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Post-Remediation Performance Assessment at a Petroleum Impacted Site

ESTCP ER-201582

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14. ABSTRACT
Many successful demonstrations have been conducted on light non-aqueous phase liquid (LNAPL) removal and plume treatment technologies. Technologies such as bioventing, dual-phase extraction (DPE), air sparging and monitored natural attenuation (MNA) were demonstrated successfully to show that LNAPL could be removed and benzene, toluene, ethylbenzene, and xylenes (BTEX) plume migration could be controlled. The expectation was that, unlike chlorinated solvents, petroleum sites could be closed after a reasonable period of time. However, in the longer term, many of these sites are still struggling to remove enough free product to meet U.S. Environmental Protection Agency (EPA) and state requirements of source control (product mobility) as well as plume treatment and are continuing to face long-term management challenges. The primary objective of this project is to help the Department of Defense (DoD) and others make a stronger case for closure of legacy petroleum sites, and expand users' knowledge of high-impact methods that can better reveal that actual risk associated with LNAPL presence and therefore help stakeholders make more informed remediation decisions.

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Acronyms and Abbreviations

ºC	degree Celsius
ºF	degree Fahrenheit
%	percent
µg/L	microgram per liter
µM/m^2-sec	micro-Molar per meter squared per second
AFB	Air Force Base
Amsl	above mean sea level
API	American Petroleum Institute
ARARs	Applicable or Relevant and Appropriate
AST	above ground storage tank
ASTDR	Agency for Toxic Substances and Disease Registry
ASTM	American Society for Testing and Materials
atm	standard atmosphere
Av	aviation
BAP	benzo(a)pyrene
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, xylene
BTU	british thermal unit
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm/s	centimeter per second
C	Carbon
CO_2	carbon dioxide
CPT	cone penetrometer
CSM	Conceptual Site Model
DCA	dichloroethane
DCB	Dichlorobenzene
DCC	Dynamic Closed Chamber
DCE	Dichloroethene
DEQ	Department of Environmental Quality
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DoD	Department of Defense
DPE	Dual Phase Extraction
DPT	direct-push technology
DRO	Diesel-range organics
EC	equivalent carbon
EDB	ethylene dibromide
e.g.	exempli gratia
EPA	United States Environmental Protection Agency
EPH	Extractable Petroleum Hydrocarbons
ER	Environmental Restoration
ERM	Environmental Resource Management
ESC	Engineering Service Center

ESTCP	Environmental Security Technology Certification Program
EXWC	Engineering and Expeditionary Warfare Center
FS	feasibility study
ft	feetft^2/day feet squared per day
FP	free product
g	gram
gal	gallons
gal/acre-yr	gallon per acre per year
g/L	grams per liter
gpm	gallon per minute
GRO	gasoline-range organics
H&S	health and safety
HCl	hydrochloric acid
HI	Hazard Index
HSA	hollow stem auger
HVDPE	high vacuum dual phase extraction
HQ	Hazard Quotient
IC	Institutional Controls
IDW	Investigation Derived Waste
i.e.	id est
IR	Installation Restoration
IRP	Installation Restoration Program
ITRC	Interstate Technology & Regulatory Council
JP	jet propellant
KCH	CH2MHill-Kleinfelder, A Joint Venture
LIF	laser-induced fluorescence
LNAPL	light non-aqueous phase liquid
LS	Lump Sum
LTM	long-term monitoring
LUC	land use control
LUST	Leaking Underground Storage Tank
MCL	maximum contaminant level
MCAS	Marine Corp Air Station
MDL	method detection limit
MEP	maximum extent practicable
mg/L	milligram per liter
mL	milliliter
m/sec	meters per second
mg/kg	milligram per kilogram
MNA	monitored natural attenuation
MPE	multi-phase extraction
mS/cm	milliSiemens per centimeter
MTBE	methyl tertiary butyl ether
mV	millivolt
MW	monitoring well
NA	not applicable/not available

NAC	Nevada Administrative Code
NAPL	Non-Aqueous Phase Liquid
NAS	Naval Air Station
NAVFAC	Naval Facilities Engineering Command
NBK	Naval Base Kitsap
ND	Non-Detect
NDEP	Nevada Division of Environmental Protection
NOU	Northern Operable Unit
NP	not published
NRC	National Research Council
NSZD	Natural Source Zone Depletion
NTU	nephelometric turbidity units
O_2	Oxygen
O&M	operation and maintenance
ORNL	Oak Ridge National Lab
ORP	oxidation reduction potential
OWS	oil/water separator
oz	ounce
PAL	project action limit
PAH	polycyclic aromatic hydrocarbon
PVI	Petroleum Vapor Instrusion
PW	pumping well
QA	quality assurance
QA/QC	quality assurance/quality control
RAIS	Risk Assessment Information System
RAO	Remedial Action Objective
RBSL	risk based screening level
RI	Remedial Investigation
RL	reporting limit
ROD	Record of Decision
RPM	remedial project manager
RSL	regional screening level
SERDP	Strategic Environmental Research and Development Program
SCAPS	Site Characterization and Analysis Penetrometer System
SSHP	Site Safety and Health Plan
SW	Southwest
TCE	Trichloroethene
TDS	Total Dissolved Solids
TPH-CWG	Total Petroleum Hydrocarbon Criteria Working Group
TPH-D	total petroleum hydrocarbons diesel range
TPH-e	total petroleum hydrocarbons extractable
TPH-G	total petroleum hydrocarbons gasoline range
TPH-p	total petroleum hydrocarbons purge
SOP	standard operating procedure
US	United States
U.S.C.	United States Code

USEPA	United States Environmental Protection Agency
UST	underground storage tank
VOC	volatile organic compound
VPH	Volatile Petroleum Hydrocarbons
WA	Washington
ZVI	zero-valent iron

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Abstract

Introduction and Objectives

Many successful demonstrations have been conducted on light non-aqueous phase liquid (LNAPL) removal and plume treatment technologies. Technologies such as bioventing, dual-phase extraction (DPE)[1], air sparging and monitored natural attenuation (MNA) were demonstrated successfully to show that LNAPL could be removed and benzene, toluene, ethylbenzene, and xylenes (BTEX) plume migration could be controlled. The expectation was that, unlike chlorinated solvents, petroleum sites could be closed after a reasonable period of time. However, in the longer term, many of these sites are still struggling to remove enough free product to meet U.S. Environmental Protection Agency (EPA) and state requirements of source control (product mobility) as well as plume treatment and are continuing to face long-term management challenges. The primary objective of this project is to help the Department of Defense (DoD) and others make a stronger case for closure of legacy petroleum sites, and expand users' knowledge of high-impact methods that can better reveal that actual risk associated with LNAPL presence and therefore help stakeholders make more informed remediation decisions.

Technology Description

The field demonstration was completed at Naval Air Station (NAS) Fallon located in Fallon, Nevada. Three methods were implemented to help assess the remaining LNAPL at a petroleum impacted site and provide guidance for future application at other DoD sites. This included

1) Applying a Natural Source Zone Depletion (NSZD) assessment using Carbon Traps to demonstrate that LNAPL bodies are not static, permanent contaminant sources but are biodegrading at the rate of hundreds or thousands of gallons per acre per year.
2) Collecting soil, groundwater and LNAPL samples per the American Petroleum Institute's (API) Total Petroleum Hydrocarbon Criteria Working Group (TPH-CWG) residual risk methodology, applying the Washington State TPH fractionation method, and demonstrating that the risk associated with weathered hydrocarbons is significantly reduced over time compared to fresh hydrocarbons.
3) Using historical recovery data to calculate the transmissivity of the LNAPL body to demonstrate that there is no or very little risk of LNAPL migration.

Performance and Cost Assessment

This project assessed multiple methodologies to better characterize remaining LNAPL at petroleum impacted sites and the evaluation of the residual risk remaining at these sites. These tools can be used as a supplement to help transition sites from active to passive recovery or even transition to site closure. Based on the results of this field investigation, active LNAPL recovery could potentially be discontinued without changing the low risk profile at the site. Costs were evaluated to determine what a similar investigation would cost to complete in order to assess the remaining LNAPL and determine a more cost-effective path forward for a site. As part of the cost assessment, transition to NSZD/MNA is compared with traditional free product recovery methods implemented for the recovery and management of LNAPL at impacted sites.

Implementation Issues

This project demonstrated three approaches for assessing residual LNAPL at petroleum impacted sites after many years of various free product recovery efforts. The project identified best practices

1 Dual-phase extraction refers to the process of simultaneously extracting groundwater, soil vapor and LNAPL.

and guidance regarding the characterization and assessment of residual LNAPL in order to make more informed decision regarding LNAPL remediation and site management strategies by refining the conceptual site model (CSM) and evaluating any residual risk. Details on the implementation of the various methodologies/tools and specific considerations are included in the Supplemental Guidance document.

Publications: There are no peer-reviewed publications to report.

Executive Summary

1.0 Introduction

Environmental Security Technology Certification Program (ESTCP) Project Number ER-201582, Post-Remediation Performance Assessment at a Petroleum Impacted Site, involves the demonstration and evaluation of multiple methods to assess residual LNAPL remaining at legacy sites. This executive summary briefly describes the methods being assessed, field activities, data evaluation and guidance developed in support of this project.

Since the 1990s, SERDP and ESTCP have conducted many demonstrations of light non-aqueous phase liquid (LNAPL) removal and plume treatment technologies. Technologies, such as bioventing, dual-phase extraction (DPE)[2], air sparging and monitored natural attenuation (MNA), were demonstrated successfully to show that LNAPL could be removed and benzene, toluene, ethylbenzene, and xylenes (BTEX) plume migration could be controlled.

These technologies were successfully applied at many sites including Department of Defense (DoD) sites and considerable free product was removed. The expectation was that unlike chlorinated solvents, petroleum sites could be closed after a reasonable period of time. However, in the longer term, many of these sites are still struggling to remove enough free product to meet U.S. Environmental Protection Agency (EPA) and state requirements of source control (product mobility) as well as plume treatment and are continuing to face long-term management challenges. In a recent survey of Navy and Marine Corps site remedial project managers (RPMs), almost one-third reported continuing remediation and long-term management challenges at petroleum sites. A review of post-remediation and long-term monitoring (LTM) data and some selective additional monitoring to evaluate residual risk are needed to accelerate the closure of these sites.

2.0 Objectives

The overall objective of this demonstration is to help the DoD make a stronger case for closure or transition to passive management of legacy petroleum sites and expand DoD's knowledge and use of alternative methods for characterizing LNAPL at petroleum-impacted sites in order to improve the conceptual site model (CSM) and make more informed decisions regarding remediation and site management. The technical objective of the demonstration was to implement three methods to assess remaining LNAPL at DoD petroleum-impacted sites and demonstrate that the weathered product remaining at these sites pose little or no significant risk. These methods included: i) API TPH-CWG residual risk methodology using the TPH fraction method; ii) Natural Source Zone Depletion (NSZD) measurements using Carbon Traps to estimate LNAPL biodegradation rates; and iii) the LNAPL transmissivity of LNAPL bodies using historical recovery data.

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2 Dual-phase extraction refers to the process of simultaneously extracting groundwater, soil vapor and LNAPL. This process typically also results in significant biodegradation due to the vapor extraction aerating soil. The process has gone by many names including bioslurping and multiphase extraction (MPE). In this report we use the term dual-phase extraction.

3.0 Technology Description

The field demonstration was completed at Naval Air Station (NAS) Fallon located in Fallon, Nevada. Three methods were implemented to help assess the remaining LNAPL at a petroleum impacted site and provide guidance for future application at other DoD sites. This included a Natural Source Zone Depletion (NSZD) assessment using Carbon Traps to estimate biodegradation rates, collection and analysis of soil, groundwater and LNAPL samples per the American Petroleum Institute's (API) Total Petroleum Hydrocarbon Criteria Working Group (TPH-CWG) residual risk methodology using the Washington State TPH fractionation method, and calculation of transmissivity rates using historical recovery data. A brief summary of each method is included below.

3.1 TPH-CWG Risk Based Method

The TPH-CWG method treats complex petroleum mixtures as a combination of fractions for conducting environmental modeling and estimating non-cancer risk. Carcinogenic petroleum compounds are evaluated separately. This approach can be used within a tiered framework to estimate human health risk and to calculate risk-based screening levels (RBSLs) for guiding cleanup decisions.

Since TPH is composed of multiple types of hydrocarbons, the TPH-CWG approach relies on the analytical separation of petroleum into 13 fractions. The fractions are based on their aliphatic or aromatic nature and their equivalent carbon (EC) number, a function of boiling point. Additionally, they have been assigned toxicological and transport parameters, derived from extensive reviews of data from individual compounds in the fraction or from petroleum mixtures represented within the fraction. The TPH-CWG fractionation data results, fraction toxicity information, and transport parameters can be used to perform a risk-based analysis for each fraction present at the site being evaluated. The hypothetical risk and the resulting soil screening level (i.e., the RBSL) for the "whole TPH" mixture are calculated by combining the non-cancer risks from individual fractions weighted by their percent composition within the TPH mixture, meaning the total risk is apportioned over the different fractions present.

The importance of this method is that it is differentiates between risks posed by fresh petroleum spills and weathered product. Compared to weathered product, fresh spills typically contain relatively higher risk factors (i.e., greater fraction of lower molecular weight compounds with higher vapor pressure, greater fraction of more toxic aromatics, greater proportion of soluble compounds, and lower proportion of compounds with strong sorption characteristics). By comparison, weathered product typically contains lower proportion of the more toxic aromatic fractions, lower soluble fractions, lower volatile fractions, and higher fractions that sorb well to soil.

The resulting risk based information on the reduced presence of the more toxic fractions and reduced leachability and volatility characteristics of the weathered fuel product will be placed in context of the state's petroleum program. Here, most states have similar rules, with minor differences, such as thickness of free product allowed in monitoring wells. Some states (e.g. Massachusetts, Texas, and Washington) created similar TPH risk screening methods based on the one developed by API's TPH-CWG.

3.2 Natural Source Zone Depletion Measurements Using Carbon Traps

NSZD is the reduction in LNAPL mass over time due to natural processes (ITRC, 2018). For petroleum hydrocarbons, this is primarily driven by biodegradation, and currently-available tools can measure these biodegradation rates. Petroleum hydrocarbons can biodegrade either anaerobically or aerobically. At sites dominated by anaerobic processes (i.e., most sites), hydrocarbons are converted to methane and carbon dioxide. Methane gas bubbles then migrate upwards in the vadose zone until oxygen is encountered. Here, methane and oxygen react to form additional carbon dioxide, as well as heat (Garg et al., 2017). Subsequently, NSZD measurements can be based on either the capture of carbon dioxide at the ground surface, the subsurface oxygen depletion profile, or measurement of the heat generation.

Monitored Natural Attenuation (MNA) is now an accepted remedial approach for managing dissolved contaminant plumes in groundwater. However, since 2006 there has been a growing realization that LNAPL itself is biodegrading at 10 or 100 times the rates previously thought. Therefore there is a general distinction that NSZD is natural attenuation of the source (actually the LNAPL in the source) while MNA is the natural attenuation of the plume (Garg et al., 2017).

For this demonstration project, Carbon Traps were utilized to measure the carbon dioxide flux at the ground surface in order to determine the NSZD rate. Note however, that NSZD rates can also be determined via other methods: i) flux chambers to measure CO_2 flux at the ground surface; ii) subsurface temperature monitoring (Thermal Monitoring); and iii) vertical subsurface gas profiles (Gradient Method). The specific measurements as well as measurement locations vary between methods, however, all can be reduced to units of mass removed per unit area per time. Specifically, a convenient and widely-used unit is gallons of LNAPL per acre per year.

3.3 Transmissivity Measurements

LNAPL transmissivity is an emerging standard for measuring free product mobility and recoverability, replacing measuring LNAPL thickness in wells. Transmissivity is defined as the volume of LNAPL through a unit width of aquifer per unit time per unit drawdown. Transmissivity can be calculated using ASTM LNAPL Transmissivity Standard ASTM E2856-13 (ASTM, Method E2856-13). Additional technical guidance can be found in the ITRC LNAPL Updated Guidance (ITRC, 2018a) and API LNAPL Transmissivity Guidance (API, 2012, Charbeneau et al., 2016). For this demonstration project, historical free product recovery measurements were utilized to calculate transmissivity. However, there are multiple methods available to quantify free product recovery measurements to determine transmissivity rates including Baildown/Slug Test, Manual Skimming Tests, or Tracer Tests.

Transmissivity rates are dependent on multiple parameters including soil type and properties (e.g. porosity, conductivity), chemical and physical properties of the LNAPL (e.g. density, viscosity, composition), LNAPL saturation in the formation, and thickness of the mobile LNAPL. As such, actual transmissivity measurement provide a much more comprehensive evaluation of product mobility and recoverability at a site than calculated LNAPL mobility parameters.

LNAPL transmissivity is now a widely accepted metric for assessing if conventional hydraulic recovery of LNAPL via pumping, skimming, etc. is practical. Empirical data suggests that LNAPL transmissivity values below a certain range indicates low recoverability and therefore, the majority of the LNAPL at a site is in a state of lesser mobile and residual saturation. Based on ITRC's LNAPL Guidance (ITRC, 2009a; ITRC, 2018a), LNAPL recovery is considered practicable if LNAPL transmissivity is greater than a range of 0.1 to 0.8 ft^2/day. If transmissivity is less than a range of 0.1 to 0.8 ft^2/day though, LNAPL recovery is not considered practicable.

4.0 Performance Assessment and Guidance

This project assessed multiple methodologies to better characterize remaining LNAPL at petroleum impacted sites and the evaluation of the residual risk remaining at these sites. The naturally occurring biodegradation can be determined by measuring the carbon dioxide (CO_2) flux and determining the rates of degradation, transmissivity rates can be used to help assess the recoverability of free product and LNAPL mobility at a site, while TPH fractionation data can be used to better assess the residual risk of the weathered free product. These tools can be used to supplement additional lines of evidence to help transition sites from active to passive recovery or even transition to site closure. Based on the results of this field investigation, active LNAPL recovery could potentially be discontinued without changing the low risk profile at the site.

5.0 Cost Assessment

As part of the project, costs were evaluated to determine what a similar investigation would cost in order to assess the residual LNAPL at a site and determine a more cost-effective path forward. Based on the demonstration, it is estimated that a similar investigation and assessment completed for a comparable site would be approximately $100,000.

Additionally, transition to NSZD/MNA was compared with traditional free product recovery methods implemented for the recovery and management of LNAPL at impacted sites. The assessment included a comparison of implementing of Land Use Controls/Institutional Controls (LUCs/ICs), transition to MNA with monitoring, and continued Free Product (FP) recovery efforts via manual methods such as bailing and skimming as well as DPE. The estimated total costs for the various alternatives compared over a duration of 15 years, range from approximately $500,000 to $4,700,000 including capital and annual O&M costs. Based on these estimated project costs, transition of a site to a more passive approach could result in significant cost savings over the lifetime of a project. However, it should be noted that costs are site-specific and depend on many factors including the current/anticipated land use, regulatory requirements, when a site may be able to transition, etc. and therefore may vary from the costs presented.

6.0 Implementation Issues

This project demonstrated three approaches for assessing residual LNAPL at petroleum impacted sites after many years of various free product recovery efforts. The project identified best practices and guidance regarding the characterization and assessment of residual LNAPL in order to make more informed decision regarding LNAPL remediation and site management strategies. In general, these methods could be implemented at most LNAPL impacted sites in order to help refine the CSM

and evaluate the residual risk posed by the remaining LNAPL at legacy sites. However, it would be imperative to evaluate specific regulations and regulatory acceptance of various lines of evidence, analytical methods and analytical results. Details on the implementation of the various methodologies/tools previously described and specific considerations are included in the Supplemental Guidance incorporated into Section 6 of the final report.

1.0 INTRODUCTION

Environmental Security Technology Certification Program (ESTCP) Project Number ER-201582 involves the demonstration of alternative techniques (other than free product thickness measurements and total TPH concentrations). These include: i) American Petroleum Institute's (API) Total Petroleum Hydrocarbon Criteria Working Group (TPH-CWG) method to assess the residual risk from highly weathered free product; and ii) use of Carbon Traps to measure NSZD rates, to help the Department of Defense (DoD) make a stronger case for closure of legacy petroleum sites, or at least cessation of active free product recovery, which hundreds of DoD sites continue to perform despite the fact that the remaining free product is highly weathered, poses little risk, and recovery rates may be low.

This document details the field activities conducted at the demonstration site Naval Air Station (NAS) Fallon Site 2 located in Fallon, Nevada, including the results as well as guidance for the application of alternative methods to evaluate the residual risk associated with remaining free product. For the field investigation, soil, groundwater and free product samples were collected from the site and analyzed using the methodology developed by API's TPH-CWG. Carbon Traps were deployed to measure NSZD rates, and transmissivity LNAPL was calculated using historic free product recovery measurements. This section includes a brief summary of the project background, objectives, and associated regulatory drivers.

1.1 BACKGROUND

Since the 1990s, the Strategic Environmental Research and Development Program (SERDP)/ESTCP conducted many demonstrations of light non-aqueous phase liquid (LNAPL) removal and plume treatment technologies (e.g., Projects ER-30, ER-20, ER-99). Technologies, such as bioventing, dual-phase extraction, and natural attenuation were demonstrated successfully to show that LNAPL could be removed and benzene, toluene, ethylbenzene, and xylenes (BTEX) plume migration could be controlled. Based on that work, these technologies were successfully applied at many DoD sites. The expectation was that unlike chlorinated solvents, petroleum sites could be closed after a reasonable period of time in the same way that private underground storage tank (UST) sites were being closed.

However, in a recent survey of Navy and Marine Corps site remedial project managers (RPMs), almost one third reported continuing remediation and long-term management challenges at petroleum sites. Examples are NAS Fallon, Naval Base Kitsap (NBK) Bangor, and Marine Corps Air Station (MCAS) Yuma. The Air Force and Army are also continuing remediation on petroleum sites (including LNAPL) for many years. Examples include Eielson Air Force Base and Kirtland Air Force Base. At Hill AFB, site representatives have been trying to close Site 870 (Patriot Hill site, ST061) for some time, despite several years of bioventing and LNAPL removal. Not only are DoD sites continuing to operate passive skimmers for continuing free product recovery, but many sites are contemplating and/or applying even more sophisticated and aggressive free product recovery systems, such as dual phase extraction (DPE) at great expense.

At many of these sites, early DoD demonstrations of free product removal technologies, such as bioventing and DPE, were considered a success and considerable free product was recovered

during each demonstration and subsequent full-scale application. However, in the longer term, many of these sites are still struggling to remove enough free product to meet EPA and state requirements of source control (product mobility) and plume treatment. There are a variety of reasons for this inability to close petroleum sites, and a review of post-remediation and long-term monitoring (LTM) data and some selective additional tests to evaluate residual risk are needed to accelerate the closure of these sites. Three methodologies were utilized and evaluated including the API TPH-CWG residual risk method, Carbon Traps for quantifying Natural Sources Zone Depletion rates and calculation of LNAPL transmissivity.

1.2 OBJECTIVE OF THE DEMONSTRATION

The overall objective of this demonstration is to help the DoD make a stronger case for closure or transition to passive management of legacy petroleum sites and expand DoD's knowledge and use of alternative methods for characterize Light Non-Aqueous Phase Liquid (LNAPL) at petroleum sites in order to improve the conceptual site model (CSM) and make more informed decisions regarding remediation and site management. The technical objective of the demonstration was to implement three methods to assess remaining LNAPL at DoD Petroleum sites and demonstrate that the weathered product remaining at these sites pose little or no significant risk. The methods were the API TPH-CWG residual risk methodology using the TPH fraction method, Natural Source Zone Depletion measurements using Carbon Traps and LNAPL transmissivity calculation using historical recovery data.

1.3 REGULATORY DRIVERS

Historically at LNAPL impacted sites, regulatory agencies have required the removal of LNAPL to the 'maximum extent practicable' as defined by 40 Code of Federal Regulations 40 CFR §280.64. Often the 'maximum extent practicable' (MEP) has been defined as a specific thickness meriting LNAPL recovery, although the specific definition is left to the regulatory or implementing agencies. In addition, many states have their own UST programs in place. As a result, the requirements for closure often vary state to state. For example, the specified thicknesses may range from less than 0.01 ft to 0.5 ft, or the state may have no specific criteria or reference MEP. Section 6 includes additional information and a table highlighting some of the differences in regulations and variability observed between LNAPL recovery limits for select states.

At many DoD sites, early demonstrations of free product removal technologies, such as bioventing and DPE, were considered a success and considerable free product was recovered during each demonstration and subsequent full-scale application. However, in the longer term, many of these sites are still struggling to remove enough free product to meet U.S. Environmental Protection Agency (EPA) and state requirements of source control and plume treatment.

In addition, , there is now a better understanding of that LNAPL thickness is a poor metric for understanding the risk at LNAPL sites. The ITRC (2018) states:

> *"Due to the dependence of in-well LNAPL thickness on geology and variable groundwater hydraulics, it should not generally be used as a sole metric for recoverability and indication of migration."*

"Thickness or concentration data alone may not provide a sound basis for defining the point at which a cleanup objective is achieved."

"If a requirement exists to remove LNAPL to a specified thickness, the implementing agency may assume that any selected removal strategy will be long and costly. This assumption could have a detrimental impact on the assessment and remediation decision."

The results of this study are intended to help DOD end users, regulators and other projects stakeholders expand their knowledge and use of alternative methods beyond LNAPL thickness to characterizing residual LNAPL and better assess the risk remaining at these LNAPL impacted legacy sites and therefore make a stronger case for closure or transition from active to passive recovery.

Specifically, the Nevada Underground Storage Tank (UST) regulations (many states have similar regulations) require cleanup of releases of contaminants that exceed action levels in soil and groundwater. Corrective action may be required when action levels for soil are exceeded unless a site owner or operator completes an evaluation of the site indicating that the contamination does not cause any current or potential threat to human health or the environment. Based on the Nevada Administrative Code (NAC) 445A.22735, the establishment of action levels for groundwater include: (1) the presence of ½ inch or more of free product based on an accuracy of 0.01 ft; (2) concentrations equal to maximum contaminant levels (MCL) established under the Safe Drinking Water Act 42 U.S.C. §§ 300f et seq., and 40 C.F.R. Part 141; and (3) the background concentration if the background concentration is greater than the MCL. Corrective action must be taken when the action levels for groundwater are exceeded, unless the owner or operator submits a written request to the Director of the State Department of Conservation and Natural Resources (Director) (NAC 445A.22725). Based on NAC 445A.22725, the Director may grant the request if the following are satisfied:

- Each source of contamination is identified and controlled, or no source remains because of the age and nature of the release;
- The magnitude and extent of the contamination of the groundwater is known;
- Data are available from at least 3 years of quarterly monitoring or another period specified by the Division and the data do not show a trend of increasing concentrations of the contamination;
- A demonstration is made which indicates that natural attenuation is sufficient to reduce contamination below action levels or prevent migration to a receptor or another point of demonstration;
- And, the groundwater is not a source of drinking water and is not likely to be a source in the future because (1) it is economically or technologically impractical to recover the water for drinking because of depth or location or render the water fit for human consumption, or (2) a legal restriction or institutional control is in place concerning the use of the groundwater.

The Director may also not require corrective action if the owner or operator files a study, acceptable to the Division, that demonstrates that it is not feasible to achieve the required remediation standard based on prohibitive cost (NAC 445A.22725).

2.0 TECHNOLOGY

This section provides a description of the three methods evaluated as part of the demonstration and presents their advantages and limitations. More information regarding the application and use of these approaches are include in the Supplemental Guidance presented in Section 6.

2.1 TECHNOLOGY DESCRIPTION

Petroleum releases to the environment can cause safety hazards, ecological harm, adverse human health effects, and unpleasant appearance and odor of soil and water. Many of DoD's petroleum sites are still struggling to remove LNAPL from the subsurface and manage the associated plumes despite many years of LNAPL recovery with conventional and innovative methods. There are several technologies used in the private industry to evaluate the residual risk associated with the remaining LNAPL, product mobility/migration potential, and rates of Natural Source Zone Depletion. Many of these methods are used to help sites obtain risk-based closure or move away from active LNAPL recovery to more passive means or MNA. Three of these methods are described below and include the TPH-CWG risk-based method, Natural Source Zone Depletion evaluation using Carbon Traps and LNAPL transmissivity measurements.

2.1.1 TPH-CWG Risk Based Method

The TPH-CWG method treats complex petroleum mixtures as a combination of fractions for conducting environmental modeling and estimating non-cancer risk. Carcinogenic petroleum compounds are evaluated separately. This approach can be used within a tiered framework to estimate human health risk and to calculate risk-based screening levels (RBSLs) for guiding cleanup decisions.

Since TPH is composed of multiple types of hydrocarbons, the TPH-CWG approach relies on the analytical separation of petroleum into 13 fractions. The fractions are based on their aliphatic or aromatic nature and their equivalent carbon (EC) number, a function of boiling point. Additionally, they have been assigned toxicological and transport parameters as a result of extensive reviews of data from individual compounds in the fraction or from petroleum mixtures represented within the fraction. The TPH-CWG fractionation data results, fraction toxicity information, and transport parameters can be used to perform a risk-based analysis for each fraction present at the site being evaluated. The hypothetical risk and the resulting soil screening level (i.e., the RBSL) for the "whole TPH" mixture are calculated by combining the non-cancer risks from individual fractions weighted by their percent composition within the TPH mixture, meaning the total risk is apportioned over the different fractions present.

The importance of this method is that it differentiates between risks posed by fresh petroleum spills and weathered product. Compared to weathered product, fresh spills typically contain relatively higher risk factors. In other words, a greater fraction of lower molecular weight compounds with higher vapor pressure, greater fraction of more toxic aromatics, greater proportion of soluble compounds, and lower proportion of compounds with strong sorption characteristics. By comparison, weathered product typically contains lower proportion of the more toxic aromatic fractions, lower soluble fractions, lower volatile fractions, and higher fractions that sorb well to soil.

The resulting risk based information on the reduced presence of the more toxic fractions and reduced leachability and volatility characteristics of the weathered fuel product will be placed in the context of the state's petroleum program (and most states have similar rules, with minor differences, such as thickness of free product allowed in monitoring wells). Some states (e.g. Massachusetts, Texas, and Washington) created similar TPH risk screening methods based on the one developed by API's TPH-CWG.

2.1.2 Natural Source Zone Depletion Measurements Using Carbon Traps

Direct methods for documenting contaminant attenuation rates in the field are an important line of evidence for supporting monitored natural attenuation (MNA), particularly if MNA is being used to manage an active source. One method that has been recently validated is the use of Carbon Traps to measure LNAPL degradation rates at petroleum hydrocarbon sites in order to quantify Natural Source Zone Depletion (NSZD). These are simple and low-cost devices that are installed at grade and specifically designed to measure natural losses of LNAPL over time (Adamson and Newell, 2014).

Following release, hydrocarbon constituents in LNAPL are subject to various natural attenuation mechanisms, including biodegradation. CO_2 is an effective signal of these attenuation processes because most of the carbon of the carbon present in LNAPL is converted to CO_2 as an end product during in situ degradation. This includes methane generated during anaerobic degradation of petroleum hydrocarbons that is aerobically biodegraded to CO_2 following migration to the O_2-rich vadose zone. By capturing the CO_2 generated from these natural processes in the surface-deployed traps, the time-integrated CO_2 in the traps can be converted to an equivalent LNAPL loss rate (after correcting for background CO_2 flux, or alternatively, using ^{14}C measurements to differentiate between fossil fuel and non-fossil fuel fractions) (Conrad et al., 1997; Adamson and Newell, 2014).

Figure 2-1 – Deployed Carbon Trap. NAVFAC EXWC ER-201582.

Carbon Traps are passive adsorption devices deployed within the shallow ground surface. They are easily installed (i.e., no special training of personnel), and minimally invasive. Thus, they can be deployed at multiple locations at a site to identify areas of high activity as well as to obtain a site-wide estimate of the LNAPL loss rate (after correcting for background CO_2 generation rates). **Figure 2-1** shows a Carbon Trap deployed at NAS Fallon.

2.1.3 Transmissivity Measurements

LNAPL Transmissivity is an emerging standard for measuring free product mobility and recoverability replacing measured LNAPL thickness in wells. Transmissivity is defined as the volume of LNAPL through a unit width of aquifer per unit time per unit drawdown. **Figure 2-2** includes a schematic showing how transmissivity correlates with LNAPL well thickness and conductivity. Units for this measurement are length^2/time. Transmissivity can be calculated using ASTM LNAPL Transmissivity Standard ASTM E2856-13. Additional technical guidance can be found in the ITRC LNAPL Updated Guidance (ITRC, 2018a) and API LNAPL Transmissivity Guidance (Charbeneau et al., 2016). For this demonstration project, historical free product recovery measurements were utilized to calculate rates of transmissivity. However, there are multiple methods available to quantify free product recovery measurements for determine transmissivity rates including baildown/slug test, manual skimming tests, or tracer tests. The recommended approach is to use historical data if available as this would decrease the costs for any supplemental investigations.

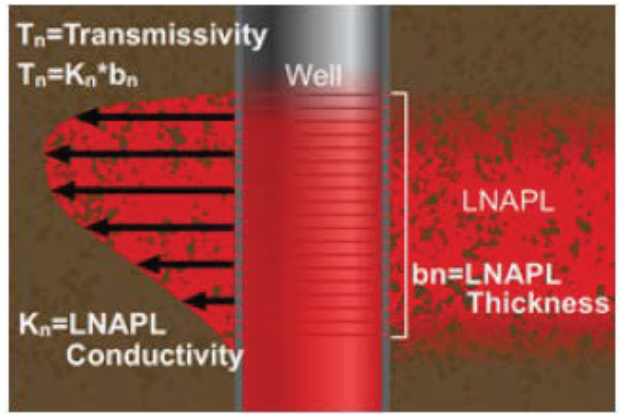


Figure 2-2 – Transmissivity Schematic (NAVFAC, 2015)

Transmissivity rates are dependent on multiple parameters including soil type and properties (e.g. porosity, conductivity), chemical and physical properties of the LNAPL (e.g. density, viscosity, composition), LNAPL saturation in the formation, and thickness of the mobile LNAPL. As such, this measurement provides a much more comprehensive evaluation of product mobility and recoverability at a site.

Based on ITRC's LNAPL Guidance (ITRC, 2009a), "the practicable limits of LNAPL recovery is represented by an LNAPL transmissivity of 0.1 to 0.8 ft^2/day." Therefore LNAPL recovery is considered practicable if transmissivity is greater than 0.1 to 0.8 ft^2/day (note the dividing line is a range, not a single value). If transmissivity is less than 0.1 to 0.8 ft^2/day though, LNAPL recovery is considered not practicable.

2.2 TECHNOLOGY DEVELOPMENT

Since this demonstration did not involve the development of a new technology, but rather an evaluation of multiple methods to assess the residual free product remaining at a site, a section on technology development was not included. However, a supplemental guidance detailing the applicability of the methods and how to implement these technologies and methods at a site has been developed and is included in Section 6.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The section below includes the overarching advantages and limitations of each technology identified for the demonstration. Additional information includes a table with the advantages and

limitations of each technology that can be found in the Supplement Guidance provided in Section 6.

Advantages of the technologies include:

- All three technologies provide alternative approaches to evaluating remaining LNAPL at DoD sites that have had ongoing active remediation for decades. They have the potential to help the DoD build a risk-based argument to reduce the amount of active remediation using quantitative methods.
- TPH-CWG Risk Based Method: fingerprints weathered TPH and provides a method for determining human health risks based on the measured TPH fractions. For this project, the goal was to determine if residual hydrocarbon in soils posed a risk to hypothetical construction workers in contact with LNAPL containing soils based on the calculated Hazard Index (no unacceptable risk if HI<1).
- Natural Source Zone Depletion Measurements using Carbon Traps: provides an estimation for LNAPL degradation rates for comparison to recovery rates to determine if active recovery is still necessary or effective.
- Transmissivity Measurements: provide a metric for evaluating LNAPL mobility and recoverability at a site. Transmissivity can be calculated using a variety of methods including the use of historical data.

Limitations associated with the technologies include:

- TPH-CWG Risk Based Method: weathering of LNAPL may not be uniform across matrices. The rates of degradation may be different for the LNAPL in the smear zone, within the soil, and on the surface of the groundwater, which could result in different levels of human health risk associated with the remaining LNAPL. Furthermore, an additional limitation to the method is the necessity of selecting surrogate compounds for each fraction. This usually results in conservative risk results, better than just TPH alone but still only a conservative approximation.
- Natural Source Zone Depletion Measurements using Carbon Traps: potential for background interference with atmospheric CO_2; resulting estimates can vary spatially and temporally. There are also specific considerations when deploying Carbon Traps at sites that must be considered as well in order to minimize any potential bias regarding the CO_2 flux.
- Transmissivity – Based on ITRC LNAPL Transmissivity Guidance (ITRC, 2009a), LNAPL recovery is practical if the transmissivity rate is greater than 0.1 to 0.8 ft^2/day and not practical if rate is less than 0.1 to 0.8 ft^2/day. Depending on the site, the observed transmissivity rate may fall within the 0.1 to 0.8 ft^2/day range and need to be further assessed in order to determine the recoverability and migration potential. Some additional disadvantages include, but are not limited to, lack of acceptance by certain regulatory authorities and temporal variability with respect to water level.

- Although these technologies may be useful for further characterizing the remaining LNAPL at a site as lines of evidence for building risk-based arguments for closure or transition to more passive remediation, the ultimate decision regarding the status of the site and the accepted path forward is to be determined by the project team, stakeholders and regulators.

3.0 PERFORMANCE OBJECTIVES

The overall objective of this demonstration is to help the DoD make a stronger case for closure of legacy petroleum sites, or cessation of active free product recovery and expand DoD's knowledge and use of alternative methods for characterizing residual LNAPL and evaluating any remaining risk at sites in order to make more informed decisions for remediation. The technical objective of this effort seeks to demonstrate that the weathered product remaining at the demonstration site, NAS Fallon, poses little or no significant risk including the API TPH-CWG residual risk method and deploying Carbon Traps to estimate biodegradation rates attributed to NSZD. **Table 3-1** below summarizes the performance objectives established for this project. In addition, average LNAPL transmissivity values were also calculated using historical data in order to assess free product recoverability and mobility using historical free product recovery data although this was not specified as one of the Performance Objectives outlined in the table below.

Table 3-1 – Performance Objectives

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives			
Fingerprint the remaining weathered LNAPL	Collect and analyze soil and groundwater samples using TPH fractionation method	A risk-based evaluation of remaining LNAPL	Soil, groundwater and LNAPL samples were collected and analyzed for TPH fractionation via the Washington State EPH/VPH method and the risk for the exposure scenario of a construction worker exposed to soil during excavation was calculated using the TPHCWG methodology which results in a hazard index (HI) of less than 1. The LNAPL fractions in the weather product were also compared to the fraction distributions of various fuel compositions and the lighter and more toxic hydrocarbon ranges have decreased indicating that these compounds have weathered away and the remaining product poses little to no risk.
Obtain degradation rates	Analyze Carbon Traps for total CO_2 and ^{14}C	A rate of degradation that can be compared to active free product removal	The NSZD rate was determined based on measuring the CO_2 flux and correcting for degradation of natural organic matter. The average NSZD rate observed at the site is 173 gal/acre-year which is within the same order of magnitude as the free product recovery rates over the last 10 years (~160 gal/acre-yr).
Calculate LNAPL transmissivity	Historical LNAPL recovery	Calculated transmissivities are below 0.1 to 0.8 ft^2/day	The average transmissivity observed at NAS Fallon for the four free product recovery periods conducted over the last decade ranged from 0.03 to 0.06 ft^2/day, lower than the threshold range of 0.1 to 0.8 ft^2/day.
Qualitative Performance Objectives			
Provide RPM with risk-based argument using data obtained from quantitative objectives	Analyzing the above data	Useful information to help RPM manage site	Final report and results to be submitted to project team.

3.1 PERFORMANCE OBJECTIVE: FINGERPRINT THE REMAINING WEATHERED LNAPL

The first step in the TPH-CWG risk-based method is to fingerprint the LNAPL to differentiate the percent composition of the various TPH components. Once this data is obtained, an analysis can be performed to look at the health risks posed by the remaining weathered LNAPL.

3.1.1 Data Requirements

Fingerprinting the residual LNAPL requires LNAPL, groundwater and soil samples to be collected and shipped to a laboratory for analysis. A total of up to five groundwater samples (including one duplicate) will be collected from existing groundwater monitoring wells near the free product plume mapped out in the 2013 investigation but not with measurable product. In addition, samples will be collected from to three soil cores (up to 7 samples, including 1 duplicate) using direct push at locations that had high readings during the 2008 Site Characterization and Analysis Penetrometer System (SCAPS) investigation. One sample of the free product, if present, will also be collected at the Site for analysis.

3.1.2 Success Criteria

Success of this objective will be determined by the resulting analytical data. If the various samples are comparable and able to be analyzed by the TPH-CWG risk-based method, then the objective will be considered successful.

3.2 PERFORMANCE OBJECTIVE: OBTAIN NSZD RATES USING CARBON TRAPS

Carbon Traps will be used in order to estimate biodegradation rates for the remaining LNAPL and assess the Natural Source Zone Depletion. NSZD rates are helpful in determining the practicality of active free product removal.

3.2.1 Data Requirements

Once installed, the Carbon Traps will need to remain deployed for two weeks before being collected and shipped to a laboratory for analysis where they will be analyzed for total CO_2 and ^{14}C (to obtain background levels). In order to provide a representative degradation rate at the site, the traps will be set up around in areas with varying levels of contamination based on historical data. After laboratory analysis is complete, the CO_2 concentrations will be corrected by subtracting the concentration of ^{14}C from the total to correct for background and statistical analysis will be performed on the data, which will yield an average NSZD rate.

3.2.2 Success Criteria

Using the method described in 3.2.1, the success of this objective will be dependent on installing the Carbon Traps in locations that will yield a representative degradation rate for the site, which should be supported by a trend in the individual sample data. If the NSZD rate is calculable and

considered representative, then the objective will be considered a success, and the rate will be compared to the recovery rate from the skimmers.

4.0 SITE DESCRIPTION

The following sections provide a brief summary regarding the site location and history, geology and hydrogeology, as well as the contaminant distribution at the selected demonstration site, Naval Air Station (NAS) Fallon IR Site 2.

