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FINAL

United States Army Corps of Engineers
New England District

Post – Record of Decision Supplemental Remedial Investigation Work Plan

Area of Contamination 43G

Former Fort Devens Army Installation

Devens, Massachusetts

Contract No. W912WJ-19-D-0014

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June 2023

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CERTIFICATION

I hereby certify that the enclosed Report, shown and marked in this submittal, is that proposed to be incorporated with Contract Number W912WJ-19-D-0014. This document was prepared in accordance with the U.S. Army Corps of Engineers (USACE) Scope of Work and is hereby submitted for Government approval.

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NOTICE

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Acronyms and Abbreviations

µg/L	microgram per liter
AAFES	Army Air Force Exchange Service
ABB	ABB Environmental Services, Inc.
AOC	Area of Contamination
Army	U.S. Army
bgs	below ground surface
BRAC	Base Realignment and Closure
BTEX	benzene, toluene, ethylbenzene, xylenes
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CMR	Code of Massachusetts Regulations
COC	contaminant of concern
CSM	conceptual site model
Devens	Former Fort Devens Army Installation
DO	dissolved oxygen
DQO	data quality objectives
EBS	Environmental Baseline Survey
EPH	Extractable Petroleum Hydrocarbons
ESD	Explanation of Significant Differences
FFA	Federal Facility Agreement
FFS	focused feasibility study
FS	feasibility study
ft/day	feet per day
FYR	Five-Year Review
gpm	gallons per minute
HAZWOPER	Hazardous Waste Operations and Emergency Response
HGL	HydroGeologic
HHRA	human health risk assessment
HLA	Harding Lawson Associates
HQ	hazard quotient
IDW	investigation-derived waste
IRA	intrinsic remediation assessment
JV	joint venture
KGS	KOMAN Government Solutions, LLC
LLC	Limited Liability Company
LOD	limit of detection
LTM	long-term monitoring
LTMMP	long-term monitoring & maintenance plan
LUC	land use control
MassDEP	Massachusetts Department of Environmental Protection
MassDevelopment	Massachusetts Development and Finance Agency
MCP	Massachusetts Contingency Plan
MEC	munitions and explosives of concern

MCL	Maximum Contaminant Levels
mg/L	milligrams per liter
MNA	monitored natural attenuation
NA	not applicable/not available
NAPL	non-aqueous phase liquid
NAVD	North American Vertical Datum
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
Nobis	Nobis Engineering, Inc.
NPL	National Priorities List
ORP	oxidation-reduction potential
OU	operable unit
PID	photoionization detector
POL	petroleum, oil, and lubricants
PRG	preliminary remediation goals
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
RAO	remedial action objective
RfD	reference dose
RI	remedial investigation
ROD	record of decision
RPMP	Real Property Master Plan
SA	Study Area
SARA	Superfund Amendments and Reauthorization Act
SI	site investigation
SOP	standard operating procedure
Sovereign	Sovereign Consulting, Inc.
SRI	supplemental remedial investigation
SSI	supplemental site investigation
SVE	soil vapor extraction
SWETS	Stone & Webster Environmental Technology & Services
TGI	technical guidance instruction
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plans
U.S.	United States
USACE	United States Army Corps of Engineers
USAEC	United States Army Environmental Center
USC	United States Code
USEPA	United States Environmental Protection Agency
UST	underground storage tank
UU/UE	unlimited use and unrestricted exposure
VPH	volatile petroleum hydrocarbons
WP	work plan

1. Introduction

The SERES-Arcadis Joint Venture (JV), Limited Liability Company (LLC)[1] (hereafter referred to as the S-A JV) has prepared this work plan (WP) on behalf of the United States (U.S.) Army Corps of Engineers (USACE) to conduct a Comprehensive Environmental Response, Compensation, and Liability Act- (CERCLA) compliant supplemental remedial investigation (SRI) at the former Fort Devens Army Installation (Devens) located in Devens, Massachusetts.

1.1. Purpose

This Post – Record of Decision (ROD) SRI WP has been prepared to confirm groundwater conditions and the current and future protectiveness of the remedy at Historical Gas Station G (Area of Contamination [AOC] 43G) located at Devens, Massachusetts related to contaminants of concern (COCs) identified in the AOC 43G ROD (United States Army Environmental Center [USAEC] 1996), as well as arsenic (COCs and arsenic).

Exceedances of applicable criteria for COCs and arsenic in environmental media at AOC 43G are attributed to petroleum discharges to ground and waste management practices associated with vehicle maintenance activities conducted at the historical gas station (Area 1) and at the Army Air Force Exchange Service (AAFES) gas station (Building 2008, Areas 2 and 3). Investigations conducted in 1992 and 1993 identified petroleum-related impacts to soil and groundwater within Areas 2 and 3.

The ROD-selected remedies for Areas 2 and 3 of AOC 43G (USAEC 1996) included intrinsic bioremediation to prevent COCs and arsenic present at concentrations that exceed groundwater cleanup levels from potentially migrating off Army property, long-term monitoring (LTM) of groundwater for site contaminants, and five-year reviews (FYRs). After an intrinsic bioremediation evaluation at AOC 43G and AOC 43J was completed by Stone & Webster Environmental Technology & Services (SWETS) and Harding Lawson Associates (HLA) between 1997 and 1999, an LTM plan was developed and implemented in 1999 (SWETS-HLA 1999) to monitor for concentrations of ROD-specified site contaminants (benzene, ethylbenzene, xylenes, nickel, iron, and manganese). Land use controls (LUCs) for AOC 43G were instituted in 2007 to prevent receptors from being exposed to impacted soil and groundwater.

In September 2020, during discussions between the Army and the United States Environmental Protection Agency (USEPA) concerning the *2020 Final Five-Year Review (FYR) Report for the Former Fort Devens* (KOMAN Government Solutions, LLC [KGS] 2020), the Army and the USEPA came to the conclusion that the two agencies would not be able to timely resolve outstanding comments to issue joint protectiveness statements by the statutory deadline of September 28, 2020. Consequently, the Army and the USEPA agreed that the two agencies would issue their own protectiveness statements to meet the statutory deadline. Thus, the USEPA's protectiveness statements included in their September 25, 2020 letter (received September 28, 2020) were different from the Army's protectiveness statements released on September 28, 2020 in the 2020 Final FYR Report.

The Army and the USEPA also agreed that, after the statutory deadline, the two agencies would work together to reconcile their differences. In the USEPA's letters to Army on September 25 and September 29, 2020, USEPA issued their independent findings of protectiveness with issues and recommendations that included 19-pages of "Additional Work." USEPA's additional work requirements were provided as an attachment to USEPA's letter to the Army dated September 29, 2020.

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[1] The SERES-Arcadis JV is composed of protégé firm SERES Engineering & Services, LLC (SERES) and its mentor, Arcadis U.S., Inc. (Arcadis).

On December 11, 2020, the Army submitted a letter to USEPA which included a statement of work to address the additional work determined by USEPA to be necessary to assess the short- and long-term protectiveness of the ongoing remedial actions at the Operable Units (OUs) evaluated in the Final Fifth 2020 FYR Report (KGS 2020).

As it pertains to this SRI WP and the additional work determined by the USEPA to be necessary to assess protectiveness, the USEPA concluded that the remedy at AOC 43G was not protective in the long-term. The USEPA stated, *"… for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness:*

- *respond to the three technical assessment questions specified in EPA's June 2001 FYR guidance, supplemental guidance (see list on Page 4 of EPA's January 20, 2016 Recommended FYR template and more specifically, EPA Region 1's FY2020 Supplemental FYR Template);*
- *develop/implement a "more aggressive" remedial action (i.e., soil vapor extraction (SVE) system in the AOC 43G source area) to ensure prompt and effective remediation of all ROD-specified groundwater COCs, attainment of RAOs* [remedial action objectives] *and ensure long-term protection of human health; a draft assessment of proposed remedial alternatives that includes the evaluation of petroleum hydrocarbons in the unsaturated overburden as a continuing source of groundwater contamination shall be prepared and submitted to EPA and MassDEP review and comment in accordance with the Devens FFA;*
- *issue draft, revised (2008) LTMMP for each AOC that includes additional sentinel monitoring well locations along the LUC/compliance boundary to more effectively evaluate COC concentration trends, confirm/deny attainment of ROD-specified cleanup goals and RAOs, and more effectively assess/evaluate potential off-site migration of all ROD-specified COCs; and;*
- *prepare/submit a draft LUCIP Update for AOC 43G and draft LUCIP for AOC 43J that outlines requirements for implementing, monitoring and enforcing ICs/LUCs and includes an Annual LUC Inspection checklist for use during annual LUC inspections and inclusion in the AOCs 43G and 43J Annual LTMMP Reports."*

The Army disagrees with the USEPA's assessment but has agreed to perform additional work to document the protectiveness of the current remedy. The following items listed by the USEPA in the bullets above are not addressed in this SRI for the following reasons:

- *"Respond to the three technical assessment questions specified in EPA's June 2001 FYR guidance."*
  - USEPA has determined that Army's updated responses to the three technical assessment questions in its final FYR Report (2020) adequately comply with USEPA guidance and templates, as requested. This task is therefore deemed completed.
- *"Prepare/submit a draft LUCIP Update for AOC 43G and draft LUCIP for AOC 43J."*
  - Per USEPA comments on Draft LUCIP WP received on November 4, 2021, a LUCIP for AOC 43G is no longer required.
  - A LUCIP for AOC 43J will be prepared by the Massachusetts Development and Finance Agency (MassDevelopment).

This SRI WP details the proposed supplemental investigation of AOC 43G to confirm the Army Protectiveness Statement in the 2020 FYR Report (KGS 2020). To address the USEPA's requirement for a revised LTMMP, the Army offered to prepare this SRI WP and an SRI report. Based on the results of the SRI, historical site data, and an updated conceptual site model (CSM), the Army will prepare a focused feasibility study (FFS) to evaluate changes to the remedy, including updates to the LTMMP, if necessary, and prepare any applicable ROD amendments.

- The SRI WP will focus on collection of data needed to evaluate remedial alternatives and to estimate remedy timeframes in an FFS, with particular focus on the source area and any continuing sources that are contributing to groundwater contamination.
- Using data collected during the SRI, Army will prepare an SRI report and update the CSM, as necessary.
- After approval of the SRI report, Army will prepare an FFS using the results of the SRI, historical site data, and the updated CSM. The FFS will develop and assess a range of remedial alternatives to address any contamination remaining at the site. The FFS will include an evaluation of alternatives for any continuing sources that are contributing to groundwater contamination.
- After approval of the FFS, Army will make appropriate changes to the remedy, including updates to the LTMMP, if necessary, and prepare any applicable ROD amendments.

In addition, the SRI will use historical and new data to evaluate the ROD-stipulated remedy for possible modification.

1.2. Regulatory Requirements

Activities completed under this AOC 43G SRI WP are subject to and consistent with CERCLA as amended (42 United States Code [USC] § 9601 et seq.), and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), with regulatory coordination from the Massachusetts Department of Environmental Protection (MassDEP) and the USEPA.

As discussed in more detail in **Section 2.1**, the USEPA interprets CERCLA section 101(14), which defines the term “hazardous substances”, to exclude petroleum, including crude oil and fractions of crude oil. As such, petroleum spills are normally regulated under state requirements, not CERCLA, unless the petroleum contains hazardous contaminants. However, the 1991 Devens Federal Facility Agreement (FFA) requires that the Army perform CERCLA investigations to characterize the nature and extent of threats to human health and the environment caused by the release or threatened release of hazardous substances, pollutants, or contaminants or oil.

1.3. Site Background

1.3.1. Fort Devens

1.3.1.1. Fort Devens Site Background

Former Fort Devens is located in the Towns of Ayer and Shirley in Middlesex County, and the Towns of Harvard and Lancaster in Worcester County, Massachusetts, approximately 35 miles northwest of Boston, Massachusetts (**Figure 1-1**). The former installation occupied approximately 9,260 acres. Fort Devens was divided into the North Post, Main Post, and South Post, with state highway Route 2 dividing the South Post from the Main Post. The Nashua River runs through the North, Main, and South Posts. The area surrounding the installation is primarily composed of rural residential properties. Portions of Devens have been redeveloped for commercial/industrial use. Several of the surrounding areas and portions of Devens are undeveloped, and consist of hardwood vegetated uplands, riparian corridors, old fields, wet meadows, emergent and forested wetlands, and open waters.

Camp Devens was established in 1917 as a temporary training area for soldiers during World War I. In 1932, the site was renamed Fort Devens and made a permanent installation with the primary mission of commanding, training, and providing logistical support for non-divisional troop units. Fort Devens was used for a variety of training missions between 1917 and 1990.

Fort Devens was identified for cessation of operations and closure under Public Law 101-510, the Defense Base Realignment and Closure (BRAC) Act of 1990, and officially closed in March 1996.

1.3.1.2. Fort Devens Regulatory Background

The former Fort Devens was placed on the National Priorities List (NPL) update of November 21, 1989 (54 Fed. Reg. 48187) due to environmental contamination at several sites and became subject to the special provisions for federal facility NPL sites in CERCLA (§ 120, 42 USC § 9620) and the Superfund Amendments and Reauthorization Act (SARA; § 211, 10 USC. § 2701, Defense Environmental Restoration Program et seq.). In 1991, the Army and the USEPA signed an FFA that established the procedural framework and timetables for identifying, investigating, and remediating human health and environmental impacts associated with the past and present activities at Devens. Since 1991, OUs (USEPA CERCLIS identifier) and AOCs (Army Administrative Record identifier) within Devens have been evaluated under the CERCLA process to identify and address risk to human health or the environment.

Five-Year Reviews for OUs/AOCs are required, at a minimum, every 5 years when, upon completion of the remedial action, hazardous substances, pollutants, or contaminants will remain on site above levels that allow for unlimited use and unrestricted exposure (UU/UE). During the FYR process, an assessment of each OU/AOC at a Site that has an active ROD and has not met UU/UE must be conducted to determine whether the ROD-specified remedy remains protective of human health and the environment and whether alternative remedial actions are needed to ensure adequate protection. The first statutory FYR for Devens was completed in 2000. Subsequent FYRs were submitted in 2005, 2010, 2015, and 2020.

1.3.2. AOC 43G (Historical Gas Station G)

1.3.2.1. AOC 43G Site Background

AOC 43G is located in the central portion of Main Post on Queenstown Road and consists of a decommissioned AAFES gas station (Building 2008) and Historical Gas Station G (**Figure 1-1**). Historical Gas Station G was used during World War II as a vehicle motor pool to support military operations and was one of 18 historical gas station sites at Fort Devens. The structures of gas station G consisted of a pump island and a small gasoline pumphouse. Reportedly, the gas station had one 5,000-gallon (or possibly 5,140-gallon) underground storage tank (UST) located between the gasoline pumphouse and the pump island (ABB Environmental Services, Inc. [ABB] 1996a). The motor pool operations were discontinued during the late 1940s or early 1950s. No records are available on the decommissioning of the motor pool, the exact location of Gas Station G, or the location or ultimate disposition of the historical gas station's UST (ABB 1996a).

Originally, AOC 43G consisted solely of Historical Gas Station G; however, after completion of the SI, AOC 43G was expanded to include the former AAFES gas station located approximately 120 feet northeast of Historical Gas Station G. The AOC was divided into three areas during the SSI to better focus the investigations (ABB 1996a)

- Area 1 comprises Historic Gas Station G.
- Area 2 was added to AOC 43G to investigate petroleum contamination observed during removal of three 9,000-gallon USTs associated with the AAFES gas station in 1990. Area 2 was expanded after removal of two 10,000-gallon gasoline USTs and associated piping in 1996 by USCACE – New England District. Although soil samples were collected from the walls of the excavation, no samples were collected from the base of the excavation.
- Area 3 was added to AOC 43G to investigate petroleum contamination observed during the removal of a 500-gallon waste oil UST associated with the AAFES gas station in 1992. Impacted soils were not

removed in 1992 due to the close proximity of Building 2008. Impacted soil was subsequently removed in 1996 during the Area 2 UST removal.

The AOC 43G property remains owned and under the control of the Army, and a portion of the property is used for equipment storage. The remainder of the property is empty parking areas and a former vehicle washing station.

1.3.2.2. AOC 43G Regulatory Background

As part of the BRAC closure process, AOC 43G, then Study Area (SA) 43G, was investigated in 1991 under the CERCLA process as part of the site investigations (SIs) conducted at historical gas stations at Fort Devens (ABB1993 [Final] and 1995 [Revised Final]). Based on the results of preliminary risk evaluations completed as part of the SIs, the Army decided to conduct supplemental site investigations (SSIs) at seven of the original historical gas stations (ABB 1996a).

- Originally, AOC 43G consisted solely of Historical Gas Station G (defined as Area 1); however, after completion of the SI, AOC 43G was expanded to include the former AAFES gas station located approximately 120 feet northeast of Historical Gas Station G.
- Area 2 was added to AOC 43G to investigate petroleum contamination observed during removal of three 9,000-gallon USTs associated with the AAFES gas station in 1990. Area 2 was expanded to include the location of two 10,000-gallon gasoline USTs removed in 1996. Although soil samples were collected from the walls of the excavation, no samples were collected from the base of the excavation.
- Area 3 was added to AOC 43G to investigate petroleum contamination observed during the removal of a 500-gallon waste oil UST associated with the AAFES gas station in 1992. Impacted soils were not removed in 1992 due to the close proximity of Building 2008. Impacted soil was subsequently removed in 1996 during the Area 2 UST removal.

Based on the results of the 1992 SI and 1994 SSI field activities, the SSI recommended no further action for AOC 43G Area 1; however, the SSI identified fuel related compounds, principally benzene, ethylbenzene, and xylenes in site soil and groundwater within Areas 2 and 3 (ABB 1996a). Subsequently, the two historical gas stations (SA 43G and 43J) were administratively changed to AOCs and the sites progressed to the remedial investigation (RI) and feasibility study (FS) phase under CERCLA. Further investigation was conducted and risks were evaluated as part of the RI for AOC 43G (ABB 1996a) and remedial alternatives for cleanup of groundwater at AOC 43G were evaluated in the AOC 43G Feasibility Study (ABB 1996b).

A human health risk assessment (HHRA) was conducted for the RI to evaluate potential health risks to individuals under current or foreseeable future site conditions at AOC 43G. Because the future reuse of the area was anticipated to remain similar to its present use, a commercial/industrial worker scenario was used to assess potential human health risks associated with contaminants detected in soil and groundwater. Due to the urbanized nature of this site and the lack of exposure pathways (the site is paved), an ecological risk assessment was not performed. The HHRA concluded that there were no unacceptable threats to human health from exposure to contaminated soil, but did find potential threats to human health from future exposure to groundwater in the source area and downgradient of the source area.

1.4. AOC 43G CERCLA Remedial Actions

In October 1996, the Army and USEPA issued a ROD for AOCs 43G and 43J that documented the selection of remedial actions to control site risks at Areas 2 and 3 of AOC 43G with intrinsic bioremediation, LTM of groundwater, and FYRs. Intrinsic bioremediation was chosen for AOC 43G "…to prevent COCs present at concentrations that exceed groundwater cleanup levels from potentially migrating off Army property." (USAEC 1996). The Army property boundaries are shown on **Figure 1-1.** To ensure continued protection of human health and the environment and future integrity of the selected remedy, in June 2006 the Army issued an Explanation of Significant Difference (ESD) to the 1996 ROD to incorporate LUCs into the remedy for AOC 43J (BRAC Environmental Office 2006). Similar LUCs for AOC 43G were subsequently incorporated into the Real Property Master Plan (RPMP) Long Range Component for Devens Reserve Forces Training Area, Addendum (2007) (KGS 2020).

To address potential risk to human health at AOC 43G, the FS identified initial remedial action objectives (RAOs) with preliminary remediation goals (PRGs) for groundwater at AOC 43G based on the results of the risk assessment, The following finalized RAOs were presented in the ROD (USAEC 1996):

- *Protect potential commercial/industrial receptors located on Army* [AOCs 43G and 43J*] property from exposure to contaminated groundwater having chemicals in excess of* [USEPA] *maximum contaminant levels (MCLs).*
- *Protect potential commercial/industrial receptors located off Army* [AOCs 43G and 43J] *property from exposure to groundwater having chemicals in excess of MCLs*.
- *Prevent contaminated groundwater having chemicals in excess of MCLs from migrating off Army* [AOCs 43G and 43J] *property*.

The Remedial Components identified in the 1996 ROD to address groundwater contamination at AOC 43G are as follows:

- Intrinsic bioremediation (discussed in **Section 1.4.1**).
- Intrinsic bioremediation assessment data collection and groundwater modeling.
- Installation of additional groundwater monitoring wells.
- Long-term groundwater monitoring (discussed in **Section 1.4.2**).
- Annual data reports to USEPA and MassDEP.
- Five-Year Reviews (discussed in **Section 1.4.4)**.

Institutional Controls (i.e., LUCs) were not included in the 1996 ROD Selected Remedy because the Army owned the property in 1996 and expected to support Army Reserve activities on the properties in the future. However, the ROD did require that, "*Should the Army change the use at either AOC, additional assessment and/or remedial actions may be required based upon the changed risk factors resulting from this change in use. In addition, if the Army transfers either site by lease or deed then an EBS* [Environmental Baseline Survey] *will need to be conducted, and a determination will be made by the Army and USEPA that the selected remedy remains protective of human health and the environment.*" Accordingly, prior to AOC 43J being transferred to MassDevelopment in 2006, the Army performed an EBS and issued an ESD, formally adding LUCs to the AOC 43J remedy. To ensure protection of human health at AOC 43G, the Army developed and memorialized LUCs to prohibit (1) residential development/use, (2) groundwater usage, and (3) unauthorized soil disturbance or construction. LUCs established for AOC 43G are discussed in more detail in **Section 1.4.3.**

1.4.1. Intrinsic Bioremediation

Remedial Component 1 (Intrinsic Bioremediation) is ongoing at AOC 43G. The progress of the remediation is monitored through Remedial Component 4 (Groundwater LTM) and is reported in Remedial Component 5 (Annual data reports to USEPA and MassDEP).

Remedial Component 3 (Installation of additional groundwater monitoring wells) and Remedial Component 2 (Intrinsic Remediation Assessment [IRA] and Groundwater Modeling) were completed between 1997 and 1999 (SWETS-HLA 1999). Results from the 1999 BIOPLUME II modeling were used to estimate remedial duration and contamination migration potential (HydroGeologic [HGL] 2010).

The 1996 ROD (USAEC) stated,

"If the intrinsic bioremediation assessment results at AOC 43G and 43J indicate that:

1) *the groundwater contaminant plume may increase in size on Army property and/or,*
2) *the groundwater contaminant plume remains the same size, but cannot be remediated within 30 years;*

a soil vapor extraction (SVE) system will be installed at the existing AOC 43G source area, and an additional cleanup action will be implemented at AOC 43J."

"Furthermore, if at any time during this remedy there is an indication that contaminants are migrating off Army property or an area located sufficiently inside the boundary in which compliance will be determined, according to cleanup criteria stated in the ROD, that at minimum will meet drinking water standards; then the Army will implement an additional remedial action which will be protective of human health and the environment."

The 1999 BIOPLUME II modeling determined that:

- *The extent of the contamination as defined by the remedial goals would be limited to about 25 feet from one of the source area wells at AOC 43G, and within the existing Devens site boundary.*
- *The benzene criterion at AOC 43G was estimated to be achieved between 11 to 13 years total following signing of the ROD, which is compliant with the 30-year criterions in the ROD*.

Therefore, in accordance with the ROD, no additional remedial actions have been implemented at AOC 43G.

1.4.2. Long-Term Monitoring

Remedial Component 4 (Long-term Monitoring) of the 1996 ROD called for groundwater LTM at AOC 43G, *"…to enable assessment of the intrinsic bioremediation progress and permit detection of any potential migration of contaminants that exceed groundwater cleanup levels beyond Army property."* (USAEC 1996).

As discussed further in **Section 4.2.5.**, the Army will update the 1999 intrinsic bioremediation evaluation during the SRI baseline sampling event. A more comprehensive intrinsic bioremediation evaluation may be conducted after evaluation of SRI data by the Army, MassDEP, and the USEPA.

The ROD stated that, "*Dependent upon the results of the fate and transport modeling, groundwater monitoring would be conducted on an annual basis until three consecutive sampling rounds indicated that cleanup objectives have been met*."

The ROD also stated that, "*If the data generated from the modeling or the long-term groundwater monitoring efforts indicate that groundwater cleanup cannot be met within 30 years, a more aggressive remedial action will take place to enhance the intrinsic bioremediation alternative."*

The ROD confirmed the contaminants of potential concern (COPCs; referred to as CPCs in the ROD) that were identified in the risk assessment included in the FS as contributing greater than or equal to a hazard quotient (HQ) of 1.0, and were, therefore, considered COCs. Arsenic, iron, manganese, and benzene contributed to unacceptable risk in the risk assessment. Nickel, lead, ethylbenzene, and xylenes had concentrations that exceeded federal or state drinking water standards. While arsenic was identified in the risk assessment as a primary contributor to risk in source area groundwater, the ROD removed arsenic as a COC because the MCL exceedance was due to high total suspended solids content and because arsenic was not detected downgradient at a concentration above the MCL. Lead was removed as a COC in the ROD because concentrations of lead in filtered samples did not exceed federal or state drinking water standards. The ROD also confirmed that PRGs established in the FS for the groundwater COCs iron, manganese, nickel, benzene, ethylbenzene, and xylenes were cleanup levels for the COCs.

LTM was first performed at AOC 43G in December 1999. In accordance with the ROD, groundwater has been sampled in the late fall on an annual basis since 1999. The initial LTM Plan, which was included as Appendix P of the IRA report (SWETS-HLA 1999), called for samples to be collected from nine monitoring wells (four source area wells and five sentry wells) and analyzed for benzene, toluene, ethylbenzene, xylenes (BTEX), volatile petroleum hydrocarbons (VPH), iron, nickel, and manganese.

The ROD does not list VPH and toluene as COCs and neither must meet screening levels to achieve RAOs. VPH was established as a monitoring marker criterion by the Army during intrinsic remediation conducted at AOC 43G between 1997 and 1999. Because there is no MCL for VPH, concentrations are compared to the Massachusetts Contingency Plan (MCP) standard. Toluene has been reported historically to provide a complete summary of BTEX laboratory parameters.

After completion of the initial LTM sampling in December 1999, the 2000 FYR (HLA 2000) noted that there was no longer an MCL for nickel, therefore nickel should no longer be considered a COC. Similarly, the 2000 FYR identified changes in risk assessment methodologies since the signing of the ROD, that, "*call[ed] into question the possible over-protectiveness of the remedy, specifically with regard to consideration of iron and manganese as COCs."* The 2000 FYR specifically stated:

> *"Iron was identified as a COC in the ROD because non-cancer risks calculated for potential exposures to iron in groundwater exceeded a* [hazard index] *HI of 1. The non-cancer risks were calculated using a provisional oral* [reference dose] *RfD developed by the National Center for Environmental Assessment. USEPA Region I has since indicated that the agency does not endorse use of the iron RfD, because the RfD was developed based on concentrations needed to protect against a nutritional deficiency, rather than on quantitative estimates related to the hazard posed by overexposure to the element (USEPA Region I Risk Updates; Number 5; August, 1999). Based on this guidance, non-cancer health risks would not be calculated for iron. Consequently, a HI for iron would not be derived, and iron would not be identified as a COC based on health risk concerns."*

While the 2000 FYR recommended that iron and nickel not be considered as COCs and not analyzed, the 2005 FYR (Nobis Engineering, Inc. [Nobis]) noted that the recommendation was not implemented and that the analysis of nickel and iron continued at AOC 43G. The 2005 FYR also repeated that nickel did not have an MCL and should not be considered a COC and that, using updated risk guidance, iron should not be considered a COC. The 2005 FYR noted that revised cleanup goals for manganese were being considered by the USEPA. The 2005 FYR recommended that the cleanup goal for manganese be updated when the revised MCL was approved and again recommended removal of nickel as a COC.

In 2008, a revised LTM Plan (HGL 2008) was issued that removed nickel from monitoring and updated the manganese cleanup goal to 375 µg/L. In 2015, the *Long-Term Monitoring and Maintenance Plan for Former Fort Devens Army Installation and Sudbury Annex* (Main Post LTMMP; Sovereign/HGL) was prepared, replacing the

AOC 43G LTM Plan. The 2015 Main Post LTMMP was finalized in accordance with provisions of the 1991 Devens FFA Section 7.8 and released without USEPA concurrence.

The current annual monitoring at AOC 43G, as presented in the 2015 Main Post LTMMP (Sovereign/HGL), consists of collection of samples from five monitoring wells. Groundwater samples are analyzed for BTEX, VPH, total iron and total manganese, and alkalinity.

Exhibit 1-1 below summarizes the COCs, arsenic, and additional analytes historically and currently included in the AOC 43G LTM program.

Exhibit 1-1: AOC 43G Screening Limits in Groundwater

Analytes	Original			Current				Selection Basis
	Cleanup Goal (µg/L)	Source Area	Down-gradient	Cleanup Goal (µg/L)	Screening Standard (µg/L)	Source Area	Down-gradient	
Iron (total)	9,100	Yes	No	9,100	NA	Yes	No	Background [a] (ROD)
Manganese (total)	291 [a]	Yes	Yes	375 [c]	NA	Yes	Yes	see notes a and c
Nickel	100	Yes	No	NA	NA	No	No	MCL (ROD)
Arsenic	NA	Yes	Yes	10	NA	Yes	Yes	See note e
Benzene [b]	5	Yes	Yes	5	NA	Yes	Yes	MCL (ROD)
Toluene	NA	Yes	Yes		1,000	Yes	Yes	MCL (Army)
Ethylbenzene [b]	700	Yes	No	700	NA	Yes	No	MCL (ROD)
Xylenes, Total [b]	10,000	Yes	No	10,000	NA	Yes	No	MCL (ROD)
VPH C_5 – C_8 Aliphatics [d]	NA	Yes	Yes	NA	300	Yes	Yes	MCP (Army)
VPH C_9 – C_{12} Aliphatics [d]	NA	Yes	Yes	NA	700	Yes	Yes	MCP (Army)
VPH C_9 – C_{10} Aromatics [d]	NA	Yes	Yes	NA	200	Yes	Yes	MCP (Army)

NOTES:
µg/L = micrograms per liter. NA – not applicable
ROD = Record of Decision

a. AOC 43G/43J ROD (USAEC 1996) identified background values for iron and manganese as determined from unfiltered samples collected from 10 select wells on base.
b. Screening levels as noted in 1996 ROD (USAEC) and 2015 LTMMP (KGS).
c. The 2008 LTM Plan (HGL) updated the cleanup goal for manganese to the approved MCL for a child.
d. MCP 2021 https://www.mass.gov/regulations/310-CMR-4000-massachusetts-contingency-plan
e. Arsenic added to investigation per USEPA requirement.

As part of a supplemental sampling event conducted in winter 2020, three additional groundwater monitoring wells were installed in areas downgradient of the original UST area. These wells, and an existing upgradient piezometer were sampled for dissolved manganese and iron in February 2020.

1.4.3. Institutional Controls

The Institutional Controls (i.e., LUCs) developed for AOC 43G are detailed in the RPMP Long Range Component for Devens Reserve Forces Training Area, Addendum (2007) and included as Appendix G of the 2015 Main Post LTMMP (Sovereign/HGL 2015). The 2007 Addendum states for AOC 43G that, "*The remedy is based on Army retention of this area and continued restricted access to groundwater; however, any proposed actions that affect this property must consider the following ROD requirements and site environmental conditions:*

- *Assure that the Property is not used for residential purposes and prohibit the use of groundwater beneath the site. If the Army changes the land-use within the AOC, then additional assessment and/or possible remedial action may be needed based upon the possible resultant changed risk factors.*
- *If the Army transfers this property by lease or deed, an Environmental Baseline Assessment will be conducted to ensure that the remedy remains protective by incorporating all necessary environmental protection provisions within the Finding of Suitability to Transfer and the property transfer deed.*
- *Any intrusive construction work must consider that residual soil and groundwater contamination has been documented for AOC 43G and that such actions should be coordinated with the Directorate of Public Works, the BRAC Environmental Office and the BRAC Clean-up Team."*

The LUC implementation plan for AOC 43G is included in Section 4.0 of the 2015 Main Post LTMMP (Sovereign/HGL). LUC inspections are conducted annually during LTM sampling events to monitor for broken ground or excavations or installation of potable water wells. The results of the annual monitoring are presented in the Main Post annual reports.

1.4.4. Five-Year Reviews

Because contaminants would remain on-site above concentrations that allow for UU/UE, statutory reviews must be performed to, "… *evaluate the alternative's effectiveness at reducing potential human health risk from exposure to groundwater on-site and downgradient considering current and potential future receptors.*" (USAEC 1996). Five-year reviews must be performed as long as hazardous substances, pollutants, or contaminants remain on-site above concentrations that allow for UU/UE.

Five-Year Reviews were completed for AOC 43G beginning in 2000 to confirm the remedial alternative for AOC 43G selected in the ROD continued to be protective of human health and the environment. The 2020 FYR concluded that concentrations of groundwater COCs have decreased (based on a review of time-concentration trends and Mann-Kendall trend analysis) and are not migrating offsite at concentrations above the cleanup goals. Benzene, ethylbenzene, and xylene concentrations are less than the groundwater cleanup goals. Manganese and iron have continued to exceed their respective cleanup goals, but their presence is consistent with the CSM, which indicates that the concentrations of these metals is associated with reducing conditions.

The 2020 FYR Protectiveness Statement (KGS 2020) concluded:

> *"The remedy at AOC 43G is protective of human health and the environment.*
>
> *Exposure pathways that could result in unacceptable risks are being controlled. The Army retains control of the property. Land use controls are in place that prevent exposure to groundwater that could pose an unacceptable human health risk, the LUCs are enforced, and no exposure are currently occurring or imminent.*
>
> *The RAOs have been achieved through 1) implementation of LUCs which prevent exposure to groundwater and 2) reduction of groundwater contamination through natural attenuation. Groundwater monitoring at AOC 43G has confirmed many of the contaminants of concern concentrations have decreased below cleanup levels and migration of contaminated groundwater at concentrations greater than the MCLs off Army property is not occurring.*
>
> *The FYR site inspection and interviews, and annual land use control inspections and interviews, confirmed that site use remains controlled by the Army, there is no residential use, and groundwater is not being used from the site."*

After review of the 2020 FYR, the USEPA issued an independent Protectiveness Statement (USEPA 2017):

> *"The remedy for OU06* [AOC 43G and AOC 43J] *currently protects human health and the environment because LUCs are implemented, monitored and enforced and no unpermitted activities (i.e. exposures) are currently occurring or imminent. However, for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness:*
>
> - *respond to the three technical assessment questions specified in EPA's June 2001 FYR guidance, supplemental guidance (see list on Page 4 of EPA's January 20, 2016 Recommended FYR template and more specifically, EPA Region 1's FY2020 Supplemental FYR Template);*
> - *develop/implement a "more aggressive" remedial action (i.e., soil vapor extraction (SVE) system in the AOC 43G source area) to ensure prompt and effective remediation of all ROD-specified groundwater COCs, attainment of RAOs and ensure long-term protection of human health; a draft assessment of proposed remedial alternatives that includes the evaluation of petroleum hydrocarbons in the unsaturated overburden as a continuing source of groundwater contamination shall be prepared and submitted to EPA and MassDEP review and comment in accordance with the Devens FFA;*
> - *issue draft, revised (2008) LTMMP for each AOC that includes additional sentinel monitoring well locations along the LUC/compliance boundary to more effectively evaluate COC concentration trends, confirm/deny attainment of ROD-specified cleanup goals and RAOs, and more effectively assess/evaluate potential off-site migration of all ROD-specified COCs; and;*
> - *prepare/submit a draft LUCIP Update for AOC 43G and draft LUCIP for AOC 43J that outlines requirements for implementing, monitoring and enforcing ICs/LUCs and includes an Annual LUC Inspection checklist for use during annual LUC inspections and inclusion in the AOCs 43G and 43J Annual LTMMP Reports."*

1.5. Work Plan Organization

This SRI WP includes:

- Project objectives.
- CSM.
- Sampling design and rationale.
- A discussion of deliverables; and
- Project schedule.

This SRI WP was prepared consistent with USEPA Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA (USEPA 1988). All work will be conducted in accordance with procedures developed in the *Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) for Annual Long-Term Monitoring and Maintenance Program, Former Fort Devens Army Installation* (LTMMP QAPP; SERES-Arcadis JV 2020) and the LTMMP QAPP *Addendum for Post-Record of Decision Supplemental Remedial Investigation at AOC 43G* (AOC 43G QAPP Addendum; **Appendix A**). The AOC 43G QAPP Addendum describes sampling and analysis procedures for implementation of the SRI along with quality assurance (QA)/ quality control (QC) criteria. The QAPP Addendum will facilitate the generation of data with acceptable precision, accuracy, representativeness, comparability, and completeness.

This AOC 43G SRI WP is organized as follows:

- **Section 1** – Introduction: Presents the purpose of the SRI, the regulatory background guiding the SRI, the project background, provides the site history, and summarizes the previous CERCLA investigations/actions.
- **Section 2** – Project Approach and Objectives: Presents the regulatory approach and overall objectives of the SRI.
- **Section 3** – CSM: Summarizes the physical characteristics of Devens and AOC 43G; describes and presents the nature and extent of COC in AOC 43G, describes any changes to current and future land use, and confirms receptors and exposure pathways used to evaluate potential risk.
- **Section 4** – SRI Implementation: Summarizes the planned SRI activities, including field methodologies.
- **Section 5** – Deliverables: Identifies the deliverables that will be generated for the project.
- **Section 6** – Project Schedule: Presents the AOC 43G SRI WP schedule.
- **Section 7** – References: Provides a list of references used in preparing the AOC 43G SRI WP.

In addition, the following appendices are provided to supplement the SRI WP:

- **Appendix A**: AOC 43G QAPP Addendum - Describes the site-specific chemical data quality objectives, field data-gathering methods, and analytical methods and measurements not included in the LTMMP QAPP.
- **Appendix B**: Response to Regulatory Comments on Draft Post–Record of Decision Supplemental Remedial Investigation Work Plan, Area of Contamination 43G, Former Fort Devens, Massachusetts

2. Project Approach and Objectives

This section discusses the WP approach and the data quality objectives (DQOs) for the project.

2.1. Evaluation of Petroleum Sites

As noted in **Section 1.2**, since 1991, AOCs within Devens have been evaluated under the CERCLA process to identify and address risk to human health or the environment from hazardous substances. Investigation, cleanup, and identification of a remedial remedy for incidental petroleum spills at AOC 43G was completed under CERCLA process. However, the USEPA interprets CERCLA section 101(14) to exclude petroleum, including crude oil and fractions of crude oil, as hazardous substances. As such, petroleum spills are normally regulated under state requirements, unless the petroleum contains hazardous contaminants. However, under the 1991 Devens FFA, impacts from oil are investigated under CERCLA.

Typically, when there is an active release of petroleum, such as from a tank or piping system containing petroleum; an initial or emergency response action is conducted to stop the ongoing release and mitigate long-term impacts by containing and cleaning up accessible petroleum before it seeps into the ground or impacts groundwater. Once the ongoing release source and obviously impacted soil are removed, an investigation may be conducted to define the nature and extent of remaining contamination in soil and groundwater and determine what, if any, long-term remedial actions are needed to address risk to human health or the environment.

Generally, if residual petroleum remains in groundwater after removal of petroleum-impacted soil, the long-term remedial actions chosen for the site are 1) monitored natural attenuation (MNA) to confirm that concentrations of contaminants in groundwater are reducing over time and 2) LUCs to restrict exposure to soil and/or groundwater. Under CERCLA, site closure occurs when all regulated soil and groundwater contaminants have been eliminated or reduced to levels where they no longer represent a significant risk to human health or the environment.

The term "natural attenuation" refers to a variety of physical, chemical, and biological processes that under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of hazardous substances in the environment. Although some degree of natural attenuation typically occurs at most contaminated sites, the effectiveness of these processes varies depending on the types and concentrations of contaminants present at the site and the physical, chemical, and biological characteristics of the site.

In 1993, the National Research Council proposed lines of evidence to assess natural attenuation processes.

- Decreasing trends in groundwater quality data for the contaminants of concern, using historical data (primary line of evidence).
- Geochemical data indicative of biodegradative processes in the groundwater (secondary line of evidence). Geochemical parameters for petroleum contaminants typically include dissolved oxygen (DO), nitrate, dissolved manganese, dissolved ferrous iron, sulfate, methane, alkalinity, oxidation-reduction potential (ORP), pH, temperature and conductivity. If, in addition to observed reductions in petroleum contamination, geochemical indicators clearly exhibit the expected trends (either decreases in reactants or increases in electron acceptors or metabolic by-products) compared to their background, then it can be concluded that substantial biodegradation is occurring at the site (American Society for Testing and Materials [ASTM] 1998).

Ongoing LTM of groundwater in Areas 2 and 3 of AOC 43G has been conducted for 23 of the 30 years anticipated in the ROD. Based on LTM site groundwater data collected between 1999 and 2022, concentrations for ROD-specified COCs and arsenic indicate decreasing trends, and geochemical data indicate active biodegradative processes. A Mann-Kendall statistical analysis completed for LTM site data in 2020 showed statistically significant decreasing trends for manganese in four of five wells evaluated, and for iron at all three wells evaluated (Arcadis 2021).

This SRI WP incorporates elements of the following guidance documents to assess the AOC 43G LTM data for ROD-specified COCs and arsenic in groundwater to confirm the protectiveness of the remedy at AOC 43G:

- American Petroleum Institute. *Methods for Measuring Indicators of Intrinsic Bioremediation: Guidance Manua*l. Publ. No. 4658, November 1997.
- American Society for Testing and Materials. *Standard guide for remediation of ground water by natural attenuation at petroleum release sites*, ASTM E 1943-98. Conshohocken, Pennsylvania. 2015
- USEPA. *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites*, OSWER Directive 9200.4-17, November 1997.

2.2. Data Quality Objectives

The objectives of the AOC 43G SRI are to confirm the Army Protectiveness Statement in the 2020 Five-Year Review Report (KGS 2020) and address items specified in the USEPA Additional Work Requirements Table. As discussed in **Section 1.1,** to address the USEPA's requirement for a revised LTMMP, the Army offered to prepare this SRI WP and an SRI report. Based on the results of the SRI, historical site data, and an updated CSM, the Army would prepare an FFS to evaluate changes to the remedy, including updates to the LTMMP, if necessary, and prepare any applicable ROD amendments. Therefore, the first step is to prepare an SRI WP. Specifically, the objectives of the SRI are to:

- Collect sufficient and accurate site-specific data needed to accurately define/confirm the lateral and vertical extent of contamination.
- Evaluate COC and arsenic concentration trends.
- Monitor attainment of ROD-specified RAOs and cleanup goals.
- Assess/evaluate potential off-site migration of all ROD-specified COCs and arsenic.
- Assess short- and long-term protectiveness of the selected remedy.

Results of the SRI will be used to evaluate if changes to the AOC 43G ROD or AOC 43G LTM program are necessary. The evaluation will also include a comparison of current site conditions to remedial endpoints for similar sites in the state of Massachusetts.

DQOs are qualitative and quantitative statements that clarify study objectives, define the appropriate type of data, and specify the tolerable levels of potential decision errors that are used as the basis for establishing the quality and quantity of data needed to support decisions. These project-specific statements describe the intended data use; the data need requirements; and the means to achieve acceptable data quality for the intended use. Guidelines followed in the preparation of DQOs for remedial investigations are set out as steps in the *Data Quality Objectives Process for Hazardous Waste Site Investigations, EPA QA/G-4 HW* (USEPA 2000a) and *Guidance for the Data Quality Objectives Process, USEPA QA/G-4, EPA/600/R-96/055* (USEPA 2000b). These seven steps are listed below and were used to develop the DQOs for this SRI WP:

Step 1. State the Problem: Summarize the problem that will require environmental data, the resources required, and the preliminary site conceptual model.

Step 2. Identify the Decision (Project Goals): Identify the decisions needed to solve the problem.

Step 3. Identify Information Inputs: Identify the information and measurements needed to make the decisions.

Step 4. Define the Boundaries of the Study: Identify the conditions such as spatial and temporal boundaries.

Step 5. Develop a Decision Rule: Define the conditions under which the data will be utilized.

Step 6. Specify Limits on Decision Errors: Identify the limits on decision errors to establish performance goals.

Step 7. Develop/Optimize the Plan for Obtaining Data: Design an effective data collection strategy based on the previous steps.

2.2.1. Problem Statement

As presented in the 2020 FYR (KGS 2020) and described below in **Section 3**, significant progress has been completed towards achieving the ROD-specified RAOs:

- ROD-specified COCs and arsenic on Army property (i.e., AOC 43G) have attenuated or are generally stable:
    - Petroleum-related COCs (and arsenic) identified in the AOC 43G ROD for monitoring in groundwater (benzene, ethylbenzene, and xylenes) have attenuated below RGs.
    - The concentrations of iron and manganese, which are naturally occurring, are elevated due to geochemical changes caused by the biodegradation of residual petroleum hydrocarbons. However, as noted above, iron and manganese concentrations in groundwater are generally stable and decreasing.
- ROD-specified COCs and arsenic are not migrating off Army property.
- The RAOs to protect potential commercial/industrial receptors located on or off Army property from exposure to groundwater having chemicals in excess of MCLs are achieved via LUCs that were incorporated into the RPMP, Long Range Component for Devens Reserve Forces Training Area, Addendum (2007) The LUCs for AOC 43G are discussed in **Section 1.4.3.**

The Army is conducting this SRI to confirm that the selected remedy for AOC 43G remains protective and that site conditions indicate natural attenuation of ROD-specified COCs and arsenic in groundwater is occurring/has occurred. Historical and new data collected will also be used evaluate the ROD-stipulated remedy for possible modification. To meet the SRI objectives, the study questions for this SRI are:

- What is the current lateral and vertical extent of benzene, ethylbenzene, and xylenes, and associated intrinsic bioremediation marker VPH, in groundwater?
- What is the current lateral and vertical extent of iron, manganese, and arsenic in groundwater at concentrations exceeding applicable standards?
- Is there a stable or decreasing trend of ROD-specified COCs, arsenic, and VPH concentrations in groundwater?

- Are current reducing aquifer conditions associated with the petroleum releases or are they naturally occurring?

2.2.2. Project Goals

To support the SRI objectives and answer the study questions, the goals of the AOC 43G SRI field activities are to:

- Confirm the current lateral and vertical extent of ROD-specified COCs, arsenic, and VPH in groundwater.

Confirm the CSM, including aquifer reducing conditions, associated impacts on iron and manganese concentration trends, and the potential impacts to receptors (if any).

2.2.3. Information Inputs / Data Needs

The information inputs required to accomplish the project goals are:

- Historical information reviewed/gathered to-date, including the results of previous investigations and remedial actions, and 23 years of LTM groundwater data to evaluate historical trends for COCs and arsenic. Historical groundwater data for VPH, iron, manganese, and field parameters are summarized in **Table 3-1**. Information on existing monitoring wells is provided in **Table 3-2**. Historical groundwater data for benzene and toluene are summarized in **Table 3-3**.
- Current analytical data for ROD-specified COCs and additional analytes arsenic and VPH from existing monitoring wells/piezometers and new proposed bedrock monitoring well locations upgradient/ downgradient of the former petroleum release areas to determine vertical and lateral extent of COCs and arsenic/VPH.
- Historical geologic, hydrogeologic/hydraulic, and chemical data required to evaluate fate and transport.
- Current geologic, hydrogeologic/hydraulic, and chemical data required to evaluate fate and transport.
    - Geologic information from new proposed monitoring well locations to evaluate potential natural sources of reducing conditions
    - Water levels for hydrogeologic/hydraulic evaluation
    - Field Parameters for evaluating temporal trends in general water quality conditions that affect stability and solubility of iron and manganese:
        - DO
        - ORP
        - Specific conductance
        - Temperature
        - Turbidity
        - pH
    - Laboratory Analyses for geochemical evaluation:
        - Alkalinity – consistent with LTMMP (Sovereign/HGL 2015).

- Aluminum (total and dissolved) –Used as a non-redox-sensitive proxy for evaluating potential for fine suspended particulates to influence other dissolved metals analyses (including iron).
- Total organic carbon (TOC) – Used to evaluate residual reducing potential in the aquifer (specifically, potential for ongoing dissolved oxygen consumption).
- Sulfate – Used as secondary line of evidence for aquifer reducing potential resulting from potential historical sulfate reduction in petroleum hydrocarbon biodegradation zones.

Site conditions at AOC 43G are well documented with historical LTM data collected between 1999 and 2021. However, during the 23 years of LTM, the number of monitoring wells sampled was reduced due to optimization. Therefore, to evaluate the ROD-stipulated remedy for possible modification, the Army will collect supplemental data at AOC 43G from three newly installed monitoring wells and a larger group of existing monitoring wells and piezometers.

2.2.4. Boundaries of Study

The general areal boundaries for the SRI are the former AAFES fuel USTs and waste oil UST and associated downgradient extents of the ROD-specified COCs and arsenic (**Figure 1-2**).

Historical impacts at AOC 43G are attributed to petroleum discharges to ground and vehicle maintenance activities conducted at Historical Gas Station G (Area 1) and at the AAFES gas station (Building 2008) (Areas 2 and 3). Investigations conducted in 1992 and 1993 identified petroleum-related impacts to soil and groundwater within Areas 2 and 3. Impacted soil was removed during UST removals in 1990, 1992, and 1996.

2.2.5. Decision Rules

To meet the goals of the SRI, groundwater samples will be collected from existing monitoring wells, existing piezometers, and from new proposed monitoring wells to accurately define/confirm the lateral and vertical extent of contamination, effectively evaluate ROD-specified COC concentration trends, monitor attainment of ROD-specified RAOs and cleanup goals, assess/evaluate potential off-site migration of all ROD-specified COCs and arsenic, and confirm the protectiveness of the remedy. All groundwater samples will be collected and analyzed in accordance with the technical guidance instruction (TGI) and Standard Operating Procedure (SOP) documents included in the LTMMP QAPP to ensure that subsequent decisions are made based on valid data. Presence/absence of the ROD-specified COCs and arsenic will be based on the laboratory limits of detection (LODs) presented in the LTMMP QAPP.

Using data collected during the SRI and historical data, the following questions will be asked to determine if additional SRI data is required. If answered yes, then the Army will propose to USEPA and MassDEP that additional sampling is not required, the remedy is protective, and the site may be suitable for reduced monitoring. If answered no, the Army will propose additional activities and/or evaluations to USEPA and MassDEP to ensure the remedy is protective.

