'-dichlorobenzidine			3.1	ug/g	3.86	79	40	140	4	30
		bis(2-ethylhexyl)phthalate			2.8	ug/g	3.86	73	40	140	10	30
		di-n-octyl phthalate			2.7	ug/g	3.86	69	40	140	13	30
		benzo(b)fluoranthene			3.0	ug/g	3.86	77	40	140	4	30
		benzo(k)fluoranthene			3.2	ug/g	3.86	83	40	140	8	30
		benzo(a)pyrene			2.9	ug/g	3.86	76	40	140	7	30
		indeno(1,2,3-cd)pyrene			2.8	ug/g	3.86	73	40	140	1	30
		dibenzo(a,h)anthracene			2.7	ug/g	3.86	70	40	140	2	30
		benzo(g,h,i)perylene			2.6	ug/g	3.86	67	40	140	1	30
		2-fluorophenol SUR			52	%			21	100		
		phenol-D5 SUR			57	%			10	102		
		2,4,6-tribromophenol SUR			83	%			10	123		
		nitrobenzene-D5 SUR			62	%			35	114		
		2-fluorobiphenyl SUR			69	%			43	116		
		p-terphenyl-D14 SUR			79	%			33	141		
SW3550C8015D	BLK12143	TPH C10-C36		<	100	ug/g						
		2-fluorobiphenyl SUR			100	%			40	140		
		o-terphenyl SUR			103	%			40	140		
SW3550C8015D	DUP12143	TPH C10-C36	50812-006	<	110	ug/g						20
		2-fluorobiphenyl SUR	50812-006		100	%			40	140		
		o-terphenyl SUR	50812-006		96	%			40	140		
SW3550C8015D	LCS12143	TPH C10-C36			2200	ug/g	2500	89	40	140		
		2-fluorobiphenyl SUR			102	%			40	140		
		o-terphenyl SUR			106	%			40	140		
SW3550C8015D	MS12143	TPH C10-C36	50812-006		2700	ug/g	2877	93	40	140		
		2-fluorobiphenyl SUR	50812-006		107	%			40	140		
		o-terphenyl SUR	50812-006		112	%			40	140		

SUBCONTRACT ORDER

ERDC-EL-EP-C

19J1703

SENDING LABORATORY:	**RECEIVING LABORATORY:**
ERDC-EL-EP-C	ARA
3909 Halls Ferry Road , Building 3299	124 Heritage Ave, #16
Vicksburg, MS 39180	Portsmouth, NH 03801
Phone: 601-634-7431	Phone :(603) 436-2001
Fax: 601-619-5138	Fax:
Project Manager: Allyson Wooley	

Bill using PR&C Order ID:
VISA 1205

Analysis	Due	Expires	Laboratory ID	Comments
Sample Name: Soil Pile				
Sample ID: 19J1703-01	**Soil/Sedi**	**Sampled: 16-Oct-2019 00:00**	50791-01	
DRO	31-Oct-2019 00:00	13-Nov-2019 00:0(		
ORO	31-Oct-2019 00:00	13-Nov-2019 00:0(		
SVOC	15-Nov-2019 00:00	30-Oct-2019 00:00		
Containers Supplied:				
Sample Name: ITC FI				
Sample ID: 19J1703-02	**Soil/Sedi**	**Sampled: 16-Oct-2019 00:00**	-02	
DRO	31-Oct-2019 00:00	13-Nov-2019 00:0(		
ORO	31-Oct-2019 00:00	13-Nov-2019 00:0(		
SVOC	15-Nov-2019 00:00	30-Oct-2019 00:00		
Containers Supplied:				

50791
Charge ERDC-EL
ATTN: Kelli Hartman
50791-01 Soil Pile - 123.376 g
-02 ITC FI - 133.153 g
ORO/ORO and SVOCs
rec via FedEx 10/16/19 @ 10:41
0°C on ice

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Rosa T. Affleck, Amanda J. Barker, Anita K. Meyer, and Jay L. Clausen

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U.S. Army Engineer Research and Development Center
Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, NH 03755-1290

Environmental and Munitions Center of Expertise
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14. ABSTRACT

The soils at McMurdo Station in Antarctica contain hydrocarbons derived from accidental fuel spills and industrial development. The current practice for contaminated soils is to remove any material with concentrations greater than 100 mg/kg of total petroleum hydrocarbons (TPH) and to transport them to the United States for disposal. Any soils that contain concentrations of TPH less than 100 mg/kg can be reused on-site. While this is the current standard practice, there remains little evidence to verify that 100 mg/kg is an appropriate reuse standard. Moreover, the current practice is based on the guidelines for cleanup values in California (the port of entry where the soils are currently shipped for treatment and disposal), which has few environmental similarities with Antarctica.

In the present study, we investigate current regulations for cleanup and soil reuse in U.S. states, Canadian territories, and other countries with cold climates. We also discuss case studies from Arctic and Antarctic regions where soil has been reused after treatment. Additionally, we present a site conceptual model for risk assessment based on known site information and recommend future focus areas for addressing hydrocarbon-contaminated soils at McMurdo Station.

15. SUBJECT TERMS

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