4.1 SITE LOCATION AND HISTORY

NAS Fallon is located approximately 7 miles southeast of Fallon, Nevada as shown in **Figure 4-1**. The selected demonstration site IRP Site 2, also known as the New Fuel Farm, at NAS Fallon is part of the Northern Operable Unit (NOU), which is located in the west central portion of NAS Fallon as shown in **Figure 4-2**.

IRP Site 2 was constructed in 1957 to replace the Old Fuel Farm (Site 16), which was taken out of service in 1963. The New Fuel Farm was initially used to store and dispense petroleum fuels, including jet propellant (JP)-5, JP-8, diesel, aviation gasoline, and motor vehicle gasoline (KCH, 2014). The site included five former underground storage tanks (USTs), a former tank bottom disposal area and drainage swale, a former oil/water separator (OWS) and OWS leach field, a truck washdown area, a loading rack area, and a fuel transfer area. Historic operations and fuel transfer practices identified in the original RI likely contributed to subsurface contamination at the site (KCH, 2014). Historical records indicate that up to approximately 85,000 gallons of fuel or fuel and water mixture were released at IRP Site 2.

IRP Site 2 stores a variety of fuels including JP-8 (about 3.3 million gallons), diesel fuel (about 8,000 gallons), and motor vehicle gasoline (about 12,000 gallons) in three aboveground storage tanks (ASTs). Storage of aviation gasoline and JP-5 in two USTs with a combined capacity of 100,000 gallons (KCH, 2014). Both of these USTs were removed in April 1992. After the tanks were removed, a product recovery sump was constructed in the excavation pit, and a monitoring/recovery well was installed. The excavation was backfilled and capped with plastic sheeted to promote drainage away from the site (KCH, 2014).

From the early 1990s through 2001, several active free product removal actions were implemented including dual phase extraction (DPE), periodic removal of product via skimming and installing of free products recovery trenches. A pilot study was conducted in 2006 to evaluate the effectiveness of multi-phase extraction (MPE) in removing free product. From 2007 through 2013, free product was removed from select wells at Site 2 and 4. From 2007 through March 2008, product was removed on a weekly basis using a portable pump and starting in April 2008, permanent pumps were deployed in a couple wells and product was continuously recovered. From August 2008 through March 2011, product was removed on a weekly basis in the western trenches. From April 2011 through March 2012 free product recovery activities were not conducted at the site as the pumps were inoperable. Free product recovery activities resumed in April 2012. Since 2007, approximately 7,353 gallons of free product were recovered through November 2013. Since the 1990s through 2013, approximately 76,000 gallons of free product from Sites 2 and 4 have

been removed or almost 89 percent of the total estimated volumes released (KCH, 2014). Based on the 2008 SCAPs survey and 2013 free product measurement event, the footprint of the LNAPL body was approximately 10 acres.

Free product recovery activities have resumed as of October 2017. As of December 2018, approximately 1,973 gallons of free product have been recovered (Amec Foster Wheeler, 2018).

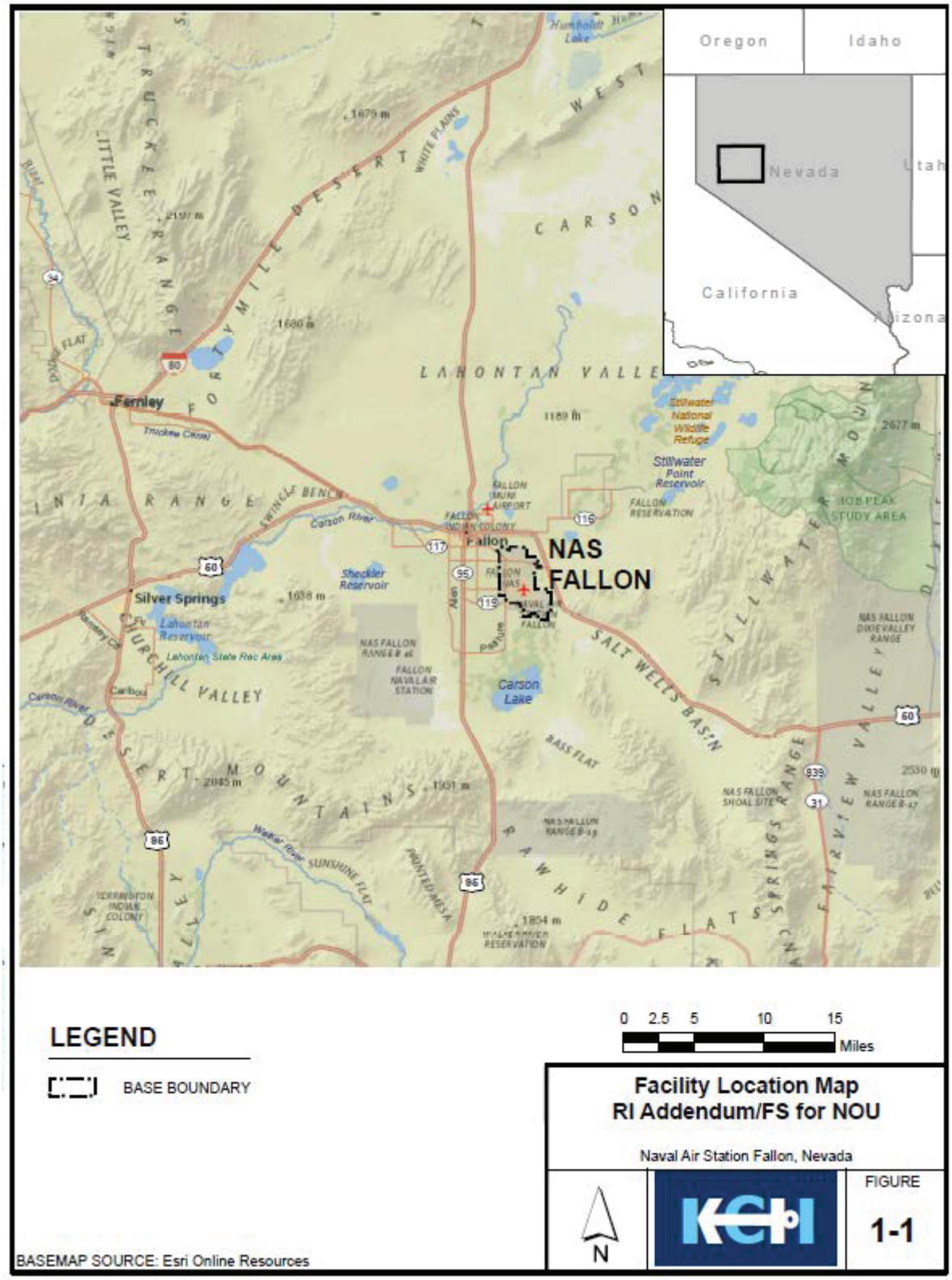


Figure 4-1 – Facility Location Map (KCH, 2014)
[Note: Figure 1-1 from 2014 RI Addendum/FS (KCH, 2014)]

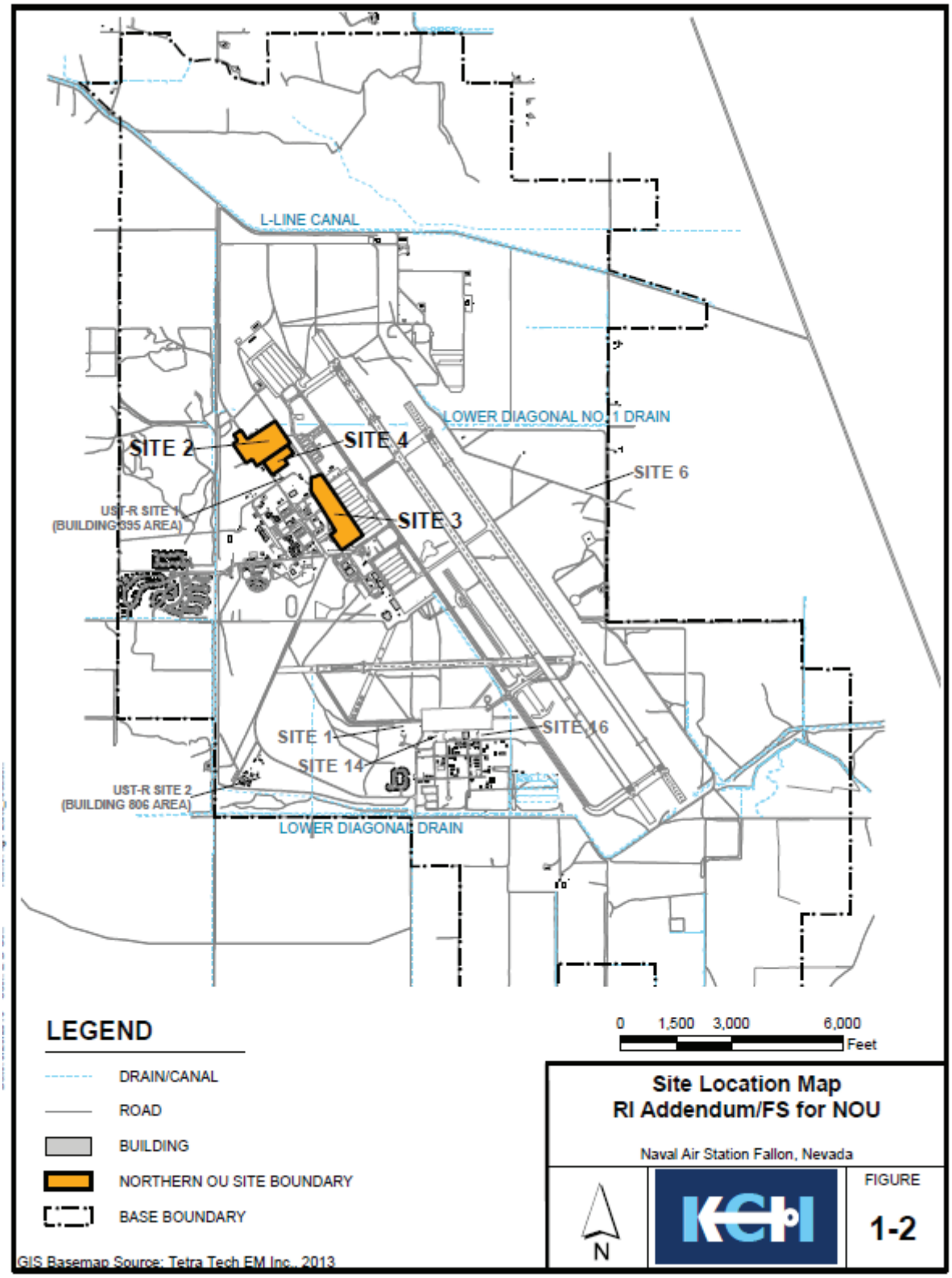


Figure 4-2 – Site Location Map (KCH, 2014)
[Note: Figure 1-2 from 2014 RI Addendum/FS (KCH, 2014)]

4.2 SITE GEOLOGY/HYDROGEOLOGY

Sites 2 and 4 are predominately silty and clayey sand in the shallow subsurface; however, other soil types, including gravel fill, silt, and clay, were also observed. The shallow subsurface at Site 2 is composed mainly of silty fine sand with some clayey sand while Site 4 is underlain by poorly graded sand with some silt and silty sand, as indicated by cross section C-C' on **Figure 4-3**. **Figure 4-4 s**hows the locations of the various geologic cross sections. Clay layers were encountered at approximately 4 to 6 feet bgs around the eastern and southern perimeter of Site 2, with the thickest layers along the central and southwest boundary of Sites 2 and 4 (KCH, 2014). Historical geologic investigations at Sites 2 and 4 by the Oak Ridge National Laboratory (ORNL) concluded that the upper 17 to 20 feet of the subsurface is part of the Fallon Formation, composed mainly of deltaic deposits, with occasional paleo-river channels deposited by the Carson River (KCH, 2014).

NAS Fallon is located with the Lahontan Valley groundwater basin where depth to groundwater is observed between 4 to 12 feet below ground surface (bgs). The primary aquifer of interest at the site is the shallow aquifer, which is approximately 10 to 18 feet thick. The hydraulic conductivities observed at NAS Fallon range from 0.19 to 13.17 feet per day. Groundwater in the shallow aquifer is considered poor quality with high TDS (greater than 10,000 mg/L) and average arsenic concentrations ranging from 426 to 3,300 µg/L. The shallow aquifer is not currently utilized for domestic or commercial purposes at NAS Fallon; however, domestic wells have been installed offsite and may be used as a drinking water source. (KCH, 2014).

Cross section C-C' (**Figure 4-3**) indicates the depth at which groundwater was encountered during the soil investigation and the static groundwater elevation extrapolated from the groundwater elevation map (**Figure 4-5**). Depth to groundwater was observed between at 5.7 to 9 feet bgs during the soil investigation. Ground surface elevations in the northern portion of the site are approximately 4.5 feet higher than the southern portion. The average hydraulic gradient observed at Site 2 and 4 is approximately 0.001 ft/day with a general groundwater flow direction to the southeast (see **Figure 4-5)**. Based on historical aquifer tests conducted as part of the original RI, the hydraulic conductivities observed at Sites 2 and 4 ranged from 2 to 220 ft/day (KHC, 2014).

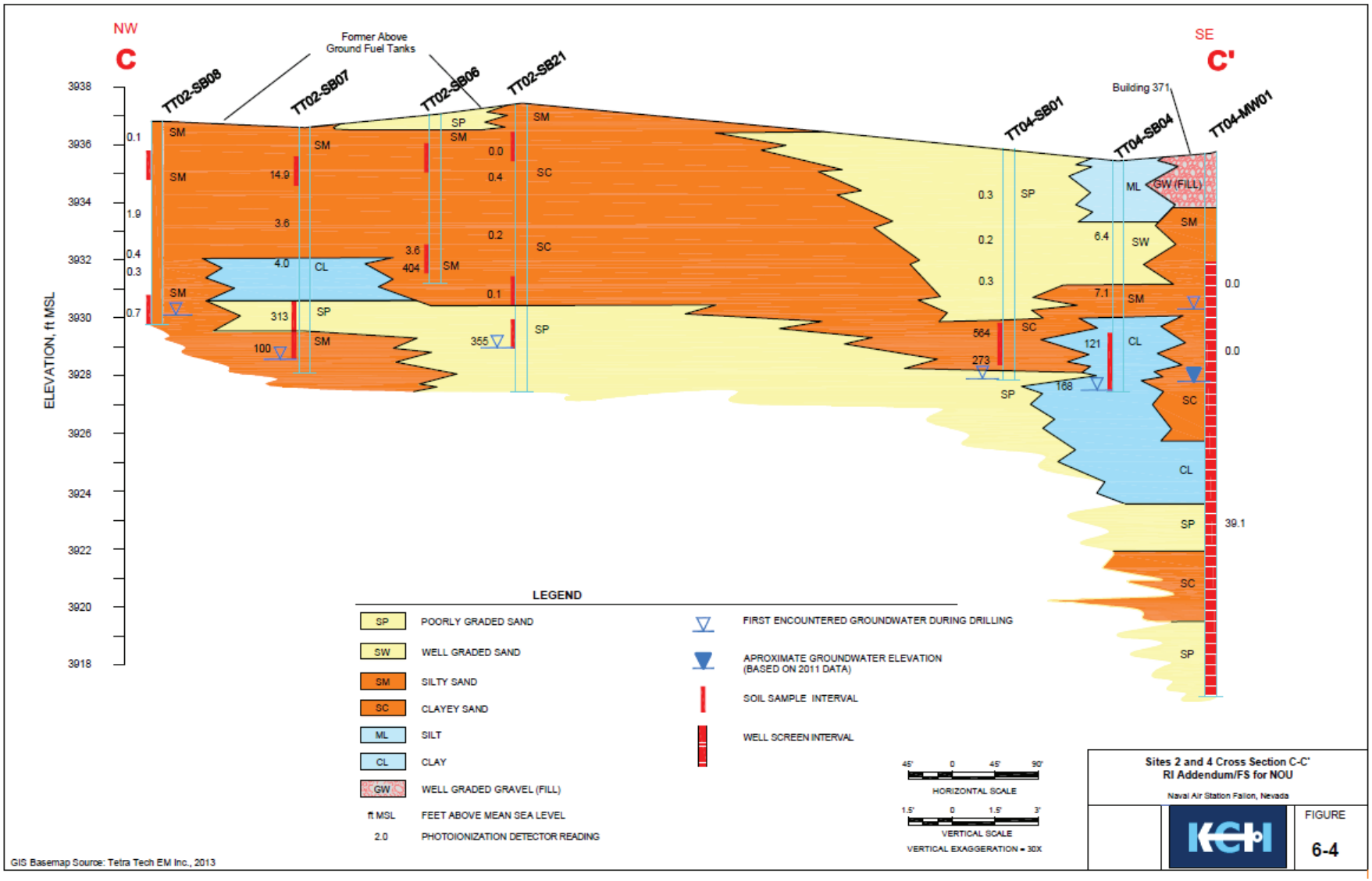


Figure 4-3 – Sites 2 and 4 Cross Section C-C' (KCH, 2014)
[Note: Figure 6-4 from 2014 RI Addendum/FS (KCH, 2014)]

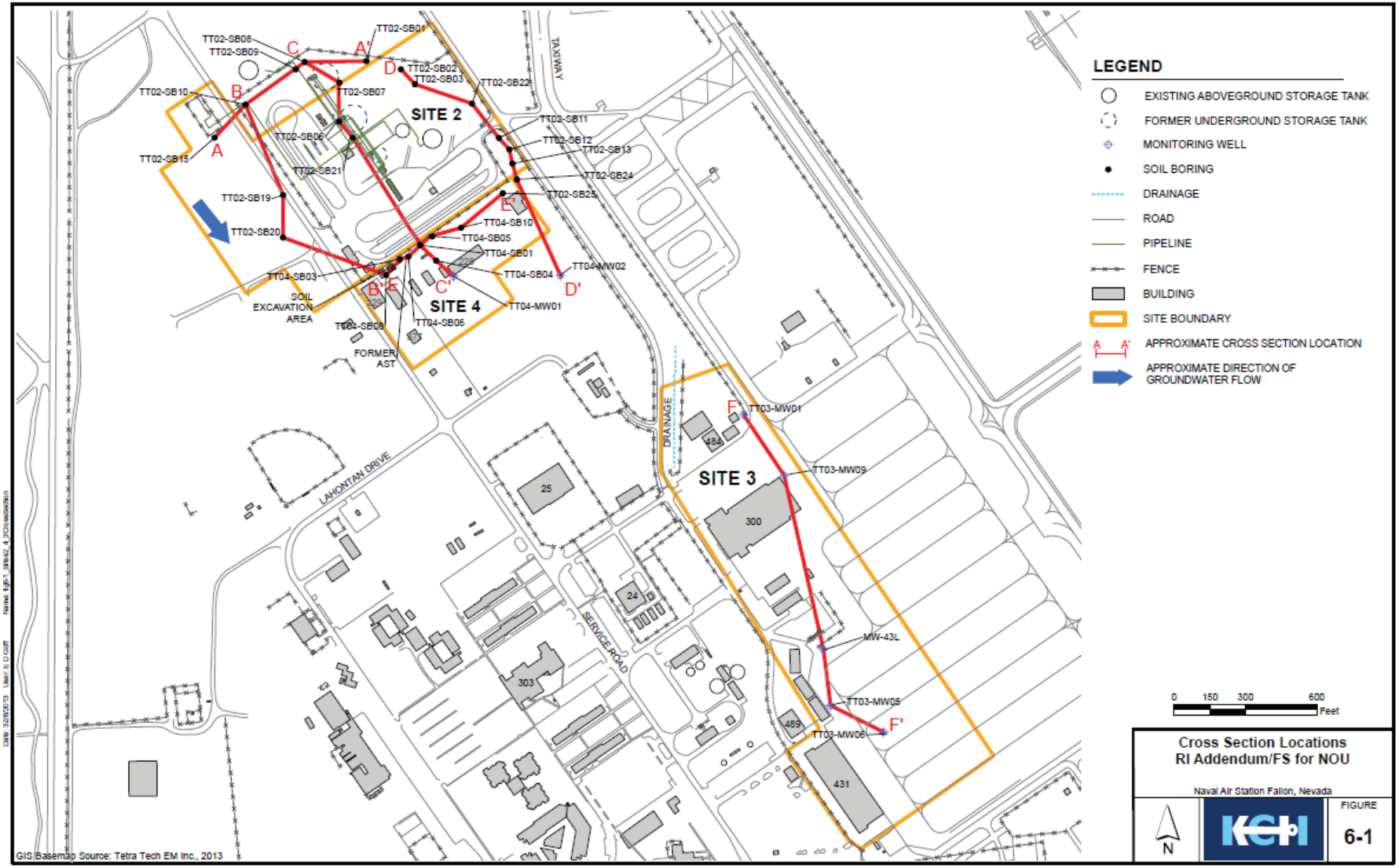


Figure 4-4 – Cross Section Locations (KCH, 2014)
[Note: Figure 6-1 from 2014 RI Addendum/FS (KCH, 2014)]

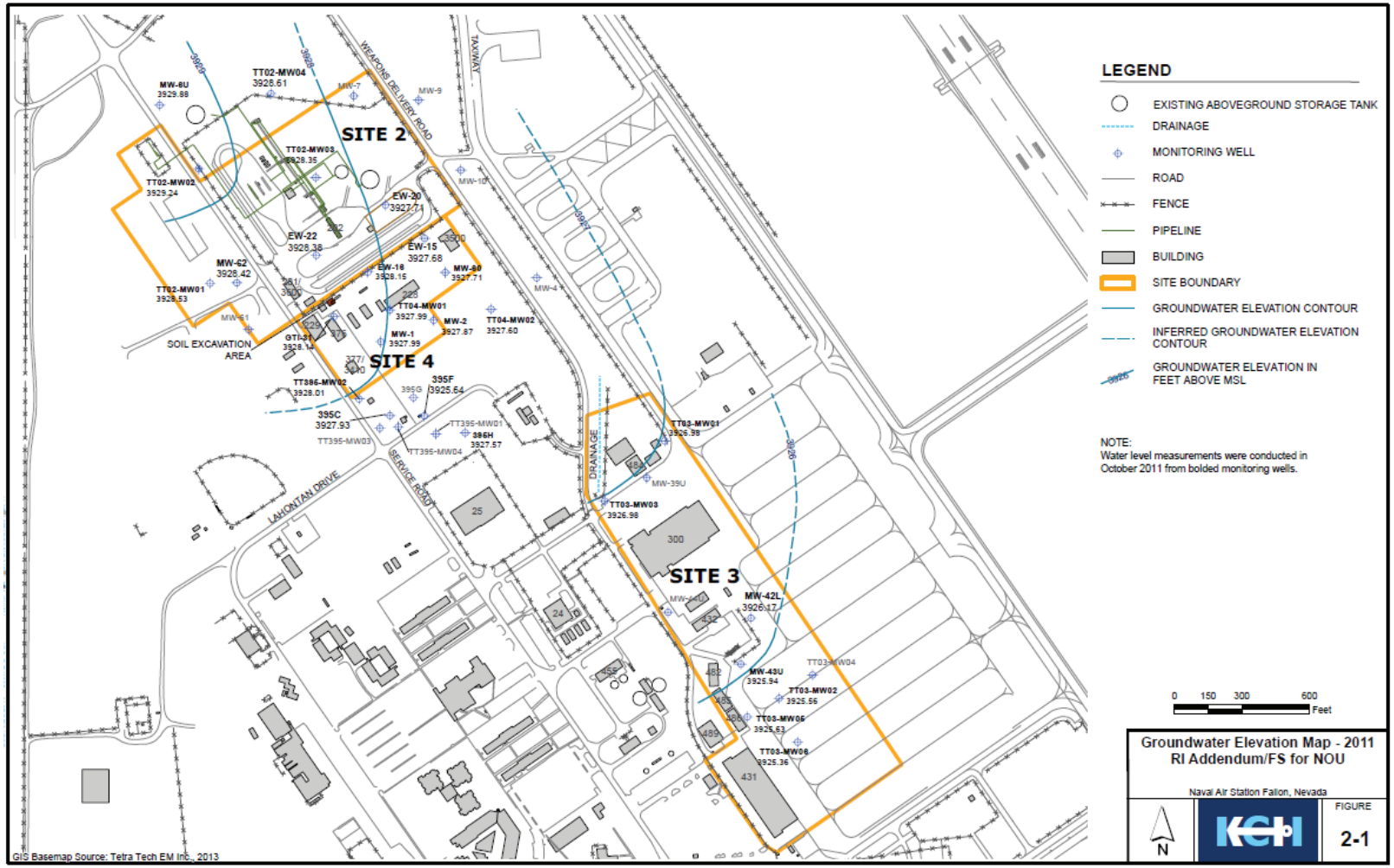


Figure 4-5 – Groundwater Elevation Map - 2011 (KCH, 2014)
[Note: Figure 2-1 from 2014 RI Addendum/FS (KCH, 2014)]

4.3 CONTAMINANT DISTRIBUTION

A SCAPS investigation was conducted in 2007 at Site 2 and Site 4 to assess the extent of free product observed at the site. Based on the LIF data, temporary wells were installed to assess the presence of free product. The average thickness observed in the wells ranged from only a sheen up to 3 feet of product.

Figure 4-6 shows the LNAPL thickness observed at the site in 2008 as well as the LIF ranges. The investigation indicated that the majority of soil hydrocarbon contamination and free product were located near the former tank locations and tank disposal area at Site 2, as well as the former tank locations in the OWS, leach field area and former AST at Site 4. During this investigation, free product samples were collected from Sites 2 and 4 to assess the composition of the free product. Three samples (FA02-57, VT-1, and VT-4) as well as two composite samples were collected from Site 2 and one composite sample was collected from Site 4. This analysis found that the product samples contained mostly jet fuel fractions in the C_9-C_{13} carbon range with less than 5 percent observed at the lighter hydrocarbon fractions less than C_8 or heavier hydrocarbons ranges (KCH, 2014).

Based on the results of the SCAPS investigation and as part of the NOU RI Addendum/FS field investigation, soil borings were completed in 2007 and 2008 to further delineate the extent of soil contamination and free product at Sites 2 and 4. In addition, up to 35 monitoring wells at Sites 2 and 4 have been monitored for free product levels since 2007 in conjunction with free product recovery activities. The approximate free product footprints and apparent LNAPL thicknesses observed at Sites 2 and 4 for 2008 and 2013 are shown in
Figure 4-6 and **Figure 4-7**. Based on the existing well network, the overall extent of free product has declined significantly between 2008 and 2013 (KCH, 2014). The area of the LNAPL footprint in 2013 is about 120,000 ft^2 or about 2.8 acres.

Soil samples were collected as part of the additional investigation conducted in 2007 and 2008 to further delineate the extent of contamination and validate the SCAPS results. These samples were analyzed for VOCs, TPH-p (gasoline range organics (GRO)), TPH-e (including JP-5, diesel range organics (DRO) and motor oil range organics), and PAHs. **Figure 4-8** includes the concentrations of compounds observed in the soil. Six boring locations had TPH at concentrations greater than 100 mg/kg detected in soil samples between 4.5 to 9.0 ft bgs. The highest concentrations of JP-5 (4,400 mg/kg) was detected at TT02-SB19, and highest GRO concentration (11,000 mg/kg) at TT02-SB06. Other constituents detected in the soils at Sites 2 and 4 included PAHs and VOCs. PAHs were detected in 16 of the 40 borings at Sites 2 and 4 with only 3 samples that exceeded industrial or residential RSLs of 0.15 mg/kg and 0.21 mg/kg respectively. BTEX constituents were detected in 12 of the 40 boring locations, however none of the concentrations were observed above the residential or industrial RSLs and only four locations had detections of BTEX and other VOCs exceeding 1 mg/kg (KCH, 2014).

Groundwater samples were collected in 2007 and 2008 as part of the NOU RI Addendum/FS field investigation and a small subset of wells were sampled as part of the base wide groundwater monitoring in 2009, 2010, and 2011. Samples were analyzed for a variety of constituents, which may have included TPH-e, TPH-p, VOCs, PAHs, TDS, and MNA parameters (anions, alkalinity, dissolved gases, sulfide, and TOC) in select wells during each event. **Figure 4-9** includes the

analytical results for the groundwater samples collected at Sites 2 and 4 between 2007 and 2011. Groundwater monitoring was conducted primarily around the perimeter of the source areas to assess the extent of dissolved fuel-related groundwater contamination and wells with free product were not sampled (KCH, 2014).

Based on the analytical results from the RI Addendum/FS, only one well, TT02-MW02, had detections of PAHs, specifically naphthalene, above the RSL of 0.14 µg/L for drinking water with concentrations ranging from 0.32 to 0.8 µg/L. Other PAHs were detected in groundwater samples collected at Sites 2 and 4, however concentrations were below screening levels. Other constituents detected in groundwater included BTEX, VOCs and TPH although none of the concentrations exceed applicable screening criteria. The BTEX and VOCs detected tend to be collocated with the PAH detections in wells TT02-MW02 and TT-MW04 at the northern boundary of Site 2. Detected BTEX and other hydrocarbon related VOCs included ethylbenzene, xylenes, trimethylbenzenes and alky-substituted benzenes and toluene. The highest concentrations of BTEX and VOCs were observed in TT02-MW02 with 1.7 µg/L of ethylbenzene and 9.4 µg/L of 1,2,4-trimethylbenzene in 2007 (KCH, 2014).

TPH-e (JP-5 or DRO) was detected in nine (9) wells in 2007 and three (3) wells in 2008 and 2009 with the highest concentrations observed at TT02-MW02 ranging from 0.42 to 0.67 mg/L. TPH-e concentrations in the motor oil range were observed in 5 wells in 2007 and 2008 with detections as high as 0.61 mg/L at Sites 2 and 4. TPH-p (GRO) was detected in TT02-MW02 at concentrations of 0.05 to 0.1 mg/L. Other concentrations of TPH-p in the GRO range were detected in two wells (TT02-MW03 and EW-16) (KCH, 2014).

Based on the comparison of groundwater analytical results and screening criteria, the dissolved phase plume consisting of primarily low-level naphthalene constituents and TPH extends approximately 1,600 feet from the northern boundary of Site 2 to the southeast of the sites. Only one well, TT02-MW02 had groundwater concentrations exceeding applicable screening levels for only one constituent. The observed groundwater concentrations of BTEX, VOC and TPH at Site 2 and 4 were low even with the presence of free product suggesting that the free product only has limited impact on surrounding groundwater and that groundwater quality is improving over time (KCH, 2014).

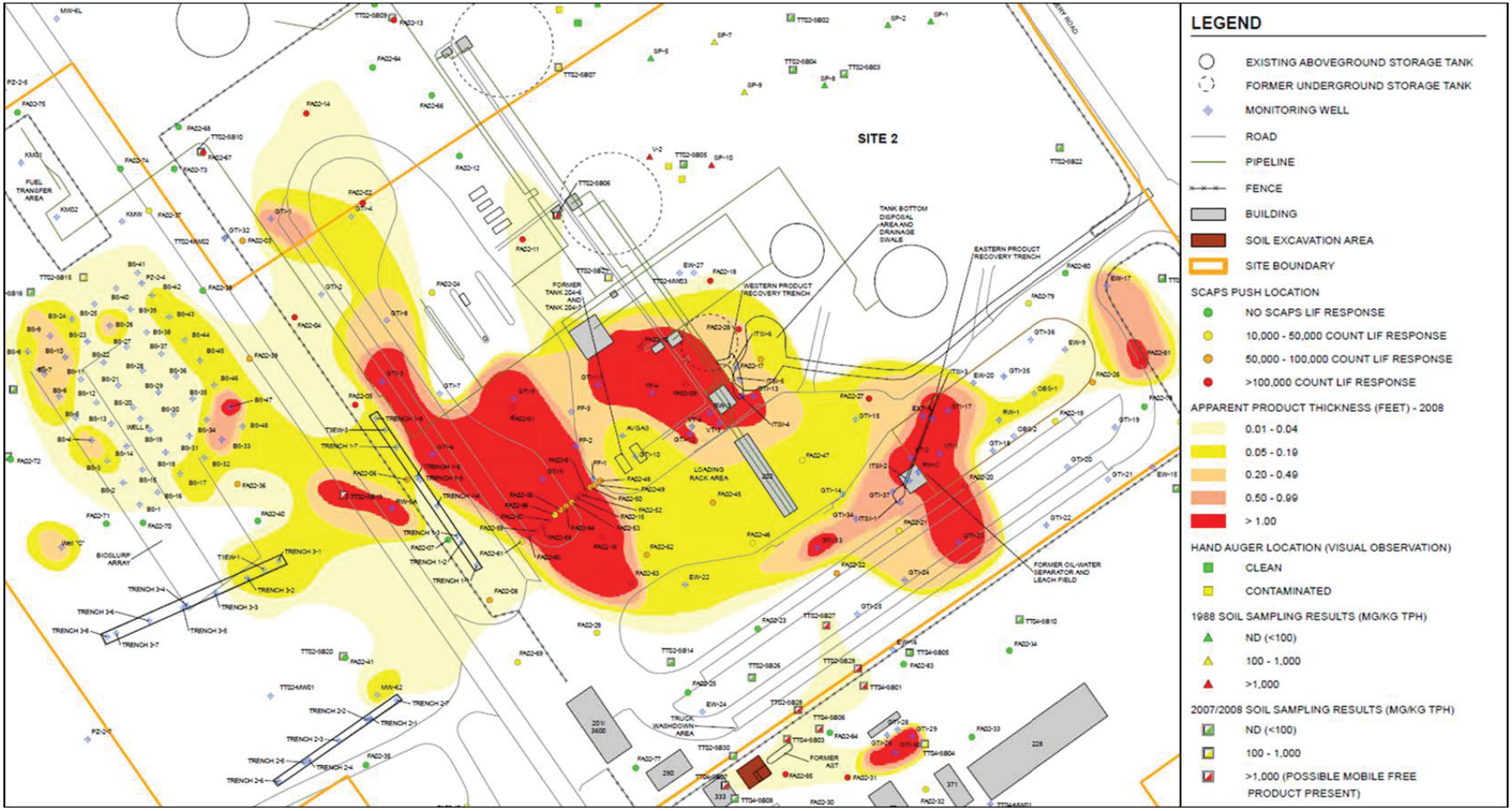


Figure 4-6 – Sites 2 and 4 Apparent Product Thickness – 2008 (KCH, 2014)
[Note: Derived from Figure 3-2 of 2014 RI Addendum/FS (KCH, 2014)]

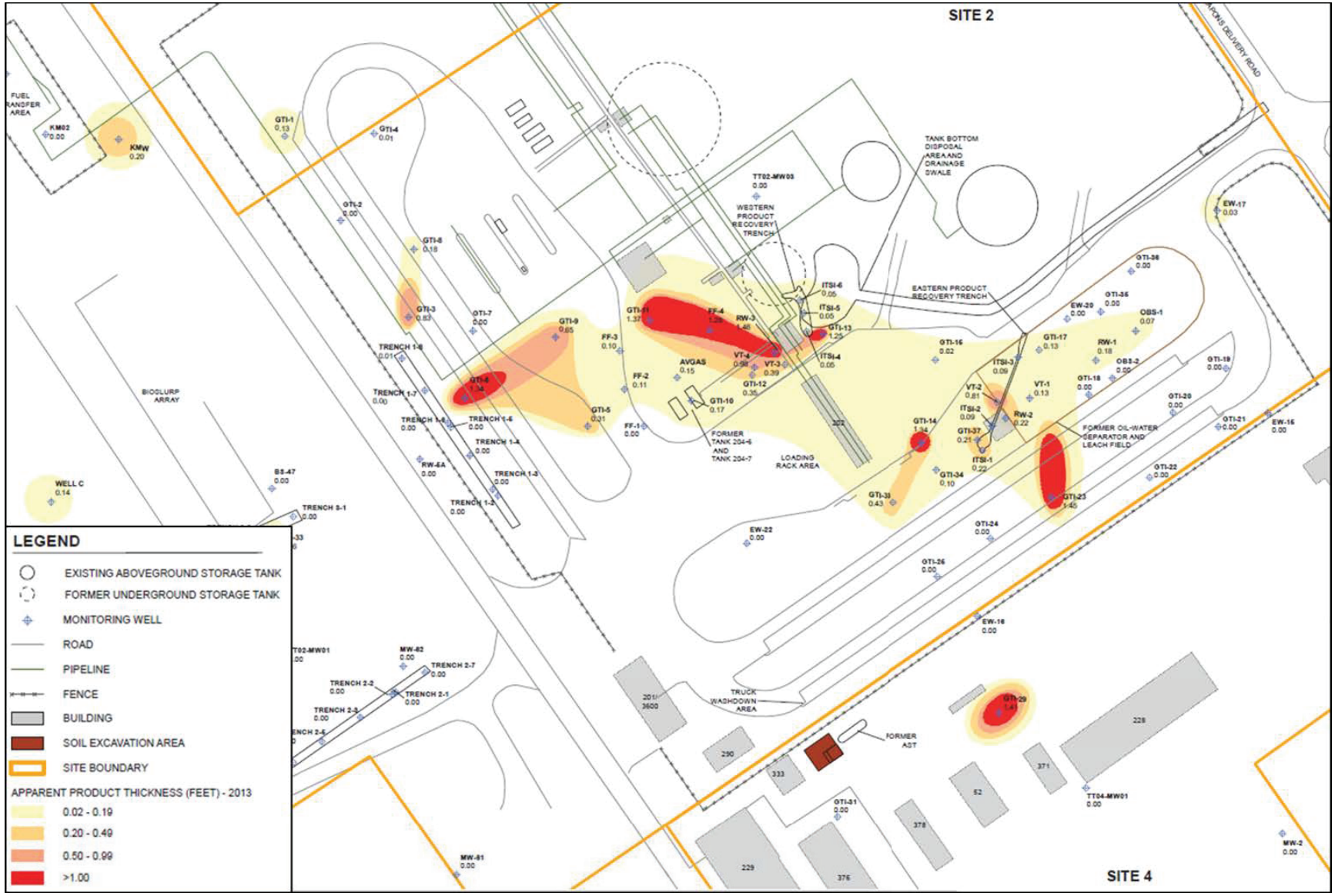


Figure 4-7 – Sites 2 and 4 Apparent Product Thickness – 2013 (KCH, 2014)
[Note: Adapted from Figure 3-3 of 2014 RI Addendum/FS (KCH, 2014)]

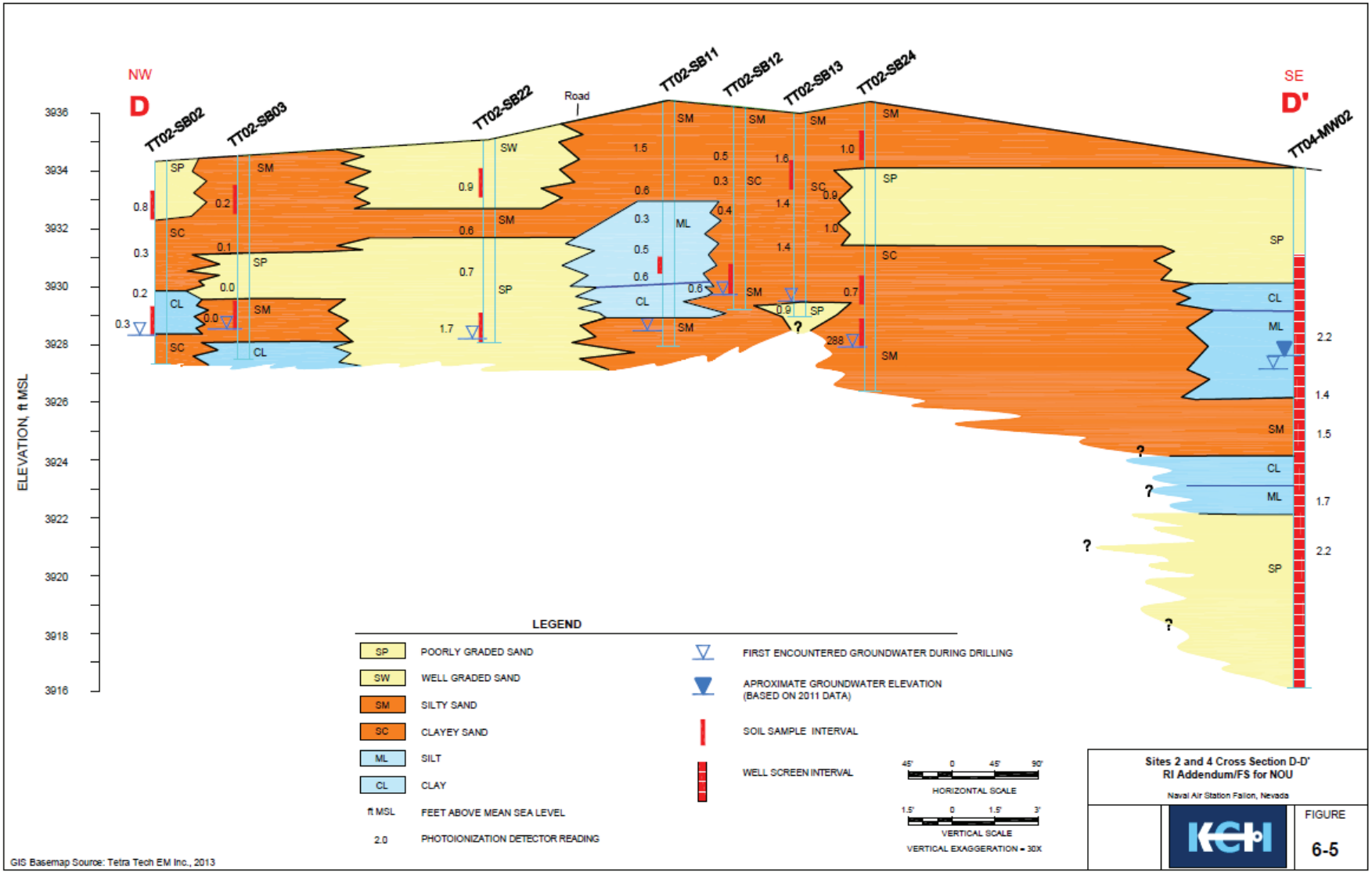


Figure 4-8 – Sites 2 and 4 Soil Sampling Results (KCH, 2014)
[Note: Figure 6-5 from 2014 RI Addendum/FS (KCH, 2014)]

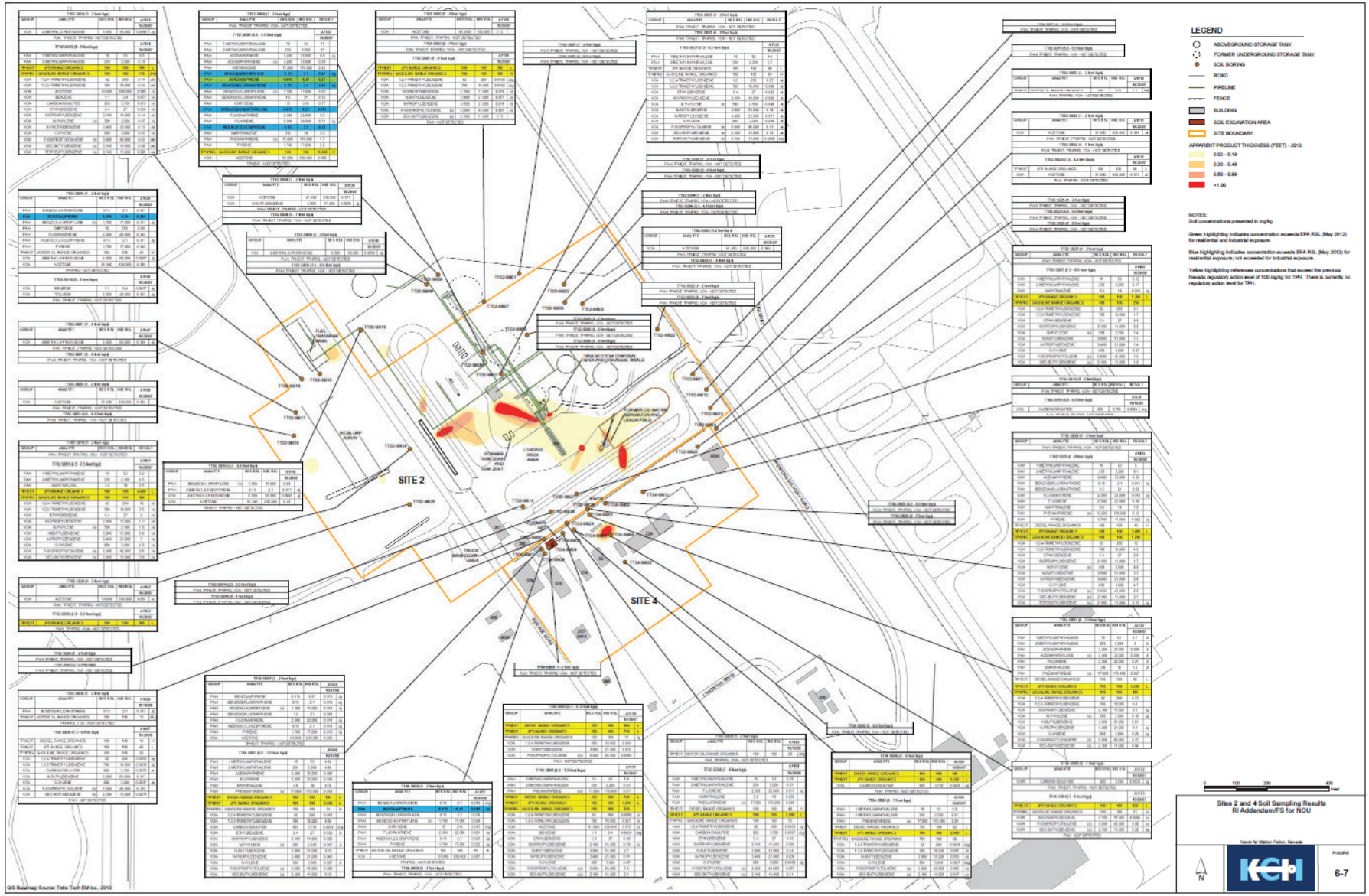


Figure 4 9 – Sites 2 and 4 Groundwater Sampling Results (KCH, 2014)-DRAFT PLACEHOLDER
[Note: Figure 6-8 from 2014 RI Addendum/FS (KCH, 2014)]

5.0 TEST DESIGN

This section provides details regarding the conceptual experimental design, baseline characterization activities, demonstration design and layout, sampling plan, and data analysis associated with the technology demonstration performed at NAS Fallon Site 2.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The conceptual experimental design associated with the primary objective of this demonstration project is to demonstrate the application of various methods to help the DoD to make more informed decisions regarding remediation and management with the potential to build a stronger case for risk-based closure of a site. For decades, the demonstration site has been performing ongoing active remediation, and previously collected data is being utilized to target areas of known contamination. The field activities associated with the demonstration project included collection of the soil, groundwater and LNAPL samples within the current footprint free product at the site and deploying Carbon Traps to measure carbon dioxide flux at the site. Soil samples were collected from three direct push borings. The groundwater samples were collected from existing groundwater monitoring wells, and the LNAPL sample was collected during one of the ongoing free product recovery activities. The Carbon Traps were deployed for two weeks before being collected and shipped off to the lab for analysis.