- Is there sufficient current data to confirm the current lateral and vertical extent of ROD-specified COCs and arsenic and additional analytes arsenic and VPH in groundwater (i.e., are locations with samples exceeding screening criteria bounded by samples from locations not exceeding screening criteria)?
    - If yes, the Army will propose to USEPA and MassDEP that no additional sampling is required during the SRI to confirm the current lateral and vertical extent of ROD-specified COCs and additional analytes arsenic and VPH.
    - If no, the Army will propose activities to USEPA and Mass DEP to collect additional data as needed.

- Is there sufficient current and historical data to establish a stable or decreasing trend of ROD-specified COCs and additional analytes arsenic and VPH in groundwater?
    - If yes for a decreasing trend for a ROD-specified COC or VPH, the Army will propose to USEPA and MassDEP that no additional sampling may be required, LTM remedy is protective, and the ROD-specified COC or VPH may be suitable for reduced monitoring or removal from LTM program.
    - If yes for a stable trend for a ROD-specified COC or VPH below screening criteria, the Army will propose to USEPA and MassDEP that no additional sampling may be required, LTM remedy is protective, and the ROD-specified COC or VPH may be suitable for reduced monitoring or removal from the LTM program.
    - If yes for a stable trend above screening criteria, additional sampling may be required, but the ROD-specified COC may be suitable for reduced monitoring.
    - If no, the Army will propose additional activities to USEPA and Mass DEP as needed based on the data..

3. Conceptual Site Model

This section presents a discussion of the CSM for Devens and, specifically, for AOC 43G.

3.1. Regional

3.1.1. Physical Characteristics

The regional topography of Devens is characterized as an undulating glacial terrain derived from glacial erosion and deposition on crystalline bedrock. Landforms at Devens include areas of extensive flat uplands interspersed with kame and kettle topography that range from areas of comparatively low topographic relief to elongated hills (i.e., drumlins) (HLA 2000). Terrain generally falls into three types encountered at Devens:

- **Bedrock Terrain** – Least common; generally consisting of crystalline bedrock topographical highs that are resistant to both glacial and fluvial erosion. Where bedrock is not directly exposed, a thin veneer of glacial sediments may be present.
- **Glacial Till** – More common; primarily consisting of highly variable sediments deposited by glaciers and conforming to the underlying bedrock surface.
- **Glacial-Meltwater Streams and Lake Deposits** – Most common; predominantly consisting of sediments deposited by glacial-meltwater outwash and ancient proglacial lake accumulations.

The major glacial sediment units consist of glacial till, deltaic deposits from former glacial Lake Nashua, and deposits from glacial meltwater streams. The thickness of glacial till at Devens varies between 10 and 60 feet, consists of unstratified gravel to silt, and typically contains boulders. The glacial lake deposits consist chiefly of sand and gravelly sand. Lake bottom deposits consist of sand, silt, and clay. Post-glacial deposits consist of river terrace sands and gravels, fine alluvial sands, and silts, as well as peat, silt, and sands in swampy areas. Overburden deposits are up to 300 feet thick (areas along Cold Spring Brook), whereas lowland Nashua River floodplain deposits, consisting of sand, fine gravel, and silt, are up to 25 feet thick.

The crystalline bedrock at Devens consists of slightly weathered, sparsely fractured, low-grade gneiss and granite (HLA 2000). Bedrock strike and dip are variable across Devens due to the folded nature of the formations and the presence of numerous faults that align with major unit contacts.

3.1.2. Hydrogeology

Regionally, groundwater and surface water bodies across Devens ultimately discharge into the Nashua River, whose tributaries include Nonacoicus Brook and Walker Brook on the former North Post.

Overburden (glacial meltwater deposits) constitutes the primary groundwater aquifer at Devens. Zones of highest transmissivity within the overburden are generally found in areas of thick glacial meltwater deposits, including the former Main Post area where AOC 43G is located. Several public water supply wells, including the Shabokin, Patton, MacPherson, and Grove Pond wells, are all installed within these meltwater deposits and can reportedly yield several hundred gallons per minute (gpm). Hydraulic conductivity values have been reported to vary between 30 to 300 feet per day (ft/day) in meltwater deposits, while lake bottom sediments are significantly less permeable with reported hydraulic conductivities ranging from 0.002 to 0.3 ft/day (HLA 2000). The zones of lowest groundwater transmissivity at Devens are typically associated with exposed till and fractured bedrock. The depth to groundwater across the former Main Post (including AOC 43G) ranges from less than 1-foot below ground surface (bgs) to more than 40 feet bgs and averages approximately 15 feet bgs. Overburden groundwater is recharged in upland areas, and flow generally follows topography—from topographic highs to topographic lows, where it discharges to wetlands, ponds, streams, and directly into the Nashua River.

3.2. AOC 43G

The physical characteristics and hydrogeology for AOC 43G are summarized in the following sections.

3.2.1. Physical Characteristics / Use

AOC 43G is located just west of Robbins Pond and mid-slope (eastern slope) along a small ridge separating the Nashua River and Willow Branch. The area is primarily covered by pavement, sloping to the southeast. Public access to AOC 43G is restricted, as the AOC is located within a secure US Army Garrison area of Devens (with gated entry). The property remains owned and under the control of the US Army and a portion of the property is used for equipment storage. The remainder of the property is empty parking areas and a former vehicle washing station.

Future residential use of land at AOC 43G is prohibited by LUCs; the Devens Reuse Plan (Vanasse Hangen Brustlin [VHB] 1994) does not include residential development of land in the vicinity of AOC 43G.

3.2.2. Topography / Geology

Surface topography across AOC 43G generally conforms to the bedrock surface topography across the area. The overburden beneath AOC 43G is composed of unconsolidated sand and gravel and contains a basal till at the base that conforms to the underlying bedrock topography. Beneath the former gas station, near Queenstown Street, the overburden is approximately 30 feet thick (i.e., top of the bedrock encountered at approximately 30 feet bgs) increasing to more than 100 feet thick along Barnum Road.

The bedrock underlying AOC 43G between Queenstown Street and monitoring well XGM-20-01A (an approximate distance of 650 feet) consists of the Oakdale Formation. Moving east towards Robbins Pond, the bedrock transitions to the Devens Gneiss Complex.

Adjacent to the former gas station/source area, the water table occurs in the deep overburden (approximately 25 feet bgs, well XGM-97-12X) slightly above the bedrock surface. Moving further downgradient, this thin saturated zone within the overburden (less than 10 feet thick near XGM-97-12X and XGM-93-02X) increases to more than 100 feet near Barnum Road/Robbins Pond.

3.2.3. Hydrogeology

Groundwater at AOC 43G flows to the east-southeast, consistent with the local topography, eventually discharging to surface water via an unnamed tributary to Robbins Pond and to Robbins Pond itself (**Figure 3-1**). The horizontal gradient varies seasonally between 0.036 and 0.052 ft/ft across the site (ABB 1996b). Near Robbins Pond, overburden groundwater turns north following/discharging along Willow Branch consistent with the local surface and bedrock topography. In-situ hydraulic conductivity estimates yield a mean value of $5.5\text{x}10^{-4}$ cm/sec for monitoring wells screened entirely in the overburden, and $1.7\text{x}10^{-5}$ cm/sec for monitoring wells screened entirely in the bedrock (ABB 1996b). Historical aquifer pumping tests completed yielded similar transmissivity values in the overburden (between 27 and 134 ft^2/day at monitoring well XGM-94-06X) and bedrock (between 27 and 340 ft^2/day at monitoring well XGM-94-04X).

3.2.4. Contaminant Source

As presented in the ROD, the primary site-related contaminants at AOC 43G were fuel-related contaminants in soil and groundwater associated with disposal of vehicle maintenance wastes in surface and near surface soil at AOC 43G associated with the former AAFES gas station located approximately 120 feet northeast of Historical Gas Station G and petroleum -related contaminants in soil and groundwater associated with three former 9,000-gallon USTs and two former 10,000-gallon gasoline USTs and associated piping and a former 500-gallon waste oil UST at the AAFES gas station.

Based on data collected during removal of the various USTs, the petroleum contamination is the result of petroleum leaks from the USTs and historical disposal of vehicle maintenance related wastes (i.e., petroleum, oil, and lubricants [POL]) to the ground surface.

3.2.5. Nature and Extent of BTEX, VPH, Iron, and Manganese

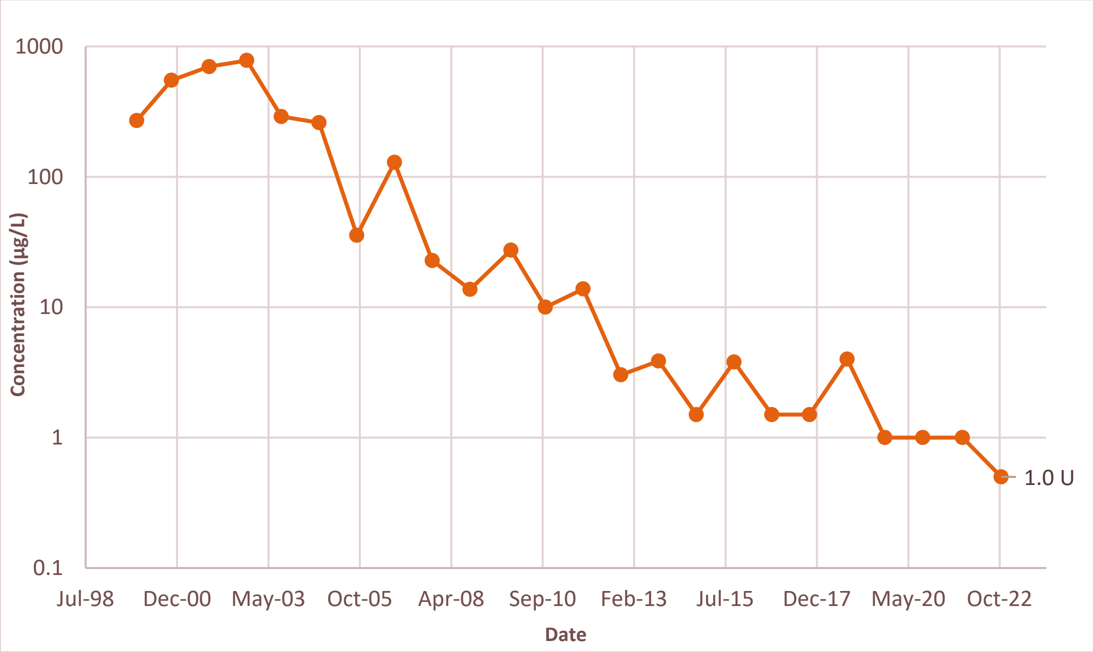
Petroleum discharges to the ground occurred in Areas 2 and 3 at AOC 43G during historical vehicle maintenance and fueling activities. While impacted soil was removed during UST removals in 1990, 1992, and 1996, residual petroleum remained in the subsurface. The natural degradation of the residual petroleum in the subsurface changed the geochemical conditions of the groundwater, which resulted in elevated concentrations of the naturally-occurring levels of iron and manganese. Groundwater has been sampled and analyzed as part of LTM since 1999. The 1996 ROD established cleanup goals for iron, manganese, nickel, benzene, ethylbenzene, and xylenes in groundwater at AOC 43G. VPH was established as an ongoing monitoring marker criterion by the Army during intrinsic remediation conducted at AOC 43G between 1997 and 1999. Because there is no MCL for VPH, concentrations are compared to the MCP standard. Toluene has been reported historically to provide a complete summary of BTEX laboratory parameters. Nickel was removed from the LTM program after 2008 because the MCL for nickel was remanded. The following sections discuss nature and extent of the AOC 43G COCs and VPH included in the current LTM program. Historical groundwater data is summarized in **Table 3-1.** Information on existing monitoring wells is provided in **Table 3-2.**

3.2.5.1. BTEX

Petroleum-related COCs identified in the 1996 ROD (USAEC) include benzene, ethylbenzene, and xylenes. The current LTMMP (Sovereign/HGL 2015) calls for BTEX analysis of groundwater samples; therefore, toluene, although not a COC, has been reported historically to provide a complete summary of BTEX laboratory parameters.

As shown in **Table 3-3,** benzene was historically detected above the cleanup goal in three monitoring well locations (AAFES-2, XGM-93-02X, and XGM-97-12X), but concentrations have been below the cleanup goal of 5 micrograms per liter (µg/L) at all LTM sampling locations since 2013. Toluene was detected above its MCL of 1,000 µg/L once in November 2000 at monitoring well XGM-97-12X (**Table 3-3**). While ethylbenzene and xylenes are analyzed for as part of the BTEX analysis, historically concentrations detected have been below cleanup goals, therefore, results are not included in **Table 3-3**. A time-concentration plots for benzene in monitoring well XGM-97-12X is provided below in **Exhibit 3-1:**

Exhibit 3-1: Historical Benzene Concentrations – Monitoring Well XGM-97-12X

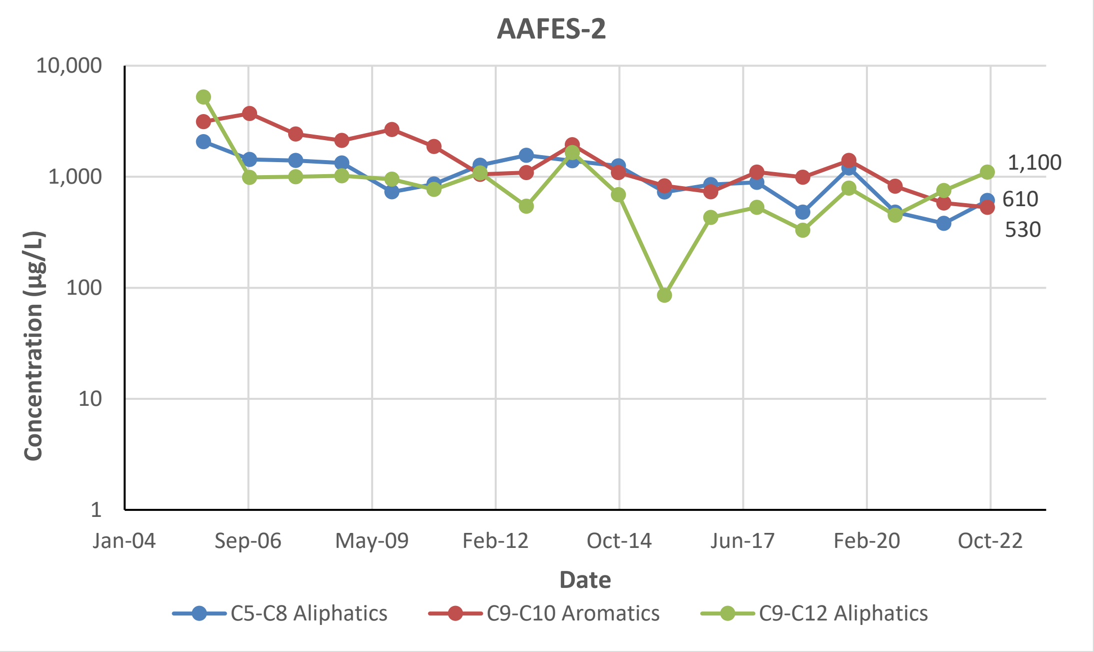


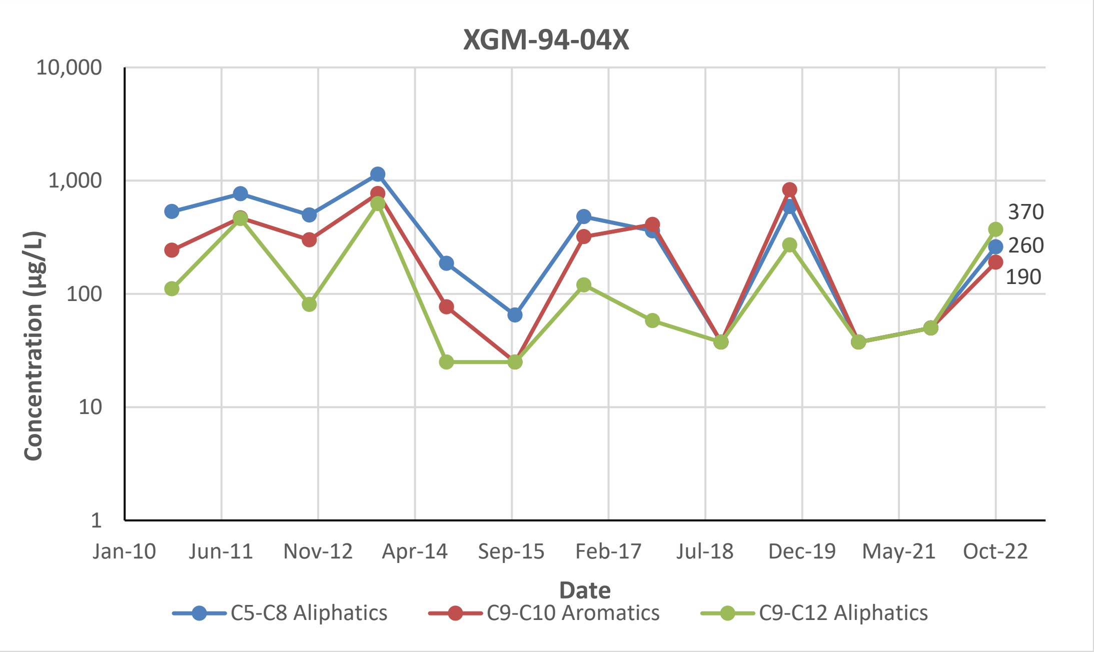
3.2.5.2. VPH

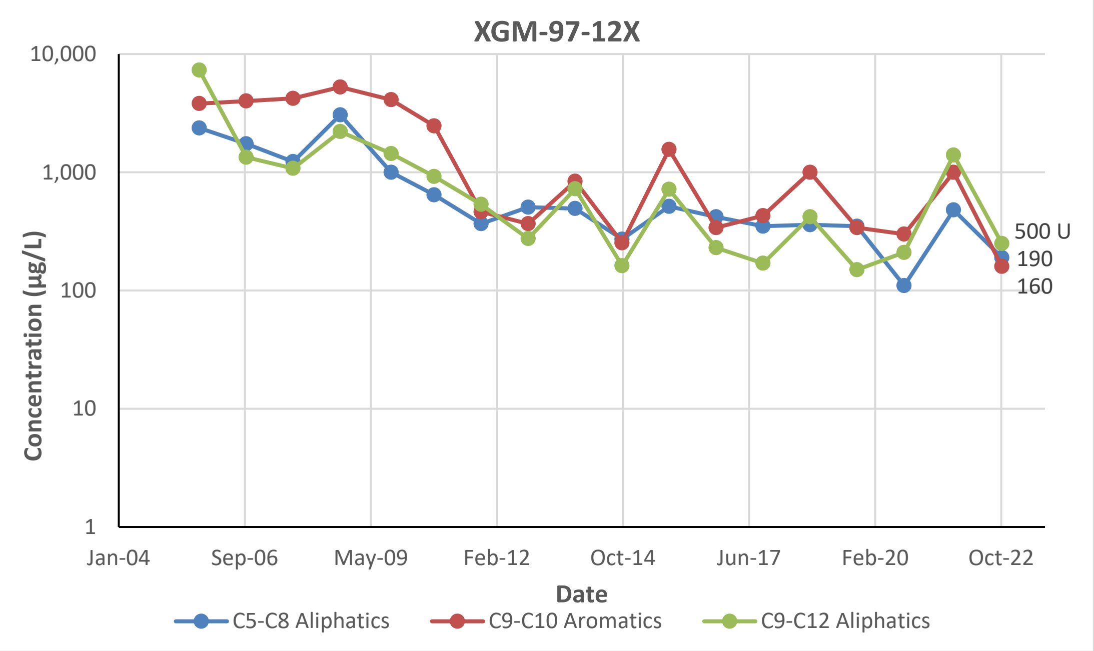
As previously discussed, the ROD (USAEC 1996) does not include VPH as a COC or establish a cleanup goal for VPH; VPH was established by the Army as a monitoring criterion during evaluation of intrinsic remediation conducted at AOC 43G between 1997 and 1999, and continues to be monitored as part of the LTMMP to track the attenuation of petroleum impacts over time (Sovereign/HGL 2015). Concentrations of VPH are compared to the MCP standard.

Concentrations of VPH consistently exceed the MCP standard for VPH in wells AAFES-2 and XGM-97-12X located adjacent to the historical petroleum release areas (**Figure 3-2**). One additional well (XGM-94-04X) has occasional exceedances of the MCP standard (five of the last 10 LTM monitoring events. Monitoring wells AAFES 6/6R and XGM-93-02X had VPH exceedances historically, but concentrations have attenuated to below laboratory reporting limits. Time-concentration plots for monitoring wells AAFES-2, XGM-94-04X, and XGM-97-12X are provided below in **Exhibit 3-2:**

Exhibit 3-2: Historical VPH Concentrations – Monitoring Wells AAFES-2, XGM-94-04X, and XGM-97-12X







3.2.5.3. Iron and Manganese

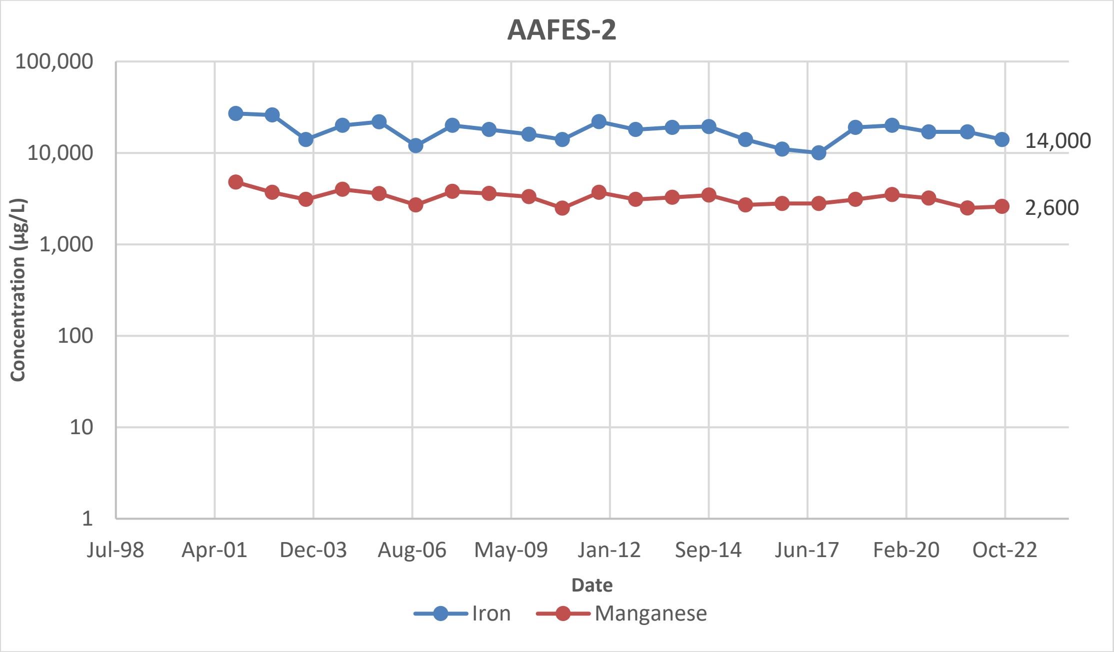
As discussed previously, elevated concentrations of naturally occurring iron and manganese in groundwater have decreased and/or stabilized at all locations but remain above the cleanup goal of 9,100 µg/L (iron) and 375 µg/L (manganese). **Figure 3-2** presents the locations of the AOC 43G monitoring wells, along with the most recent VPH and total iron/manganese concentrations collected from each historical sampling location.

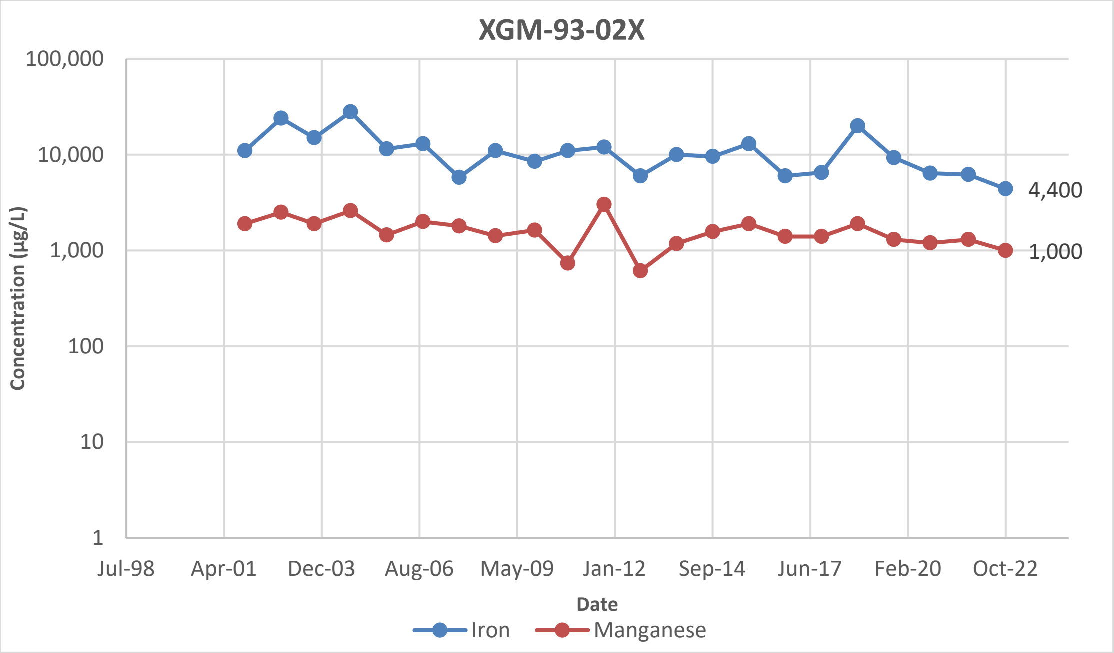
A recent statistical analysis was completed in 2021 using the Mann-Kendall analysis method. The following observations were noted and presented in the 2021 Annual Operations, Maintenance, and Monitoring Report (JV 2022):

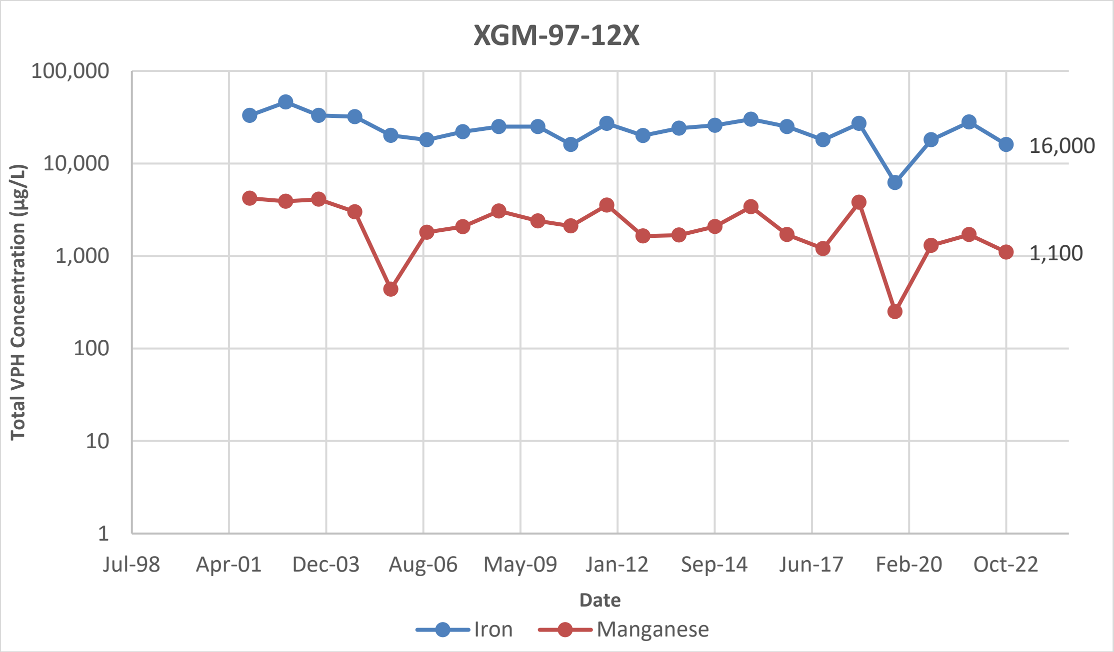
- Total manganese exceeded the 375 µg/L cleanup goal at three of five sampled wells. Concentrations were observed to be consistent with historical data. Of the wells evaluated using Mann-Kendall, three of five had statistically significant decreasing trends for total manganese: AAFES-2, XGM-93-02X, and XGM-97-12X. There was not a statistically significant trend at well AAFES-7.
- Total iron exceeded the 9,100 µg/L cleanup goal at two of four sampled wells. There was a statistically significant decreasing trend in total iron concentrations at the three wells evaluated: AAFES-2, XGM-93-02X, and XGM-97-12X.

Time-concentration plots for three of the above wells evaluated for both total manganese and iron (AAFES-2, XGM-93-02X, and XGM-97-12X) are provided below in **Exhibit 3-3.** Groundwater samples from these wells have historically contained the highest concentrations of total manganese and iron.

Exhibit 3-3: Historical Total Iron and Manganese Concentrations – Monitoring Wells AAFES-2, XGM-93-02X, and XGM-97-12X







3.2.6. Fate and Transport

As presented in the 1996 RI (ABB 1996a), the primary route of contaminant migration at AOC 43G are releases of POLs to surface and subsurface soils, then transport via leaching to groundwater. The release of POLs caused the historical VPH concentrations in groundwater and have contributed to the observed concentrations of iron and manganese in groundwater due to changes in geochemical conditions associated with the natural degradation of the residual petroleum compounds. As described in the 2020 FYR (KGS 2020) and 2020 Annual Operations, Maintenance, and Monitoring Report (JV 2021), groundwater flow at AOC 43G is to the east/southeast consistent with the local topography, eventually discharging to surface water via an unnamed tributary to Robbins Pond and to Robbins Pond itself.

The correlation between ORP, DO, and concentrations of the site COCs and arsenic have been examined historically, most recently in the 2020 FYR (KGS 2020). Historical ORP and DO field measurements are included in **Table 3-1**, and an average of measurements collected over the last five to 10 LTM sampling events (some wells have been sampled during less than 10 events historically, and arsenic has been analyzed 5 sampling events historically) are provided below in **Exhibit 3-4**:

Exhibit 3-4: Summary of Geochemical Conditions, October 2013 to October 2022

Well ID	ORP (mV)	DO (mg/L)	Geochemical Condition	Iron (µg/L)	Manganese (µg/L)	Arsenic (ug/L)
AAFES-2	-73.5	0.84	Reducing	16,040	2,993	21
AAFES-7	154.1	4.09	Oxidizing	1,286	864	2.9
XGM-93-02X	-36.1	0.93	Reducing	9,138	1,415	6.5
XGM-94-04X	-13.1	0.81	Reducing	1,516	2,017	3.8
XGM-94-07X	-2.4	1.13	Moderately reducing	9,280	5,255	6.7
XGM-94-08X	110.8	0.69	Moderately reducing	3,264	4,028	16
XGM-97-12X	-72.9	0.78	Reducing	21,800	1,821	17

Reducing conditions (negative ORP, DO less than 1 milligrams per liter (mg/L), manganese above 1,000 µg/L and iron above 5,000 µg/L) are observed in wells AAFES-2, XGM-93-02X, and XGM-97-12X with reducing conditions (negative ORP, DO less than 1 mg/L, iron and manganese above 1,000 µg/L) also observed, but to a lesser extent, in well XGM-94-04X. Moderately reducing conditions are observed in well XGM-94-07X and XGM-94-08X (positive ORP or DO greater than 1 mg/L), and metals concentrations remain elevated (iron and manganese above 3,000 µg/L). Well AAFES-7 is oxidizing and iron/manganese concentrations are lower compared to the other wells. Additional monitoring will be conducted at these locations, as detailed in **Section 4** of this SRI WP.

3.3. Potential Receptors and Exposure Pathways

Potential human and ecological receptors and exposure pathways were presented in the 1996 RI (ABB 1996a) based on the current and future land uses at AOC 43G and used to prepare human health and ecological risk assessments. The sections below present assumptions used in those assessments.

3.3.1. Human Receptors and Exposure Pathways

The current land use for AOC 43G is partially for equipment storage and partially empty parking areas. It is anticipated that the foreseeable future land use will be consistent with current land use (VHB 1994). Therefore, land use assumptions used for the HHRA prepared as part of the 1996 RI (ABB 1996a) remain the same.

Also consistent with the 1996 HHRA, potential current and future human receptors to groundwater may include site maintenance or utility workers. Future construction workers may be considered additional receptors in the event of site expansion or redevelopment.

The HHRA concluded that there were no unacceptable threats to human health from exposure to contaminated soil but did find potential threats to human health from future exposure to groundwater in the source area and downgradient of the source area. However, as discussed previously, there are existing LUCs at AOC 43G that prohibit residential development of the site and the use of site groundwater for drinking water.

Because there has been no change to underlying assumptions used to prepare the HHRA, no review of the HHRA is planned as part of the SRI.

3.3.2. Ecological Receptors and Exposure Pathways

Due to the urbanized nature of this site and the lack of exposure pathways (the site is paved), an ecological risk assessment was not performed as part of the 1996 RI.

Because there has been no change to site conditions, and no changes are anticipated, no ecological risk assessment is planned as part of the SRI.

4. Supplemental Remedial Investigation Implementation

As presented in **Section 2.2**, the objectives of the AOC 43G SRI are to confirm the Army Protectiveness Statement in the 2020 Five-Year Review Report (KGS 2020) and address items specified in the USEPA Additional Work Requirements Table. Specifically, the objectives of the SRI are to:

- Collect sufficient and accurate site-specific data needed to accurately define/confirm the lateral and vertical extent of contamination.
- Evaluate concentration trends of ROD-specified COCs and additional analytes (arsenic and VPH).
- Monitor attainment of ROD-specified RAOs and cleanup goals.
- Assess/evaluate potential off-site migration of ROD-specified COCs and additional analytes (arsenic and VPH).
- Assess short- and long-term protectiveness of the selected remedy.

To meet the SRI objectives, the study questions for this SRI are:

- What is the current lateral and vertical extent of benzene, ethylbenzene, and xylenes, and associated intrinsic bioremediation marker VPH, in groundwater?
- What is the current lateral and vertical extent of iron, manganese, and arsenic in groundwater at concentrations exceeding applicable standards?
- Is there a stable or decreasing concentration trend of ROD-specified COCs and additional analytes (arsenic and VPH) in groundwater?
- Are current reducing aquifer conditions associated with the petroleum releases or are they naturally occurring?
- Are ROD-specified COCs and arsenic migrating off Army property?

This section presents the comprehensive project approach, methods, and operational procedures to be used for the investigations performed at AOC 43G at former Fort Devens to meet the SRI objectives. Detailed descriptions are presented in the AOC 43G QAPP Addendum (**Appendix A**). Proposed investigation locations are discussed below.

4.1. Proposed Activities

As discussed in **Section 3**, historical data (**Table 3-1 and Table 3-3**) indicate that the extent of ROD-specified COCs and arsenic in groundwater at AOC 43G are well defined. The concentrations of petroleum-related COCs benzene, ethylbenzene, and xylenes have been below cleanup goals at all LTM sampling locations since 2013. Elevated concentrations of VPH (monitoring marker only; wells AAFES-2, XGM-94-04X, and XGM-97-12X) and iron/manganese (wells AAFES-2, AAFES-6/6R, AAFES-7, XGM-93-02X, XGM-94-04X, XGM-94-06X, XGM-94-07X, XGM-94-08X, and XGM-97-12X) are currently present in groundwater at AOC 43G **(Figure 3-2)**.

As discussed in **Section 1.4.2**, LTM groundwater data has been collected at AOC 43G for 23 years. This SRI WP proposes sampling of a subset of monitoring wells and piezometers installed at the site, including several of which were previously eliminated from the monitoring program as part of LTMMP optimization. This proposed sampling will provide a snapshot of current conditions and will support the decision-making process. Data generated during the SRI, along with historical data, will be used to determine if the remedy is still protective and answer the study questions established in **Section 2.2.1**.

To address the study questions for AOC 43G, the following activities are proposed:

- **To confirm that the current lateral extent of ROD-specified COCs and arsenic exceeding MCLs**, one new monitoring well (XGM-23-01) will be installed upgradient of the historical petroleum release areas. In addition, all locations shown on **Figure 4-1** will be sampled, including piezometers and monitoring wells installed in 2019/2020 by KGS (43GPZ-19-01 to 43GPZ-19-06, XGM-20-01A, XGM-20-02A, and XGM-20-03A). Information on existing monitoring wells is provided in **Table 3-2** and summarized below in **Exhibit 4-1**.

- **To confirm the current vertical extent of ROD-specified COCs and arsenic exceeding MCLs**, two new monitoring wells (XGM-23-02 and XGM-23-03) will be installed slightly downgradient of the historical petroleum release areas **(Figure 4-1)**. Up to two soil samples will be collected from each monitoring well boring during drilling to evaluate current source area petroleum hydrocarbon concentrations. Additional information on the proposed well installation depths and rationale is provided in **Section 4.2.3**. In addition, all locations shown on **Figure 4-1** will be sampled.

- **To determine if current reducing aquifer conditions are associated with the historical petroleum releases or are naturally occurring**, groundwater samples will be analyzed for VPH, Extractable Petroleum Hydrocarbons (EPH), BTEX, and total iron/manganese, as well as additional parameters (total and dissolved aluminum/arsenic, dissolved iron/manganese, TOC, and sulfate); the analytical results will be compared against the historical VPH/BTEX and iron/manganese data, as well as the spatial location of the sampling location. As presented in detail in **Section 2.2.3**, the field water quality parameters (DO, ORP, specific conductance, temperature, turbidity, and pH) and laboratory geochemical data will be used to evaluate residual reducing potential in the aquifer and assess the potential for fine suspended particulates to influence other dissolved metals analyses (including iron and manganese).

- **To evaluate trends in ROD specified COCs, arsenic, and EPH /VPH concentrations**, the existing and new monitoring wells listed above will be sampled on a quarterly basis for a period of one year. A statistical trend analysis (Mann Kendall + Theil-Sen slope analysis) of the new and existing data will be performed upon completion of the sampling.

Exhibit 4-1 presents the proposed groundwater sample locations and analytes. The proposed sample locations are shown on **Figure 4-1.**

Exhibit 4-1: AOC 43G Proposed Groundwater Sampling Locations and Laboratory Analyses

Well ID	Location Type	Rationale / Location	Analyte List					
			VPH, EPH + BTEX	Total As, Al, Mn, Fe	Dissolved As, Al, Mn, Fe	TOC	Sulfate	Intrinsic Bio-Remediation Parameters^3
XGM-23-01	MW (proposed)	Confirm lateral and vertical extent of petroleum compounds and iron/manganese/arsenic.	X	X	X	X	X	X
XGM-23-02			X	X	X	X	X	X
XGM-23-03			X	X	X	X	X	X
AAFES-2	MW (existing)	Source area well with COC exceedances (iron/manganese) and elevated VPH/arsenic.	X	X	X	X	X	X
AAFES-5		Confirm lateral extent of petroleum compounds and iron/manganese/arsenic.	X	X	X	X	X	X
AAFES-6R		Historical location with COC exceedances (iron and/or manganese).	X	X	X	X	X	X
AAFES-7			-	X	X	X	X	X
XGM-93-02X			X	X	X	X	X	X
XGM-94-04X		Source area well with elevated VPH. Historical location with COC exceedances (manganese).	X	X	X	X	X	X
XGM-94-06X		Historical location with COC exceedances (iron and/or manganese).	-	X	X	X	X	X
XGM-94-07X			X	X	X	X	X	X
XGM-94-08X			X	X	X	X	X	X
XGM-94-10X			-	X	X	X	X	X
XGM-97-12X		Source area well with COC exceedances (iron/manganese) and elevated VPH/arsenic.	X	X	X	X	X	X
XGM-20-01A		Confirm vertical and lateral extent of iron/manganese/arsenic.	-	X	X	X	X	X
XGM-20-02A			-	X	X	X	X	X
XGM-20-03A			-	X	X	X	X	X
43GPZ-19-01	PZ (existing)	Confirm lateral extent of iron/manganese/arsenic.	-	X	X	X	X	X
43GPZ-19-02			-	X	X	X	X	X
43GPZ-19-03		Confirm lateral extent of VPH and iron/manganese/arsenic.	X	X	X	X	X	X
43GPZ-19-04		Confirm lateral extent of iron/manganese/arsenic.	-	X	X	X	X	X
43GPZ-19-05			-	X	X	X	X	X
43GPZ-19-06			-	X	X	X	X	X

<u>NOTES</u>:
Al = aluminum
As -= arsenic
BTEX = benzene, toluene, ethylbenzene, xylenes
Fe = iron
Mn = manganese
TOC – total organic carbon
VPH = volatile petroleum hydrocarbons

1. Filtered groundwater samples will be sampled for dissolved metals only.
2. Water quality parameters, including DO, ORP, specific conductance, temperature, turbidity, and pH, will be collected during sampling to assess the degree of dissolved particulates and oxidizing/reducing conditions.
3. Nitrate/nitrite, phosphate, sulfide, alkalinity, ferrous iron, methane (baseline event only).

4.2. Methodology

Field activities will be conducted in accordance with the following TGIs and SOPs:

- TGI – Ground Penetrating Radar
- TGI – Manual Water-Level Monitoring
- TGI – Monitoring Well Installation
- TGI – Monitoring Well Development
- TGI – In-Situ and Ex-Situ Water Quality Parameters
- TGI – Sample Chain of Custody
- TGI – Investigation-Derived Waste Handling and Storage
- TGI – Groundwater and Soil Sampling Equipment Decontamination
- TGI – Soil Description
- SOP – Low Stress (low flow) Purging and Sampling Procedure for the Collection of Groundwater Samples from Monitoring Wells

These TGIs are included in the AOC 43G QAPP Addendum (**Appendix A**). Additional details concerning field activities are provided below.

4.2.1. Site Preparation

Before any intrusive activities, the S-A JV will implement the following utility locating procedures:

- Notify the Massachusetts Dig Safe System a minimum of 72-hours before any intrusive field work for underground utility clearance.
- Clear each drilling location of utilities with ground-penetrating radar.
- Conduct a detailed visual site inspection and review existing plans for possible utilities that potentially conflict with the planned activities.
- Use a soft dig method to a depth of 5 feet bgs to further clear the proposed locations before advancing any borings.

S-A JV field personnel will complete the site-specific munitions and explosives of concern (MEC) awareness training with the Devens Fire Department before the start of field activities. Field personnel will also have current health and safety training as required by state/federal regulations, such as 40-hour Hazardous Waste Operations and Emergency Response (HAZWOPER) training. Personnel responsible for overseeing drilling operations will have at least 5 years of prior relevant drilling experience.

4.2.2. Soil Boring Installation

Continuous logging of overburden soils will be conducted using hollow-stem auger or drive-and-wash methods at the proposed new monitoring well locations (XGM-23-01 to XGM-23-03). Soil borings will extend to the top of bedrock. An S-A JV field geologist will oversee the work and record soil lithology. Consistent with environmental investigation protocols, and because drilling is occurring within an area with historical petroleum impacts, soil will be screened for volatile organic compounds with a photoionization detector (PID) every 1 foot at the continuous logging locations. Soil descriptions will be recorded in accordance with the Unified Soil Classification System. The following will be recorded from each soil core at a minimum: depth interval, recovery, particle size, sorting, angularity/plasticity/dilatancy, principal and minor components, moisture, consistency/density, and color. When possible, the recovered soil cores will be photographed. Up to two soil samples will be collected from each boring for analysis of EPH and VPH to evaluate petroleum hydrocarbon source concentrations. Soil samples will be collected from the depth interval exhibiting the greatest indication of petroleum hydrocarbon contamination based on visual (i.e., staining) and/or screening (i.e., PID readings) observations and the interval directly above the water table (if present in the overburden).

4.2.3. Monitoring Well Installation

At location XGM-23-01, a permanent monitoring well will be installed to “straddle” the observed water table. Due to the unknown bedrock depth and water table at this location, the permanent monitoring well will either be an overburden, hybrid (screened across the overburden/bedrock contact) or shallow bedrock monitoring well. If hollow-stem auger or drive-and-wash methods are insufficient for achieving the target depth, air rotary or air-hammer drilling will used to drill into shallow bedrock. The installation of permanent steel casing is not anticipated to be necessary at this location. Instead, temporary steel casing will be utilized if needed.

At locations XGM-23-02 and XGM-23-03, shallow bedrock wells will be installed. Based on available drilling logs, existing wells AAFES-2 (adjacent to the XGM-23-02 drilling location) and XGM-94-04X (adjacent to the XGM-23-03 drilling location) are both installed to approximately 30 feet bgs, and the bedrock surface is at approximately 20 feet bgs. At each new well location, air hammer drilling will be used to drill to 40 feet bgs and create a socket for surface casing. Surface casing will be constructed of 4-inch diameter steel. Casing will be grouted in place and allowed to cure for a minimum of 24 hours before drilling resumes. Each bedrock borehole will be subsequently drilled to 50 feet bgs using 4-inch diameter air hammer drilling methods. While drilling, the field geologist will log changed drilling conditions include water-production, drilling rate, increased “chatter”, or changes in drilling return water color or turbidity. The driller will maintain an estimate of drilling water lost to the formation, if any. Rock cuttings will be logged for lithology to the extent possible. Once the target depth of 50 feet bgs is reached, a borehole yield test will be conducted to determine if the drilled section of the borehole has encountered water-bearing fractures of sufficient yield to test or build monitoring wells. The test will be completed as a drilling-water falling head test. With the tools removed from the borehole, water will be added to the top of casing. The water level in the borehole will be manually measured for 10 minutes. The rate of decline will be measured directly with a water level interface probe, and specific capacity (gpm per foot) will be estimated based on the casing diameter and volume. The recovery rate will be evaluated as follows:

- A total borehole recovery rate of greater than 0.25 gpm will be considered sufficient yield for well construction.
- A total borehole recovery rate of less than 0.25 gpm will be considered insufficient yield for well construction. Drilling will continue to 60 feet bgs, and the test will be repeated. If insufficient yield is encountered in the subsequent test, the location will be abandoned and no well will be installed.

The wells will be completed flush with the surface grade encased by a 2-foot by 2-foot concrete pad and secured using an 8-inch protective roadbox or 4-inch-diameter steel standpipe. Well construction details (including any materials used) will be recorded by a SERES-Arcadis JV field geologist. At the proposed XGM-23-01 location, it is anticipated that the permanent monitoring well will be constructed of 2-inch diameter schedule 40 polyvinyl chloride with a 10-foot-long screen (10-slot size [0.01-inch]). At the proposed XGM-23-02 and XGM-23-03 locations, it is anticipated that open borehole construction will be used, due to the planned permanent casing depth (40 feet bgs) and maximum drilling depth (60 feet bgs). The measuring points and well labels will be marked with an indelible ink pen on both the inner and outer well casings or inside the roadbox lid. All drilling and well construction will be completed by a licensed Massachusetts driller under the oversight of a SERES-Arcadis

JV geologist and will be conducted in accordance with all promulgated state and federal laws. All well locations will be surveyed by a licensed Massachusetts surveyor for northing, easting, and ground/top of casing elevations.

4.2.4. Monitoring Well Development

Each monitoring well will be developed using a submersible pump and surge block to remove fines and improve the hydraulic connection of the well with the native formation. In addition, each open bedrock borehole will be initially developed with the drill rig using air-lift methods to remove any remaining sediment and rock flour generated during the drilling process. This development will ensure hydraulic communication of any fractures encountered with the borehole.

4.2.5. Groundwater Sampling and Water Level Measurements

Prior to collecting groundwater samples, a synoptic water level gauging event will be conducted at all wells and piezometers within the study shown on **Figure 4-1** prior to sampling to confirm groundwater flow direction and vertical hydraulic gradients. This synoptic event will also include obtaining a measurement from the existing staff gauge in Robbins Pond (RPSG-01).

Groundwater samples will be collected from each new monitoring well location, as well as existing monitoring wells and piezometers, as described in **Exhibit 4-1**. Samples will be collected in accordance with the TGI. Groundwater sampling will be completed on a quarterly basis for one year (four sampling events), and a synoptic water level gauging event will be conducted prior to each sampling event to confirm groundwater flow direction.

To evaluate redox status and attenuation potential, samples from monitoring wells will be analyzed for the following additional parameters (in addition ROD-specified analytes [total iron and manganese], total arsenic, and VPH):

- **Total and dissolved aluminum**, to assess the potential for presence of sub-0.45-micron particulates. Aluminum is anticipated to exhibit extremely low solubility at the observed groundwater pH. The presence of total aluminum would therefore indicate suspended particulates present in the groundwater sample, while the presence of dissolved aluminum correlated to total aluminum would indicate the presence of very fine (sub-0.45-micron) particulates.

- **Dissolved iron, manganese, and arsenic**. Dissolved iron, manganese, and arsenic will be collected to evaluate redox status and attenuation potential via iron coprecipitation upon reoxidation, and as an additional line of evidence regarding potential for suspended particulates affecting COC and arsenic concentrations.

- **TOC and sulfate**, to assess redox status and residual reducing potential. TOC will contribute to ongoing reducing potential by consuming dissolved oxygen (potentially limiting iron reoxidation and extending the timeframe for iron and manganese attenuation), while comparison of sulfate concentrations inside and outside of the historical petroleum hydrocarbon impacts may inform extent of historical sulfate reduction. If sulfate reduction has occurred, sulfide minerals in the formation may further extend time for attenuation of iron and manganese.

To update the previous intrinsic bioremediation evaluation, samples collected during the baseline event at all locations will be analyzed for the following additional groundwater parameters:

- Nitrate/nitrite
- Phosphate
- Sulfide

- Alkalinity
- Ferrous iron.
- Dissolved methane

In addition to the above parameters, DO, ORP, specific conductance, temperature, turbidity, and pH, will be collected during sampling at each monitoring well location. Field parameter stabilization requirements will be followed for each monitoring well location.

4.2.6. Waste Management

Investigation-derived waste (IDW) generated during the proposed activities will include purged groundwater and drill cuttings, as well as general site refuse. IDW management procedures are presented in Worksheet #17-12 of the QAPP Addendum and will be managed in accordance with TGI – Investigation-Derived Waste Handling and Storage and previous waste management practices at Devens.