5.2 BASELINE CHARACTERIZATION

This section provides details regarding available site historical data as well as subsurface clearance and baseline sampling activities performed prior to commencement of the work at the Site.

5.2.1 Utility Clearance

Standard underground utility clearance activities including utility locate services were performed at NAS Fallon prior to the start of any intrusive subsurface work at the site. A dig permit was also obtained prior conducting to any intrusive subsurface field activities to avoid damage to any existing underground utilities at the site.

5.2.2 Baseline Measurements

Prior to the start of the groundwater and soil sampling activities conducted as part of the demonstration field investigation, select monitoring wells at NAS Fallon Site 2 were gauged to confirm the presence of free product using an interphase probe. Several groundwater monitoring wells located within and on the fringe of the current free product plume were gauged to assess the presence of free product, and subsequently determine which locations would warrant groundwater sample collection. If measurable free product was present in a monitoring well, the well was not selected for groundwater sample collection. **Table 5-1** includes the list of the select wells that were gauged for the presence of free product and their corresponding measurements. Please note that this is not an all-inclusive list of monitoring wells present at the site.

Table 5-1 – Baseline Groundwater Monitoring Well Gauging Details

Monitoring Well ID	Depth to LNAPL (ft bgs)	Depth to Water (ft bgs)	Total Depth (ft bgs)	Free Product Thickness (ft)	Comments
FF2	9.2	9.33	--	0.13	
FF1	--	8.92	9.39	--	
ITSI-6	11.64	11.95	--	0.31	
GTI-9	9.8	10.27	--	0.47	
FF-3	9.53	9.57	--	0.04	
GTI-5	9.47	9.76	--	0.29	
GTI-10	13.78	14.03	--	0.25	
ITSI-4	11.86	12.19	--	0.33	Strong Odor
GTI-15	--	9.35	15.32	--	
GTI-17	--	10.14	15.72	--	
GTI-34	--	--	--	--	Strong Odor
VT-1	--	10.14	12.34	--	
GTI-8	--	9.03	15.32	--	
RW-5A	--	9.28	16.35	--	Sheen

Notes:
ft = feet
LNAPL -= light non aqueous phase liquid

5.3 TREATABILITY OR LABORATORY STUDY RESULTS

A treatability study was not conducted as part of this demonstration project.

5.4 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

The following sections detail the general design and layout of the components pertinent to the field demonstration at NAS Fallon Site 2.

5.4.1 Description of Soil and Groundwater Sampling and Required Equipment

The TPH-CWG risk-based method assesses the health risks of LNAPL by analyzing the various TPH fractions that make up its composition. The purpose of performing this method at Site 2 is to identify the risks associated with the remaining weathered product. There is a potential for differing rates of degradation at the site in the various matrices, so collection of both groundwater and soil samples was conducted. In addition, one LNAPL sample was also collected to evaluate the TPH fractionation in the free product being recovered from the site. The selected locations for all of the field samples and Carbon Trap deployment locations are shown in

Figure 5-1. These locations were selected based on the data from the former SCAPS investigation and the 2013 monitoring data as well as any requirements for each methodology.

Soil samples were collected using direct push technology (DPT) due to the shallow groundwater and the lithology of NAS Fallon Site 2. Advantages include the smaller size of the DPT rigs, which allows for sampling in spaces that would be impossible for larger, conventional hollow stem auger (HSA) rigs; and quicker penetration, allowing for more efficient and economical site characterization. An additional benefit is that a minimal amount of waste material is produced when compared to traditional drilling methods. DPT devices may be driven by manual, mechanical, or hydraulic methods, and may be truck-mounted or stand-alone. A DPT tool string includes the sample collection tool and extension rods for advancement and retrieval of the sample tool.

A total of 7 soil samples were collected from 3 soil borings, which includes one duplicate. The primary concern for collecting grab samples for the fractionation analysis was detecting concentrations of TPH in vadose zone soil above the water table. Therefore, soil samples were collected based on the observed presence of gross contamination (staining and odor) just above the water table at each boring location. Soil sample locations shown in
Figure 5-1 were selected based on the 2008 SCAPS investigation and the 2013 free product measurements and targeted in areas where apparent free product thickness was historically greater than one foot.

Figure 4-6 and **Figure 4-7** from the previous section show the free product thickness observed at the site in 2008 and 2013. Historically, groundwater has been encountered while drilling at depths ranging from approximately 5.7 to 9 feet bgs at the site. The three sample location areas included:

1) Between wells RW-3 and FF-4 (duplicate was collected here);
2) Between wells GTI-6 and GTI-9; and
3) Adjacent to well FF-4.

Five groundwater samples were collected (4 samples and 1 duplicate) from the existing monitoring wells at Site 2. Groundwater samples were collected using low flow purge methodology from groundwater wells GTI-17 (duplicate), GTI-15, GTI-8, and RW-5A. These wells were selected based on their proximity to the free product plume measured in 2013 as well as the TPH concentrations measured during the 2007 and 2008 investigations. Final groundwater well locations were determined based on field measurements and presence of free product during the sampling event. Section 5.6 contains details on the sampling method. Locations of all sampling locations are displayed in **Figure** 5-1 below.

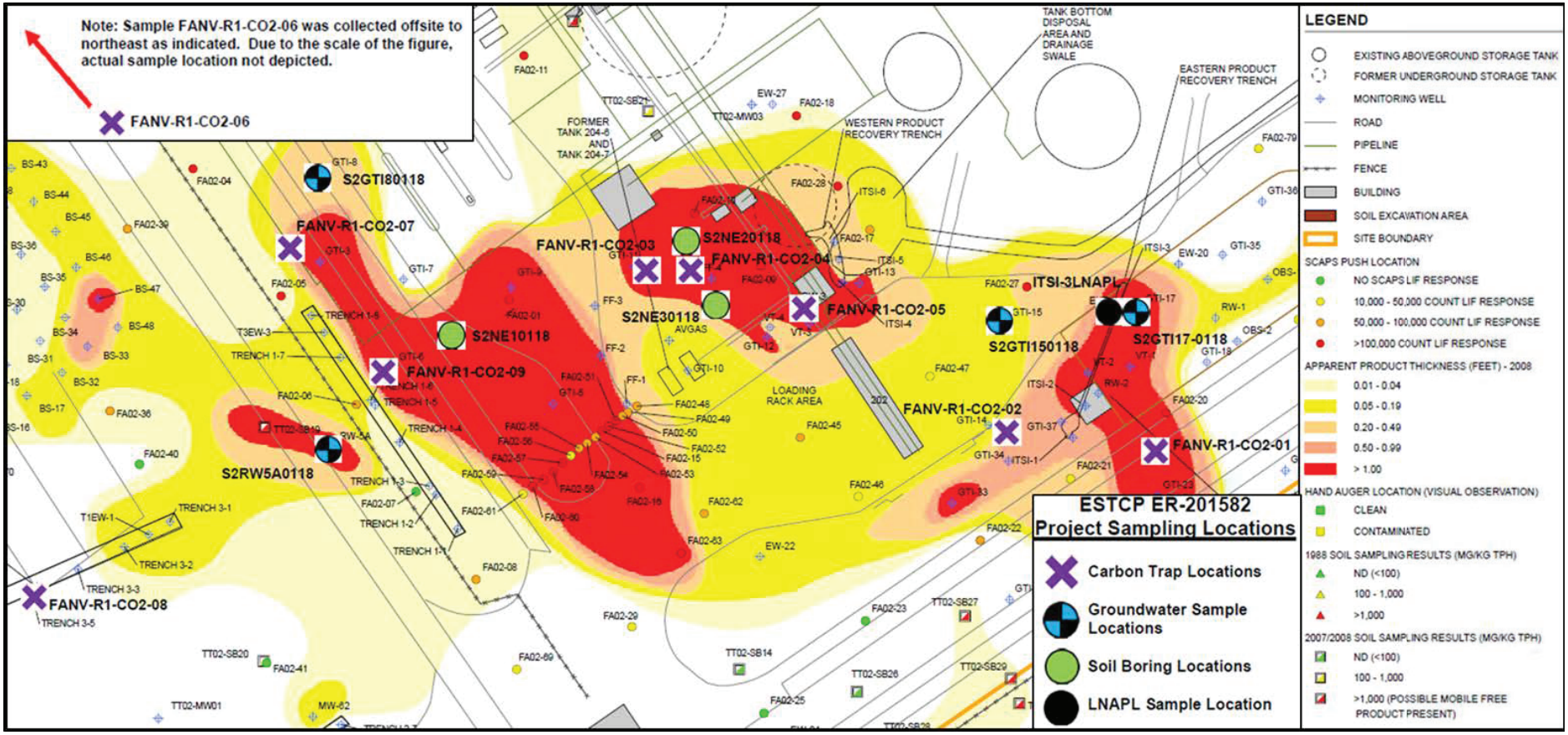


Figure 5-1 – Site 2 Sampling Locations for ER-201582 (Adapted Figure from KCH, 2014)
[Note: Base map adapted from Figure 6-8 from 2014 RI Addendum/FS (KCH, 2014), sample locations inserted on figure]

5.4.2 Carbon Trap Activities

Carbon Traps are manufactured and analyzed by E-Flux. For the field demonstration, Carbon Traps were installed for two weeks at the site during October 2017 and then returned to the vendor for analysis. In summary, carbon dioxide exiting the ground surface is trapped for a period of 2 weeks, then the carbon trapping material (soda lime) is retrieved and analyzed to determine the amount of carbon trapped, from which an efflux rate can be calculated (units of $\mu mol/m^2/s$). An additional correction is performed to remove any background signal from the decay of natural organic materials using a ^{14}C analysis. Finally, the carbon dioxide efflux rate from hydrocarbon degradation is converted to units of gallons per acre per year.

Nine Carbon Traps were deployed following receiver installation and analyzed for this demonstration. Eight of the traps were installed on the site in the vicinity of the residual free product footprint, and one was placed in a remote unimpacted location to measure background CO_2 concentrations. In order to get a representative degradation rate for the site, the eight on site traps will be dispersed across a spectrum of low to high LNAPL impacted locations. These locations are displayed in **Figure** 5-1. After the Carbon Traps were deployed for 2 weeks, they were collected and shipped in a dry cooler to E-Flux Laboratories where they were analyzed for total CO_2 as well as ^{14}C analysis to correct for carbon flux generated from the decay of natural organic materials.

5.5 FIELD TESTING

For this demonstration, the field effort was conducted in three primary phases. The first was performed in October 2017 to deploy Carbon Traps, and this was followed by free product sample collection in December 2017 in conjunction with ongoing free product recovery activities at the site. The third field effort conducted in January 2018 was performed to collect soil and groundwater samples within the residual LNAPL footprint at the site.

5.5.1 Carbon Trap Analysis

For the carbon flux assessment, passive Carbon Traps from E-Flux were deployed at the site to measure CO_2 flux from the subsurface. After a two-week deployment period, the Carbon Traps were then shipped to the E-Flux Analytical laboratory in Fort Collins, Colorado for analysis.

Additional details regarding Carbon Trap analysis and calculation of the equivalent LNAPL NSZD rate are included with the analytical results in **Appendix B**.

5.5.2 Soil and Groundwater Analysis

For this demonstration, the field sampling program consisted of soil collection, groundwater and free product sampling, and TPH fractionation analysis, per the Washington State EPH and VPH analytical method. The rationale for analyzing these various matrices using this analytical method is to complete human health risk evaluations of petroleum-impacted sites using the TPH-CWG risk-based method. This method treats complex petroleum mixtures as a combination of fractions for estimating non-cancer risk within a tiered framework and to calculate risk-based screening

levels as well. The TPH-CWG risk-based method has identified 13 fractions which are separated into different classes by compound type (aliphatic vs. aromatic) and by carbon number.

The Washington State EPH method was designed to measure concentrations of extractable aliphatic and aromatic petroleum hydrocarbons in water and soil. Additionally, the Washington State VPH method was designed to measure volatile aliphatic and aromatic petroleum hydrocarbons in water and soil as well as other volatile constituents and gases. **Table 5-2** below include the various TPH fractions and compounds analyzed in soil and water as part of both methods.

Table 5-2 – List of Analytes per Washington EPH and VPH Methods

Washington EPH Method	Washington VPH Method
C8-C10 Aliphatics	C5-C6 Aliphatics
C10-C12 Aliphatics	C6-C8 Aliphatics
C21-C34 Aliphatics	C8-C10 Aromatics
C8-C10 Aromatics	C10-C12 Aromatics
C10-C12 Aromatics	C12-C13 Aromatics
C-12-C16 Aromatics	Methyl tert-butyl Ether
C-16-C21 Aromatics	Benzene
C21-C34 Aromatics	Toluene
	Ethylbenzene
	m,p-Xylene
	o-Xylene
	1,2,3 Trimethylbenzene
	Naphthalene
	1-Methylnaphthalene
	n-Pentane
	n-Hexane
	n-Octane
	n-Decane
	n-Dodecane

Field parameters including pH, conductivity, dissolved oxygen, oxidation-reduction potential (ORP), turbidity, and total dissolved solids (TDS) were measured concurrently with collection of aforementioned groundwater samples. These are standard general water quality parameters used to assess stability during low flow purging prior to sample collection.
Soil samples were collected using direct push technology (DPT), and groundwater samples were collected using a low-stress, low-flow groundwater sampling technique. LNAPL samples were collected during ongoing free product recovery activities at the site.

Additional details on sample collection and analysis are included in Section 5.6.

5.5.3 IDW Management

Investigation derived water (IDW) generated during the field activities included excess soil cuttings from direct push core collection, purge water from groundwater sampling, and equipment decontamination wastes. The IDW was sampled and characterized following field activities. Disposal and IDW management was completed by NAS Fallon in accordance with local, state and federal regulations.

5.6 SAMPLING METHODS

As described in Section 5.5, the field sampling was conducted in three events. **Table 5-3** includes the total number of type of samples collected during the field demonstration. **Table 5-4** includes details on the analytical methods for the soil, ground and LNAPL sample collection.

Following the two-week deployment period in October 2017, the Carbon Traps were shipped to E-Flux's Analytical Laboratory in Fort Collins, Colorado for analysis. CO_2 flux was analyzed using method ASTM 4373-02. Corresponding corrective analyses were performed to understand contributions of NOM degradation (^{14}C isotope analysis) to CO_2 flux measurements according to method ASTM D6686-12.

In December 2018, an LNAPL sample was collected from one well during concurrent free product recovery activities and submitted for analysis in 40mL VOA vials. The sample was then shipped on ice to Analytical Resources Laboratory in Tukwila, Washington for analysis.

During the January 2019 field event, groundwater samples were collected via a low flow purging protocol. Once groundwater parameters stabilized, samples were collected in amber bottles and 40 mL VOA vials for analysis as specified in **Table 5-4**. Soil cores were collected using DPT, and samples were taken based on observed gross contamination above the water table. Two samples from each soil core, plus one duplicate, were submitted to the laboratory in 8 oz glass jars for EPH analysis. Approximately 5 mg of sample mass was collected in 40 mL VOA vials, and this was submitted for VPH analysis. The groundwater and soil samples were stored on ice, then shipped to Analytical Resources Laboratory in Tukwila, Washington for analysis.

Following analysis of the soil samples, two of the remaining bulk soil samples were submitted to Eurofins Laboratory in Lancaster, Pennsylvania for reanalysis in July 2018. These samples were reanalyzed for WA EPH and WA VPH method and were also analyzed for VOCs using EPA Method 8260C and TPH Method 8015B for comparison purposes.

Table 5-3 – Total Number and Types of Samples Collected.

Component	Matrix	Number of Samples	Analyte	Location
Field Demonstration	Soil	7	TPH (WA EPH/VPH method)	3 boring locations within current free product footprint. 2 samples collected per boring location in vadose zone just above the water table.
	Groundwater	5	TPH (WA EPH/VPH method) including select VOCs, Water Quality Parameters[1]	One sample each from existing groundwater monitoring wells within historical free product footprint; no measurable product present.
	Free Product Sample (LNAPL)	1	TPH (WA EPH/VPH method)	From current LNAPL recovery well.
	CO_2 Flux	9	CO_2 and ^{14}C	Distributed across the Site.

Notes:
1. Water quality parameters include pH, conductivity dissolved oxygen, ORP, turbidity, and TDS

Table 5-4 – Analytical Methods for Sample Analysis

Matrix	Analyte	Analytical Methods	Container (number, size, and type)	Preservative Requirements	Holding Time
Groundwater	TPH Fractionation Analysis (Aliphatic/ Aromatic)	-WA EPH Aromatics in Water -WA EPH Aliphatics in Water -WA VPH in Water	-1 x Glass NM, Amber, 500 mL -1 x Glass NM, Amber, 500 mL -3 x VOA Vial, Amber, 40mL	-Cool to < 6ºC -Cool to < 6ºC -HCl pH < 2	7 days 7 days 14 days
	pH	Parameters measured in the field using a multi-parameter water quality meter.	NA	NA	NA
	DO				
	Conductivity				
	Turbidity				
	Temperature				
	ORP				
	TDS				
Soil	TPH Fractionation Analysis (Aliphatic/ Aromatic)	-WA EPH Aromatics in Solid -WA EPH Aliphatics in Solid -WA VPH in Solid	-1 x Glass WM, Clear, 8 oz (min 150 g) -1 x Glass WM, Clear, 8 oz (min 150 g) -1 x VOA Vial, Amber, 40mL (min 10 g)	-Cool to < 6ºC -Cool to < 6ºC -MeOH, Cool < 6ºC	14 days 14 days 14 days
Free Product	TPH Fractionation Analysis (Aliphatic/Aromatic)	WA State Method EPH/VPH	1 x VOA Vial	Cool to < 6ºC	14 days
Sorbent Resin in Carbon Trap	CO_2 and ^{14}C	ASTM D 4373 – 02 D6866 – 12	9 Carbon Traps	None	--

Notes:

1. mL: milliliter; g: gram; NA: not applicable; ºC: degree Celsius

5.6.1 Quality Assurance and Quality Control (QA/QC)

The container and preservative requirements are shown in **Table 5-4** in Section 5.6. Analytical methods and reporting limits are listed in **Appendix B**. Quality assurance sampling included triplicate blanks, field duplicates, equipment blanks. Calibration of field equipment was conducted as per manufacturers' or subcontractors' recommendations. Calibration of analytical equipment followed the analytical laboratory's in-house QA/QC protocols. These details are listed in **Appendix B**. The specific methods for calibration, decontamination, and sample documentation are also presented in **Appendix B**.

As described in Section 5.6, two soil samples were also reanalyzed to assess the validity of the initial results. It is important to note, however, that samples were reanalyzed outside of the standard holding time.

5.6.2 Inspections and Documentation

A NAVFAC EXWC field representative supervised all on site demonstration activities. Field inspections were performed to verify that all work is in conformance with the approved work plan, and Site Safety and Health Plan (SSHP) (to be provided by contractor). Inspection of field activities included but is not limited to the following:

- All DPT locations are abandoned in accordance with all local, state, and federal regulations
- Visual inspection of all equipment being used for the demonstration.
- Health and safety briefing is held daily and appropriate monitoring is performed.
- All field activities including DPT soil sampling, groundwater sampling, Carbon Trap deployment and air monitoring are documented.

Field documentation consisted of photographic records and observation and testing data sheets. Relevant aspects of the demonstration project were photographically documented.

The field representative maintained a field copy of the approved demonstration plan and SSHP for the purposing of documenting any deviations. Copies of all change orders, notes, sketches, and memoranda will be available for reference.

5.6.3 Decontamination Procedures

All field sampling equipment were properly decontaminated to minimize the potential for exposure and off-site transport of impacted materials. Such equipment included, but were not limited to sampling tools, heavy equipment, vehicles, PPE, and various handheld tools.

Equipment decontamination was performed near the sampling location. All employees that performed equipment decontamination wore appropriate PPE to protect against exposure to contaminated materials. The level of PPE was equivalent to the level of protection required in the site exclusion zone.

Field crews and subcontractor personnel performed decontamination of vehicles and equipment that were used to perform work within controlled work areas. Reusable equipment was

decontaminated between sampling events using the triple-rinse method (i.e., distilled water, followed by phosphate-free detergent, and then distilled water). Following equipment decontamination, employees followed proper personal decontamination procedures. For smaller equipment, the following steps for decontamination were used during this demonstration:

1. Remove the majority of visible gross contamination in the exclusion zone.
2. Wash equipment in decontamination solution with a scrub brush and/or power wash heavy equipment.
3. Rinse equipment.
4. Visually inspect for remaining contamination.
5. Follow appropriate personal decontamination steps.

All decontaminated equipment was visually inspected for contamination prior to leaving the site. Signs of visible contamination included any oily sheen, residue or contaminated soil left on the equipment. All equipment with visible signs of contamination were discarded or decontaminated until cleaned. Solid and liquid decontamination waste were separated, containerized, labelled, and disposed of according to state and federal regulations.

5.7 SAMPLING RESULTS FOR NAS FALLON

The following section includes the analytical results and calculations completed as part of the field demonstration. All laboratory analytical reports can be found in **Appendix B** and supplement calculations in **Appendix C** and **Appendix D**. The field forms from the various field efforts, as well as photographs, have also been included in **Appendix E**.

5.7.1 LNAPL Sample Analysis and Results

The following tables, **Table 5-5** and **Table 5-6**, include the analytical results from the LNAPL TPH Fractionation analysis via Washington State VPH and EPH methods. Only one sample was collected from the site for LNAPL fractionation analysis on December 7, 2017. The sample was collected from one of the wells with the greatest amount of free product observed during the free product recovery activities (ITSI-3). Based on the VPH analytical results, BTEX was not detected in the sample. Aromatic constituents were only detected in the C_8 to C_{13} range and aliphatics only from C_{10}-C_{12} range. As for the EPH analysis, aromatic and aliphatic ranges were only detected for carbon chain ranges C_8-C_{10}, C_{10}-C_{12} and C_{12}-C_{16}. Based on the analytical results, the remaining product appears to be highly weathered, and the more soluble compounds are not the predominant constituents present in the residual product.

Table 5-5 – LNAPL Analytical Results: Volatile Petroleum Hyrdocarbons (VPH) Analysis at ITSI-3 (mg/L)

Analyte	Concentration (mg/L)
VPH C_5-C_6 Aliphatics	< 4,410 U
VPH >C_6-C_8 Aliphatics	< 4,410 U
VPH >C_8-C_{10} Aliphatics	< 4,410 U
VPH >C_{10}-C_{12} Aliphatics	**49,800 E,D**
VPH >C_8-C_{10} Aromatics	**15,700 D**
VPH >C_{10}-C_{12} Aromatics	**62,900 D**
VPH >C_{12}-C_{13} Aromatics	**44,000 D**
MTBE	< 441 U
Benzene	< 441 U
Toluene	< 441 U
Ethylbenzene	< 441 U
m, p-Xylene	<882 U
o-Xylene	< 441 U
Benzene, 1,2,3-Trimethyl-	**2,010 D**
Naphthalene	**962 D**
1-Methylnaphthalene	**1,600 D**
n-Pentane	< 441 U
n-Hexane	< 441 U
n-Octane	< 441 U
n-Decane	**2,390 D**
n-Dodecane	**13,700 D**

Notes:
mg/L – milligram per liter
VPH – Volatile Petroleum Hydrocarbon
U – This analyte is not detected above the applicable reporting or detection limit.
D – The reported value is from a dilution

E – The analyte concentration exceeds the upper limit of the calibration range of the instrument established by the initial calibration (ICAL)
MTBE – Methyl tert-butyl ether

Table 5-6 – LNAPL Analytical Results: Extractable Petroleum Hydrocarbon (EPH) Analysis (mg/kg)

Analyte	Concentration (mg/kg)
C_8-C_{10} Aliphatics	**32,000**
>C_{10}-C_{12} Aliphatics	**262,000**
>C_{12}-C_{16} Aliphatics	**254,000**
>C_{16}-C_{21} Aliphatics	< 2,000 U
>C_{21}-C_{34} Aliphatics	< 2,000 U
C_8-C_{10} Aromatics	**4,080**
>C_{10}-C_{12} Aromatics	**24,200**
>C_{12}-C_{16} Aromatics	**54,800**
>C_{16}-C_{21} Aromatics	< 2,000 U
>C_{21}-C_{34} Aromatics	< 2,000 U

Notes:
mg/kg – milligram per kilogram
EPH – Extractable Petroleum Hydrocarbon
U – This analyte is not detected above the applicable reporting or detection limit.

Typically, as product weathers, more of the higher molecular weight compounds with lower vapor pressure/volatility remain while less of the toxic aromatics and more soluble compounds are present. **Table 5-7** below includes the fractions for various hydrocarbon ranges observed in the LNAPL at NAS Fallon and specific characteristics/properties including vapor pressure and solubility for both aliphatic and aromatic components. The table also includes the results of the fraction analysis for NAS Fallon as part of the field demonstration which are discussed in more detail below. Roughly 80% of the carbon fractions present in the LNAPL sample were aliphatic compounds as opposed to the lighter more soluble aromatics which were approximately 20%. Arrows have been included with the table below indicating the effect of weathering on vapor pressure and solubility properties. Typically, as product weathers, the lighter more volatile compound degrade more quickly, and the heavier fractions remain. The lighter aromatic compounds also degrade more quickly that than the aliphatic compounds as indicated by the arrows adjacent to **Table 5-7**. The percentages for the carbon chain ranges were calculated by adding the total TPH for both aliphatic and aromatic carbon chain ranges and calculating the percentages by dividing each fraction by the total TPH value.

Table 5-7 – TPH Fractionation Carbon Chain Ranges and Corresponding Properties (USEPA, 2010)

Fraction	Solubility (mg/l)		Vapor Pressure (atm)	NAS Fallon LNAPL Sample
	Aliphatics	Aromatics		
C_6-C_8	5.4	--	0.063	ND
C_8-C_{10}	0.43	65	0.0063	8%
C_{10}-C_{12}	0.034	25	0.00063	36%
C_{12}-C_{16}	0.00076	5.8	0.000048	56%
C_{16}-C_{21}	0.0000013	0.65	0.0000011	ND

More Weathered

Figure 5-2 below includes a comparison of the compositional analysis conducted on LNAPL samples from 2007 and 2017, which were collected within the same vicinity of the free product footprint. Based on the compositional analysis conducted in 2007, the predominant carbon chain ranges that were present in both samples are similar; although there is a greater percentage of higher carbon change ranges present in the most recent sample (2017), indicating continued weathering of the residual free product at the site. When looking at the carbon chain fractions present in 2007 versus 2017, the heavy hydrocarbon fraction percentages are increasing, while the C_3-C_8 fraction has disappeared between 2007 and 2017, indicating that the product is weathering. Based on the compositional characterization, a majority of the carbon chain fraction present in the LNAPL sample collected in 2017 is predominately C_{10}-C_{16}, while only approximately 8% is present as C_8-C_{10}.

Additional figures have been included below comparing the NAS Fallon samples to unweathered fuel product samples (Geosphere & CH2MHill, 2006) based on carbon chain range and presence of aliphatic versus aromatic constituents. **Table 5-8** below includes a summary of the various fractionation data for various unweathered fuel samples and the NAS Fallon sample from 2017. The sample collected in 2007 was not analyzed for aliphatic and aromatic constituents, only carbon chain range fractions. It is important to note that the 2007 and 2017 samples were analyzed for slightly different carbon change ranges than the fuels analyzed, therefore the approximate ranges and distributions are presented in **Figure 5-3**, **Figure 5-4**, and **Figure 5-5** and **Table 5-8** included below for comparison purposes.

In **Figure 5-3**, the NAS Fallon Sample from 2017 did not have carbon chain ranges detected for C_{10} or below, compared to the unweathered product samples for a variety of fuels. The various fuel types that may have previously stored at the site include JP-5, JP-8, diesel, aviation gasoline, and motor vehicle gasoline. Although, we do not have JP-8 nor JP-5 unweathered data to compare, JP-5 is similar to that of Jet A which is represented in **Figure 5-3**, **Figure 5-4**, and **Figure 5-5** and **Table 5-8** below. **Figure 5-4**, includes a comparison of the aromatic versus aliphatic constituents present in the various LNAPL samples. The NAS Fallon sample from 2017 is predominantly represented by aliphatic constituents compared to aromatic constituents and therefore representative of a non-gasoline fuel.

Figure 5-5 below includes individual graphs for each LNAPL sample parsing out the distribution of aliphatic and aromatic compounds by carbon chain range. The sample from NAS Fallon as previously indicated is predominately aliphatic constituents with a majority in the C_{12}-C_{16} range which is the same for the aromatic constituents. Based on these results it appears that the LNAPL at Fallon is continuing to weather as the lighter constituents are degrading and a majority of the composition is aliphatic constituents.

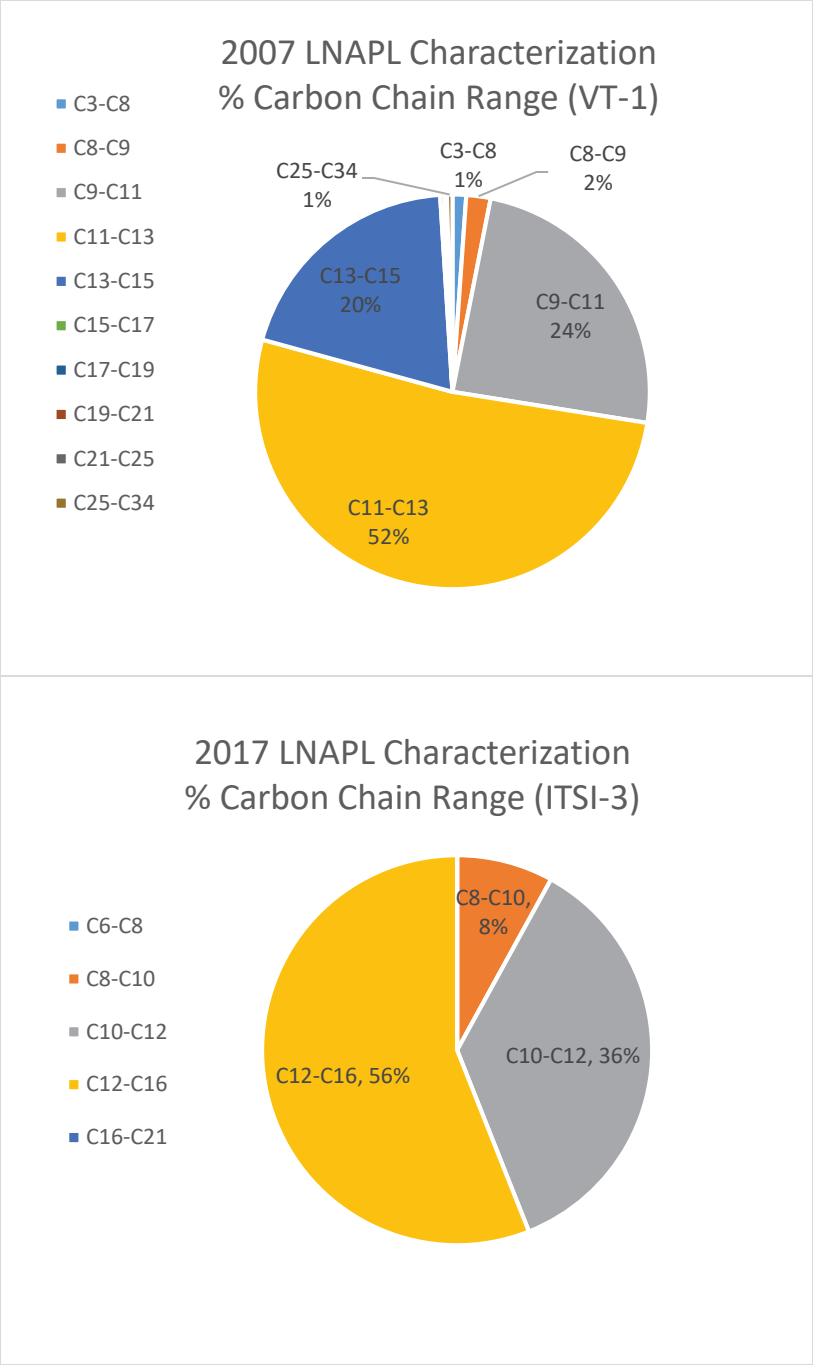


Figure 5-2 – Comparison 2007 (top panel) and 2017 (bottom panel) Carbon Chain Ranges for NAS Fallon Samples with Fresh Product. Note the disappearance of the C3-C8 fraction between sampling intervals.