Drill cuttings generated during investigation activities will be spread on the ground surface adjacent to the site of generation or moved to nearby wooded areas located within the site boundaries. Groundwater generated (including drilling water and rinsate water) will be discharged to the ground surface at the site of generation. If petroleum impacts/sheens are observed in any of the drill cuttings or purge water, the IDW will be containerized and transported to a central staging area for subsequent characterization and off-site disposal.

4.3. Risk Assessment

The 1996 HHRA (ABB 1996a) evaluated potential health risks to commercial/industrial workers associated with contaminants detected in soil and groundwater at AOC 43G. Due to the urbanized nature of this site and the lack of exposure pathways (the site is paved), an ecological risk assessment was not performed. The HHRA concluded that there were no unacceptable threats to human health from exposure to contaminated soil but did find potential threats to human health from future exposure to groundwater in the source area and downgradient of the source area.

Because there has been no change to underlying assumptions, and no changes are anticipated, no review of the HHRA or preparation of an ecological risk assessment is planned as part of the SRI.

5. Deliverables

5.1. Supplemental Remedial Investigation Report

After completion of the field activities, a Post-ROD SRI Report will be prepared to present and evaluate the efficacy of the data for meeting the stated DQOs.

The report will also include the following:

- Site description to include climate, topography, vegetation, geology, hydrology and hydrogeology, and natural resources.
- Site history and previous investigations.
- Description of the SRI field activities (i.e., groundwater sample collection).
- Results of the field activities.
- CSM update, including the nature and extent of contamination, and contaminant fate and transport.
- Findings and conclusions.
- Recommendations.

As appropriate, soil and geologic logs, survey reports, cross sections, geophysical test results, laboratory data, data validation reports, and pertinent field data logs will be included as appendices to the SRI Report.

6. Schedule

The anticipated project schedule is presented below in **Table 6-1**.

Table 6-1 Anticipated Project Schedule

Task	Date
Work Plan	
Army Submits Draft AOC 43G Supplemental RI Work Plan to USEPA/MassDEP	6/13/22
USEPA/MassDEP Review of Draft AOC 43G Supplemental RI Work Plan	8/4/22
Army Issues Response Letter to USEPA/MassDEP Comments on Draft AOC 43G Supplemental RI Work Plan	10/3/22
USEPA/MassDEP Review of Response Letter to USEPA/MassDEP Comments on Draft AOC 43G Supplemental RI Work Plan	12/20/22
Army Submits Draft Final AOC 43G Supplemental RI Work Plan to USEPA/MassDEP	1/19/23
USEPA/MassDEP Review of Draft Final AOC 43G Supplemental RI Work Plan[1]	4/20/23
Army Submits Revised Draft Final AOC 43G Supplementation RI Work Plan to USEPA/MassDEP[2]	4/26/23
EPA/DEP Review Revised Draft Final AOC 43G Supplementation RI Work Plan to USEPA/MassDEP[2]	5/11/23
Army Submits Final AOC 43G Supplemental RI Work Plan to USEPA/MassDEP	6/02/23
Field Work (tentative)	**Summer 2023 – Summer 2024**
Submit Draft Supplemental RI Report (pending field work)	**Winter 2024**

Notes:

[1] USEPA provided proposed revisions to Draft Final Work Plan text on 4/20/23.

[2] Army submitted proposed revisions to Draft Final Work Plan text to USEPA (MassDEP copied) on 4/25/23.

7. References

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Tables

Table 3-1
Historical Groundwater Monitoring Results - VPH, Metals, Field Parameters
AOC 43G Supplemental Remedial Investigation Work Plan
Former Fort Devens Army Installation
Devens, Massachusetts

Analyte		VPH***			Total Metals			Field Parameters			
		C5-C8	C9-C10	C9-C12	Arsenic	Iron	Manganese	pH	SPC	ORP	DO
Unit		(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	SU	µS/cm	mV	mg/L
Cleanup Goal*		NS	NS	NS	NS	9,100	375				
Monitoring Criteria**		300	200	700	10	9,100	291				
Well ID	Date										
AAFES-2	Dec-99	1,000 U	**9,400**	250 U	--	**24,000**	**4,600**	--	--	--	--
	Nov-00	**1,400**	**7,200**	81	--	**20,000**	**3,900**	--	--	--	--
	Nov-01	ND	**5,300**	ND	--	**27,000**	**4,800**	--	--	--	--
	Nov-02	**1,200**	**13,000**	200	--	**26,000**	**3,700**	--	--	--	--
	Oct-03	**1,200**	**6,600**	250 U	--	**14,000**	**3,100**	--	--	-133	0.54
	Oct-04	**1,100**	**6,700**	57	--	**20,000**	**4,000**	--	--	-269	0.33
	Oct-05	**2,070**	**3,130**	**5,220**	--	**21,900**	**3,590**	--	--	-151	0.47
	Oct-06	**1,430**	**3,710**	**987**	--	**12,000**	**2,700**	--	--	-109	0.60
	Oct-07	**1,400**	**2,420**	**1,000**	--	**20,000**	**3,790**	--	--	-185	0.26
	Oct-08	**1,330**	**2,120**	**1,020**	--	**18,000**	**3,600**	--	--	1.0	0.59
	Nov-09	**730**	**2,660**	**950**	--	**16,000**	**3,320**	7.0	880	-124	2.5
	Oct-10	**859**	**1,870**	**768**	--	**14,000**	**2,490**	--	--	--	--
	Oct-11	**1,270**	**1,050**	**1,080**	--	**22,000**	**3,700**	6.7	1,240	-93	0.37
	Oct-12	**1,560 J**	**1,090**	542 J	--	**18,000**	**3,100**	7.2	1,001	-136	0.65
	Oct-13	**1,390**	**1,940**	**1,650**	--	**19,000**	**3,270**	7.0	1,020	-56	1.2
	Oct-14	**1,250**	**1,090**	688	--	**19,400**	**3,460**	7.0	1,010	-111	0.49
	Oct-15	**728**	**827**	85.7	--	**14,000**	**2,700**	7.3	1,200	-79	1.4
	Oct-16	**850**	**730**	430	**16**	**11,000**	**2,800**	7.2	990	-80	0.48
	Oct-17	**890**	**1,100 J**	530 J	**13**	**10,000**	**2,800**	7.1	1,400	-82	0.32
	Oct-18	**480 J**	**990**	330 J	**20**	**19,000**	**3,100**	6.6	2,100	-64	0.45
	Oct-19	**1,200**	**1,400**	**790**	**42**	**20,000**	**3,500**	6.8	1,900	-57	2.6
	Oct-20	**480**	**820**	450 J	**13**	**17,000**	**3,200**	6.6	1,610	11	0.32
	Oct-21	**380 J**	**580**	**750**	--	**17,000**	**2,500**	6.8	1,700	-111	0.61
	Oct-22	**610**	**530**	**1,100**	--	**14,000**	**2,600**	6.8	1,740	-106	0.54
AAFES-5	Dec-99	100 U	25 U	25 U	--	25 J	**710**	--	--	--	--
	Nov-00	--	--	--	--	--	180	--	--	--	--
	Nov-01	--	--	--	--	--	190	--	--	--	--
	Nov-02	--	--	--	--	--	27	--	--	--	--
	Oct-03	100 U	25 U	25 U	--	660	21	--	--	202	5.6
	Oct-04	100 U	25 U	25 U	--	170	89	--	--	248	5.1
	Oct-05	--	--	--	--	916	118	--	--	130	2.2
	Oct-06	--	--	--	--	120	50	--	--	259	5.8
	Oct-07	--	--	--	--	120	34	--	--	54	3.1
	Oct-08	50 U	50 U	50 U	--	80 U	10 U	--	--	247	2.8
	Nov-09	50 U	50 U	50 U	--	60 U	10 U	5.8	1,140	15	6.8
	Oct-10	--	--	--	--	--	244	--	--	--	--
	Oct-11	50 U	50 U	70.9	--	40 J	36	5.9	1,160	-123	1.8
	Oct-12	50 U	50 U	50 U	--	220	206	6.2	1,130	234	0.68
	Oct-13	50 U	50 U	66	--	50 U	127	6.0	1,520	275	1.7
	Oct-14	50 U	50 U	50 U	--	50 U	33	5.8	680	228	4.5
AAFES-6/6R	Dec-99	**370**	170	25 U	--	**11,000**	**2,900**	--	--	--	--
	Nov-00	**420**	--	--	--	**9,200**	**9,200**	--	--	--	--
	Nov-01	290	--	--	--	**13,000**	**3,400**	--	--	--	--
	Nov-02	ND	--	--	--	**9,400**	**3,000**	--	--	--	--
	Oct-06	**305**	--	--	--	**11,000**	**2,900**	--	--	-76	0.30
	Oct-07	ND	--	--	--	**11,000**	**3,090**	--	--	-143	2.7
	Oct-08	177	50 U	50 U	--	6,500	**3,630**	--	--	54	1.0
	Nov-09	56	11.3 J	19.5 J	--	4,300	**907**	6.6	980	6.9	2.2
	Oct-10	114	--	--	--	3,300	**1,670**	--	--	--	--
	Oct-11	50 U	50 U	50 U	--	1,100	**1,830**	6.5	1,050	-204	0.35
	Oct-12	215	50 U	50 U	--	6,900	**3,220**	6.8	890	-74	0.22
	Oct-13	287	50 U	107	--	**9,200**	**2,820**	6.7	1,130	5.0	0.70
	Oct-14	188	50 U	50 U	--	8,240	**3,000**	6.6	1,600	-29	1.9
AAFES-7	Jun-08	--	--	--	--	--	106	--	--	202	4.5
	Oct-08	--	--	--	--	--	20 U	--	--	223	6.4
	Nov-09	--	--	--	--	--	81	6.5	606	130	9.3
	Oct-10	--	--	--	--	--	79	--	--	--	--
	Oct-11	--	--	--	--	--	5.0 J	6.2	1,041	109	1.6
	Oct-12	--	--	--	--	--	**706**	6.5	1,418	230	1.9
	Oct-13	--	--	--	--	--	**2,390**	6.4	1,720	175	5.2
	Oct-14	--	--	--	--	53 J	**1,640**	6.2	1,380	119	4.2
	Oct-15	--	--	--	--	--	140	5.8	1,800	160	6.9
	Oct-16	--	--	--	1.5 U	180	**510**	6.5	1,150	67	3.3
	Oct-17	--	--	--	1.5 U	--	**330**	6.5	1,700	140	3.4
	Oct-18	--	--	--	3.0 U	--	16	6.1	1,700	190	0.57
	Oct-19	--	--	--	3.0 U	110	86	6.3	2,300	170	5.6
	Oct-20	75 U	75 U	75 U	10	4,800	**3,400**	6.2	1,200	180	2.4
	Oct-21	--	--	--	--	--	47	6.5	986	160	2.4
	Oct-22	--	--	--	--	--	77	6.4	2,100	180	6.9

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Analyte		VPH***			Total Metals			Field Parameters			
		C5-C8	C9-C10	C9-C12	Arsenic	Iron	Manganese	pH	SPC	ORP	DO
Unit		(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	SU	µS/cm	mV	mg/L
Cleanup Goal*		NS	NS	NS	NS	9,100	375				
Monitoring Criteria**		300	200	700	10	9,100	291				
Well ID	Date										
XGM-93-02X	Dec-99	1,000 U	**510**	250 U	--	**30,000**	**3,900**	--	--	--	--
	Nov-00	**570**	**2,300**	39	--	**18,000**	**2,500**	--	--	--	--
	Nov-01	270	**1,100**	ND	--	**11,000**	**1,900**	--	--	--	--
	Nov-02	**790**	**3,600**	58	--	**24,000**	**2,500**	--	--	--	--
	Oct-03	**410**	**1,600**	33	--	**15,000**	**1,900**	--	--	-113	0.39
	Oct-04	**570**	**3,700**	34	--	**28,000**	**2,600**	--	--	-106	0.60
	Oct-05	**788**	**918**	**1,570**	--	**11,500**	**1,450**	--	--	-162	5.8
	Oct-06	**519**	**766**	268	--	**13,000**	**2,000**	--	--	-117	0.20
	Oct-07	ND	**228**	94	--	5,800	**1,800**	--	--	-166	3.4
	Oct-08	**311**	**325**	182	--	**11,000**	**1,420**	--	--	-14	0.60
	Nov-09	132	110	55.5	--	8,500	**1,630**	6.7	979	-19	0.44
	Oct-10	124	73.4	ND	--	**11,000**	**737**	--	--	--	--
	Oct-11	50 U	50 U	85.1	--	**12,000**	**3,020**	6.4	1,220	-180	0.50
	Oct-12	50 U	50 U	50 U	--	6,000	**612**	6.5	890	-21	0.35
	Oct-13	65	ND	100	--	**10,000**	**1,180**	6.8	1,070	20	0.46
	Oct-14	268	113	76.6	--	**9,580**	**1,570**	6.7	369	-91	1.9
	Oct-15	101	62.3	50 U	--	**13,000**	**1,900**	6.9	1,400	-60	0.40
	Oct-16	94	100 U	56	--	6,000	**1,400**	--	--	--	--
	Oct-17	79 J	100 U	78 J	4.3	6,500	**1,400**	6.8	1,900	-55	0.26
	Oct-18	84 J	75 J	75 U	**11**	**20,000**	**1,900**	6.6	2,600	-63	2.4
	Oct-19	210	100	79 J	5.2	**9,300**	**1,300**	6.6	2,300	-45	0.39
	Oct-20	150	66 J	64 J	5.4	6,400	**1,200**	6.7	1,200	-51	0.80
	Oct-21	130	100 U	94 J	--	6,200	**1,300**	6.3	1,973	44	0.64
	Oct-22	110	100 U	100 U	--	4,400	**1,000**	6.5	1,200	-24	1.08
XGM-94-04X	Dec-99	1,000 U	200	25 U	--	5,500	**2,900**	--	--	--	--
	Nov-00	**420**	**570**	--	--	--	**2,200**	--	--	--	--
	Nov-01	140	170	--	--	--	**3,400**	--	--	--	--
	Nov-02	ND	28	--	--	--	**2,000**	--	--	--	--
	Oct-03	100 U	25 U	25 U	--	210	**1,400**	--	--	23	0.50
	Oct-04	100 U	25 U	25 U	--	350	**790**	--	--	260	0.81
	Oct-05	ND	ND	--	--	205	**1,580**	--	--	-98	6.9
	Oct-06	ND	ND	--	--	50 U	**1,100**	--	--	-76	0.40
	Oct-07	ND	ND	--	--	50 U	**559**	--	--	1.0	0.74
	Oct-08	50 U	50 U	50 U	--	50 U	68	--	--	153	0.80
	Nov-09	50 U	50 U	50 U	--	1,800	**2,730**	6.7	785	140	3.9
	Oct-10	**533**	**243**	111	--	4,500	**6,490**	7.3	788	-212	0.92
	Oct-11	**765**	**469**	462	--	1,900	**2,140**	6.7	1,077	-32	0.19
	Oct-12	**497 J**	**300 J**	80.7 J	--	1,000	**2,580**	7.1	766	-105	0.24
	Oct-13	**1,140**	**769**	626	--	2,200	**2,730**	7.1	1,030	-13	0.64
	Oct-14	186	76.8	50 U	--	684	**1,510**	7.0	1,340	-43	0.34
	Oct-15	65	50 U	50 U	--	670	**1,100**	7.3	1,100	-9.6	0.40
	Oct-16	**480**	**320**	120	4.3	1,600 J	**1,500**	7.1	970	25	1.2
	Oct-17	**360**	**410 J**	58 J	3.5	1,400	**1,700**	7.0	1,600	-1.9	0.35
	Oct-18	75 U	75 U	75 U	1.6 J	140	230	6.5	2,300	180	0.44
	Oct-19	**590**	**830**	270 J	8.1	3,200	**5,500**	7.1	2,000	-78	0.20
	Oct-20	75 U	75 U	75 U	3.0 U	50 U	13	6.9	1,080	-51	3.0
	Oct-21	100 U	100 U	100 U	--	440	290	6.7	1,885	-0.5	0.82
	Oct-22	260	190	370	--	4,800 J	**5,600**	7.3	1,710	-139	0.71
XGM-94-06X	Jun-08	--	--	--	--	--	**793**	--	--	-96	6.6
	Oct-19	--	--	--	--	5,500	**1,400**	6.8	1,700	-6.6	0.87
	Oct-20	75 U	75 U	75 U	2.6 J	1,600	**1,800**	6.8	1,500	57	0.56
XGM-94-07X	Dec-99	100 U	25 U	25 U	--	3,500	**5,700**	--	--	--	--
	Nov-00	ND	ND	ND	--	2,900	**3,700**	--	--	--	--
	Nov-01	ND	ND	ND	--	5,800	**6,100**	--	--	--	--
	Nov-02	ND	ND	ND	--	2,300	**4,500**	--	--	--	--
	Oct-03	100 U	25 U	25 U	--	1,000	**3,600**	--	--	33	1.8
	Oct-04	100 U	25 U	25 U	--	300	**1,000**	--	--	-238	2.3
	Oct-05	ND	ND	ND	--	1,610	**6,120**	--	--	75	0.54
	Oct-06	113	ND	ND	--	1,400	**5,100**	--	--	12	0.40
	Oct-07	ND	ND	ND	--	4,500	**4,120**	--	--	-111	0.55
	Oct-08	157	45.1 J	89.8	--	**9,300**	**5,100**	--	--	25	0.24
	Nov-09	151	76.4	89.1	--	8,800	**4,990**	6.6	960	-3.4	2.2
	Oct-10	159	77.8	54.5	--	**12,000**	**3,870**	6.7	715	-137	1.6
	Oct-11	50 U	50 U	90.5	--	**13,000**	**6,060**	6.5	1,174	-32	2.4
	Oct-12	66	50 U	50 U	--	**23,000**	**5,560**	6.6	1,066	-58	0.24
	Oct-13	120	50 U	66.8	--	**10,000**	**5,380**	6.7	1,470	21	1.3
	Oct-14	58.8	50 U	50 U	--	6,820	**6,940**	6.5	2,260	-11	0.92
	Oct-19	--	--	--	--	8,300	**4,200**	6.8	2,700	-19	0.50
	Oct-20	75 U	75 U	75 U	6.7	**12,000**	**4,500**	6.5	1,830	-0.4	1.8

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Analyte		VPH***			Total Metals			Field Parameters			
Unit		C5-C8 (µg/L)	C9-C10 (µg/L)	C9-C12 (µg/L)	Arsenic (µg/L)	Iron (µg/L)	Manganese (µg/L)	pH SU	SPC µS/cm	ORP mV	DO mg/L
Cleanup Goal*		NS	NS	NS	NS	9,100	375				
Monitoring Criteria**		300	200	700	10	9,100	291				
Well ID	**Date**										
XGM-94-08X	Dec-99	120	25 U	25 U	--	4,800	**4,500**	--	--	--	--
	Nov-00	150	ND	ND	--	**13,000**	**4,600**	--	--	--	--
	Nov-01	100	ND	ND	--	4,500	**4,900**	--	--	--	--
	Nov-02	140	ND	ND	--	4,600	**3,600**	--	--	--	--
	Oct-03	120	25 U	25 U	--	3,200	**3,600**	--	--	-57	0.78
	Oct-04	ND	ND	ND	--	2,500	**3,800**	--	--	-11	1.6
	Oct-05	ND	ND	ND	--	4,520	**7,260**	--	--	-116	7.7
	Oct-06	125	ND	ND	--	6,100	**4,200**	--	--	-138	0.50
	Oct-07	ND	ND	ND	--	4,600	**3,380**	--	--	-94	5.5
	Oct-08	73.6	50 U	50 U	--	2,200	**3,100**	--	--	69	0.16
	Nov-09	50 U	50 U	6.19 J	--	1,300	**2,150**	6.8	826	122	2.1
	Oct-10	50 U	50 U	50 U	--	1,000	**2,070**	6.7	649	143	0.46
	Oct-11	50 U	50 U	50 U	--	750	**2,780**	6.6	1,190	38	0.13
	Oct-12	50 U	50 U	50 U	--	2,300	**4,620**	7.0	1,020	218	0.80
	Oct-13	50 U	50 U	50 U	--	910	**2,300**	6.8	1,330	241	1.1
	Oct-14	50 U	50 U	50 U	--	147	**3,210**	6.7	1,050	43	0.22
	Oct-19	--	--	--	--	1,000	**3,500**	6.6	1,800	50	0.22
	Oct-20	75 U	75 U	75 U	**16**	**11,000**	**7,100**	6.8	1,290	109	1.2
XGM-94-10X	Dec-99	100 U	25 U	25 U	--	510	**830**	--	--	--	--
	Nov-00	--	--	--	--	--	**2,000**	--	--	--	--
	Nov-01	--	--	--	--	--	**2,600**	--	--	--	--
	Nov-02	--	--	--	--	--	31	--	--	--	--
	Oct-03	100 U	25 U	25 U	--	250	120	--	--	238	7.8
	Oct-04	100 U	25 U	25 U	--	120	**960**	--	--	233	2.5
	Oct-05	--	--	--	--	120	**960**	--	--	-23	4.7
	Oct-06	--	--	--	--	170	**330**	--	--	182	1.8
XGM-97-12X	Dec-99	**970**	**4,500**	96	--	**32,000**	**6,300**	--	--	--	--
	Nov-00	**1,300**	**5,500**	ND	--	**26,000**	**4,100**	--	--	--	--
	Nov-01	**1,100**	**5,400**	ND	--	**33,000**	**4,200**	--	--	--	--
	Nov-02	**1,100**	**7,500**	130	--	**46,000**	**3,900**	--	--	--	--
	Oct-03	**1,100**	**8,700**	250 U	--	**33,000**	**4,100**	--	--	-102	0.33
	Oct-04	ND	**7,400**	90	--	**32,000**	**3,000**	--	--	-80	0.83
	Oct-05	**2,370**	**3,810**	**7,310**	--	**20,100**	**437**	--	--	-80	0.30
	Oct-06	**1,740**	**4,010**	**1,340**	--	**18,000**	**1,800**	--	--	-111	0.20
	Oct-07	**1,230**	**4,220**	**1,080**	--	**22,000**	**2,070**	--	--	--	--
	Oct-08	**3,060**	**5,260**	**2,210**	--	**25,000**	**3,060**	--	--	-52	1.1
	Nov-09	1,000 U	**4,110**	**1,440**	--	**25,000**	**2,390**	6.7	1,140	-34	0.21
	Oct-10	**644**	**2,470 J**	**922**	--	**16,000**	**2,110**	6.6	726	-81	0.30
	Oct-11	**367**	**463**	535	--	**27,000**	**3,540**	6.6	1,240	-75	0.31
	Oct-12	**507 J**	**367 J**	275 J	--	**20,000**	**1,640**	6.5	1,160	-97	0.20
	Oct-13	**494**	**840**	**724**	--	**24,000**	**1,680**	6.5	1,680	-18	0.17
	Oct-14	272	**253**	162	--	**25,800**	**2,080**	6.7	486	-99	0.49
	Oct-15	**515**	**1,560**	**718**	--	**30,000**	**3,400**	7.5	1,300	-140	0.38
	Oct-16	**420**	**340**	230	**21**	**25,000**	**1,700**	6.8	1,400	-39	0.20
	Oct-17	**350**	**430 J**	170 J	**14**	**18,000**	**1,200**	6.8	1,700	-76	0.19
	Oct-18	**360**	**1,000**	420 J	9.8	**27,000**	**3,800**	6.6	2,300	-79	3.1
	Oct-19	**350**	**340**	150 J	**18**	6,200	250	6.3	280	-2.9	0.38
	Oct-20	110	**300**	210 J	**21**	**18,000**	**1,300**	6.3	1,500	-40	1.3
	Oct-21	**480**	**1,000**	**1,400**	--	**28,000**	**1,700**	7.0	1,704	-126	0.64
	Oct-22	190 J	160	500 U	--	**16,000**	**1,100**	6.8	1,430	-110	0.94
43GPZ-19-03	Feb-20	--	--	--	--	50 U	1.5 J	6.8	1,880	223	6.6
XGM-20-01A	Feb-20	--	--	--	--	50 U	64	7.6	1,790	211	8.7
XGM-20-02A	Feb-20	--	--	--	--	22 J	360	6.8	1,830	190	6.1
XGM-20-03A	Feb-20	--	--	--	--	210	**400 J**	6.4	1,800	171	4.8

120 = Above cleanup goal and/or monitoring criteria

-- = Not analyzed

* = The cleanup goal for iron is the background level. The cleanup goal for manganese is a site-specific goal established as part of the long-term monitoring plan for the site (Long-Term Monitoring Plan Former Fort Devens Army Installation, HGL, 2008).

** = The monitoring criteria for iron and manganese is the background from the RI (Final Remedial Investigation Report Area of Contamination (AOC) 43G, ABB Environmental Services, Inc., 1996). The monitoring criterion for arsenic is the MCL.

[3] The VPH carbon ranges are not contaminants of concern and are evaluated against Massachusetts Contingency Plan GW-1 standards for comparison purposes.

µg/L = microgram per liter
µS/cm = microSiemen per centimeter
J = Estimated result
mg/L = milligram per liter

mV = millivolt
ORP = oxidation-reduction potential
U = Non-detect

Table 3-2
Existing Monitoring Wells
AOC 43G Supplemental Remedial Investigation Work Plan
Former Fort Devens Army Installation
Devens, Massachusetts

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Location ID	Well Type	Top of Casing Elevation	Ground Surface Elevation	Bedrock Depth	Top of Screen Interval	Bottom of Screen Interval	Top of Screen Interval	Bottom of Screen Interval	DTW October 2021	GWE October 2021
		(ft NAVD88)	(ft NAVD88)	(ft BGS)	(ft BGS)	(ft BGS)	(ft NAVD88)	(ft NAVD88)	(ft BTOR)	(ft NAVD88)
Monitoring Wells										
AAFES-2	HYB	301.72	299.47	20	16.2	31.2	283.27	268.27	22.21	279.51
AAFES-5	OB	299.80	300.01	30	15.5	30.5	284.21	269.51	21.71	278.09
AAFES-6R	OB	298.74	296.77	25	15.0	25.0	281.77	271.77	18.61	280.13
AAFES-7	OB	258.80	256.21	NE	4.5	14.5	251.21	241.71	7.52	251.28
XGM-93-02X	HYB	309.01	309.40	34.5	28.0	39.0	281.40	271.40	28.03	280.98
XGM-94-04X	BR	300.69	298.30	18	20.5	30.5	280.10	270.10	18.72	281.97
XGM-94-06X	HYB	284.07	281.40	27	17.0	27.0	264.40	254.40	19.04	265.03
XGM-94-07X	HYB	294.82	292.20	20.5	17.0	27.0	275.20	265.20	19.34	275.48
XGM-94-08X	HYB	298.98	296.40	27	23.5	33.5	272.90	262.90	25.04	273.94
XGM-94-10X	OB	301.96	299.60	NE	21.5	31.5	278.10	268.10	24.13	277.83
XGM-97-12X	HYB	308.70	306.26	30	24.0	34.0	285.26	275.26	24.52	284.18
XGM-20-01A	BR	257.50	257.91	15	10.5	20.5	247.41	237.41	--	--
XGM-20-02A	BR	265.10	265.36	11	13.0	23.0	252.36	242.36	--	--
XGM-20-03A	HYB	268.69	268.88	25	20.0	30.0	248.88	238.88	--	--
Piezometers										
43GPZ-19-01	--	280.67	281.14	20	9.8	19.8	271.31	261.31	--	--
43GPZ-19-02	--	290.09	290.39	30	19.3	29.3	271.06	261.06	--	--
43GPZ-19-03	--	307.99	308.22	26.5	15.0	25.0	293.22	283.22	--	--
43GPZ-19-04	--	256.75	254.20	26	2.0	12.0	252.20	242.20	--	--
43GPZ-19-05	--	254.82	255.09	37	6.0	16.0	249.09	239.09	--	--
43GPZ-19-06	--	254.86	255.05	51	10.0	20.0	245.05	235.05	--	--
43GPZ-19-07	--	246.59	246.73	25	3.0	13.0	243.73	233.73	--	--
43GPZ-19-08	--	257.69	257.85	106	13.0	23.0	244.85	234.85	--	--

Notes:

* feet below ground surface
AOC = Area of Contamination
BR = bedrock
COC = chemical of concern
ft = feet
ft BTOR = feet below top of riser

HYB = overburden/bedrock hybrid
LTM = long-term monitoring
NAVD 88 = North American Vertical Datum of 1988
NE = not encountered
OB = overburden

Table 3-3
Historical Groundwater Monitoring Results – Benzene/Toluene
AOC 43G Supplemental Remedial Investigation Work Plan
Former Fort Devens Army Installation
Devens, Massachusetts

Sample Location	Dec-99	Nov-00	Nov-01	Nov-02	Oct-03	Oct-04	Oct-05	Oct-06	Oct-07	Oct-08	Nov-09	Oct-10	Oct-11	Oct-12	Oct-13	Oct-14	Oct-15	Oct-16	Oct-17	Oct-18	Oct-19	Oct-20	Oct-21	Oct-22
Benzene- 5 µg/L Cleanup Goal																								
AAFES-2	**62**	**36**	**43**	**26**	**9.0**	**6.6**	**6.1**	1.3	40 U	20 U	3.93 J	20 U	20 U	**6.60 J**	**5.04**	3.7	4.2	3.0 U	3.0 U	2.0	1.5 J	2.0 U	2.0 U	1.0 U
XGM-93-02X	**81**	**32**	**12**	**140**	**24**	**39**	**29**	**18.5**	**8.8**	2.6	0.997 J	2.0 U	2.0 U	2.0 U	2.0 U	0.77 J	2.0 U	3.0 U	0.38 J	0.60 J	2.0 U	2.0 U	2.0 U	1.0 U
XGM-97-12X	**270**	**550**	**700**	**780**	**290**	**260**	**35.6**	**129**	**22.8**	**13.7 J**	**27.4 J**	20 U	**13.8**	3.03 J	3.87	1.5	3.8	3.0 U	3.0 U	4.0	2.0 U	2.0 U	2.0 U	1.0 U
Toluene- 1,000 µg/L Monitoring Criteria																								
XGM-97-12X	390	**1,100**	870	1,000	610	460	53.4	239	15.9	11.4 J	5.3 J	20 U	10 U	2.0 U	2.54	5.0 U	7.4	5.0 U	5.0 U	5.1	1.6 J	3.8 U	1.9 J	1.0 U

Notes:

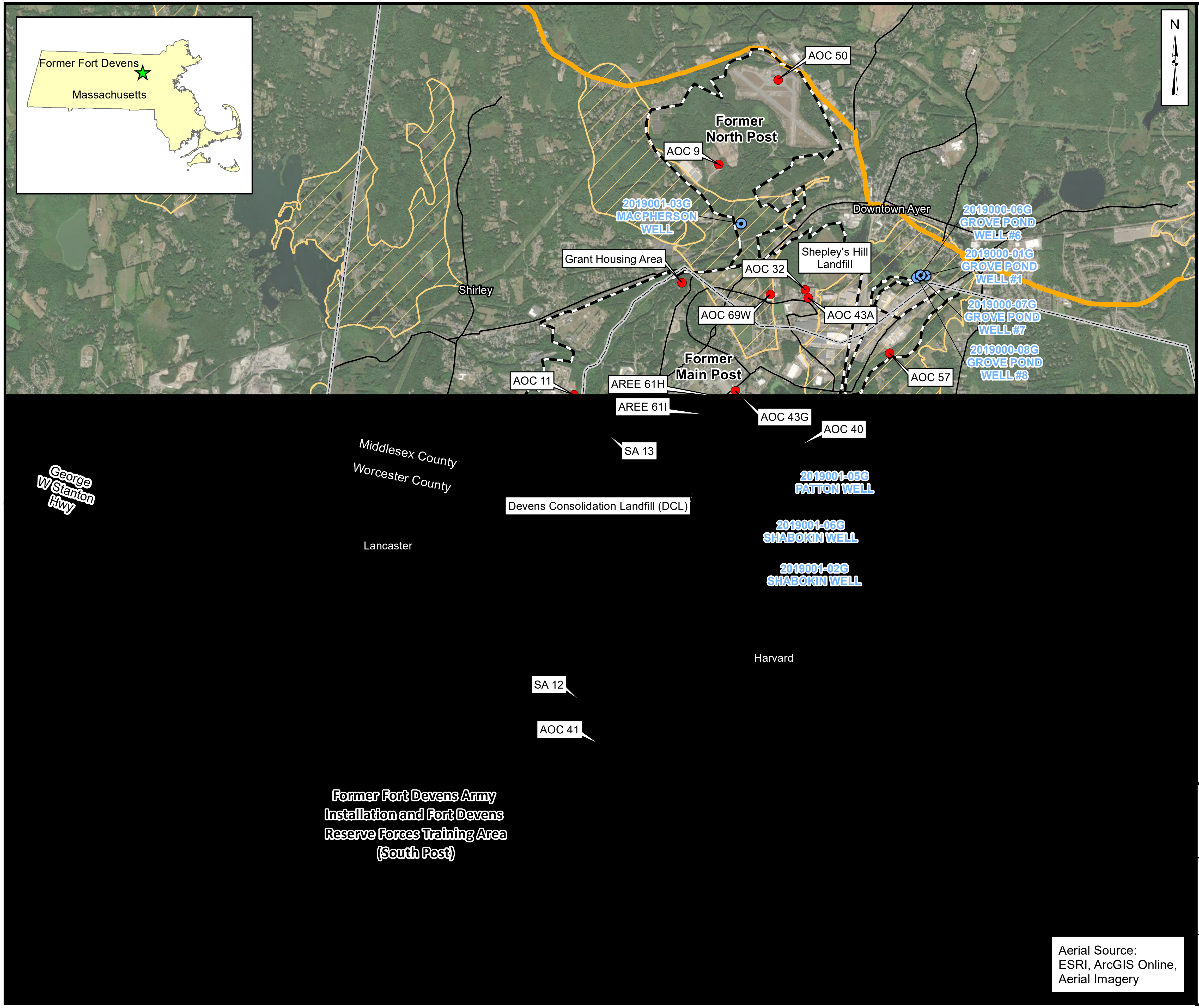
118 = Above cleanup goal and/or monitoring criteria `

Benzene, ethylbenzene, xylenes, and toluene are not contaminants of concern but the cleanup goals are the Maximum Contaminant Levels.

The ROD does not include a Cleanup Goal for toluene; this parameter has been reported historically to provide a complete summary of BTEX laboratory parameters.

µg/L = microgram per liter
J = Estimated result
U = Non-Detect

Figures



Aerial Source:
ESRI, ArcGIS Online,
Aerial Imagery

Legend

▭	Former Fort Devens Boundary
●	Area of Contamination (AOC)
⦿	Water Supply Well
---	County Line
▬	Highway
―	Major Road
▨	MassDEP Zone II Wellhead Protection Area

MassDEP = Massachusetts Department of Environmental Protection

AOC 43G Supplemental Remedial Investigation Work Plan
Former Fort Devens Army Installation
Devens, Massachusetts

Site Location
Former Fort Devens
Army Installation

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Figure
1-1

T:_ENV\Devens_RFTA\Seed_Task_Order\MXDs\Area 1 Phase 2 Work Plan\01052022\Figure 1-1 - Site Location.mxd 1/5/2022 1:25:46 PM User Name: MSMiller

Aerial Source:
Google Earth, 2018

Legend

●	LTM Sample Well
●	LTM Well - Gauge Only
●	Monitoring Well
●	Piezometer
▲	Staff Gauge
▭	Approximate Historical Extent of Groundwater Contamination in Exceedance of Cleanup Goals (based on 1999 to 2008 analytical data) (2008 Annual Report, HGL, 2009)
🟪	Area 1
🟥	Area 2 - Former UST Area
▭	Area 3 - Former UST Area
🟩	Former Gasoline UST(s)
🟫	Former Waste Oil UST
🟨	Former Waste Oil AST
〰	Stream
▨	Waterbody
∧	Topographic Contour (ft AMSL)
▨	MassDEP Zone II Wellhead Protection Area

AST = aboveground storage tank
ft AMSL = feet above mean sea level
LTM = long-term monitoring
MassDEP = Massachusetts Department of Environmental Protection
UST = underground storage tank

0 300 600
Feet

AOC 43G Supplemental Remedial Investigation Work Plan
Former Fort Devens Army Installation
Devens, Massachusetts

Site Layout
AOC 43G

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Figure
1-2

T:_ENV\Devens_RFTA\Seed_Task_Order\MXDs\AR2023 - MP\Figure 1-2 - AOC43G Site Layout.mxd 1/19/2023 2:04:14 PM User Name: ski01076

Aerial Source:
Google Earth, 2018

Legend

●	LTM Sample Well
●	LTM Well - Gauge Only
●	Monitoring Well
●	Piezometer
〰	Groundwater Elevation Contour (ft NAVD88) (Contour Interval = 5 ft)
☐	Approximate Historical Extent of Groundwater Contamination in Exceedance of Cleanup Goals (based on 1999 to 2008 analytical data) (2008 Annual Report, HGL, 2009)
☐	Area 1
☐	Former Gasoline UST(s)
☐	Former Waste Oil UST
☐	Former Waste Oil AST
☐	Former UST Area
〰	Stream
▨	Waterbody
〰	Topographic Contour (ft AMSL)
▨	MassDEP Zone II Wellhead Protection Area
(261.33)	Groundwater Elevation (ft NAVD88)

Notes:
AST = aboveground storage tank
ft AMSL = feet above mean sea level
LTM = long-term monitoring
MassDEP = Massachusetts Department of Environmental Protection
NAVD88 = North American Vertical Datum of 1988
UST = underground storage tank

0 300 600
Feet

AOC 43G Supplemental Remedial Investigation Work Plan
Former Fort Devens Army Installation
Devens, Massachusetts

Groundwater Elevation Contour Map
AOC 43G
Fall 2022

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Figure
3-1

Document Path: T:_ENV\Devens_RFTA\Seed_Task_Order\MXDs\AR2022 - MP\2022-02-23\Figure 11 - AOC43G GWC1020.mxd

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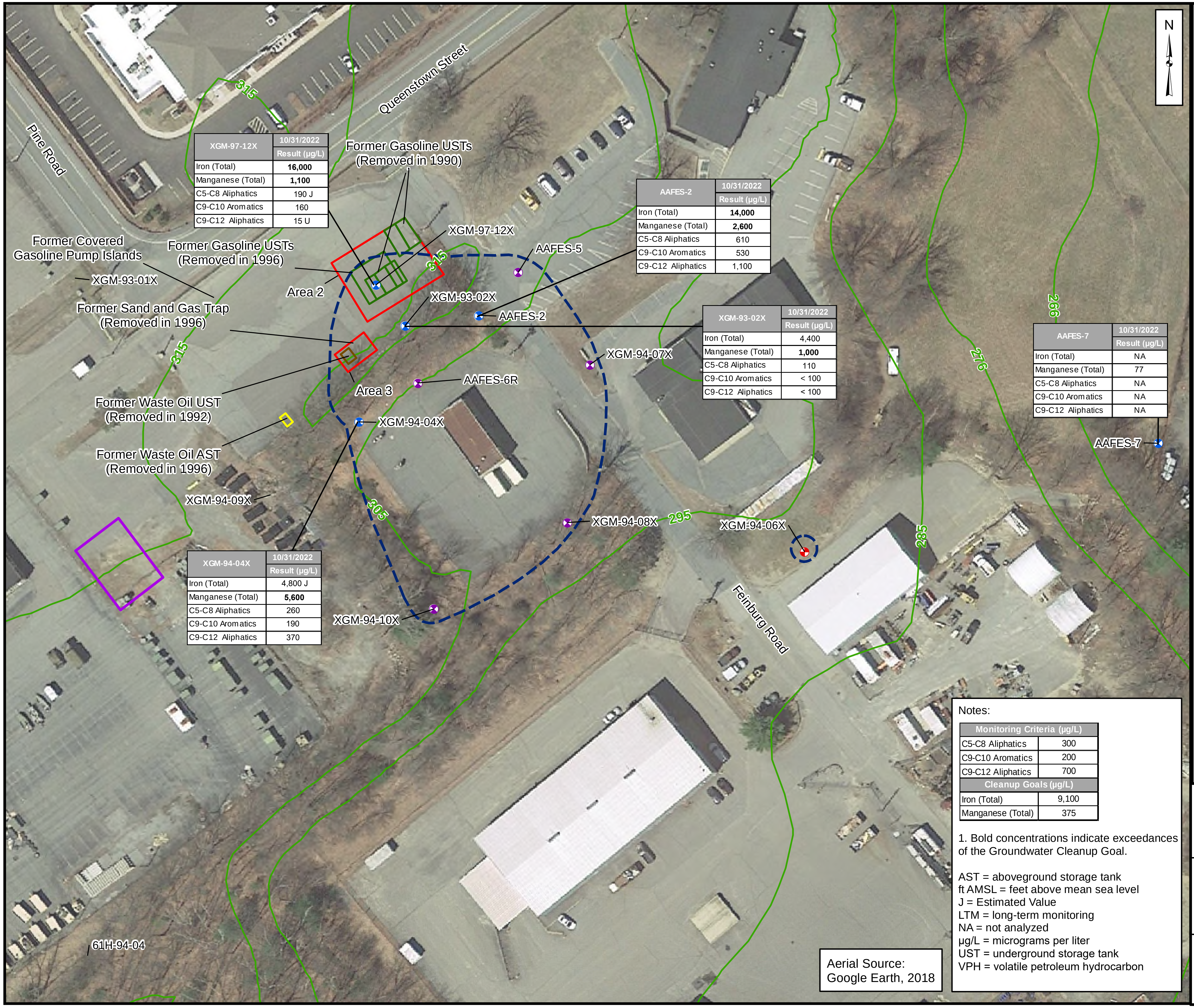

XGM-97-12X	10/31/2022 Result (µg/L)
Iron (Total)	**16,000**
Manganese (Total)	**1,100**
C5-C8 Aliphatics	190 J
C9-C10 Aromatics	160
C9-C12 Aliphatics	15 U

AAFES-2	10/31/2022 Result (µg/L)
Iron (Total)	**14,000**
Manganese (Total)	**2,600**
C5-C8 Aliphatics	610
C9-C10 Aromatics	530
C9-C12 Aliphatics	1,100

XGM-93-02X	10/31/2022 Result (µg/L)
Iron (Total)	4,400
Manganese (Total)	**1,000**
C5-C8 Aliphatics	110
C9-C10 Aromatics	< 100
C9-C12 Aliphatics	< 100

AAFES-7	10/31/2022 Result (µg/L)
Iron (Total)	NA
Manganese (Total)	77
C5-C8 Aliphatics	NA
C9-C10 Aromatics	NA
C9-C12 Aliphatics	NA

XGM-94-04X	10/31/2022 Result (µg/L)
Iron (Total)	4,800 J
Manganese (Total)	**5,600**
C5-C8 Aliphatics	260
C9-C10 Aromatics	190
C9-C12 Aliphatics	370

Aerial Source:
Google Earth, 2018

Notes:

Monitoring Criteria (µg/L)	
C5-C8 Aliphatics	300
C9-C10 Aromatics	200
C9-C12 Aliphatics	700
Cleanup Goals (µg/L)	
Iron (Total)	9,100
Manganese (Total)	375

1. Bold concentrations indicate exceedances of the Groundwater Cleanup Goal.

AST = aboveground storage tank
ft AMSL = feet above mean sea level
J = Estimated Value
LTM = long-term monitoring
NA = not analyzed
µg/L = micrograms per liter
UST = underground storage tank
VPH = volatile petroleum hydrocarbon

Legend

●	LTM Sample Well
●	LTM Well - Gauge Only
●	Monitoring Well
▭	Approximate Historical Extent of Groundwater Contamination in Exceedance of Cleanup Goals (based on 1999 to 2008 analytical data) (2008 Annual Report, HGL, 2009)
🟪	Area 1
🟩	Former Gasoline UST(s)
🟫	Former Waste Oil UST
🟨	Former Waste Oil AST
🟥	Former UST Area
╱╲	Topographic Contour (ft AMSL)

0 100 200
Feet

AOC 43G Supplemental Remedial Investigation Work Plan
Former Fort Devens Army Installation
Devens, Massachusetts

VPH and Metals Concentrations in Groundwater, AOC 43G
Fall 2022

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Figure
3-2

File: Figure 12 - AOC43G GW Results - Fall2021.mxd

Aerial Source:
Google Earth, 2018

Legend

⊗	Monitoring Well (to be sampled)
▲	Piezometer (to be sampled)
▲	Piezometer (no sampling)
△	Staff Gauge
●	Proposed Monitoring Well Location
⬚	Approximate Historical Extent of Groundwater Contamination in Exceedance of Cleanup Goals (based on 1999 to 2008 analytical data) (2008 Annual Report, HGL, 2009)
☐	Area 1
☐	Area 2 - Former UST Area
☐	Area 3 - Former UST Area
☐	Former Gasoline UST(s)
☐	Former Waste Oil UST
☐	Former Waste Oil AST
〰	Stream
●	Waterbody
∧	Topographic Contour (ft AMSL)
▨	MassDEP Zone II Wellhead Protection Area

Notes:
AST = aboveground storage tank
ft AMSL = feet above mean sea level
LTM = long-term monitoring
MassDEP = Massachusetts Department of Environmental Protection
UST = underground storage tank

0 300 600
Feet

AOC 43G Supplemental Remedial Investigation Work Plan
Former Fort Devens Army Installation
Devens, Massachusetts

Proposed Investigation Locations
AOC 43G

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Figure
4-1

File: Figure 4-1 - AOC43G Proposed Investigation Locations.mxd

Appendix A

Uniform Federal Policy for Quality Assurance Project Plan - Annual Long-Term Monitoring and Maintenance Program, Addendum for Post-Record of Decision Supplemental Remedial Investigation - AOC 43G

VERSION 2

FINAL

UNIFORM FEDERAL POLICY FOR QUALITY ASSURANCE PROJECT PLAN - ANNUAL LONG-TERM MONITORING AND MAINTENANCE PROGRAM

ADDENDUM FOR POST – RECORD OF DECISION SUPPLEMENTAL REMEDIAL INVESTIGATION – AOC 43G

FORMER FORT DEVENS ARMY INSTALLATION
DEVENS, MASSACHUSETTS

JUNE 2023

Contract No. W912WJ-19-D-0014
Task Order No. W912WJ-21-F-0060

Prepared For:

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Introduction

The SERES-Arcadis Joint Venture (JV), Limited Liability Company (LLC)[1] (hereafter referred to as the S-A JV) prepared this Addendum to the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) – Annual Long-Term Monitoring and Maintenance Program (QAPP Addendum) under Contract No. W912WJ-19-D-0014, Contract Delivery Order No. W912WJ-21-F-0060. This QAPP Addendum) is directed by and used in conjunction with the UFP-QAPP, Annual Long-Term Monitoring and Maintenance Program (LTMMP QAPP; SERES-Arcadis JV 2020) at the former Fort Devens Army Installation (Devens), located in Devens, Massachusetts (**Figure 1-1**). This QAPP Addendum provides detailed information on the execution of the field activities to be conducted as part of a post – Record of Decision (ROD) supplemental remedial investigation (SRI) at area of contamination (AOC) 43G, a long-term-monitoring (LTM) site at Devens.

All samples collected will be sent to the Eurofins Savannah laboratory for analysis. Results of the investigation will be used to confirm the Army Protectiveness Statement for AOC 43G in the 2020 Five-Year Review Report (KOMAN Government Solutions, LLC [KGS] 2020) by assessing the short- and long-term protectiveness of the ongoing remedial actions at the site. Environmental investigation at the former Fort Devens is governed by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); therefore, results of the SRI will be submitted to state and federal regulatory agencies for review as part of the CERCLA process.

UFP-QAPP worksheets are developed to systematically document the planning process, sampling rationale, sampling protocols, and quality assurance (QA)/quality control (QC) procedures included in the CERCLA investigation process.

Only Worksheets modified for the SRI are included in this QAPP Addendum.

Worksheet 2 provides cross-references to the location of CERCLA-required content within this QAPP Addendum that has been modified from the LTMMP QAPP. Elements of the LTMMP QAPP that were not modified and are not included in the QAPP Addendum are indicated as Not Applicable (NA). The LTMMP QAPP and this QAPP Addendum were developed with the understanding that unanticipated conditions may dictate a change in the plan as currently written.

Staff who will be participating in project and field efforts are required to read this plan and understand the objectives of the work to be performed, as well as the procedures to be used for conducting the field investigation, performing the laboratory analyses, and evaluating and reporting the data that are collected. In addition, key personnel are responsible for mentoring assigned staff in aspects of this QAPP Addendum potentially impacting their assigned work to ensure project activities are executed in accordance with the plan.

Project Goals

As stated above, the objective of the SRI is to confirm the Army Protectiveness Statements in the 2020 Five-Year Review Report (KGS 2020) by assessing the short- and long-term protectiveness of the ongoing remedial actions at the site.

---

[1] The SERES-Arcadis JV is composed of protégé firm SERES Engineering & Services, LLC (SERES) and its mentor Arcadis U.S., Inc. (Arcadis).

To support these objectives, the goal of the SRI field activities is to:

- Confirm the current lateral and vertical extent of ROD-specified contaminants of concern (COCs) and additional analytes arsenic and VPH in groundwater.

The objectives of this QAPP are to generate project data that are technically valid, legally defensible, and useful in meeting the project goals. The SRI will collect data sufficient to meet USACE and regulatory requirements and support remedial alternative decisions, if needed. The technical approach for the SRI is designed to achieve the data quality objectives (DQOs) listed in **Worksheet #11**.

The following attachments are provided to supplement the information presented in this QAPP Addendum:

Attachment A	Field Sampling Standard Operating Procedures
Attachment B	Field Method Standard Operating Procedures (Ferrous Iron and Phosphate)

TABLE OF CONTENTS

LIST OF FIGURES

ATTACHMENTS

LIST OF ACRONYMS AND ABBREVIATIONS

µg/L	microgram per liter
AAFES	Army Air Force Exchange Service
ABB	ABB Environmental Services, Inc.
AOC	area of contamination
Army	U.S. Army
bgs	below ground surface
BRAC	Base Realignment and Closure
BTEX	benzene, toluene, ethylbenzene, and xylenes
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CMR	Code of Massachusetts Regulations
CoC	chain-of-custody
COC	contaminant of concern
CSM	conceptual site model
Devens	Former Fort Devens Army Installation
DO	dissolved oxygen
DOC	dissolved organic carbon
DoD	Department of Defense
DPT	direct push technology
DQO	data quality objective
EDD	electronic database deliverable
EM	Engineer Manual
ESD	Explanation of Significant Differences
FD	field duplicate
FS	feasibility study
ft/day	feet per day
FYR	Five-Year Review
gpm	gallons per minute
HAZWOPER	Hazardous Waste Operations and Emergency Response
HGL	HydroGeoLogic, Inc.
HHRA	human health risk assessment
HLA	Harding Lawson Associates
JV	Seres-Arcadis JV
KGS	Koman Government Solutions, LLC
LLC	Limited Liability Company
LOD	limit of detection
LTM	long-term monitoring
LTMMP	Long-Term Monitoring and Maintenance Program
LUC	land use control
MassDEP	Massachusetts Department of Environmental Protection
MCP	Massachusetts Contingency Plan
MCL	Maximum Contaminant Levels
MS	matrix spike
MSD	matrix spike duplicate
NA	not applicable

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

No.	Number
ORP	oxidation-reduction potential
PM	project manager
POC	point of contact
PVC	polyvinyl chloride
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
RG	remedial goal
RI	remedial investigation
RPMP	Real Property Master Plan
ROD	Record of Decision
SA	Study Area
SI	site investigation
SOP	standard operating procedures
Sovereign	Sovereign Consulting, Inc.
SRI	supplemental remedial investigation
SSI	supplemental site investigation
SWETS	Stone & Webster Environmental Technology & Services
TBD	to be determined
TGI	technical guidance instruction
TOC	total organic carbon
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plans
U.S.	United States
USACE	United States Army Corps of Engineers
USACE	United States Army Environmental Center
USEPA	United States Environmental Protection Agency
UST	underground storage tank
VAP	vertical aquifer profile
VPH	volatile petroleum hydrocarbons

QAPP WORKSHEET #1 AND #2

Title and Approval Page

This worksheet identifies the principal points of contact for all organizations having decision authority in the project and documents their commitment to implement the UFP-QAPP. Signatories usually include the Project Manager (PM) and QA Manager, and individuals with approval or oversight authority. Signatures indicate that officials have reviewed the UFP-QAPP and concur with the implementation as written. It is the lead organization's responsibility to make sure all signatures are in place before work begins.

1. Project Identifying Information:
   a. Site name/project name: Former Fort Devens Army Installation (Devens), Supplemental Remedial Investigation
   b. Site location: Historical Gas Station 43G (AOC 43G), Devens, Massachusetts
   c. Contract/work assignment number: Seres Engineering & Services, LLC - Arcadis U.S., Inc. Joint Venture (Seres-Arcadis JV) W912WJ-19D-0014, Task Order W912WJ-21-F-0060, Environmental Services and Remedial Action Operations for BRAC Legacy Sites – Former Fort Devens, Devens, Massachusetts
   d. Lead Organization: USEPA Region 1 and USACE
   e. Geographical Corps District: New England District
2. Department of Defense Organization(s):
   a. U.S. Army (Army), Base Realignment and Closure (BRAC)
      i. Name: Thomas Lineer
      ii. Title: BRAC Environmental Coordinator
   b. USACE, New England District
      i. Name: Penelope Reddy
      ii. Title: USACE PM
3. Contractor: SERES-Arcadis JV
   a. SERES-Arcadis JV PM
      i. Name: Andy Vitolins, Professional Geologist
      ii. Title: SERES-Arcadis JV PM
   b. SERES-Arcadis JV Corporate QA Manager
      i. Name: John Nocera, Professional Engineer
      ii. Corporate Quality Manager

4. Federal Regulatory Agency: USEPA Region I
5. State/Territory Regulatory Agency: Massachusetts Department of Environmental Protection (MassDEP)
6. Other Stakeholders:
    a. Restoration Advisory Board
    b. Local Residents and Businesses
7. Plans and reports from previous investigations in the following table:

1993	Final SI Report, Groups 2 & 7, and Historic Gas Stations. May.	ABB Environmental Services, Inc. (ABB).
1994	Supplemental Site Investigation Data Package, Fort Devens, Groups 2 and 7, and Historic Gas Stations. January.	ABB
1996	Area of Contamination (AOC) 43G and AOC 43J, Remedial Investigation, Devens, Massachusetts. February.	ABB
1996	Area of Contamination 43G, Feasibility Study, Devens, Massachusetts. June.	ABB
1996	Record of Decision, Areas of Contamination, Devens, Massachusetts AOCs 43G and 43J. October.	U.S. Army Environmental Center (USAEC)
1999	Final Intrinsic Remediation Assessment Report Area of Contamination 43G, Historic Gas Station, Devens, Massachusetts' (Volumes I and II); and Appendix D - "Long Term Monitoring Plan" (Volume III), Massachusetts. November.	Stone & Webster Environmental Technology & Services (SWET) and Harding Lawson Associates (HLA)
2000	First Five-Year Review for Devens Reserve Forces Training Area, Devens, Massachusetts. September.	HLA
2008	Long-Term Monitoring Plan, Former Fort Devens Army Installation, Devens Massachusetts. October.	HydroGeologic, Inc. (HGL).
2015	Long Term Monitoring and Maintenance Plan – Former Fort Devens Army Installation and Sudbury Annex. March.	Sovereign Consulting Inc.(Sovereign)/ HGL
2020	Five Year Review. Former Fort Devens Army Installation, Devens, Massachusetts	KOMAN Government Solutions, LLC (KGS)

Required UFP-QAPP elements that have been modified or are not included in the LTMMP QAPP are indicated in the table below with their location within this QAPP Addendum. Required UFP-QAPP elements that are included in the LTMMP QAPP and do not need modification for SRIs are indicated as "not applicable" (NA):

Worksheet #	Required Information	Crosswalk to Related Information
A. Project Management and Objectives		
Documentation		
1	Title and Approval Page	Page 1
2	UFP-QAPP Identifying Information	Page 1
3	Distribution List	Page 5
4	Project Personnel Sign-Off Sheet	NA
Project Organization		
5	Project Organizational Chart	NA
6	Communication Pathways	NA
7	Personnel Responsibilities and Qualifications Table	NA
8	Special Personnel Training Requirements Table	NA
Project Planning/Problem Definition		
9	Project Scoping Session Participants Sheet	NA
10	Problem Definition	Page 7
11	Project Quality Objectives/Systematic Planning Process Statements	Page 12
12	Measurement Performance Criteria Table	NA
13	Secondary Data and Limitations Table	NA
14	Summary of Project Tasks	Page 15
15	Reference Limits and Evaluation Table	NA
16	Project Schedule/Timeline Table	Page 15
B. Measurement/Data Acquisition		
Sampling Tasks		
17	Sampling Design and Rationale	Page 16
18	Sampling Locations and Methods/SOP Requirements Table Sample Location Map(s)	Page 19
19	Analytical Methods/SOP Requirements Table	Page 21
20	Field QC Sample Summary Table	NA
21	Project Sampling SOP References Table	Page 22
22	Field Equipment Calibration, Maintenance, Testing, and Inspection Table	NA

Worksheet #	**Required Information**	**Crosswalk to Related Information**
Analytical Tasks		
23	Analytical SOPs Analytical SOP References Table	NA
24	Analytical Instrument Calibration Table	NA
25	Analytical Instrument and Equipment Maintenance, Testing, and Inspection Table	NA
Sample Collection		
26	Sample Handling System, Documentation Collection, Tracking, Archiving and Disposal, and Custody SOPs Sample Handling Flow Diagram	NA
27	Sample Custody Requirements	NA
Quality Control Samples		
28	Laboratory QC Samples Table	NA
Data Management Tasks		
29	Project Documents and Records Table	NA
30	Analytical Services Table	NA
C. Assessment Oversight		
31	Planned Project Assessments Table	NA
32	Assessment Findings and Corrective Action Responses Table	NA
33	QA Management Reports Table	NA
D. Data Review		
34	Verification (Step I) Process Table	NA
35	Validation (Steps IIa and IIb) Process Table	NA
36	Validation (Steps IIa and IIb) Summary Table	NA
37	Data Usability Assessment Table	NA

QAPP WORKSHEET #3

Distribution List for Devens

QAPP Recipients	Title	Organization	Telephone Number	E-mail Address
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Ian Martz	Field Operations Lead	JV	(978) 322-4526	ian.martz@arcadis.com
Theresa Cansler	Task Lead	JV	(518)528-8347	Theresa.cansler@arcadis.com
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Jerry Lanier	Laboratory PM	Eurofins TestAmerica - Savannah	(912) 250-0281	jerry.lanier@et.eurofinsus.com
Pei Geng	Data Validation PM	Laboratory Data Consultants, Inc (LDC)	(760) 827-1110	pgeng@lab-data.com
Penelope Reddy	PM	USACE	(978) 318-8160	penelope.reddy@usace.army.mil
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Thomas Lineer	BRAC Environmental Coordinator	U.S. Army (Army)	703-545-2487 (Office) 703-371-6785 (Mobile)	thomas.a.lineer.civ@army.mil
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QAPP WORKSHEET #10

Conceptual Site Model

10.1. AOC 43G Site Description and History

AOC 43G consists of a decommissioned Army Air Force Exchange Service (AAFES) gas station (Building 2008) and Historical Gas Station G (**Figure 1-1**). Historical Gas Station G was used during World War II as a vehicle motor pool to support military operations and was one of 18 historical gas station sites at Fort Devens. The structures of gas station G consisted of a pump island and a small gasoline pumphouse. Reportedly, the gas station had one 5,000-gallon (or possibly 5,140-gallon) underground storage tank (UST) located between the gasoline pumphouse and the pump island (ABB 1996a). The motor pool operations were discontinued during the late 1940s or early 1950s. No records are available on the decommissioning of the motor pool, the exact location of Gas Station G, or the location or ultimate disposition of the historical gas station's UST (ABB 1996a).

As part of the BRAC closure process, AOC 43G, then Study Area (SA) 43G, was investigated in 1991 under the CERCLA process as part of the site investigations (SIs) conducted at historical gas stations at Fort Devens (ABB1993 [Final] and 1995 [Revised Final]). Based on the results of preliminary risk evaluations completed as part of the SIs, the Army decided to conduct supplemental site investigations (SSIs) at seven of the original historical gas stations (ABB 1996a).

Originally, AOC 43G consisted solely of Historical Gas Station G (defined as Area 1); however, after completion of the SI, AOC 43G was expanded to include the former AAFES gas station located approximately 120 feet northeast of Historical Gas Station G.

Area 2 was added to AOC 43G to investigate petroleum contamination observed during removal of three 9,000-gallon USTs associated with the AAFES gas station in 1990. Area 2 was expanded to include the location of two 10,000-gallon gasoline USTs removed in 1996. Although soil samples were collected from the walls of the excavation, no samples were collected from the base of the excavation.

Area 3 was added to AOC 43G to investigate petroleum contamination observed during the removal of a 500-gallon waste oil UST associated with the AAFES gas station in 1992. Impacted soils were not removed in 1992 due to the close proximity of Building 2008. Impacted soil was subsequently removed in 1996 during the Area 2 UST removal.

Based on the results of the 1992 SI and 1993 SSI field activities, the SSI recommended no further action for AOC43G Area 1; however, the SSI identified fuel related compounds, principally benzene, ethylbenzene, and xylenes in site soil and groundwater within Areas 2 and 3 (ABB 1994). Subsequently, the two historical gas stations (SA 43G and 43J) were administratively changed to AOCs and the sites progressed to the remedial investigation (RI) and feasibility study (FS) phase under CERCLA. Further investigation was conducted and risks were evaluated as part of the RI for AOC 43G (ABB 1996a) and remedial alternatives for cleanup of groundwater at AOC 43G were evaluated in the AOC 43G Feasibility Study (FS; ABB 1996b).

A human health risk assessment (HHRA) was conducted for the RI to evaluate potential health risks to individuals under current or foreseeable future site conditions at AOC 43G. Because the future reuse of the area was anticipated to remain similar to its present use, a commercial/industrial worker scenario was used to assess potential human health risks associated with contaminants detected in soil and groundwater. Due to the urbanized nature of this site and the lack of exposure pathways (the site is paved), an ecological risk assessment was not performed. The HHRA concluded that there were no unacceptable threats to human health from exposure to contaminated soil but did find potential threats to human health from future exposure to groundwater in the source area and downgradient of the source area. Benzene, manganese, iron, and arsenic were identified in the HHRA as the primary contributors for risk in source area groundwater. Manganese and benzene were the primary contributors for risk in downgradient groundwater.

In 1996, the Army and USEPA issued a Record of Decision (ROD) for AOCs 43G and 43J with a selected remedial alternative for AOC 43G that included intrinsic bioremediation to prevent contaminants of concern (COCs) present at concentrations that exceed groundwater cleanup levels from potentially migrating off Army property (ABB 1996d), LTM of groundwater, and FYRs. Intrinsic bioremediation was chosen for AOC 43G "*…to prevent COCs present at concentrations that exceed groundwater cleanup levels from potentially migrating off Army property*." (USAEC 1996). To ensure continued protection of human health and the environment and future integrity of the selected remedy, in June 2006 the Army issued an Explanation of Significant Difference (ESD) to the 1996 ROD to incorporate LUCs into the remedy for AOC 43J (BRAC Environmental Office 2006). Similar LUCs for AOC 43G were subsequently incorporated into the Real Property Master Plan (RPMP) Long Range Component for Devens Reserve Forces Training Area, Addendum (2007) (KGS 2020).

The AOC 43G property remains owned and under the control of the Army.

10.2. AOC 43G Site Contaminants of Concern

Petroleum discharges to ground are assumed to be the source of contaminants at AOC 43G. The ROD identified benzene, ethylbenzene, xylenes, nickel, iron, and manganese as COCs in groundwater for AOC 43G. The preliminary remediation goals (PRGs) established in the ROD for benzene, ethylbenzene, xylenes, and nickel in source area groundwater were the USEPA Maximum Contaminant Levels (MCLs) in effect at the time.

Table 10-1. AOC 43G Screening Limits in Groundwater

Analytes	Original Cleanup Goal (µg/L)	Current Screening Standard (µg/L)	Selection Basis
Source Area Locations			
Iron (total)	9,100	9,100	Background [a] (ROD)
Manganese (total)	291 [a]	375 [c]	see notes a and c
Nickel	100	NA	MCL (ROD)
Benzene [b]	5	5	MCL (ROD)
Toluene	NA	1,000	MCL (Army)
Ethylbenzene [b]	700	700	MCL (ROD)
Xylenes [b]	10,000	10,000	MCL (ROD)
VPH $C_5 – C_8$ Aliphatics	NA	300	MCP (Army)
VPH $C_9 – C_{12}$ Aliphatics	NA	700	
VPH $C_9 – C_{10}$ Aromatics	NA	200	
Downgradient			
Manganese	291 [a]	375 [c]	see notes a and c
Benzene	5	5	MCL (ROD)
VPH $C_5 – C_8$ Aliphatics	NA	300	MCP (Army)
VPH $C_9 – C_{12}$ Aliphatics	NA	700	
VPH $C_9 – C_{10}$ Aromatics	NA	200	

NOTE:

NA – not applicable
µg/L = micrograms per liter.
ROD = Record of Decision

a. AOC 43G/43J ROD (USAEC 1996) identified background values for iron and manganese as determined from unfiltered samples collected from 10 select wells on base.
b. Screening levels as noted in 1996 ROD (USAEC) and 2015 LTMMP (KGS).
c. The 2008 LTM Plan (HGL) updated the cleanup goal for manganese to the approved MCL for a child.
d. Massachusetts Contingency Plan (MCP) 2021 https://www.mass.gov/regulations/310-CMR-4000-massachusetts-contingency-plan

Current annual monitoring at AOC 43G, as presented in the 2015 Long-Term Monitoring and Maintenance Plan for Former Fort Devens Army Installation and Sudbury Annex (Main Post LTMMP; Sovereign/HGL), consists of collection of samples from five monitoring wells. Groundwater samples are analyzed for benzene, toluene, ethylbenzene, and xylenes (BTEX), volatile petroleum hydrocarbons (VPH), total iron and total manganese, and alkalinity. Nickel was eliminated from the LTM program. VPH and toluene are not included in the ROD, but the analyses are used to gauge the cleanup of the site. VPH concentrations are evaluated against Massachusetts Contingency Plan (MCP) standards and toluene is compared to the USEPA MCL.

10.3 Key Physical Aspects of the Site

AOC 43G – Historical Gas Station G is located in the central portion of the former Main Post of Fort Devens at the southwestern corner of Feinburg Road and Queenstown Street (**Figure 1-1**). The reported location of Gas Station G was southwest of the former AAFES gasoline station (Building 2008) and southwest of Building 2009. The area is heavily developed and primarily paved.

10.3.1 Site Groundwater Hydrology

Groundwater at AOC 43G flows to the east-southeast consistent with the local topography, eventually discharging to surface water via an unnamed tributary to Robbins Pond and to Robbins Pond itself. Near Robbins Pond, overburden groundwater turns north following/discharging along Willow Branch and consistent with the bedrock topography.

10.3.2 Site Geology

AOC 43G is located just west of Robbins Pond and mid-slope (eastern slope) along a small ridge separating the Nashua River and Willow Branch. Surface topography across AOC 43G generally conforms to the bedrock surface topography across the area. The overburden beneath AOC 43G is composed of unconsolidated sand and gravel and contains a basal till at the base that conforms to the underlying bedrock topography. Beneath the former gas station, near Queenstown Street, the overburden is approximately 30 feet thick (i.e., top of the bedrock encountered at approximately 30 feet below ground surface [bgs]) increasing to more than 100 feet thick along Barnum Road.

The bedrock underlying AOC 43G transitions eastward from the Oakdale Formation near Queenstown Street to the Devens Gneiss Complex towards Robbins Pond.

In the upgradient portions of AOC 43G (i.e., former gas station/source area), the overburden is generally dry, with the water table occurring within the shallow bedrock at approximately 30 feet bgs. Moving downgradient, the overburden eventually becomes saturated at a depth of approximately 25 feet bgs. Moving downgradient, this thin saturated zone within the overburden increases to more than 100 feet near Barnum Road/Robbins Pond. Depth to groundwater becomes shallower moving downgradient.

10.4 Primary Release Mechanism/Fate and Transport Consideration

As presented in the ROD, the primary site-related contaminants at AOC 43G are solvent and fuel-related contaminants in soil and groundwater consistent with use of the site as a gas station. The petroleum-related concentrations detected in Areas 2 and 3 indicate that residual soil contamination is still present in these areas from leaks and spills associated with the former gasoline and waste oil

USTs (USAEC 1996). The primary migration pathway/transport mechanism at AOC 43G is infiltration into groundwater from source area contaminants above the water table.

10.5 Data Gaps

Specific study questions for AOC 43G and the proposed scope to address them include:

- **What is the current lateral and vertical extent of benzene, ethylbenzene, and xylenes, and associated intrinsic bioremediation marker VPH, in groundwater?** The vertical extent of benzene, ethylbenzene, and xylenes, and associated intrinsic bioremediation marker VPH will be evaluated through collection of supplemental data at AOC 43G from existing monitoring wells, existing piezometers, and from new proposed monitoring wells.

- **What is the current lateral and vertical extent of iron, manganese, and arsenic in groundwater at concentrations exceeding applicable standards?** The vertical extent of iron, manganese, and arsenic will be evaluated through collection of supplemental data at AOC 43G from existing monitoring wells, existing piezometers, and from new proposed monitoring wells.

- **Is there a stable or decreasing trend of ROD-specified COCs and VPH concentrations in groundwater?** Historical and current analytical data will be used to evaluate trends for the ROD-specified COCs and VPH.

- **Are current reducing aquifer conditions associated with the petroleum releases or are they naturally occurring?** Historical and current analytical data will be used to evaluate reducing conditions and trends for iron and manganese concentrations.

Using data collected during the SRI, the following questions will be asked:

- Is there sufficient current data to confirm the current lateral and vertical extent of ROD-specified COCs and additional analytes arsenic and VPH in groundwater (i.e., are locations with samples exceeding screening criteria bounded by samples from locations not exceeding screening criteria)?

    - If yes, no additional sampling is required during the SRI to confirm the current lateral and vertical extent of ROD-specified COCs and additional analytes arsenic and VPH.

    - If no, collect additional data as needed.

- Is there sufficient current and historical data to establish a stable or decreasing trend of ROD-specified COCs and VPH in groundwater?
    - If yes for a decreasing trend for a ROD-specified COC or VPH, no additional sampling may be required, LTM remedy is protective, and for the COC or VPH may be suitable for reduced monitoring.
    - If yes for a stable trend for a ROD-specified COC or VPH below screening criteria, no additional sampling may be required, LTM remedy is protective, and the COC or VPH may be suitable for reduced monitoring.
    - If yes for a stable trend above screening criteria, additional sampling may be required, but the ROD-specified COC may be suitable for reduced monitoring.
    - If no, LTM for ROD-specified COCs and/or VPH will continue.

QAPP WORKSHEET #11

Data Quality Objectives

The Data Quality Objectives (DQOs) are qualitative and quantitative statements that clarify study objectives, define the appropriate type of data, and specify the tolerable levels of potential decision errors that are used as the basis for establishing the quality and quantity of data needed to support decisions. The JV utilized the DQO guidelines established in the Data Quality Objectives Process for Hazardous Waste Site Investigations*, EPA QA/G-4 HW (January 2000) EPA/600/R-00/007* (USEPA 2000a) to develop the DQOs for the SRI activities at Devens, as summarized in the tables below:

DQO	AOC 43G Historical Gas Station G					
Problem Statement	**Project Goals**	**Information Inputs**	**Study Boundaries**	**Decision Rules**	**Performance Criteria**	**Plan for Obtaining Data**
Define the problem that necessitates this study	*Identify study questions*	*Identify data and information needed to answer study questions*	*Specify the spatial and temporal boundaries.*	*Define the conditions under which the data will be utilized.*	*Specify the limits on decision errors*	*Design an effective data collection strategy based on previous steps*
Is the remedy selected in the AOC 43G ROD still protective of human health?	1. What is the current lateral and vertical extent of benzene, ethylbenzene, and xylenes, and associated intrinsic bioremediation marker VPH, in groundwater? 2. What is the current lateral and vertical extent of iron and manganese in groundwater? 3. Is there a stable or decreasing trend of ROD-specified COCs and VPH concentrations in groundwater? 4. Are current reducing aquifer conditions associated with the petroleum releases or are they naturally occurring?	The information inputs are required to accomplish the project goals are: • All information reviewed/gathered to date including historical information, the results of previous investigations, and previous remedial actions completed. • Analytical data from environmental media, specifically, groundwater samples.	The general areal boundary for the SRI is AOC 43G.	• All samples will be collected and analyzed in accordance with the LTMMP QAPP and QAPP Addendum technical guidance instruction (TGI) and Standard operating procedures (SOPs) documents to ensure that subsequent decisions are made based on valid data. • Presence/ absence of COCs and VPH will be based on the laboratory limits of detection (LODs) presented in the LTMMP QAPP in Worksheet #15.	The Data Usability Assessment Process will be used to limit decision errors based on field and analytical data. Project-specific MPCs, which are the criteria that collected data must meet to satisfy the DQOs, are presented in Worksheet #12 of the LTMMP QAPP.	The plan for obtaining the data necessary to meet the goals of the SRI is presented in Section 4.0 of the AOC 43G SRI Work Plan.

Data previously collected during LTM field activities at the site have been reviewed, and the CSM and data screened against the DQOs established in the site-specific SRI Work Plan for the site. Data gaps to be addressed and the field investigation activities planned are discussed in **Worksheet #17**. The proposed sampling locations and analytical parameters are summarized in **Worksheet#18**. Standard operating procedures (SOPs) and technical guidance instruction (TGI) for field sampling and analytical procedures are summarized in **Worksheet #21** (*Field SOPs*). The field SOPs are provided in **Attachment A**.

Data generated from field activities will be documented using a digital data management approach to reduce the time needed for field data to be collected, reviewed, acted upon, and reported. Mobile technology and an enterprise platform will be used to collect and host the data. Digital data collection will include (but is not limited to) chain-of-custody (CoC) forms, field notes, groundwater sampling and gauging logs, and site photographs. In addition, notes from critical project meetings and telephone conversations will be filed. PDF copies of all field records will be stored electronically in the JV project network.

Laboratory data will be reported in analytical packages (produced in PDF format) that will, at a minimum, contain all necessary information to allow for validation in accordance with the USEPA Stage 2B as described in Guidance for Labeling Externally Validated Laboratory Analytical Data for Superfund Use (USEPA, 2009) and U.S. Department of Defense (DoD) General Data Validation Guidelines (DoD, November 2019) (see **Worksheets #34 through #36** of the LTMMP QAPP). Electronic database deliverables (EDDs) will meet the requirements of Automated Data Review A1 and A3 files. All EDDs will be uploaded and stored on the Former Fort Devens electronic data management system portal. Field data and observations will be recorded in bound logbooks or electronically on sampling log sheets. Well stabilization parameters will be recorded on pre-printed field sheets.

USACE, USEPA, MassDEP, JV, and stakeholders will use the data to support the project-specific decisions to be made, as outlined in **Worksheet #10**.

QAPP Worksheet #14 & 16
Project Tasks and Schedule
(UFP-QAPP Manual Section 2.8.2) / (USEPA 2106-G-05 Section 2.2.4)

The general project schedule, including the specific task/activity and the person or group responsible for execution is provided in the following table. The SRI schedule, including planning document preparation and field activities, report preparation, and meeting support, are presented in **Attachment C** of this QAPP. Note that the schedules are subject to updates and revisions based on field conditions.

Activity	Responsible Party	Deliverable(s)	Deliverable due date
DFW 1: Pre-Mobilization Activities			
Final Post-ROD SRI Work Plan and QAPP Addendum	Andy Vitolins *SERES-Arcadis JV PM*	Draft and Draft Final Work Plan and QAPP Addendum Submittals	One week after resolution of Draft Final Work Plan and QAPP Addendum comments.
DFW 2: Mobilization/Site Preparation			
Mobilization	Ian Martz *SERES-Arcadis JV Field Supervisor*	Field notes, Daily QC Report	Weekly submittals due Friday of the week following performance of the activity.
DFW 3: Environmental Data Collection			
Field Activities	Theresa Cansler *SERES-Arcadis JV Task Manager*	Data Package, including data validation summary	Twelve weeks after completion of field activities.
DFW 4: Final Report			
Draft Post-ROD SRI Report	Andy Vitolins *SERES-Arcadis JV PM*	Draft Post-ROD SRI Report	Approx. one year after completion of field activities.
Draft Final/Final Post ROD SRI Report	Andy Vitolins *SERES-Arcadis JV PM*	Draft Final/Final Post ROD SRI Report	45 days after receipt of Draft/Draft Final comment resolution.

QAPP WORKSHEET #17

Sampling Design and Rationale

As stated in the **Introduction**, the primary goal of the SRI field activities is to confirm the Army Protectiveness Statement for AOC 43G in the 2020 Five-Year Review Report (KGS 2020) by assessing the short- and long-term protectiveness of the ongoing remedial actions at the site.

17.1 Overall Investigation Approach Rationale

This worksheet describes the design for data collection and documents Step 7 of the DQO process. For each general field task, this section summarizes the data gap, the rationale for data collection, and the approach for filling the data gap. The general process for the investigation will consist of collection of sufficient groundwater data to confirm the lateral and vertical extent of contamination, assess contaminant distribution, and assess aquifer conditions (including reducing conditions and associated impacts on metals concentrations).

Groundwater sampling will be conducted in accordance with the following updated SOPs, which replace SOP-003 (Water Level Measurement), SOP-004 (Groundwater Sampling), SOP-005 (Field Decontamination Procedures), SOP-006 (Sample Handling, CoC Forms, and Shipping), and SOP-007 (Low-Flow Sampling) included with the LTMMP QAPP (see also **Worksheet #21**):

- **RI-SOP-03:** USEPA – *Low Stress (low flow) Purging and Sampling Procedure for the Collection of Groundwater Samples from Monitoring Wells*, (Rev #4, 19 September 2017)
- **RI-SOP-05:** SERES-Arcadis TGI – *Ground Penetrating Radar* (Rev #5, 3 January 2022)
- **RI-SOP-06:** SERES-Arcadis TGI – *Manual Water-Level Monitoring* (JV; Rev #2, 5 April 2022)
- **RI-SOP-07:** SERES-Arcadis TGI - *In-Situ and Ex-Situ Water Quality Parameters* (Rev #1, 15 April 2022)
- **RI-SOP-08:** SERES-Arcadis TGI - *Sample Chain of Custody* (Rev #3, 28 March 2022)
- **RI-SOP-09:** SERES-Arcadis TGI - *Investigation-Derived Waste Handling and Storage* (Rev #1, 15 May 2020)
- **RI-SOP-10:** SERES-Arcadis TGI - *Groundwater and Soil Sampling Equipment Decontamination* (Rev#1, 8 May 2020)
- **RI-SOP-11:** SERES-Arcadis TGI – *Monitoring Well Development* (Rev #1, 12 April 2022).
- **RI-SOP-13:** SERES-Arcadis TGI - *Soil Description* (Rev #3, 15 April 2022)
- **RI-SOP-16:** SERES-Arcadis TGI – *Monitoring Well Installation* (Rev #0, 24 April 2017).

17.1.1 Installation of Monitoring Wells and Soil Sampling

The existing monitoring well network at AOC 43G was evaluated and three new monitoring wells are proposed to be installed upgradient and downgradient of the historical petroleum release areas. The new wells will be installed with the objective of investigating horizontal and/or vertical data gaps.

Overburden soil will be logged by a SERES-Arcadis JV field geologist, and soil samples will be collected from two well locations (XGM-23-01 and XGM-23-02) for VPH and extractable petroleum hydrocarbons (EPH). Drill cuttings generated during investigation activities will be spread on the ground surface adjacent to the site of generation.

All drilling will be completed by a licensed Massachusetts driller under the oversight of a JV geologist and will be conducted in accordance with all promulgated state and federal laws.

17.1.2 Water-Level Monitoring

Prior to the collection of groundwater samples, synoptic water levels will be collected to confirm groundwater flow direction and vertical hydraulic gradients.

Water levels in all wells will be measured from the established measurement point before each groundwater sampling event using a combination electronic water level and oil-water interface probe. Water levels will then be converted to water table elevations referenced to the measuring point elevations surveyed by a Massachusetts -licensed surveyor.

17.1.3 Groundwater Sampling

Groundwater from wells will be purged and sampled in accordance with the USEPA Region 1*, Low Stress (Low-Flow) Purging and Sampling Procedure for the Collection of Groundwater Samples from Monitoring Wells* (USEPA, Region 1 2017). Field parameters (temperature, pH, conductivity, dissolved oxygen [DO], turbidity, and oxidation-reduction potential [ORP]) will be collected in accordance with established procedures during groundwater sampling to ensure that a stable sample is collected. Turbidity samples will be collected from a T-valve placed on the sample tubing prior to the flow-through cell and measured with a stand-alone meter. Purging will be considered complete after water quality parameters specified under the low-flow protocols can be demonstrated to be stabilized. Sampling conditions will be noted in the sampling logs. Groundwater samples will be collected using the same flow rate at which the well was purged.

Samples to be submitted for dissolved metals analysis will be field filtered using a 0.45-micron filter. Static depth to groundwater measurements will be measured in accordance with established procedures. In addition, the pump intake depth will be recorded on field logs to provide information on pumping depth relative to the observed water table. The sampling pump intake depth will be set at the mid-point of the saturated screened interval for all wells with screen lengths of ten feet or less. Groundwater samples will be analyzed for the parameters listed in **Worksheet #18.**

17.2 AOC 43G Sampling Design and Rationale

Groundwater sampling is proposed at AOC 43G from 20 existing monitoring wells/piezometers and three new wells on a quarterly basis for one year (four total sampling events).

Samples will be analyzed for the ROD-specified COCs, VPH, and EPH. As requested by the USEPA, samples will also be analyzed for total and dissolved arsenic.

To evaluate redox status and attenuation potential, samples from monitoring wells will be analyzed for the following additional parameters :

- **Total and dissolved aluminum**, to assess the potential for presence of sub-0.45-micron particulates. Aluminum is anticipated to exhibit extremely low solubility at the observed groundwater pH. The presence of total aluminum would therefore indicate suspended particulates present in the groundwater sample, while the presence of dissolved aluminum correlated to total aluminum would indicate the presence of very fine (sub-0.45-micron) particulates.

- **Dissolved iron and manganese,** to evaluate redox status and attenuation potential via iron coprecipitation upon reoxidation, and as an additional line of evidence regarding potential for suspended particulates affecting COC concentrations.

- **TOC and sulfate**, to assess redox status and residual reducing potential. TOC will contribute to ongoing reducing potential by consuming dissolved oxygen (potentially limiting iron reoxidation and extending the timeframe for iron and manganese attenuation), while comparison of sulfate concentrations inside and outside of the historical petroleum hydrocarbon impacts may inform extent of historical sulfate reduction. If sulfate reduction has occurred, sulfide minerals in the formation may further extend time for attenuation of iron and manganese.

To update the previous intrinsic bioremediation evaluation, samples collected during the baseline event will be analyzed for the following additional groundwater parameters:

- **Nitrate/nitrite**

- **Phosphate**

- **Sulfide**

- **Alkalinity**

- **Methane**

- **Ferrous iron**

QAPP WORKSHEET #18

Sampling Locations and Methods

Worksheet#17 and **Section 4.1** of the SRI WP describe the planned sampling events for the SRI at AOC 43G. Both existing and new monitoring wells will be sampled. **Section 4.2.3** of the SRI WP details the locations and specifications of the new monitoring wells. Sampling locations and analyses for the evaluation are summarized below:

Sampling Location	Matrix	Sample Depth /Screening Interval (feet below ground surface)	Sample ID [a]	VPH /EPH, BTEX	Total Metals [a]	Dissolved Metals [b]	TOC + Sulfate	Intrinsic Bio-Remediation Parameters [c]	Sample Type	Sampling SOP Reference	Rationale for Sampling Location
Existing monitoring wells	Groundwater	See Table 3-2 of the SRI WP for wells construction details. Samples will be collected consistent with previous LTM sampling.	AAFES-2 (DDMMYY)	**X**	**X**	**X**	**X**	**X**	Discrete	RI-SOP-03, RI-SOP-06, RI-SOP-07, RI-SOP-08, RI-SOP-09, & RI-SOP-10	Source area well with elevated VPH. Historical location with ROD-specified COC exceedances (iron/manganese).
			AAFES-5 (DDMMYY)	**X**	**X**	**X**	**X**	**X**			Confirm lateral extent of VPH and iron/manganese.
			AAFES-6R (DDMMYY)	**X**	**X**	**X**	**X**	**X**			Historical location with ROD-specified COC exceedances (iron and/or manganese).
			AAFES-7 (DDMMYY)	**NA**	**X**	**X**	**X**	**X**			
			XGM-93-02X (DDMMYY)	**X**	**X**	**X**	**X**	**X**			
			XGM-94-04X (DDMMYY)	**X**	**X**	**X**	**X**	**X**			Source area well with elevated VPH. Historical location with ROD-specified COC exceedances (manganese).
			XGM-94-06X (DDMMYY)	**NA**	**X**	**X**	**X**	**X**			Historical location with ROD-specified COC exceedances (manganese).
			XGM-94-07X (DDMMYY)	**X**	**X**	**X**	**X**	**X**			
			XGM-94-08X (DDMMYY)	**X**	**X**	**X**	**X**	**X**			
			XGM-94-10X (DDMMYY)	**NA**	**X**	**X**	**X**	**X**			
			XGM-97-12X (DDMMYY)	**X**	**X**	**X**	**X**	**X**			Source area well with elevated VPH.
			XGM-20-01A (DDMMYY)	**NA**	**X**	**X**	**X**	**X**			Confirm vertical and downgradient extent of iron/manganese.
			XGM-20-02A (DDMMYY)	**NA**	**X**	**X**	**X**	**X**			
			XGM-20-03A (DDMMYY)	**NA**	**X**	**X**	**X**	**X**			

Sampling Location	**Matrix**	**Sample Depth /Screening Interval (feet below ground surface)**	**Sample ID [a]**	**VPH /EPH, BTEX**	**Total Metals [a]**	**Dissolved Metals [b]**	**TOC + Sulfate**	**Intrinsic Bio-Remediation Parameters [c]**	**Sample Type**	**Sampling SOP Reference**	**Rationale for Sampling Location**
Existing Piezometers	Groundwater	See Table 3-2 of the SRI WP for piezometer construction details. Samples will be collected consistent with previous LTM sampling.	43GPZ-19-01 (DDMMYY)	**NA**	**X**	**X**	**X**	**X**	Discrete	RI-SOP-03, RI-SOP-06, RI-SOP-07, RI-SOP-08, RI-SOP-09, & RI-SOP-10	Confirm lateral extent of iron/manganese.
			43GPZ-19-02 (DDMMYY)	**NA**	**X**	**X**	**X**	**X**			
			43GPZ-19-03 (DDMMYY)	**X**	**X**	**X**	**X**	**X**			Confirm lateral extent of VPH / BTEX and iron/manganese.
			43GPZ-19-04 (DDMMYY)	**NA**	**X**	**X**	**X**	**X**			Confirm lateral extent of iron/manganese.
			43GPZ-19-05 (DDMMYY)	**NA**	**X**	**X**	**X**	**X**			
			43GPZ-19-06 (DDMMYY)	**NA**	**X**	**X**	**X**	**X**			
New Monitoring Wells	Groundwater	See Section 4.2.3 of the SRI WP for proposed well construction details.	XGM-23-01 (DDMMYY)	**X**	**X**	**X**	**X**	**X**	Discrete	RI-SOP-03, RI-SOP-06, RI-SOP-07, RI-SOP-08, RI-SOP-09, RI-SOP-10, RI-SOP-11, & RI-SOP-16	Confirm lateral extent of VPH/BTEX and iron/manganese.
			XGM-23-02 (DDMMYY)	**X**	**X**	**X**	**X**	**X**			
			XGM-23-03 (DDMMYY)	**X**	**X**	**X**	**X**	**X**			
	Soil	TBD – discrete samples to be collected based on observations during drilling	XGM-23-01 (X-X) to XGM-23-03 (X-X)	**X**					Discrete		

NOTE:

NA = not analyzed

a. Total Metals= aluminum, arsenic, iron, and manganese.

b. Dissolved Metals= aluminum, arsenic, iron, and manganese. Dissolved samples will be field-filtered.

c. Intrinsic bio-remediation parameters include nitrate, nitrite, phosphate, sulfide, alkalinity, methane, and ferrous iron.

QAPP WORKSHEET #20

Field QC Sample Quantities and Control Frequencies

(UFP-QAPP Section 3.1.1 and 3.1.2) / (USEPA 2106-G-05 Section 2.3.5)

Matrix/ Analysis	Estimated Parent Sample Quantity [a]	Field QC Sample						Laboratory QC Sample				Total
		Field Duplicate		Field Blank*		Equipment Blank*		Matrix Spike		Matrix Spike Duplicate		
		Freq	Number	Freq	Number	Freq	Number	Freq [b]	Number	Freq [b]	Number	
AOC 43G - Groundwater												
VPH/EPH + BTEX	**60**	1/10	6	1/cooler	4	1/day	8	1/20	3	1/20	3	**84**
Metals - Total	**92**	1/10	9	NA	NA	NA	NA	1/20	5	1/20	5	**111**
Metals - Dissolved	**92**	1/10	9	NA	NA	NA	NA	1/20	5	1/20	5	**111**
TOC	**92**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**92**
Sulfate	**92**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**92**
Intrinsic Bio-Remediation Parameters [c]	**23**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**23**
AOC 43G - Soil												
VPH/EPH + BTEX	**4**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**4**

Notes:

a. Sample quantities are approximate and assume quarterly sampling for one year (four total sampling events).
b. Frequency for MS/MSD samples is 1 per 20 field samples, not including field blanks and field duplicates.
c. Intrinsic bio-remediation parameters include nitrate, nitrite, phosphate, sulfide, alkalinity, methane, and ferrous iron.

QC = quality control
NA = not applicable
*Field blanks and equipment blanks will be submitted concurrent with VPH+BTEX groundwater samples.

QAPP WORKSHEET #21

Project Sampling SOP References Table

The field SOPs associated with the project sampling are listed in the following table and provided in **Attachment A**.

SOP# or Reference	Title, Revision Date, and/or Number	Originating Organization	Equipment Type (if SOP provides different options)	Modified for Field Work? (Yes/No)
RI-SOP-03	Low Stress (low flow) Purging and Sampling Procedure for the Collection of Groundwater Samples from Monitoring Wells (Rev #4, 19 September 2017)	USEPA	NA	No
RI-SOP-05	Ground Penetrating Radar (Rev #5, 3 January 2022)	SERES-Arcadis JV	NA	No
RI-SOP-06	Manual Water-Level and NAPL Monitoring (Rev #2, 5 April 2022)	SERES-Arcadis JV	NA	No
RI-SOP-07	In-Situ and Ex-Situ Water Quality Parameters (Rev #1, 15 April 2022)	SERES-Arcadis JV	NA	No
RI-SOP-08	Sample Chain of Custody (Rev #3, 28 March 2022)	SERES-Arcadis JV	NA	No
RI-SOP-09	Investigation-Derived Waste Handling and Storage (Rev #1, 15 May 2020)	SERES-Arcadis JV	NA	No
RI-SOP-10	Groundwater and Soil Sampling Equipment Decontamination (Rev #1, 8 May 2020)	SERES-Arcadis JV	NA	No
RI-SOP-11	Monitoring Well Development (Rev #1, 12 April 2022).	SERES-Arcadis JV	NA	No
RI-SOP-13	Soil Description (Rev #3, 15 April 2022)	SERES-Arcadis JV	NA	No
RI-SOP-16	Monitoring Well Installation (Rev #0, 24 April 2017).	SERES-Arcadis JV	NA	No

QAPP WORKSHEET #23: ANALYTICAL STANDARD OPERATING PROCEDURE REFERENCES

(UFP-QAPP Manual Section 3.2.1)
(USEPA 2106-G-05 Section 2.3.4)

All method SOPs pertinent to environmental investigations are included for reference in **Attachment B.**

SOP #	Title, Revision Date, and/or Number	Definitive or Screening Data	Matrix/ Analytical Group	Instrument	Organization Performing Analysis	Modified for Project Work? (Yes/No)
DOC316.5 3.01049	Iron, Ferrous 1,10-Phenanthroline (Method 8146, Powder Pillows, 0.02 to 3.00 mg/L Fe2+)	Screening	Aqueous/ Metals	Field Test Kit	S-A JV	No
SA-GE-001	Measurements of Analytes Using the Konelab Analyzer, Rev. 10, 8/30/2022	Definitive	Aqueous/ Phosphate	Konelab Autoanalyzer	Eurofins Environment Testng	No

Notes:

LC/MS/MS = liquid chromatography with tandem mass spectrometry
N/A = not applicable

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USACE. 2001. Requirements for the Preparation of Sampling and Analysis Plans. EM 200-1-3. February.

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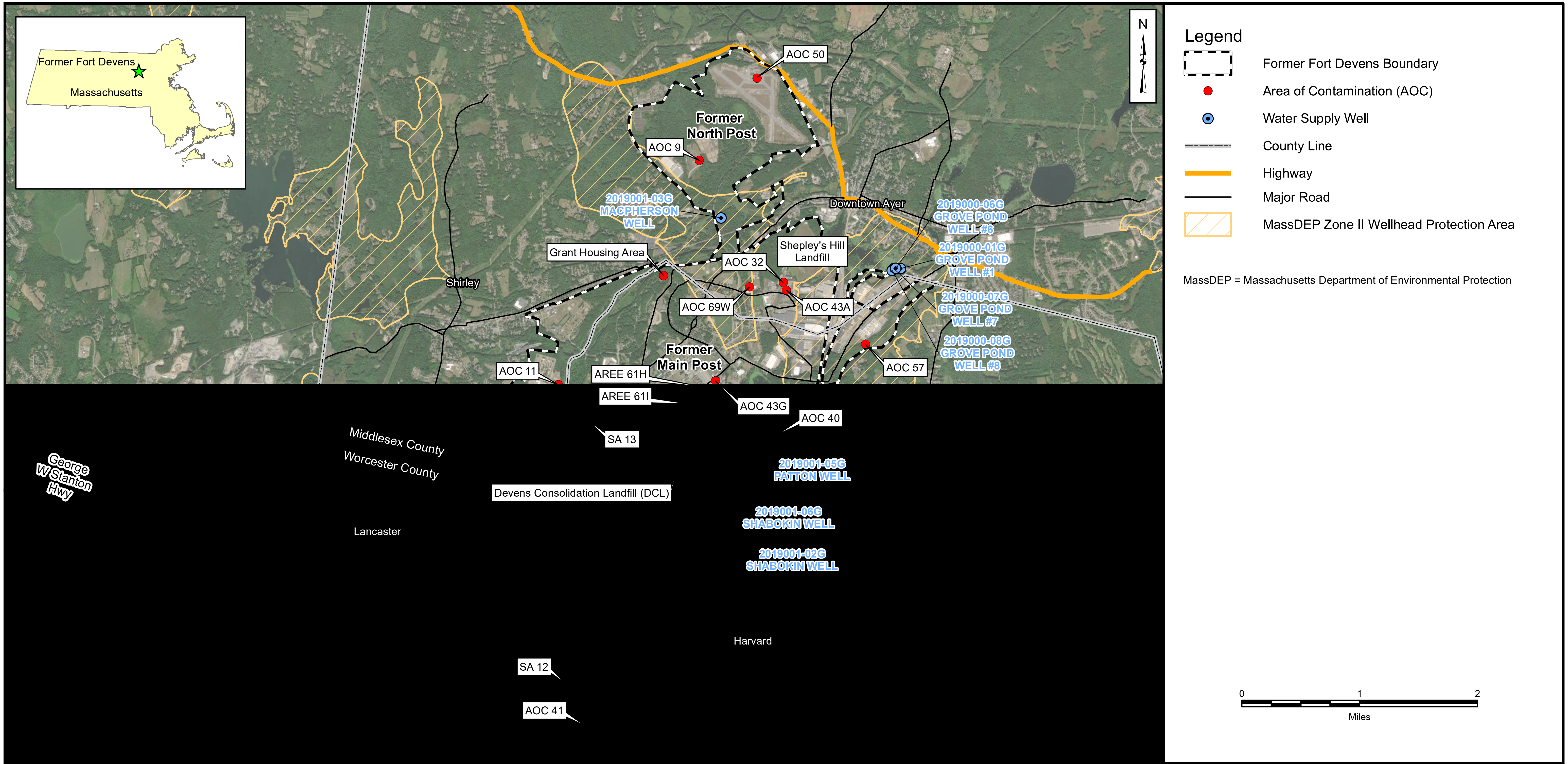
USEPA. 2000a. Data Quality Objectives Process for Hazardous Waste Site Investigations, EPA QA/G-4 HW EPA/600/R-00/007. January.

USEPA. 2000b. Guidance for the Data Quality Objectives Process. USEPA QA/G-4. EPA/600/R-96/055. August.

USEPA-New England, Region I. 2017. Low Stress (Low-Flow) Purging and Sampling Procedure for the Collection of Groundwater Samples from Monitoring Wells. September.

FIGURES



MassDEP = Massachusetts Department of Environmental Protection

Aerial Source:
ESRI, ArcGIS Online,
Aerial Imagery

AOC 43G Supplemental Remedial Investigation Work Plan
Former Fort Devens Army Installation
Devens, Massachusetts

Site Location
Former Fort Devens
Army Installation

SERES Engineering & Services, LLC
ARCADIS
a joint venture

Figure
1-1

T:_ENV\Devens_RFTA\Seed_Task_Order\MXDs\Area 1 Phase 2 Work Plan\012052022\Figure 1-1 - Site Location.mxd 1/5/2022 1:25:46 PM User Name: MSMiller

ATTACHMENT A

FIELD SAMPLING SOPs and TGIs

Attachment A

Field Standard Operating Procedures and TGIs

U.S. ENVIRONMENTAL PROTECTION AGENCY REGION I

LOW STRESS (low flow) PURGING AND SAMPLING PROCEDURE FOR THE COLLECTION OF GROUNDWATER SAMPLES FROM MONITORING WELLS

Quality Assurance Unit
U.S. Environmental Protection Agency – Region 1
11 Technology Drive
North Chelmsford, MA 01863

The controlled version of this document is the electronic version viewed on-line only. If this is a printed copy of the document, it is an uncontrolled version and may or may not be the version currently in use.

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Prepared by:__________________________________ ____________
(Robert Reinhart, Quality Assurance Unit) Date

Approved by:__________________________________ ____________
(John Smaldone, Quality Assurance Unit) Date

Revision Page

Date	**Rev #**	**Summary of changes**	**Sections**
7/30/96	1	Finalized	
01/19/10	2	Updated	All sections
3/23/17	3	Updated	All sections
9/20/17	4	Updated	Section 7.0

Table of Contents

1.0 USE OF TERMS

Equipment blank: The equipment blank shall include the pump and the pump's tubing. If tubing is dedicated to the well, the equipment blank needs only to include the pump in subsequent sampling rounds. If the pump and tubing are dedicated to the well, the equipment blank is collected prior to its placement in the well. If the pump and tubing will be used to sample multiple wells, the equipment blank is normally collected after sampling from contaminated wells and not after background wells.

Field duplicates: Field duplicates are collected to determine precision of the sampling procedure. For this procedure, collect duplicate for each analyte group in consecutive order (VOC original, VOC duplicate, SVOC original, SVOC duplicate, etc.).

Indicator field parameters: This SOP uses field measurements of turbidity, dissolved oxygen, specific conductance, temperature, pH, and oxidation/reduction potential (ORP) as indicators of when purging operations are sufficient and sample collection may begin.

Matrix Spike/Matrix Spike Duplicates: Used by the laboratory in its quality assurance program. Consult the laboratory for the sample volume to be collected.

Potentiometric Surface: The level to which water rises in a tightly cased well constructed in a confined aquifer. In an unconfined aquifer, the potentiometric surface is the water table.

QAPP: Quality Assurance Project Plan

SAP: Sampling and Analysis Plan

SOP: Standard operating procedure

Stabilization: A condition that is achieved when all indicator field parameter measurements are sufficiently stable (as described in the “Monitoring Indicator Field Parameters” section) to allow sample collection to begin.

Temperature blank: A temperature blank is added to each sample cooler. The blank is measured upon receipt at the laboratory to assess whether the samples were properly cooled during transit.

Trip blank (VOCs): Trip blank is a sample of analyte-free water taken to the sampling site and returned to the laboratory. The trip blanks (one pair) are added to each sample cooler that contains VOC samples.

2.0 SCOPE & APPLICATION

The goal of this groundwater sampling procedure is to collect water samples that reflect the total mobile organic and inorganic loads (dissolved and colloidal sized fractions) transported through the subsurface under ambient flow conditions, with minimal physical and chemical alterations from sampling operations. This standard operating procedure (SOP) for collecting groundwater samples will help ensure that the project's data quality objectives (DQOs) are met under certain low-flow conditions.