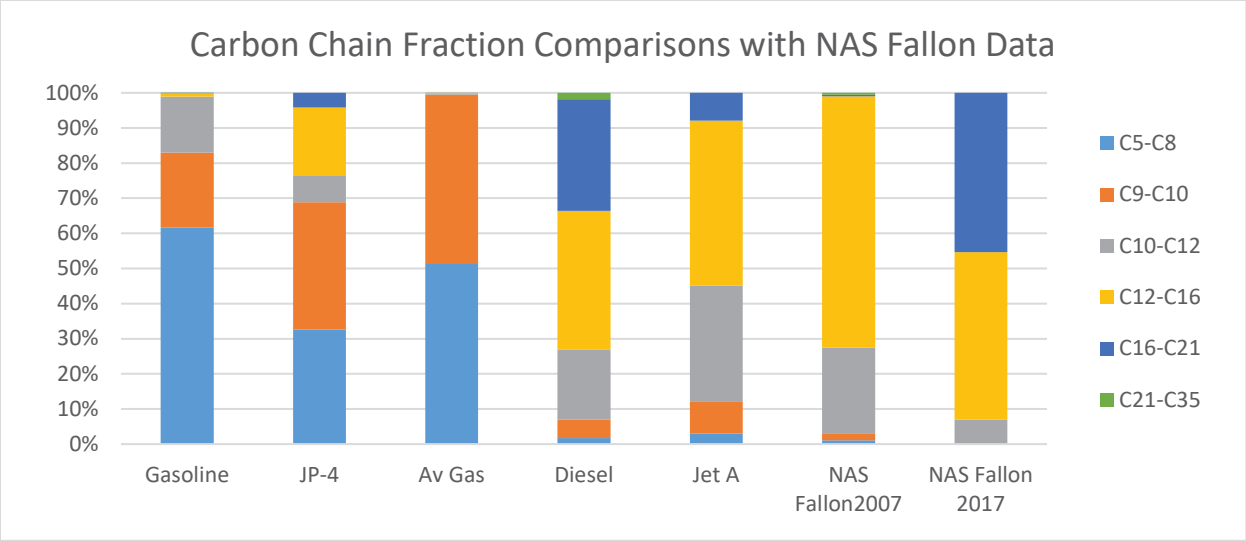


Figure 5-3 – Carbon Chain Fraction Comparison of Unweathered LNAPL Fuel Samples to NAS Fallon Samples

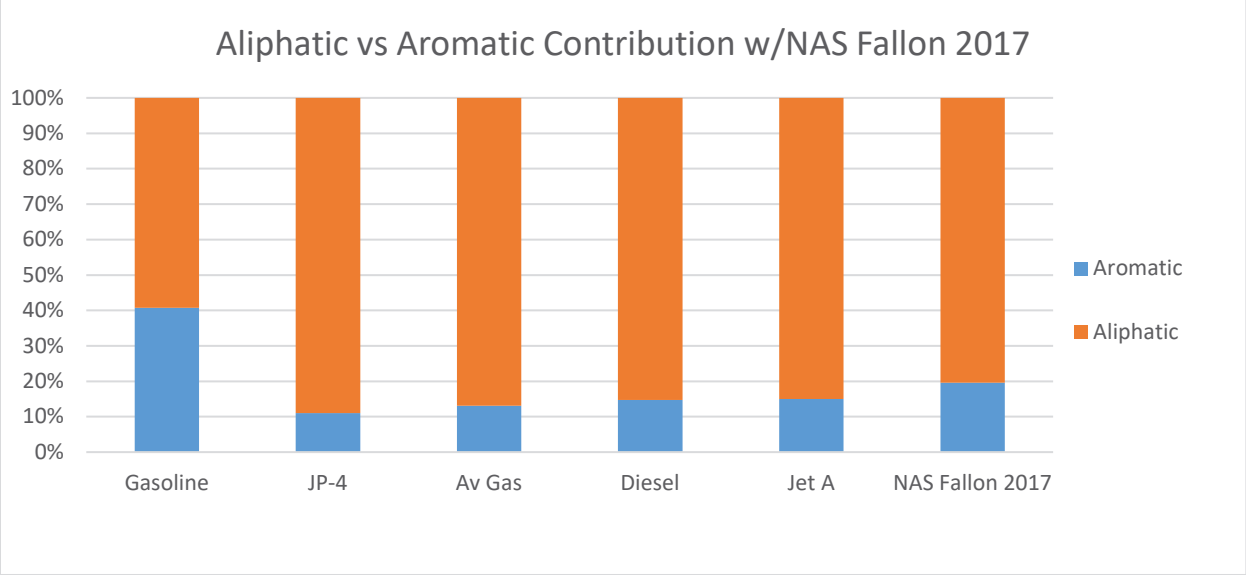


Figure 5-4 – Aliphatic and Aromatic Contributions of Unweathered LNAPL Fuel Samples Compared to NAS Fallon Sample

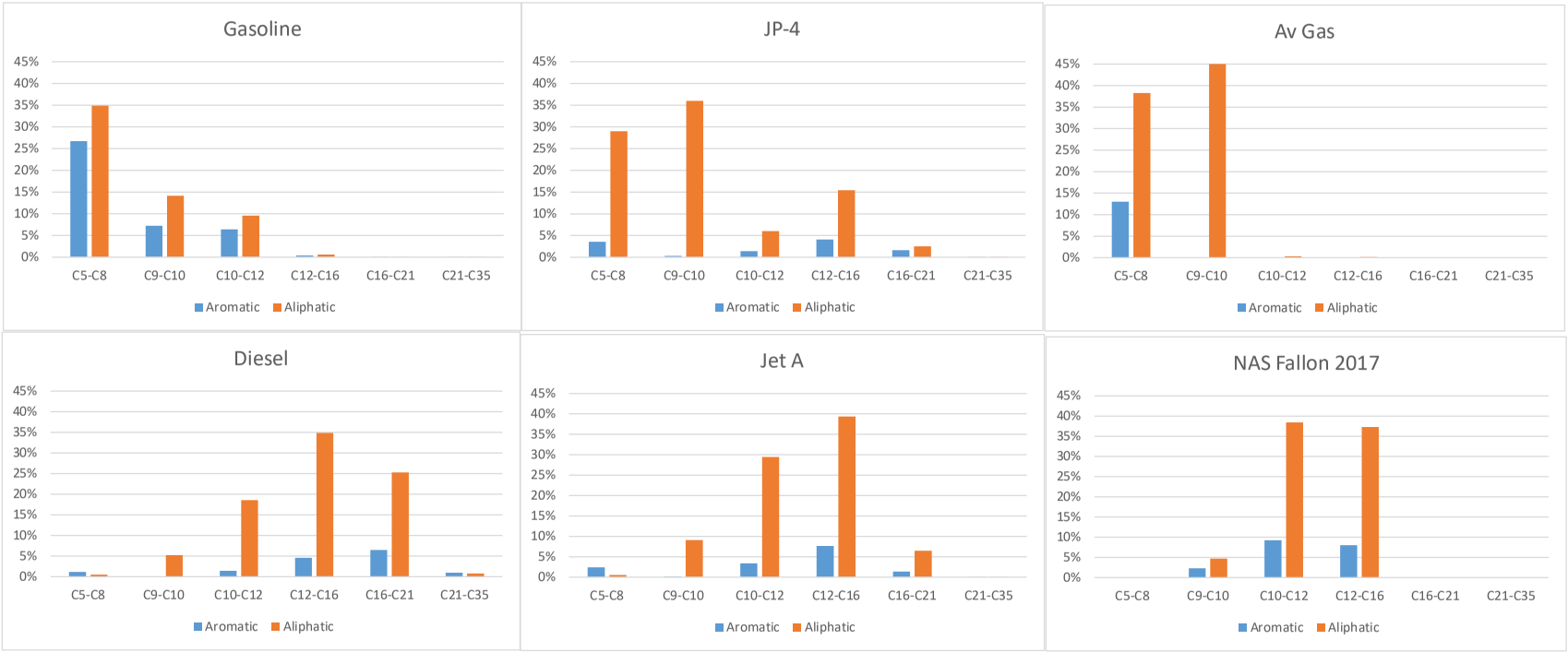


Figure 5-5 – Aliphatic versus Aromatic Carbon Chain Ranges Present in Various Unweathered LNAPL Samples and NAS Fallon Sample

Table 5-8 – Summary Table with Aromatic and Aliphatic Percentages by Carbon Chain Range for Unweathered LNAPL Samples and NAS Fallon Data

Carbon Chain Fraction	Gasoline (Fuel Sample #1)		JP-4 (Fuel Sample #3)		Av Gas (Fuel Sample #8)		Diesel (Fuel Sample #10)		Jet A (Fuel Sample #11)		NAS Fallon	
	Aromatic	Aliphatic	Aromatic	Aliphatic	Aromatic	Aliphatic	Aromatic	Aliphatic	Aromatic	Aliphatic	Aromatic	Aliphatic
C_5-C_8	26.71%	34.91%	3.55%	29.03%	13.03%	38.29%	1.18%	0.51%	2.43%	0.53%	0.0%	0.0%
C_9-C_{10}	7.23%	14.13%	0.33%	35.98%	0.03%	48.12%	0.06%	5.22%	0.18%	9.10%	2.30%	4.70%
C_{10}-C_{12}	6.39%	9.58%	1.40%	6.04%	0.06%	0.31%	1.43%	18.58%	3.38%	29.45%	9.23%	38.45%
C_{12}-C_{16}	0.40%	0.60%	4.10%	15.43%	0.0%	0.14%	4.58%	34.88%	7.65%	39.39%	8.04%	37.28%
C_{16}-C_{21}	0.0%	0.0%	1.63%	2.51%	0.0%	0.01%	6.50%	25.28%	1.38%	6.50%	0.0%	0.0%
C_{21}-C_{35}	0.02%	0.03%	0.02%	0.0%	0.0%	0.01%	0.99%	0.81%	0.02%	0.0%	0.0%	0.0%

Notes: Reference: Geosphere & CH2MHill 2006 Report

5.7.2 Groundwater Monitoring Results

The following section includes the field parameters measured during the groundwater monitoring event, which are presented in **Table 5-9**, as well as the groundwater analytical results for TPH Fractionation Analysis via the Washington State VPH and EPH methods in **Table 5-10** and **Table 5-11** respectively.

For the volatile analysis, VPH aromatic hydrocarbon chain ranges were detected at high concentrations for the aromatics compared to the aliphatics for ranges C_6-C_8, C_8-C_{10}, C_{10}-C_{12}. Benzene was only detected in three of the samples with 'J' flagged concentrations ranging from 3 to 4 µg/L. Toluene was only detected in two of the sample at a concentration of 7 µg/L. Ethylbenzene was detected in all samples with concentrations ranging from 6 to 19 µg/L. Only three of the samples had detections of m,p-xylene with concentrations ranging from 5 to 23 µg/L and o-xylene was detected in all but one sample with concentrations ranging from 5 to 25 µg/L. Naphthalene was detected in all samples with concentrations ranging from 11 to 37 µg/L.

Based on the EPH analysis, the greatest concentrations were observed in the carbon chain ranges from C_8-C_{10}, C_{10}-C_{12}, C_{12}-C_{16} for both aliphatic and aromatic compounds. Only one sample, S2GTI80118 had detection for C_{16}-C_{21} aliphatic carbon chain range at concentration of 7 µg/L, which was 'J' flagged. For the aromatic carbon chain range for C_{16}-C_{21}, all five samples were detected at 'J' flag concentration ranging from 13 to 28 µg/L. Only one sample had a detection in the C_{21}-C_{34} carbon chain range and only for aromatics at a 'J' flagged concentration of 27 µg/L.

Based on the analytical results for volatile analysis of groundwater, none of the samples collected had detections of BTEX greater than the maximum contaminant levels (MCLs). **Table 5-12** below includes a summary of the groundwater analytical results for VPH analysis and established MCLs for the select compounds analyzed. The groundwater samples were collected within the historic residual free product footprint and in wells as close to the measurable free product footprint observed at the time of sampling. The groundwater wells were selected based on gauging effort conducted prior to sampling and did not have measurable free product observed at the time of sampling. Based on the results, the remaining product appears to be highly weathered and the more soluble, and therefore toxic compounds such as BTEX are not the predominant constituents present or solubilizing into the groundwater.

Table 5-9 – Water Quality Parameters

Sample ID	Temperature (ºF)	pH	Conductivity (mS/cm)	ORP (mV)	DO (mg/L)	Turbidity (NTU)	TDS (g/L)
S2GTI150118	65.8	7.85	6.09	-268	0.65	41.9	3.83
S2GTI17-0118	63.7	7.86	17.5	-394	0.02	35.8	--
S2GTI80118	68.9	7.68	3.44	-300	0.00	80.8	2.2
S2RW5A0118	67.6	8.21	18.4	-405	0.00	54.7	--

Notes:
°F = degrees Fahrenheit
g/L = grams per liter
mg/L = milligrams per liter
mS/cm = milliSiemens per centimeter
mV= millivolts
NTU = nephelometric turbidity units
ORP = oxidation/reduction potential
TDS = total dissolved solids

Table 5-10 – Volatile Petroleum Hydrocarbon (VPH) Analysis for Groundwater Samples (µg/L)

	S2GTI15 0118	S2GTI15 0118 (RE1)	S2GTI17 0118-FD	S2GTI17-0118	S2GTI8 0118	S2RW5A 0118	S2RW5A 0118 (RE1)
VPH C_5-C_6 Aliphatics	< 50 U	< 50 U	30 J	29 J	31 J	26 J	< 50 U
VPH >C_6-C_8 Aliphatics	47 J	48 J	274	265	< 50 U	< 50 U	< 50 U
VPH >C_8-C_{10} Aliphatics	< 50 U	66	< 50 U	32 J	< 50 U	< 50 U	< 50 U
VPH >C_{10}-C_{12} Aliphatics	118	174	266	334	< 50 U	169	127
VPH >C_8-C_{10} Aromatics	208	215	334	352	114	242	201
VPH >C_{10}-C_{12} Aromatics	780	806	777	823	698	1140	794
VPH >C_{12}-C_{13} Aromatics	510	536	390	414	607	704	438
MTBE	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U
Benzene	3 J	3 J	< 5 U	< 5 U	4 J	< 5 U	< 5 U
Toluene	< 5 U	< 5 U	7	7	< 5 U	< 5 U	< 5 U
Ethylbenzene	17	17	8	9	6	19	18
m, p-Xylene	< 10 U	< 10 U	22	23	< 10 U	5 J	< 10 U
o-Xylene	25	25	13	13	< 5 U	5	6
Benzene, 1,2,3-Trimethyl-	50	52	63	64	38	55	57
Naphthalene	32	33	31	32	11	35	26
1-Methylnaphthalene	28	29	27	28	26	37	29
n-Pentane	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U
n-Hexane	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U
n-Octane	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U
n-Decane	< 5 U	3 J	< 5 U	3 J	< 5 U	14	4 J
n-Dodecane	53	59	80	86	88	118	51

Notes:
µg/L - microgram per liter
VPH - Volatile Petroleum Hydrocarbon
U - This analyte is not detected above the applicable reporting or detection limit.
J - Estimated concentration value detected below the reporting limit.
E - The analyte concentration exceeds the upper limit of the calibration range of the instrument established by the initial calibration (ICAL)
MTBE – Methyl tert-butyl ether
Sample Reanalyzed

Table 5-11 – Extractable Petroleum Hydrocarbon (EPH) Analysis for Groundwater Samples (µg/L)

	S2GTI15 0118	S2GTI17-0118	S2GTI17 0118-FD	S2GTI8 0118	S2RW5A 0118
EPH C_8-C_{10} Aliphatics	93	107	124	49	123
EPH >C_{10}-C_{12} Aliphatics	582	412	486	994	1,460
EPH >C_{12}-C_{16} Aliphatics	596	275	320	1,390	2,260
EPH >C_{16}-C_{21} Aliphatics	< 40 U	< 40 U	< 40 U	7 J	< 40 U
EPH >C_{21}-C_{34} Aliphatics	< 40 U	< 40 U	< 40 U	< 40 U	< 40 U
EPH C_8-C_{10} Aromatics	69	97	107	29 J	78
EPH >C_{10}-C_{12} Aromatics	277	302	308	259	463
EPH >C_{12}-C_{16} Aromatics	412	268	264	620	842
EPH >C_{16}-C_{21} Aromatics	19 J	17 J	13 J	28 J	27 J
EPH >C_{21}-C_{34} Aromatics	< 40 U	< 40 U	< 40 U	27 J	< 40 U

Notes:
µg/L - microgram per liter
EPH - Extractable Petroleum Hydrocarbon
U - This analyte is not detected above the applicable reporting or detection limit.
J - Estimated concentration value detected below the reporting limit.

Table 5-12 – MCLs Compared to Ground Analytical Results

Sample ID	Water - Volatile Petroleum Hydrocarbons Analysis (µg/L)				
	Benzene	Toluene	Ethyl-benzene	m, p-Xylene	o-Xylene
S2GTI150118	3 J	< 5 U	17	< 10 U	25
S2GTI150118 (RE1)	3 J	< 5 U	17	< 10 U	25
S2GTI170118-FD	< 5 U	7	8	22	13
S2GTI17-0118	< 5 U	7	9	23	13
S2GTI80118	4 J	< 5 U	6	< 10 U	< 5 U
S2RW5A0118	< 5 U	< 5 U	19	5 J	5
S2RW5A0118 (RE1)	< 5 U	< 5 U	18	< 10 U	6
EPA MCLs (µg/L)	**5**	**700**	**1,000**	**10,000***	

Notes:

µg/L - microgram per liter

VPH - Volatile Petroleum Hydrocarbon

U - This analyte is not detected above the applicable reporting or detection limit.

J - Estimated concentration value detected below the reporting limit.

E - The analyte concentration exceeds the upper limit of the calibration range of the instrument established by the initial calibration (ICAL)

Sample Reanalyzed

MCL - Maximum Contaminant Level

* - Total Xylenes

5.7.3 Soil Sampling Results

The following section includes analytical results for the soil sample analysis by the TPH Fractionation Analysis via the Washington State Method for EPH and VPH. The analytical results from the sample reanalysis for two of the bulk soil samples have also been incorporated into this section. The two samples, S2NE30118-10 and S2NE30118-10-FD, were reanalyzed in July of 2018 to validate the results of the initial analysis and conduct qualitative evaluation of residual free product using traditional analytical methods for comparison. However, it should be noted that these samples were ran outside of the method hold times and were analyzed for Washington State EPH and VPH Method, VOCs by EPA Method 8260C, and TPH GRO for C_6-C_{10}, TPH C_{10}-C_{24}, TPH C_{24}-C_{36} and Total TPH for comparison purposes.

Based on the VPH analytical results for the 7 soil (including one duplicate), there were no detectable concentrations of Benzene. Toluene only had one detection at a concentration of 2.25 mg/kg. Ethylbenzene was detected in 5 of the 7 samples collected and concentrations ranged from 1.53 to 33.5 mg/kg. Xylene was detected in 5 of the 7 samples and concentrations ranged from 4.20 to 89.5 mg/kg for m,p-xylene and 2.72 to 47.8 mg/kg for o-xylene respectively. Naphthalene was detected in all of the samples and concentrations ranged from 4.48 to 69.9 mg/kg. All the samples had detections in VPH aromatic carbon chain ranges C_8-C_{10}, C_{10}-C_{12} and C_{12}-C_{13} as indicated in **Table 5-13** below. For VPH aliphatic carbon chain ranges only two samples had detections for VPH C_5-C_6 which were 'J' flagged with concentrations ranging from 9.01 to 13.1 mg/kg. Six of the 7 soil samples had detections for VPH C_6-C_8 for Aliphatics with concentrations ranging from 6.75 J to 139 mg/kg. Three of the samples had detections for VPH C_8-C_{10} aliphatic carbon chain range with concentrations ranging from 11.9 J to 259 mg/kg. All the samples had detections for VPH C_{10}-C_{12} aliphatic carbon chain range with concentrations ranging from 266 to 5,020 mg/kg. The reanalyzed samples had similar detections for the various constituents, although the variations observed may be due to the fact that the reanalysis was conducted outside of the hold time and samples were analyzed from the bulk composite soil samples.

Based on the extractable hydrocarbon (EPH) analytical results, all of the soil samples had detections for ranges C_8-C_{10}, C_{10}-C_{12}, C_{12}-C_{16} for both Aliphatics and Aromatics as shown in **Table 5-14** below. Only two samples, S2NE20118-10 and S2NE30018-9 had 'J' flag detections of EPH C_{21}-C_{34} for Aliphatics and four samples (S2NE20118-9, S2NE20118-10, S2NE30118-9) with detections of EPH C_{21}-C_{34} Aromatics. The two samples reanalyzed had detections in the same carbon chain ranges and EPH C_{21}-C_{34} for both Aliphatics and Aromatics were non-detect.

Table 5-13 – Volatile Petroleum Hydrocarbon (VPH) Results for Soil (mg/kg)

	S2NE1 0118-8	S2NE1 0118-10	S2NE2 0118-9	S2NE2 0118-10	S2NE3 0118-9	S2NE3 0118-10	S2NE3 0118-10-FD	S2NE3 0118-10*	S2NE3 0118-10-FD*
VPH C_5-C_6 Aliphatics	< 12.9 U	< 14.5 U	< 11.9 U	13.1 J	< 12.6 U	9.01 J	< 10.4 U	ND (< 12.6)	ND (< 9.80)
VPH >C_6-C_8 Aliphatics	6.76 J	<14.5 U	31.1	92.1	77.5	139	9.85 J	8.61 J	6.12 J
VPH >C_8-C_{10} Aliphatics	< 12.9 U	11.9 J	94.5 J, D	259 D	< 12.6 U	< 14.5 U	< 10.4 U	688	548
VPH >C_{10}-C_{12} Aliphatics	356 D	266 D	531 D	672 D	1,860 D	5,020 E, D	754 D	--	--
VPH >C_8-C_{10} Aromatics	111	75.4	205	304 D	837 D	3,380 D	351 D	523	413
VPH >C_{10}-C_{12} Aromatics	658	398	572	847	1,880 D	6,200 D	958 D	--	--
VPH >C_{12}-C_{13} Aromatics	406	267	288	407	1,130 D	3,150 D	623 D	--	--
MTBE	< 1.29 U	< 1.45 U	< 1.19 U	< 1.36 U	< 1.26 U	< 1.45 U	< 1.04 U	ND (< 0.410)	ND (< 0.318)
Benzene	< 1.29 U	< 1.45 U	< 1.19 U	< 1.36 U	< 1.26 U	< 1.45 U	< 1.04 U	ND (< 0.378)	ND (< 0.294)
Toluene	< 1.29 U	< 1.45 U	< 1.19 U	2.25	< 1.26 U	< 1.45 U	< 1.04 U	ND (< 0.378)	ND (< 0.294)
Ethylbenzene	< 1.29 U	< 1.45 U	1.53	6.13	12.9	33.5	2	ND (< 0.291)	ND (<0.227)
m, p-Xylene	< 2.59 U	< 2.89 U	4.2	17.7	23.6	89.5	5.24	6.57 J	8.78
o-Xylene	< 1.29 U	< 1.45 U	2.72	9.55	17.9	47.8	4.01	10.3	7.86
Benzene, 1,2,3-Trimethyl-	15.6	11.6	21.6	36.3	74.6	133	28	--	--
Naphthalene	6.27	4.48	9.35	14.3	58.3	69.9	20.3	--	--
1-Methylnaphthalene	10.5	7.69	9.31	16.3	62	67	25.8	--	--
n-Pentane	1.06 J	3.01	1.43	2.88	1.76	2.35	< 1.04 U	--	--
n-Hexane	< 1.29 U	< 1.45 U	0.644 J	2.28	< 1.26 U	< 1.45 U	< 1.04 U	--	--
n-Octane	< 1.29 U	< 1.45 U	1.69	5.81	10.7	15.8	2.08	--	--
n-Decane	16.1	17.1	43.6	66.1	63.7	90.3	37.3	--	--
n-Dodecane	102	70.9	113	92.1	168	162	62.7	--	--

Notes:
mg/kg - milligram per kilogram
VPH - Volatile Petroleum Hydrocarbon
U - This analyte is not detected above the applicable reporting or detection limit.
J - Estimated concentration value detected below the reporting limit.

D - The reported value is from a dilution
E - The analyte concentration exceeds the upper limit of the calibration range of the instrument established by the initial calibration (ICAL)
Reported 'E' value replaced with concentration from dilution
ND - Non-Detect
MTBE – Methyl tert-butyl ether
*Sample Reanalyzed at Eurofins

Table 5-14 – Extractable Petroleum Hydrocarbon (EPH) Results for Soil (mg/kg)

	S2NE1 0118-8	S2NE1 0118-10	S2NE2 0118-9	S2NE2 0118-10	S2NE3 0118-9	S2NE3 0118-10	S2NE3 0118-10-FD	S2NE3 0118-10*	S2NE3 0118-10-FD*
EPH C_8-C_{10} Aliphatics	25.3	12.7	19.5	53.9	157	122	115	--	--
EPH >C_{10}-C_{12} Aliphatics	476	418	249	504	1,520	1,310	1,080	4,500	3,000
EPH >C_{12}-C_{16} Aliphatics	718	861	434	919	2,400	2,120	1,590	6,400	4,300
EPH >C_{16}-C_{21} Aliphatics	1.22 J	1.68 J	19.5	39	77.4	63.7	45.5	170 J	130 J
EPH >C_{21}-C_{34} Aliphatics	< 2.53 U	< 2.49 U	< 2.32 U	2.00 J	0.305 J	< 2.32 U	< 2.22 U	ND (< 190)	ND (<130)
EPH C_8-C_{10} Aromatics	1.68 J	1.15 J	2.29 J	5.92	12.7	7.53	7.63	--	--
EPH >C_{10}-C_{12} Aromatics	26.3	24.8	24.2	45.3	100	67.7	62.2	680	470
EPH >C_{12}-C_{16} Aromatics	106	133	93.6	173	328	244	202	1,700	1,200
EPH >C_{16}-C_{21} Aromatics	2.48 J	4.1	19	35.4	54.4	37.2	30.3	250	180
EPH >C_{21}-C_{34} Aromatics	< 2.53 U	< 2.49 U	1.93 J	3.27	1.38 J	< 2.32 U	< 2.22 U	ND (< 25)	ND (< 11)

Notes:
mg/kg - milligram per kilogram
EPH - Extractable Petroleum Hydrocarbon
U - This analyte is not detected above the applicable reporting or detection limit.
J - Estimated concentration value detected below the reporting limit.
ND - Non-Detect

*Sample Reanalyzed at Eurofins

The two samples that were reanalyzed to QC purposes were also analyzed for select VOCs using 8260C. Results for select VOCs reanalysis are shown in **Table 5-15** below. Benzene, Toluene, and MTBE were not detected in either sample. Ethylbenzene was detected at concentrations ranging from 1.2 to 3.2 mg/kg. Naphthalene was detected at concentrations of 6.4 and 9.2 mg/kg and Total Xylene at 7.3 and 18 mg/kg. Detections were comparable to volatile analyses conducted via the Washington State VPH method. However, Ethylbenzene was only detected by Method 8260C and xylene concentrations were within the same order of magnitude. Naphthalene was not analyzed for the Washington State VPH method for the re-analyzed samples.

Table 5-15 – Select Volatile Organic Compound Results for Soil Sample Reanalysis

Sample ID	Soil VOC Analysis - EPA Method 8260C (mg/kg)					
	Benzene	Toluene	Ethylbenzene	Total Xylenes	MTBE	Naphthalene
S2NE30118-10*	ND (< 0.031)	ND (< 0.063)	3.2	18	ND (< 0.031)	9.2
S2NE30118-10-FD*	ND (< 0.029)	ND (< 0.058)	1.2	7.3	ND (< 0.029)	6.4

Notes:
mg/kg - microgram per kilogram
*Sample Reanalyzed at Eurofins
ND - Non-Detect
VOC - Volatile Organic Compound
MTBE – methyl tert-butyl ether

The samples that were submitted for reanalysis were also analyzed for Total Petroleum Hydrocarbons using EPA Method 8015D. Results for TPH reanalysis are shown in **Table 5-16** below. TPH-GRO C_6-C_{10} and TPH C_{10}-C_{20} had detections, whereas TPH C_{24}-C_{36} were not detected in the reanalyzed samples. Total TPH observed for the two reanalyzed samples ranged from 14,000 to 15,000 mg/kg.

Table 5-16 – Total Petroleum Hydrocarbon Results for Soil Sample Reanalysis

Sample ID	Soil - TPH Analysis EPA Method 8015D (mg/kg)			
	TPH-GRO C_6-C_{10}	TPH C_{10}-C_{24}	TPH >C_{24}-C_{36}	Total TPH
S2NE30118-10*	750	14,000	ND (< 260)	14,000
S2NE30118-10-FD*	1,300	15,000	ND (< 220)	15,000

Notes:
mg/kg - microgram per kilogram
*Sample Reanalyzed at Eurofins
ND - Non-Detect
TPH - Total Petroleum Hydrocarbon

5.7.4 Natural Source Zone Depletion Analytical Results

Natural Source Zone Depletion (NSZD) measurements were completed in October 2017 after successful deployment of nine Carbon Traps. **Table 5-17** below includes the CO_2 flux measured at each Carbon Trap location and the calculated rate of biodegradation associated with each location. The average rate of NSZD observed at the site is 173 gal/acre-year. **Figure 5-1** from **Section 5.4.1** includes a schematic with the sample locations. The analytical results and calculations to determine the equivalent biodegradation are included in **Appendix B**.

Table 5-18 below includes a comparison of free product recovery rates for multiple free product recovery events to the NSZD rate. Free product removal rates were calculated in gal/acre-year, and these calculations were conducted by dividing the amount of LNAPL recovered per event by the duration of recovery and acreage of the free product footprint. This was based on the 2008 SCAPs survey and 2013 free product measurement event (approximately 10 acres). Carbon dioxide flux analysis revealed that biodegradation is occurring at a rate similar to that of active free product recovery efforts being conducted at the site. The average free product recovery rate over the last four recovery events since 2007 is 161 gal/acre-year, and the average rate from the most recent event is 166 gal/acre-year. In comparison, the NSZD rate is 173 gal/acre-year.

However, based on the most recent free product recovery events conducted at the site, the amount of free product recovered each quarter was roughly 415 gallons which equates to a rate of recovery of approximately 166 gal/acre/yr. The rate of recovery for this period is comparable to the previous recovery period both of which have decreased since the second recovery period as shown in **Table 5-18**.

Table 5-17 – Carbon Trap Analytic Results Summary

Location	CO_2 Flux ($\mu M/m^2$-sec)	Modern Carbon (%)	Adjusted Fossil Fuel Carbon (%)	Equivalent Fossil Fuel Based NAPL Loss Rate (gal/acre-yr)
FANV-R1-CO2-01	0.6	78%	26%	101
FANV-R1-CO2-02	1.1	65%	38%	328
FANV-R1-CO2-03	0.7	71%	32%	175
FANV-R1-CO2-04	0.5	84%	20%	37
FANV-R1-CO2-05	0.7	81%	23%	94
FANV-R1-CO2-07	0.9	77%	27%	154
FANV-R1-CO2-08	1.3	70%	34%	317
FANV-R1-CO2-09	1.0	77%	27%	177
Average	**0.9**	**75%**	**28%**	**173**
Background	1.8	96%	8%	5

Notes:
CO_2 = Carbon Dioxide
$\mu M/m^2$-sec = micro Molar per meter squared per second

gal/acre-yr = gallon per acre per year

Table 5-18 – Comparison of Active LNAPL Recovery to Average NSZD Rate Assuming 10 Acre LNAPL Free Product Footprint

LNAPL Recovery Period	LNAPL Recovered (gallons)	Duration (years)	Removal Rate (gal/acre-yr)
1st (4/07 to 11/08)	2,312	1.56	149
2nd (8/09 to 3/11)	3,214	1.56	207
3rd (5/12 to 11/13)	1,828	1.48	124
4th (10/17 to 12/18)	1937	1.17	166
Total	9,290	5.8	
Current Recovery Average (gal/acre-yr)			**161**
Average NSZD Rate (gal/acre-yr)			**173**

Notes:
gal/acre-year = gallons per acre per year

5.7.5 Transmissivity Calculations

Average transmissivity rates for the LNAPL entire recovery system were calculated over four active recovery phases conducted at the site since 2007. Transmissivity rates were calculated using ASTM LNAPL Transmissivity Standard (E2856-13) equation 16 (below) and the free product recovery data. Transmissivity was calculated for an average across four recovery periods and for the last FP recovery event in December 2018. Furthermore, transmissivity rates were calculated based on Sn (drawdown). Detailed calculations with assumptions have been included in **Appendix C**.

$$T_n = \frac{Q_n ln\left(\frac{R_{oi}}{r_w}\right)}{2\pi s_n} \quad (ASTM\ E2856 - 13\ Eq.16)$$

where:

T_n = LNAPL transmissivity (ft^2/day)
Q_n = measured LNAPL recovery rate (ft^3/day)
R_{oi} = radius of influence
r_w = well radius
Note: the term $\ln(R_{oi}/r_w)$ can be assumed to be 4.6

ITRC guidance (ITRC, 2009) indicates that LNAPL recovery is considered practical if transmissivity is greater than a range of 0.1 to 0.8 ft^2/day and LNAPL is not practically recoverable if less than a range of 0.1 to 0.8 ft^2/day.

Average transmissivity rates were calculated over four active recovery phases conducted at the site since 2007. **Table 5-19** below includes the transmissivity rates calculated over that last four free product recovery phases. Based on the calculated LNAPL transmissivity rates and ITRC's recent guidance, the average transmissivity observed at NAS Fallon for the four free product recovery periods conducted over the last decade range from 0.03 to 0.06 ft^2/day, lower than the threshold range of 0.1 to 0.8 ft^2/day. Based on the last free product recovery event conducted in December 2018, only eight wells were gauged, and free product was recovered. **Table 5-20** below summarizes the cumulative recovery totals, the average thicknesses observed, and the average transmissivities calculated for the eight wells.

Looking at the individual wells from the December event, the average transmissivities range from 0.004 ft^2/day to 2.43 ft^2/day. Compared to the transmissivity threshold range of 0.1 to 0.8 ft^2/day for the eight wells evaluated:

- One well, GTI-1.0 falls above the range of (2.43 ft^2/day);
- Two wells, ITSI-4 and ITSI-5, fall within this range (0.15 and 0.17 ft^2/day); and
- Five wells are all below this range (0.003 to 0.078 ft^2/day).

Figure 5-6 includes the average transmissivity rates calculated for the eight wells overlaying the free product thicknesses observed in 2008. Although it should be noted that ITSI-4, ITSI-5, and ITSI-6 are part of the Western Trench so only an average transmissivity for the trench has been included.

Although product may still be practically recoverable at select wells across the site, the overall footprint of the residual free product has remained stable. Based on the proximity of the wells with the greatest free product recovery observed to the fringe of the residual free product footprint, the mobile free product observed at this location does not appear to pose a risk of migration. Therefore, active free product recovery may be able to be discontinued or reduced without altering the low risk profile of the site.

For additional details on evaluating transmissivity, see Section 6.

Table 5-19 – Transmissivity Rates Calculated Over Four Free Product Recovery Phases

LNAPL Recovery Period	Duration (day)	LNAPL recovered (gal)	Wells in operation	Average Transmissivity (ft^2/day)
1st (4/07 to 11/08)	568	2,312	18	0.06
2nd (8/09 to 3/11)	568	3,214	21	0.03
3rd (5/12 to 11/13)	539	1,828	21	0.05
4th (10/17 to 12/18)	427	1,937	36	0.04

Notes:
ft = feet
gal = gallons

Table 5-20 – Average Transmissivities for Wells from December 11, 2018 Free Product Recovery Event

Well ID	LNAPL Recovery Period	Duration (day)	LNAPL recovered (gal)	Average LNAPL Thickness (ft)	Average Transmissivity (ft^2/day)
GTI-10	4th (10/17 to 12/18)	427	318	0.25	2.43
GTI-11	4th (10/17 to 12/18)	427	50	1.09	0.028
GTI-5	4th (10/17 to 12/18)	427	18	0.62	0.004
GTI-9	4th (10/17 to 12/18)	427	9	0.63	0.004
FF-4	4th (10/17 to 12/18)	427	62	1.01	0.062
ITSI-4	4th (10/17 to 12/18)	427	200	0.25	0.15
ITSI-5	4th (10/17 to 12/18)	427	113	0.24	0.17
RW-3	4th (10/17 to 12/18)	427	123	1.17	0.078

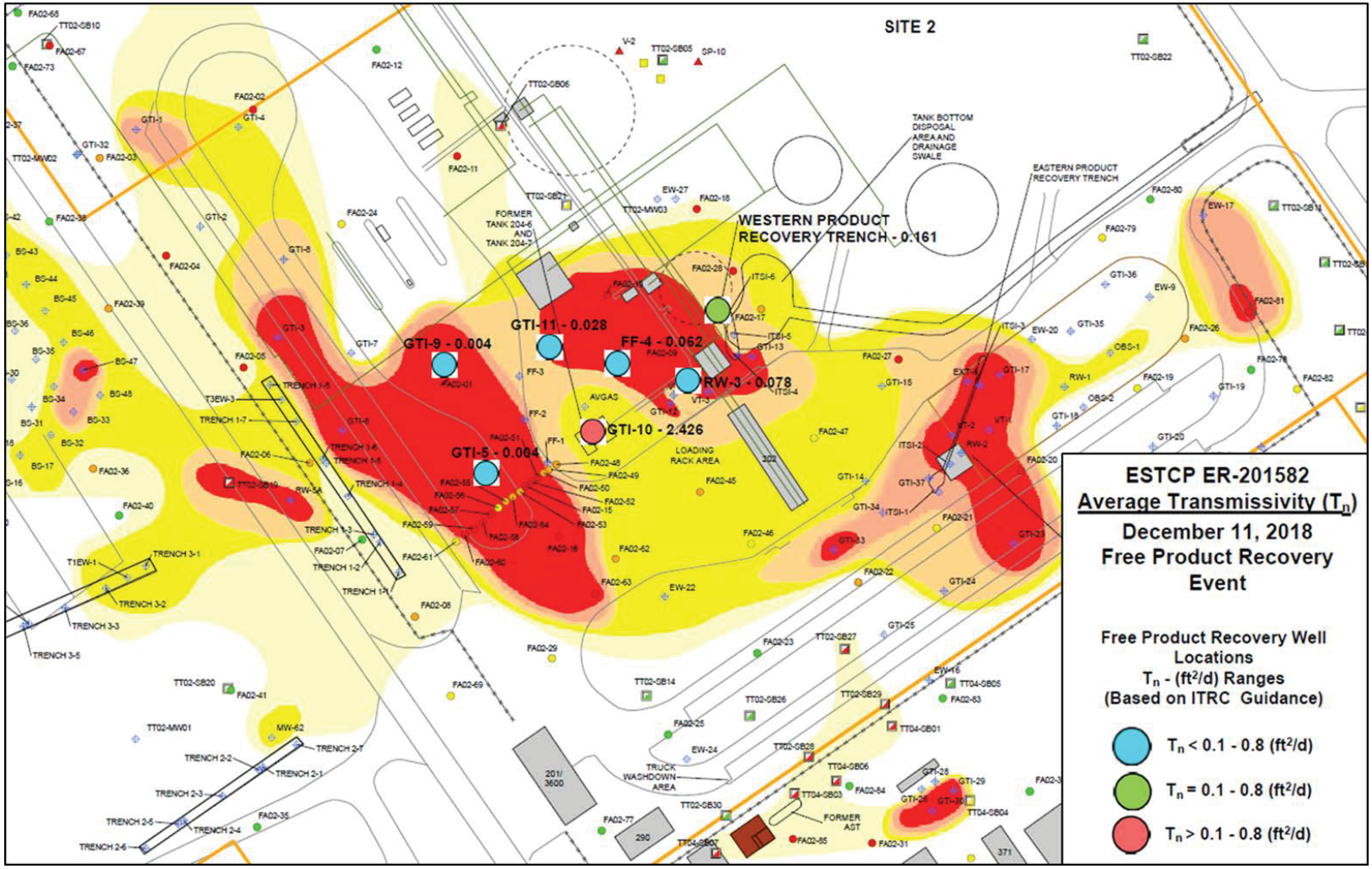


Figure 5-6 – Average Transmissivity Rates Calcualted for Select Wells at NAS Fallon Site 2 for ER-201582 (Adapted Figure from KCH, 2014)

[Note: Base map adapted from Figure 6-8 from 2014 RI Addendum/FS (KCH, 2014), Average transmissivity rates and locations inserted on figure]

5.7.6 TPH-CWG Risk Based Method

The following exposure scenarios were evaluated using the TPH-CWG Risk Based Method to better understand the potential for current and anticipated future use of the site.

- **Soil Excavation** – This scenario addresses short-term exposure to COCs for construction workers, such that would be encountered during activities such as underground line maintenance and installation (https://rais.ornl.gov)

The calculated results for the risk associated with Soil Excavation Exposure are included in **Table 5-21** below. The total risk is less than 1 on the Hazard Index. The highest concentrations observed in the soil boring sample S2NE30118-9 were used for the risk calculations. The RAIS Contaminated Media (Risk) Calculator was used to perform the calculations (https://rais.ornl.gov/cgi-bin/prg/RISK_search?select=chem). Surrogates were selected from ASTDR (ASTDR, 1995-2005).

Calculations and additional details for the risk assessment/analysis are included in **Appendix D**.

Table 5-21 – Soil Excavation Exposure Risk

Fraction	Surrogate	Soil (mg/kg)	Ingestion HQ	Inhalation HQ	Dermal HQ	Total HI	Inhalation Risk	Total Risk
C_8-C_{10} Aromatics	Cumene	13	0.0000072	0.000018	-	0.000025	-	-
C_{10}-C_{12} Aromatics	Naphthalene	100	0.000038	0.0041	0.000016	0.00418	6.01E-09	6.01E-09
C_{12}-C_{16} Aromatics	Fluorene	328	0.00019	-	0.000077	0.00026	-	-
C_{16}-C_{21} Aromatics	Pyrene	54	0.000041	-	0.000017	0.000058	-	-
C_{21}-C_{34} Aromatics	Fluoranthene	1.4	0.0000031	-	0.0000013	0.0000044	-	-
C_8-C_{10} Aliphatics	Hexane	157	0.00012	0.0000098	-	0.000128	-	-
C_{10}-C_{12} Aliphatics	Nonane	1,520	0.12	0.00095	-	0.115	-	-
C_{12}-C_{16} Aliphatics	JP-7	2,400	-	0.00100	-	0.0010	-	-
C_{16}-C_{21} & C_{21}-C_{34} Aliphatics	Mineral oils	78	0.0000006	-	-	0.00000059	-	-
Total HI/Risk		-	0.12	0.0061	0.00011	**0.121**	6.01E-09	**6.01E-09**

5.8 SECTION CONCLUSIONS

At NAS Fallon Site 2, Given the current/anticipated land use and there being no known exposure routes as most of the residual hydrocarbons are present at depths below 8 feet, the residual LNAPL appears to represent little risk. First, based on the historic LNAPL footprint, the area of measurable free product has remained stable and reduced overtime, see **Figure** 4-6 and **Figure 4-7**. LNAPL transmissivity rates calculated (**Table 5-19** and **Table 5-20**) also indicate that the product mobility is low and the rate is continuing to decrease over time. NSZD measurements indicate that LNAPL is naturally depleting at the site at rates comparable to the active free product recovery methods, see **Table 5-19**. Therefore, while LNAPL recovery is possible and ongoing, it is only marginally practicable to continue recovery as the average recovery system transmissivity and most of the individual recovery wells has transmissivity below the ITRC transmissivity guidelines..

Based on historical groundwater data, the dissolved phase plume does appear to extend much beyond the extent of the residual free product footprint and appears to be stable. As discussed in Section 5.7, the groundwater samples collected within the residual LNAPL footprint for this demonstration did not have any concentrations of BTEX compounds that were detected above the MCLs. Benzene, for example, was only detected in two wells at estimated concentrations below the MCL of 5 µg/L. **Table 5-10**, **Table 5-11**, and **Table 5-12** include a summary of the groundwater analytical results and comparison to MCLs.

In addition, the LNAPL in this study appears to be weathered JP-5, posing little risk as presented in **Table 5-7** and **Table 5-21**, especially for sub-chronic exposure. Also, no detectable benzene or other BTEX components were observed in the LNAPL. As LNAPL continues to weather, typically less of the more soluble and more toxic compounds are present while the heavier hydrocarbons with lower solubility and lower volatility remain. Based on the exposure scenarios evaluated for the site and using the TPHCWG Method with the highest soil concentrations observed from the soil sampling event, the total risk was calculated to be less than 1 on the Hazard Index for sub-chronic exposure.

6.0 GUIDANCE

This section is intended to provide strategic guidance to managers responsible for petroleum hydrocarbon impacted sites. Significant and quite detailed technical guidance has been published by others and is widely available (ITRC, 2018). The intent here is not to duplicate that guidance but rather to help the user understand what technologies and know-how is available and where it can be found, and to put that information into a helpful management context.

The emphasis is on LNAPL management, however issues related to dissolved and vapor phase hydrocarbons will also be discussed. This discussion will be limited to petroleum hydrocarbons derived from crude oil, petroleum hydrocarbon.[3]

6.1 LNAPL BASICS

Petroleum hydrocarbons are materials made up of molecules composed entirely of carbon and hydrogen. Crude oil is predominantly petroleum hydrocarbon and most of the petroleum hydrocarbons we work with are derivatives of crude oil. The most common petroleum products we work with are fuels, gasoline, diesel, jet fuels, etc. Other petroleum hydrocarbon products such as lubricants and hydraulic fluids may be important at some sites. It is important to understand that the petroleum products we deal with are made up of thousands of individual hydrocarbon molecules varying in properties such as solubility, vapor pressure, and biodegradability. **Figure 6-1** shows the boiling point ranges (based on distillation in the refining process) for some commonly used petroleum products.