The SOP emphasizes the need to minimize hydraulic stress at the well-aquifer interface by maintaining low water-level drawdowns, and by using low pumping rates during purging and sampling operations. Indicator field parameters (e.g., dissolved oxygen, pH, etc.) are monitored during purging in order to determine when sample collection may begin. Samples properly collected using this SOP are suitable for analysis of groundwater contaminants (volatile and semi-volatile organic analytes, dissolved gases, pesticides, PCBs, metals and other inorganics), or naturally occurring analytes. This SOP is based on Puls, and Barcelona (1996).

This procedure is designed for monitoring wells with an inside diameter (1.5-inches or greater) that can accommodate a positive lift pump with a screen length or open interval ten feet or less and with a water level above the top of the screen or open interval (Hereafter, the "screen or open interval" will be referred to only as "screen interval"). This SOP is not applicable to other well-sampling conditions.

While the use of dedicated sampling equipment is not mandatory, dedicated pumps and tubing can reduce sampling costs significantly by streamlining sampling activities and thereby reducing the overall field costs.

The goal of this procedure is to emphasize the need for consistency in deploying and operating equipment while purging and sampling monitoring wells during each sampling event. This will help to minimize sampling variability.

This procedure describes a general framework for groundwater sampling. Other site specific information (hydrogeological context, conceptual site model (CSM), DQOs, etc.) coupled with systematic planning must be added to the procedure in order to develop an appropriate site specific SAP/QAPP. In addition, the site specific SAP/QAPP must identify the specific equipment that will be used to collect the groundwater samples.

This procedure does not address the collection of water or free product samples from wells containing free phase LNAPLs and/or DNAPLs (light or dense non-aqueous phase liquids). For this type of situation, the reader may wish to check: Cohen, and Mercer (1993) or other pertinent documents.

This SOP is to be used when collecting groundwater samples from monitoring wells at all Superfund, Federal Facility and RCRA sites in Region 1 under the conditions described herein. Request for modification of this SOP, in order to better address specific situations at individual wells, must include adequate technical justification for proposed changes. <u>All changes and modifications must be approved and included in a revised SAP/QAPP before implementation in field.</u>

3.0 BACKGROUND FOR IMPLEMENTATION

It is expected that the monitoring well screen has been properly located (both laterally and vertically) to intercept existing contaminant plume(s) or along flow paths of potential contaminant migration. Problems with inappropriate monitoring well placement or faulty/improper well installation cannot be overcome by even the best water sampling procedures. This SOP presumes that the analytes of interest are moving (or will potentially move) primarily through the more permeable zones intercepted by the screen interval.

Proper well construction, development, and operation and maintenance cannot be overemphasized. The use of installation techniques that are appropriate to the hydrogeologic setting of the site often prevent "problem well" situations from occurring. During well development, or redevelopment, tests should be conducted to determine the hydraulic characteristics of the monitoring well. The data can then be used to set the purging/sampling rate, and provide a baseline for evaluating changes in well performance and the potential need for well rehabilitation. Note: if this installation data or well history (construction and sampling) is not available or discoverable, for all wells to be sampled, efforts to build a sampling history should commence with the next sampling event.

The pump intake should be located within the screen interval and at a depth that will remain under water at all times. It is recommended that the intake depth and pumping rate remain the same for all sampling events. The mid-point or the lowest historical midpoint of the saturated screen length is often used as the location of the pump intake. For new wells, or for wells without pump intake depth information, the site’s SAP/QAPP must provide clear reasons and instructions on how the pump intake depth(s) will be selected, and reason(s) for the depth(s) selected. If the depths to top and bottom of the well screen are not known, the SAP/QAPP will need to describe how the sampling depth will be determined and how the data can be used.

Stabilization of indicator field parameters is used to indicate that conditions are suitable for sampling to begin. Achievement of turbidity levels of less than 5 NTU, and stable drawdowns of less than 0.3 feet, while desirable, are not mandatory. Sample collection may still take place provided the indicator field parameter criteria in this procedure are met. If after 2 hours of purging indicator field parameters have not stabilized, one of three optional courses of action may be taken: a) continue purging until stabilization is achieved, b) discontinue purging, do not collect any samples, and record in log book that stabilization could not be achieved (documentation must describe attempts to achieve stabilization), c) discontinue purging, collect samples and provide full explanation of attempts to achieve stabilization (note: there is a risk that the analytical data obtained, especially metals and strongly hydrophobic organic analytes, may reflect a sampling bias and therefore, the data may not meet the data quality objectives of the sampling event).

It is recommended that low-flow sampling be conducted when the air temperature is above 32°F (0°C). If the procedure is used below 32°F, special precautions will need to be taken to prevent the groundwater from freezing in the equipment. Because sampling during freezing temperatures may adversely impact the data quality objectives, the need for water sample collection during months when these conditions are likely to occur should be evaluated during site planning and special sampling measures may need to be developed. Ice formation in the flow-through-cell will cause the monitoring probes to act erratically. A transparent flow-through-cell needs to be used to observe if ice is forming in the cell. If ice starts to form on the other pieces of the sampling equipment, additional problems may occur.

4.0 HEALTH & SAFETY

When working on-site, comply with all applicable OSHA requirements and the site’s health/safety procedures. All proper personal protection clothing and equipment are to be worn. Some samples may contain biological and chemical hazards. These samples should be handled with suitable protection to skin, eyes, etc.

5.0 CAUTIONS

The following cautions need to be considered when planning to collect groundwater samples when the below conditions occur.

If the groundwater degasses during purging of the monitoring well, dissolved gases and VOCs will be lost. When this happens, the groundwater data for dissolved gases (e.g., methane, ethene, ethane, dissolved oxygen, etc.) and VOCs will need to be qualified. Some conditions that can promote degassing are the use of a vacuum pump (e.g., peristaltic pumps), changes in aperture along the sampling tubing, and squeezing/pinching the pump’s tubing which results in a pressure change.

When collecting the samples for dissolved gases and VOCs analyses, avoid aerating the groundwater in the pump’s tubing. This can cause loss of the dissolved gases and VOCs in the groundwater. Having the pump's tubing completely filled prior to sampling will avoid this problem when using a centrifugal pump or peristaltic pump.

Direct sun light and hot ambient air temperatures may cause the groundwater in the tubing and flow-through-cell to heat up. This may cause the groundwater to degas which will result in loss of VOCs and dissolved gases. When sampling under these conditions, the sampler will need to shade the equipment from the sunlight (e.g., umbrella, tent, etc.). If possible, sampling on hot days, or during the hottest time of the day, should be avoided. The tubing exiting the monitoring well should be kept as short as possible to avoid the sun light or ambient air from heating up the groundwater.

Thermal currents in the monitoring well may cause vertical mixing of water in the well bore. When the air temperature is colder than the groundwater temperature, it can cool the top of the water column. Colder water which is denser than warm water sinks to the bottom of the well and the warmer water at the bottom of the well rises, setting up a convection cell. "During low-flow sampling, the pumped water may be a mixture of convecting water from within the well casing and aquifer water moving inward through the screen. This mixing of water during low-flow sampling can substantially increase equilibration times, can cause false stabilization of indicator parameters, can give false indication of redox state, and can provide biological data that are not representative of the aquifer conditions" (Vroblesky 2007).

Failure to calibrate or perform proper maintenance on the sampling equipment and measurement instruments (e.g., dissolved oxygen meter, etc.) can result in faulty data being collected.

Interferences may result from using contaminated equipment, cleaning materials, sample containers, or uncontrolled ambient/surrounding air conditions (e.g., truck/vehicle exhaust nearby).

Cross contamination problems can be eliminated or minimized through the use of dedicated sampling equipment and/or proper planning to avoid ambient air interferences. Note that the use of dedicated sampling equipment can also significantly reduce the time needed to complete each sampling event, will promote consistency in the sampling, and may reduce sampling bias by having the pump's intake at a constant depth.

Clean and decontaminate all sampling equipment prior to use. All sampling equipment needs to be routinely checked to be free from contaminants and equipment blanks collected to ensure that the equipment is free of contaminants. Check the previous equipment blank data for the site (if they exist) to determine if the previous cleaning procedure removed the contaminants. If contaminants were detected and they are a concern, then a more vigorous cleaning procedure will be needed.

6.0 PERSONNEL QUALIFICATIONS

All field samplers working at sites containing hazardous waste must meet the requirements of the OSHA regulations. OSHA regulations may require the sampler to take the 40 hour OSHA health and safety training course and a refresher course prior to engaging in any field activities, depending upon the site and field conditions.

The field samplers must be trained prior to the use of the sampling equipment, field instruments, and procedures. Training is to be conducted by an experienced sampler before initiating any sampling procedure.

The entire sampling team needs to read, and be familiar with, the site Health and Safety Plan, all relevant SOPs, and SAP/QAPP (and the most recent amendments) before going onsite for the sampling event. It is recommended that the field sampling leader attest to the understanding of these site documents and that it is recorded.

7.0 EQUIPMENT AND SUPPLIES

A. Informational materials for sampling event

A copy of the current Health and Safety Plan, SAP/QAPP, monitoring well construction data, location map(s), field data from last sampling event, manuals for sampling, and the monitoring instruments' operation, maintenance, and calibration manuals should be brought to the site.

B. Well keys.

C. Extraction device

Adjustable rate, submersible pumps (e.g., centrifugal, bladder, etc.) which are constructed of stainless steel or polytetrafluoroethylene (PTFE, i.e. Teflon®) are preferred. PTFE, however, should not be used when sampling for per- and polyfluoroalkyl substances (PFAS) as it is likely to contain these substances.

Note: If extraction devices constructed of other materials are to be used, adequate information must be provided to show that the substituted materials do not leach contaminants nor cause interferences to the analytical procedures to be used. Acceptance of these materials must be obtained before the sampling event.

If bladder pumps are selected for the collection of VOCs and dissolved gases, the pump setting should be set so that one pulse will deliver a water volume that is sufficient to fill a 40 mL VOC vial. This is not mandatory, but is considered a "best practice". For the proper operation, the bladder pump will need a minimum amount of water above the pump; consult the manufacturer for the recommended submergence. The pump's recommended submergence value should be determined during the planning stage, since it may influence well construction and placement of dedicated pumps where water-level fluctuations are significant.

Adjustable rate, peristaltic pumps (suction) are to be used with caution when collecting samples for VOCs and dissolved gases (e.g., methane, carbon dioxide, etc.) analyses. Additional information on the use of peristaltic pumps can be found in Appendix A.
If peristaltic pumps are used, the inside diameter of the rotor head tubing needs to match the inside diameter of the tubing installed in the monitoring well.

Inertial pumping devices (motor driven or manual) are not recommended. These devices frequently cause greater disturbance during purging and sampling, and are less easily controlled than submersible pumps (potentially increasing turbidity and sampling variability, etc.). This can lead to sampling results that are adversely affected by purging and sampling operations, and a higher degree of data variability.

D. Tubing

PTFE (Teflon®) or PTFE-lined polyethylene tubing are preferred when sampling is to include VOCs, SVOCs, pesticides, PCBs and inorganics. As discussed in the previous section, PTFE tubing should not be used when sampling for PFAS. In this case, a suitable alternative such as high-density polyethylene tubing should be used.

PVC, polypropylene or polyethylene tubing may be used when collecting samples for metal and other inorganics analyses.

Note: If tubing constructed of other materials is to be used, adequate information must be provided to show that the substituted materials do not leach contaminants nor cause interferences to the analytical procedures to be used. Acceptance of these materials must be obtained before the sampling event.

The use of 1/4 inch or 3/8 inch (inside diameter) tubing is recommended. This will help ensure that the tubing remains liquid filled when operating at very low pumping rates when using centrifugal and peristaltic pumps.

Silastic tubing should be used for the section around the rotor head of a peristaltic pump. It should be less than a foot in length. The inside diameter of the tubing used at the pump rotor head must be the same as the inside diameter of tubing placed in the well. A tubing connector is used to connect the pump rotor head tubing to the well tubing. Alternatively, the two pieces of tubing can be connected to each other by placing the one end of the tubing inside the end of the other tubing. The tubing must not be reused.

E. The water level measuring device

Electronic ”tape”, pressure transducer, water level sounder/level indicator, etc. should be capable of measuring to 0.01 foot accuracy. Recording pressure transducers, mounted above the pump, are especially helpful in tracking water levels during pumping operations, but their use must include check measurements with a water level “tape” at the start and end of each sampling event.

F. Flow measurement supplies

Graduated cylinder (size according to flow rate) and stopwatch usually will suffice.

Large graduated bucket used to record total water purged from the well.

G. Interface probe

To be used to check on the presence of free phase liquids (LNAPL, or DNAPL) before purging begins (as needed).

H. Power source (generator, nitrogen tank, battery, etc.)

When a gasoline generator is used, locate it downwind and at least 30 feet from the well so that the exhaust fumes do not contaminate samples.

I. Indicator field parameter monitoring instruments

Use of a multi-parameter instrument capable of measuring pH, oxidation/reduction potential (ORP), dissolved oxygen (DO), specific conductance, temperature, and coupled with a flow-through-cell is required when measuring all indicator field parameters, except turbidity. Turbidity is collected using a separate instrument. Record equipment/instrument identification (manufacturer, and model number).

Transparent, small volume flow-through-cells (e.g., 250 mLs or less) are preferred. This allows observation of air bubbles and sediment buildup in the cell, which can interfere with the operation of the monitoring instrument probes, to be easily detected. A small volume cell facilitates rapid turnover of water in the cell between measurements of the indicator field parameters.

It is recommended to use a flow-through-cell and monitoring probes from the same manufacturer and model to avoid incompatibility between the probes and flow-through-cell.

Turbidity samples are collected before the flow-through-cell. A “T” connector coupled with a valve is connected between the pump’s tubing and flow-through-cell. When a turbidity measurement is required, the valve is opened to allow the groundwater to flow into a container. The valve is closed and the container sample is then placed in the turbidimeter.

Standards are necessary to perform field calibration of instruments. A minimum of two standards are needed to bracket the instrument measurement range for all parameters except ORP which use a Zobell solution as a standard. For dissolved oxygen, a wet sponge used for the 100% saturation and a zero dissolved oxygen solution are used for the calibration.

Barometer (used in the calibration of the Dissolved Oxygen probe) and the conversion formula to convert the barometric pressure into the units of measure used by the Dissolved Oxygen meter are needed.

J. Decontamination supplies

Includes (for example) non-phosphate detergent, distilled/deionized water, isopropyl alcohol, etc.

K. Record keeping supplies

Logbook(s), well purging forms, chain-of-custody forms, field instrument calibration forms, etc.

L. Sample bottles

M. Sample preservation supplies (as required by the analytical methods)

N. Sample tags or labels

O. PID or FID instrument

If appropriate, to detect VOCs for health and safety purposes, and provide qualitative field evaluations.

P. Miscellaneous Equipment

Equipment to keep the sampling apparatus shaded in the summer (e.g., umbrella) and from freezing in the winter. If the pump's tubing is allowed to heat up in the warm weather, the cold groundwater may degas as it is warmed in the tubing.

8.0 EQUIPMENT/INSTRUMENT CALIBRATION

Prior to the sampling event, perform maintenance checks on the equipment and instruments according to the manufacturer's manual and/or applicable SOP. This will ensure that the equipment/instruments are working properly before they are used in the field.

Prior to sampling, the monitoring instruments must be calibrated and the calibration documented. The instruments are calibrated using U.S Environmental Protection Agency Region 1 *Calibration of Field Instruments (temperature, pH, dissolved oxygen, conductivity/specific conductance, oxidation/reduction [ORP], and turbidity),* March 23, 2017, or latest version or from one of the methods listed in 40CFR136, 40CFR141 and SW-846.

The instruments shall be calibrated at the beginning of each day. If the field measurement falls outside the calibration range, the instrument must be re-calibrated so that all measurements fall within the calibration range. At the end of each day, a calibration check is performed to verify that instruments remained in calibration throughout the day. This check is performed while the instrument is in measurement mode, not calibration mode. If the field instruments are being used to monitor the natural attenuation parameters, then a calibration check at mid-day is highly recommended to ensure that the instruments did not drift out of calibration. Note: during the day if the instrument reads zero or a negative number for dissolved oxygen, pH, specific conductance, or turbidity (negative value only), this indicates that the instrument drifted out of calibration or the instrument is malfunctioning. If this situation occurs the data from this instrument will need to be qualified or rejected.

9.0 PRELIMINARY SITE ACTIVITIES (as applicable)

Check the well for security (damage, evidence of tampering, missing lock, etc.) and record pertinent observations (include photograph as warranted).

If needed, lay out a sheet of clean polyethylene for monitoring and sampling equipment, unless equipment is elevated above the ground (e.g., on a table, etc.).

Remove well cap and if appropriate measure VOCs at the rim of the well with a PID or FID instrument and record reading in field logbook or on the well purge form.

If the well casing does not have an established reference point (usually a V-cut or indelible mark in the well casing), make one. Describe its location and record the date of the mark in the logbook (consider a photographic record as well). All water level measurements must be recorded relative to this reference point (and the altitude of this point should be determined using techniques that are appropriate to site's DQOs.

If water-table or potentiometric surface map(s) are to be constructed for the sampling event, perform synoptic water level measurement round (in the shortest possible time) before any purging and sampling activities begin. If possible, measure water level depth (to 0.01 ft.) and total well depth (to 0.1 ft.) the day before sampling begins, in order to allow for re-settlement of any particulates in the water column. This is especially important for those wells that have not been recently sampled because sediment buildup in the well may require the well to be redeveloped. If measurement of total well depth is not made the day before, it should be measured after sampling of the well is complete. All measurements must be taken from the established referenced point. Care should be taken to minimize water column disturbance.

Check newly constructed wells for the presence of LNAPLs or DNAPLs before the initial sampling round. If none are encountered, subsequent check measurements with an interface probe may not be necessary unless analytical data or field analysis signal a worsening situation. This SOP cannot be used in the presence of LNAPLs or DNAPLs. If NAPLs are present, the project team must decide upon an alternate sampling method. All project modifications must be approved and documented prior to implementation.

If available check intake depth and drawdown information from previous sampling event(s) for each well. Duplicate, to the extent practicable, the intake depth and extraction rate (use final pump dial setting information) from previous event(s). If changes are made in the intake depth or extraction rate(s) used during previous sampling event(s), for either portable or dedicated extraction devices, record new values, and explain reasons for the changes in the field logbook.

10.0 PURGING AND SAMPLING PROCEDURE

Purging and sampling wells in order of increasing chemical concentrations (known or anticipated) are preferred.

The use of dedicated pumps is recommended to minimize artificial mobilization and entrainment of particulates each time the well is sampled. Note that the use of dedicated sampling equipment can also significantly reduce the time needed to complete each sampling event, will promote consistency in the sampling, and may reduce sampling bias by having the pump's intake at a constant depth.

A. Initial Water Level

Measure the water level in the well before installing the pump if a non-dedicated pump is being used. The initial water level is recorded on the purge form or in the field logbook.

B. Install Pump

Lower pump, safety cable, tubing and electrical lines slowly (to minimize disturbance) into the well to the appropriate depth (may not be the mid-point of the screen/open interval). The Sampling and Analysis Plan/Quality Assurance Project Plan should specify the sampling depth (used previously), or provide criteria for selection of intake depth for each new well. If possible keep the pump intake at least two feet above the bottom of the well, to minimize mobilization of particulates present in the bottom of the well.

Pump tubing lengths, above the top of well casing should be kept as short as possible to minimize heating the groundwater in the tubing by exposure to sun light and ambient air temperatures. Heating may cause the groundwater to degas, which is unacceptable for the collection of samples for VOC and dissolved gases analyses.

C. Measure Water Level

Before starting pump, measure water level. Install recording pressure transducer, if used to track drawdowns, to initialize starting condition.

D. Purge Well

From the time the pump starts purging and until the time the samples are collected, the purged water is discharged into a graduated bucket to determine the total volume of groundwater purged. This information is recorded on the purge form or in the field logbook.

Start the pump at low speed and slowly increase the speed until discharge occurs. Check water level. Check equipment for water leaks and if present fix or replace the affected equipment. Try to match pumping rate used during previous sampling event(s). Otherwise, adjust pump speed until there is little or no water level drawdown. If the minimal drawdown that can be achieved exceeds 0.3 feet, but remains stable, continue purging.

Monitor and record the water level and pumping rate every five minutes (or as appropriate) during purging. Record any pumping rate adjustments (both time and flow rate). Pumping rates should, as needed, be reduced to the minimum capabilities of the pump to ensure stabilization of the water level. Adjustments are best made in the first fifteen minutes of pumping in order to help minimize purging time. During pump start-up, drawdown may exceed the 0.3 feet target and then "recover" somewhat as pump flow adjustments are made. Purge volume calculations should utilize stabilized drawdown value, not the initial drawdown. If the initial water level is above the top of the screen do not allow the water level to fall into the well screen. The final purge volume must be greater than the stabilized drawdown volume plus the pump’s tubing volume. If the drawdown has exceeded 0.3 feet and stabilizes, calculate the volume of water between the initial water level and the stabilized water level. Add the volume of the water which occupies the pump’s tubing to this calculation. This combined volume of water needs to be purged from the well after the water level has stabilized before samples are collected.

Avoid the use of constriction devices on the tubing to decrease the flow rate because the constrictor will cause a pressure difference in the water column. This will cause the groundwater to degas and result in a loss of VOCs and dissolved gasses in the groundwater samples.

Note: the flow rate used to achieve a stable pumping level should remain constant while monitoring the indicator parameters for stabilization and while collecting the samples.

Wells with low recharge rates may require the use of special pumps capable of attaining very low pumping rates (e.g., bladder, peristaltic), and/or the use of dedicated equipment. For new monitoring wells, or wells where the following situation has not occurred before, if the recovery rate to the well is less than 50 mL/min., or the well is being essentially dewatered during purging, the well should be sampled as soon as the water level has recovered sufficiently to collect the volume needed for all anticipated samples. The project manager or field team leader will need to make the decision when samples should be collected, how the sample is to be collected, and the reasons recorded on the purge form or in the field logbook. A water level measurement needs to be performed and recorded before samples are collected. If the project manager decides to collect the samples using the pump, it is best during this recovery period that the pump intake tubing not be removed, since this will aggravate any turbidity problems. Samples in this specific situation may be collected without stabilization of indicator field parameters. Note that field conditions and efforts to overcome problematic situations must be recorded in order to support field decisions to deviate from normal procedures described in this SOP. If this type of problematic situation persists in a well, then water sample collection should be changed to a passive or no-purge method, if consistent with the site's DQOs, or have a new well installed.

E. Monitor Indicator Field Parameters

After the water level has stabilized, connect the "T" connector with a valve and the flow-through-cell to monitor the indicator field parameters. If excessive turbidity is anticipated or encountered with the pump startup, the well may be purged for a while without connecting up the flow-through-cell, in order to minimize particulate buildup in the cell (This is a judgment call made by the sampler). Water level drawdown measurements should be made as usual. If possible, the pump may be installed the day before purging to allow particulates that were disturbed during pump insertion to settle.

During well purging, monitor indicator field parameters (turbidity, temperature, specific conductance, pH, ORP, DO) at a frequency of five minute intervals or greater. The pump's flow rate must be able to "turn over" at least one flow-through-cell volume between measurements (for a 250 mL flow-through-cell with a flow rate of 50 mLs/min., the monitoring frequency would be every five minutes; for a 500 mL flow-through-cell it would be every ten minutes). If the cell volume cannot be replaced in the five minute interval, then the time between measurements must be increased accordingly. Note: during the early phase of purging, emphasis should be put on minimizing and stabilizing pumping stress, and recording those adjustments followed by stabilization of indicator parameters. Purging is considered complete and sampling may begin when all the above indicator field parameters have stabilized. Stabilization is considered to be achieved when three consecutive readings are within the following limits:

Turbidity (10% for values greater than 5 NTU; if three Turbidity values are less than 5 NTU, consider the values as stabilized),
Dissolved Oxygen (10% for values greater than 0.5 mg/L, if three Dissolved Oxygen values are less than 0.5 mg/L, consider the values as stabilized),
Specific Conductance (3%),
Temperature (3%),
pH (± 0.1 unit),
Oxidation/Reduction Potential (±10 millivolts).

All measurements, except turbidity, must be obtained using a flow-through-cell. Samples for turbidity measurements are obtained before water enters the flow-through-cell. Transparent flow-through-cells are preferred, because they allow field personnel to watch for particulate build-up within the cell. This build-up may affect indicator field parameter values measured within the cell. If the cell needs to be cleaned during purging operations, continue pumping and disconnect cell for cleaning, then reconnect after cleaning and continue monitoring activities. Record start and stop times and give a brief description of cleaning activities.

The flow-through-cell must be designed in a way that prevents gas bubble entrapment in the cell. Placing the flow-through-cell at a 45 degree angle with the port facing upward can help remove bubbles from the flow-through-cell (see Appendix B Low-Flow Setup Diagram). Throughout the measurement process, the flow-through-cell must remain free of any gas bubbles. Otherwise, the monitoring probes may act erratically. When the pump is turned off or cycling on/off (when using a bladder pump), water in the cell must not drain out. Monitoring probes must remain submerged in water at all times.

F. Collect Water Samples

When samples are collected for laboratory analyses, the pump's tubing is disconnected from the "T" connector with a valve and the flow-through-cell. The samples are collected directly from the pump's tubing. Samples must not be collected from the flow-through-cell or from the "T" connector with a valve.

VOC samples are normally collected first and directly into pre-preserved sample containers. However, this may not be the case for all sampling locations; the SAP/QAPP should list the order in which the samples are to be collected based on the project's objective(s). Fill all sample containers by allowing the pump discharge to flow gently down the inside of the container with minimal turbulence.

If the pump's flow rate is too high to collect the VOC/dissolved gases samples, collect the other samples first. Lower the pump's flow rate to a reasonable rate and collect the VOC/dissolved gases samples and record the new flow rate.

During purging and sampling, the centrifugal/peristaltic pump tubing must remain filled with water to avoid aeration of the groundwater. It is recommended that 1/4 inch or 3/8 inch (inside diameter) tubing be used to help ensure that the sample tubing remains water filled. If the pump tubing is not completely filled to the sampling point, use the following procedure to collect samples: collect non-VOC/dissolved gases samples first, then increase flow rate slightly until the water completely fills the tubing, collect the VOC/dissolved gases samples, and record new drawdown depth and flow rate.

For bladder pumps that will be used to collect VOC or dissolved gas samples, it is recommended that the pump be set to deliver long pulses of water so that one pulse will fill a 40 mL VOC vial.

Use pre-preserved sample containers or add preservative, as required by analytical methods, to the samples immediately after they are collected. Check the analytical methods (e.g. EPA SW-846, 40 CFR 136, water supply, etc.) for additional information on preservation.

If determination of filtered metal concentrations is a sampling objective, collect filtered water samples using the same low flow procedures. The use of an in-line filter (transparent housing preferred) is required, and the filter size (0.45 µm is commonly used) should be based on the sampling objective. Pre-rinse the filter with groundwater prior to sample collection. Make sure the filter is free of air bubbles before samples are collected. Preserve the filtered water sample immediately. Note: filtered water samples are not an acceptable substitute for unfiltered samples when the monitoring objective is to obtain chemical concentrations of total mobile contaminants in groundwater for human health or ecological risk calculations.

Label each sample as collected. Samples requiring cooling will be placed into a cooler with ice or refrigerant for delivery to the laboratory. Metal samples after acidification to a pH less than 2 do not need to be cooled.

G. Post Sampling Activities

If a recording pressure transducer is used to track drawdown, re-measure water level with tape.

After collection of samples, the pump tubing may be dedicated to the well for re-sampling (by hanging the tubing inside the well), decontaminated, or properly discarded.

Before securing the well, measure and record the well depth (to 0.1 ft.), if not measured the day before purging began. Note: measurement of total well depth annually is usually sufficient after the initial low stress sampling event. However, a greater frequency may be needed if the well has a “silting” problem or if confirmation of well identity is needed.

Secure the well.

11.0 DECONTAMINATION

Decontaminate sampling equipment prior to use in the first well, and then following sampling of each subsequent well. Pumps should not be removed between purging and sampling operations. The pump, tubing, support cable and electrical wires which were in contact with the well should be decontaminated by one of the procedures listed below.

The use of dedicated pumps and tubing will reduce the amount of time spent on decontamination of the equipment. If dedicated pumps and tubing are used, only the initial sampling event will require decontamination of the pump and tubing.

Note if the previous equipment blank data showed that contaminant(s) were present after using the below procedure or the one described in the SAP/QAPP, a more vigorous procedure may be needed.

Procedure 1

Decontaminating solutions can be pumped from either buckets or short PVC casing sections through the pump and tubing. The pump may be disassembled and flushed with the decontaminating solutions. It is recommended that detergent and alcohol be used sparingly in the decontamination process and water flushing steps be extended to ensure that any sediment trapped in the pump is removed. The pump exterior and electrical wires must be rinsed with the decontaminating solutions, as well. The procedure is as follows:

Flush the equipment/pump with potable water.

Flush with non-phosphate detergent solution. If the solution is recycled, the solution must be changed periodically.

Flush with potable or distilled/deionized water to remove all of the detergent solution. If the water is recycled, the water must be changed periodically.

Optional - flush with isopropyl alcohol (pesticide grade; must be free of ketones {e.g., acetone}) or with methanol. This step may be required if the well is highly contaminated or if the equipment blank data from the previous sampling event show that the level of contaminants is significant.

Flush with distilled/deionized water. This step must remove all traces of alcohol (if used) from the equipment. The final water rinse must not be recycled.

Procedure 2

Steam clean the outside of the submersible pump.

Pump hot potable water from the steam cleaner through the inside of the pump. This can be accomplished by placing the pump inside a three or four inch diameter PVC pipe with end cap. Hot water from the steam cleaner jet will be directed inside the PVC pipe and the pump exterior will be cleaned. The hot water from the steam cleaner will then be pumped from the PVC pipe through the pump and collected into another container. Note: additives or solutions should not be added to the steam cleaner.

Pump non-phosphate detergent solution through the inside of the pump. If the solution is recycled, the solution must be changed periodically.

Pump potable water through the inside of the pump to remove all of the detergent solution. If the solution is recycled, the solution must be changed periodically.

Pump distilled/deionized water through the pump. The final water rinse must not be recycled.

12.0 FIELD QUALITY CONTROL

Quality control samples are required to verify that the sample collection and handling process has not compromised the quality of the groundwater samples. All field quality control samples must be prepared the same as regular investigation samples with regard to sample volume, containers, and preservation. Quality control samples include field duplicates, equipment blanks, matrix spike/matrix spike duplicates, trip blanks (VOCs), and temperature blanks.

13.0 FIELD LOGBOOK

A field log shall be kept to document all groundwater field monitoring activities (see Appendix C, example table), and record the following for each well:

Site name, municipality, state.

Well identifier, latitude-longitude or state grid coordinates.

Measuring point description (e.g., north side of PVC pipe).

Well depth, and measurement technique.

Well screen length.

Pump depth.

Static water level depth, date, time and measurement technique.

Presence and thickness of immiscible liquid (NAPL) layers and detection method.

Pumping rate, drawdown, indicator parameters values, calculated or measured total volume pumped, and clock time of each set of measurements.

Type of tubing used and its length.

Type of pump used.

Clock time of start and end of purging and sampling activity.

Types of sample bottles used and sample identification numbers.

Preservatives used.

Parameters requested for analyses.

Field observations during sampling event.

Name of sample collector(s).

Weather conditions, including approximate ambient air temperature.

QA/QC data for field instruments.

Any problems encountered should be highlighted.

Description of all sampling/monitoring equipment used, including trade names, model number, instrument identification number, diameters, material composition, etc.

14.0 DATA REPORT

Data reports are to include laboratory analytical results, QA/QC information, field indicator parameters measured during purging, field instrument calibration information, and whatever other field logbook information is needed to allow for a full evaluation of data usability.

Note: the use of trade, product, or firm names in this sampling procedure is for descriptive purposes only and does not constitute endorsement by the U.S. EPA.

15.0 REFERENCES

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U.S Environmental Protection Agency, 40 CFR 136.

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Vroblesky, Don A., Clifton C. Casey, and Mark A. Lowery, Summer 2007, Influence of Dissolved Oxygen Convection on Well Sampling, *Ground Water Monitoring & Remediation* 27, no. 3: 49-58.

APPENDIX A

PERISTALTIC PUMPS

Before selecting a peristaltic pump to collect groundwater samples for VOCs and/or dissolved gases, (e.g., methane, carbon dioxide, etc.) consideration should be given to the following:

- The decision of whether or not to use a peristaltic pump is dependent on the intended use of the data.
- If the additional sampling error that may be introduced by this device is NOT of concern for the VOC/dissolved gases data's intended use, then this device may be acceptable.
- If minor differences in the groundwater concentrations could affect the decision, such as to continue or terminate groundwater cleanup or whether the cleanup goals have been reached, then this device should NOT be used for VOC/dissolved gases sampling. In these cases, centrifugal or bladder pumps are a better choice for more accurate results.

EPA and USGS have documented their concerns with the use of the peristaltic pumps to collect water sample in the below documents.

- "Suction Pumps are not recommended because they may cause degassing, pH modification, and loss of volatile compounds" *A Compendium of Superfund Field Operations Methods*, EPA/540/P-87/001, December 1987.
- "The agency does not recommend the use of peristaltic pumps to sample ground water particularly for volatile organic analytes" *RCRA Ground-Water Monitoring Draft Technical Guidance*, EPA Office of Solid Waste, November 1992.
- "The peristaltic pump is limited to shallow applications and can cause degassing resulting in alteration of pH, alkalinity, and volatiles loss", *Low-flow (Minimal drawdown) Ground-Water Sampling Procedures*, by Robert Puls & Michael Barcelona, April 1996, EPA/540/S-95/504.
- "Suction-lift pumps, such as peristaltic pumps, can operate at a very low pumping rate; however, using negative pressure to lift the sample can result in the loss of volatile analytes", USGS Book 9 Techniques of Water-Resources Investigation, Chapter A4. (Version 2.0, 9/2006).

APPENDIX B

SUMMARY OF SAMPLING INSTRUCTIONS

These instructions are for using an adjustable rate, submersible pump or a peristaltic pump with the pump's intake placed at the midpoint of a 10 foot or less well screen or an open interval. The water level in the monitoring well is above the top of the well screen or open interval, the ambient temperature is above 32°F, and the equipment is not dedicated. Field instruments are already calibrated. The equipment is setup according to the diagram at the end of these instructions.

1. Review well installation information. Record well depth, length of screen or open interval, and depth to top of the well screen. Determine the pump's intake depth (e.g., mid-point of screen/open interval).

2. On the day of sampling, check security of the well casing, perform any safety checks needed for the site, lay out a sheet of polyethylene around the well (if necessary), and setup the equipment. If necessary a canopy or an equivalent item can be setup to shade the pump's tubing and flow-through-cell from the sun light to prevent the sun light from heating the groundwater.

3. Check well casing for a reference mark. If missing, make a reference mark. Measure the water level (initial) to 0.01 ft. and record this information.

4. Install the pump's intake to the appropriate depth (e.g., midpoint) of the well screen or open interval. Do not turn-on the pump at this time.

5. Measure water level and record this information.

6. Turn-on the pump and discharge the groundwater into a graduated waste bucket. Slowly increase the flow rate until the water level starts to drop. Reduce the flow rate slightly so the water level stabilizes. Record the pump's settings. Calculate the flow rate using a graduated container and a stop watch. Record the flow rate. Do not let the water level drop below the top of the well screen.

If the groundwater is highly turbid or discolored, continue to discharge the water into the bucket until the water clears (visual observation); this usually takes a few minutes. The turbid or discolored water is usually from the well-being disturbed during the pump installation. If the water does not clear, then you need to make a choice whether to continue purging the well (hoping that it will clear after a reasonable time) or continue to the next step. Note, it is sometimes helpful to install the pump the day before the sampling event so that the disturbed materials in the well can settle out.

If the water level drops to the top of the well screen during the purging of the well, stop purging the well, and do the following:

> Wait for the well to recharge to a sufficient volume so samples can be collected. This may take a while (pump may be removed from well, if turbidity is not a problem). The project manager will need to make the decision when samples should be collected and the reasons recorded in the site's log book. A water level measurement needs to be performed and recorded before samples are collected. When samples are being collected, the water level must not drop below the top of the screen or open interval. Collect the samples from the pump's tubing. Always collect the VOCs and dissolved gases samples first. Normally, the samples requiring a small volume are collected before the large volume samples are collected just in case there is not sufficient water in the well to fill all the sample containers. All samples must be collected, preserved, and stored according to the analytical method. Remove the pump from the well and decontaminate the sampling equipment.

If the water level has dropped 0.3 feet or less from the initial water level (water level measure before the pump was installed); proceed to Step 7. If the water level has dropped more than 0.3 feet, calculate the volume of water between the initial water level and the stabilized water level. Add the volume of the water which occupies the pump's tubing to this calculation. This combined volume of water needs to be purged from the well after the water level has stabilized before samples are be collected.

7. Attach the pump's tubing to the "T" connector with a valve (or a three-way stop cock). The pump's tubing from the well casing to the "T" connector must be as short as possible to prevent the groundwater in the tubing from heating up from the sun light or from the ambient air. Attach a short piece of tubing to the other end of the end of the "T" connector to serve as a sampling port for the turbidity samples. Attach the remaining end of the "T" connector to a short piece of tubing and connect the tubing to the flow-through-cell bottom port. To the top port, attach a small piece of tubing to direct the water into a calibrated waste bucket. Fill the cell with the groundwater and remove all gas bubbles from the cell. Position the flow-through-cell in such a way that if gas bubbles enter the cell they can easily exit the cell. If the ports are on the same side of the cell and the cell is cylindrical shape, the cell can be placed at a 45-degree angle with the ports facing upwards; this position should keep any gas bubbles entering the cell away from the monitoring probes and allow the gas bubbles to exit the cell easily (see Low-Flow Setup Diagram). Note:

make sure there are no gas bubbles caught in the probes' protective guard; you may need to shake the cell to remove these bubbles.

8. Turn-on the monitoring probes and turbidity meter.

9. Record the temperature, pH, dissolved oxygen, specific conductance, and oxidation/reduction potential measurements. Open the valve on the "T" connector to collect a sample for the turbidity measurement, close the valve, do the measurement, and record this measurement. Calculate the pump's flow rate from the water exiting the flow-through-cell using a graduated container and a stop watch, and record the measurement. Measure and record the water level. Check flow-through-cell for gas bubbles and sediment; if present, remove them.

10. Repeat Step 9 every 5 minutes or as appropriate until monitoring parameters stabilized. Note: at least one flow-through-cell volume must be exchanged between readings. If not, the time interval between readings will need to be increased. Stabilization is achieved when three consecutive measurements are within the following limits:

> **Turbidity** (10% for values greater than 5 NTUs; if three Turbidity values are less than 5 NTUs, consider the values as stabilized),
> **Dissolved Oxygen** (10% for values greater than 0.5 mg/L, if three Dissolved Oxygen values are less than 0.5 mg/L, consider the values as stabilized),
> **Specific Conductance** (3%),
> **Temperature** (3%),
> **pH** (± 0.1 unit),
> **Oxidation/Reduction Potential** (±10 millivolts).

If these stabilization requirements do not stabilize in a reasonable time, the probes may have been coated from the materials in the groundwater, from a buildup of sediment in the flow-through-cell, or a gas bubble is lodged in the probe. The cell and the probes will need to be cleaned. Turn-off the probes (not the pump), disconnect the cell from the "T" connector and continue to purge the well. Disassemble the cell, remove the sediment, and clean the probes according to the manufacturer's instructions. Reassemble the cell and connect the cell to the "T" connector. Remove all gas bubbles from the cell, turn-on the probes, and continue the measurements. Record the time the cell was cleaned.

11. When it is time to collect the groundwater samples, turn-off the monitoring probes, and disconnect the pump's tubing from the "T" connector. If you are using a centrifugal or peristaltic pump check the pump's tubing to determine if the tubing is completely filled with water (no air space).

All samples must be collected and preserved according to the analytical method. VOCs and dissolved gases samples are normally collected first and directly into pre-preserved sample containers. However, this may not be the case for all sampling locations; the SAP/QAPP should list the order in which the samples are to be collected based on the project's objective(s). Fill all sample containers by allowing the pump discharge to flow gently down the inside of the container with minimal turbulence.

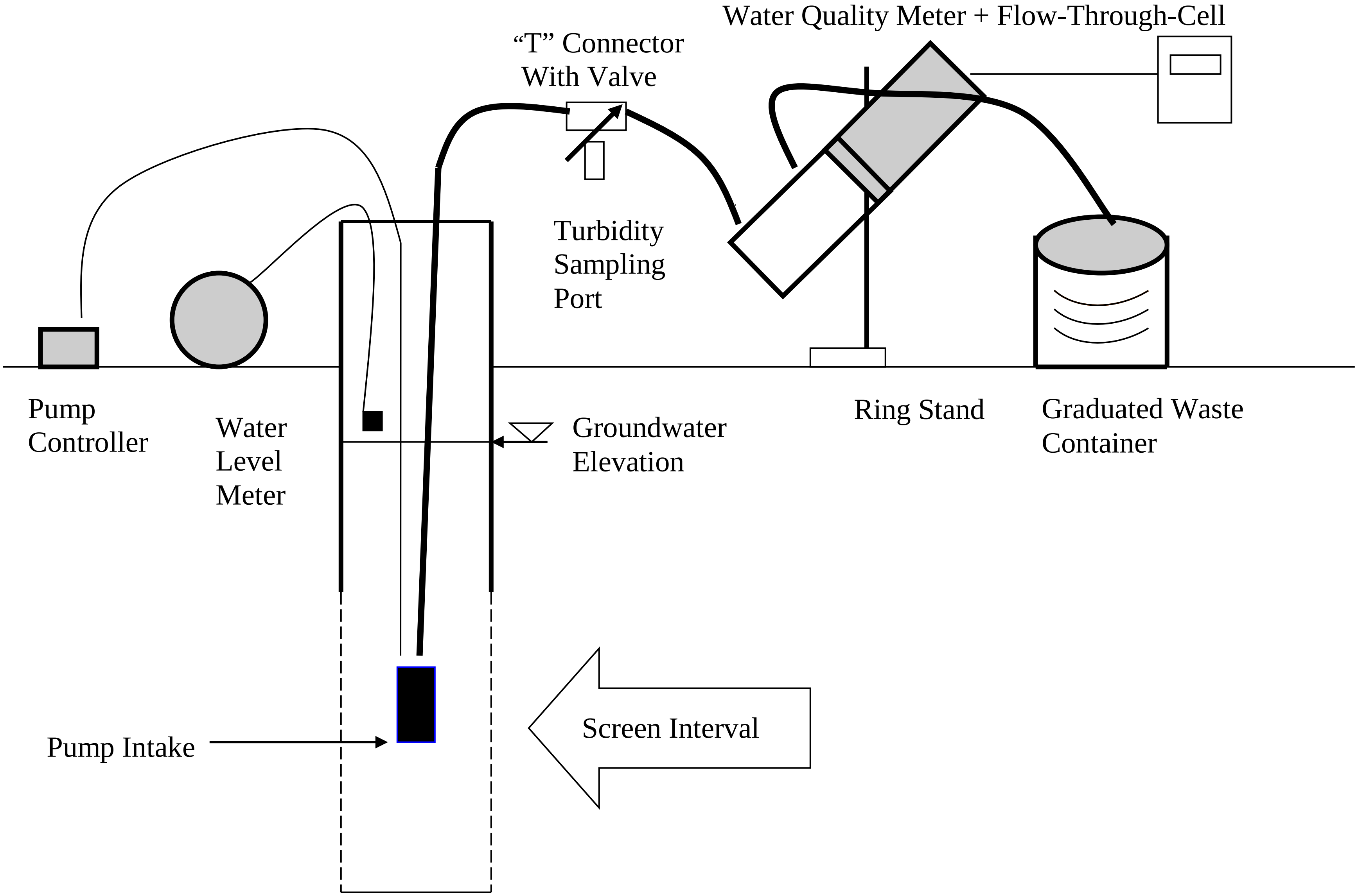
If the pump's tubing is not completely filled with water and the samples are being collected for VOCs and/or dissolved gases analyses using a centrifugal or peristaltic pump, do the following:

> All samples must be collected and preserved according to the analytical method. The VOCs and the dissolved gases (e.g., methane, ethane, ethene, and carbon dioxide) samples are collected last. When it becomes time to collect these samples increase the pump's flow rate until the tubing is completely filled. Collect the samples and record the new flow rate.

12. Store the samples according to the analytical method.

13. Record the total purged volume (graduated waste bucket). Remove the pump from the well and decontaminate the sampling equipment.

Low-Flow Setup Diagram



APPENDIX C

EXAMPLE (Minimum Requirements)

WELL PURGING-FIELD WATER QUALITY MEASUREMENTS FORM

Location (Site/Facility Name)________________________________
Well Number_________________ Date________________________
Field Personnel____
Sampling Organization______________________________________
Identify MP____

Depth to ________/_________ of screen
(below MP) top bottom
Pump Intake at (ft. below MP)_________
Purging Device; (pump type)__________
Total Volume Purged ________________

Clock Time 24 HR	Water Depth below MP ft	Pump Dial^1	Purge Rate ml/min	Cum. Volume Purged liters	Temp. "C	Spec. Cond.^{2} µS/cm	pH	ORP^3 mv	DO mg/L	Tur-bidity NTU	Comments

Stabilization Criteria 3% 3% ±0.1 ±10 mv 10% 10%

1. Pump dial setting (for example: hertz, cycles/min, etc).
2. µSiemens per cm(same as µmhos/cm)at 25°C.
3. Oxidation reduction potential (ORP)

TGI – Ground Penetrating Radar

Rev: 5

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Version Control

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Approval Signatures

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1/3/2022

Date

1 Introduction

This Technical Guidance Instruction (TGI) is intended to provide general guidance on the use of ground penetrating radar systems for environmental, engineering, and other applications requiring detailed imaging of the subsurface. U.S. Army Corps of Engineers (1995) provides technical background regarding the applicability of ground penetrating radar. This guidance is intended to be used to provide Arcadis CPMs and technical staff with a uniform set of procedures either in cases where Arcadis is subcontracting the data collection and processing or in circumstances where the CPM and affiliated technical staff are participating in a ground penetrating radar survey led by designated Arcadis geophysical specialists. Whether the data collection and processing are being subcontracted or performed in-house, directed by geophysical specialists, in all cases the non-geophysical CPM and/or technical staff should consult with Arcadis geophysical specialists for survey design and scoping, data management and processing, and proper data interpretation procedures. It should be noted that it is commonplace to perform ground penetrating radar surveys as a part of a larger scope of work that may include other geophysical techniques such as seismic, electrical resistivity, magnetics, electromagnetics as well as direct observation (ground truthing) with drilling and borehole geophysics.

2 Intended Use and Responsibilities

This document describes general and/or specific procedures, methods, actions, steps, and considerations to be used and observed by Arcadis staff when performing work, tasks, or actions under the scope and relevancy of this document. This document may describe expectations, requirements, guidance, recommendations, and/or instructions pertinent to the service, work task, or activity it covers.

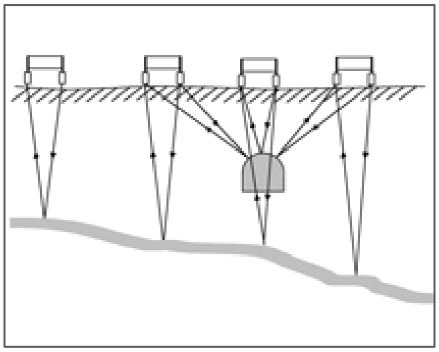
It is the responsibility of the Arcadis Certified Project Manager (CPM) to provide this document to the persons conducting services that fall under the scope and purpose of this procedure, instruction, and/or guidance. The Arcadis CPM will also ensure that the persons conducting the work falling under this document are appropriately trained and familiar with its content. The persons conducting the work under this document are required to meet the minimum competency requirements outlined herein, and inquire to the CPM regarding any questions, misunderstanding, or discrepancy related to the work under this document.

This document is not considered to be all inclusive nor does it apply to all projects. It is the CPM’s responsibility to determine the proper scope and personnel required for each project. There may be project- and/or client- and/or state-specific requirements that may be more or less stringent than what is described herein. The CPM is responsible for informing Arcadis and/or Subcontractor personnel of omissions and/or deviations from this document that may be required for the project. In turn, project staff are required to inform the CPM if or when there is a deviation or omission from work performed as compared to what is described herein.

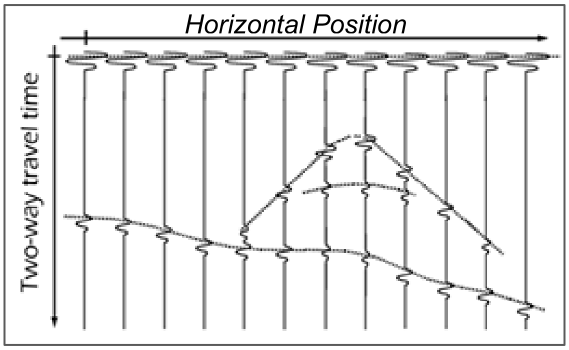
In following this document to execute the scope of work for a project, it may be necessary for staff to make professional judgment decisions to meet the project’s scope of work based upon site conditions, staffing expertise, regulation-specific requirements, health and safety concerns, etc. Staff are required to consult with the CPM when or if a deviation or omission from this document is required that has not already been previously approved by the CPM. Upon approval by the CPM, the staff can perform the deviation or omission as confirmed by the CPM.

3 Scope and Application

This Technical Guidance Instruction (TGI) document outlines the applications, limitations, and methodology for acquiring and interpreting subsurface data using ground penetrating radar (GPR). GPR is a non-invasive and non-destructive tool that transmits pulsed high frequency (generally between 100 and 1000 Megahertz [MHz]) electromagnetic waves into the ground and detects and records the energy returned to the surface with a frequency-matched receiver (see Table 1 for frequencies and applications). The transmitted pulse is reflected from boundaries that possess contrasting dielectric constants[1].



Field Data Collection with a pair of transmitter and receiver antennas moved laterally across the site



Resulting radargram with horizontal distance along the top and the two-wave travel time of the reflected radar pulses on the vertical axis

Reflections typically occur at lithologic contacts where there may be changes in water content and/or mineral composition. Table 2 contains examples of some geologic materials and their typical ranges of electromagnetic properties. Where subsurface materials have extremely high electrical conductivity and magnetic susceptibility including metal objects such as underground storage tanks (USTs), steel drums, and metallic utility pipes anomalously high amplitude reflections, as compared to geologic materials, are generally observed. Non-metallic pipes and utilities often produce weaker GPR reflections due to a lower contrast in dielectric constant between non-metallics and soil.

The two most common performance objectives GPR investigations are matching the survey design with the required depth of penetration and vertical and lateral resolution. For a given set of geologic conditions, both depth of penetration and vertical resolution are inversely related to the transmitter center frequency. The depth of penetration decreases with increasing frequency due to signal attenuation at higher frequencies. Vertical resolution is determined by the wavelength of the pulse. Since higher frequency will potentially yield better resolution, but a loss of total depth of penetration, a compromise in frequency selection may be the result. Conversely, a lower frequency will yield less vertical resolution while offering deeper penetration since attenuation will be lower. At some sites attenuation of the GPR signal may be the overriding limitation. As a rule, environments that are electrically conductive such where there is a high clay content or where the groundwater is groundwater high in total dissolved solids tend to offer the greatest signal attention and may be so severe as to limit the success of the GPR survey, regardless of frequency chosen. Environments with little or no clay minerals

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[1] Strength of reflection is determined by a contrast in GPR velocity (see Table 2). At an electrical conductivity of zero, the reflection coefficient is $(V_2 – V_1)/(V_2 + V_1)$, where V_1 and V_2 are the GPR velocities of Layer 1 and Layer 2

or soil moisture, frozen ground, or massive non-conductive rock offer the greatest success to GPR surveys. Table 2 provides the electrical conductivity of some common geologic materials.

Table 1. GPR Antenna Frequencies and Applications

Antenna Center Frequency (MHz)	Typical Applications
1000 or greater	Concrete studies (delaminations, condition of rebar, rebar dimensions, etc.), shallow void surveys (beneath pavement), bridge decking analysis, Subfloor utility investigations (floor drains, conduits, etc.)
500 to 1000	Ice and snow thickness mapping, forensics, search and rescue applications, shallow utility mapping
250 to 500	Search for underground storage tanks or other buried metals such as drums, utility mapping surveys, characterization of fill materials, search for excavations such as graves, roadway mapping, boring clearance work
100 to 250	Shallow geologic investigations, fracture mapping in rock quarries, stratigraphic analysis, fill and waste mapping
100 or less	Deep geologic investigations, permafrost investigations, glacial studies, mining applications

GPR units come in a number of configurations as shown below.

The most common type is a wheeled cart with both antennas in a closed housing (A-C). Low frequency antennas used for deep geologic work are generally large and are kept separate (D). Some units are designed to be towed with a skid plate (E). Units are also manufactured which contain multiple antenna pairs to increase data production (F). Positional control is usually managed using measuring tapes and ground markings, although it is also possible to gather the GPR data using a GPS unit (A). For most surveys where computer analysis is planned after the field activities, the data collection should be done in a methodical manner either in a series of parallel lines in a single direction or a grid of lines crossing at right angles to allow subsequent computer processing and analysis.

Table 2. Electromagnetic Properties of Earth Materials

Material	ε (dimensionless)	σ (mS/m)	Velocity (m/ns)	Attenuation (db/m)
Air	1	0	.3	0
Distilled Water	80	.01	.033	.002
Fresh Water	80	.5	.033	.1
Sea Water	80	3,000	.01	1,000
Dry Sand	3-5	.01	.15	.01
Wet Sand	20-30	.1-1	.06	.03-.3
Limestone	4-8	.5-2	.12	.4-1
Shales	5-15	1-100	.09	1-100
Silts	5-30	1-100	.07	1-100
Clays	5-40	2-1,000	.06	1-300
Granite	4-6	.01-1	.13	.01-1
Dry Salt	5-6	.01-1	.13	.01-1
Ice	3-4	.01	.16	.01
Metals	*	∞		∞

Table 1 Notes:

1. Intrinsic properties of earth materials at GPR frequencies are:
    ε = relative permittivity, also known as dielectric constant (dimensionless)
    σ = electrical conductivity in mS/m
2. Simplified equations for attenuation (a) and velocity (V) (at low loss) are:
    $V = (3x10^8)/\varepsilon^{1/2}$
    $a = 1.69\sigma/\varepsilon^{1/2}$
3. mS/m = milliSiemens per meter | m/ns = meters per nanosecond | db/m = decibels per meter
4. Information Source: U.S. Army Corps of Engineers (1995)

4 Personnel Qualifications

GPR investigations should be conducted by qualified and experienced operators, such as an experienced field technician and/or geophysicist. The GPR operator should be experienced in evaluating data quality in the field and be able to adjust data acquisition procedures in response to variable site conditions in order to identify anomalies and resolve target features. Inexperienced Arcadis personnel directing or supervising GPR data acquisition or interpreting processed GPR data should seek appropriate guidance and technical peer review from qualified and experienced personnel available from the relevant members of the Subsurface Investigation Community of Practice.

5 Equipment List

The following equipment will be available, as required, during GPR surveys.

- Personal protective equipment (PPE), as required in the site Health and Safety Plan (HASP).
- Appropriate data collection forms (paper or electronic), field instructions, site plans, field notebook or tablet, spray paint or other means for ground marking of control grid, engineering tape measure, traffic cones or other visible markers for visual control of alignment.
- Specific GPR systems matched to project objectives and site conditions. There are a number of options; however, if Arcadis is self-performing the data collection, a geophysical specialist must be consulted prior to renting equipment (unless company owned) to assure that proper equipment and adequate familiarity with use of that equipment exists. Each manufacturer has their range of products, many of which are designed with specific applications in mind. In general, Arcadis will require that GPR data be stored and downloaded in digital format for later processing. Not all manufacturers offer data storage, and use of those GPR systems is discouraged. The most common acceptable GPR system manufactures include (not comprehensive and subject to change):
    - GSSI – https://www.geophysical.com
    - Sensors & Software – https://www.sensoft.ca
    - Mala - https://www.guidelinegeo.com/products/category/mala-ground-penetrating-radar-gpr/
- A primary and secondary antenna, of appropriate signal frequencies to match anticipated dimension and depth of objective(s). For example, it is good practice to have a 400-500 MHz antenna available at the project site if using a 200-250 MHz antenna in the event that conditions allow use of the higher frequency antenna as needed. Another example is if the lower frequency antenna is used as the primary reconnaissance antenna for mapping the entire site, and the higher frequency antenna is used for follow-up detailed mapping of select anomalous areas found with the lower frequency antenna. This second example is particularly relevant in the situation where the rate of travel of the GPR unit is limited by the memory buffer capacity of the unit (typically the demands on data streaming and store increase with antenna frequency).
- Optionally, a GPS unit which can be mounted to the GPR system for integration of GPS position into GPR data files (if option is available).
- Data processing software for use in the field and office. Generally, each GPR manufacturer has developed proprietary software to process their particular GPR system. Arcadis currently has licenses for Radan (GSSI), Ekko_Project (Sensors & Software), and Reflex (a general seismic and GPR processing program capable of converting most manufacturer-specific formats to industry standard formats). Other software for other GPR systems may be available for short term rental for specific projects. Note that GPR data processing is a highly specialized task and requires an experienced geophysical specialist to perform this task. The scope of GPR processing is beyond the scope of this TGI.

6 Cautions

The effectiveness of GPR is highly site-specific due to a number of possible types of interference and may be subject to the skill level of the operator in certain environments. Reliability and efficiency are enhanced when used in conjunction with other geophysical methods and/or direct observations. Soils with elevated electrical conductivity rapidly attenuate the radar energy, reducing the penetration depth and resolution. Clayey soils and saturated soils, particularly when high in dissolved solids, can significantly limit or even negate the applicability of GPR. Other potential interference sources include subsurface debris, rebar reinforced concrete, above ground, particularly overhead, reflective metal objects (cars, surface water, transmission lines, canopies, ceilings, etc.), and sources of electromagnetic signal (electrical generators, radio transmitters, etc.).

Both metallic and non-metallic utilities may be imaged by GPR under proper conditions. However, it should be noted that due to differences in the electromagnetic properties of materials (dielectric constant, see above), locating a non-metallic utility (e.g., plastic, vitrified clay tile, etc.) may be more difficult than a metallic pipe because of a low contrast in dielectric constant between non-metallics and soil. A general guideline for effective locating depth for utilities is 1-inch (2.5 cm) diameter of utility can be discerned for each foot (0.3 m) down to the maximum depth of penetration (highly site specific). For instance, one may expect to resolve a utility 10 inches (25 cm) in diameter at a depth of 10 feet (3 m) *if the maximum depth of penetration allows*. This is a general rule of thumb that can be applied to both metallic and non-metallic utilities but should be used cautiously as the type of material can affect the resolution. It is critical to perform initial testing to determine the total depth of penetration prior to beginning the methodical data collection process.

Also, the presence of reinforcing bar (rebar) in concrete can limit or negate the ability to resolve utilities present below the concrete. The resolution of smaller diameter pipes found within or just below the concrete may be completed masked by the strong reflections generated by the rebar.

Working inside of buildings can be especially challenging due the multiple surfaces (walls and ceilings) and fixtures above ground. The operator must know how to account for unwanted data artifacts. Generally, the GPR velocity in air is about 3 to 4 times faster than in the subsurface. For example, a metallic ceiling located 12 feet above the floor will appear in the GPR data at a position in the two-way travel time as a subsurface “depth” of about 3 to 4 feet. Remember, GPR records two-way travel time of the GPR pulse, which is converted to depth based on a measured or assumed GPR wave velocity.

Standing water is problematic. Typically, if a GPR unit is passed through a puddle of standing water a strong ringing response will be recorded, often obscuring subsurface information entirely.

7 Health and Safety Considerations

Minimize physical hazard exposure through use of proper PPE as prescribed in the HASP. Maintain awareness of other potential hazards associated with the physical location where the GPR investigation is being conducted and any ingress or egress conditions.

8 Procedure

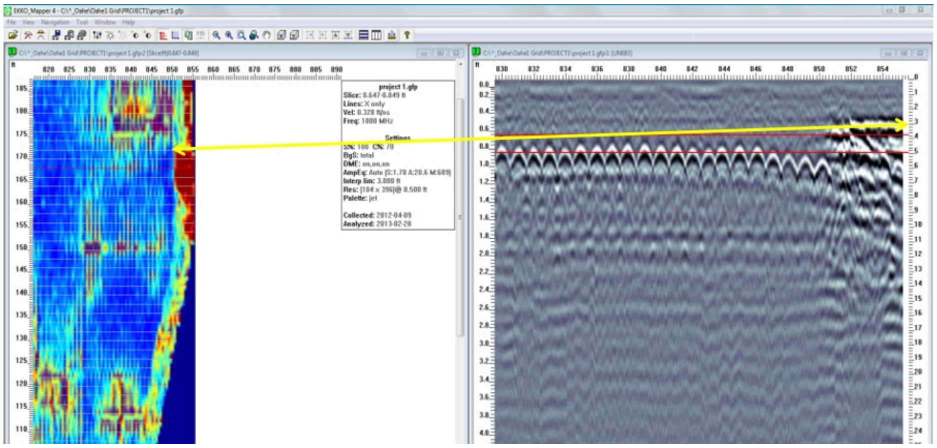
1. Become familiar with the details of the applicability and limitations of GPR.
2. Evaluate site-specific soil information to determine suitability of soils (clay content, saturation, TDS of groundwater) for GPR. In general, soils with greater than 35% clay content are considered restrictive, and soils with less than 10% clay content are considered favorable for reasonably deep penetration with GPR.
3. Evaluate meteorological information regarding recent or forecasted precipitation that could impact soil moisture content and GPR effectiveness. Standing water in paved areas is a condition that may limit or delay the GPR survey. Schedule GPR surveys appropriately.

4. Perform site reconnaissance in advance to identify potential sources of surface interference such as reinforced concrete, large metal objects, electrical equipment, overhead utilities, canopies, etc.
5. Consider complimentary technologies to supplement GPR and provide multiple lines of evidence. Geophysical technologies may include radio frequency tracing, magnetics, electromagnetic surveys, or electrical resistivity surveys. Direct observation (under proper health and safety guidance) is also an appropriate means of ground-truthing.
6. Employ only qualified and experienced GPR operators. For utility locating and mapping applications, the GPR operator should be specifically experienced in evaluating data quality and identifying anomalies in the field requiring variations in data acquisition procedures to positively interpret and locate targets of concern. If uncertain of a subcontractor's capabilities, consult with an Arcadis geophysical specialist.
7. Consider the depth and size of subsurface target features being sought with GPR. Attempt to match the signal frequency to the expected depth and size of the subsurface features. Change antenna as necessary for variable depths and sizes of target objects. Consider the selection of a primary and secondary choice of antennas and use multiple antennas as necessary. Test GPR at well-known, confirmed utility locations as means to verify depth of penetration. GPR wave velocity can also be confirmed by passing over a known utility, assuming it can be imaged.
8. Establish a reference grid over the area to be investigated and identify traverse locations in the field notebook or on a site plan map. It is preferable to perform a bidirectional grid. That is, lines collected both along the X and Y axes. The line separation should be a constant value based on the project objectives and the frequency of the GPR antenna. It is preferable to create a grid that has parallel base lines to minimize distance measurement errors.
9. Most GPR systems are equipped with an odometer to keep track of the distance moved. It is important to confirm the accuracy of the odometer calibration and adjust if necessary. This is done by laying out a measuring tape along a level, smooth surface and traversing a known distance. Recalibrate as needed.
10. Select and input a dielectric constant or average velocity into the GPR unit based on knowledge of the type of subsurface materials. Bear in mind that the dielectric constant or velocity is an approximation based on assumed subsurface materials and may vary based on the variability of the subsurface materials. The dielectric constant or velocity is necessary to estimate the depth of a target but should be considered an approximation not an absolute. Multiple passes over a known utility may be necessary using different dielectric constants before an accurate depth to a target can be estimated. Some manufacturers include the ability to perform hyperbola fitting to estimate dielectric constant or velocity from data collected in the field, and if this option is available, it should be used during initial testing.
11. Depending on the system and antenna frequency, the pace at which the GPR unit is moved along a traverse may affect the target resolution. It is recommended that an initial starting pace should be approximately 1.5 feet (0.5m) per second and modified if necessary, during field operations. Appropriate pacing can be determined in advance if the size of the smallest target is known.
12. Record GPR data while slowly pushing or pulling the antenna along each survey traverse. It is good practice to annotate periodic grid crossings using the system's ability to create fiducial markers. This is especially important for long traverses or locations where the ground surface is rough.
13. The data collection approach is generally one of two types.
    a. One approach, often used by utility location specialists, is to walk in a systematic pattern and mark out targets as they are found using paint or some other means. Once the area of interest is marked out, complete the survey by going back and storing key transects in the system memory for final reporting.

The locations of the final stored traverses should be properly surveyed either by high resolution GPS and/or triangulated using engineer tapes tied to known locations. This first approach is most appropriate for marking out USTs relatively simple utility patterns.

b. The second approach is applicable to mapping large areas, complex utility layouts, fill mapping, or other geologic objectives such as mapping a bedrock surface. In such circumstances the best practice is to layout a control grid and optionally using GPR mounted to the GPR system. The grid can either be a series of parallel lines at right angles to a known fabric, or if conditions are unknown, a bidirectional grid of lines at orthogonal orientations. It is important to start and end the GPR unit at marked out grid points and to keep good notes about the data collection process. Long lines should also be supplemented with fiducial marks at intermediate grid crossings. It is anticipated in this approach that data will be stored in memory and processed using appropriate GPR processing software as mentioned above.

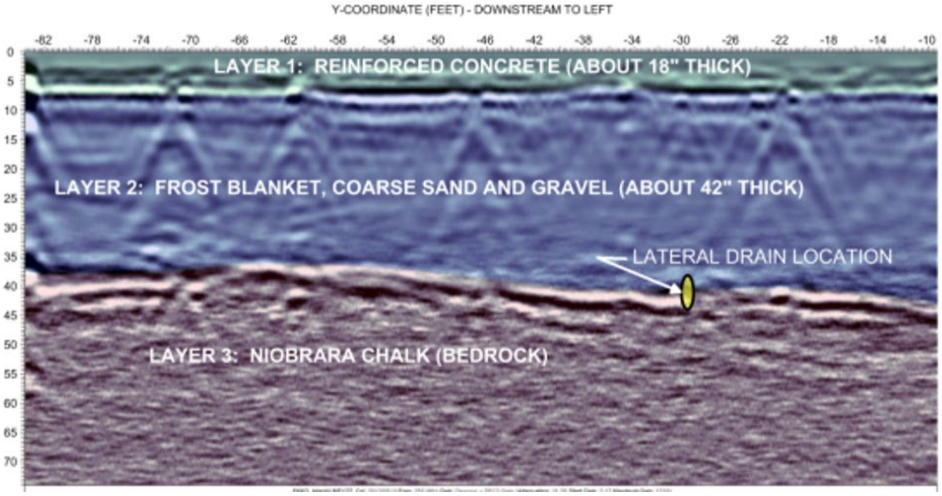
14. For projects where a complete grid of data is stored (13b above), the results may be interpreted either as a series of horizontal slice maps or 3-dimensional data sets. Most contemporary software has the capability of digitizing discrete objects or horizons on a line-by-line basis, after which the interpretations can be exported to a vector drawing format such as DXF or SHP files in the form of 3D points and polylines. Below are examples of GPR outputs.



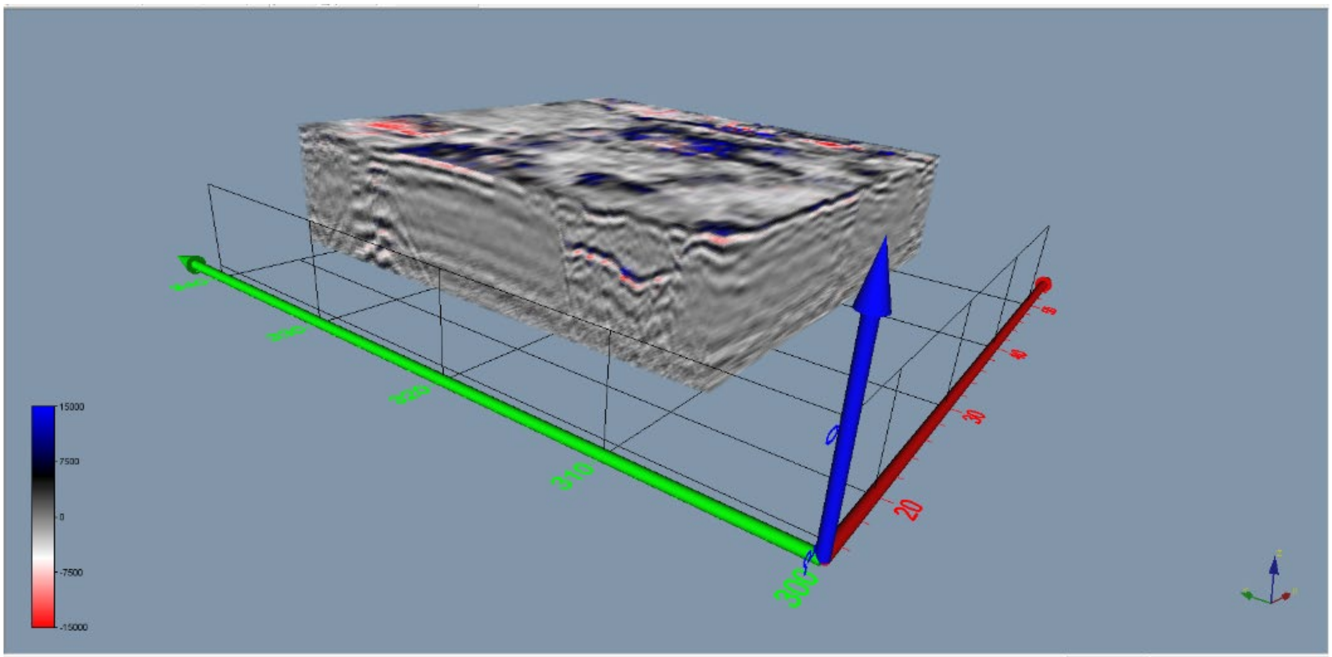
project 1.gfp
Slice: 0.647-0.849 ft
Lines: X only
Vel: 0.328 ft/ns
Freq: 1000 MHz

Settings
SN: 100 CN: 70
BgS: total
DME: on,on,on
AmpEq: Auto [S:1.78 A:20.6 M:689]
Interp lim: 3.000 ft
Res: [104 x 396]@ 0.500 ft
Palette: jet

Collected: 2012-04-09
Analyzed: 2013-02-28



GPR Example 2. GPR vertical section imaging fill sand and bedrock beneath a concrete slab (250 MHz antenna).



GPR Example 3. 3D GPR image showing two vertical sections and horizontal slice at a crossing of a waste burial pit (250 MHz antenna).

9 Waste Management

GPR is a non-invasive procedure and should not result in the generation of derived wastes. Any trash or rubbish generated during the course of field activities should be disposed of in a proper trash receptacle.

10 Data Recording and Management

Digital data collection is the Arcadis standard using available FieldNow® applications that enable real-time, paperless data collection, entry, and automated reporting. Paper forms should only be used as backup to FieldNow® digital data collection and/or as necessary to collect data not captured by available FieldNow® applications. The Field Now® digital form applications follow a standardized approach, correlate to most TGIs and are available to all projects accessible with a PC or capable mobile device. Once the digital forms are saved within FieldNow®, the data is instantly available for review on a web interface. This facilitates review by project management team members and SMEs enabling error or anomalous data detection for correction while the staff are still in the field. Continual improvements of FieldNow® applications are ongoing, and revisions are made as necessary in response to feedback from users and subject matter experts.

During GPR data collection, the GPR data files are stored in a memory within the manufacture's data logging computer. Generally, each traverse of the GPR unit is stored as a separate, uniquely named file. Often the file naming scheme either encodes the geometric information related to the data grid or a sequential naming scheme. Accurate note taking should be performed to assure that file names are properly associated with the grid notations. At periodic points during the GPR survey, it is best practice to download and backup the GPR data files to a company laptop and at least daily to copy the GPR data files and field notes to a secure SharePoint drive on the Arcadis system.

11 Quality Assurance

The following quality control procedures should be observed:

- Seek appropriate input prior to conducting a GPR survey to identify site-specific features (soil conditions/sources of interference) that may impact data acquisition.
- Operate all equipment in accordance with manufacturer's instructions and recommended procedures. Record all system components (Unit, antennae frequency, etc.) information in the field book or a pre-made field form.
- Regardless of which data collection approach is taken, data quality should always be checked in the field to identify factors that may require adjustment to the data acquisition procedures. Make appropriate adjustments to data acquisition methods to achieve survey objectives, as feasible.
- It is recommended that the operation and performance of the GPR equipment is field checked (if possible) by locating existing underground utilities or structures of known depth, size, and construction. These characteristics should be similar to that of unidentified target objects.
- Data interpretation should undergo peer review by appropriate qualified and experienced personnel.

12 References

U.S. Army Corps of Engineers (1995). Geophysical Exploration for Engineering and Environmental Investigations, Engineering Manual (EM) 1110-1-1802.

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TGI - Manual Water-Level and NAPL Monitoring

Rev: 2

Rev Date: April 5, 2022

Version Control

Issue	Revision No.	Date Issued	Page No.	Description	Reviewed By
0	0	October 11, 2018	All	Updated and re-written as TGI	Marc Killingstad Everett H. Fortner III
1	1	May 8, 2020	All	Updated and added NAPL gauging	Marc Killingstad Everett H. Fortner III Andy Pennington
2	2	April 5, 2022	All	Formatting and Revisions	Martha Wulftange

Approval Signatures

Prepared by: 4/5/2022

Everett H. Fortner III, PG (Preparer) Date

Reviewed by: 4/5/2022

Marc Killingstad (Subject Matter Expert) Date

1 Introduction

This TGI describes the equipment, field procedures, materials, and documentation procedures to measure and record water-levels using an electronic water-level probe or an oil-water level indicator. This TGI also describes procedures for measuring in-well thicknesses of non-aqueous phase liquid (NAPL), both light and/or dense (LNAPLs and DNAPLs, respectively).

2 Intended Use and Responsibilities

This document describes general and/or specific procedures, methods, actions, steps, and considerations to be used and observed by Arcadis staff when performing work, tasks, or actions under the scope and relevancy of this document. This document may describe expectations, requirements, guidance, recommendations, and/or instructions pertinent to the service, work task, or activity it covers.

It is the responsibility of the Arcadis Certified Project Manager (CPM) to provide this document to the persons conducting services that fall under the scope and purpose of this procedure, instruction, and/or guidance. The Arcadis CPM will also ensure that the persons conducting the work falling under this document are appropriately trained and familiar with its content. The persons conducting the work under this document are required to meet the minimum competency requirements outlined herein, and inquire to the CPM regarding any questions, misunderstanding, or discrepancy related to the work under this document.

This document is not considered to be all inclusive nor does it apply to all projects. It is the CPM’s responsibility to determine the proper scope and personnel required for each project. There may be project- and/or client- and/or state-specific requirements that may be more or less stringent than what is described herein. The CPM is responsible for informing Arcadis and/or Subcontractor personnel of omissions and/or deviations from this document that may be required for the project. In turn, project staff are required to inform the CPM if or when there is a deviation or omission from work performed as compared to what is described herein.

In following this document to execute the scope of work for a project, it may be necessary for staff to make professional judgment decisions to meet the project’s scope of work based upon site conditions, staffing expertise, regulation-specific requirements, health and safety concerns, etc. Staff are required to consult with the CPM when or if a deviation or omission from this document is required that has not already been previously approved by the CPM. Upon approval by the CPM, the staff can perform the deviation or omission as confirmed by the CPM.

3 Scope and Application

The objective of this Technical Guidance Instruction (TGI) is to describe procedures to measure and record water-levels (groundwater and surface-water) using manual water-level meters. Water levels may be measured using an electronic water-level probe or an oil-water level indicator from established reference points (e.g., top of casing). Reference points must be surveyed to evaluate fluid level elevations relative to a vertical datum (e.g., North America Vertical Datum of 1988 [NAVD88] relative to sea level). This TGI also describes procedures for measuring in well thickness of NAPL and DNAPLs.

Surface water-levels can be measured from stilling wells or fixed points (bridges, walls, etc.) and measuring from an established point of reference using a water-level meter. In some cases, surface water water-levels may be determined from a graduated stream gauge, attached to a pole located in open water with known elevation, without the use of a water-level meter.

The use of pressure transducers or other automated devices for the collection of groundwater elevation data will be subject of *TGI – Water-Level Monitoring using Pressure Transducers and TGI – Water-Level Measurements using Sonic Meters.*

4 Personnel Qualifications

Arcadis field sampling personnel will have completed or are in the process of completing site-specific training as well as having current health and safety training as required by Arcadis, client, or regulations, such as 40-hour HAZWOPER training and/or OSHA HAZWOPER site supervisor training. Arcadis personnel will also have current training as specified in the Health and Safety Plan (HASP) which may include first aid, cardiopulmonary resuscitation (CPR), Blood Borne Pathogens (BBP) as needed. In addition, Arcadis field sampling personnel will be knowledgeable in the relevant processes, procedures, and TGIs and possess the demonstrated required skills and experience necessary to successfully complete the desired field work. The HASP and other documents will identify other training requirements or access control requirements.

5 Equipment List

The following field equipment is suggested for water-level measurements:

- Site-specific Health and Safety Plan (HASP)
- Appropriate personal protective equipment (PPE) as specified in the HASP
- Electronic water-level indicator graduated in 0.01 ft. increments
- Electronic oil-water (interface) level indicator graduated in 0.01 ft. increments, if necessary
- Non-phosphate laboratory soap (Alconox or equivalent), brushes, clean buckets or clean wash tubs.
- Distilled or de-ionized (required for some sites) water for equipment decontamination
- Photoionization detector (PID) and/or organic vapor analyzer (optional)
- 150-foot measuring tape (or sufficient length for the maximum site depth requirement) – if required for total depth measurements of deeper wells
- Solvent (methanol/acetone/isopropyl alcohol) rinse – optional
- Spray bottle for solvent - optional
- Plastic drop cloth (e.g. Weatherall Visqueen) to place beneath the buckets or tubs to reduce potential for contamination of the tape or probe
- Tools and/or keys required for opening wells
- Well construction summary table and/or well construction logs
- Summary table of previous water-level measurements
- Field notebook and/or smart device (phone or tablet) or appropriate field forms (see Attachment 1).
- Indelible ink pen

6 Cautions

Electronic water-level indicators and oil-water interface probes may sometimes produce false-positive readings. For example, if the inside casing surface of the well or stilling tube has condensation above the water level, then an electronic water-level probe may produce a signal by contacting the sidewall of the well, rather than the true water-level surface. For accuracy, the electronic water-level probe and/or interface probe should be raised and lowered several times at the approximate depth where the instrument produces a tone indicating a fluid interface to verify consistent, repeatable results (three or more times). Additionally, some wells may be constructed with a sump. If local/regional groundwater levels have declined such that the water-level is below the base of the well screen, a sump may still contain water and provide an erroneous measurement. Therefore, possessing and comparing measurements with a well construction summary table or well construction log is recommended for proper reporting.

If the presence of a NAPL is known or suspected within specific wells, do not use an electronic water- level indicator. Use an oil-water interface probe instead. If NAPL presents ignition or explosion hazards, an intrinsically safe oil-water interface probe is required to be used with grounding and following the manufacturer’s instructions.

If the NAPL is known to be very viscous or problematic to gauge, the data quality will require additional consideration prior to measuring. Staff will consider the data quality objectives for the gauging activity – e.g., if quantifying NAPL thickness is necessary, or if assessing the presence/absence is sufficient.

Alternate NAPL measurement methods (such as using drop pipes or temporary coatings for down-well equipment) may be considered.

When measuring total well depths with an electronic water-level indicator, the measurement must have a correction factor applied for post processing or completed at the time of measurement that is equal to the length of the probe beneath the circuit closing electrodes (if applicable to the instrument). This is necessary because the tape distance markings are referenced to the electrode, rather than the end of the probe. Some newer instruments do not have an offset electrode and this correction factor is needed. In addition, total depth measurements are difficult with wells that have large water columns due to buoyancy issues. In addition, the total depth measurement will include notes that indicate a soft or hard bottom if recognized during the measurement.

Ensure that the type of electronic water-level indicator is compatible with the depth and diameter of the wells to be measured. Some smaller piezometers or larger diameter well stilling tubes will accommodate only smaller diameter probes.

7 Health and Safety Considerations

The HASP will be followed, as appropriate, to ensure the safety of field personnel. Access to wells may expose field personnel to hazardous materials such as contaminated groundwater or oil. Other potential hazards include pressurized wells, stinging insects that may inhabit well heads, other biologic hazards (e.g. ticks in long grass/weeds around well head), and potentially the use of sharp cutting tools (scissors, knife). Appropriate personal protective equipment (PPE) will be worn during these activities. Only use non-toxic peppermint oil spray for stinging insect nests. Open well caps slowly and keep face and body away to allow to vent any built-up pressure. Field personnel will thoroughly review client-specific health and safety requirements, which may preclude the use of fixed/folding-blade knives.

Obtaining measurements from active pumping wells requires knowledge of the construction and design, as the indicator probe and tape can become intertwined within down-well equipment (such as pump impellers) causing a serious health and safety hazard and equipment damage. Ensure that stilling wells have a perforated end and capped bottom to inhibit tape from extending into the downhole pump depth. If a stilling tube is not present or the still tube construction is not known, determine a conservative "not to exceed" measurement depth based on the top of pump depth with an added safety factor. If all information is not known, a water-level will not be taken from the pumping well until clarification on depths are available.

8 Procedure

Calibration procedures and groundwater level measurement procedures for electronic water-level indicators and oil-water indicators are described in the sections below. Calibration documentation can berequested from the rental or manufacturer.

Calibration Procedures

If the indicator requires length and markings verification is required by project data quality plan or other reasons, then the following steps may be used:

- Measure the lengths between each increment marker on the indicator with a measuring tape. The appropriate length of indicator measuring tape, suitable to cover the depth range for the wells of interest, will be checked for accuracy.
- If the indicator measuring tape is inaccurate, the probe will require to be sent back to the manufacturer or rental company. If a replacement can't immediately be available, then an offset can be measured to correct the measurements.
- If multiple water-level indicators and/or oil-water interface probes are being used for an event, calibration of the multiple devices will be required by measuring a water-level at a single well contemporaneously with all indicators to be used and calculated correction factors provided for data processing (typical corrections are small and range from 0.01 to 0.03 foot).
- Equipment calibration will be recorded in the field logbook and/or smart device.

Water-Level Measurement Procedures

The general procedures to be followed for the collection of fluid level measurements and well depths from the monitoring wells are as follows:

- Check that the water-level/oil-water level indicator battery is functional, before mobilization and prior to each work day (e.g., turn power on and check that meter sounds when probe is lowered into a bucket of water – note that water-level meters will not work with low-electrical-conductivity liquids such as distilled water).
- Record instrument make, model, serial number, and (if present) Arcadis ID number in the field form or electronic field form.
- Don disposable nitrile gloves. Decontaminate the water-level/oil-water indicator, any attached tape and the spool with laboratory-grade soap and distilled water (see Initial Decontamination Procedures below). The spool requires caution with cleaning as it is not water-proof and can be damaged during cleaning.

- The top of the monitoring well will be cleaned with a clean rag to prevent loose particulate matter from falling into the well.
- Perform a well inspection (note that a well inspection form may be required to be filled out along with a photo to document the conditions).
- Place clean plastic sheeting on the ground next to the well.
- Unlock and/or open the monitoring well cover while standing upwind from the well (note that some wells may be under pressure and precaution should be taken with opening well caps – see Section 6).
- Measure the volatile organics present in the monitoring well head space with a PID and record the PID reading (if applicable and requirement for the site).
- Allow the water-level in the well to equilibrate with atmospheric pressure for a few minutes (check previous field forms or field books for equilibration time, if noted).
- Locate the measuring reference point that correlates to the survey point on the well casing. If one is not found, make a reference point by notching the highest and/or north point on the inner casing (or outer if an inner casing is not present) or mark with a permanent mark. All downhole measurements will be taken from the reference point. Document any changes or new reference point addition.
- Measure to the nearest 0.01 foot and record the height of the inner well casing and outer protective casing to ground level (note that some well pads are raised and are not at true ground surface).
- Lower the indicator probe into the center of the well until contact with the water surface is indicated by either an audible alarm or light. The sensitivity of the probe may need adjustment if the alarm or light is not strong signal. Use and install a tape guide (available from some manufacturers) to help with accuracy and provide protection with damaging the measurement tape. If a tape guide is not available, make sure that the tape does rub on the inner or outer casing which could fray and damage the tape.
- If an oil-water interface probe is being used to measure depth and thickness of NAPL, lower the interface probe into the center of the well until a contact with the NAPL surface is indicated by either audible alarm or light. The sensitivity of the probe may need adjustment if the alarm or light is not strong signal. To gauge the water level in a well which contains LNAPL (LNAPL-water interface), advance the interface probe past the LNAPL-water interface until the probe produces a solid audible alarm indicating water. While slowly retrieving the probe upward, the equipment will produce a different tone when the LNAPL-water interface is reached (typically this is a multiple alarm sound or flashing light). This level should represent the depth to water. The depth indicating the bottom of the water column and top of DNAPL layer, if any, is indicated by the multiple alarm signal or flashing light emitted by the interface probe.
- Hold the tape at the measuring point and repeat the measurement two more times.
- Read and record measurement to the nearest 0.01 foot. Check the measurement with previous measurements, if available, and note any anomalies/discrepancies; if significant, contact the project staff.

- Measure and record total depth of well (see Total Depth Measurement Procedures below); note that measurement of total depth is not always performed at wells containing LNAPL or DNAPL, in order to reduce decontamination of the instrument and reduce potential exposure to NAPL.
- Record all measurements (with date and time collected to the nearest minute) and note any inconsistencies/anomalies and relevant observations in the field notebook and/or smart device or appropriate field forms.
- Follow decontamination procedure outlined below before measuring subsequent wells (see
- Decontamina*tion after Water Level and Total Depth Measurements* below).
- Replace cap and lock the well when all activities are completed.

Total Depth Measurement Procedures

- Weighted tape or electronic water-level indicator can be used to measure the total well depth.
- Follow initial procedures noted above in Water-Level Measurements above.
- Lower indicator probe (or tape) until weighted end is resting on the bottom of the well. Raise indicator slowly until there is no slack in the tape. Gently estimate the bottom of the well by slowly raising and lowering the indicator: great care should be taken to avoid damaging the sensor on the probe. The operator may find it easier to allow the weight to touch bottom and then detect the 'tug' on the tape while lifting the weight off the well bottom.
- Because of tape buoyancy and weight effects encountered in deep wells with long water columns, it may be difficult to determine when the probe is in contact the bottom of the well and sediment in the bottom of the well can also make it difficult to determine total depth. Care must be taken in these situations to ensure accurate measurements.
- If total depth measurements are to be collected during low-flow sampling events, the measurement will be made only after low-flow sampling has been completed or at least 12 hours prior to initiating sample collection from the well, in order to minimize: 1) mixing of the stagnant water at the top of the well column with potential formation water underneath; and/or 2) agitation and subsequent entrainment of possible sediment collected at the well bottom).
- Read and record measurement to the nearest 0.1 foot. Please refer to the note regarding total depth measurements described in Section 5 Cautions above.
- Follow decontamination procedure outlined below before gauging the next well (see Decontaminationafter *Water Level, NAPL Level, and Total Depth Measurements* below).

Initial Decontamination

- Note that there may be project specific decontamination procedure documents that will be followed in lieu of the below procedures.
- Set up a decontamination station consisting of three clean buckets (e.g., 5-gallon buckets). The buckets should not be used to containerize purge water; they will be used for decontamination purposes only.
- Fill the first bucket with one gallon of distilled water (use deionized water if metals are a contaminant at the site) and add non-phosphate laboratory-grade soap. Fill the second bucket

with distilled water (use deionized water if metals are a contaminant at the site) and leave the third bucket empty. Place the drop cloth underneath.

- Unwind the entire tape from the spool into a bucket with non-phosphate laboratory-grade soap and distilled water; Brush the tape carefully to remove dirt and possible contamination, using a brush dedicated to the wash bucket.
- Carefully brush all dirt of the spool and wipe down with a soapy cloth or paper towel.
- Transfer the tape into the second bucket containing rinse water. Carefully brush the tape using a second brush, dedicated to the rinse bucket. Lift the tape out of the bucket and allow rinse water to drip off the tape.
- Transfer the tape to the third bucket. Wind the tape onto the spool while wiping excess water off the tape using a paper towel.

Decontamination after Water Level, NAPL Level, and Total Depth Measurements

- Set up a decontamination station consisting of three clean buckets, fill according to the initial decon procedure.
- Unwind the only the length of tape used for gauging from the spool into a bucket with laboratory-grade soap and distilled water. Brush the tape carefully to remove dirt and possible contamination, using a brush dedicated to the wash bucket.
- Continue as described above.
- Extra care should be taken to clean the probe after a total depth measurement. All sediment or dirt needs to be removed during decontamination.
- If an oil-water interface probe is used to gauge NAPL, a solvent may be necessary to remove all NAPL residue. After decontaminations steps above, use a spray bottle filled with chosen solvent (ex. isopropyl alcohol) and spray across all surfaces of the tape. Use paper towels to wipe off solvent and/or residue. This step may be repeated if necessary.

Notes:

- Collect equipment blanks if required by the work plan (minimum 1 per 20 samples or 1 per sampling event).
- Prepare new wash solution and rinse water when necessary (e.g., every 10 to 20 wells). The spent wash and rinse solution should be discharged according to site practices.
- The decontamination station may be expanded by adding extra rinse and/or detergent stations (i.e., solvent wash station) to the set up. The addition of more stations depends on the requirements of the work plan or the site-specific Field Sampling and Quality Assurance Plan and outlined in the project field plan or kick-off meeting.
- Small crates or washtubs are a possible substitute for the buckets. In any case, it is recommended to use containers with a lid.

9 Waste Management

Decontamination fluids, PPE, and other disposable equipment will be properly stored on site in labeledcontainers and disposed of properly. Be certain that waste containers are properly labeled and documented in the field log book. Review *TGI – Investigation Derived Waste Handling and Storage*, foradditional information and state- or client-specific requirements.

10 Data Recording and Management

Digital data collection is the Arcadis standard using available FieldNow® applications that enable real-time, paperless data collection, entry, and automated reporting. Paper forms should only be used as backup to FieldNow® digital data collection and/or as necessary to collect data not captured by available FieldNow® applications. The Field Now® digital form applications follow a standardized approach, correlate to most TGIs and are available to all projects accessible with a PC or capable mobile device. Once the digital forms are saved within FieldNow®, the data is instantly available for review on a web interface. This facilitates review by project management team members and SMEs enabling error or anomalous data detection for correction while the staff are still in the field. Continual improvements of FieldNow® applications are ongoing, and revisions are made as necessary in response to feedback from users and subject matter experts.

If paper forms are used, fluid level measurements as well as all relevant observations should be documented in the field logbook, field forms and/or PDA as appropriate. The following information must be documented:

- Well or location identification;
- Measurement time;
- Total well depth or depth of the water body at the location;
- Depth to water and, where necessary, depth to NAPL.

Once all the data has been collected and recorded, all notes/forms/data must be uploaded to the appropriate project directory on the Arcadis server, and an email should be sent to the Task Manager and/or Technical Lead for notification. A summary of the work completed that day and any relevant observations noted (such as well inspections) during the daily activities as well as copies of the data mentioned above should be included with the email. The appropriate team member will review the datafor accuracy and provide feedback.

11 Quality Assurance

Suggested quality control measures are below; project teams may implement some or all of these at their discretion and based on project data quality needs.

- As described in the detailed procedure, the electronic water-level meter and/or oil-water interfaceprobe can be calibrated prior to use versus an engineer’s rule to ensure accurate length demarcations on the tape or cable. The results will be recorded.
- Measurements will be completed three times, with the final measurement recorded.
- Fluid interface measurements will be verified by gently raising and lowering the instrument through each interface to confirm repeatable results.

- Field notes will be reviewed by the project team once the field data has been delivered.

12 References

Cunningham, W.L., and Schalk, C.W., comps., 2011. *Groundwater technical procedures of the U.S.Geological Survey: U.S. Geological Survey Techniques and Methods 1–A1, 151 pp*.

U.S. Environmental Protection Agency, 2013. *SESD Operating Procedure, Groundwater level and WellDepth Measurement.* January 29.

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TGI - In-Situ and Ex-Situ Water Quality Parameters – Surface Water and Groundwater

Rev: 1

Rev Date: April 15, 2022

Version Control

Issue	Revision No.	Date Issued	Page No.	Description	Reviewed By
	0	October 16, 2018	All	Updated and re-written as TGI (in-situ and ex-situ adaptation)	Marc Killingstad
	1	April 15, 2022	All	Review and update to include surface water turbidity sensors	Shannon Dunn / Marc Killingstad

Approval Signatures

Prepared by: 4/15/2022

Chris Shepherd

Chris Shepherd, PG Date

Reviewed by: 4/15/2022

Marc Killingstad (Subject Matter Expert) Date

1 Introduction

This Technical Guidance Instruction (TGI) describes methods used to measure water quality parameters in surface water as well as groundwater both in-situ and ex-situ.

2 Intended Use and Responsibilities

This document describes general and/or specific procedures, methods, actions, steps, and considerations to be used and observed by Arcadis staff when performing work, tasks, or actions under the scope and relevancy of this document. This document may describe expectations, requirements, guidance, recommendations, and/or instructions pertinent to the service, work task, or activity it covers.

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3 Scope and Application

Water quality parameters (e.g., turbidity, specific conductivity, pH, and temperature) of natural waters are usually measured in the field. The temperature, pH, specific conductivity, dissolved oxygen (DO), and oxidation reduction potential (ORP) and turbidity of water will be measured in-situ or ex-situ with amultiparameter water quality meter (i.e., multimeter).

Conductivity is the ability of a solution to pass an electric current. This current is carried by inorganic dissolved solids. The measurement is useful to quantify the chemical purity of the water relative to the amount of dissolved solids in a solution. Generally, temperature-compensated conductivity, termed specific conductivity, is measured by a water quality meter. Specific conductivity can also be used to estimate total dissolved solids (TDS) in solution (grams per liter or g/L) by multiplying the specific conductivity (measured in milli-siemens per centimeter or mS/cm) by 0.65 or a matrix specific factor, which assumes that sodiumchloride is a reasonable surrogate for the dissolved solids in solution.

Measuring the concentration of DO in water is an important component in evaluating the quality of naturalas well as contaminated waters. The effects of wastes on rivers/streams, the suitability of water for fish and other organisms, as well as the effects of remediation efforts, can often be ascertained from the DO content. Dissolved oxygen levels generally range from 5 to 9 milligrams per liter (mg/L) when measured inwater that is in equilibrium with air, depending on the temperature and barometric pressure; however, levels may be lower in a 'reducing' environment where anoxic conditions exist in water (e.g., gasoline plume undergoing bioremediation). DO is measure in both mg/L and percent.

The measurement from an ORP sensor represents the net status of all the oxidation and reduction reactions in the sample being measured. Positive results indicate an oxidizing environment while negativeresults indicate a reducing environment. ORP is determined by measuring the potential of a chemically- inert electrode which is immersed in the solution. The sensing electrode potential is read relative to the reference electrode of the pH probe and the value is presented in millivolts (mV).

ORP meter results can indicate possible contamination and can be particularly useful if it is known that one component of the sample is primarily responsible for the observed value. For example, excess chlorine in a sample will result in a large positive ORP value while the presence of hydrogen sulfide willresult in a large negative ORP value. Together with pH, temperature, and knowledge of the dominant species in a sample, ORP results help predict the oxidation state of ions in solution and whether certainreactions may take place.

Temperature readings will be taken at each water sampling location to assist understanding the water quality as well as compensating measurements. A thermometer is typically part of the multimeter. If not,a temperature probe or thermometer will be used.

Turbidity is a measure of the relative clarity of water. It is an optical measurement of the amount of light scattered in the water. Turbidity is often used as a proxy for the amount of suspended particles in the water. Turbidity is typically reported in nephelometric turbidity units (NTUs) or Formazin Nephelometric Units (FNUs).

Refer to the appropriate TGI(s) for surface water sampling and/or groundwater sampling, if applicable. In addition, the water quality instruments should be cleaned in accordance the manufacturers specifications and the *TGI for Groundwater and Soil Sampling Equipment Decontamination* and all investigative derived wastes (IDW) should be managed in accordance with project plans.

4 Personnel Qualifications

Arcadis field sampling personnel will have completed or are in the process of completing site-specific training as well as having current health and safety training as required by Arcadis, client, or regulations, such as 40-hour HAZWOPER training and/or OSHA HAZWOPER site supervisor training. Arcadis personnel will also have current training as identified in the site-specific Health and Safety Plan (HASP) which may include first aid, cardiopulmonary resuscitation (CPR), Blood Borne Pathogens (BBP) as needed. The HASP will also identify any access control requirements.

Prior to mobilizing to the field, the sampling team will review and be thoroughly familiar with relevant site-specific documents including but not limited to the task-specific work plan or field implementation plan (FIP), Quality Assurance Project Plan (QAPP), HASP, historical information, and other relevant site documents.

Arcadis field sampling personnel will be knowledgeable in the relevant processes, procedures, and TGIs and possess the demonstrated required skills and experience necessary to successfully complete the desired field work. Additionally, the field sampling team will review and be thoroughly familiar with documentation provided by equipment manufacturers and become familiar with the operation of (i.e., hands-on experience) all equipment that will be used in the field prior to mobilization.

5 Equipment List

The following materials, as required, will be available during field measurement of water qualityparameters:

- Site-specific HASP and health and safety documents identified in the HASP (e.g., job safetyassessments [JSAs])
- Field Implementation Plan (FIP) that includes site map with sampling locations, well constructionrecords (table or logs), sampling plan, and prior sampling records (if available)
- Field notebook, pen(s) (indelible ink) and/or smart device (smart phone or tablet, see Section 10)
- Field laptop / smart device / data manager, as appropriate
- Water Quality Measurement Log (**Attachment 1**) or smart device with a digital form; alternatively, the surface water sampling or groundwater sampling form may be used, if appropriate.
- Water Quality Meter Calibration Log (**Attachment 2**)
- Appropriate personal protective equipment (PPE) (e.g., latex or nitrile gloves, safety glasses, etc.) asspecified in the HASP
- Traffic cones, delineators, and caution tape as appropriate for securing the work area as specified inthe Traffic Safety Plan (TSP)
- Well key(s), as needed
- Photoionization detector (PID), flame ionization detector (FID) or other air monitoring equipment, asneeded, in accordance with the HASP
- Plastic sheeting (e.g., Weatherall Visqueen) or other clean surface to prevent sampling equipment from coming in contact with potentially contaminated surfaces, as needed
- Multiparameter (temperature/pH/specific conductivity/ORP/turbidity/DO) water quality meter or sondewith flow-through cell (as appropriate) plus reader and protective housing, for example:
    - YSI Professional Plus Multiparameter Instrument
    - YSI EX01 or EX02 Multiparameter Sonde
    - Horiba W-22 XD Multiparameter Instrument
    - Hydrolab DS5 Multiprobe and Display

- Turbidity meter (e.g., Lamotte 1974) and sample vessels, as required by FIP or QAPP.
    - Some multiparameter meters have a turbidity sensor; however, the team must verify the sensor will meet the data quality objectives in the FIP or QAPP.
- Operation manual(s) for meter(s)
- Water quality meter extension cable (as needed for in-situ readings of wells)
- Standard solutions for calibration, check expiration dates
- Multimeter maintenance kit and extra DO membranes if using amperometric DO probe
- Extra batteries for the various instruments and/or charging cables
- Electronic water-level indicator (e.g., Solinist Model 101) or oil/water interface probe with 0.01-foot accuracy), as needed
- Tape measure, as needed
- Cleaning equipment (buckets, distilled or deionized water, cleansers appropriate for removingexpected chemicals of concern, paper towels), as needed.

6 Cautions

NOTE: *Proper operation and maintenance are very important for a functioning meter and accuratereadings. Carefully follow manufacturer's instructions for operation (including down-hole use), maintenance, and calibration as each manufacturer's instructions will vary. Some meters require periodic manufacturer calibration.*

Verify the meters meet the project data quality objectives in the FIP and QAPP. In some cases, it may be necessary to use a separate turbidity meter (nephelometer) or higher accuracy and precision meter(s) if the measurements are intended to be used for compliance purposes.