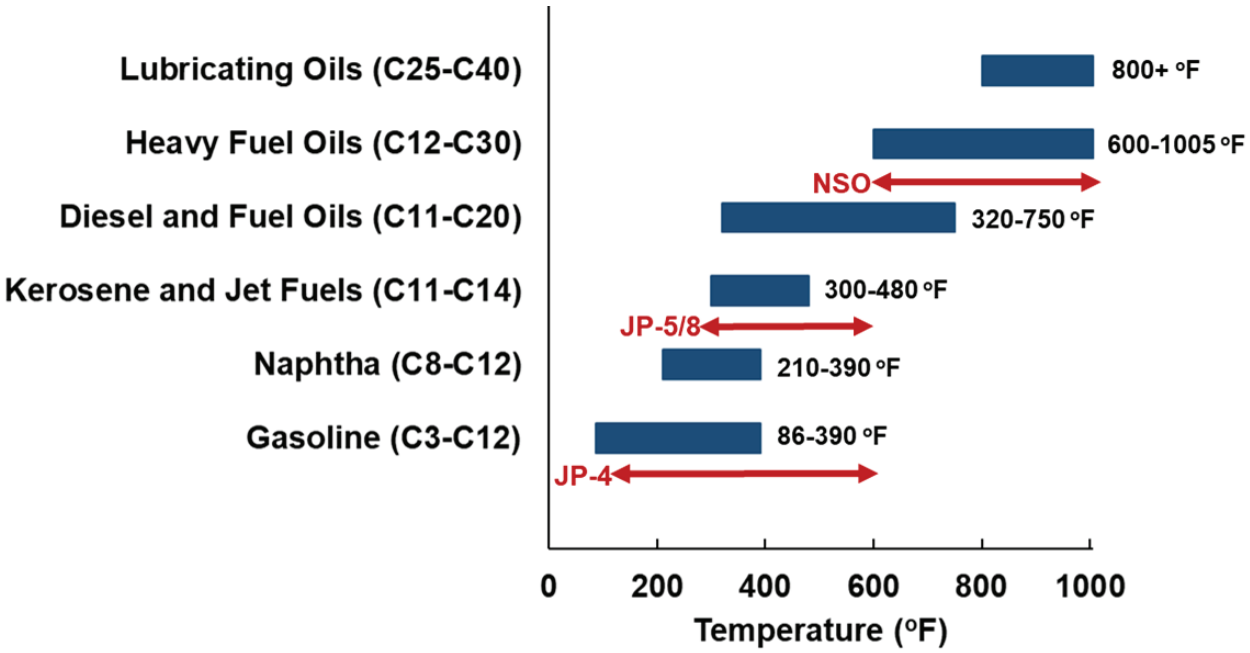


Figure 6-1 – Boiling Point Ranges for Various Petroleum Hydocarbon Products (Data were adapted from ITRC, 2018)

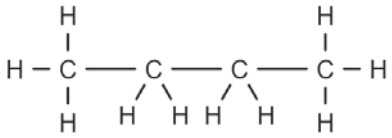
3 Other LNAPLs such as vegetable oil and bio diesels exist, but are not addressed here.

Figure 6-1 includes examples of different petroleum hydrocarbon products as a function of boiling point and distillation cuts. Distillates are products that are boiled off from crude oil and decondensed, residuals are products that do not evaporate and are left behind after distillation.

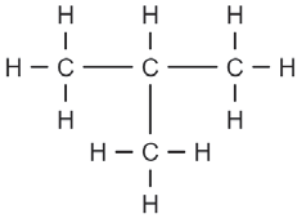
In general, lower boiling point petroleum products are less viscous, more soluble, more biodegradable, and more volatile than heavier products.

Petroleum products contain two primary groups of petroleum hydrocarbons, aromatics and aliphatics. Aromatics contain an aromatic ring, benzene is the smallest aromatic, heavier aromatics can contain many rings and are polycyclic aromatics (PAH). Aliphatics do not contain an aromatic ring and can consist of straight, branched, or cyclic compounds. The distinction is important, because although aromatics typically make up well less than half of petroleum products, they are often the most soluble and toxic fraction. **Figure 6-2** shows some typical smaller hydrocarbon molecules.

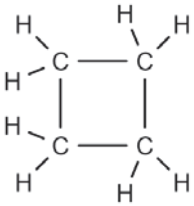
Aliphatics



n-Alkane

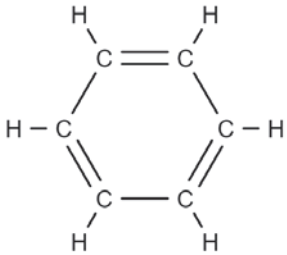


Iso-alkane

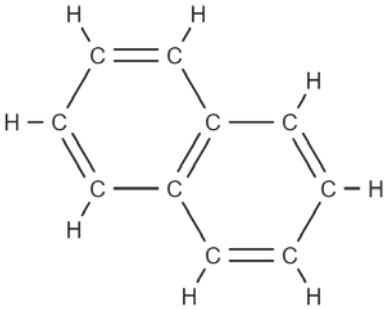


Cycloalkane

Aromatics



Benzene



Naphthalene

Figure 6-2 – Examples of Smaller Molecular Molecular Weight Aromatic and Aliphatic Petroleum Hydrocarbons

Non-petroleum hydrocarbons are sometimes added to petroleum products, particularly gasoline. Some non-petroleum hydrocarbon additives have become environmental problems, most notably MTBE and related oxygenates, and 1,2-dichloroethane (1,2-DCA). MTBE was a gasoline additive

mostly used from the early 80s until recently. MTBE is more soluble and tends to migrate further in groundwater than petroleum hydrocarbons and has been a contaminant requiring remediation at some sites. 1,2-DCA was an additive to leaded gasoline, for on-road vehicles it was phased out with lead in the 1980s. Lead continues to be used in some aviation gasolines, however 1,2-DCA is not typically added. Aviation gasoline more likely contains 1,2-dibromoethane (1,2-DCB). Like MTBE 1,2-DCE can also be found in groundwater associated with gasoline release; 1,2-DCB may also but it appears to be a less frequent concern.

When release petroleum hydrocarbons can migrate downward, if sufficient quantity is released it may encounter and spread out on the water table, sometimes migrating according to the slope of the surface it spreads out on. Petroleum hydrocarbons are only sparing soluble in water and so typically most of the material remains in a separate oil phase, being lighter than water it is called Light Non-Aqueous Phase Liquid (LNAPL). **Figure 6-3** illustrates this process.

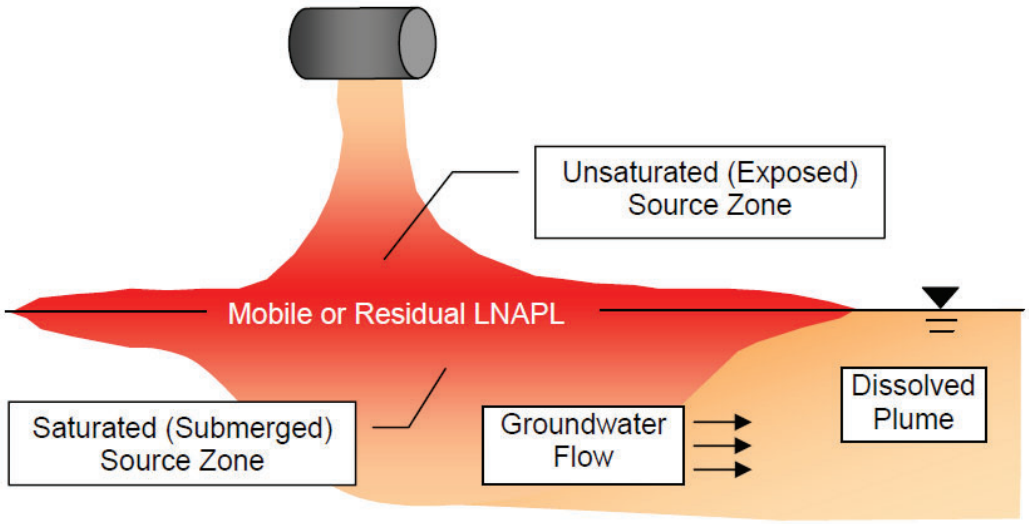


Figure 6-3 – Example of a Petroleum Hydrocarbon Release and Subsurface Behavior (ITRC, 2009)

Many processes can affect petroleum hydrocarbons after release, notably:

LNAPL Migration, migration of the oil phase, this is movement of the LNAPL either downward to the water table or on the surface of the water table. Migration is defined as spreading or expanding the area of LNAPL, this is different from mobility discussed below. Although the LNAPL oil phase migrates under its own head and is not transported by groundwater in most cases LNAPL migration on the surface of the water table is in the same direction as groundwater. LNAPL Migration is limited by interfacial tension, the LNAPL will only migrate so long as there is sufficient pressure within the LNAPL body to overcome the capillary forces created by water holding it back. As a result, at many LNAPL sites although significant thicknesses of LNAPL may be measurable in wells migration is not occurring. At most LNAPL sites LNAPL migration has ceased.

LNAPL Mobility, is movement of LNAPL that may or may not be migration. In order for LNAPL to be mobile it must be present in a concentration above what is called the residual capacity of soil. LNAPL can be present below its residual capacity physically this is in the form of droplets or ganglia of LNAPL not sufficiently continuous to move. The residual capacity of soil for LNAPL can vary, but is typically in the thousands or tens of thousands of mg/L. Mobile LNAPL[4] can enter a monitoring well where it can be measured and possible extracted or recovered. At most sites where mobile LNAPL is observed it is not migrating, to migrate LNAPL must exceed its residual capacity at the down gradient extreme of the plume and must have sufficient head or pressure to drive migration. Most of the LNAPL sites we work at are old and LNAPL reached its maximum extent years ago when there was pressure within in the LNAPL body as a result of the release. After reaching some maximum extent, controlled by capillary pressure the LNAPL body weathered[5] reducing the LNAPL concentration stopping further migration.

Dissolution and Migration in Groundwater, particularly the lighter and aromatic petroleum hydrocarbons will dissolve at some concentration into groundwater and migrate with groundwater. Dissolved petroleum hydrocarbons are biodegradable, and this biodegradation is what usually limits the extent of migration of a dissolved hydrocarbon plume, as a rule of thumb the dissolved plume rarely extends more than about 200 feet beyond the LNAPL plume. This dissolution and biodegradation also slowly deplete the LNAPL mass. At most sites dissolved petroleum hydrocarbon migration has ceased.

Volatilization and Migration in the Vapor Phase, particularly the lighter weight petroleum hydrocarbons will volatilize from the LNAPL and migrate, primarily as a result of diffusion, in the vadose zone. At most sites this volatile migration is limited by biodegradation and vapor phase petroleum hydrocarbons rarely reach the ground surface. The process also slowly reduces the LNAPL mass.

Biodegradation, already mentioned above is a very important process in understanding the limited migration and long-term fate of petroleum hydrocarbons in the environment.

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4 The term free product is commonly used to refer to mobile LNAPL; in most cases the terms are interchangeable.
5 Weathering is a term that refers to processes including evaporation, dissolution, and biodegradation that change the LNAPL body and reduce its concentration.

Petroleum hydrocarbons are naturally occurring compounds and worldwide it has been estimated that natural petroleum seeps still account for as much or more release to the environment as manmade spills (Kvenvolden and Cooper, 2003). As a result, many naturally occurring organisms have evolved to use petroleum hydrocarbons as a food source, and over time most petroleum hydrocarbon spills will eventually biodegrade. This is not to say that in many cases remediation is unnecessary, but rather the natural effects of biodegradation need to be considered in any remedial strategy. Historic process understanding indicated that biodegradation only occurs associated with water, the dissolved fraction in groundwater, and in pore water in the vadose zone, with some biodegradation occuring at water/oil interfaces. More recent NSZD research indicates that rapid biodegradation of low-solubility compounds can also occur in the pores directly in contact with LNAPL (e.g., Garg et al., 2017 for a summary), explaining the high NSZD rates observed in most LNAPL source zones.

Petroleum hydrocarbons biodegrade either aerobically, in the presence of oxygen, or aerobically in the absence of oxygen. Aerobic biodegradation in which oxygen is the oxidant called the electron acceptor usually occurs most rapidly, however significant rates of anaerobic biodegradation are often observed. Anaerobic biodegradation can occur using electron acceptors such as nitrate, sulfate, or carbon dioxide. Biodegradation reduces hydrocarbon mass, and limit dissolved and vapor phase migration. One important biodegradation process is methanogenesis, an anaerobic process that produces methane. This occurs in the pore water found in the LNAPL body, the methane is then typically released to the vadose zone where it encounters oxygen diffusing in from the atmosphere and biodegrades. This process is responsible for most of the petroleum hydrocarbon mass reduction at many sites.

6.2 PETROLEUM HYDROCARBON SITE MANAGEMENT

Petroleum Hydrocarbon site management is driven by a wide variety of factors including:

Risk to Human Health or the Environment, some petroleum constituents are known to be toxic. This has resulted in standards being set for some of the petroleum hydrocarbon constituents, for example the USEPA has set a drinking water standard for benzene of 5 µg/L. Benzene can be present in gasoline or JP-4 jet fuel in the 1% range, and can result in groundwater concentrations well in excess of 1,000 µg/L. For an actual risk to occur some route of exposure is required. Actual expose to LNAPL is rare, more commonly the concern is exposure to its dissolved components in drinking water, or its vapor constituents in vapor.

LNAPL Recovery the extraction and removal of LNAPL is often done, at times independent of risk. It is not uncommon for site owners to implement some form of LNAPL recovery whenever measurable LNAPL (mobile LNAPL) is encountered in monitoring wells. What often happens is LNAPL recovery for a time, rarely until all measurable LNAPL is removed. This does remove mass, but unless the LNAPL is migrating[6], typically does little to reduce risk.

Historically, implementing agencies have required removal of mobile LNAPL to the maximum extent practicable based on 40 CFR §280.64. Unfortunately, "extent practicable or practical" is not defined in the CFR and has been subject to many different interpretations. Some example endpoints are shown in **Table 6-1**. The authors do not advocate the application of many of these endpoints, these are simply exampling of endpoints that have been applied.

Table 6-1 – Example endpoints, or definitions of "to the extent practical which have been applied." (Adapted in part from ITRC, 2018a).

Metric	Example Endpoints
LNAPL Transmissivity, a measure of LNAPL mobility.	LNAPL Transmissivity < practicable recovery limit (0.1 to 0.8 ft^2/day)
Stable or controlled LNAPL plume	LNAPL plume no longer migrating.
Stable dissolved plume	Dissolved concentrations no longer migrating.
Relative removal rates compared to natural removal processes.	Engineered recovery rate similar to or less NSZD rate
Water/oil recovery ratio	250 gals:1 gal
Cost of LNAPL recovered	$10 to $100/gallon recovered
Decline in recovery rates	Less than 2 gallons/month. Less than 10% of initial recovery rates.
Measured LNAPL thickness in a well	0.1 inches to greater than 1 ft
Hydrocarbon concentration in soil	Usually based on some calculated estimate of residual capacity.

6 Migrating LNAPL does not always represent a risk, but at most sites where LNAPL is migrating some action to stop the migration is required.

The authors advocate selection of endpoints that are achievable and risk based. This is not always consistent with regulations, the authors do not advocate ignoring regulation, to the contrary site managers must comply with all applicable regulation. However, it has been the authors' experience that most regulators are open to consideration of risk and many will make exceptions to normal policy and practice if a risk-based case can be made. Requirements vary from state to state. Some states do not generally allow measurable LNAPL be left in place such as Washington Department of Ecology and Montana DEQ. Some states like California have low-threat closure policy which outline general criteria to be satisfied in order to achieve closure at a site with presence of LNAPL. Other states like Texas have developed Risk Based LNAPL Management guidance. **Figure 6-4** summarizes the LNAPL recovery requirements of some select states (NAVFAC EXWC, 2017). The requirements include in **Figure 6-4** are necessarily briefly summarized; actual requirements may vary on a site-specific basis.

State	Measurable Level that Permits Closure	Closed Sites with LNAPL Greater Than Measurable Level? If So, Additional Criteria Used?	Source
CA	Removed to extent practicable	Yes. "LUST sites can be closed if the required level of water quality will be attained within a reasonable period of time. California has closed several sites with LNAPL."	Menatti, 2010; NEIWPCC, 2006; Lund et al., 2014
FL	0.01 ft	Yes. "A site with residual soil contamination or groundwater contamination above cleanup target levels can only receive No Further Action if there are institutional controls (deed restrictions) on the property."	NEIWPCC, 2006
HI		Yes. "Only if BTEX and PAHs are ND or well below action levels and no other receptors."	NEIWPCC, 2006
IA	<0.01 ft	Yes. "Following NAPL recovery activities, a site may be closed if product does not return in a monitoring well in excess of 0.02 ft for a period of one year."	NEIWPCC, 2006
IL		Yes. Obtained closures in Illinois with notable NAPL thicknesses. Site-specific basis, essentially along the same lines as Massachusetts.	Payne, 2016
MA		Yes. "Non-Stable NAPL is not present under current site conditions and for the foreseeable future, and all NAPL with Micro-Scale Mobility is removed if and to the extent feasible based upon consideration of CSM principles."(*)	Marra, 2014
MI		Yes. "Recovery of all LNAPL with a transmissivity greater than 0.5 ft2/day and that can be recovered in a cost-effective and efficient manner."	Lund et al., 2014
MO	Maximum extent practicable	Yes. "Site-specific criteria."	NEIWPCC, 2006
NC	< 0.01 ft	No. "No receptors and removal is technically and economically infeasible."	NEIWPCC, 2006; Lund et al., 2014
NV	0.5 inch	Yes. "If a risk-based analysis was performed showing no vulnerable receptors and a fate and transport analysis performed showing that there was little potential for migration."	NEIWPCC, 2006
RI		No	Lund et al., 2014
TX	Unrecoverable or impractical	Yes "Closure can be granted when recoverable NAPL is still present if there are no receptors and the plume is stable."	NEIWPCC, 2006
UT	1/8-inch	Yes. "RBCA-based approach considered on site-specific basis."	Menatti, 2010
VA	<0.01 ft	Yes. "The data should support the claim that the technologies used and/or evaluated are no longer effective and that additional recovery is not practicable. If >0.01 ft exists also have to show: a) Remaining LNAPL and dissolved-phase constituents are not a risk to human health or the environment, and b) NSZD of the LNAPL body and natural attenuation of the dissolved-phase plume are documented as occurring at the site and are expected to further mitigate risk from the release, and c) The areal extent of the free phase plume at the site is shown to be stable or decreasing"	NEIWPCC, 2006; Steers, J., 2012; Lund et al., 2014
WA	<0.01 ft	No. "Ecology won't close LUST sites with measurable free product"	NEIWPCC, 2006

Notes: *Non-Stable NAPL: a NAPL with a footprint that is expanding laterally or vertically by: (a) migrating along or within a preferred flow path; (b) discharging or periodically discharging to a building, utility, drinking water supply well, or surface water body; or (c) spreading as a bulk fluid through or from subsurface strata; and NAPL with Micro-Scale Mobility: a NAPL with a footprint that is not expanding, but which is visibility present in the subsurface in sufficient quantities to migrate or potentially migrate as a separate phase over a short distance and visibility impact an excavation, boring, or monitoring well. (Marra, 2014).

Figure 6-4 – Summary of LNAPL Recovery Limits for Site Closure for Key Navy States, (NAVFAC EXWC, 2017)

In managing LNAPL remediation, the authors advocate the most cost-effective approach that will satisfy applicable regulatory requirements. At many sites this can be a demonstration that risk-based end points have been achieved. On other sites additional remediation may be required. In situations where regulation requires additional remediation without risk basis the authors recommend the lowest cost actions that will satisfy regulation.

LNAPL remediation endpoints advocated by the authors include:

- Mandatory or baseline endpoints:
    - No unacceptable risk. This is a minimal endpoint; the authors do not ever advocate ignoring unacceptable risk.
    - No LNAPL migration or potential for migration. Although it is possible that a migrating LNAPL plume does not present risk no further migration means no further environmental impact and most regulatory agencies and responsible site owners accept nothing less.
    - Compliance with regulatory requirements. Note that the authors have listed this as a mandatory endpoint, and it is, however we know from experience that many regulators are open to negotiation and discussion as to what is acceptable. We recommend setting technical endpoints first and then working with regulators to achieve the most cost-effective solution possible.
- Practicability endpoints, to be applied only after the baseline endpoints have been addressed:
    - No unacceptable risk may be sufficient, even if LNAPL recovery is possible or practical, this should always be considered.
    - Engineered active remediation does not significantly improve on the removal rates due to natural processes (NSZD). A rational case can be made that it is not practical to expend additional remediation dollars if no great improvement on natural rem
    - Cost, the cost of LNAPL removal is within a reasonable range, in practice a cost of $10/gallon of recovered LNAPL is often used, a higher cost of $100/gallon is sometimes also used. There is a consensus amongst practitioners that higher per gallon costs are not reasonable. Other cost factors should be considered, for example at some shallow or small sites the cost of excavation may be less than the cost of longer-term management. And there is the rare site where the cost of LNAPL recovery is less than the value of the recovered LNAPL, which can at times be sold.

6.3 LNAPL SITE MANAGEMENT TOOLS

In this section, we discuss tools recommended to site managers to develop risk-based approaches to manage and close LNAPL sites. These tools are well described in the literature, particularly in ITRC and API websites and documents. It is not the intent of the authors to provide the details that can be found on those sites, rather will direct site managers to those sources through citation.

6.3.1 Natural Source Zone Depletion (NSZD)

NSZD is the sum of various processes that reduce LNAPL mass over time. This is also called natural attenuation (typically abbreviated as monitored natural attenuation, MNA). Some authors

distinguish the terms using MNA to refer to processes that occur in groundwater which limit hydrocarbon plume growth, and NSZD to refer to processes that are expressed in the vadose zone and tend to be rates that can be used to estimate mass removal over time. We will adhere to that practice.

MNA is an important to demonstrate dissolved plume stability. Over the past 20 years many hundreds of petroleum hydrocarbons sites have been studied and with rare exception it has been demonstrated that dissolved plumes do not migrate more than a hundred feet or so downgradient of LNAPL plumes, so at most sites LNAPL migration limits dissolved plume migration. Insuring MNA operation and a stable plume is important to LNAPL site management.

NSZD is the reduction in LNAPL mass over time due to natural processes. For petroleum hydrocarbons this is primarily biodegradation driven, and the available tools are to measure biodegradation rates. Petroleum hydrocarbons can biodegrade either anaerobically or aerobically. When biodegradation is anaerobic at many sites the primary process is methanogenic, the petroleum hydrocarbons are converted to methane. Methane being gaseous with limited solubility migrates upwards in the vadose zone until it encounters aerobic conditions where it biodegrades producing carbon dioxide. Other petroleum hydrocarbon degrading processes, both anaerobic and aerobic, also produce carbon dioxide. These degradation processes are all heat generating. Measurement of NSZD depends on the measurement of carbon dioxide production, oxygen depletion or heat generation. Tools currently available and in use today include:

- Oxygen consumption, the rate of oxygen consumption can be determined from the vertical distribution of oxygen and other gases in the vadose zone. This was the original NSZD technique first published by the ITRC in 2009 (ITRC, 2009b). It requires soil vapor monitoring at various depths and some measure or estimate of oxygen diffusion rates. While less used than other methods now, it is still in practice and a method to be considered, particularly at sites where the vapor monitoring points may already exist.
- Carbon dioxide production can be measured and used to determine petroleum hydrocarbon biodegradation rates. Techniques include:
    - Carbon Traps such as those used at the Fallon site are typically a device placed on the ground surface that is left in place for a time, typically a few weeks and carbon dioxide is trapped in a solid hydroxide-based media. The traps are then returned to a laboratory where the mass of accumulated carbon dioxide is determined.
    - Flux chambers can be placed on the ground measuring directly the more or less instantaneous carbon dioxide flux. This is a shorter-term measurement typically requiring less time and often providing real time data. A common approach is based on the Dynamic Closed Chamber (DCC) illustrated in **Figure 6-5** below.

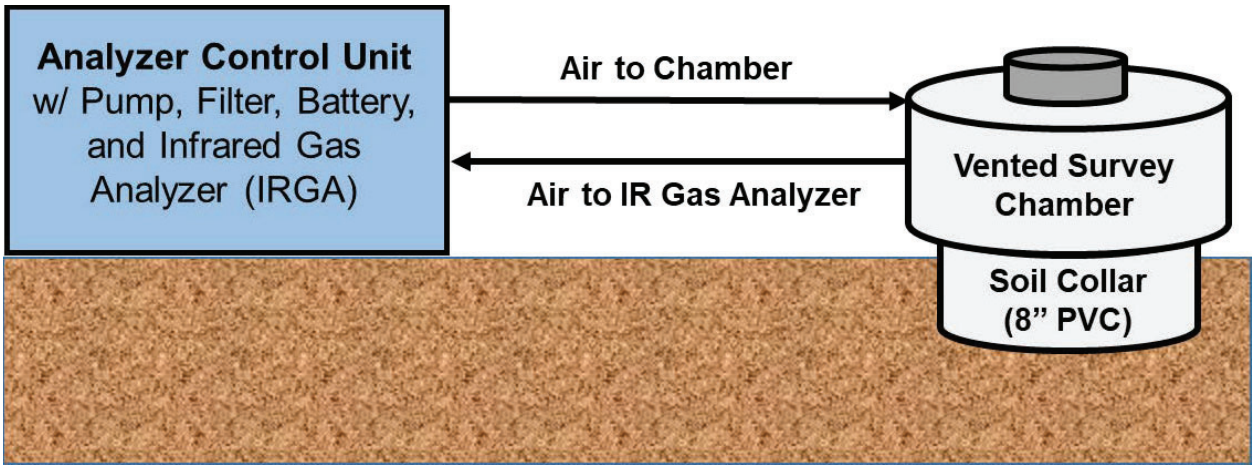

Figure 6-5 – Animation Depicting Dynamic Closed Chamber (DCC) Apparatus and Setup

- Temperature based methods depend on measurements of temperature increases due to petroleum hydrocarbon biodegradation (Sale et al., 2014; Sale et al., 2018). This can be as simple as lowering a temperature probe in a well and comparing temperature profiles in contaminated and uncontaminated locations to a more complex array of temperature probes continuously monitored (Sweeney and Ririe, 2014).

The measurements vary from technique to technique; however, all can be reduced to some unit of mass removed per unit area, a very convenient and widely used unit is gallons of LNAPL per acre per year.

When evaluating NSZD many factors should be considered, a partially important factor is the background associated with the method, that is for example what would the rate of carbon dioxide production or temperature profile be without petroleum hydrocarbon biodegradation. A variety of techniques have been developed to address this background issue, detailing all of them is beyond the scope of this report, but can be found in the various documents cited. At some sites it is possible to find a background location, where no contamination has impacted, but at many locations this is difficult. One particularly creative approach that has been applied to carbon dioxide production is to analyze the trapped carbon dioxide for ^{14}C content. ^{14}C is a naturally occurring, but unstable carbon isotope found in atmospheric carbon dioxide, but not in ancient crude petroleum. By determining the ^{14}C content of the carbon dioxide any effect of the decay of more recent plant-based material can be deducted leaving carbon dioxide produced by the petroleum hydrocarbons. Other background considerations relevant to other methods exist and are available in cited documents.

There are other considerations that need to be given to the interpretation of NSZD data, including timing (rates may vary seasonally and with water table elevation) and spatial variability. For example, surface carbon dioxide flux rates often very considerably over short distances, this may be due to variable degradation rates, it can also be the result of differing underlying soils and the ability to transmit carbon dioxide vertically. At most sites the measured rates are assumed to be representative of the footprint of the LNAPL plume, however particularly at deeper sites the gas

production/consumption or thermal effects can be spread over a larger area. **Table 6-2** identifies some of the pros and cons of the various NSZD measurement methods.

Table 6-2 – Pros and Cons of Various NSZD Measurements and Methods.

Method	Pros	Cons	Sources of more information
Gradient (typically oxygen consumption)	The original method, well understood. On sites where soil vapor probes already exist it can be low cost.	Requires multi depth soil vapor probes and a measure of estimate of soil vapor diffusivity.	Lundegard and Johnson, 2006; Sihota et al., 2011
Carbon Traps	Easy to deploy well understood method. Longer term data collection reduces variability.	Can be higher cost per location than flux chamber or thermal.	McCoy et al., 2014
Flux chambers	Typically, fast and lower cost per point. Well understood method.	Short term measurements can be subject to higher variability, due to factors such as barometric pressure changes.	Sihota et al., 2011
Thermal	Strong technical basis, becoming better understood.	The emerging technique, less well understood and accepted, but this is changing.	Stockwell, 2015

Before measuring NSZD rates, it is important to consider how the data will be used to support the site remediation and management strategy. This will often dictate the number of samples required as well as the frequency of sampling. It should also be noted that NSZD measurements are not precise and that rates measurements are not accurate as a forecasting tool but rather a tool to help make site management decisions, often for comparison to what can be achieved with engineered remediation.

Additional information regarding Natural Source Zone Depletion can be found in ITRC LNAPL Guidance (ITRC, 2018a).

6.3.2 LNAPL Mobility, Migration Potential and Recoverability

For any site, it is important to understand LNAPL mobility and to determine the potential for migration. The practicality of LNAPL recovery is related to mobility. LNAPL mobility and migration are complex processes the intent of this section is to provide an overview of the principals of LNAPL movement and available tools for assessing LNAPL. More detailed and in-depth information is available in the resources cited.

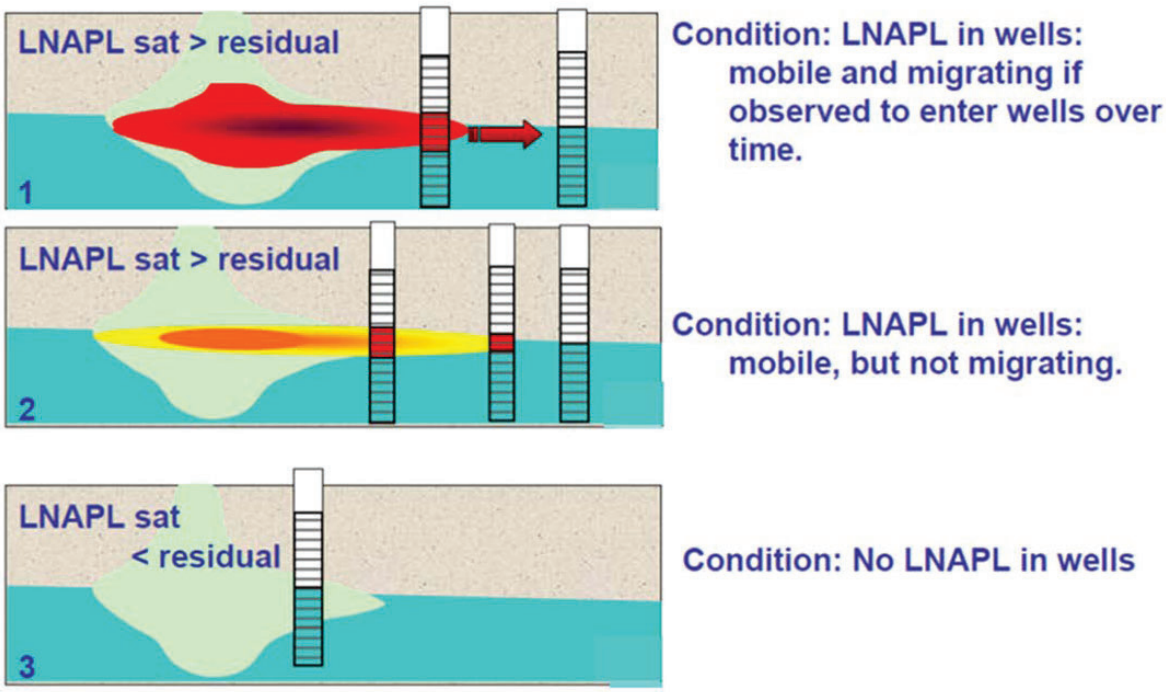

Figure 6-6 - Example of Petroleum Hydrocarbon Release and Subsurface Behavior (ITRC, 2009)

6.3.2.1 LNAPL Mobility

Mobile LNAPL is defined as LNAPL present in soil at concentrations above residual saturation – it will migrate into a monitoring well and can be measured. However, as discussed below, mobile LNAPL is not always the proper descriptor of migrating LNAPL.

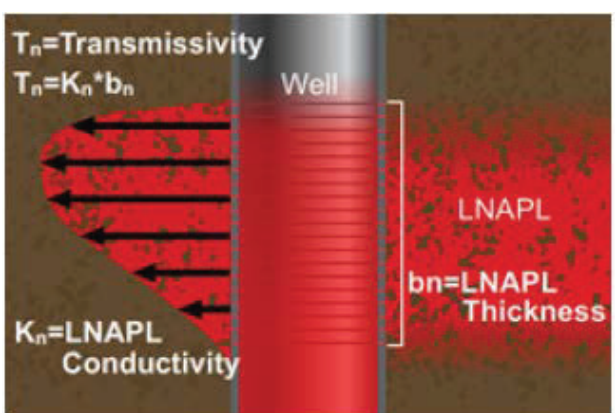

Figure 6-7 – Transmissivity Schematic (NAVFAC, 2015)

LNAPL Transmissivity has emerging as the standard for measuring free product mobility and assessing recoverability it has largely replaced measurement of LNAPL thickness in wells[7]. Transmissivity is defined as the volume of LNAPL movement through a unit width of aquifer per unit time per unit drawdown. Units for this measurement are length^2/time. Transmissivity can be calculated using ASTM LNAPL Transmissivity Standard (E2856-13). Additional technical guidance can be found in

7 LNAPL thickness in wells, commonly called free product thickness is still measured at LNAPL sites and has utility, sometimes as a remedial goal or standard. However, it is not clear that LNAPL thickness does not directly relate to LNAPL mass, recoverability, or migration potential.

the ITRC LNAPL Updated Guidance (ITRC, 2018) and API LNAPL Transmissivity and other Guidance.

Transmissivity rates are dependent on multiple parameters including soil type and properties (e.g. porosity, conductivity), chemical and physical properties of the LNAPL (E.g. density, viscosity, composition), LNAPL saturation in the formation, and thickness of the mobile LNAPL. As such, this measurement provides a much more comprehensive evaluation of product mobility and recoverability at a site.

LNAPL transmissivity can be measured using a variety of methods including:

- The short term **baildown or slug test**, LNAPL is removed from a well and the rate of its recovery measured over time. This is probably the most common technique.
- The **manual skimming** method is accomplished by achieving steady state LNAPL recovery at a rate that maintains a consistent drawdown.
- Long term **LNAPL recovery data** can be used to determine transmissivity. This can be a convenient technique on sites where long term LNAPL recovery operations have been in place and the data are available.
- A less commonly used but effective approach is based on the use of an **LNAPL tracer** placed in a well and the rate of tracer disappearance is observed to derive LNAPL transmissivity.

A discussion of the application of these methods is beyond the scope of this document but there are many quite good guidance documents available.

Based on ITRC's LNAPL Transmissivity Guidance (ITRC, 2018a), LNAPL recovery is considered practical if transmissivity is greater than 0.1 to 0.8 ft^2/day, it is not considered practical at lower transmissivities. Some states have set remedial goals based on transmissivity.

Other techniques including laboratory analysis are available to determine LNAPL mobility. For example, one test involves a centrifuge test where a centrifugal force of 1,000 times gravity is used to evaluate product mobility (ASTM D425M). An issue of concern with these laboratory tests is that they test only a small sample of aquifer material and are less likely to provide useful mobility data than the field-based transmissivity measurements.

6.3.2.2 LNAPL Recoverability

The ITRC based guidance that LNAPL is recoverable above the transmissivity range of 0.1 to 0.8 ft/day range but not below is widely accepted. This does not mean that LNAPL recovery is always necessary above that range, as discussed previously if there is no unacceptable risk, and the LNAPL is not migrating recovery may not be necessary. On the other hand, in some regulatory jurisdictions there are requirements to recover LNAPL at lower transmissivities. When this is the case the potential for removing sufficient mass to provide any cost-effective benefit is limited.

Ultimately, the decision to recover or not recovery and the level of effort expended if recovery is chosen is a cost benefit analysis constrained by regulatory requirements. Technical guidance can inform that decision.

6.3.2.3 LNAPL Migration

It is important to understand the migration or potential for migration of an LNAPL plume. Most of the LNAPL plumes encountered at DoD sites have long past the potential for mobility, however plumes with new or ongoing LNAPL releases do have the potential to migrate.

LNAPL migrates after release until capillary forces stop the migration. Over time as LNAPL weathers and concentrations are reduced the potential for migration is reduced, so that at most since once migration stops it will not restart. There are exceptions, for example LNAPL has a lower residual saturation and is therefore mobile at lower concentrations in unsaturated soil than in saturated soil. As a result, at some sites and under some conditions a falling water table can make immobile LNAPL mobile.[8]

Tools available to determine LNAPL migration and migration potential include:

- Historic plume data when available is the most definitive tool. There are a number of approaches to evaluating plume data:
    - Extent of LNAPL and dissolved phase plume, if these are stable or being reduced over time this is clear evidence of no migration.
    - Declining transmissivity and/or LNAPL thickness (less effective than transmissivity) in wells over time, particularly when coupled with a stable extent.
    - Measured mobile LNAPL in wells over a smaller area than evidence of history LNAPL migration is a very effective means of evaluating the lack of migration. At many sites the maximum historic extent of LNAPL migration can only be known through observation of LNAPL concentrations in soil down gradient of the existing mobile LNAPL plume. This can be determined by means such as soil samples showing high LNAPL concentrations, LIF probing showing LNAPL presence downgradient of existing LNAPL, and even observations of strong hydrocarbon odors or texture in soil samples collected down gradient of the LNAPL Plume.
- Lower LNAPL transmissivity near the down gradient extent of the LNAPL plume can be evidence of limited migration, high LNAPL transmissivity near the downgradient extent of the LNAPL plume can be evidence of potential for migration.
- The API (1998) has published a technique to determine the critical LNAPL thickness above which spreading or migration can occur and below which the LNAPL will not migrate.

6.3.3 Risk Assessment

LNAPL can create a number of risks, **Figure 6-8** illustrates most of these.

8 This is most likely to occur at sites where during the migratory phase of plume development migration was halted by a rising water table, then when the water table falls to or below its former level migration may restart. This is not common and depends on trapped LNAPL below the water table at concentrations below the saturated residual capacity and above the unsaturated residual capacity.

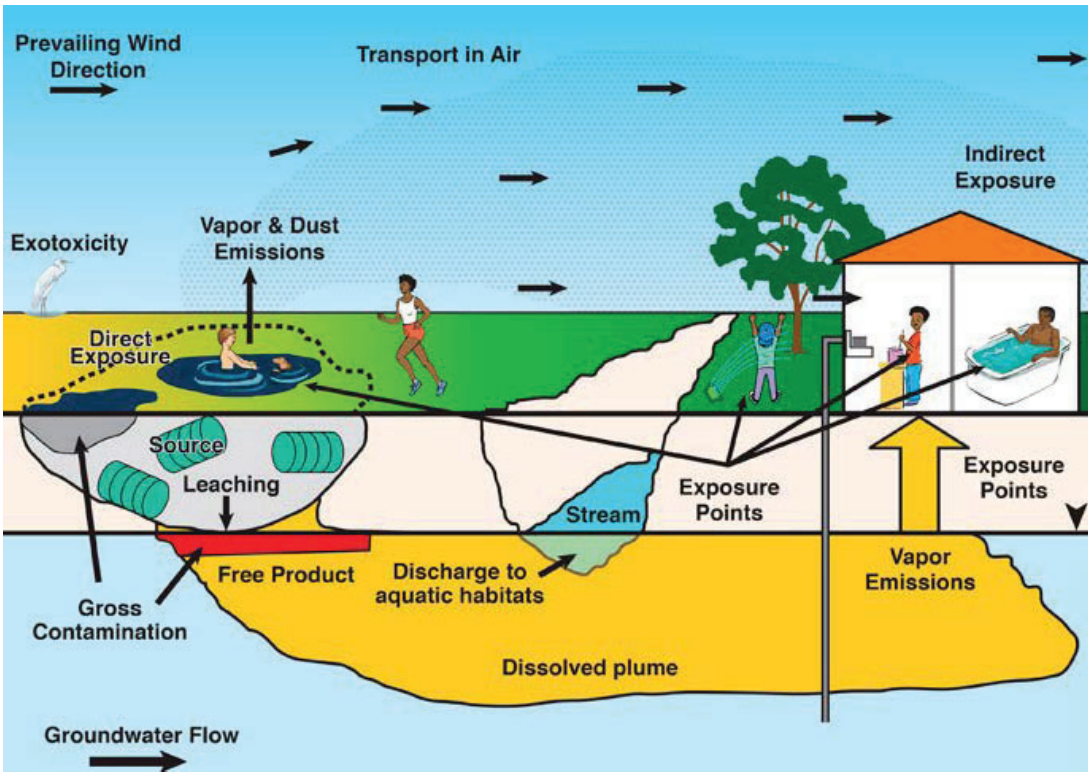

Figure 6-8 – Possible Exposure Routes Associated with LNAPL (ITRC, 2018b)

At most DoD sites the exposure routes of greatest concern are groundwater, soil exposure and vapor intrusion, but the other risks should be considered. Explosive risk from vapors are rare as petroleum hydrocarbons typically biodegrade before becoming problematic in buildings. At some sites methane generated as the result of anaerobic degradation of LNAPL constituents has been raised as a concern. ASTM (E2993 − 16) has published guidance for assessing this risk, but the actual risk at most petroleum hydrocarbon sites has been found to be quite low. Migration to surface water, in the form of sheens, can occur but is rare at DoD sites and will not be addressed here.

Vapor intrusion can be a risk, however due to the biodegradability of LNAPL constituents the risk is lower than for comparably volatile chlorinated solvents. As a rule of thumb ITRC guidance suggests vapor intrusion may be a risk if LNAPL is present within about 15 to 20 feet of a structure. This is rate at DoD sites, and many DoD LNAPLs are heavier products containing little of the VOCs such as benzene that are of vapor intrusion concern.

Risk based on exposure to contaminated soil or groundwater is the concern that drives remediation at most DoD LNAPL sites. Risk of exposure to individual petroleum hydrocarbon compounds such as benzene or naphthalene can be managed using conventional risk assessment techniques. However, since LNAPLs are a mixture of many different petroleum hydrocarbons, most of which are never individually quantified as a mixture assessing chemical risk can be more challenging. Fortunately, many regulatory agencies recognize this and base cleanup standards on individual compounds, such as the drinking water MCL for benzene.

Most regulatory agencies do not require address the LNAPL material as a whole, however some do require total petroleum hydrocarbon (TPH) analysis and some even set cleanup standards for soil or groundwater based on TPH. This is not risk based, however there is an approach originally published by the TPH working group to estimate risk associated with TPH. The method basically involves analyzing different TPH fractions, aromatic and aliphatic based on carbon number and then assigning risk to these individual categories based on the assumption of some surrogate compound representative of the fraction. This approach though not as quantitatively risk based as setting standards for individual hydrocarbons can represent a significant improvement on simple TPH standards.

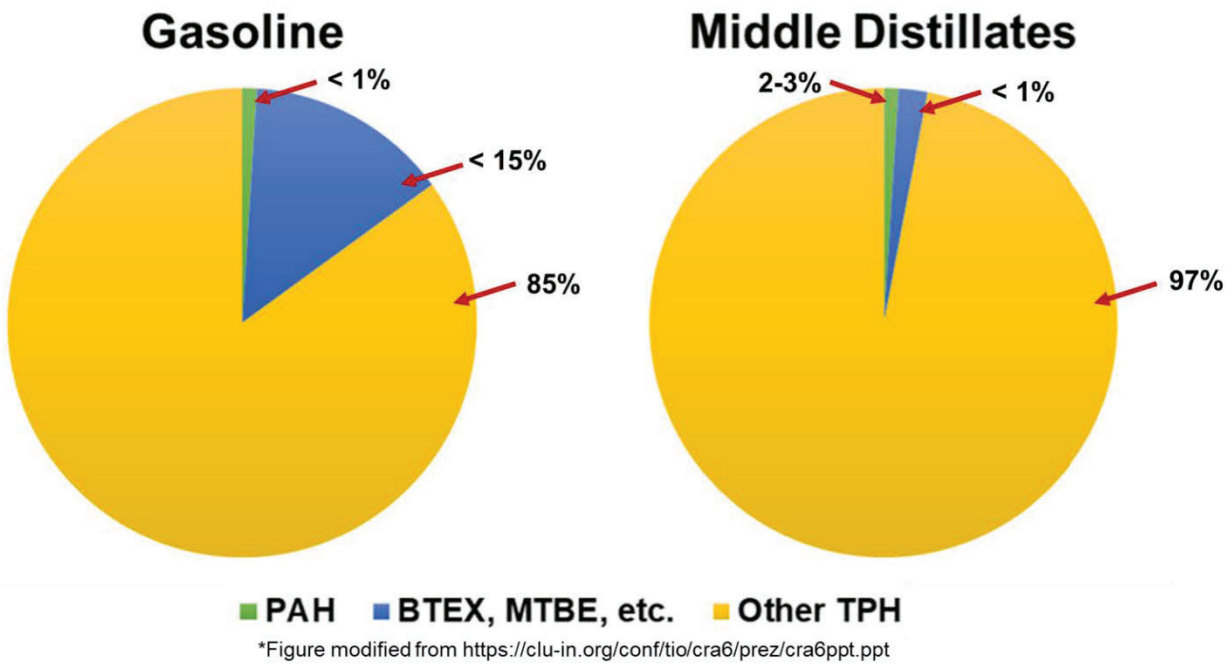

Figure 6-9 – Comparison of Gasoline and Middle Distillates Petroleum Hydrocarbon Component Distribution. These data indicate that most petroleum hydrocarbons in LNAPL are not identified and not of toxic concern (Data adapted from Brewer, 2009).

Since the original TPH working group method was published in 1999 other versions of the method have been adopted, for example the state of Massachusetts has an approach that is widely used as do the states of Texas and Alaska. The ITRC has recently published guidance updating the approach (ITRC, 2018b).

If compounds other than those typically analyzed with known risk factors are to be considered in a remedial strategy the TPH working group approach to estimating risk is recommended. Many of the compounds of greatest risk are only present in relatively low concentrations in LNAPL, this method takes that into account.

6.4 Resources

LNAPL site management requires reliance on many tools and underlying guidance documents. In this report our objective is to inform site managers of the state of the practice for LNAPL site

management and the tools available that site managers should be aware of and consider using. **Table 6-3** lists many of the resources that can be accessed for technical guidance and support.

Table 6-3 – Resources for Technical Guidance and Support

Source	Applications	Link or full citation
API	API has a resource center with links to may useful tools	https://www.api.org/oil-and-natural-gas/environment/clean-water/ground-water/lnapl
	LNAPL Transmissivity Workbook: A Tool for Baildown Test Analysis	https://www.api.org/~/media/4762%20LNAPL%20Tn%20wkbk%20Baildown%20userguide%20Apr2016%20(2).pdf
	LNAPL Distribution and Recovery Model (LDRM)	https://www.api.org/oil-and-natural-gas/environment/clean-water/ground-water/lnapl/ldrm
	Evaluating Hydrocarbon Removal From Source Zones And Its Effect On Dissolved Plume Longevity And Concentration	https://www.api.org/oil-and-natural-gas/environment/clean-water/ground-water/lnapl/evaluating-hydrocarbon-removal
	Interactive LNAPL Guide	https://www.api.org/oil-and-natural-gas/environment/clean-water/ground-water/lnapl/interactive-guide
	Methods For Determining Inputs To Environmental Petroleum Hydrocarbon Mobility And Recovery Models	https://www.api.org/oil-and-natural-gas/environment/clean-water/ground-water/lnapl/mobility-recovery
ASTM	E2856 - 13 Standard Guide for Estimation of LNAPL Transmissivity	https://www.astm.org/Standards/E2856.htm
ITRC	LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies	https://lnapl-3.itrcweb.org

7.0 COST ASSESSMENT

This section provides an overview of relevant costs associated with the demonstration project and conducting an assessment and evaluation of residual LNAPL at a site as well as a discussion of the potential costs benefits from implementing these methodologies and further characterizing residual LNAPL. As part of the cost assessment, transition to NSZD/MNA is compared with traditional free product recovery methods implemented for the recovery and management of LNAPL at impacted sites. The costs that are unique to this technology demonstration include the sampling and analysis for the TPH-CWG (or equivalent) risk-based method, the installation and analysis of the Carbon Traps and determination of transmissivity rates using historical free product recovery data. In addition, as part of the cost assessment, various alternatives including transition to NSZD/MNA is compared with traditional free product recovery methods implemented for the recovery and management of LNAPL at impacted sites. Associated costs are provided in Sections 7.1 and 7.2 below. This assessment includes comparison of implementing of LUCs/ICs, transition to MNA with monitoring, and continued FP recovery efforts via manual method such as bailing and skimming as well as DPE. Transition of a site to a more passive approach could result in significant cost savings over the lifetime of a project.

7.1 COST MODEL

The approximate costs to complete the assessment and evaluation of residual LNAPL at a site based on this demonstration and field effort are summarized **Table 7-1** on the following page. Depending on site conditions as well as the size of the residual free product footprint, these costs may vary.

Table 7-1 – Cost Model for Additional Characterization of Weathered LNAPL

Cost Element	Data Tracked During Demonstration	Costs	
Baseline Characterization (Gauging and Sampling)	Misc. Materials/Field Equipment	LS	$750
	Labor	36	$5,400
	Shipping	LS	$200
Carbon Traps Deployment	Materials + Analysis	LS	$20,000
	Labor	20	$3,000
	Shipping	LS	$100
Field Sampling Analytical Costs	LNAPL	2	$800
	Water	10	$4,000
	Soil	10	$6,000
Drilling Costs	Utility Locate - Subcontract	LS	$2,000
	Drillings Costs	LS	$5,000
Waste Disposal	Characterization and Standard Disposal	LS	$2,000
O&M	N/A	--	--
Data Analysis & Risk Calculations	Labor	LS	$50,000
Total			$99,250

7.2 COST DRIVERS

Depending on the lithology and depth to impacted soil, DPT may not be a viable drilling method for soil sample collection. Therefore, soil sample costs may increase depending on the type of drill rig that can access the site. However, if future soil sampling or well installation is planned, costs may be reduced by collecting additional samples during ongoing site characterization for TPH Fractionation Analysis.

Other cost drivers include the size of the free product footprint and the deployment of Carbon Traps. At a minimum, 5 Carbon Traps should be deployed in order to get a representative average flux across the site. However, depending on the size of the footprint, more Carbon Traps may be required therefore increasing the overall cost for deployment and analysis.

Similarly, depending on the size of the site, the number of samples to analyze for TPH Fraction Analysis for soil and groundwater may vary in order to get a representative date set. The level of effort for sample collection and analytical costs will depend on the number samples to be collected.

Additional details regarding the implementation of these methods and specific considerations for each method are discussed in more detail in the supplemental guidance.

7.3 COST ANALYSIS

As part of the cost analysis and assessment transition to NSZD/MNA is compared with traditional free product recovery methods implemented for the recovery and management of LNAPL at impacted sites. The assessment includes a comparison of implementing of LUCs/ICs, transition to MNA with monitoring, and continued FP recovery efforts via manual method such as bailing and skimming as well as DPE.

Cost estimates for NSZD/MNA are based on this demonstration. For comparison purposes, cost estimates for manual free product recovery and dual phase extraction (DPE) with flushing for a hypothetical site (Section 7.3.1) are based on current costs and estimates from NAS Fallon including Appendix H of the RI Addendum/FS from 2014. **Table 7-2** below presents a summary of the costs comparison between three free product recovery technologies. For costs comparison purposes, annual costs including long-term monitoring and reporting costs, residual waste management, 5-Year Reviews, Remedial Action Completion reports, decommissioning/site closure costs have not been included as many of these costs will be approximately the same for each alternative assessed and will not significantly impact the costs savings potentially realized by demonstrating lines of evidence to support transition from active or passive recovery methods to NSZD/MNA.

Based on the cost comparison for a site with impacted with a 10-acre residual LNAPL footprint that is characterized as a low risk site where the free product is no longer migrating and has low mobility, the dissolved phased plume is stable and residual free product is naturally degrading as described in Section 7.3.1, transition to NSZD/MNA would result in significant cost savings. Depending on when a site is able to transition to NSZD/MNA and cease free product recovery activities, the potential annual costs savings may be on the order of $150,000 to $300,000. However, it should be noted that costs are site specific and depend on many factors including the current/anticipated land use, regulatory requirements, when a site may be able to transition, etc. and therefore may vary from the costs presented in the section below.

Table 7-2 – Cost Comparision Summary

Technology	Capital ($K)	Annual O&M ($K)	Total Cost ($K)	Timeframe (years)
1 - LUCs + NSZD/MNA Eval	100	25	475	15
2 - NSZD/MNA Eval + Monitoring	100	100	1,000	15
3 - Bi-weekly FP Recovery + NSZD/MNA Eval	163	151	2,428	15
4 - DPE + Bi-weekly FP Recovery + NSZD/MNA Eval	921	151-302	4,696	15

7.3.1 Cost Comparison Details and Assumptions

The hypothetical site for this analysis is based on the field demonstration and has the following characteristics:

- 10-acre residual LNAPL footprint at legacy site
- Mobile NAPL (free product) present, however, not migrating (no expanding LNAPL footprint)
- Dissolved phase plume is stable and not migrating
- Current land use is industrial and LUCs are in place
- Depth to GW is 7-10 ft bgs
- Monitoring wells and free product recovery wells exist
- No PVI risk

For cost comparison purposes four alternatives were compared over 15 years of implementation. This duration is based on historical free product recovery activities that have continued for many years at legacy sites in order to meet regulatory requirements or recovery of free product to the maximum extent practicable. It is assumed that all alternatives assessed will eventually transition to NSZD/MNA as part of the site management strategy and will require additional characterization/assessment in order to established multiple lines of evidence that may be required to transition a site. **Table 7-3** below includes annual costs summaries for each alternative as described.

The first alternative is Land Use Controls/Institutional Controls (LUCs/ICs) in place after completing the NZSD/MNA evaluation. The estimated cost for LUCs/ICs with NSZD/MNA evaluation for the **base case is $475,000** for an estimated duration of 15 years and that the site has demonstrated various lines of evidence to transition to NSZD/MNA in order to meet site restoration requirements. For this alternative, it is assumed that additional characterization and residual risk evaluation demonstrated that the residual LNAPL poses little to no risk to receptors, NSZD is occurring at rates comparable to current free product recovery rates, and transmissivity measurements are equal to or less than 0.1 to 0.8 ft^2/day. Only IC Inspections & Review were incorporated into the annual O&M, no and other LTM and reporting costs have not been included as previously discussed.

The second alternative is NSZD/MNA with monitoring for an estimated duration of 15 years and that the site has demonstrated various lines of evidence to transition to NSZD/MNA with MNA monitoring in order to meet site restoration requirements. For this alternative, it is assumed that additional characterization and residual risk evaluation demonstrated that the residual LNAPL poses little to no risk to receptors, NSZD is occurring at rates comparable to current free product recovery rates, and transmissivity measurements are equal to or less than 0.1 to 0.8 ft^2/day. MNA monitoring is assumed to be required and continued at a frequency of once for the first 5 years, biannually for the next 5 years, and every 5 years thereafter. No additional O&M or LTM costs were included. The estimated cost over 15 year is $1 million.

The third alternative evaluated for cost purposes was bi-weekly free product recovery using manual bailing/skimming techniques for 15 years and then transitional to NSZD/MNA. Assumptions for this alternative include:

- Bi-weekly bailing/skimming methods using manual or automated systems
- 14 wells have free product present at thicknesses greater than 0.5”
- FP recovery activities estimated to continue for 15 years.
- Site will transition to NSZD/MNA

The estimated cost for the bi-weekly free product recovery over 15 years is $2.4 million.

The fourth alternative evaluated for costs purposes was dual phase extraction with flushing including manual free product recovery for a duration of 15 years and then transition to NSZD/MNA. Assumptions for this cost alternative include:

- Dual Phase Extraction with flushing will be conducted for 10 years
- DPE system will include 10 injection wells and 25 extraction wells
- FP recovery using manual recovery methods will be conducted in wells not included in DPE that have free product present above 0.5”
- Manual free product recovery will continue in wells that have not met regulatory requirements for free product for 5 years following DPE

The estimated cost for the bi-weekly free product recovery over 15 years is $4.7 million.

Based on this cost analysis, transition of a site to a more passive approach could result in significant cost savings over the lifetime of a project. Especially if the site is able to transition to a passive approach with monitoring or to implementation of LUCs/ICs or potentially even closure based on regulations and site-specific remediation goals.

Table 7-3 – Cost Comparison Annual Cost Detail

1 - LUCs + NSZD/MNA Eval																
Technology Name	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**	**Total**
Capital Cost																
NSZD/MNA Evaluation/Residual Risk Eval	$100,000	--	--	--	--	--	--	--	--	--	--	--	--	--	--	$100,000
Subtotal	$100,000	--	--	--	--	--	--	--	--	--	--	--	--	--	--	$100,000
O&M																
ICs Inspection & Review	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$375,000
Subtotal	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$375,000
Total	$125,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	**$475,000**

2 - NSZD/MNA Eval + Monitoring																
Technology Name	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**	**Total**
Capital Cost																
NSZD/MNA Evaluation/Residual Risk Eval	$100,000	--	--	--	--	--	--	--	--	--	--	--	--	--	--	$100,000
Subtotal	$100,000	--	--	--	--	--	--	--	--	--	--	--	--	--	--	$100,000
O&M																
MNA Monitoring	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	--	$100,000	--	$100,000	--	--	--	--	$100,000	$800,000
Subtotal	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	--	$100,000	--	$100,000	--	--	--	--	$100,000	$100,000
Total	$200,000	$100,000	$100,000	$100,000	$100,000	$100,000	--	$100,000	--	$100,000	--	--	--	--	$100,000	**$1,000,000**

3 - Bi-weekly FP Recovery + NSZD/MNA																
Technology Name	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**	**Total**
Capital Cost																
Remedial Design	62,529	--	--	--	--	--	--	--	--	--	--	--	--	--	--	$62,529
NSZD/MNA Evaluation/Residual Risk Eval	--	--	--	--	--	--	--	--	--	--	--	--	--	--	$100,000	$100,000
Subtotal	$62,529	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$100,000	$162,529
O&M																
Free Product Recovery (14 wells, biweekly)	151,000	151,000	151,000	151,000	151,000	151,000	151,000	151,000	151,000	151,000	151,000	151,000	151,000	151,000	151,000	2,265,000
Subtotal	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$2,265,000
Total	$213,529	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$251,000	**$2,427,529**

Continued next page.

Table 7-3 – Cost Comparison Annual Cost Detail (continued)

4 - DPE + Bi-weekly FP Recovery + NSZD/MNA																
Technology Name	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**	**Total**
Capital Cost																
Remedial Design	$154,421	--	--	--	--	--	--	--	--	--	--	--	--	--	--	$154,421
Install full-scale system	$666,404	--	--	--	--	--	--	--	--	--	--	--	--	--	--	$666,404
NSZD/MNA Evaluation/Residual Risk Eval	--	--	--	--	--	--	--	--	--	--	--	--	--	--	$100,000	$100,000
Subtotal	$820,825	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$100,000	$920,825
O&M																
Treatment system O&M (12 months)	$150,993	$150,993	$150,993	$150,993	$150,993	$150,993	$150,993	$150,993	$150,993	$150,993	--	--	--	--	--	$1,509,930
Free product removal (14 wells, biweekly)	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$151,000	$2,265,000
Subtotal	$301,993	$301,993	$301,993	$301,993	$301,993	$301,993	$301,993	$301,993	$301,993	$301,993	$151,000	$151,000	$151,000	$151,000	$151,000	$3,774,930
Total	$1,122,818	$301,993	$301,993	$301,993	$301,993	$301,993	$301,993	$301,993	$301,993	$301,993	$151,000	$151,000	$151,000	$151,000	$251,000	**$4,695,755**

Notes:

1 - Costs Adapted from Final 2014 RI Addendum/FS NOU NAS Fallon, Appendix H

8.0 IMPLEMENTATION ISSUES

A variety of strategies were evaluated in this effort to better understand potential risks associated with the presence of LNAPL at legacy petroleum sites. Details on the implementation of these methodologies/tools and specific considerations are included in Section 6 of this document. In general, these methods could be implemented at most LNAPL impacted sites in order to help refine the CSM and evaluate any residual risk posed by the remaining LNAPL.

Due to the investigative nature of this work, there were no significant implementation issues encountered. However, in the event similar efforts are to be conducted at other legacy petroleum sites, some important considerations were evaluated:

1.) To better elucidate potential risks and exposure pathways from residual LNAPL, careful judgement must be taken to ensure representative soil and groundwater samples are collected.

2.) Determine whether historical free product recovery data is sufficient to calculate transmissivity or whether field measurements will be required to perform these calculations.

3.) Evaluate specific regulations and regulatory acceptance of analytical methods prior to conducting additional characterization in order to ensure the adequacy of the analytical results.

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APPENDICES

APPENDIX A
Points of Contact

Appendix A: Points of Contact

Point of Contact Name	Organization Name Address	E-mail	Role in Project
Jovan Popovic	NAVFAC EXWC	jovan.popovic@navy.mil	Principal Investigator
Jennifer Segura	NAVFAC EXWC	jennifer.segura@navy.mil	Co- Principal Investigator
Travis Lewis	NAVFAC EXWC	travis.b.lewis@navy.mil	Co-Principal Investigator
Charles Newell	GSI Environmental	cjnewell@gsi-net.com	Project Partner
Poonam Kulkarni	GSI Environmental	prkulkarni@gsi-net.com	Project Partner
Andrea Leeson	ESTCP	andrea.leeson.civ@mail.mil	Project Sponsor

APPENDIX B
Analytical Results

Appendix B: Analytical Results and QA/QC

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ANALYSIS REPORT

Prepared by:	Prepared for:
Eurofins Lancaster Laboratories Environmental 2425 New Holland Pike Lancaster, PA 17601	NAVFAC EXWC 100 23rd Avenue Port Hueneme CA 93043

Report Date: August 02, 2018 14:53

Project: NAVFAC EXWC ER-201582

Account #: 43430
Group Number: 1966958
SDG: NVF01
State of Sample Origin: CA

Electronic Copy To NAVFAC EXWC Attn: Jennifer Segura

Respectfully Submitted,

Kay Hower

(717) 556-7364

SAMPLE INFORMATION

Client Sample Description	Sample Collection Date/Time	ELLE#
S2NE30118-10 Soil	01/31/2018 11:55	9709184
S2NE30118-10 Soil	01/31/2018 11:55	9709185
S2NE30118-10-FD Soil	01/31/2018 12:00	9709186
S2NE30118-10-FD Soil	01/31/2018 12:00	9709187

The specific methodologies used in obtaining the enclosed analytical results are indicated on the Laboratory Sample Analysis Record.

eurofins | Lancaster Laboratories Environmental

Analysis Report

[illegible]

Sample Description: S2NE30118-10 Soil
NAVFAC EXWC

Project Name: NAVFAC EXWC ER-201582

Submittal Date/Time: 07/18/2018 10:00
Collection Date/Time: 01/31/2018 11:55
SDG#: NVF01-01

NAVFAC EXWC
ELLE Sample #: SW 9709184
ELLE Group #: 1966958
Matrix: Soil

CAT No.	Analysis Name	CAS Number	Dry Result	Dry Detection Limit*	Dry Limit of Detection	Dry Limit of Quantitation	DF
GC/MS Volatiles	**SW-846 8260C**		**ug/kg**	**ug/kg**	**ug/kg**	**ug/kg**	
11995	Benzene	71-43-2	N.D.	31	130	310	48.54
11995	Ethylbenzene	100-41-4	3,200	63	130	310	48.54
11995	Methyl Tertiary Butyl Ether	1634-04-4	N.D.	31	130	310	48.54
11995	Naphthalene	91-20-3	9,200	63	130	310	48.54
11995	Toluene	108-88-3	N.D.	63	130	310	48.54
11995	Xylene (Total)	1330-20-7	18,000	63	130	310	48.54
The holding time was not met. The sample was submitted to the laboratory outside of the holding time.							
GC Volatiles	**SW-846 8015D Rev.4, June 2003**		**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	
10599	TPH-GRO soil C6-C10	n.a.	750	20	40	99	1908.4
The holding time was not met. The client was notified and the data reported.							
GC Petroleum Hydrocarbons	**ECY 97-602 WA EPH**		**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	
14100	>C10-C12 Aliphatic	n.a.	4,500	32	63	160	25
14100	>C10-C12 Aromatic	n.a.	680	13	25	63	10
14100	>C12-C16 Aliphatic	n.a.	6,400	32	63	160	25
14100	>C12-C16 Aromatic	n.a.	1,700	13	25	63	10
14100	>C16-C21 Aliphatic	n.a.	170 J	95	190	190	25
14100	>C16-C21 Aromatic	n.a.	250	25	51	63	10
14100	>C21-C34 Aliphatic	n.a.	N.D.	190	380	380	25
14100	>C21-C34 Aromatic	n.a.	N.D.	25	51	63	10
The holding time was not met. The sample was submitted to the laboratory outside of the holding time.							
GC Petroleum Hydrocarbons	**ECY 97-602 WA VPH**		**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	
05666	Benzene	71-43-2	N.D.	0.378	0.788	3.94	304.02
05666	C5-C8 Aliphatic Hydrocarbons	n.a.	N.D.	12.6	39.4	39.4	304.02
05666	C8-C8 Aliphatic Hydrocarbons	n.a.	8.61 J	4.10	15.8	39.4	304.02
05666	C8-C10 Aliphatic Hydrocarbons	n.a.	688	9.14	31.5	78.8	608.05
05666	C8-C10 Aromatic Hydrocarbons	n.a.	523	4.41	15.8	78.8	608.05
05666	Ethylbenzene	100-41-4	N.D.	0.291	0.788	3.94	304.02
05666	Methyl t-butyl ether	1634-04-4	N.D.	0.410	0.788	3.94	304.02
05666	Toluene	108-88-3	N.D.	0.378	0.788	3.94	304.02
05666	o-Xylene	95-47-6	10.3	0.402	0.788	3.94	304.02
05666	m,p-Xylenes	179601-23-1	6.57 J	0.725	1.58	7.88	304.02
The holding time was not met. The sample was submitted to the laboratory outside of the holding time.							

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Analysis Report

Sample Description:	**S2NE30118-10 Soil NAVFAC EXWC**	**NAVFAC EXWC ELLE Sample #:**	**SW 9709184**
		ELLE Group #:	**1966958**
Project Name:	**NAVFAC EXWC ER-201582**	**Matrix: Soil**	
Submittal Date/Time:	07/18/2018 10:00		
Collection Date/Time:	01/31/2018 11:55		
SDG#:	NVF01-01		

CAT No.	Analysis Name	CAS Number	Dry Result	Dry Detection Limit*	Dry Limit of Detection	Dry Limit of Quantitation	DF
GC Petroleum Hydrocarbons		**SW-846 8015D Rev.4, June 2003**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	
13260	C10-C24	n.a.	14,000	260	520	770	50
13260	>C24-C36	n.a.	N.D.	260	520	770	50
13260	Total TPH	n.a.	14,000	260	520	770	50
	The holding time was not met. The sample was submitted to the laboratory outside of the holding time.						
Wet Chemistry		**SM 2540 G-1997 %Moisture Calc**	**%**	**%**	**%**	**%**	
00111	Moisture	n.a.	22.8	0.50	0.50	0.50	1
	Moisture represents the loss in weight of the sample after oven drying at 103 - 105 degrees Celsius. The moisture result reported is on an as-received basis.						

Sample Comments

The analysis for boiling point was subcontracted to another laboratory. See attached report.

Laboratory Sample Analysis Record

CAT No.	Analysis Name	Method	Trial#	Batch#	Analysis Date and Time	Analyst	Dilution Factor
11995	BTEX,MTBE,Naphthalene	SW-846 8260C	1	Q182073AA	07/26/2018 23:52	Patrick T Herres	48.54
00374	GC/MS - Bulk Soil Prep	SW-846 5035A Modified	1	201820050555	07/19/2018 12:29	Anastasia K Jaynes	n.a.
06846	GC/MS HL Bulk Sample Prep	SW-846 5035A Modified	1	201820050555	07/19/2018 12:16	Anastasia K Jaynes	n.a.
10599	TPH-GRO soils C6-C10	SW-846 8015D Rev.4, June 2003	1	18205A16A	07/25/2018 20:14	Jeremy C Giffin	1908.4
01150	GC - Bulk Soil Prep	SW-846 5035A Modified	1	201820050555	07/19/2018 12:17	Anastasia K Jaynes	n.a.
14100	WA EPH DoD Soil	ECY 97-602 WA EPH	1	182050016A	07/26/2018 20:52	Amy Lehr	10
14100	WA EPH DoD Soil	ECY 97-602 WA EPH	1	182050016A	07/26/2018 21:32	Amy Lehr	25
05666	WA- VPH soils	ECY 97-602 WA VPH	1	18211A08A	07/30/2018 18:18	Nicholas R Rossi	304.02
05666	WA- VPH soils	ECY 97-602 WA VPH	1	18211A08B	07/31/2018 15:10	Nicholas R Rossi	608.05
13260	C10-C24, >C24-36	SW-846 8015D Rev.4, June 2003	1	182010036A	07/27/2018 17:13	Timothy M Emrick	50
11213	WA EPH Soils Extraction	ECY 97-602 WA EPH	1	182050016A	07/23/2018 08:00	Bradley W VanLeuven	1
13394	Microwave Ext. - TPH ranges	SW-846 3546	1	182010036A	07/23/2018 08:00	Bradley W VanLeuven	1
00497	Silica Gel Fractionation	SW-846 3630C modified	1	182050016A	07/25/2018 12:25	Edwin Ortiz	1
06170	GC - Bulk Soil Prep (VPH)	SW-846 5035A Modified	1	201820050555	07/19/2018 12:18	Anastasia K Jaynes	n.a.
00111	Moisture	SM 2540 G-1997 %Moisture Calc	1	18200820004B	07/19/2018 10:35	William C Schwebel	1

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Analysis Report

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Sample Description: S2NE30118-10 Soil
NAVFAC EXWC

Project Name: NAVFAC EXWC ER-201582

Submittal Date/Time: 07/18/2018 10:00
Collection Date/Time: 01/31/2018 11:55
SDG#: NVF01-02

NAVFAC EXWC
ELLE Sample #: SW 9709185
ELLE Group #: 1966958
Matrix: Soil

CAT No.	Analysis Name	CAS Number	As Received Result	As Received Detection Limit*	As Received Limit of Detection	As Received Limit of Quantitation	DF
GC Petroleum Hydrocarbons		**SW-846 8015D Rev.4, June 2003**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	
13260	C10-C24	n.a.	9,600	200	400	600	50
13260	>C24-C36	n.a.	N.D.	200	400	600	50
13260	Total TPH	n.a.	9,600	200	400	600	50

The holding time was not met. The sample was submitted to the laboratory outside of the holding time.

Laboratory Sample Analysis Record

CAT No.	Analysis Name	Method	Trial#	Batch#	Analysis Date and Time	Analyst	Dilution Factor
13260	C10-C24, >C24-36	SW-846 8015D Rev.4, June 2003	1	182070030A	07/30/2018 13:19	Timothy M Emrick	50
13394	Microwave Ext. - TPH ranges	SW-846 3546	2	182070030A	07/23/2018 08:00	Bradley W VanLeuven	1

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Analysis Report

[illegible]

Sample Description: S2NE30118-10-FD Soil
NAVFAC EXWC

Project Name: NAVFAC EXWC ER-201582

Submittal Date/Time: 07/18/2018 10:00
Collection Date/Time: 01/31/2018 12:00
SDG#: NVF01-03FD

NAVFAC EXWC
ELLE Sample #: SW 9709186
ELLE Group #: 1966958
Matrix: Soil

CAT No.	Analysis Name	CAS Number	Dry Result	Dry Detection Limit*	Dry Limit of Detection	Dry Limit of Quantitation	DF
GC/MS Volatiles		**SW-846 8260C**	**ug/kg**	**ug/kg**	**ug/kg**	**ug/kg**	
11995	Benzene	71-43-2	N.D.	29	120	290	52.08
11995	Ethylbenzene	100-41-4	1,200	58	120	290	52.08
11995	Methyl Tertiary Butyl Ether	1634-04-4	N.D.	29	120	290	52.08
11995	Naphthalene	91-20-3	6,400	58	120	290	52.08
11995	Toluene	108-88-3	N.D.	58	120	290	52.08
11995	Xylene (Total)	1330-20-7	7,300	58	120	290	52.08
The holding time was not met. The sample was submitted to the laboratory outside of the holding time.							
GC Volatiles		**SW-846 8015D Rev.4, June 2003**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	
10599	TPH-GRO soil C6-C10	n.a.	1,300	18	36	89	1988.07
The holding time was not met. The client was notified and the data reported.							
GC Petroleum Hydrocarbons		**ECY 97-602 WA EPH**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	
14100	>C10-C12 Aliphatic	n.a.	3,000	22	44	110	20
14100	>C10-C12 Aromatic	n.a.	470	5.5	11	27	5
14100	>C12-C16 Aliphatic	n.a.	4,300	22	44	110	20
14100	>C12-C16 Aromatic	n.a.	1,200	5.5	11	27	5
14100	>C16-C21 Aliphatic	n.a.	130 J	66	130	130	20
14100	>C16-C21 Aromatic	n.a.	180	11	22	27	5
14100	>C21-C34 Aliphatic	n.a.	N.D.	130	260	260	20
14100	>C21-C34 Aromatic	n.a.	N.D.	11	22	27	5
The holding time was not met. The sample was submitted to the laboratory outside of the holding time.							
GC Petroleum Hydrocarbons		**ECY 97-602 WA VPH**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	
05666	Benzene	71-43-2	N.D.	0.294	0.612	3.06	273.78
05666	C5-C6 Aliphatic Hydrocarbons	n.a.	N.D.	9.80	30.6	30.6	273.78
05666	C6-C8 Aliphatic Hydrocarbons	n.a.	6.12 J	3.18	12.2	30.6	273.78
05666	C8-C10 Aliphatic Hydrocarbons	n.a.	548	3.55	12.2	30.6	273.78
05666	C8-C10 Aromatic Hydrocarbons	n.a.	413	3.43	12.2	61.2	547.57
05666	Ethylbenzene	100-41-4	N.D.	0.227	0.612	3.06	273.78
05666	Methyl t-butyl ether	1634-04-4	N.D.	0.318	0.612	3.06	273.78
05666	Toluene	108-88-3	N.D.	0.294	0.612	3.06	273.78
05666	o-Xylene	95-47-6	7.86	0.312	0.612	3.06	273.78
05666	m,p-Xylenes	179601-23-1	8.78	0.563	1.22	6.12	273.78
The holding time was not met. The sample was submitted to the laboratory outside of the holding time.							

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Analysis Report

Sample Description: S2NE30118-10-FD Soil
NAVFAC EXWC

Project Name: NAVFAC EXWC ER-201582

Submittal Date/Time: 07/18/2018 10:00
Collection Date/Time: 01/31/2018 12:00
SDG#: NVF01-03FD

NAVFAC EXWC
ELLE Sample #: SW 9709186
ELLE Group #: 1966958
Matrix: Soil

CAT No.	Analysis Name	CAS Number	Dry Result	Dry Detection Limit*	Dry Limit of Detection	Dry Limit of Quantitation	DF
GC Petroleum Hydrocarbons		**SW-846 8015D Rev.4, June 2003**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	
13260	C10-C24	n.a.	15,000	220	440	660	50
13260	>C24-C36	n.a.	N.D.	220	440	660	50
13260	Total TPH	n.a.	15,000	220	440	660	50
The holding time was not met. The sample was submitted to the laboratory outside of the holding time.							
Wet Chemistry		**SM 2540 G-1997 %Moisture Calc**	**%**	**%**	**%**	**%**	
00111	Moisture	n.a.	10.6	0.50	0.50	0.50	1
Moisture represents the loss in weight of the sample after oven drying at 103 - 105 degrees Celsius. The moisture result reported is on an as-received basis.							

Sample Comments

The analysis for boiling point was subcontracted to another laboratory. See attached report.

Laboratory Sample Analysis Record

CAT No.	Analysis Name	Method	Trial#	Batch#	Analysis Date and Time	Analyst	Dilution Factor
11995	BTEX,MTBE,Naphthalene	SW-846 8260C	1	Q182073AA	07/27/2018 00:15	Patrick T Herres	52.08
00374	GC/MS - Bulk Soil Prep	SW-846 5035A Modified	1	201820050555	07/19/2018 12:29	Anastasia K Jaynes	n.a.
00374	GC/MS - Bulk Soil Prep	SW-846 5035A Modified	2	201820050555	07/19/2018 12:29	Anastasia K Jaynes	n.a.
06646	GC/MS HL Bulk Sample Prep	SW-846 5035A Modified	1	201820050555	07/19/2018 12:20	Anastasia K Jaynes	n.a.
10599	TPH-GRO soils C6-C10	SW-846 8015D Rev.4, June 2003	1	18205A16A	07/25/2018 20:52	Jeremy C Giffin	1988.07
01150	GC - Bulk Soil Prep	SW-846 5035A Modified	1	201820050555	07/19/2018 12:21	Anastasia K Jaynes	n.a.
14100	WA EPH DoD Soil	ECY 97-602 WA EPH	1	182050016A	07/26/2018 19:31	Amy Lehr	5
14100	WA EPH DoD Soil	ECY 97-602 WA EPH	1	182050016A	07/26/2018 20:12	Amy Lehr	20
05666	WA- VPH soils	ECY 97-602 WA VPH	1	18211A08A	07/30/2018 19:00	Nicholas R Rossi	273.78
05666	WA- VPH soils	ECY 97-602 WA VPH	1	18211A08B	07/31/2018 15:52	Nicholas R Rossi	547.57
13260	C10-C24, >C24-36	SW-846 8015D Rev.4, June 2003	1	182010036A	07/27/2018 18:18	Timothy M Emrick	50
11213	WA EPH Soils Extraction	ECY 97-602 WA EPH	1	182050016A	07/23/2018 08:00	Bradley W VanLeuven	1
13394	Microwave Ext. - TPH ranges	SW-846 3546	1	182010036A	07/23/2018 08:00	Bradley W VanLeuven	1
00497	Silica Gel Fractionation	SW-846 3630C modified	1	182050016A	07/25/2018 12:25	Edwin Ortiz	1
06170	GC - Bulk Soil Prep (VPH)	SW-846 5035A Modified	1	201820050555	07/19/2018 12:22	Anastasia K Jaynes	n.a.
00111	Moisture	SM 2540 G-1997 %Moisture Calc	1	18200820004B	07/19/2018 10:35	William C Schwebel	1

*=This limit was used in the evaluation of the final result

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Analysis Report

Sample Description:	**S2NE30118-10-FD Soil NAVFAC EXWC**	**NAVFAC EXWC ELLE Sample #:**	**SW 9709187**
		ELLE Group #:	**1966958**
Project Name:	**NAVFAC EXWC ER-201582**	**Matrix: Soil**	
Submittal Date/Time:	07/18/2018 10:00		
Collection Date/Time:	01/31/2018 12:00		
SDG#:	NVF01-04FD		

CAT No.	Analysis Name	CAS Number	As Received Result	As Received Detection Limit*	As Received Limit of Detection	As Received Limit of Quantitation	DF
GC Petroleum Hydrocarbons		**SW-846 8015D Rev.4, June 2003**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	
13260	C10-C24	n.a.	8,500	200	400	590	50
13260	>C24-C36	n.a.	N.D.	200	400	590	50
13260	Total TPH	n.a.	8,500	200	400	590	50

The holding time was not met. The sample was submitted to the laboratory outside of the holding time.

Laboratory Sample Analysis Record

CAT No.	Analysis Name	Method	Trial#	Batch#	Analysis Date and Time	Analyst	Dilution Factor
13260	C10-C24, >C24-36	SW-846 8015D Rev.4, June 2003	1	182070030A	07/30/2018 14:24	Timothy M Emrick	50
13394	Microwave Ext. - TPH ranges	SW-846 3546	2	182070030A	07/23/2018 08:00	Bradley W VanLeuven	1

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Analysis Report

Quality Control Summary

Client Name: NAVFAC EXWC
Reported: 08/02/2018 14:53

Group Number: 1966958

Matrix QC may not be reported if insufficient sample or site-specific QC samples were not submitted. In these situations, to demonstrate precision and accuracy at a batch level, a LCS/LCSD was performed, unless otherwise specified in the method.

All Inorganic Initial Calibration and Continuing Calibration Blanks met acceptable method criteria unless otherwise noted on the Analysis Report.

Method Blank

Analysis Name	Result	DL**	LOD	LOQ
	ug/kg	ug/kg	ug/kg	ug/kg
Batch number: Q182073AA	Sample number(s): 9709184,9709186			
Benzene	N.D.	25	100	250
Ethylbenzene	N.D.	50	100	250
Methyl Tertiary Butyl Ether	N.D.	25	100	250
Naphthalene	N.D.	50	100	250
Toluene	N.D.	50	100	250
Xylene (Total)	N.D.	50	100	250
	mg/kg	mg/kg	mg/kg	mg/kg
Batch number: 18205A16A	Sample number(s): 9709184,9709186			
TPH-GRO soil C6-C10	N.D.	0.2	0.4	1.0
Batch number: 182010036A	Sample number(s): 9709184,9709186			
C10-C24	N.D.	4.0	8.0	12
>C24-C36	N.D.	4.0	8.0	12
Total TPH	N.D.	4.0	8.0	12
Batch number: 182050016A	Sample number(s): 9709184,9709186			
>C10-C12 Aliphatic	N.D.	1.0	2.0	5.0
>C10-C12 Aromatic	N.D.	1.0	2.0	5.0
>C12-C16 Aliphatic	N.D.	1.0	2.0	5.0
>C12-C16 Aromatic	N.D.	1.0	2.0	5.0
>C16-C21 Aliphatic	N.D.	3.0	6.0	6.0
>C16-C21 Aromatic	N.D.	2.0	4.0	5.0
>C21-C34 Aliphatic	N.D.	6.0	12	12
>C21-C34 Aromatic	N.D.	2.0	4.0	5.0
Batch number: 182070030A	Sample number(s): 9709185,9709187			
C10-C24	N.D.	4.0	8.0	12
>C24-C36	N.D.	4.0	8.0	12
Total TPH	N.D.	4.0	8.0	12
Batch number: 18211A08A	Sample number(s): 9709184,9709186			
Benzene	N.D.	0.0480	0.100	0.500
C5-C6 Aliphatic Hydrocarbons	N.D.	1.60	5.00	5.00
C6-C8 Aliphatic Hydrocarbons	N.D.	0.520	2.00	5.00
C8-C10 Aliphatic Hydrocarbons	N.D.	0.580	2.00	5.00
Ethylbenzene	N.D.	0.0370	0.100	0.500
Methyl t-butyl ether	N.D.	0.0520	0.100	0.500
Toluene	N.D.	0.0480	0.100	0.500
o-Xylene	N.D.	0.0510	0.100	0.500
m,p-Xylenes	N.D.	0.0920	0.200	1.00

*- Outside of specification
**-This limit was used in the evaluation of the final result for the blank
(1) The result for one or both determinations was less than five times the LOQ.
(2) The unspiked result was more than four times the spike added.
(3) The surrogate spike amount was less than the LOD.

Quality Control Summary

Client Name: NAVFAC EXWC
Reported: 08/02/2018 14:53

Group Number: 1966958

Method Blank (continued)

Analysis Name	Result mg/kg	DL** mg/kg	LOD mg/kg	LOQ mg/kg
Batch number: 18211A08B	Sample number(s): 9709184,9709186			
C8-C10 Aliphatic Hydrocarbons	N.D.	0.580	2.00	5.00
C8-C10 Aromatic Hydrocarbons	N.D.	0.280	1.00	5.00

LCS/LCSD

Analysis Name	LCS Spike Added ug/kg	LCS Conc ug/kg	LCSD Spike Added ug/kg	LCSD Conc ug/kg	LCS %REC	LCSD %REC	LCS/LCSD Limits	RPD	RPD Max
Batch number: Q182073AA	Sample number(s): 9709184,9709186								
Benzene	1000	985	1000	1073.96	98	107	77-121	9	20
Ethylbenzene	1000	913.93	1000	1011.48	91	101	78-122	10	20
Methyl Tertiary Butyl Ether	1000	975.45	1000	1089.17	98	109	73-125	11	20
Naphthalene	1000	921.36	1000	962.85	92	96	62-129	4	20
Toluene	1000	929.07	1000	1019	93	102	77-121	9	20
Xylene (Total)	3000	2681.53	3000	2930.25	89	98	78-124	9	20
	mg/kg	mg/kg	mg/kg	mg/kg					
Batch number: 18205A16A	Sample number(s): 9709184,9709186								
TPH-GRO soil C6-C10	11	11.34	11	11.2	103	102	79-122	1	30
	mg/kg	mg/kg	mg/kg	mg/kg					
Batch number: 182010036A	Sample number(s): 9709184,9709186								
Total TPH	133	130.44			98		67-115		
Batch number: 182050016A	Sample number(s): 9709184,9709186								
>C10-C12 Aliphatic	4.01	2.92	4.01	3.02	73	75	31-137	3	50
>C10-C12 Aromatic	4.01	3.04	4.01	3.29	76	82	22-119	8	50
>C12-C16 Aliphatic	8.02	6.55	8.02	6.68	82	83	42-146	2	50
>C12-C16 Aromatic	12	10.09	12	10.59	84	88	24-136	5	50
>C16-C21 Aliphatic	12	10.43	12	10.6	87	88	57-111	2	50
>C16-C21 Aromatic	20.1	19.23	20.1	20.08	96	100	34-143	4	50
>C21-C34 Aliphatic	20	16.21	20	16.29	81	81	50-124	1	50
>C21-C34 Aromatic	32.1	30.34	32.1	30.98	95	97	44-134	2	50
Batch number: 182070030A	Sample number(s): 9709185,9709187								
Total TPH	133	115.5			87		67-115		
Batch number: 18211A08A	Sample number(s): 9709184,9709186								
Benzene	2.53	2.27	2.53	2.29	90	90	70-130	1	50
C5-C8 Aliphatic Hydrocarbons	5.08	4.66	5.08	4.58	92	90	70-130	2	50
C8-C8 Aliphatic Hydrocarbons	2.55	2.30	2.55	2.24	90	88	70-130	3	50

*- Outside of specification
**-This limit was used in the evaluation of the final result for the blank
(1) The result for one or both determinations was less than five times the LOQ.
(2) The unspiked result was more than four times the spike added.
(3) The surrogate spike amount was less than the LOD.