Verify the meter is intended for in-situ measurements (i.e., can be fully submerged in water) and that all necessary parts are available prior tofield mobilization. Check and record the expiration dates of calibration fluids. Verify that calibration readings are reasonableand correspond to previous calibration readings when available. Expired or contaminated calibration fluids may result in erroneous results. If accurate measurements of TDS are required, site-specific calibration will be necessary in accordance with the manufacturer's specifications.

When taking measurements in the field, verify that readings make sense and compare to historicalreadings when possible. See Section 3.

7 Health and Safety Considerations

The HASP will be followed, as appropriate, to ensure the safety of field personnel.

Appropriate personal PPE will be worn at all times in line with the task and the site-specific HASP. Also, at a minimum, wear latex gloves and safety glasses when working with calibration solutions.

Review all site-specific and procedural hazards as they are provided in the HASP, and review Job Safety Analysis (JSA) documents in the field each day prior to beginning work.

Access to wells and some surface water bodies may expose field personnel to hazardous materials such as contaminated groundwater ornon-aqueous phase liquid (NAPL) (e.g., oil). Other potential hazards include pressurized wells, stinging insects that may inhabit well heads, other biologic hazards (e.g. ticks in long grass/weeds around wellhead), and potentially the use of sharp cutting tools (scissors, knife)—open well caps slowly and keep face and body away to allow to vent any built-up pressure; only use non-toxic peppermint oil spray for stinging insect nests; review client-specific health and safety requirements, which may preclude the use of fixed/folding-blade knives, and use appropriate hand protection.

If working near surface water bodies, it may be necessary to use personal flotation devices and/or use additional safety measures. Consult with the HASP and JSA for site- and task-specific health and procedures.

If working at a site with hazardous levels of volatile organic compounds, headspace and/or breathingzone readings will be measured prior to working at/in the well, in accordance with the HASP.

8 Procedures

This Procedures Section is divided into:

- General Procedures – calibration, operation, and maintenance procedures that apply to all methods and meters
- Calibration – general calibration procedures for:
    - Multimeter
    - Separate turbidity meter, if required
- Operation – general measurement operations for:
    - Ex-situ measurements
        - Multimeter
        - Separate turbidity meter, if required
    - In-situ measurements (downhole/well or submerged applications)
- Maintenance
    - Multimeter
    - Turbidity meter

8.1 General Procedures

The following, general procedures apply to most instruments regardless of whether measuring in-situ or ex-situ. For groundwater, most measurement are conducted ex-situ (i.e., not within the groundwater well/aquifer). It is also possible to use in-situ measurements for some parameters and ex-situ measurements for other parameters. If in-situ measurements are carried out, a special probe and/or cables are required.

- Read through all relevant procedures before field implementation and familiarize yourself with the equipment
- Verify all equipment is present and the instrument is fully functioning prior to field mobilization, if possible
    - Check batteries/power levels
- The meter(s) should be cleaned prior to each use in accordance with cleaning and decontamination procedures as specified in the FIP or QAPP and in accordance with the instruction manual.
    - Most meters can only handle light washing with a mild soap and warm water.
    - After cleaning the sensors should be soaked in distilled/deionized water and then rinsed in distilled/deionized water. The recommended soaking periods vary depending on the sensor (see Section 8.2)
    - It is recommended that you temporarily store the probes in distilled/deionized water uses between measurements as some probes like conductivity require long soaking periods (see Section 8.2).
- The meter will be calibrated following the manufacturer's instructions as calibration steps vary bymanufacturer
    - Probes should be rinsed with a small amount of the calibration solution and then discard that used solution prior to calibration, if applicable. This will reduce cross-contamination of the calibration solution during calibration
    - Two or three-point calibrations are preferred over single point calibrations, where applicable. See Section 8.2 and should be selected based on expected water quality
    - Verify calibration solutions, if applicable, are not expired
    - Caution: calibration solutions should not be reused as it can cross-contaminate the solution unless authorized by the QA/QC manager
    - Ensure the sensor is completely submerged in the calibration solution, if applicable
    - Calibration information will be recorded in the calibration log (Attachment 2) and the field notebook
    - More frequent calibration may be necessary in harsh conditions or per project plans
    - Barometric verification or calibration may be required for some instruments
- The meter will be operated following the manufacturer's instructions
- Multimeters can be operated in-situ (down-hole, in water, etc.) or ex-situ (water is transferred to container for measurement)
    - Ex situ operation is described in Section 8.3.1
    - In situ operation is described in Section 8.3.2
- The meter will be maintained according to the manufacturer's instructions
    - Maintenance information will be recorded in the field notebook or instrument log
    - Manufacturer recalibration or replacement probes may be required on a routine basis
    - Additional details for pH, conductivity, temperature, dissolved oxygen, and turbidity maintenance

    are presented in section 8.4 Maintenance below
  - More frequent maintenance (probe replacement, sensor reconditioning, etc.) may be necessary in harsh conditions or per project plans
- A replacement meter and probes will be available onsite or ready for overnight shipment, as necessary
- Store the meters in accordance with manufacturer's specifications
  - Most multi-meter sensors should be stored with a small amount of water in the cap to keep it moist but not saturated/submerged.

The complete procedures are described in Section 8.2 through 8.4.

8.2 Calibration

8.2.1 Multimeter Calibration

1) Connect cables from meter to reader
2) Check probes and ensure they are clean
3) Switch on instrument and allow to warm-up, warm up may take from 5 to 15 minutes depending on the instrument and sensors used
4) Check battery life and replace, if needed
5) Adjust date/time, if needed
6) Soak all probes in distilled or de-ionized water for at least 5 minutes (some probes may requirelonger soak times, see below and manufacturer instructions) and then shake off excess liquid
    i. NOTE: *If the probes are recently reconditioned or have slight build-up, allow for longer soaking period*
7) Navigate to calibration display/mode; enable auto stabilization feature, if appropriate
8) **pH Calibration** – when in use, the pH meter will be calibrated daily, at a minimum.
    a. Connect electrode (if applicable) or remove protective cap from electrode
    b. Rinse end of electrode in distilled/deionized water and shake off excess water
    c. Measure and record temperature of buffer solutions
    d. Immerse pH electrode in pH buffer 7.00, set the temperature to that of the buffer 7.00, andallow sufficient time for the electrode to stabilize
    e. Adjust the calibration for the correct readout and temperature
    f. Confirm/press the calibration button
    g. Remove electrode from buffer and rinse with distilled/deionized water
    h. Immerse pH electrode in buffer 4.00, set the temperature control to that of the buffer 4.00,and allow sufficient time for the electrode to stabilize

    i. Adjust the calibration for the correct readout and temperature
    j. Confirm/press the calibration button
    k. Rinse electrode with distilled/deionized water
    l. A pH 10 calibration will also be performed if high pH (>9) is anticipated, following manufacturers procedures
    m. The pH meter is calibrated

9) **Conductivity Calibration** – when in use, the conductivity meter will be calibrated daily, at aminimum.

    a. Conductivity is generally measured in specific conductivity (temperature compensated),verify with the FIP/work plan
    b. Soak the probe in distilled/deionized water for at least 30 minutes
    c. Remove the probe from the water and fling out drops clinging inside
    d. Immerse the probe to or beyond the vent holes in a beaker containing 1.413 mS/cmstandard solution for freshwater measurements or a standard with a higher concentration for marine water, and gently agitate vertically to remove entrapped air
    e. Repeat Steps 3 and 4 at least once more
    f. Press calibration button

10) **Temperature calibration** – temperature will be verified according to FIP/work plan, if applicable.

11) **Dissolved Oxygen (DO) calibration** – when in use, the DO meter will be calibrated daily usingthe air calibration method or less frequently if using an optical sensor (see below).

    a. Preparation
        i. Polarographic sensor – periodically recondition sensor, replace fluids, and Teflon®membrane, per manufacturer, and air bubbles should not be present
        ii. Galvanic sensor – Periodically recondition sensor, replace fluids, and membrane,per manufacturer, and air bubbles should not be present
        iii. Optical sensor – Per manufacturer, most will only require field checks and maintenance, however, weekly checks are recommended to verify the accuracy, ata minimum
    b. Obtain a barometric pressure reading from a daily weather report or from the instrument,as required by instrument
    c. Keep instrument upright and vent cap/cover while retaining a small amount of clean water(do not cover probes) for non-optical sensors only
    d. Allow 5 to 15 minutes for optimum probe stabilization and polarization, for non-optical sensors (reading will range between 5 to 9 mg/L depending on temperature and barometricpressure)
    e. Press calibration button if reading is more than 2% from the standard

12) **Oxidation reduction potential (ORP) calibration** – when in use, the ORP meter will becalibrated daily, if required.
    a. Rinse the probe in distilled/deionized water
    b. Remove the probe from the water and fling out drops clinging inside
    c. Immerse the probe in the ORP solution. Gently agitate vertically to remove entrapped air.
    d. Adjust calibration target based on temperature in accordance with manufacturer and calibration solution guide
    e. Allow the sensor to equilibrate to solution
    f. Press calibration button if reading is more than 2% from the standard
13) **Turbidity, if used** – when in use, turbidity sensor will be checked daily and calibrated weekly, at aminimum
    a. Verify with the FIP/work plan if the turbidity sensor will be used and the proper units (NTU, FNU, etc.)
    b. Gently clean the sensor to remove and sediments or buildup and then rinse the sensor with distilled/deionized water one to two times
    c. Remove the probe from the water and fling out drops clinging inside
    d. Next do a final rinse with the calibration solution starting with lower calibration solution and dispose of the used solution.
    e. Immerse the probe in the calibration cup with the guard. It is important to calibrate with the guard on or verify the cup is designed to match the guard as turbidity measurements are affected by the dimensions and reflectivity of the guard. Verify the there are no air bubbles.
    f. Repeat Steps c, d, and e at least once more with higher turbidity calibration solutions
    g. Press calibration button
14) Adjust the instrument to READ or LOGGING mode, per instruction manual and project plans; theinstrument is now ready for use
15) Record the calibration on the field form or smart device.

8.2.2 Turbidity Meter Calibration (if required)

When in use, the turbidity meter will be checked daily and calibrated weekly. The turbidity meter will be calibrated per steps below:

1) Switch on instrument and allow time to warm-up
2) Check battery life and replace, if needed
3) Turbidity sample tubes will always be washed prior to use, but not the calibration standard tubes,using a mild detergent to remove any dirt or fingerprints that could bias the results
4) Dry the outside of the sample turbidity tubes with a clean, lint-free cloth or disposable wipe (non-scratch)

andallow the turbidity tubes to air-dry in an inverted position to prevent dust from entering the tube,as allowable (but, not the calibration standard tubes)—dirt or fingerprints can lead to inaccurateresults.

5) Wipe the 1 NTU standard and place in the chamber after aligning the arrows (manufacturer dependent)
6) Place the light shield over the turbidity standard and allow the meter to stabilize
7) Press the read and/or CAL button, per instructions
8) Repeat steps 3 thru 5 above
9) Adjust to READ mode and the instrument is now ready for use
10) Record the calibration and/or verification in the calibration log.

8.3 Operation

Water quality parameters can be measured ex-situ or in-situ in accordance with the FIP/work plan. The operating procedures for each method are described below. It is also possible to collect a depth-specific water sample from a well or water body for ex-situ measurement.

8.3.1 Ex-situ Operation

For ex-situ operation one or two representative water samples will be collected from the well or surface water body for measurement using the required meters. If two representative samples are collected, both values for each parameter should be reported, however, the average of the two results should be used as the final value.

8.3.1.1 Multimeter

1) Fill two 100-mL plastic clean, disposable containers or cleaned beakers with water from the sample
2) Insert the probe into the first beaker immersing all sensors and allow to stabilize (2 minutes atminimum)
3) Record readings
    a. Temperature – in degrees Celsius or Fahrenheit
    b. pH – in standard units between 0 and 14, in 0.01 increments
    c. Specific conductivity – in mS/cm or micro siemens per centimeter (uS/cm)
    d. DO – in mg/L and percent (will typically read between 0 and 15 mg/L)
    e. ORP – in millivolts (mV; will typically read between -1,400 mV and + 1,400 mV), if required
    f. Turbidity, if used – in NTU or NFU
4) Rinse probe off with distilled/deionized water
5) Repeat Steps 2 thru 4 for the other beaker, if applicable
6) Record results on the water quality measurement log and/or in field notebook - the average will bethe actual result, after stabilization if two samples are used

7) Rinse probe off with distilled/deionized water

NOTE: *If a flow through cell is used during sampling, a single reading can be obtained from the multimeter during each step of the wells purging in accordance with TGI - Low FlowGroundwater Purging and Sampling.*

8.3.1.2 Turbidity Meter, if needed

1) Fill the two cleaned, manufacturer provided sample tubes with water from the sample
    a. If using a flow through cell, it is recommended to collect the turbidity samples before the flow through cell
2) Wipe off and dry the outside of the sample turbidity tubes with a clean, lint-free cloth ordisposable wipe
3) Insert the first sample tube and close the cover
4) Push the READ button
5) Record turbidity reading in NTUs (0 to 1,100 NTUs)
    a. If readings are over the instrument limit, a single 2X dilution can be run by mixing thesample with equal parts distilled or de-ionized water and gently mixing
    b. The resulting value will need to be doubled (for example, if the diluted reading is 750 NTUs, the estimated turbidity would be 750 x 2 = 1,500 NTUs. Diluted samples will bequalified as estimated)
6) Repeat steps 2 thru 5 with the second sample tube
7) Log the results on the water quality measurement log and/or in field notebook - the average willbe the actual result
8) Rinse sample tubes with distilled/deionized water.

NOTE: *If a flow through cell is used during low flow groundwater sampling, a single reading can be obtained from the multimeter during each step of the wells purging in accordance with TGI - Low FlowGroundwater Purging and Sampling. The turbidity sample is recommended to be collected prior to passing through the flow through cell.*

8.3.2 In-situ Operation

1) Connect extension cable and protective housing to meter
2) Measure water level from reference point
3) Lay out plastic sheeting as needed to keep the multimeter clean
4) Clean multimeter and cable per decontamination procedures and instruction manual and rinse with distilled/deionized water using caution, as most meters can only handle light washing with amild soap and warm water
5) Organize work area to prevent dirt or objects from falling in the well
6) Measure and mark extension cable at planned measurement intervals in accordance with the FIP
7) Slowly lower the probe into the well or water body to the desired measurement interval usingcaution to prevent rubbing of cable on the well and minimize water and sediment disturbance

8) Allow readings to stabilize (typically 1 to 3 minutes)
    a. For many instruments, the instrument may need to be slowly oscillated up and down a fewinches to circulate water around the probes
9) Record readings
    a. Temperature – in degrees Celsius or Fahrenheit
    b. pH – in standard units between 0 and 14, in 0.01 increments
    c. Specific conductivity – in mS/cm or uS/cm
    d. DO – in mg/L <u>and</u> percent (will typically read between 0 and 15 mg/L)
    e. ORP – in mV (will typically read between -1,400 mV and +1,400 mV), if required
    f. Turbidity, if used – in NTU or NFU
10) Repeat steps 4 through 9 to complete targeted in-situ measurements
11) Record results on the water quality measurement log or smart device
12) Slowly retrieve the multimeter
13) Clean multimeter and cable per decontamination procedures and instruction manual and rinse with distilled/deionized water using caution, as most meters can only handle light washing with amild soap and warm water

8.4 Maintenance

8.4.1 Multimeter

1) After use, the meter will be inspected and maintained according to the manufacturer's specifications and the inspection/maintenance activities will be recorded in the field notebook
2) Keep records of usage, maintenance, calibration, problems, and repairs
3) Recharge/replace batteries on a regular basis
4) Store meters or electrodes in protective casing when not in use
5) DO membranes will be stored moist, unless specified otherwise by manufacturer
6) Focused probe cleaning may be necessary in accordance with the operation manual and may be needed more frequently in harsh conditions
7) A replacement meter will be available onsite or ready for rapid delivery/shipment
8) Periodic manufacturer calibration may be necessary per operation manual and/or field plans.

8.4.2 Turbidity Meter, if used

1) Recharge battery on a regular basis

2) Store in protective casing when not in use
3) Keep records of usage, maintenance, calibration, problems, and repairs
4) After use, the meter will be inspected with results recorded in the field notebook
5) Keep sample tubes clean inside and out replacing them when they become scratched or etchedand avoid handling the tubes in the region where the light beam enters them.
6) Clean lens periodically per instruction manual
7) Turbidity meter will be sent back to the manufacturer for service when needed

9 Waste Management

IDW, including decontamination liquids, and disposable materials (well material packages, PPE, etc.), will be placed in clearly labeled, appropriate containers, or managed as otherwise specified in the Work Plan (or equivalent), FSP, and/or IDW management guidance document.

10 Data Recording and Management

Digital data collection is the Arcadis standard using available FieldNow® applications that enable real-time, paperless data collection, entry, and automated reporting. Paper forms should only be used as backup to FieldNow® digital data collection and/or as necessary to collect data not captured by available FieldNow® applications. The FieldNow® digital form applications follow a standardized approach, correlate to most TGIs and are available to all projects accessible with a PC or capable mobile device. Once the digital forms are saved within FieldNow®, the data is instantly available for review on a web interface. This facilitates review by project management team members and SMEs enabling error or anomalous data detection for correction while the staff are still in the field. Continual improvements of FieldNow® applications are ongoing, and revisions are made as necessary in response to feedback from users and subject matter experts.

Management of the original documents from the field will be completed in accordance with the site- specific QAPP. Records generated as a result of this TGI will be controlled and maintained in the projectrecord files in accordance with project requirements.

In general, documentation of the following information is required:

- Calibration – calibration information will be recorded on a calibration form, field log, or electronicdevice per project plans
    - Meter manufacturer and model
    - Serial number
    - Calibration personnel
    - Calibration date/time
    - Standard value, initial and final reading
    - Observations, if applicable

- Readings - data will be recorded on a field log, sampling form, or electronic device per projectplans
    - Instrument model
    - Measurement date/time
    - Field personnel
    - Weather
    - Measurement location and depth, if applicable
    - Source of water (surface water, groundwater, etc.)
    - In-situ vs ex-situ measurement method
    - Value of readings and average reading, if applicable
    - Units of readings
    - Key observations

All records will be provided to the project manager and retained in the project files. Any maintenanceneeds will be communicated to the project manager promptly.

11 Quality Assurance

Quality assurance procedures will be conducted in accordance with the Arcadis Quality ManagementSystem or the site-specific QAPP. Refer to the QAPP or FIP/sampling plan/work plan for the frequency of calibrations.

12 References

Not applicable.

13 Attachments

Attachment A - Water Quality Measurement Log

Attachment B - Water Quality Meter Calibration Log

Attachment A

Water Quality Measurement Log

ARCADIS Design & Consultancy for natural and built assets

WATER QUALITY MEASUREMENT LOG

Page______of ________

GENERAL INFORMATION

Date ____
Project No ____
Site Name ____
Site Location ____
Site/Well No. ____

Weather ____
Sample Personnel ____
Sample ID ____
Start reading time ____
End reading time ____

MEASUREMENT DATA

Measuring Point (MP) description ____________________________
Depth to Water (ft)/Time ____________________________
Well Screen Interval (ft) ____________________________
Casing Diameter (in) ____________________________
Meters calibrated (Y/N) ____________________________

☐ Surface Water or ☐ Groundwater
Instruments model/serial no. ____________________________
Instrument model /serial no. 2 ____________________________
☐ In-situ ☐ Ex-situ reading
(see calibration log, if applicable)

Water Quality Parameters

Time	Depth	pH	Spec. Cond.	Temp	DO		ORP	Turbidity	Observations
	(ft)	(S.U.)	(mS/cm or uS/cm)	(°C or °F)	(mg/L)	(%)	(mV)	(NTU)	(Odor, clarity, etc., if applicable)

REMARKS

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Attachment B

Water Quality Meter Calibration Log

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WATER QUALITY METER CALIBRATION LOG

PROJECT NAME	
PROJECT NO.	
MODEL(s)	
SERIAL #(s)	
SAMPLER	
DATE	

TURBIDITY CALIBRATION

CAL. READING		CAL. READING		CAL. RANGE	TIME
(LOT #)		(LOT #)			
(EXP. DATE)		(EXP. DATE)			
PRE-CAL. / POST-CAL		PRE-CAL. / POST-CAL			
/		/		☐ WITHIN RANGE	
/		/		☐ WITHIN RANGE	
/		/		☐ WITHIN RANGE	
/		/		☐ WITHIN RANGE	

MULTIMETER CALIBRATION

AUTOCAL SOLUTION (Y / N)		CAL. READING	CAL. RANGE	TIME	CALIBRATION RANGES (1)	
(LOT #)						
(EXP. DATE)						
PARAMETER	LOT / EXP. DATE	PRE-CAL. / POST-CAL				
☐ pH		/	☐ WITHIN RANGE		pH	± 0.2 S.U.
☐ CONDUCTIVITY		/	☐ WITHIN RANGE		COND	± 1% OF CAL. STANDARD
☐ ORP		/	☐ WITHIN RANGE		ORP	± 25 mV
☐ DO		/	☐ WITHIN RANGE		DO	Atmospheric
☐ TURBIDITY		/	☐ WITHIN RANGE		TURB	± 5% OF CAL. STANDARD
☐		/	☐ WITHIN RANGE			
☐		/	☐ WITHIN RANGE			

(1) CALIBRATION RANGES ARE SPECIFIC TO THE MODEL OF THE WATER QUALITY METER

NOTES:

SIGNED DATE

CHECKED BY DATE

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TGI – Sample Chain of Custody

Rev: 3

Rev Date: March 28, 2022

Version Control

Issue	Revision No.	Date Issued	Page No.	Description	Reviewed By
	0	April 19, 2017	All	Re-write to COC only	Richard Murphy
	1	May 23, 2017	4,7,9	Add: Guidance on use of previous version of TGI. Add: Info on COCs for multiple shipping containers Modify: Move letter i. to letter m. and change to "when appropriate"	Peter Frederick
	2	April 29, 2020	4, 11	Remove obsolete link	Lyndi Mott
	3	December 28, 2022	All	Updated Arcadis format Added to 6c. Collection time between COC and container must match. Added to 6o. Add name of overnight courier when relinquishing samples. Updated reference documents and added internet links.	Lyndi Mott

Approval Signatures

Prepared by: 3/28/2022

Lyndi Mott (Preparer) Date

Reviewed by: Dennis K. Capria 3/28/2022

Dennis Capria (Chain of Custody Reviewer) Date

Reviewed by: 12/22/2021

Lyndi Mott (Subject Matter Expert) Date

1 Introduction

This Technical Guidance Instruction (TGI) provides the procedure for Arcadis field personnel for required documentation during the collection of environmental field samples and transfer of custody to a laboratory. It provides direction for completion of the Chain of Custody form that must accompany collected field samples for analysis by a laboratory.

2 Intended Use and Responsibilities

This document describes general and/or specific procedures, methods, actions, steps, and considerations to be used and observed by Arcadis staff when performing work, tasks, or actions under the scope and relevancy of this document. This document may describe expectations, requirements, guidance, recommendations, and/or instructions pertinent to the service, work task, or activity it covers.

It is the responsibility of the Arcadis Certified Project Manager (CPM) to provide this document to the persons conducting services that fall under the scope and purpose of this procedure, instruction, and/or guidance. The Arcadis CPM will also ensure that the persons conducting the work falling under this document are appropriately trained and familiar with its content. The persons conducting the work under this document are required to meet the minimum competency requirements outlined herein, and inquire to the CPM regarding any questions, misunderstanding, or discrepancy related to the work under this document.

This document is not considered to be all inclusive nor does it apply to all projects. It is the CPM’s responsibility to determine the proper scope and personnel required for each project. There may be project- and/or client- and/or state-specific requirements that may be more or less stringent than what is described herein. The CPM is responsible for informing Arcadis and/or Subcontractor personnel of omissions and/or deviations from this document that may be required for the project. In turn, project staff are required to inform the CPM if or when there is a deviation or omission from work performed as compared to what is described herein.

In following this document to execute the scope of work for a project, it may be necessary for staff to make professional judgment decisions to meet the project’s scope of work based upon site conditions, staffing expertise, regulation-specific requirements, health and safety concerns, etc. Staff are required to consult with the CPM when or if a deviation or omission from this document is required that has not already been previously approved by the CPM. Upon approval by the CPM, the staff can perform the deviation or omission as confirmed by the CPM.

3 Scope and Application

This TGI describes the general Chain of Custody (COC) procedures and guidance instructions for samples collected from project sites that are relinquished from Arcadis’ possession.

COC is defined as the maintenance of an unbroken record of possession of an item from the time of its collection through some analytical or testing procedure. COC is typically documented by a written record of the collection, possession, and handling of samples collected from a project location. Each sample will be tracked by a documented record that efficiently documents the individuals who were responsible for the sample during each successive transfer of that sample to various recipients beyond Arcadis’ possession. This information can be used to legally establish the integrity of the samples and therefore the analytical results derived from the samples. This information can be used in addition to other records and documentation regarding the samples, such as field forms, field logs, and photographs.

A sample is considered under custody if:

- It is in your possession; or
- It is in your view, after being in your possession; or
- It was in your possession and then you then locked it up to prevent tampering; or
- It is in a designated secure area.

Continued use of previous version of TGI:

Although not recommended, Arcadis program-, project-, and client-teams may be able to use the previous version of this TGI provided that it meets all of the quality expectations of Arcadis and client and meets applicable regulatory requirements. It is up to the program, project, and/or client-team leader to determine whether it is appropriate to adopt the current TGI or to continue using the previous version.

However, all new work not associated with the previous version of this TGI must be performed with the current version of the TGI.

When adopting this new TGI, users of the previous versions must be aware that specific handling, packing, and shipping procedures and guidance has been removed and that those should be addressed within program or project plans (e.g., Quality Assurance Project Plans (QAPP), Work Plans, Sampling and Analysis Plans (SAPs), etc.) or in a more detailed TGI specific to that sampling activity, whether related to media, constituent/analyte, client, state, etc.

In addition, adopting this new TGI will require users to refer to the Arcadis Department of Transportation (DOT) Safety Program for procedures and guidance on the determination and handling, packing, and shipping of samples that are or may be considered hazardous materials.

4 Personnel Qualifications

Arcadis personnel performing work under the purview of this TGI will have received appropriate training and have field experience regarding the collection of samples from project locations. Arcadis personnel will have all other applicable and appropriate training relevant to the sampling work and project site.

5 Equipment List

The following list provides materials that may be required for each COC. Project reporting and documentation requirements must be reviewed with the CPM prior to execution of work. Additional materials, tools, equipment, etc. may be required, and project staff are required to verify with the CPM and/or Technical Expert what specific equipment is required to complete the COC.

- Indelible ink pen (preferably either black or blue ink);
- COC form **(Appendix A)** from either Arcadis, laboratory receiving and analyzing the samples, or other applicable and appropriate entity for the work performed;
- When appropriate, such as for litigation or expert testimony work, custody seals or tape.

6 Cautions

One way in which the law tries to ensure the integrity of evidence is by requiring proof of the chain of custody by the party who is seeking to introduce a particular piece of evidence.

A proper chain of custody requires three types of affirmations: (1) affirmation that a sample is what it purports to be (for example, soil collected from a specified location and depth); (2) affirmation of continuous possession by each individual who has had possession of the sample from the time it is collected until the time it is analyzed or held by a laboratory; and (3) affirmation by each person who has had possession that sample remained in substantially the same condition and not contaminated or affected by outside influences from the moment one person took possession until the moment that person released the evidence into the custody of another (for example, affirmation that the sample was stored in a secure location where no one but the person in custody had access to it).

Proving chain of custody is necessary to "lay a foundation" for the samples in question, by showing the absence of alteration, substitution, or change of condition.

Ensure that appropriate sample containers with applicable preservatives, coolers, and packing material are planned for and provided at the site at the time of sample collection.

Understand the offsite transfer requirements of the samples for the facility at which samples are collected.

If overnight courier service is required schedule pick-up or know where the drop-off service center is located and the hours of operation.

An Arcadis employee appropriately trained at the correct level of internal hazardous materials/DOT)shipping must complete an Arcadis shipping determination to address applicable DOT and International Air Transport Association (IATA) shipping requirements. Review the applicable Arcadis procedures and guidance instructions for sample packaging, and labeling. Prior to using air transportation, confirm air shipment is acceptable under DOT and IATA regulations.

The person relinquishing possession of the samples or other member of the project team should contact the final recipient of the samples to confirm receipt and review any special provisions on the COC or questions that they may have.

7 Health and Safety Considerations

Follow the health and safety procedures outlined in the project/site Health and Safety Plan (HASP) as well as other applicable H&S requirements, such as:

- Arcadis Hazardous Material/DOT handling, packaging, and shipping training
- Project site-specific H&S training
- Client-specific H&S training
- Constituent-specific H&S training
- Media-specific H&S training

8 Procedure

Collected samples must be uniquely identified, and properly documented, containerized, labeled with unique identifier, possessed in a secure manner during remainder of sampling event, packaged, and shipped to recipient laboratory.

Sample Identification

The method of sample identification depends on the type of measurement or analyses performed. In some cases, in-situ measurements of existing conditions and/or sample location must be made during sample collection.

These data will be recorded directly on field forms, logbooks, or other project record data sheets used to permanently retain this information for the project file. Examples of location identification information includes: latitude/longitudinal measurements, compass directions, well number, building number, floor number, room name, or proximity to a site feature unique to the site. Examples of in-situ measurements are pH, temperature, conductivity, flow measurement, or physical condition of the media being sampled. Physical samples collected are identified by a unique identifying number or code on a sample tag or label. These physical samples are removed from the sample location and transported to a laboratory for analyses.

In some cases, before samples are placed into individual containers and labeled as individual samples, samples may be separated into portions depending upon the analytical methods and required duplicate or triplicate analyses to be performed.

When completing a COC for samples, personnel must complete the following:

1. Written COCs must be completed with indelible ink (preferably either black or blue colored ink).
2. Written COCs must be completed using legible printed writing, and not cursive writing.
3. All entry fields on the COC form must be completed. If information is not applicable for a specific entry field, personnel will either put “N/A” or use a strike-out line or dash like “-----------“ to indicate no applicable information is needed for that field.
4. Use of quotation marks or lines/down arrows to represent repetitive/duplicative text in similar fields.
5. Regardless of the type or specific COC form, the following pertinent information must be provided on the COC form:
    a. Arcadis project number
    b. Arcadis project name
    c. Project location, including street address, city, state, building number, providing as much detail as appropriate
    d. Recipient laboratory contact and sample receiving shipping location information
    e. Entities’/persons’ contact information for who will be receiving analytical results
    f. Name of sampler, i.e., person collecting sample and relinquishing possession of samples to the next entity in the chain of custody
    g. Date of sample collection
    h. If appropriate for the sample media, contaminant/constituent of concern, or analytical method, document time of sample collection using standard military time
    i. Sample analytical method(s)

   j. Turnaround time required for analyses and/or reporting
   k. Instructions to laboratory regarding handling, timing, analyses, etc. as applicable and appropriate.
   l. Printed name and signature of the individual person who collected the samples and relinquishing possession of the samples
   m. If appropriate or when documentation of the specific sample collection method will influence how the laboratory handles, prepares, or analyzes the samples, document the sample collection methodology used for collecting the samples (e.g., ASTM D5755)

6. The following additional specific information will be entered on the COC form, regardless of what type of COC is being used:
   a. Unique Sample Identifier – The sample identifier (ID) must be unique to the individual sample it is applied to. The information in which the sample ID conveys is determined by the CPM, Technical Expert, and/or other project team members in advance of sample collection so that sample identification is consistently applied for the project. The sample nomenclature may be dictated by a specific client, program, or project database and require unique identification for each sample collected for the project. Consult with the CPM and/or Technical Expert for additional information regarding sample identification.

      The sample ID could convey specific information regarding the sample to aid personnel in recognizing what the sample represents, or they may be arbitrary so as to facilitate the anonymity of the sample location, media, constituent of concern, project site, etc.

      Examples of unique identifiers include:

      1. Well locations, grid points, or soil boring identification numbers (e.g., MW-3, X-20, SB-30). When the depth interval is included, the complete sample ID would be “SB-30 (0.5-1.0) where the depth interval is in feet. Please note it is very important that the use of hyphens in sample names and depth units (i.e., feet or inches) remain consistent for all samples entered on the chain of custody form. DO NOT use the apostrophe or quotes in the sample ID.
      2. Sample names may also use the abbreviations “FB,” “TB,” “FD” and “DUP” as prefixes or suffixes to indicate that the sample is a field blank, trip blank, or field duplicate, respectively.
   b. List the date of sample collection. All indicated dates must be formatted using either mm/dd/yy (e.g., 03/07/09) or mm/dd/yyyy (e.g., 03/07/2009).
   c. List the local time that the sample was collected. The time value should be presented using military format. For example, 3:15 P.M. should be entered as 15:15. The time listed on the COC form must match the sample collection time on the sample container(s).
   d. Samples should be indicated to be either “Grab” or “Composite”. Grab samples are collected from only one unique location at one specific point in time.
   e. Composite samples are a group of individual samples that are combined for analysis in their totality. Composite samples need to be documented if they are either collected from a number of different locations over a broader area to be representative of the entire area being sampled, or if they are representative of a single location over an extended period of time.

f. If used, preservatives for the individual sample will be noted.

g. The requested analytical method(s) that the samples are being analyzed for must be indicated. As much detail, as necessary, should be presented to allow the analytical laboratory to properly analyze the samples. For example, polychlorinated biphenyl (PCB) analyses may be represented by entering “EPA Method 8082 – PCBs” or “EPA PLM 600-R93-116.” In cases where multiple analytical methods and/or analytical parameters are required for an individual sample, each method should be indicated for the sample (e.g., EPA 8082/8260/8270 or EPA PLM/400-point count).

h. If there are project-specific sample analytes to be reported, they should be specifically listed for each individual sample (e.g., 40 CFR 264 Appendix IX).

i. The total number of containers for each analytical method requested should be documented. This information may be included under the parameter or as a total for the sample.

j. When necessary, note which samples should be used for site specific matrix spikes in the Remarks or Comments field.

k. Indicate special project-specific requirements pertinent to the handling, shipping, or analyses. These requirements may be on a per sample basis such as “extract and hold sample until notified,” or may be used to inform the laboratory of special reporting requirements for the entire sample delivery group (SDG).

l. Indicate turnaround time (TAT) required for samples on COC. If individual samples have differing TATs, the different TATs for each sample or groups of samples must be clearly indicated.

m. Provide contact name and phone number in the event that problems are encountered when samples are received at the laboratory. The person relinquishing possession of the samples or other member of the project team should contact the final recipient of the samples to confirm receipt and review any special provisions on the COC or questions that they may have.

n. If available, attach the Laboratory Task Order or Work Authorization forms.

o. The “Relinquished By” field must contain the signature of the Arcadis person who relinquished custody of the samples to the next entity in the chain of custody, which may be another person, the shipping courier, or the analytical laboratory. If a courier, enter the shipping courier in the “Received by” such as FedEx. The date/time relinquished should be when the person signs the COC and seals the cooler or shipping container for pick-up by the shipping courier.

p. Dates and times must be indicated using the following format:

   1) Date: either mm/dd/yy e.g., 01/01/17 OR mm/dd/yyyy e.g., 01/01/2017

   2) Time: use military format, e.g., 9:30 a.m. is 0930 and 9:30 p.m. is 2130

q. The “Received By” section is signed by sample courier or laboratory representative who received the samples from the sampler. The laboratory will sign upon laboratory receipt from the overnight courier service.

7. When more than one page of the COC form is required to complete the total number of samples, use as many sheets as necessary to accurately and clearly, document the samples and information. Some COCs may have a standard first page/cover page, and subsequent pages may not contain all the detailed fields as

the first page/cover page. Ensure that any subsequent pages convey all of the necessary and pertinent information for each individual sample as required in this procedure document.

8. Pages of the COC must retain a page count of the total number of pages; e.g., Page 1 of 3, Page 2 of 3, Page 3 of 3.
9. Upon completing the COC forms, forward the original signed COC with the sample package. Ensure that the original COC form is secured with the sample package so that it remains with the physical samples for the duration of transport and handling to its final destination and ensure that the COC form will not be become damaged or rendered unreadable due to sample breakage/leakage if stored inside the sample shipping container or outside influences if COC is stored in an outside plastic pouch to the container.
10. If you've collected enough samples that would require more than one container to ship them all to the same laboratory or location, then each separate/individual container that contains any number of samples must have a separate COC representing only those samples contained within that specific container. For example, if you have 3 total shipping containers for all of your samples, you must have a total of 3 separate, individual COCs for each of the 3 containers representing only those samples in their representative container. Thus, every container holding samples must have its own, individual COC.
11. If electronic chain of custody (eCOC) forms are utilized, ensure that the requirements of this procedure and guidance instructions are followed to the extent possible. Verify that proper signature and COC procedures are maintained with the CPM and/or Technical Expert when using eCOC.

9 Waste Management

Not Applicable.

10 Data Recording and Management

The original signed COC shall be submitted with the samples. Copies of COC records will be transmitted to the CPM or designee at the end of each day unless otherwise directed by the CPM. The sampling team leader retains copies of the chain of custody forms for filing in the project file. Record retention shall be in accordance with client- and project-specific requirements and Arcadis policies, the most stringent will apply.

The option to use the Electronic Chain of Custody (eCOC) form in conjunction with the appropriate sample application(s) may be available through the FieldNow® program but is currently limited to a select list of approved analytical laboratories. Use of the eCOC application is intended to reduce common transcription errors both by field staff and laboratory staff on a conventional handwritten paper COC. Once the eCOC form is completed and approved on the field tablet by field staff, a PDF version of the form is automatically emailed to each assigned team member. In addition, a dedicated or mobile printer is recommended for printing a hard copy of the completed eCOC to be included in each sample cooler to meet laboratory requirements.

11 Quality Assurance

COC forms will be legibly completed in accordance with this procedure and guidance instruction document, as well as other applicable and appropriate project documents such as SAP, Quality QAPP, Work Plan, or other project guidance documents.

COC records will be reviewed by the CPM or their appropriate designee for completeness and accuracy to the applicable requirements. Non-conformances will be noted and corrected in a timely manner on the copies retained by Arcadis as well as contacting the ultimate receiving entity for correction to the originally signed COC in their possession.

12 References

Arcadis Transportation Safety Program requirements, procedures, and guidance instructions.

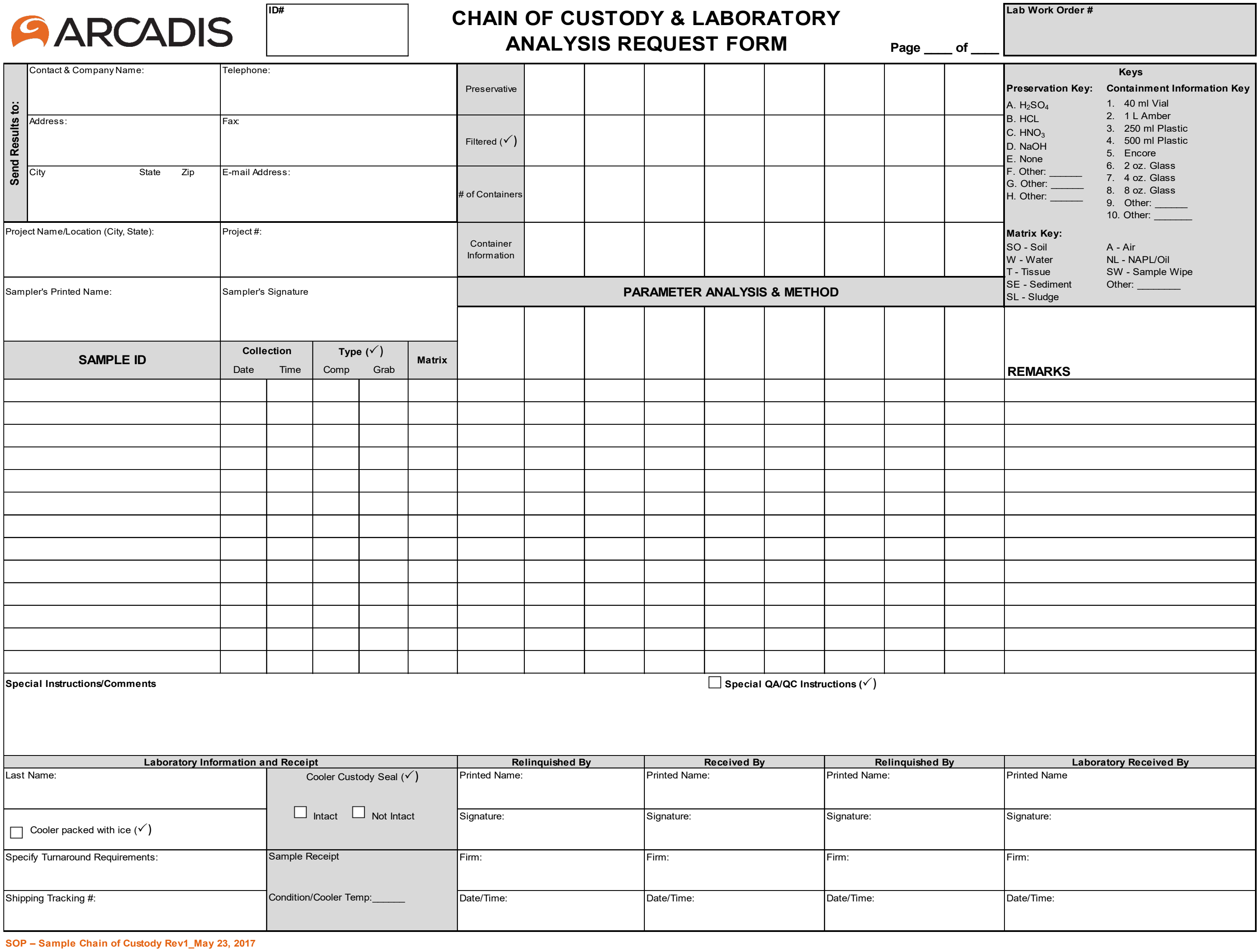
EPA Samplers' Guide – Contract Laboratory Program Guidance for Field Samplers, EPA document EPA-540-R014-013 October 2014 https://www.epa.gov/sites/default/files/2015-03/documents/samplers_guide.pdf.

EPA Region III – Sample Submission Procedures for the Office of Analytical Services and Quality Assurance (OASQA) Laboratory Branch revision 14.0 October 18, 2018, https://www.epa.gov/sites/default/files/2018-12/documents/sample-submission-procedures-rev14.pdf.

EPA Region IV Science and Ecosystem Support Division Operating Procedure for Sample and Evidence Management May 25, 2016, https://www.epa.gov/sites/default/files/2015-06/documents/Sample-and-Evidence-Management.pdf.

Attachment A

Chain of Custody and Laboratory Analysis Request Form



ID#

CHAIN OF CUSTODY & LABORATORY ANALYSIS REQUEST FORM

Page ____ of ____

Lab Work Order #

Send Results to:	Contact & Company Name:	Telephone:
	Address:	Fax:
	City State Zip	E-mail Address:
Project Name/Location (City, State):		Project #:
Sampler's Printed Name:		Sampler's Signature

Preservative								
Filtered (✓)								
# of Containers								
Container Information								

PARAMETER ANALYSIS & METHOD

Keys

Preservation Key:
A. H_2SO_4
B. HCL
C. HNO_3
D. NaOH
E. None
F. Other: ______
G. Other: ______
H. Other: ______

Containment Information Key
1. 40 ml Vial
2. 1 L Amber
3. 250 ml Plastic
4. 500 ml Plastic
5. Encore
6. 2 oz. Glass
7. 4 oz. Glass
8. 8 oz. Glass
9. Other: ______
10. Other: _______

Matrix Key:

SO - Soil	A - Air
W - Water	NL - NAPL/Oil
T - Tissue	SW - Sample Wipe
SE - Sediment	Other: ________
SL - Sludge	

SAMPLE ID	**Collection**		**Type (✓)**		**Matrix**										**REMARKS**
	Date	Time	Comp	Grab											

Special Instructions/Comments

☐ **Special QA/QC Instructions (✓)**

Laboratory Information and Receipt		**Relinquished By**	**Received By**	**Relinquished By**	**Laboratory Received By**
Last Name:	Cooler Custody Seal (✓)	Printed Name:	Printed Name:	Printed Name:	Printed Name
☐ Cooler packed with ice (✓)	☐ Intact ☐ Not Intact	Signature:	Signature:	Signature:	Signature:
Specify Turnaround Requirements:	Sample Receipt	Firm:	Firm:	Firm:	Firm:
Shipping Tracking #:	Condition/Cooler Temp:______	Date/Time:	Date/Time:	Date/Time:	Date/Time:

SOP – Sample Chain of Custody Rev1_May 23, 2017

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Design & Consultancy
for natural and
built assets

TGI - INVESTIGATION-DERIVED WASTE HANDLING AND STORAGE

Rev #: 1

Rev Date: May 15, 2020

VERSION CONTROL

Revision No	Revision Date	Page No(s)	Description	Reviewed by
0	February 23, 2017	ALL	Conversion from SOP to TGI	Ryan Mattson / Peter Frederick
1	May 15, 2020	ALL	Updated to reflect regulatory changes	

APPROVAL SIGNATURES

Prepared by: Derrick Maurer 02/23/2017

Derrick Maurer Date:

Technical Expert Reviewed by: 05/15/2020

Ryan Mattson (Technical Expert) Date:

1 INTRODUCTION

This document describes general and/or specific procedures, methods, actions, steps, and considerations to be used and observed by Arcadis staff when performing work, tasks, or actions under the scope and relevancy of this document. This document may describe expectations, requirements, guidance, recommendations, and/or instructions pertinent to the service, work task, or activity it covers.

It is the responsibility of the Arcadis Certified Project Manager (CPM) to provide this document to the persons conducting services that fall under the scope and purpose of this procedure, instruction, and/or guidance. The Arcadis CPM will also ensure that the persons conducting the work falling under this document are appropriately trained and familiar with its content. The persons conducting the work under this document are required to meet the minimum competency requirements outlined herein, and inquire to the CPM regarding any questions, misunderstanding, or discrepancy related to the work under this document.

This document is not considered to be all inclusive nor does it apply to any and all projects. It is the CPM's responsibility to determine the proper scope and personnel required for each project. There may be project- and/or client- and/or state-specific requirements that may be more or less stringent than what is described herein. The CPM is responsible for informing Arcadis and/or Subcontractor personnel of omissions and/or deviations from this document that may be required for the project. In turn, project staff are required to inform the CPM if or when there is a deviation or omission from work performed as compared to what is described herein.

In following this document to execute the scope of work for a project, it may be necessary for staff to make professional judgment decisions to meet the project's scope of work based upon site conditions, staffing expertise, state-specific requirements, health and safety concerns, etc. Staff are required to consult with the CPM when or if a deviation or omission from this document is required that has not already been previously approved by the CPM. Upon approval by the CPM, the staff can perform the deviation or omission as confirmed by the CPM.

2 SCOPE AND APPLICATION

The objective of this Technical Guidance Instruction (TGI) is to describe the procedures to manage investigation-derived wastes (IDW), both hazardous and nonhazardous, generated during site activities, which may include, but are not limited to: drilling, trenching/excavation, construction, demolition, monitoring well sampling, soil sampling, decontamination and remediation. For the purposes of this TGI, IDW is considered to be discarded materials which are defined as solid waste by United States Environmental Protection Agency (EPA) standard 40 CFR § 261.2 (which may include liquids, solids, or sludges). IDW may include soil, groundwater, drilling fluids, decontamination liquids, as well as contaminated personal protective equipment (PPE), sorbent materials, construction and demolition debris, and disposable sampling materials. Hazardous or uncharacterized IDW will be collected and staged at the point of generation. Quantities small enough to be containerized in 55-gallon drums will be taken to a designated temporary onsite storage area (discussed in further detail under Drum Storage) pending characterization and disposal. IDW materials will be characterized using process knowledge and appropriate laboratory analyses to determine the waste classification and evaluate proper safe handling and disposal methods.

This TGI describes the necessary equipment, field procedures, materials, regulatory references, and documentation procedures necessary for proper handling and storage of IDW up to the time it is properly transported from the project site and disposed. The procedures included in this TGI for handling and temporary storage of IDW are based on the EPA's guidance document *Guide to Management of Investigation Derived Wastes* (USEPA, 1992). IDW is assumed to be contaminated with the site constituents of concern (COCs) until analytical evidence indicates otherwise. IDW will be managed to ensure the protection of human health and the environment and will comply with all applicable or relevant and appropriate requirements (ARAR). Although not comprehensive, the following laws and regulations on Hazardous Waste Management should be considered as potential ARAR. It is the Arcadis Certified Project Manager (CPM) and/or designated Technical Expert to determine which laws and regulations, at all levels of government, are applicable to each project site and activity falling under this TGI.

Federal Laws and Regulations

- Resource Conservation and Recovery Act (RCRA) 42 USC § 6901-6987.
- Federal Hazardous Waste Regulations 40 CFR § 260-265

Department of Transportation (DOT) Hazardous Materials Transportation 49 CFR

Occupational Safety and Health Administration (OSHA) Regulations 29 CFR

State Laws and Regulations

- To be determined based on location of site and location of treatment, storage, and/or disposal facility (TSDF) to be utilized.

Regional, County, Municipal, and Local Regulations

- To be determined based on location of site and location of treatment, storage, and/or disposal facility (TSDF) to be utilized.

Initial Storage

Pending characterization, IDW will be temporarily stored appropriately within each area of contamination (AOC). Under RCRA, "storage" is defined as the "holding of hazardous waste for a temporary period, at the end of which the hazardous waste is treated, disposed of, or stored elsewhere" (40 CFR § 260.10). The onsite waste staging area will be in a secure and controlled area. Uncharacterized wastes are considered potentially hazardous wastes and must be stored in DOT approved packaging. Liquid wastes must be stored in DOT approved closed head drums or other approved containers (e.g., portable tank containers) that are compatible with the type of material stored therein. Solid materials must be stored in DOT approved open head drums where practicable. Larger quantities of solid IDW can be containerized in bulk containers (such as in a roll-off box). Soil from large excavation projects may be managed in stockpiles with within the AOC and does not need to be containerized until exiting the AOC.

Characterization

Waste characterization can either be based on generator knowledge, such as using historical process knowledge and safety data sheets (SDS), or can be based upon characterization sampling analytical results. IDW typically is not characterized using SDS as it is a mixture of aged chemicals and environmental media. Historical process knowledge should be used to determine if the IDW is a listed hazardous waste (40 CFR § 261.31-33). If the IDW is not a listed hazardous waste, waste characterization can be completed by laboratory analysis of representative samples of the IDW. The laboratory used for waste characterization analysis must have the appropriate state and federal accreditations and may be required to be pre-approved by the Client. IDW will be classified as RCRA hazardous or non-regulated under RCRA based on the waste characterization determination.