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Analysis Report

Quality Control Summary

Client Name: NAVFAC EXWC
Reported: 08/02/2018 14:53

Group Number: 1966958

LCS/LCSD (continued)

Analysis Name	LCS Spike Added mg/kg	LCS Conc mg/kg	LCSD Spike Added mg/kg	LCSD Conc mg/kg	LCS %REC	LCSD %REC	LCS/LCSD Limits	RPD	RPD Max
C8-C10 Aliphatic Hydrocarbons	2.55	2.29	2.55	2.33	90	91	70-130	2	50
Ethylbenzene	2.54	2.29	2.54	2.31	90	91	70-130	1	50
Methyl t-butyl ether	2.55	2.38	2.55	2.38	93	93	70-130	1	50
Toluene	2.54	2.29	2.54	2.29	90	90	70-130	0	50
o-Xylene	2.50	2.28	2.50	2.31	91	92	70-130	1	50
m,p-Xylenes	5.10	4.55	5.10	4.58	89	90	70-130	1	50
Batch number: 18211A08B	Sample number(s): 9709184,9709186								
C8-C10 Aliphatic Hydrocarbons	2.55	2.29	2.55	2.33	90	91	70-130	2	50
C8-C10 Aromatic Hydrocarbons	2.57	2.23	2.57	2.24	87	87	70-130	1	50
	%	%	%	%					
Batch number: 182008200048	Sample number(s): 9709184,9709186								
Moisture	89.5	89.42			100		99-101		

MS/MSD

Unspiked (UNSPK) = the sample used in conjunction with the matrix spike

Analysis Name	Unspiked Conc mg/kg	MS Spike Added mg/kg	MS Conc mg/kg	MSD Spike Added mg/kg	MSD Conc mg/kg	MS %Rec	MSD %Rec	MS/MSD Limits	RPD	RPD Max
Batch number: 182010036A	Sample number(s): 9709184,9709186 UNSPK: 9709184									
Total TPH	10725.11	133	9179.28			-1161 (2)		67-115		
Batch number: 182070030A	Sample number(s): 9709185,9709187 UNSPK: 9709185									
Total TPH	9616.06	133	7828.18			-1343 (2)		67-115		

Laboratory Duplicate

Background (BKG) = the sample used in conjunction with the duplicate

Analysis Name	BKG Conc mg/kg	DUP Conc mg/kg	DUP RPD	DUP RPD Max
Batch number: 182010036A	Sample number(s): 9709184,9709186 BKG: 9709184			
C10-C24	10719.98	10616.61	1	20
>C24-C36	N.D.	N.D.	0 (1)	20
Total TPH	10725.11	10625.45	1	20
Batch number: 182050016A	Sample number(s): 9709184,9709186 BKG: 9709184			

*- Outside of specification
**-This limit was used in the evaluation of the final result for the blank
(1) The result for one or both determinations was less than five times the LOQ.
(2) The unspiked result was more than four times the spike added.
(3) The surrogate spike amount was less than the LOD.

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Analysis Report

Quality Control Summary

Client Name: NAVFAC EXWC
Reported: 08/02/2018 14:53

Group Number: 1966958

Laboratory Duplicate (continued)

Background (BKG) = the sample used in conjunction with the duplicate

Analysis Name	BKG Conc mg/kg	DUP Conc mg/kg	DUP RPD	DUP RPD Max
>C10-C12 Aliphatic	3487.82	3647.26	4	25
>C10-C12 Aromatic	525.08	497.72	5	25
>C12-C16 Aliphatic	4917.83	5012.22	2	25
>C12-C16 Aromatic	1280.47	1197.97	7	25
>C16-C21 Aliphatic	130.79	142.02	8 (1)	25
>C16-C21 Aromatic	195.32	178.95	9 (1)	25
>C21-C34 Aliphatic	N.D.	N.D.	0 (1)	25
>C21-C34 Aromatic	N.D.	N.D.	0 (1)	25
Batch number: 182070030A	Sample number(s): 9709185,9709187 BKG: 9709185			
C10-C24	9613.35	9164.9	5	20
>C24-C36	N.D.	N.D.	0 (1)	20
Total TPH	9616.06	9166.49	5	20
	%	%		
Batch number: 18200820004B	Sample number(s): 9709184,9709186 BKG: 9709184			
Moisture	22.8	23.41	3	5

Surrogate Quality Control

Surrogate recoveries which are outside of the QC window are confirmed unless attributed to dilution or otherwise noted on the Analysis Report.

Analysis Name: BTEX,MTBE,Naphthalene
Batch number: Q182073AA

	Dibromofluoromethane		1,2-Dichloroethane-d4		Toluene-d8		4-Bromofluorobenzene	
	%Rec	LOD (ug/kg)	%Rec	LOD (ug/kg)	%Rec	LOD (ug/kg)	%Rec	LOD (ug/kg)
9709184	69*	240 (3)	72	240 (3)	66*	240 (3)	115	240 (3)
9709186	84	260 (3)	85	260 (3)	83*	260 (3)	86	260 (3)
Blank	97	250 (3)	97	250 (3)	90	250 (3)	91	250 (3)
LCS	94	250 (3)	94	250 (3)	88	250 (3)	92	250 (3)
LCSD	104	250 (3)	102	250 (3)	97	250 (3)	102	250 (3)
Limits:	78-119		71-136		85-116		79-119	

Analysis Name: TPH-GRO soils C6-C10
Batch number: 18205A16A

	Trifluorotoluene-F	
	%Rec	LOD (mg/kg)
9709184	84	76 (3)

*- Outside of specification
**-This limit was used in the evaluation of the final result for the blank
(1) The result for one or both determinations was less than five times the LOQ.
(2) The unspiked result was more than four times the spike added.
(3) The surrogate spike amount was less than the LOD.

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Analysis Report

Quality Control Summary

Client Name: NAVFAC EXWC
Reported: 08/02/2018 14:53

Group Number: 1966958

Surrogate Quality Control (continued)

Surrogate recoveries which are outside of the QC window are confirmed unless attributed to dilution or otherwise noted on the Analysis Report.

Analysis Name: TPH-GRO soils C6-C10
Batch number: 18205A16A

	Trifluorotoluene-F %Rec	LOD (mg/kg)
9709186	105	80 (3)
Blank	91	1.0 (3)
LCS	97	1.0 (3)
LCSD	98	1.0 (3)
Limits:	50-142	

Analysis Name: C10-C24, >C24-36
Batch number: 182010036A

	Chlorobenzene %Rec	LOD (mg/kg)	Orthoterphenyl %Rec	LOD (mg/kg)
9709184	476*	16 (3)	108	16 (3)
9709186	501*	16 (3)	111	16 (3)
Blank	110	0.33	104	0.33
DUP	437*	16 (3)	104	16 (3)
LCS	136	0.33	111	0.33
MS	412*	16 (3)	108	16 (3)
Limits:	54-137		48-135	

Analysis Name: WA EPH DoD Soil
Batch number: 182050016A

	Orthoterphenyl %Rec	LOD (mg/kg)	1-chlorooctadecane %Rec	LOD (mg/kg)
9709184	100	20 (3)	71	49 (3)
9709186	70	9.8 (3)	65	39 (3)
Blank	83	2.0	62	2.0
DUP	90	20 (3)	72	49 (3)
LCS	89	2.0	62	2.0
LCSD	59	2.0	65	2.0
Limits:	42-115		33-122	

Analysis Name: C10-C24, >C24-36
Batch number: 182070030A

*- Outside of specification
**-This limit was used in the evaluation of the final result for the blank
(1) The result for one or both determinations was less than five times the LOQ.
(2) The unspiked result was more than four times the spike added.
(3) The surrogate spike amount was less than the LOD.

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Analysis Report

Quality Control Summary

Client Name: NAVFAC EXWC
Reported: 08/02/2018 14:53

Group Number: 1966958

Surrogate Quality Control (continued)

Surrogate recoveries which are outside of the QC window are confirmed unless attributed to dilution or otherwise noted on the Analysis Report.

Analysis Name: C10-C24, >C24-36
Batch number: 182070030A

	Chlorobenzene		Orthoterphenyl	
	%Rec	LOD (mg/kg)	%Rec	LOD (mg/kg)
9709185	381*	16 (3)	99	16 (3)
9709187	246*	16 (3)	115	16 (3)
Blank	88	0.33	95	0.33
DUP	355*	16 (3)	97	16 (3)
LCS	91	0.33	102	0.33
MS	299*	16 (3)	95	16 (3)
Limits:	54-137		48-135	

Analysis Name: WA- VPH soils
Batch number: 18211A08A

	Trifluorotoluene-P		Trifluorotoluene-F	
	%Rec	LOD (mg/kg)	%Rec	LOD (mg/kg)
9709184	91	912 (3)	90	912 (3)
9709186	83	821 (3)	84	821 (3)
Blank	90	150 (3)	93	150 (3)
LCS	95	150 (3)	98	150 (3)
LCSD	94	150 (3)	94	150 (3)
Limits:	60-140		60-140	

*- Outside of specification
**-This limit was used in the evaluation of the final result for the blank
(1) The result for one or both determinations was less than five times the LOQ.
(2) The unspiked result was more than four times the spike added.
(3) The surrogate spike amount was less than the LOD.

Carbon Trap Deployment Data

Sample ID	Deployment Dates			Raw Results (not blank corrected)					Blank Corrected Results[a] and ^{14}C Analysis (Fossil Fuel)									
	Deployed	Retrieved	Days	Moisture	Dry Sorbent Mass (g)	Num. of Reps	Avg CO_2	CV CO_2	Carbon Content[d] %	Carbon Content[d] (g)	CO_2 Flux[e] (microM/ m^2.sec)	Modern Carbon, As Reported[g]	Std. Dev. Modern	Modern CO_2 Flux (microM/ m^2.sec)	Adjusted Fossil Fuel Carbon [h]	Grams Of Fossil Fuel CO_2(g)	Fossil Fuel CO_2 Flux (microM/ m^2.sec)	Equivalent Fossil Fuel-Based NAPL Loss Rate (gallons/ acre.yr)
FANV-R1-CO2-TB	NA	NA	0.00	17.9%	42.141	2	0.81%	1.10%	-	-	-	78.0%	0.24%	-	25.7%	-	-	-
FANV-R1-CO2-01	10/5/17 9:30	10/19/17 8:40	13.97	14.2%	41.244	2	1.44%	0.73%	0.6%	0.26	0.6	77.5%	0.23%	0.4	26.2%	0.07	0.16	101
FANV-R1-CO2-02	10/5/17 9:55	10/19/17 8:45	13.95	12.6%	42.912	2	1.94%	0.79%	1.1%	0.48	1.1	65.2%	0.22%	0.6	37.9%	0.23	0.52	328
FANV-R1-CO2-03	10/5/17 10:15	10/19/17 8:55	13.94	5.7%	41.883	2	1.54%	2.54%	0.7%	0.31	0.7	71.3%	0.24%	0.4	32.1%	0.12	0.28	175
FANV-R1-CO2-04	10/5/17 10:20	10/19/17 9:00	13.94	7.1%	41.758	2	1.34%	1.17%	0.5%	0.22	0.5	84.0%	0.30%	0.5	20.0%	0.03	0.06	37
FANV-R1-CO2-05	10/5/17 10:30	10/19/17 9:05	13.94	5.8%	43.022	2	1.54%	2.32%	0.7%	0.32	0.7	80.6%	0.29%	0.6	23.2%	0.06	0.15	94
FANV-R1-CO2-09*	10/5/17 10:45	10/19/17 9:15	13.94	4.4%	43.749	2	2.57%	1.39%	1.8%	0.77	1.8	96.2%	0.33%	1.8	8.4%	0.00	0.01	5
FANV-R1-CO2-07	10/5/17 11:00	10/19/17 9:20	13.93	5.5%	41.325	2	1.74%	0.31%	0.9%	0.38	0.9	77.0%	0.22%	0.6	26.7%	0.11	0.25	154
FANV-R1-CO2-08	10/5/17 11:15	10/19/17 9:25	13.92	2.6%	43.654	2	2.09%	2.05%	1.3%	0.56	1.3	69.6%	0.21%	0.8	33.7%	0.22	0.51	317
FANV-R1-CO2-06*	10/5/17 11:25	10/19/17 9:30	13.92	5.7%	41.932	2	1.84%	0.28%	1.0%	0.43	1.0	76.6%	0.25%	0.7	27.0%	0.12	0.28	177

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Analytical Method Information

Analyte	DL	LOD	LOQ / RL	Surrogate %R	Duplicate RPD	Matrix Spike %R	Matrix Spike RPD	Blank Spike / LCS %R	Blank Spike / LCS RPD
WA EPH Aromatics (WA EPH) in Solid									
Preservation: Cool <6°C									
Container: Glass WM, Clear, 8 oz		**Minimum Sample Weight:** 150 g			**Hold Time:** 14 days				
C8-C10 Aromatics	468 ug/kg		2000 ug/kg						
C10-C12 Aromatics	269 ug/kg		2000 ug/kg		30	30 - 160	30	30 - 160	30
C12-C16 Aromatics	145 ug/kg		2000 ug/kg		30	30 - 160	30	30 - 160	30
C16-C21 Aromatics	599 ug/kg		2000 ug/kg		30	30 - 160	30	30 - 160	30
C21-C34 Aromatics	857 ug/kg		2000 ug/kg		30	30 - 160	30	30 - 160	30
surr: o-Terphenyl				30 - 160					

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Analytical Method Information

Analyte	DL	LOD	LOQ / RL	Surrogate %R	Duplicate RPD	Matrix Spike %R	Matrix Spike RPD	Blank Spike / LCS %R	Blank Spike / LCS RPD
WA EPH Aromatics (WA EPH) in Water									
Preservation: Cool <6°C									
Container: Glass NM, Amber, 500 mL		**Minimum Sample Volume:** 500 mL			**Hold Time:** 7 days				
C8-C10 Aromatics	7.04 ug/L		40.0 ug/L						
C10-C12 Aromatics	2.12 ug/L		40.0 ug/L		30	29 - 120	30	29 - 120	30
C12-C16 Aromatics	2.55 ug/L		40.0 ug/L		30	39 - 120	30	39 - 120	30
C16-C21 Aromatics	8.90 ug/L		40.0 ug/L		30	54 - 120	30	54 - 120	30
C21-C34 Aromatics	14.6 ug/L		40.0 ug/L		30	29 - 120	30	29 - 120	30
surr: o-Terphenyl				41 - 120					

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Analytical Method Information

Analyte	DL	LOD	LOQ / RL	Surrogate %R	Duplicate RPD	Matrix Spike %R	Matrix Spike RPD	Blank Spike / LCS %R	Blank Spike / LCS RPD
WA EPH Aliphatics (WA EPH) in Solid									
Preservation: Cool <6°C									
Container: Glass WM, Clear, 8 oz		**Minimum Sample Weight:** 150 g			**Hold Time:** 14 days				
C8-C10 Aliphatics	327 ug/kg		2000 ug/kg		30	30 - 160	30	30 - 160	30
C10-C12 Aliphatics	128 ug/kg		2000 ug/kg		30	30 - 160	30	30 - 160	30
C12-C16 Aliphatics	174 ug/kg		2000 ug/kg		30	30 - 160	30	30 - 160	30
C16-C21 Aliphatics	269 ug/kg		2000 ug/kg		30	30 - 160	30	30 - 160	30
C21-C34 Aliphatics	193 ug/kg		2000 ug/kg		30	30 - 160	30	30 - 160	30
surr: 1-Chloro-octadecane				30 - 160					

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Analytical Method Information

Analyte	DL	LOD	LOQ / RL	Surrogate %R	Duplicate RPD	Matrix Spike %R	Matrix Spike RPD	Blank Spike / LCS %R	Blank Spike / LCS RPD
WA EPH Aliphatics (WA EPH) in Water									
Preservation: Cool <6°C									
Container: Glass NM, Amber, 500 mL		**Minimum Sample Volume:** 500 mL			**Hold Time:** 7 days				
C8-C10 Aliphatics	5.63 ug/L		40.0 ug/L		30	12 - 120	30	12 - 120	30
C10-C12 Aliphatics	3.86 ug/L		40.0 ug/L		30	15 - 120	30	15 - 120	30
C12-C16 Aliphatics	3.48 ug/L		40.0 ug/L		30	39 - 120	30	39 - 120	30
C16-C21 Aliphatics	6.33 ug/L		40.0 ug/L		30	56 - 120	30	56 - 120	30
C21-C34 Aliphatics	5.02 ug/L		40.0 ug/L		30	10 - 120	30	10 - 120	30
surr: 1-Chloro-octadecane				36 - 120					

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Analytical Method Information

Analyte	DL	LOD	LOQ / RL	Surrogate %R	Duplicate RPD	Matrix Spike %R	Matrix Spike RPD	Blank Spike / LCS %R	Blank Spike / LCS RPD
WA VPH (WA VPH) in Solid									
Preservation: MeOH, Cool <6°C									
Container: VOA Vial, Amber, 40 mL		**Minimum Sample Weight:** 10 g			**Hold Time:** 14 days				
C5-C6 Aliphatics	4500 ug/kg		9000 ug/kg				30		30
C6-C8 Aliphatics	4500 ug/kg		9000 ug/kg				30		30
C8-C10 Aliphatics	4500 ug/kg		9000 ug/kg				30		30
C10-C12 Aliphatics	4500 ug/kg		9000 ug/kg				30		30
C8-C10 Aromatics	4500 ug/kg		9000 ug/kg				30		30
C10-C12 Aromatics	4500 ug/kg		9000 ug/kg				30		30
C12-C13 Aromatics	4500 ug/kg		9000 ug/kg				30		30
Methyl tert-butyl Ether	450 ug/kg		900 ug/kg			70 - 130	30	70 - 130	30
Benzene	450 ug/kg		900 ug/kg			70 - 130	30	70 - 130	30
Toluene	450 ug/kg		900 ug/kg			70 - 130	30	70 - 130	30
Ethylbenzene	450 ug/kg		900 ug/kg			70 - 130	30	70 - 130	30
m,p-Xylene	900 ug/kg		1800 ug/kg			70 - 130	30	70 - 130	30
o-Xylene	450 ug/kg		900 ug/kg			70 - 130	30	70 - 130	30
1,2,3-Trimethylbenzene	450 ug/kg		900 ug/kg			70 - 130	30	70 - 130	30
Naphthalene	450 ug/kg		900 ug/kg			70 - 130	30	70 - 130	30
1-Methylnaphthalene	450 ug/kg		900 ug/kg			70 - 130	30	70 - 130	30
n-Pentane	450 ug/kg		900 ug/kg			70 - 130	30	70 - 130	30
n-Hexane	450 ug/kg		900 ug/kg			70 - 130	30	70 - 130	30
n-Octane	450 ug/kg		900 ug/kg			70 - 130	30	70 - 130	30
n-Decane	450 ug/kg		900 ug/kg			70 - 130	30	70 - 130	30
n-Dodecane	450 ug/kg		900 ug/kg			70 - 130	30	70 - 130	30
surr: PID: 2,5-Dibromotoluene				60 - 140					
surr: FID: 2,5-Dibromotoluene				60 - 140					

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Analytical Method Information

Analyte	DL	LOD	LOQ / RL	Surrogate %R	Duplicate RPD	Matrix Spike %R	Matrix Spike RPD	Blank Spike / LCS %R	Blank Spike / LCS RPD
WA VPH (WA VPH) in Water									
Preservation: HCl, pH <2									
Container: VOA Vial, Amber, 40 mL, HCL		**Minimum Sample Volume:** 120 mL			**Hold Time:** 14 days				
C5-C6 Aliphatics	25.0 ug/L	50.0 ug/L	50.0 ug/L				30		30
C6-C8 Aliphatics	25.0 ug/L	50.0 ug/L	50.0 ug/L				30		30
C8-C10 Aliphatics	25.0 ug/L	50.0 ug/L	50.0 ug/L				30		30
C10-C12 Aliphatics	25.0 ug/L	50.0 ug/L	50.0 ug/L				30		30
C8-C10 Aromatics	25.0 ug/L	50.0 ug/L	50.0 ug/L				30		30
C10-C12 Aromatics	25.0 ug/L	50.0 ug/L	50.0 ug/L				30		30
C12-C13 Aromatics	25.0 ug/L	50.0 ug/L	50.0 ug/L				30		30
Methyl tert-butyl Ether	2.50 ug/L	5.00 ug/L	5.00 ug/L			70 - 130	30	70 - 130	30
Benzene	2.50 ug/L	5.00 ug/L	5.00 ug/L			70 - 130	30	70 - 130	30
Toluene	2.50 ug/L	5.00 ug/L	5.00 ug/L			70 - 130	30	70 - 130	30
Ethylbenzene	2.50 ug/L	5.00 ug/L	5.00 ug/L			70 - 130	30	70 - 130	30
m,p-Xylene	5.00 ug/L	10.0 ug/L	10.0 ug/L			70 - 130	30	70 - 130	30
o-Xylene	2.50 ug/L	5.00 ug/L	5.00 ug/L			70 - 130	30	70 - 130	30
1,2,3-Trimethylbenzene	2.50 ug/L	5.00 ug/L	5.00 ug/L			70 - 130	30	70 - 130	30
Naphthalene	2.50 ug/L	5.00 ug/L	5.00 ug/L			70 - 130	30	70 - 130	30
1-Methylnaphthalene	2.50 ug/L	5.00 ug/L	5.00 ug/L			70 - 130	30	70 - 130	30
n-Pentane	2.50 ug/L	5.00 ug/L	5.00 ug/L			70 - 130	30	70 - 130	30
n-Hexane	2.50 ug/L	5.00 ug/L	5.00 ug/L			70 - 130	30	70 - 130	30
n-Octane	2.50 ug/L	5.00 ug/L	5.00 ug/L			70 - 130	30	70 - 130	30
n-Decane	2.50 ug/L	5.00 ug/L	5.00 ug/L			70 - 130	30	70 - 130	30
n-Dodecane	2.50 ug/L	5.00 ug/L	5.00 ug/L			70 - 130	30	70 - 130	30
surr: PID: 2,5-Dibromotoluene				60 - 140					
surr: FID: 2,5-Dibromotoluene				60 - 140					

APPENDIX C
Transmissivity Calculations

9.0 Appendix C: Transmissivity Calculations

Transmissivity rates were calculated using ASTM LNAPL Transmissivity Standard (E2856-13) Equation 16 (applied under Section 8.3 Data Analysis – Long-Term Recovery System Data).. Average transmissivity rates were calculated over four active recovery phases conducted at the site since 2007. In addition, average transmissivity rates for select individual wells where product was recovered during the last free product recovery event in 2018 during the 4th active FP recovery phase were calculated as well. The equations, assumptions and detailed calculations are included below.

$$T_n = \frac{Q_n ln\left(\frac{R_{oi}}{r_w}\right)}{2\pi s_n} \quad (ASTM\ E2856 - 13\ Eq.16)$$

Where:

T_n = LNAPL transmissivity (ft^2/day)
Q_n = measured LNAPL recovery rate (ft^3/day)
R_{oi} = radius of influence
r_w = well radius
s_n = LNAPL drawdown (ft)
Note: the term $\ln(R_{oi}/r_w)$ can be assumed to be 4.6 (ASTM E2856-13 Section 8.3.1.5)

9.1 References:

ASTM Standard Guide for Estimation of LNAPL Transmissivity ASTM E2856 - 13

Calculations continued on next page.

9.2 Average Transmissivity Calculations for Free Product Recovery Periods

Example Calculation – 4th Free Product Recovery Event (10/17 to 12/18)

$$T_n = \frac{Q_n ln\left(\frac{R_{oi}}{r_w}\right)}{2\pi s_n} = \frac{0.020\left(ft^3/gal\right) * (4.6)}{2\pi * (0.4\,ft)} = 0.04\,ft^2/day$$

Assumptions:

Q_n = the average free product recovery per well over the entire free product recovery event.

Note: Q_n was calculated based on the total cumulative amount of free product recovered during the entire free product recovery event divided by the total duration and the average number of wells in operation during the active free product recovery phase. Please see detailed calculation and table below.

$$Q_n = \frac{LNAPL\ (gal) * 0.13368056\left(ft^3/gal\right)}{t\ (days) * avg.\#\ of\ wells} = \frac{1973\ (gal) * 0.13368056\left(ft^3/gal\right)}{427\ (days) * (30)}$$

$$= 0.020\left(ft^3/day\right)$$

$ln\left(\frac{R_{oi}}{r_w}\right)$= 4.6 (based on ASTM Standard E2856-13 guidance)

s_n = drawdown determined from difference between LNAPL thickness from start of free product recovery period to end. Please see the table include below with the average drawdowns determined for each FP recovery period.

Tabulated Results

LNAPL Recovery Period	Duration (day)	LNAPL recovered (gal)	Wells in operation	Qn (ft^3/day)	s_n	ln(R_{oi}/r_w)	Tn (ft^2/day)
1st (4/07 to 11/08)	568	2,312	18	0.030	0.4	4.6	0.06
2nd (8/09 to 3/11)	568	3,214	21	0.036	1.0	4.6	0.03
3rd (5/12 to 11/13)	539	1,828	21	0.022	0.3	4.6	0.05
4th (10/17 to 12/18)	427	1,937	30	0.020	0.4	4.6	0.04

9.3 Average Transmissivity for Select Wells During December 11, 2018 Recovery Event

Example Calculation - Well GTI-10

$$T_n = \frac{Q_n ln\left(\frac{R_{oi}}{r_w}\right)}{2\pi s_n} = \frac{0.099\left(ft^3/gal\right) * (4.6)}{2\pi * (0.03\ ft)} = 2.426\ ft^2/day$$

Assumptions:

Q_n = the average free product recovery per well over the entire 4th free product recovery event.

Note: Q_n was calculated based on the total cumulative amount of free product recovered for each well during the entire 4th free product recovery event divided by the total duration. Please see detailed calculation and table below.

$$Q_n = \frac{LNAPL\ (gal) * 0.13368056\left(ft^3/gal\right)}{t\ (days)} = \frac{318\ (gal) * 0.13368056\left(ft^3/gal\right)}{427\ (days)}$$

$$= 0.099\left(ft^3/day\right)$$

$ln\left(\frac{R_{oi}}{r_w}\right)$= 4.6 (based on ASTM Standard E2856-13 guidance)

s_n = drawdown determined from difference between LNAPL thickness from start of 4th free product recovery period and average lower thickness observed for each well through December 11, 2018. Please see the table below with the average drawdowns determined for each well during the 4th Free Product Recovery Event.

Tabulated Results

Well	LNAPL Recovery Period	Duration (day)	LNAPL recovered (gal)	Qn (ft^3/day)	s_n	$\ln(R_{oi}/r_w)$	T_n (ft^2/day)
GTI-10	4th (10/17 to 12/18)	427	318	0.099	0.03	4.6	2.426
GTI-11	4th (10/17 to 12/18)	427	50	0.016	0.40	4.6	0.028
GTI-5	4th (10/17 to 12/18)	427	18	0.006	1.11	4.6	0.004
GTI-9	4th (10/17 to 12/18)	427	9	0.003	0.59	4.6	0.004
FF-4	4th (10/17 to 12/18)	427	62	0.020	0.23	4.6	0.062
ITSI-4	4th (10/17 to 12/18)	427	200	0.063	0.31	4.6	0.148
ITSI-5	4th (10/17 to 12/18)	427	113	0.035	0.15	4.6	0.173
RW-3	4th (10/17 to 12/18)	427	123	0.038	0.36	4.6	0.078

APPENDIX D
Risk Calculations

10.0 Appendix D: Risk Calculations

The following calculations were derived from Jacobs (1999) and The Risk Assessment Information System Guidebook (https://rais.ornl.gov/tools/rais_chemical_risk_guide.html).

Equation 1:

$$HQ = \frac{CDI}{RfD}$$

Equation 2:

$$HI_{Total} = \sum HQ$$

Where

HI = Total hazard for a specific exposure pathway
HQ = Hazard quotient for COC
CDI = Chronic daily intake
RfD = Oral reference dose for the toxicant

<u>Calculations for Excavation Workers (Soil; subchronic)</u>

CDI for incidental ingestion of soil (non-carcinogenic; Equation 3):

$$CDI_{ew\text{-}soil\text{-}nc\text{-}ing}\left(mg/kg\text{-}day\right) = \frac{C_{soil}\left(\frac{mg}{kg}\right) \times EF_{ew}\left(\frac{20\ days}{year}\right) \times ED_{ew}\left(1\ year\right) \times IRS_{ew}\left(\frac{330\ mg}{day}\right) \times RBA \times \left(\frac{10^{-6}\ kg}{1\ mg}\right)}{AT_{ew\text{-}a}\left(\frac{365\ days}{year} \times ED_{ew}\left(1\ year\right)\right) \times BW_{ew}\left(80\ kg\right)}$$

CDI for inhalation of particulates emitted from soil (non-carcinogenic; Equation 4):

$$CDI_{ew\text{-}soil\text{-}nc\text{-}inh}\left(mg/m^3\right) = \frac{C_{soil}\left(\frac{mg}{kg}\right) \times EF_{ew}\left(\frac{20\ days}{year}\right) \times ED_{ew}\left(1\ year\right) \times ET_{ew}\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times \left(\frac{1}{VF_s\left(\frac{m^3}{kg}\right)} + \frac{1}{PEF_w\left(\frac{m^3}{kg}\right)}\right)}{AT_{ew\text{-}a}\left(\frac{365\ days}{year} \times ED_{ew}\left(1\ year\right)\right)}$$

Dermal exposure (non-carcinogenic; Equation 5):

$$CDI_{ew\text{-}soil\text{-}nc\text{-}der}\left(mg/kg\text{-}day\right) = \frac{C_{soil}\left(\frac{mg}{kg}\right) \times EF_{ew}\left(\frac{20\ days}{year}\right) \times ED_{ew}\left(1\ year\right) \times SA_{ew}\left(\frac{3{,}527\ cm^2}{day}\right) \times AF_{ew}\left(\frac{0.3\ mg}{cm^2}\right) \times ABS_d \times \left(\frac{10^{-6}\ kg}{1\ mg}\right)}{AT_{ew\text{-}a}\left(\frac{365\ days}{year} \times ED_{ew}\left(1\ year\right)\right) \times BW_{ew}\left(80\ kg\right)}$$

Incidental ingestion of soil (carcinogenic; Equation 6):

$$CDI_{ew\text{-}soil\text{-}ca\text{-}ing}\left(mg/kg\text{-}day\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{ew}\left(\frac{20\ days}{year}\right)\times ED_{ew}\left(1\ year\right)\times IRS_{ew}\left(\frac{330\ mg}{day}\right)\times RBA\times\left(\frac{10^{-6}\ kg}{1\ mg}\right)}{AT_{ew}\left(\frac{365\ days}{year}\times LT\left(70\ years\right)\right)\times BW_{ew}\left(80\ kg\right)}$$

Inhalation of particulates emitted from soil (carcinogenic; Equation 7):

$$CDI_{cw\text{-}sol\text{-}ca\text{-}inh}\left(\mu g/m^3\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{ew}\left(\frac{20\ days}{year}\right)\times ED_{ew}\left(1\ year\right)\times ET_{ew}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times\left(\frac{1}{VF_s\left(\frac{m^3}{kg}\right)}+\frac{1}{PEF_w\left(\frac{m^3}{kg}\right)}\right)}{AT_{ew}\left(\frac{365\ days}{year}\times LT\left(70\ years\right)\right)\times\left(\frac{1\ mg}{1000\ \mu g}\right)}$$

Dermal exposure (carcinogenic; Equation 8):

$$CDI_{ew\text{-}soil\text{-}ca\text{-}der}\left(mg/kg\text{-}day\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{ew}\left(\frac{20\ days}{year}\right)\times ED_{ew}\left(1\ year\right)\times SA_{ew}\left(\frac{3{,}527\ cm^2}{day}\right)\times AF_{ew}\left(\frac{0.3\ mg}{cm^2}\right)\times ABS_d\times\left(\frac{10^{-6}\ kg}{1\ mg}\right)}{AT_{ew}\left(\frac{365\ days}{year}\times LT\left(70\ years\right)\right)\times BW_{ew}\left(80\ kg\right)}$$

References:

Jacobs, B., 1999. *Guidance for Conducting Risk Assessments and Related Risk Activities for the DOE-ORO Environmental Management Program*. BJC/OR-271, Oak Ridge, TN.

The Risk Assessment Information System. https://rais.ornl.gov/tools/rais_chemical_risk_guide.html. Accessed January 28, 2020.

APPENDIX E

Field Reports and Photographs

11.0 Appendix E: Field Reports and Photographs

BROADBENT

DAILY REPORT
Page 1 of 1

Project: NAS Fallon Project No.: 16-02-130
Field Representative(s): Somerholm Day: THURSDAY Date: 1/18/18
Time Onsite: From: 0850 To: 1100 ; From: _____ To: _____; From: _____ To: _____

✓ Signed HASP ✓ Safety Glasses ✓ Hard Hat ✓ Steel Toe Boots ✓ Safety Vest
___ UST Emergency System Shut-off Switches Located ✓ Proper Gloves ___ Drum Count
___ Proper Level of Barricading ___ Other PPE (describe)_____

Weather: Overcast, cool

Equipment In Use: NA

Visitors:

TIME:	WORK DESCRIPTION:
0730	MOB TO NAS Fallon
0850	ARRIVE AT PASS & ID OFFICE TO OBTAIN VISITOR PASS
0900	MEET WITH MIKE ESTEBAN (NAVFAC) and MIKE FITZGIBBONS
	(WINSTICK INSPECTION)
0910	ARRIVE AT WORK SITE. TAILGATE SAFETY BRIEFING,
	SIGN IN, SITE WALK
0930	BEGIN SURVEY OF PROPOSED BORING LOCATIONS
	ALL OK
	unable to locate clearances from ~~[illegible]~~ CC Communications
	cleared by NV ENERGY, SW GAS, Charter Comm - Fallon, &
	Paiute Pipeline
1050	SIGN OUT
1100	OFF SITE

Signature: [signature]

Revision 2013/5/17

BROADBENT

DAILY REPORT

Page ___ of ___

Project: Fallon NAS Site
Project No.: 16-02-130
Field Representative(s): Sonerholm/Yopes
Day: ~~Monday~~ TUESDAY
Date: 1/30/18
Time Onsite: From: 0800 To: ___ ; From: ___ To: ___ ; From: ___ To: ___

___ Signed HASP ___ Safety Glasses ___ Hard Hat ___ Safety Toe Boots ___ Safety Vest
___ UST Emergency System Shut-off Switches Located ___ Proper Gloves ___ Drum Count
___ Proper Level of Barricading ___ Other PPE (describe) ___

Weather: ___
Equipment in Use: ___

Visitors: ___

CALIBRATION LOG

Flow Cell:	Auto Cal.	Temp.:	42.9	°F	Conductivity:	4.60	mS/cm	DO:	13.82	mg/L
		pH:	4.00		ORP:	268	mV	Turbidity:	0.0	NTU
	Drift Check	Temp.:	73.5	°F	Conductivity:	4.32	mS/cm	DO:	6.81	mg/L
		pH:	4.26		ORP:	26	mV	Turbidity:	2.7	NTU

TIME:	WORK DESCRIPTION:
0800	Sign in at security
0815	Stop by environmental department
0825	Sign in at fuel area site 2
0830	Site walk to identify wells
0845	Begin water level measurements
0942	Begin sampling GTI-15
1050	begin sampling GTI-17
1148	Begin sampling GTI-8
1228	Begin sampling RW-5A

Signature: [signature]

Revision: 03/16/2017

BROADBENT

DAILY REPORT

Page 1 of 1

Project: NAS Fallon
Project No.: 16 02-130
Field Representative(s): Somerhalm
Day: WEDNESDAY
Date: 1/31/18
Time Onsite: From: 0930 To: ; From: To: ; From: To:

- [x] Signed HASP
- [x] Safety Glasses
- [x] Hard Hat
- [x] Safety Toe Boots
- [x] Safety Vest
- [ ] UST Emergency System Shut-off Switches Located
- [x] Proper Gloves
- [ ] Drum Count
- [ ] Proper Level of Barricading
- [ ] Other PPE (describe)

Weather: Cool
Equipment in Use: Direct push Geoprobe, PID

Visitors: TRAVIS LEWIS, RICKY BARRAGAN

CALIBRATION LOG

PID: Fresh Air: _____ ppm Span: _____ ppm

TIME:	WORK DESCRIPTION:
0930	ARRIVE AT FALLON NAS PASS & ID OFFICE. MEET W/ TRAVIS LEWIS
	(NAVFAC) AND RICKY BARRAGAN (CASCADE)
0800	TAILGATE MEETING
0825	BEGIN HAND AUGERING NE1
0950	SAMPLE NE-1
1016	Begin Hand Augering NE-2
1055	SAMPLE NE-2
1128	Begin Hand Augering NE-3
1150	SAMPLE NE-3

Signature:

Revision: 03/16/2017

BROADBENT

GROUNDWATER MONITORING SITE SHEET

Page ____ of ____

Project: NAS Fallon Project No.: 16-02-130 Date: 1/30/18

Field Representative: Somerholm / Yupes Elevation: ____

Formation recharge rate is historically: **High** Low *(circle one)*

W. L. Indicator ID #: ____ Oil/Water Interface ID #: ____ *(List #s of all equip used.)*

WELL ID RECORD					WELL GAUGING RECORD					LAB ANALYSES
Well ID	Well Sampling Order	As-Built Well Diameter (inches)	As-Built Well Screen Interval (ft)	Previous Depth to Water (ft)	Time (24:00)	Depth to LNAPL (ft)	Apparent LNAPL Thickness (ft)*	Depth to Water (ft)	Well Total Depth (ft)	
~~FF-2 GT1-2~~ RM 1/30	–	4	–	–	0851	9.20	0.13	9.33	–	
RY 1/30 ~~FF-1~~ FF-1	~~1~~ RM 1/30	4	–	–	0854	–	–	8.92	RY 1/30 9.~~29~~ 9.39	
ITSI-6	–	4	–	–	0859	11.64	0.31	11.95	–	
GT1-9	–	4	–	–	0905	9.80	0.57	10.37	–	
FF-3	4	4	–	–	0917	9.53	0.04	9.57	–	
GT1-5	–	4	–	–	0924	9.47	0.29	9.76	–	
GT1-10	~~2~~ RM 1/30	4	–	–	0925	13.78	0.25	14.03	–	
ITS1-4	–	4	–	–	0930	11.86	0.33	12.19	–	
GT1-15	1 ~~2~~ RM 1/30	4	–	–	0934	–	–	9.35	15.32	
~~ITS1-03~~										
GT1-17	2	4	–		1038	–	–	10.14	15.72	
VT1		2	–		1042	–	–	10.14	12.34	
GT1-8	3	4	–		1147	–	–	9.03	15.32	
RW-58	4	6	–		1226	9.28	sheen	9.28	16.35	

* Device used to measure LNAPL thickness: Bailer Oil/Water Interface Meter *(circle one)*

If bailer used, note bailer dimensions (inches): Entry Diameter ____ Chamber Diameter ____

Signature: ____

Revision: 1/24/2012

BROADBENT

GROUNDWATER SAMPLING DATA SHEET

Page ____ of ____

Project: NAS Fallon | Project No.: 1602-130 | Date: 1/30/18

Field Representative: Aaron Somerlatta / Kyle Yopps | Start Time: 0942 | End Time: 1030

Well ID: GT1 15 | Total Time (minutes): 48

PURGE EQUIPMENT (AMOUNT USED)

15' Disp. Tubing	___ Disp. Bailer	___ 120V Pump	X Flow Cell	Other/ID#:
X Oil/Water Intreface Probe	1 Peristaltic Pump Tubing	X Peristaltic Pump	___ Water Level Indicator	Other/ID#:
	___ 12V Pump	___ Ferrous Iorn Kit	___ Alkalinity Kit	

WELL HEAD INTEGRITY (cap, lock, vault, etc.) Comments:

Good Improvement Needed *(circle one)*

PURGING/SAMPLING METHOD Predetermined Well Volume (Low-Flow) Other: (cirlce one)

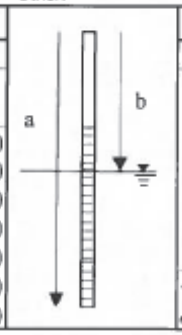
PREDETERMINED WELL VOLUME

Casing Diameter | Unit Volume (gal/ft) *(circle one)*

1" | (0.04) 1.25" | (0.08) 2" | (0.17) 3" | (0.38 Other:

4" | (0.66) 6" | (1.50) 8" | (2.60) 12" | (5.81 __" | (____)

Total Well Depth (a):	____(ft)
Initial Depth to Water (b):	____(ft)
Water Column Height (WCH) = (a - b):	____(ft)
Water Column Volume (WCV) = WCH x Unit Volume:	____(gal)
Three Casing Volumes = WCV x 3:	____(gal)
Five Casing Volumes = WCV x 5:	____(gal)
Pump Depth (if pump used):	____(ft)



LOW-FLOW

Previous Low-Flow Purge Rate:		(gpm)
Total Well Depth (a):	15.32	(ft)
Initial Depth to Water (b):	9.35	(ft)
Pump In-take Depth = b + (a-b)/2:	12.34	(ft)
Maximum Allowable Drawdown = (a-b)/8:	0.75	(ft)
Low-Flow Purge Rate:	0.1	(gpm)*

Comments:

*Low-flow purge rate should be within range of instruments used but should not exceed 0.25 gpm. Drawdown should not exceed Maximum Allowable Drawdown.

GROUNDWATER STABILIZATION PARAMETER RECORD

Time (24:00)	Cumulative Volume (gal)	Temperature (°F)	Δ ±0.36 °F	pH	Δ ±0.1 pH	Conductivity (mS/cm)	%RPD 3%	ORP (mV)	DO (mg/L)	Turbidity (NTU)	TDS (g/L)	Comments
1008	0	56.4	--	7.73	--	6.44	--	-234	2.30	43.2	4.02	
1010	|	61.5	5.1	7.82	0.09	6.21	3.64	-256	1.08	41.8	3.90	
1012	|	64.1	2.6	7.84	0.02	6.12	1.46	-265	1.51	41.7	3.86	
1014	|	64.8	0.7	7.84	0.00	6.11	0.16	-267	1.02	41.0	3.85	
1016	|	65.5	0.7	7.85	0.01	6.10	0.16	-268	1.10	42.2	3.84	
1018	1.25	65.8	0.3	7.85	0.00	6.09	0.16	-268	0.65	41.9	3.83	
Previous Stabilized Parameters			-		-		-					

$$\%RPD = 200X \frac{Read1 - Read2}{Read1 + Read2}$$

PURGE COMPLETION RECORD X Low Flow & Parameters Stable ___ 3 Casing Volumes & Parameters Stable ___ 5 Casing Volumes ___ Other:

SAMPLE COLLECTION RECORD

Depth to Water at Sampling: 11.15 (ft)

Sample Collected Via: ___ Disp. Bailer ___ Dedicated Pump Tubing

X Disp. Pump Tubing Other:

Sample ID: ____ Sample Collection Time: 1020 (24:00)

Containers 2 VOA (X preserved or ___ unpreserved) ___ Liter Amber

2 Other: 500 ml Amber ___ Other: ____

___ Other: ____ ___ Other: ____

GEOCHEMICAL PARAMETERS

Parameter	Time	Measurement
Ferrous Iron (mg/L)		
Alkalinity (mg/L)		
Other:		

REQUESTED ANALYTICAL

BTEX ___ Other: EPH/VPH

MTBE ___ Other:

Signature: [signature]

Revision: 3/16/2017

BROADBENT

GROUNDWATER SAMPLING DATA SHEET

Page ____ of ____

Project: NAS Fallon | Project No.: 14-02-130 | Date: 1/30/18

Field Representative: Somerholm / Yapps | Start Time: 1050 | End Time: 1142

Well ID: GT1-17 | Total Time (minutes): 52

PURGE EQUIPMENT (AMOUNT USED)

	___ Disp. Bailer	___ 120V Pump	X Flow Cell	Other/ID#:
15 Disp. Tubing	Peristaltic Pump 2 Tubing	X Peristaltic Pump	Water Level Indicator	Other/ID#:
X Oil/Water Intreface Probe	___ 12V Pump	___ Ferrous Iorn Kit	___ Alkalinity Kit	

WELL HEAD INTEGRITY (cap, lock, vault, etc.) Comments:

Good Improvement Needed *(circle one)*

PURGING/SAMPLING METHOD Predetermined Well Volume Low-Flow Other: (cirlce one)

PREDETERMINED WELL VOLUME

Casing Diameter | Unit Volume (gal/ft) *(circle one)*

1" | (0.04) 1.25" | (0.08) 2" | (0.17) 3" | (0.38 Other:

4" | (0.66) 6" | (1.50) 8" | (2.60) 12" | (5.81 __" | (____)

Total Well Depth (a): ____ (ft)

Initial Depth to Water (b): ____ (ft)

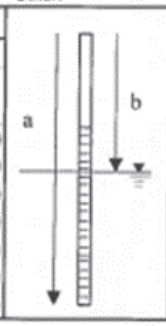
Water Column Height (WCH) = (a - b): ____ (ft)

Water Column Volume (WCV) = WCH x Unit Volume: ____ (gal)

Three Casing Volumes = WCV x 3: ____ (gal)

Five Casing Volumes = WCV x 5: ____ (gal)

Pump Depth (if pump used): ____ (ft)



LOW-FLOW

Previous Low-Flow Purge Rate: (gpm)

Total Well Depth (a): 15.72 (ft)

Initial Depth to Water (b): 10.14 (ft)

Pump In-take Depth = b + (a-b)/2: 12.93 (ft)

Maximum Allowable Drawdown = (a-b)/8: 0.70 (ft)

Low-Flow Purge Rate: 0.08 (gpm)*

Comments:

*Low flow purge rate should be within range of instruments used but should not exceed 0.25 gpm. Drawdown should not exceed Maximum Allowable Drawdown.

GROUNDWATER STABILIZATION PARAMETER RECORD

Time (24:00)	Cumulative Volume (gal)	Temperature (°F)	Δ ±0.36 °F	pH	Δ ±0.1 pH	Conductivity (mS/cm)	%RPD 3%	ORP (mV)	DO (mg/L)	Turbidity (NTU)	Comments
1101	0	63.0	--	7.98	--	22.3	--	-380	0.48	34.1	
1103		63.8	0.8	7.97	0.01	22.8	2.22	-393	0.00	30.1	
1105		63.9	0.1	7.97	0.00	28.0	20.47	-401	0.37	30.1	
1107		64.0	0.1	7.96	0.01	22.8	20.47	-399	0.00	31.3	
1109		64.0	0.0	7.95	0.01	22.2	2.67	-398	0.00	36.5	
1111		64.0	0.0	7.93	0.02	21.1	5.08	-397	0.00	37.6	
1113		63.9	0.1	7.90	0.03	19.6	7.37	-396	0.00	38.6	
1115		63.8	0.1	7.88	0.02	18.8	4.17	-395	0.00	38.5	
1117		63.7	0.1	7.87	0.01	18.1	3.79	-395	0.44	37.4	
1119		63.7	0.0	7.87	0.00	17.7	2.23	-397	0.72	36.4	
1121		63.7	0.0	7.86	0.01	17.6	0.57	-394	0.00	35.9	
1123	1.75	63.7	0.0	7.86	0.00	17.5	0.57	-394	0.02	35.8	
Previous Stabilized Parameters											

$$\%RPD = 200X \frac{Read1 - Read2}{Read1 + Read2}$$

PURGE COMPLETION RECORD X Low Flow & Parameters Stable ___ 3 Casing Volumes & Parameters Stable ___ 5 Casing Volumes

Other:

SAMPLE COLLECTION RECORD

Depth to Water at Sampling: 13.44 (ft)

Sample Collected Via: ___ Disp. Bailer ___ Dedicated Pump Tubing

X Disp. Pump Tubing Other:

Sample ID: S2-GT1-17-0118/FD Sample Collection Time: 1123 (24:00)

Containers ___ VOA (___ preserved or ___ unpreserved) ___ Liter Amber

___ Other: ___ Other: ___

___ Other: ___ Other: ___

GEOCHEMICAL PARAMETERS

Parameter	Time	Measurement
Ferrous Iron (mg/L)		
Alkalinity (mg/L)		
Other:		

REQUESTED ANALYTICAL

BTEX ___ Other:

MTBE ___ Other:

Signature:

Revision: 3/16/2017

BROADBENT

GROUNDWATER SAMPLING DATA SHEET

Page ____ of ____

Project: | Project No.: 14-02-150 | Date: 1/30/18

Field Representative: Somerholm / Yopps | Start Time: 1150 | End Time: 1220

Well ID: GT1-8 | Total Time (minutes): ____

PURGE EQUIPMENT (AMOUNT USED)

	___ Disp. Bailer	___ 120V Pump	X Flow Cell	Other/ID#: ____
15 Disp. Tubing	Peristaltic Pump 2 Tubing	X Peristaltic Pump	___ Water Level Indicator	Other/ID#: ____
X Oil/Water Intreface Probe	___ 12V Pump	___ Ferrous Iorn Kit	___ Alkalinity Kit	

WELL HEAD INTEGRITY (cap, lock, vault, etc.) Comments: ____

Good Improvement Needed *(circle one)*

PURGING/SAMPLING METHOD Predetermined Well Volume Low-Flow Other: (cirlce one)

PREDETERMINED WELL VOLUME

Casing Diameter | Unit Volume (gal/ft) *(circle one)*

1" | (0.04) 1.25" | (0.08) 2" | (0.17) 3" | (0.38 Other:

4" | (0.66) 6" | (1.50) 8" | (2.60) 12" | (5.81 __" | (____)

Total Well Depth (a): ____ (ft)

Initial Depth to Water (b): ____ (ft)

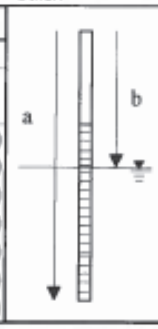
Water Column Height (WCH) = (a - b): ____ (ft)

Water Column Volume (WCV) = WCH x Unit Volume: ____ (gal)

Three Casing Volumes = WCV x 3: ____ (gal)

Five Casing Volumes = WCV x 5: ____ (gal)

Pump Depth (if pump used): ____ (ft)



LOW-FLOW

Previous Low-Flow Purge Rate: ____ (gpm)

Total Well Depth (a): 15.32 (ft)

Initial Depth to Water (b): 9.03 (ft)

Pump In-take Depth = b + (a-b)/2: 12.18 (ft)

Maximum Allowable Drawdown = (a-b)/8: 0.79 (ft)

Low-Flow Purge Rate: 0.1 (gpm)*

Comments: ____

*Low-flow purge rate should be within range of instruments used but should not exceed 0.25 gpm. Drawdown should not exceed Maximum Allowable Drawdown.

GROUNDWATER STABILIZATION PARAMETER RECORD

Time (24:00)	Cumulative Volume (gal)	Temperature (°F)	Δ ±0.36 °F	pH	Δ ±0.1 pH	Conductivity (mS/cm)	%RPD 3%	ORP (mV)	DO (mg/L)	Turbidity (NTU)	TDS (g/L)	Comments
1200	0	67.7	--	7.84	--	3.69	--	298	0.76	114	2.31	sheen on
1202	|	68.9	1.2	7.77	0.07	3.53	4.13	-301	0.20	85.8	2.25	purged
1204	|	69.1	0.2	7.72	0.05	3.48	1.43	-302	0.00	86.6	2.22	water
1206	|	68.9	0.2	7.70	0.02	3.45	0.87	-301	0.00	88.2	2.20	
1208	1.0	68.9	0.0	7.68	0.02	3.44	0.29	-300	0.00	80.8	2.20	
Previous Stabilized Parameters			-		-		-					

$$\%RPD = 200X \frac{Read1 - Read2}{Read1 + Read2}$$

PURGE COMPLETION RECORD X Low Flow & Parameters Stable ___ 3 Casing Volumes & Parameters Stable ___ 5 Casing Volumes ___ Other:

SAMPLE COLLECTION RECORD

Depth to Water at Sampling: 10.08 (ft)

Sample Collected Via: ___ Disp. Bailer ___ Dedicated Pump Tubing

X Disp. Pump Tubing Other:

Sample ID: S2-GTES-0118 Sample Collection Time: 1210 (24:00)

Containers 2 VOA (X preserved or ___ unpreserved) ___ Liter Amber

2 Other: 500 mL Amber ___ Other: ____

___ Other: ____ ___ Other: ____

GEOCHEMICAL PARAMETERS

Parameter	Time	Measurement
Ferrous Iron (mg/L)		
Alkalinity (mg/L)		
Other:		

REQUESTED ANALYTICAL

BTEX ___ Other: EPH/VPH

MTBE ___ Other:

Signature: [signature]

Revision: 3/16/2017

BROADBENT

GROUNDWATER SAMPLING DATA SHEET

Page ____ of ____

Project: NAS Fallon | Project No.: 16-02-130 | Date: 1/30/18

Field Representative: Somerholm / Hopps | Start Time: 1231 | End Time: 1300

Well ID: RW 5A | Total Time (minutes): 29

PURGE EQUIPMENT (AMOUNT USED)

(5 Disp. Tubing | ___ Disp. Bailer | ___ 120V Pump | 1 Flow Cell | Other/ID#:

2 Peristaltic Pump Tubing | 1 Peristaltic Pump | ___ Water Level Indicator | Other/ID#:

1 Oil/Water Intreface Probe | ___ 12V Pump | ___ Ferrous Iorn Kit | ___ Alkalinity Kit

WELL HEAD INTEGRITY (cap, lock, vault, etc.) Comments:

Good Improvement Needed *(circle one)*

PURGING/SAMPLING METHOD Predetermined Well Volume Low-Flow Other: (cirlce one)

PREDETERMINED WELL VOLUME

Casing Diameter | Unit Volume (gal/ft) *(circle one)*

1" | (0.04) 1.25" | (0.08) 2" | (0.17) 3" | (0.38 Other:

4" | (0.66) 6" | (1.50) 8" | (2.60) 12" | (5.81 __" | (____)

Total Well Depth (a): ____(ft)

Initial Depth to Water (b): ____(ft)

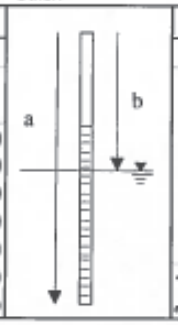
Water Column Height (WCH) = (a - b): ____(ft)

Water Column Volume (WCV) = WCH x Unit Volume: ____(gal)

Three Casing Volumes = WCV x 3: ____(gal)

Five Casing Volumes = WCV x 5: ____(gal)

Pump Depth (if pump used): ____(ft)



LOW-FLOW

Previous Low-Flow Purge Rate: (gpm)

Total Well Depth (a): 16.35 (ft)

Initial Depth to Water (b): 9.28 (ft)

Pump In-take Depth = b + (a-b)/2: 12.81 (ft)

Maximum Allowable Drawdown = (a-b)/8: 0.88 (ft)

Low-Flow Purge Rate: 0.07 (gpm)*

Comments:

*Low-flow purge rate should be within range of instruments used but should not exceed 0.25 gpm. Drawdown should not exceed Maximum Allowable Drawdown.

GROUNDWATER STABILIZATION PARAMETER RECORD

Time (24:00)	Cumulative Volume (gal)	Temperature (°F)	Δ ±0.36 °F	pH	Δ ±0.1 pH	Conductivity (mS/cm)	%RPD 3%	ORP (mV)	DO (mg/L)	Turbidity (NTU)	Comments
1239	0	69.3	--	8.12	--	17.8	--	-375	0.25	63.6	
1241		69.5	0.2	8.16	0.04	17.9	0.56	-389	0.00	63.9	
1243		69.2	0.3	8.18	0.02	18.0	0.56	-400	0.00	62.4	
1245		67.9	1.3	8.20	0.02	18.3	1.65	-403	0.00	58.0	
1247		67.2	0.7	8.21	0.01	18.4	0.54	-407	0.00	59.6	
1249		67.8	0.6	8.21	0.00	18.3	0.54	-409	0.00	56.6	
1251		67.8	0.0	8.22	0.01	18.3	0	-407	0.00	57.3	
1253	1.0	67.6	0.2	8.21	0.01	18.4	0.54	-405	0.00	54.7	
Previous Stabilized Parameters											

$$\%RPD = 200X\frac{Read1 - Read2}{Read1 + Read2}$$

PURGE COMPLETION RECORD X Low Flow & Parameters Stable ___ 3 Casing Volumes & Parameters Stable ___ 5 Casing Volumes ___ Other:

SAMPLE COLLECTION RECORD

Depth to Water at Sampling: 9.88 (ft)

Sample Collected Via: ___ Disp. Bailer ___ Dedicated Pump Tubing

X Disp. Pump Tubing Other:

Sample ID: ____ Sample Collection Time: 1253 (24:00)

Containers 2 VOA (2 preserved or ___ unpreserved) ___ Liter Amber

2 Other: 500mL Amber ___ Other: ____

___ Other: ____ ___ Other: ____

GEOCHEMICAL PARAMETERS

Parameter	Time	Measurement
Ferrous Iron (mg/L)		
Alkalinity (mg/L)		
Other:		

REQUESTED ANALYTICAL

BTEX ___ Other: ____

MTBE ___ Other: ____

Signature: [signature]

Revision: 3/16/2017

BROADBENT & ASSOCIATES, INC.
ENGINEERING, WATER RESOURCES & ENVIRONMENTAL

LITHOLOGIC AND MONITOR WELL CONSTRUCTION LOG

PROJECT NAME: NAS FALLON
SITE ADDRESS:
PROJECT NUMBER: 16-02-130
DIAMETER: SCREEN SLOT SIZE: SAND SIZE:
LOGGED BY: SONERHOLM
DATE: 1/31/18 START: 1128 DRILLING COMPANY: CASCADE DRILLER: BARRAGAN
WELLID: NE-3 STOP: 1155 DRILLING METHOD: DIRECT PUSH SAMPLE METHOD:

DEPTH (FEET)	MONITOR WELL CONSTRUCTION DIAMETER:	SAMPLE ID	PID	MOISTURE	COLOR	CONSISTENCY	GRAIN SIZE	CLASSIFICATION	REMARKS & ODORS
0.25							SANDY GRAVEL		
1					Lt Brown		Silty Sand	SM	
4.2							clay	CL	
6.2							Silty Sand	SM	
7.1									
7.7					Gray		Clay	CL	
							Silty Sand	SM	
8.8									
			284				Poorly Graded Sand	SP	

TOTAL BORING DEPTH: 10 PAGE NO: 1 OF 1 ESTIMATED GROUND WATER DEPTH:

THIS SUMMARY APPLIES ONLY AT THIS LOCATION AND AT THE TIME OF LOGGING. SUBSURFACE CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH THE PASSAGE OF TIME. THE DATA PRESENTED IS A SIMPLIFICATION OF ACTUAL CONDITIONS ENCOUNTERED.

BROADBENT & ASSOCIATES, INC.
ENGINEERING, WATER RESOURCES & ENVIRONMENTAL

LITHOLOGIC AND MONITOR WELL CONSTRUCTION LOG

PROJECT NAME: NAS Fallon
SITE ADDRESS:
PROJECT NUMBER: 16-02-130
DIAMETER: SCREEN SLOT SIZE: SAND SIZE:
LOGGED BY: Sonecholm
DATE: 1/31/18 START: 1016 DRILLING COMPANY: CASCADE DRILLER: BARRAGAN
WELLID: NE-2 STOP: 1050 DRILLING METHOD: DIRECT PUSH SAMPLE METHOD:

DEPTH (FEET)	MONITOR WELL CONSTRUCTION DIAMETER:	SAMPLE ID	PID	MOISTURE	COLOR	CONSISTENCY	GRAIN SIZE	CLASSIFICATION	REMARKS & ODORS
0.25							Sandy Gravel (Road Base)		
					Lt Brown		Silty Sand	SM	
4.0									
					Dk Brown		Clay	CL	
5.0									
					Lt Brown		Silty Sand	SM	
7.7					Dk Brown		Clay	CL	
7.8					Gray		Silty Sand	SM	
8.7							Clay	OC	
9.0			274				Poorly Graded Sand	SP	

TOTAL BORING DEPTH: 10 PAGE NO: 1 OF 1 ESTIMATED GROUND WATER DEPTH:

THIS SUMMARY APPLIES ONLY AT THIS LOCATION AND AT THE TIME OF LOGGING. SUBSURFACE CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH THE PASSAGE OF TIME. THE DATA PRESENTED IS A SIMPLIFICATION OF ACTUAL CONDITIONS ENCOUNTERED.

BROADBENT & ASSOCIATES, INC.
ENGINEERING, WATER RESOURCES & ENVIRONMENTAL

LITHOLOGIC AND MONITOR WELL CONSTRUCTION LOG

PROJECT NAME: NAS FALLON
SITE ADDRESS:
PROJECT NUMBER: 16-02-130
DIAMETER: ____ SCREEN SLOT SIZE: ____ SAND SIZE: ____
LOGGED BY: Sorenholm
DATE: 1/31/18 START: 0825 DRILLING COMPANY: CASCADE DRILLER: BARRAGAN
WELLID: NE-1 STOP: 0920 DRILLING METHOD: DIRECT PUSH SAMPLE METHOD: ____

DEPTH (FEET)	MONITOR WELL CONSTRUCTION DIAMETER: ____	SAMPLE ID	PID	MOISTURE	COLOR	CONSISTENCY	GRAIN SIZE	CLASSIFICATION	REMARKS & COORS
0.25							GRAVELLY SAND (ROAD BASE)		
					Lt Brown				
								SM	
							Silty Sand		
6.3									
6.4					DK BRO		Clayey Sand	SC	
6.7							Poorly Graded Sand	SP	
					Lt Brown		Silty Sand	SM	
8.0								CH	
			37.4		BLACK				
8.7									
			114		DK Gray		Silty Sand	SM	

TOTAL BORING DEPTH: 10' PAGE NO: 1 OF 1 ESTIMATED GROUND WATER DEPTH: ____

THIS SUMMARY APPLIES ONLY AT THIS LOCATION AND AT THE TIME OF LOGGING. SUBSURFACE CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH THE PASSAGE OF TIME. THE DATA PRESENTED IS A SIMPLIFICATION OF ACTUAL CONDITIONS ENCOUNTERED.

Chain of Custody Record & Laboratory Analysis Request

ARI Assigned Number:	Turn-around Requested:
ARI Client Company:	Phone:
Client Contact: SAME	
Client Project Name:	
Client Project #:	Samplers:

Date: 1/31/18
Page: 2 of 2
No. of Coolers: 2 Cooler Temps:

Analytical Resources, Incorporated
Analytical Chemists and Consultants
4611 South 134th Place, Suite 100
Tukwila, WA 98168
206-695-6200 206-695-6201 (fax)

Sample ID	Date	Time	Matrix	No. Containers	EPH	VPH							Notes/Comments
S2GTI150118	1/30/18	10:20	AQ	4	X	X							
S2GTI170118-FD	1/30/18	11:23	AQ	4	X	X							
S2GTI17-0118	1/30/18	11:23	AQ	4	X	X							
S2GTI80118-FB	1/30/18	12:05	AQ	4	X	X							
S2GTI80118	1/30/18	12:10	AQ	4	X	X							LCSD/MS-MSD
S2RW5A0118	1/30/18	12:54	AQ	4	X	X							
S2RW5A0118-EQ	1/30/18	13:10	AQ	4	X	X							
TRIP BLANK					X	X							

Analysis Requested

Comments/Special Instructions	Relinquished by: (Signature)	Received by: (Signature)	Relinquished by: (Signature)	Received by: (Signature)
	Printed Name: R. Kevin Sonderbaker	Printed Name:	Printed Name:	Printed Name:
	Company: Broadbent	Company:	Company:	Company:
	Date & Time: 1/31/18 17:30	Date & Time:	Date & Time:	Date & Time:

Limits of Liability: ARI will perform all requested services in accordance with appropriate methodology following ARI Standard Operating Procedures and the ARI Quality Assurance Program. This program meets standards for the industry. The total liability of ARI, its officers, agents, employees, or successors, arising out of or in connection with the requested services, shall not exceed the invoiced amount for said services. The acceptance by the client of a proposal for services by ARI release ARI from any liability in excess thereof, not withstanding any provision to the contrary in any contract, purchase order or co-signed agreement between ARI and the Client.

Sample Retention Policy: Unless specified by workorder or contract, all water/soil samples submitted to ARI will be discarded or returned, no sooner than 90 days after receipt or 60 days after submission of hardcopy data, whichever is longer. Sediment samples submitted under PSDDA/PSEP/SMS protocol will be stored frozen for up to one year and then discarded.

Chain of Custody Record & Laboratory Analysis Request

ARI Assigned Number:	
Turn-around Requested:	Standard
ARI Client Company:	Broadbent & Associates
Phone:	775-322-7969
Client Contact:	Bryan Vetrano
Client Project Name:	NAS Fallon
Client Project #:	16-02-130
Samplers:	Aaron Sonerholm
Date:	1/31/18
Page:	1 of 1
No. of Coolers:	
Cooler Temps:	

Analytical Resources, Incorporated
Analytical Chemists and Consultants
4611 South 134th Place, Suite 100
Tukwila, WA 98168
206-695-6200 206-695-6201 (fax)

Sample ID	Date	Time	Matrix	No Containers	EPH	VPH	8260 full range TPH	TCLP rcra 8 metals	pH				Notes/Comments
S2NE10118-8	1/31/18	09:50	soil	3	x	x							
S2NE10118-10	1/31/18	09:55	soil	3	x	x							
S2NE20118-9	1/31/18	10:55	soil	3	x	x							
S2NE20118-10	1/31/18	11:00	soil	3	x	x							
S2NE30118-9	1/31/18	11:50	soil	3	x	x							ms/msd
S2NE30118-10	1/31/18	11:55	soil	3	x	x							
S2NE30118-10-FD	1/31/18	12:00	soil	3	x	x							
S2NE30118-EQ	1/31/18	11:15	AQ	4	x	x							
S2NECOMP0118-WC	1/31/18	11:20	soil	1			x	x	x				waste characterizatio

Comments/Special Instructions	Relinquished by: (Signature)	Received by: (Signature)	Relinquished by: (Signature)	Received by: (Signature)
	Printed Name: Aaron Sonerholm	Printed Name:	Printed Name:	Printed Name:
	Company: Broadbent	Company:	Company:	Company:
	Date & Time: 1/31/18 17:30	Date & Time:	Date & Time:	Date & Time:

Limits of Liability: ARI will perform all requested services in accordance with appropriate methodology following ARI Standard Operating Procedures and the ARI Quality Assurance Program. This program meets standards for the industry. The total liability of ARI, its officers, agents, employees, or successors, arising out of or in connection with the requested services, shall not exceed the invoiced amount for said services. The acceptance by the client of a proposal for services by ARI release ARI from any liability in excess thereof, not withstanding any provision to the contrary in any contract, purchase order or co-signed agreement between ARI and the Client.

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NAVFAC

Field Notes

Project:	Weather: Partially cloudy
Date: 1/31/2018	Temperature: 20-30
Location: Site 2, NAS Fallon	Precipitation: 0"
Summary of Field Activities: 3 soil samples above	Wind: 0-2 mph
the water table ~8-9 ft	Humidity: Low
Field Personnel: Travis Lewis (Navy)	

Time In/Out:	Name:	Company/Affiliation:
7:30	Ricky Barrington	CDLP
0730	Aaron Sonnenberg	Broadbent

Samples Collected:

Field Notes: 0735 - Arrive on site
0740 - setup drilling equipment
0800 - Tailgate discuss hazards w/ drilling equipment
↳ discussed hazards w/ handling soil core samples
0815 - staging cones around rig & wheel locks on truck
0825 - Begin taking 5 ft handauger @ NE1
UTM (0351835 / 4365872) NOTE: No product observed in 0-5 ft
0850 - Hallow step auger to 10 ft
* Product observed 7-10 ft (strong odor & staining)
* PID reading: ~~[illegible] ppm~~ ~~4.7 ppm~~ 37.4 ppm - 114 ppm
0900 - Collected soil @ 8ft-8.7ft (1 5gal) - Fat clay
9ft-10 ft (1 5gal) - silty clay
* start seeing product at 7.5 ft
1000 - Collect syring sample (5 grams) placed in 50 mL sample vial w/ methanol. Collected soil samples @ 8-8.7 ft & 9-10 ft (2 vials)
1015 - Moved drill rig to NE-2
* Grouted entire hole with cement.
* Took PID reading @ end of the sampling (114 ppm)
↳ better issues w/ PID prevented us from taking an immediate reading

Page ___ of ___

Completed by: _____

Field Notes

Project:	ESTCP Carbon Trap NAS Fallon
Date:	01-31-18
Location:	Site 2, NAS Fallon

Field Notes Continued:

1015 - Begin handaugering at NE-2
↳ plastic sheeting was laided down to collect soil sample 0-5 ft. looking for presence of product.
1035 - Finished hand augering NE2 to a depth of 5 ft
↳ No product observed in soil samples
1045 - Begin hallow stem auger sample to 5-10 ft

NOTE: UTM NE2 (0351896, 4365900)

1050 - Extracted sample 5-10 ft (strong odor & staining)
PID = 274 ppm
* Wet soil observed @ end of PID
1055 - collected soil samples for jars @ 9 - 9.5 ft and 9.5 - 10 ft.
- Used syring samplers to collect soil samples (5g) @ 9-9.5 ft & 9.5-10 ft. Then placed in a jar w/ methanol.
1100: Grouting entire 10 ft hole with cement
1110: Decon equipment with Alconox
1115: Mobilizing to NE3 → UTM (0351895, 4365881)
1130: Begin hand augering hole to 5 ft @ NE3
↳ hit clay @ 4 ft
1140: Begin hallow stem auger to 10 ft
1150: Extract sample, strong odor & distinct product evident from 6.75 ft to 10 ft.
- PID reading: 284 ppm
1200: Decon equipment
1300: Equipment blank in 3 voa vials & 2 liter amber bottle
1305: collected a waste characterization sample (7.5 gal)
1310: left site, collected base pass from Cascade drilling

Page 2 of 2

Completed By: Travis Lewis

GTI-9 (0351850 / 4365883)

Depth to Product 9.8 ft
Depth to water 10.27 ft
LNAPL Thickness 0.47 ft

FF3 (0351868 / 4365881)

Depth to Product 9.53 ft
Depth to water 9.57 ft
LNAPL Thickness 0.04 ft (good-Sheen)

GTI-5 (0351862 / 4365858)

Depth to product 9.47 ft
Depth to water 9.76 ft
LNAPL Thickness (.29 ft) (~~good~~ too much product)

GTI-10 (0351889 / 4365865)

Depth to product 13.78 ft
Depth to water 14.03 ft
LNAPL Product 0.25 ft

ITSI-4 (0351927 / 4365887)

Product to LNAPL
Product to water 11.86 ft
LNAPL Thickness 12.19 ft

GTI-15 (0351964 / 4365878)

Depth to water : 9.35 ft
Depth to base : 15.32 ft

Purge Low Flow (Time 10:08)
- Taking 3 continuous measurements prior to collection of sample
- pH, Temp, ORP, TDS, DO, EC Turbidity

GTI-15 Sample collection (10:20)
(2) 500 mL amber bottle
(2) VOA samples

GTI-17 (0351996 / 4365883)

Depth to water 10.14
Total depth 15.72

GTI-34 (smell strong product)

VT-1 (0351993 / 4365866)

Depth water 10.14 ft
Depth to base 12.34 ft

RW-5A purge begin 12:35
(2) 500 mL
(2) VOA VIAS
Time 13:00
Took 1 equipment blank of tubing
Run DI water through teflon tubing to
(2) 500 mL bottles ~~VOA VIAL~~ using parastatic pump

Equipment decon 13:10

Horiba meter (U52)
Barnat portable sampler peristaltic pump

NAVFAC

Field Notes

Project:		Weather: Sunny
Date: 01/30/18 0830		Temperature: 40-50°F
Location: Site 2		Precipitation: 0"
Summary of Field Activities: Gauging wells & using a peristaltic pump to collect GW		Wind: 0-5 mph
		Humidity:
Field Personnel:		
Time In/Out:	Name:	Company/Affiliation:
0800	P. Aaron Somerholter Kyle Yopps	Broadbent & Associates Broadbent & Associates
Samples Collected:	GW - Looking for No product in well	

Field Notes: 0830 - Tailgate meet to discuss safety concerns in handling GW samples due to presence of LNAPL.
0845 - Located all proposed GW sampling wells
0850 - setup equipment for GW gauging & sampling

FF2 UTM (0351870, 4365866)
- Depth to Product ~~9.77~~ 9.20 ft
- Depth to water 9.33 ft
- LNAPL Thickness 0.13 ft (Too much product)

FF1 UTM (0351875, 4365861)
- Depth to ~~product~~ water 8.92 ft
- Depth to ~~water~~ bottom of well. 9.39 ft (Not much water)

ITS1-6 (0351931, 4365901)
- Depth to ~~water~~ product 11.64
- Depth to water 11.95
- LNAPL Thickness 0.39 ft

Page ___ of ___

Completed By: _____

Field Notes

Project:	
Date:	01-30-18
Location:	SAP Site 2

Field Notes Continued:

GTI-17 Low Flow Purge (10:50)
Purge 7 Qt till stable values

Sample Time (11:23)

(2) 500 mL bottle
(2) VOA Vials

*Collected Duplicate @ GTI-17
Final depth to water: 10.44 ft
Purge: 1.75 ft

NOTE: When gauging well some product was noted in the noise emanating from the gauge. Possible that some product seeped into well during purge.

GTI-8 (0351811 / 4365913) Time: 11:45

Depth to water 9.03
Total depth 15.32

Purge well to stabilize (noon)

*Collected 7 field blank @ 12:15
*Sheen observed on water sample.

RW-5A (0351812 / 4365853)

Depth to ~~product~~ water: 9.28 ft (little sheen observed)
Total depth: 16.35
water thickness: 7.13

Page ___ of ___

Completed By: _____

Field Notes

Project:		Weather: Sunny
Date: 01/30/2018		Temperature: 50
Location: Tank Farm Site 2, NAS Fallon		Precipitation: None
Summary of Field Activities: Gauging wells and collecting groundwater samples from wells without product.		Wind: 0 -5 mph Humidity: low
Field Personnel: Travis Lewis (NAVFAC EXWC)		
Time In/Out:	Name:	Company/Affiliation:
0800/13:45	Aaron Sonerholm Ryle Yopps	Broadbent & Associates
Samples Collected:	Groundwater without product	

Field Notes:
0830: Tailgate meeting to disucss safety concerns with handling groundwater samples and acid
Preservatives in sample vials.
0845: Located all proposed GW sampling wells
0850: Setup equipment for GW gauging and decon.
0855: Gauge FF2; Depth to product: 9.20 ft; Depth to water: 9.33ft; Product thickness: 0.13 ft
* Too much product at FF2
0905: Gauge FF1; Depth to water: 8.92 ft; Total Depth: 9.39 ft; Water thickness: 0.47 ft
* Not enough water for sample collection
0915: Gauge ITSI-6; Depth to product: 11.64; Depth to water: 11.95; Product thickness: 0.31 ft
* Too much product at ITSI-6
0925: Gauge GTI-9; Depth to product: 9.8 ft; depth to water: 10.27 ft; Product thickness: 0.47 ft
* Too much product at GTI-9
* Per correspondence with Jennifer Segura a new set of groundwater wells were proposed for gauging.
0935: Gauge FF-3; Depth to product: 9.53 ft; depth to water: 9.57 ft; Product thickness: 0.04 ft
* Some product in well but it would require a bailer to extract prior to sampling. We did not
have a bailer on-site.
0940: Gauge GTI-5; Depth to product: 9.47 ft; depth to water: 9.76 ft; Product thickness: 0.29 ft
* Too much product at GTI-5
0945: Gauge GTI-10; Depth to product: 13.78 ft; depth to water: 14.03 ft; Product thickness: 0.25 ft
* Too much product at GTI-10
0950: Gauge ITSI-4; Depth to product: 11.86 ft; depth to water: 12.19 ft; Product thickness: 0.23 ft
* Too much product at ITSI-4
1000: Gauge GTI-15; Depth to water: 9.35 ft; Total Depth of well: 15.32 ft; Water Thickness: 5.97 ft
* GTI-15 was selected for sampling

Field Notes

Project:
Date: 01.30.2018
Location: Tank Farm Site 2; NAS Fallon

Field Notes Continued:
GTI-15: UTM (0351964; 4365878)
Low flow purge using HARIBA Meter (U52) and Barnat Portable Sampler (parastatic pump)
1010: Purge initiated till 3 consecutive readings showed stable parameters for: pH, temperature,
ORP, TDS, DO, EC, and turbidity
* 1.5 ft drawdown from purging well
10:20: Groundwater samples collected from GTI-15 using (2) 500 ml amber bottles (no preservative), and
(2) 50 ml VOA vials (with acid preservative)
10:35: Gauge GTI-17; Depth to water: 10.14 ft; Total depth of well: 15.72 ft; Water thickness: 5.58 ft
* Good candidate well selected for sampling
1045: GTI-34 had very strong odor (same as ITSI-4)
1046: Gauge VT-1; Depth to water 10.14 ft; Total depth of well: 12.34 ft; Water thickness: 2.2 ft
* Good candidate well for sampling
1050: Collect groundwater from GTI-17: UTM (0351996; 4365883)
Low flow purge of GTI-17 till 3 consecutive readings showed stable parameters
* 7 quarts of water had to be purged to achieve stable parameters (drawdown 1.75 ft)
1120: Collected groundwater samples from GTI-17 in (2) 500 ml amber bottles (no preservative), and
(2) 50 ml VOA vials (with acid preservative)
* Duplicate samples were taken at GTI-17 using (2) 500 ml amber bottles and (2) 50 ml VOA vials
NOTE: When gauging GTI-17 after collecting groundwater sample some product was noted by the noise
emanating from the gauge. It is possible that product may have been drawn into well during purge.
* Per correspondence with Jennifer Segura a new set of groundwater wells were proposed for gauging.
1145: Gauge GTI-8; Depth to water: 9.03 ft; Total depth: 15.32 ft; Water thickness: 6.29 ft
* Well was selected for groundwater sampling
* GTI-8 sample location UTMS (0351811; 4365913)
1200: Low flow purge till parameters stabilized
1215: Groundwater samples collected along with 1 field blank.
* Sheen was observed in groundwater well.
1230: Gauge RW-5A; Depth to water: 9.28 ft; Total Depth of well: 16.35 ft; Water thickness: 7.13 ft
* Little sheen was observed in well; however location was selected for groundwater sampling
1235: Purge well RW-5A till groundwater parameters stabilized.
1245: Collected groundwater samples using (2) 500 ml amber bottles and (2) VOA vials
* 1250: One equipment blank was collected by running DI water through the Teflon tubing (2) 500 ml
amber bottles.
1310: Equipment decontamination and purge water consolidation.
1345: Dropped off a 5-gallon bucket of purge water at the storage shed located on site. Permission to
Leave purge water bucket (sealed and labeled) by Steve Bonaker.

Page ___ of ___

Completed By: _____

Naval Air Station Fallon Nevada Photography Pass for Official and Unofficial Photography

NAS FALLON NEVADA

Unofficial Photography -- Photography for personal purposes not for publication

Per NASINST 5512.M unofficial photography is allowed with the consent of the Commanding Officer in non-restricted areas. Personnel wishing to take photographs must be briefed on prohibited restricted and non-restricted areas and acknowledge such briefing by signing below.

Prohibited - No photography is allowed
*Electronic Warfare Range
*Communication spaces and cryptographic equipment
*Ground electronics transmitter and receiver sites
*Aircraft interiors and / or open panels

Restricted - Photography allowed with specific permission from the division or department head responsible for the particular area. Coordination with visiting squadron duty officer is required for photographing air wing aircraft. A physical escort from the responsible command is required for photography in restricted areas.
*All areas and buildings within the fenced flight line, bombing ranges, liquid oxygen plant, ground electronics, fuel farm, tower cab and TRACON facility, Naval Strike and Air Warfare headquarters and Fleet training buildings (inside), weapons compound and magazine, armory and EOD building #424
*Any physical security facilities, procedures or personnel

Non-restricted -- All other areas not specified as prohibited or restricted are open for photography

Official Photography -- Photography by DoD personnel in direct mission support

Official photography may be conducted by DoD personnel but must remain within the confines of supporting their specific mission. All requirements pertaining to restricted photography apply to official photographers.

Media -- All personnel working for a media outlet or photography which will be given or sold to an accredited media outlet

All accredited media, or persons photographing with intent of distribution to a media outlet will be escorted by a representative from the Public Affairs Office.

Applicant's Name [redacted] ID# [redacted]

PAO Representative [redacted] Date ~~02/01/2018~~ 01-30-18

Photo pass active dates: 01-30-18 thru 02/01/2018

E-FLUX

CO2 TRAP SHIPMENT AND INSTALLATION LOG
LNAPL NATURAL ATTENUATION STUDY

Date Returned to E-Flux:_____

Containment Type	Deployment Location	Retrieval Location	Identification on Outside of Trap Box	Trap Placed in Field		Trap Recovered from Field		Comments	Depth to Ground Water	LNAPL Thickness in Well	Smear Zone Thickness	
#				Date	Time	Date	Time				Vadose Zone	Groundwater
Trap Data												
	GTI-23		FANV-R1-CO2-01	10/5	9:30	10/19	8:40	~8' from wall				
	GTI-14		FANV-R1-CO2-02	10/5	9:55		8:45	~10' towards GTI-34				
	GTI-11		FANV-R1-CO2-03	10/5	10:15		8:55	~4' towards FF-4				
	FF-4		FANV-R1-CO2-04	10/5	10:20		9:00	~4' east of FF-4				
	RW-3		FANV-R1-CO2-05	10/5	10:30		9:05	3' towards VT-3				
	GTI-6		FANV-R1-CO2-~~06~~ 05	10/5	10:45		9:15	6' east				
	GTI-3		FANV-R1-CO2-07	10/5	11:00		9:20	20' SE				
	BSC		FANV-R1-CO2-08	10/5	11:15		9:25	1' SW				
	BG		FANV-R1-CO2-~~07~~ 06	10/5	11:25		9:30	Between Trees				
Travel Blanks												
				Date Received			Date Returned					
Travel Blank	TB		FANV-R1-CO2-TB	~~10/5~~ 10/5	9:00		9:40					

Installation Steps – KEEP TRAPS UPRIGHT - CAUTION, CONTAINS CAUSTIC MATERIAL
Find the appropriate trap for the location chosen (see map). Remove housing from over Receiver.
Remove screw-on caps (top and bottom). Add rain cover to top. Keep trap upright.
Place trap on receiver in ground using 4 in rubber coupler. Tighten hose clamps on rubber coupler.
At end of monitoring period, reverse steps. Cap both top and bottom of the trap.
Keep upright while handing and shipping.

Return Traps to:
(970) 492-4360
E-Flux, LLC
200 West Lake St, RIC Room D230
Fort Collins, CO 80521-0922
Attn: E-Flux Receiving

Technician Name:

Note 6 + 9 switched

SITE 2
SITE 4
LEGEND
KEH
4-11

Tim Appleman installing Carbon Traps

Deployed Carbon Trap

Deployed Carbon Trap

Deployed Carbon Trap

Deployed Carbon Trap

Deployed Carbon Trap

Deployed Carbon Trap

Deployed Carbon Trap

Deployed Carbon Trap