If IDW is characterized as RCRA hazardous waste, RCRA and DOT requirements must be followed for packaging, labeling, transporting, storing, and record keeping as described in 40 CFR § 262 and 49 CFR § 171-178. Waste material classified as RCRA nonhazardous may be handled and disposed of as nonhazardous waste in accordance with applicable federal, state, and local regulations.

Storage Time Limitations

Containerized hazardous wastes can be temporarily stored for a maximum of 90 calendar days from the accumulation start date for a large quantity generator or a maximum of 180 calendar days from the accumulation start date for a small quantity generator. Wastes classified as nonhazardous may be handled and disposed of as nonhazardous waste and are not subject to storage time limitations.

This is TGI may be modified by the CPM and/or Technical Expert for a specific project or client program, as required, dependent upon client requirements, site conditions, equipment limitations, or limitations imposed by the procedure. The resulting procedure employed to execute the work will be documented in the project work plans or reports. If changes to the sampling procedures are required due to unanticipated field conditions, the changes will be discussed with the CPM and/or Technical Expert as soon as practicable, and if approved to be performed, be documented.

3 PERSONNEL QUALIFICATIONS

Arcadis field sampling personnel will have current regulatory- and Arcadis-required health and safety training including 40-hour HAZWOPER training, site supervisor training, site-specific training, first aid, and cardiopulmonary resuscitation (CPR), as needed. Personnel handling and packaging hazardous waste and performing hazardous waste characterizations must have RCRA hazardous waste management training per 40 CFR § 264.16. Additional state-specific hazardous waste management training is required in certain states (i.e., California).

Although not common practice, in certain situations Arcadis personnel may sign waste profiles and/or waste manifests on a case by case basis for clients, provided the appropriate agreement is in place between Arcadis and the client documenting that Arcadis is not the generator, but is acting as an authorized representative of the generator. Arcadis personnel who sign waste profiles and/or waste manifests will have both current RCRA hazardous waste management training per 40 CFR § 264.16 and current DOT hazardous materials transportation training per 49 CFR § 172.704. Arcadis field personnel will also comply with client-specific training. In addition, Arcadis field sampling personnel will be knowledgeable in the relevant processes, procedures, and Technical Guidance Instructions (TGIs) and possess the demonstrated required skills and experience necessary to successfully complete the desired field work. The project health and safety plan (HASP) and other documents will identify other training requirements or access control requirements.

4 EQUIPMENT LIST

The Following Materials, as required, will be available for IDW handling and Storage:

- Appropriate personal protective equipment as specified in the Site Health and Safety Plan (HASP)
- DOT approved containers
- Hammer
- Leather gloves
- Drum dolly
- Appropriate drum labels (outdoor waterproof self-adhesive)
- Portable tank container
- Appropriate labeling, packing, chain-of-custody forms, and shipping materials as determined by the CPM and/or Technical Expert.
- Indelible ink and/or permanent marking pens
- Plastic sheeting
- Appropriate sample containers, labels, and forms
- Stainless-steel bucket auger
- Stainless steel spatula or knife
- Stainless steel hand spade
- Stainless steel scoop
- Digital camera
- Field logbook

5 CAUTIONS

Filled drums can be very heavy, become unbalanced, or spill its contents. Therefore, use appropriate moving techniques and equipment for safe handling. Similar media (e.g. soils with other soils; or liquids with other liquids) will be stored in the same drums to aid in sample analysis and disposal. Drum lids must be secured to prevent rainwater from entering the drums and leakage during movement. Drums containing solid material may not contain any free liquids. Waste containers stored for extended periods of time may be subject to deterioration. Drum Over Packs may be used as secondary containment. All drums must be visually inspected for condition to ensure that they are in good condition without visible evidence of rusting, holes, breakage, etc., to prevent potential leakage and facilitate subsequent disposal. All drum lids must be verified as having a properly functioning secured lid prior to use.

6 HEALTH AND SAFETY CONSIDERATIONS

As determined by the site's known and suspected hazards, appropriate PPE must be worn by all field personnel within the designated work area. Exposure air monitoring may be required during certain field activities as required in the Site Health and Safety Plan. If soil excavation in areas with potentially hazardous contaminants is possible, contingency plans will be developed to address the potential for encountering gross contamination or non-aqueous phase liquids. All excavation activities shall be in compliance with OSHA standard 29 CFR 1926.651 Excavations, and any other applicable regulations.

Arcadis field personnel and subcontractors will be trained in and perform their work in compliance with all applicable federal, state, and local health and safety regulations as well as Arcadis' HASP and applicable Client health and safety requirements.

7 PROCEDURE

Specific waste temporary storage and handling procedures to be used are dependent upon the type of generated waste, including type of media (e.g. soils or free liquids) and constituents of concern. For this reason, IDW can be stored in a secure location onsite in separate 55-gallon storage drums, where solids can be stockpiled onsite (if nonhazardous) and purge water may be stored in portable tank containers. Waste materials such as broken sample bottles or equipment containers and wrappings will be stored in 55-gallon drums unless they were not in contact with sample media.

Management of IDW

Minimization of IDW should be considered by the project team during all phases of the project. Site managers may want to consider techniques such as replacing solvent based cleaners with aqueous-based cleaners for decontamination of equipment, reuse of equipment (where it can be properly decontaminated), limitation of traffic between exclusion and support zones, and drilling methods and sampling techniques that minimize the generation of waste. Alternative drilling and subsurface sampling methods may include the use of small diameter boreholes, as well as borehole testing methods such as a core penetrometer or direct push technique instead of coring.

Drum Storage

Drums containing hazardous waste will be stored in accordance with the requirements of 40 CFR 265 Subpart I (for containers) and 265 Subpart DD (for containment buildings). All 55-gallon drums will be stored at a secure, centralized onsite location that is readily accessible for vehicular pick-up. Drums confirmed as, or assumed to contain hazardous waste will be stored over an impervious surface provided with secondary spill containment. The storage location will, for drums containing liquid, have a containment system that can contain at least the larger of 10% of the aggregate volume of staged materials or 100% of the volume of the largest container. Drums will be closed during storage and be in good condition in accordance with the Guide to Management of Investigation-Derived Wastes (USEPA, 1992).

Hazardous Waste Determination

Waste material must be characterized to determine if it meets any of the federal definitions of hazardous waste as required by 40 CFR § 262.11. If the waste does not meet any of the federal definitions, it must then be established if any state-specific or local-specific hazardous waste criteria exist/apply.

Generator Status

Once hazardous waste determination has been made, the generator status will be determined. Large quantity generators (LQG) are generators who generate more than 1,000 kilograms of hazardous waste in a calendar month. Small quantity generators (SQG) of hazardous waste are generators who generate greater than 100 kilograms but less than 1,000 kilograms of hazardous waste in a calendar month. Very small quantity generators (VSQG) are generators who generate less than 100 kilograms of hazardous waste per month. Please note that a generator status may change from month to month and that a notice of this change is usually required by the generator's state agency.

Accumulation Time for Hazardous Waste

A LQG may accumulate hazardous waste on site for 90 calendar days or less without a permit and without having interim status, provided that such accumulation is in compliance with requirements in 40 CFR § 262.17. A SQG may accumulate hazardous waste on site for 180 calendar days or less without a permit or without having interim status, subject to the requirements of 40 CFR § 262.16. VSQG requirements are found in 40 CFR § 262.14. NOTE: The federal VSQG and SQG provisions may not be recognized by some states (e.g., California and Rhode Island). State-specific and local-specific regulations must be reviewed and understood prior to the generation of hazardous waste.

Satellite Accumulation of Hazardous Waste Satellite accumulation (SAA) will mean the accumulation of as much as fifty-five (55) gallons of hazardous waste, or the accumulation of as much as one quart of acutely hazardous waste, in containers at or near any point of generation where the waste initially accumulates, which is under the control of the operator of the process generating the waste, without a permit or interim status and without complying with the requirements of 40 CFR § 262.15 and without any storage time limit, provided that the generator complies with 40 CFR § 262.15.

Once more than 55 gallons of hazardous waste accumulates in SAA, the generator has three days to move this waste into storage.

Storage recommendations for hazardous waste include:

- Ignitable or reactive hazardous wastes must be >50 feet from the property line per 40 CFR § 265.176 (LQG generators only).
- Hazardous waste should be stored on a concrete slab (asphalt is acceptable if there are no free liquids in the waste).
- Drainage must be directed away from the accumulation area.
- Area must be properly vented.
- Area must be secure.

Drum/Container Labeling

Drums will be labeled on both the side and lid of the drum using a permanent marking pen. Old drum labels must be removed to the extent possible, descriptions crossed out should any information remain, and new labels affixed on top of the old labels. Other containers used to store various types of waste (e.g., polyethylene tanks, roll-off boxes, end-dump trailers, etc.) will be labeled with an appropriate "Waste Container" or “Testing in Progress” label pending characterization. Drums and containers will be labeled as follows:

- Appropriate waste characterization label (Pending Analysis, Hazardous, or Nonhazardous)
- Waste generator's name (e.g., client name)
- Project Name
- Name and telephone number of Arcadis project manager
- Composition of contents (e.g., used oil, acetone 40%, toluene 60%)
- Media (e.g., solid, liquid)
- Accumulation start date

- Drum number of total drums as reconciled with the Drum Inventory maintained in the field log book.

IDW containers will remain closed except when adding or removing waste. Immediately upon beginning to place waste into the drum/container, a “Waste Container” or “Pending Analysis” label will be filled out to include the information specified above, and affixed to the container. Once the contents of the container are identified as either non-hazardous or hazardous, the following additional labels will be applied.

- Containers with waste determined to be non-hazardous will be labeled with a green and white "Nonhazardous Waste" label over the "Waste Container" label.
- Containers with waste determined to be hazardous will be stored in an onsite storage area and will be labeled with the "Hazardous Waste" label and affixed over the "Waste Container" label.

The ACCUMULATION DATE for the hazardous waste is the date the waste is first placed in the container and is the same date as the date on the "Waste Container" label. DOT hazardous class labels must be applied to all hazardous waste containers for shipment offsite to an approved disposal or recycling facility. In addition, a DOT proper shipping name will be included on the hazardous waste label. The transporter should be equipped with the appropriate DOT placards. However, placarding or offering placards to the initial transporter is the responsibility of the generator per 40 CFR § 262.33.

Inspections and Documentation

All IDW will be documented as generated on a Drum Inventory Log maintained in the field log book. The Drum Inventory will record the generation date, type, quantity, matrix and origin (e.g., Boring-1, Test Pit 3, etc.) of materials in every drum, as well as a unique identification number for each drum. The drum inventory will be used during drum pickup to assist with labeling of drums. The drum storage area and any other areas of temporarily staged waste, such as soil/debris piles, will be inspected weekly. The weekly inspections will be recorded in the field notebook or on a Weekly Inspection Log. Digital photographs will be taken upon the initial generation and drumming/staging of waste, and final labeling after characterization to document compliance with labeling and storage protocols, and condition of the container. Evidence of damage, tampering or other discrepancy should be documented photographically.

Emergency Response and Notifications

Specific procedures for responding to site emergencies will be detailed in the HASP. If the generator is designated as a LQG, a Contingency Plan will need to be prepared to include emergency response and notification procedures per 40 CFR § 265 Subpart D. In the event of a fire, explosion, or other release which could threaten human health outside of the site or when Client or Arcadis has knowledge of a spill that has reached surface water, Client or Arcadis must immediately notify the National Response Center (800-424-8802) in accordance with 40 CFR § 262.265. Other notifications to state and/or other local regulatory agencies may also be necessary.

Drilling Soil Cuttings and Muds

Soil cuttings are solid to semi-solid soils generated during trenching activities, subsurface soil sampling, or installation of monitoring wells. Depending on the drilling method, drilling fluids known as "muds" may be used to remove soil cuttings. Drilling fluids flushed from the borehole must be directed into a settling section of a mud pit. This allows reuse of the decanted fluids after removal of the settled sediments. Soil cuttings will be labeled and stored in 55-gallon drums with bolt-sealed lids.

Excavated Solids

Excavated solids may include, but are not limited to: soil, fill, and construction and demolition debris. Prior to permitted treatment or offsite disposal, potentially hazardous excavated solids may be temporarily stockpiled onsite as long as the stockpile remains in the same AOC from where it was excavated. Potentially hazardous excavated solids removed from the AOC must be immediately containerized in labeled drums or closable top roll-offs lined with 9-mil polyvinyl chloride (PVC) sheeting and are subject to LQG storage time limits. Nonhazardous excavated solids can be stockpiled either inside or outside of the AOC, do not have to be containerized and are not subject to hazardous waste regulations. Potentially hazardous excavated solids must not be mixed with nonhazardous excavated solids. All classes of excavated solid stockpiles should be maintained in a secure area onsite. At a minimum, the floor of the stockpile area will be covered with a 20-mil high density polyethylene liner that is supported by a foundation or at least a 60-mil high density polyethylene liner that is not supported by a foundation. The excavated material will not contain free liquids. The owner/operator will provide controls for windblown dispersion, run-on control, and precipitation runoff. The run-on control system will prevent flow onto the active portion of the pile during peak discharge from at least a 25-year storm and the run-off management system will collect and control at least the water volume resulting from a 24-hour, 25-year storm (USEPA, 1992). Additionally, the stockpile area will be inspected on a weekly basis and after storm events. Individual states may require that the stockpile be inspected/certified by a licensed professional engineer. Stockpiled material will be covered with a 6-mil polyvinyl chloride (PVC) liner or sprayed dust control product. The stockpile cover will be secured in place with appropriate material (concrete blocks, weights, etc.) to prevent the movement of the cover.

Decontamination Solutions

Decontamination solutions are generated during the decontamination of personal protective equipment and sampling equipment. Decontamination solutions may range from detergents, organic solvents and acids used to decontaminate small field sampling equipment to steam cleaning rinsate used to wash heavy field equipment. These solutions are to be labeled and stored in closed head drums compatible with the decontamination solution. Decontamination procedures, including personnel and field sampling equipment, must comply with applicable Arcadis procedural documents.

Disposable Equipment

Disposable equipment includes personal protective equipment (e.g., tyvek coveralls, gloves, booties and APR cartridges) and disposable sampling equipment such as trowels or disposable bailers. If the media sampled exhibits hazardous characteristics per results of waste characterization sampling, contaminated disposable equipment will also be disposed of as a hazardous waste. If compatible with the original IDW waste stream (i.e., the IDW is a solid and the disposal equipment is a solid), the disposable equipment can be combined with the IDW. If these materials are not compatible (i.e., the IDW is a liquid and the disposal equipment is a solid), the disposable equipment will be stored onsite in separate labeled 55-gallon drums. Uncontaminated or decontaminated disposable equipment can be considered nonhazardous waste.

Purge Water

Purge water includes groundwater generated during well development, groundwater sampling, or aquifer testing. The volume of groundwater generated will dictate the appropriate storage procedure. Monitoring well development and groundwater sampling may generate three well volumes of groundwater or more. This volume will be stored in labeled 55-gallon drums. Aquifer tests may generate significantly greater volumes of groundwater depending on the well yield and the duration of the test. Therefore, large-volume portable polyethylene tanks will be considered for temporary storage pending groundwater-waste characterization.

Purged Water Storage Tank Decontamination and Removal

The following procedures will be used for inspection, cleaning, and offsite removal of storage tanks used for temporary storage of purge water. These procedures are intended to be used for rented portable tanks such as Baker Tanks or Rain for Rent containers. Storage tanks will be made of inert plastic materials. The major steps for preparing a rented tank for return to a vendor include characterizing the purge water, disposing of the purge water, decontaminating the tank, final tank inspection, and mobilization. Decontamination and inspection procedures are described in further detail below.

- Tank Cleaning: Most vendors require that tanks be free of any visible sediment and water before returning, a professional cleaning service may be required. Each specific vendor should be consulted concerning specific requirements for returning tanks.
- Tank Inspection: After emptying the tank, purged water storage tanks should be inspected for debris, chemical staining, and physical damage. The vendors require that tanks be returned in the original condition (i.e., free of sediment, staining and no physical damage).

8 WASTE MANAGEMENT

Soil/Solids Characterization

Waste characterization will be conducted in accordance with waste hauler, waste handling facility, and local/state/federal requirements. In general, RCRA hazardous wastes are those solid wastes determined by a Toxicity Characteristic Leaching Procedure (TCLP) test or to contain levels of certain toxic metals, pesticides, or other organic chemicals above specific applicable regulatory agency thresholds. If the one or more of 40 toxic compounds listed in Table I of 40 CFR § 261.24 are detected in the sample at levels above the maximum unregulated concentrations, the waste must be characterized as a toxic hazardous waste. Wastes can also be considered “listed” hazardous waste depending on site-specific processes.

Composite soil samples will be collected at a frequency of one sample per 250 cubic yard basis for stockpiled soil or one per 55-gallon drum per different waste stream for containerized. A four-point composite sample will be collected per 250 cubic yards of stockpiled material and for each drum waste stream. Sample and composite frequencies may be adjusted in accordance with the waste handling facility’s requirements and may be reduced for large volumes of waste with consistent properties. Waste characterization samples will be considered valid for consistent waste streams for a period of 1 year. Waste characterization samples may be analyzed for the TCLP volatile organic compounds (VOCs), TCLP semi-volatile organic compounds (SVOCs), TCLP RCRA metals, and polychlorinated biphenyls (PCBs), as well as reactivity and flammability (flashpoint). Additional samples may be collected and analyzed by the laboratory on a contingency basis. Site-specific constituents of concern including pesticides may require additional sampling. Please note that state- or local-specific regulations may require a different or additional sampling approaches.

Wastewater Characterization

Waste characterization will be conducted in accordance with the requirements of the waste hauler, waste handling facility, and local/state/federal governments. In general, purge water should be analyzed by methods appropriate for the known contaminants, if any, that have been historically detected in the monitoring wells. Samples will be collected and analyzed in accordance with the requirements of the waste disposal facility. Wastewater characterization samples may be analyzed for TCLP volatile organic compounds (VOCs), TCLP semi-volatile organic compounds (SVOCs), TCLP RCRA metals, and polychlorinated biphenyls, as well as corrosivity (pH), reactivity and flammability (flashpoint). Additional samples may be collected and analyzed by the laboratory on a contingency basis. Site-specific constituents of concern including pesticides may require additional sampling. Please note that state- and/or local-specific regulations may require different or additional sampling approaches.

Sample Handling and Shipping

All samples will be appropriately labeled, packed, and shipped, and the chain-of-custody will be filled out in accordance with current Arcadis sample chain of custody, handling, packing, and shipping procedures and guidance instructions.

It should be noted that additional training is required for packaging and shipping of hazardous and/or dangerous materials. Please refer to the current Arcadis training requirements related to handling and shipping of samples, shipping determinations, and hazardous materials.

Preparing Waste Shipment Documentation (Hazardous and Nonhazardous)

Waste profiles will be prepared by the Arcadis CPM and forwarded, along with laboratory analytical data to the Client for approval/signature. The Client will then return the profile to Arcadis who will then forward to the waste removal contractor for preparation of a manifest. The manifest will be reviewed by Arcadis prior to forwarding to the Client for approval. Upon approval of the manifest, the Client will return the original signed manifest directly to the waste contractor or to the Arcadis CPM for forwarding to the waste contractor. Arcadis personnel may sign waste profiles and/or waste manifests on a case by case basis for clients, provided the appropriate agreement is in place between Arcadis and the client documenting that Arcadis is not the generator, but is acting as an authorized representative of the generator.

Final drum labeling and pickup will be supervised by an Arcadis representative who is trained and experienced with applicable waste labeling procedures. The Arcadis representative will have a copy of the drum inventory maintained in the field book and will reconcile the drum inventory with the profile numbers on the labels and on the manifest. Different profile numbers will be generated for different matrices or materials in the drums. For example, the profile number for drill cuttings will be different than the profile number for purge water. When there are multiple profiles it is critical that the proper label, with the profile number appropriate to a specific material be affixed to the proper drums. A copy of the Arcadis drum inventory will be provided to the waste transporter during drum pickup and to the facility receiving the waste.

9 DATA RECORDING AND MANAGEMENT

Waste characterization sample handling, packing, and shipping procedures will be documented in accordance with relevant Arcadis procedures and guidance instructions as well as applicable client and/or project requirements, such as a Quality Assurance Project Plan or Sampling and Analysis Plan. Copies of the chain-of-custody forms will be maintained in the project file. Arcadis should photograph or maintain a copy of any hazardous waste manifest signed on behalf of Client in the corresponding office DOT record file.

10 QUALITY ASSURANCE

The CPM or APM will review all field documentation once per week for errors or omissions as compared to applicable project requirements including but not limited to: the proposal/scope of work, QAPP, SAP, HASP, etc. Deficiencies will be noted, tracked, and resolved. Upon correction, they will be noted for project documentation.

11 REFERENCES

United States Environmental Protection Agency (USEPA). 1992. Guide to Management of Investigation-Derived Wastes. Office of Remedial and Emergency Response. Hazardous Site Control Division. January 1992.

TGI – GROUNDWATER AND SOIL SAMPLING EQUIPMENT DECONTAMINATION

Rev: 1

Rev Date: May 8, 2020

VERSION CONTROL

Revision No	Revision Date	Page No(s)	Description	Reviewed by
0	February 23, 2017	ALL	Conversion from SOP to TGI	Cassandra McCloud / Pete Frederick
1	May 8, 2020	4-5	Added note regarding use of Liquinox and 1,4-Dioxane	Marc Killingstad

APPROVAL SIGNATURES

Prepared by: Derrick Maurer Date: 02/23/2017

Derrick Maurer

Technical Expert Reviewed by: Date: May 8, 2020

Marc Killingstad (Technical Expert)

1 INTRODUCTION

This document describes general and/or specific procedures, methods, actions, steps, and considerations to be used and observed by Arcadis staff when performing work, tasks, or actions under the scope and relevancy of this document. This document may describe expectations, requirements, guidance, recommendations, and/or instructions pertinent to the service, work task, or activity it covers.

It is the responsibility of the Arcadis Certified Project Manager (CPM) to provide this document to the persons conducting services that fall under the scope and purpose of this procedure, instruction, and/or guidance. The Arcadis CPM will also ensure that the persons conducting the work falling under this document are appropriately trained and familiar with its content. The persons conducting the work under this document are required to meet the minimum competency requirements outlined herein, and inquire to the CPM regarding any questions, misunderstanding, or discrepancy related to the work under this document.

This document is not considered to be all inclusive nor does it apply to any and all projects. It is the CPM’s responsibility to determine the proper scope and personnel required for each project. There may be project- and/or client- and/or state-specific requirements that may be more or less stringent than what is described herein. The CPM is responsible for informing Arcadis and/or Subcontractor personnel of omissions and/or deviations from this document that may be required for the project. In turn, project staff are required to inform the CPM if or when there is a deviation or omission from work performed as compared to what is described herein.

In following this document to execute the scope of work for a project, it may be necessary for staff to make professional judgment decisions to meet the project’s scope of work based upon site conditions, staffing expertise, state-specific requirements, health and safety concerns, etc. Staff are required to consult with the CPM when or if a deviation or omission from this document is required that has not already been previously approved by the CPM. Upon approval by the CPM, the staff can perform the deviation or omission as confirmed by the CPM.

2 SCOPE AND APPLICATION

Decontamination is performed on sampling equipment prior to sample collection to ensure that the sampling equipment that contacts a sample, or monitoring equipment that is brought into contact with environmental media to be sampled, is free from analytes of interest and/or constituents that could interfere with laboratory analysis for analytes of interest. Sampling equipment must be appropriately cleaned prior to use for sampling or coming into contact with environmental media to be sampled, and following completion of the sampling event prior to shipment or storage. The effectiveness of the decontamination procedure should be verified by collecting and analyzing equipment blank samples.

The sampling equipment cleaning procedures described herein includes pre-field, in the field, and post-field cleaning of sampling equipment which may be conducted at an established equipment decontamination area (EDA) on site, as appropriate and necessary. Sampling equipment that may require decontamination at a given site includes: soil sampling tools; groundwater, sediment, and surface-water sampling devices; water testing instruments; down-hole instruments; and other activity-specific sampling equipment. Non-disposable equipment will be cleaned before collecting each sample, between each sample collected, and prior to placing sampling equipment in protective cases, or containers for transport. Cleaning procedures for sampling equipment should be monitored by collecting equipment blank samples as required in project work plans, field sampling plans, quality assurance project plans (QAPP), or other pertinent project documents. Dedicated and/or single-use (i.e., not to be re-used) sampling equipment will not require decontamination.

3 PERSONNEL QUALIFICATIONS

Arcadis field sampling personnel will have completed or are in the process of completing site-specific training as well as having current health and safety training as required by Arcadis, client, or regulations, such as 40-hour HAZWOPER training and/or OSHA HAZWOPER site supervisor training. Arcadis personnel will also have current training as specified in the Health and Safety Plan (HASP) which may include first aid, cardiopulmonary resuscitation (CPR), Blood Borne Pathogens (BBP) as needed. In addition, Arcadis field sampling personnel will be knowledgeable in the relevant processes, procedures, and Technical Guidance Instructions (TGIs) and possess the demonstrated required skills and experience necessary to successfully complete the desired field work. The project health and safety plan (HASP) and other documents will identify other training requirements or access control requirements.

4 EQUIPMENT LIST

The equipment required for equipment decontamination is presented below:

- Health and safety equipment, including appropriate PPE, as required in the site Health and Safety Plan (HASP)
- Deionized water that meets that analytical criteria for deionized water with no detectable constituents above the reporting limits for the methods to be used and analytes being analyzed for. Deionized water is used for inorganics, and organic-free water for VOCs, SVOCs, pesticides, etc.
- Non-phosphate detergent such as Alconox or, if sampling for phosphorus or phosphorus-containing compounds, Liquinox (or equivalent). NOTE: *Liquinox has shown to provide false positives for 1,4-Dioxane and should not be used at sites where that may be a constituent of concern (COC).*
- Tap water
- Rinsate collection plastic containers
- DOT-approved waste shipping container(s), as specified in the work plan, field sampling plan, or regulatory requirements if decontamination waste is to be shipped for disposal
- Brushes
- Large heavy-duty garbage bags
- Spray bottles

- (Optional) – Isopropyl alcohol (free of ketones) or methanol. These can be wipes or diluted with water (usually 1part isopropyl/methanol to 10 parts water) if a spray is needed.
- Airtight, sealable plastic baggies, such as Ziploc-type
- Plastic sheeting

5 CAUTIONS

Rinse equipment thoroughly and allow the equipment to dry before re-use or storage to prevent introducing solvent into sample medium. If manual drying of equipment is required, use clean lint-free material to wipe the equipment dry. Ensure all rinsate materials do not adversely affect sample collection efficiency or analytical results.

Store decontaminated equipment in a clean, dry environment. Do not store near combustion engine exhausts. Properly containerize equipment to ensure cross-contamination doesn't happen from other uncontaminated surfaces or equipment.

If equipment is damaged to the extent that decontamination is uncertain due to cracks, gouges, crevices, or dents, the equipment should not be used and should be discarded or submitted for repair prior to use for sample collection.

A proper shipping determination regarding hazardous materials will be performed by a DOT-trained individual for cleaning materials shipped by Arcadis.

Caution should be exercised to avoid contact with the pump casing and water in the container while the pump is running (do not use metal drums or garbage cans) to avoid electric shock.

6 HEALTH AND SAFETY CONSIDERATIONS

Review the safety data sheets (SDS) for the cleaning agents and materials used in decontamination. If solvent is used during decontamination, use appropriate PPE and work in a well-ventilated area and stand upwind while applying solvent to equipment. Apply solvent in a manner that minimizes potential for exposure to workers and bystanders. Follow health and safety procedures outlined in the HASP.

7 PROCEDURE

A designated area will be established to clean sampling equipment in the field prior to and following sample collection. Equipment cleaning areas will be set up within or adjacent to the specific work area, but not at a location that expose equipment to contamination (i.e. exposed to combustion engine exhaust). Detergent solutions will be prepared in clean containers for use in equipment decontamination. Decontaminated equipment should be handled by workers wearing clean gloves, properly changed to prevent cross-contamination.

Cleaning Sampling Equipment

1. Wash the equipment/pump with potable water.

2. Wash with detergent solution (Alconox, Liquinox or equivalent) to remove all visible particulate matter and any residual oils or grease. NOTE: *Liquinox has shown to provide false positives for 1,4-Dioxane and should not be used at sites where that may be a constituent of concern (COC).*

3. If equipment is very dirty, precleaning gross debris with a brush and tap water may be necessary.

4. If non-aqueous phase liquids are present, the use of isopropyl alcohol (free of ketones) or methanol is recommended. Cloth wipes or diluted solution can be used to remove the non-aqueous phase liquids that are hard to remove with detergent solution in step 2. Consult with project manager if non-aqueous phase liquids are present onsite and design an appropriate decontamination procedure that includes step 4.

5. Rinse with deionized water.

Decontaminating Submersible Pumps

Submersible pumps may be used during well development, groundwater sampling, or other investigative activities. The pumps must be cleaned and flushed before and between uses. This cleaning process will consist of an external detergent solution wash and tap water rinse, a flush of detergent solution through the pump, followed by a flush of potable water through the pump. Flushing will be accomplished by using an appropriate container filled with detergent solution and another container filled with potable water. The pump should be flushed with deionized water as the last step prior to use. The pump will run long enough to effectively flush the pump housing and hose (unless new, disposable hose is used). Disconnect the pump from the power source before handling. The pump and hose should be placed on or in clean polyethylene sheeting to avoid contact with the ground surface.

8 WASTE MANAGEMENT

Equipment decontamination rinsate will be managed in conjunction with all other waste produced during the field sampling effort. Waste management procedures are outlined in the work plan or Waste Management Plan (WMP).

9 DATA RECORDING AND MANAGEMENT

Equipment cleaning and decontamination will be noted in the field notebook for project documentation. Information will include the type of equipment cleaned, the decontamination location, specific procedures utilized, solvents and/or cleaning agents used, source of water, and deviations or omissions from this TGI.

Unusual field conditions should be noted if there is potential to impact the efficacy of the decontamination or subsequent sample collection.

An inventory of the solvents brought on site and used and removed from the site will be maintained in the project documentation. Records will be maintained for solvents used in decontamination, including lot number and expiration date.

Containers with decontamination fluids will be labeled.

10 QUALITY ASSURANCE

Equipment blanks should be collected to verify that the decontamination procedures are effective in minimizing potential for cross contamination. The equipment blank is prepared by pouring deionized water (or organic-free water, for organic analyses) over the clean and dry tools and collecting the water into appropriate sample containers. Equipment blanks should be analyzed for the same set of parameters that are performed on the field samples collected with the equipment that was cleaned as specified in the sampling and analysis plan. Equipment blanks are collected per equipment set, which represents all of the tools needed to collect a specific sample.

11 REFERENCES

USEPA Region 9 - Field Sampling Guidance #1230, Sampling Equipment Decontamination.

USEPA Region 1 - Low Stress (low flow) Purging and Sampling Procedure for the Collection of Groundwater Samples from Monitoring Wells.

TGI – Soil Description

Rev: 3.0

Rev Date: April 15, 2022

Version Control

Issue	Revision No.	Date Issued	Page No.	Description	Reviewed By
	0	May 20, 2008	17	Original SOP	Joe Quinnan Joel Hunt
	1	September 2016	15	Updated to TGI	Nick Welty Patrick Curry
	2	February 16, 2018	15	Updated descriptions, attachments and references in text	Nick Welty Patrick Curry
	3	April 15, 2022		Minor description edits, intro of grain-size K analysis, revised boring log template	Matt McCaughey Patrick Curry

Approval Signatures

Prepared by: 4/15/2022

Matthew C. McCaughey

Matthew C. McCaughey, PG (Preparer) Date

Reviewed by: 4/15/2022

Patrick Curry, PG (Subject Matter Expert) Date

1 Introduction

This Arcadis Technical Guidance Instruction (TGI) describes proper soil description procedures based on visual inspection and testing of soil cores and samples. This document has been developed to emphasize field observation and documentation of details required to:

- Make hydrostratigraphic interpretations guided by depositional environment/geologic settings
- Provide information needed to understand the distribution of constituents of concern; properly design wells, piezometers, and/or additional field investigations; and develop appropriate remedial strategies.

2 Intended Use and Responsibilities

This document describes general and/or specific procedures, methods, actions, steps, and considerations to be used and observed by Arcadis staff when performing work, tasks, or actions under the scope and relevancy of this document. This document may describe expectations, requirements, guidance, recommendations, and/or instructions pertinent to the service, work task, or activity it covers.

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3 Scope and Application

This TGI should be followed for unconsolidated material unless there is an established client-required specific procedure or regulatory-required specific procedure. In cases where there is a required specific procedure, it should be followed and should be referenced and/or provided as an appendix to reports that include soil classifications and/or boring logs. When following a required non-Arcadis procedure, additional information required by this TGI should be included in field notes with client approval.

This TGI incorporates elements from various standard systems such as ASTM D2488-06, Unified Soil Classification System, Burmister and Udden Wentworth. However, none of these standard systems focus specifically on contaminant hydrogeology and remedial design. Therefore, although each of these systems contain valuable guidance and information related to correct descriptions, strict application of these systems can omit information critical to our clients and the projects that we perform.

This TGI includes the following attachments:

- **Attachment A –** Field Soil Description Guide
- **Attachment B –** Particle Size System Comparison
- **Attachment C –** Description of Logging Terms
- **Attachment D –** Blank Boring Log
- **Attachment E –** Completed Boring Log

This TGI does not address details of health and safety; drilling method selection; boring log preparation; sample collection; or laboratory analysis. Refer to other Arcadis procedure, guidance, and instructional documents, the project work plans including the quality assurance project plan, sampling plan, and health and safety plan (HASP), as appropriate.

4 Personnel Qualifications

Soil descriptions should only be performed by Arcadis personnel or authorized sub-contractors with a degree in geology or a geology-related discipline. Field personnel will complete training on the Arcadis soil description TGI in the office and/or in the field under the guidance of an experienced field geologist with at least 2 years of prior experience applying the Arcadis soil description method.

5 Equipment List

The following equipment should be taken to the field to facilitate soil descriptions:

- Field book, field forms or digital devices to record soil descriptions
- Field book for supplemental notes
- This TGI for Soil Descriptions and any project-specific procedure, guidance, and/or instructional documents (if required)
- Field card showing Wentworth scale
- Munsell® soil color chart
- Tape measure divided into tenths of a foot
- Stainless steel knife or spatula
- Hand lens
- Water squirt bottle
- 4-ounce glass jars with lids (for collecting soil core samples)
- Personal protective equipment (PPE), as required by the HASP
- Digital camera

- Folding table

6 Cautions

Drilling and drilling-related hazards including subsurface utilities are discussed in other procedure documents and site-specific HASPs and are not discussed herein.

Soil samples may contain hazardous substances that can result in exposure to persons describing soils. Routes for exposure may include dermal contact, inhalation and ingestion. Refer to the project specific HASP for guidance in these situations.

7 Health and Safety Considerations

Field activities associated with soil sampling and description will be performed in accordance with a site-specific HASP, a copy of which will be present on site during such activities. Know what hazardous substances may be present in the soil and understand their hazards. Always avoid the temptation to touch soils with bare hands, detect odors by placing soils close to your nose, or tasting soils.

8 Procedure

8.1 General Procedures

- Select the appropriate sampling method to obtain representative samples in accordance with the selected sub-surface exploration method, e.g., split-spoon or Shelby sample for hollow-stem drilling, acetate sleeves for direct push, bagged core for sonic drilling, etc.
- Proceed with field activities in required sequence. Although completion of soil descriptions is often not the first activity after opening sampler, identification of stratigraphic changes is often necessary to select appropriate intervals for field screening and/or selection of laboratory samples.
- Set up boring log field sheet.
    - Determine the proper units of measure. Drillers in both the US and Canada generally work in feet due to equipment specifications. Field geologists typically record drilling depths, core recovery, and sample intervals in feet and grain size in millimeters
    - Use the Arcadis standard boring log form (**Attachment D**). *Note that as of April 2022, several digital logging applications are available through the FieldNow™ program and the Fulcrum app. A future revision of this TGI, likely in early 2023, will emphasize digital logging methods and field boring log forms will no longer be acceptable. FieldNow is discussed further in Section 10.*
    - The boring log template includes a graphic log of the primary soil texture to support quick visual evaluation of grain size. The purpose of the graphic log is to quickly assess relative soil permeability. Note, for poorly sorted soils (e.g., glacial till), the principal component may not correlate to permeability of the sample. In this case, the geologist should use best judgement to graph overall soil type consistent with relative soil permeability. For example, for a dense sand/silt/clay till, the graphic log would reflect the silt/clay, rather than sand.

  - Record depths along the left-hand side at a standard scale to aid in the use of this tool.
- Examine each soil core (this is different than examining each sample selected for laboratory analysis) and record the soil conditions in accordance with guidelines provided in Section 8.2.
- At the end of the boring, record the amount of drilling fluid used (if applicable) and the total depth logged.
- At a minimum, a written or digital boring log should be prepared with the following information:
  - Describe type of surface material (asphalt, grass, topsoil, gravel, etc.)
  - Describe the type of fill or non-native soils and estimated depth to native soils
  - Record sample intervals (soil cores, environmental and/or geotechnical samples)
  - Describe soil conditions in accordance with this TGI
  - Record moisture content and estimated depth to water table or saturated zone
  - Record the total depth and document why drilling was stopped (refusal, target depth achieved, etc.)

8.2 Soil Description Procedures

The standard soil description order is presented below.

- Depth
- PRIMARY TEXTURE
- Principal and Minor Components with Descriptors
  - % Modifiers and grain size fraction
  - Angularity for very coarse sand and larger particles
  - Consistency or Density
  - Plasticity for silt and clay
  - Dilatancy for silt and silt-sand mixtures
- Sorting
- Moisture Content
- Color
- Notes

Depth. To measure and record the depth below ground surface (bgs) of top and bottom of each stratum, the following information should be recorded.

- Measured depth to the top and bottom of sampled interval. Use starting depth of sample based upon measured tool length information and the length of sample interval.
- Length of sample recovered, not including slough (material that has fallen into hole from previous interval), expressed as fraction with length of recovered sample as numerator over length of sampled interval as denominator (e.g., 36/60 for 36 inches recovered from 5-ft [60-inch] sampling interval).
- Thickness of each stratum measured sequentially from the top of recovery to the bottom of recovery.
- Any observations of sample condition or drilling activity that would help identify whether there was loss from the top of the sampling interval, loss from the bottom of the sampling interval, or compression of the sampling interval. Examples: 14/24, gravel in nose of spoon; or 36/60 bottom 12 inches of core empty.

Determination of Components. Obtain a representative sample of soil from a single stratum. If multiple strata are present in a single sample interval, each stratum should be described separately. More specifically, if the sample is from a 2-foot-long split-spoon where strata of coarse sand, fine sand and clay are present, then the resultant description should be of the three individual strata unless a combined description can clearly describe the interbedded nature of the three strata. Example: SAND, fine; with interbedded lenses of Silt and Clay, ranging between 1 and 3 inches thick.

Identify principal component and express volume estimates for minor components on logs using the following standard modifiers.

Modifier	**Percent of Total Sample (by volume)**
and	36 – 50
some	21 - 35
little	10 - 20
trace	<10

Determination of components is based on using the Udden-Wentworth particle size classification (see below) and measurement of the average grain size diameter. Each size class differs from the next larger class by a constant ratio of ½. Due to visual limitations, the finer classifications of Wentworth's scale cannot be distinguished in the field and the subgroups are not included. Visual determinations in the field should be made carefully by comparing the sample to the Soil Description Field Guide (**Attachment A**) that shows Udden-Wentworth scale or by measuring with a ruler.

The following table summarized the modified Udden-Wentworth Scale for grain size classification. Note that gravel is a size category encompassing the granule, pebble, cobble, and boulder size classes.

Udden-Wentworth Scale (Modified by Arcadis, 2008)

Size Category	**Size Class**	**Millimeters**	**Inches**	**Standard Sieve #**
Gravel (Cobble)	Boulder	256 – 4096	10.08+	
	Large cobble	128 - 256	5.04 -10.08	
	Small cobble	64 - 128	2.52 – 5.04	
Gravel (Pebble)	Very large pebble	32 – 64	0.16 - 2.52	
	Large pebble	16 – 32	0.63 – 1.26	
	Medium pebble	8 – 16	0.31 – 0.63	
	Small pebble	4 – 8	0.16 – 0.31	No. 5 +
	Granule	2 – 4	0.08 – 0.16	No.5 – No.10

Sand	Very coarse sand	1 -2	0.04 – 0.08	No.10 – No.18
	Coarse sand	½ - 1	0.02 – 0.04	No.18 - No.35
	Medium sand	¼ - ½	0.01 – 0.02	No.35 - No.60
	Fine sand	1/8 -¼	0.005 – 0.1	No.60 - No.120
	Very fine sand	1/16 – 1/8	0.002 – 0.005	No. 120 – No. 230
Fines	Silt (subgroups not included)	1/256 – 1/16	0.0002 – 0.002	Not applicable (analyze by pipette or hydrometer)
	Clay (subgroups not included	1/2048 – 1/256	0.00002 – 0.0002	

Identify components as follows. Remove particles greater than very large pebbles (64-mm diameter) from the soil sample. Record the volume estimate of the greater than very large pebbles. Examine the sample fraction of very large pebbles and smaller particles and estimate the volume percentage of the pebbles, granules, sand, silt and clay. Use the jar method, visual method, and/or wash method (Appendix X4 of ASTM D2488) to estimate the volume percentages of each category.

Sieve and hydrometer grain-size analysis can be used to vet the visual description, as well as used to estimate hydraulic conductivity. Lab or field sieve analysis is advisable to characterize the variability and facies trends within each hydrostratigraphic unit. It is recommended that sieve-hydrometer analysis be performed on representative samples from each soil type to estimate the fraction of each grain size category using ASTM D422 Standard Test Method for Particle-Size Analysis of Soils. If desired sieve sizes can be specified to follow the Udden-Wentworth classification (U.S. Standard sieve sizes 6; 12; 20; 40; 70; 140; and 270) to retain pebbles; granules; very coarse sand; coarse sand; medium sand; fine sand; and very fine sand, respectively.

Several empirical formulas provide a reliable means of estimating hydraulic conductivity (K) from grain-size distribution data, provided that the formation does not contain abundant fines that result in cohesive or plastic behavior or include cobble-sized grains (Payne et al. 2008). Grain-size analysis can help bracket the permeability of hydrostratigraphic units (HSUs) and identify order-of-magnitude spatial variations in K. Arcadis has completed modifications to the Excel-based program HydroGeoSieveXL (Devlin 2015) to process sieve data quickly and estimate K. The tool calculates estimated K values from grain-size data using 15 different empirical formulas. A decision matrix then selects which of the formulas is relevant for the soil type and calculates an average K.

Principal Component. The principal component is the size fraction or range of size fractions containing the majority of the volume. Examples: the principal component in a sample that contained 55% small to medium pebbles would be "PEBBLES, small to medium"; or the principal component in a sample that was 20% fine sand, 30% medium sand and 25% coarse sand would be "SAND, fine to coarse" or for a sample that was 40% silt and 45% clay the principal component would be "CLAY and SILT".

The boring log form (**Appendix D**) includes a graphic log to visually illustrate a relative estimate of soil permeability. To use the graphic log, place an 'X' or shade the appropriate column for the primary soil texture. If the soils have a high percentage of a secondary soil texture (i.e., when the 'and' modifier' is used), it's acceptable to mark off the appropriate column for the secondary soil texture in this instance. However, care should be used to avoid marking off the columns for other minor soil textures because doing so will make it difficult to determine the relative soil permeability of the poorly sorted soils.

As noted above, for poorly sorted soils such as glacial till, the principal component may not correlate to permeability of the sample. In this case, the geologist should use best judgement to graph overall soil type consistent with relative soil permeability.

Minor Component(s). The minor component(s) are the size fraction(s) containing less than 50% volume. Example: the identified components are estimated to be 60% medium sand to granules, 25% silt and clay; 15% pebbles – there are two identified minor components: silt and clay; and pebbles.

Include a standard modifier to indicate percentage of minor components (see particle size table) and the same descriptors that would be used for a principal component. An example of minor constituents with modifiers include: some silt and clay, low plasticity; little medium to large pebbles, sub-round.

8.2.1 Secondary Descriptors

The following are the descriptors used outside of the principal and minor components. Note that plasticity should be provided as a descriptor for clay and clay mixtures. Dilatancy should be provided for silt and silt mixtures. Angularity should be provided as a descriptor for pebbles and coarse sand.

Angularity. Describe the angularity for very coarse sand and larger particles in accordance with the table below (ASTM D-2488-06). Figures showing examples of angularity are available in ASTM D-2488-06 and the Arcadis Soil Description Field Guide (**Appendix B**).

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Sub-Angular	Particles are like angular description but have rounded edges
Sub-Rounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges.

Plasticity. Describe the plasticity for silt and clay based on observations made during the following test method (ASTM D-2488-06).

- As in the dilatancy test (described below), select enough material to mold into a ball about ½ inch (12 mm) in diameter. Mold the material, adding water, if necessary, until it has a soft, but not sticky, consistency.
- Shape the test specimen into an elongated pat and roll by hand on a smooth surface or between the palms into a thread about 1/8 inch (3 mm) in diameter. If the sample is too wet to roll easily, it should be spread into a thin layer and allowed to lose some water by evaporation. Fold the sample threads and reroll repeatedly until the thread crumbles at a diameter of about 1/8 inch. The thread will crumble when the soil is near the plastic limit.

Description	Criteria
Non-plastic	A 1/8-inch (3 mm) thread cannot be rolled at any water content.
Low	The thread can barely be rolled, and the lump cannot be formed when drier than the plastic limit.
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.

Dilatancy. Describe the dilatancy for silt and silt-sand mixtures using the following field test method (ASTM D-2488-06).

- From the specimen, select enough material to mold into a ball about ½ inch (12 mm) in diameter. Mold the material adding water, if necessary, until it has a soft, but not sticky, consistency.
- Smooth the ball in the palm of one hand with a small spatula.
- Shake horizontally, striking the side of the hand vigorously with the other hand several times.
- Note the reaction of water appearing on the surface of the soil.
- Squeeze the sample by closing the hand or pinching the soil between the fingers, and not the reaction as none, slow, or rapid in accordance with the table below. The reaction is the speed with which water appears while shaking and disappears while squeezing.

Description	Criteria
None	No visible change in the specimen
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

Note that silt and silt-sand mixtures will be non-plastic and display dilatancy. Clay mixtures will have some degree of plasticity but do not typically react to dilatancy testing. Therefore, the tests outlined above can be used to differentiate between silt-dominated and clay-dominated soils.

Sorting. Sorting is the opposite of grading, which is a commonly used term in the USCS or ASTM methods to describe the uniformity of the particle size distribution in a sample. Well-sorted samples are poorly graded and poorly sorted samples are well graded. Arcadis prefers the use of sorting for particle size distributions and grading to describe particle size distribution trends in the vertical profile of a sample or hydrostratigraphic unit because of the relationship between sorting and the energy of the depositional process. For soils with sand-sized or larger particles, sorting should be determined as follows:

Description	Criteria
Well Sorted	the range of particle sizes is limited (e.g., the sample is comprised of predominantly one or two grain sizes)
Poorly Sorted	A wide range of particle sizes are present

You can also use sieve analysis to estimate sorting from a sedimentological perspective; sorting is the statistical equivalent of standard deviation. Smaller standard deviations correspond to higher degree of sorting (see Remediation Hydraulics, 2008).

Consistency or Density. This can be determined by standard penetration test (SPT) blow counts (ASTM D-1586) obtained when using hollow-stem auger drilling methods and a split spoon sampling device. Otherwise, some field tests are available as outlined below. When drilling with hollow-stem augers and split-spoon sampling, the SPT blow counts and N-value is used to estimate density. The N-value is the blows per foot for the 6” to 18” interval. For example, for a 24-inch split spoon soil core, the recorded blows per 6-inch interval are: 4/6/9/22. Since the second interval is 6” to 12”, the third interval is 12” to 18”, the N value is 6+9, or 15. Fifty blow counts for less than 6 inches is considered refusal. In recent years, more common drilling methods include rotary-sonic or direct push. When blow counts are not available, density is determined using a thumb test. Note however, the thumb test only applies to fine-grained soils.

Fine-grained soil – Consistency

Description	Criteria	Blow Counts (6-12 to 12-18-inch split spoon interval)
Very soft	Easily penetrated several inches by thumb	N-value < 2
Soft	Easily penetrated one inch by thumb	N-value 2-4
Medium Stiff	Indented about ½ inch with much effort	N-value 5-8
Stiff	Indented with ¼ inch with great effort	N-value 9-15
Very Stiff	Readily indented by thumbnail	N-value 16-30
Hard	Indented by thumbnail with difficulty	N-value > than 30

Coarse-grained soil – Density

Description	Criteria	Blow Counts (6-12 to 12-18-inch split spoon interval)
Very loose	Density classification of coarse-grained soils is only required when blow counts from standard penetration tests are performed during hollow-stem auger drilling	N-value 1- 4
Loose		N-value 5-10
Medium dense		N-value 11-30
Dense		N-value 31- 50
Very dense		N-value >50

Moisture Content. Moisture content should be described for each soil sample in accordance with the table below (percentages should not be used unless determined in the laboratory). *Note that some drilling methods (e.g., sonic) can compress and dry out the sample during drilling. Therefore, it can be difficult to determine if a sample is saturated, or merely moist. In this case, care should be taken to try and determine a static water level within the borehole by measuring depth to water through the drill casing, if possible.*

Description	Criteria
Dry	Absence of moisture, dry to touch, dusty
Moist	Damp but no visible water
Wet	Visibly free water

Color. Color should be described using simple basic terminology and modifiers based on the Munsell system. Munsell alpha-numeric codes are required for all samples. If the sample contains layers or patches of varying colors this should be noted, and all representative colors should be described. The colors should be described for moist samples. If the sample is dry, it should be wetted prior to comparing the sample to the Munsell chart.

Notes. Additional comments should be made where observed and should be presented as notes with reference to a specific depth interval(s) to which they apply. Some of the significant information that may be observed includes the following.

- Odor - You should not make an effort to smell samples by placing near your nose since this can result in unnecessary exposure to hazardous materials. However, odors should be noted if they are detected during the normal sampling procedures. Odors should be based upon descriptors such as those used in NIOSH “Pocket Guide to Chemical Hazards”, e.g., “pungent” or “sweet” and should not indicate specific chemicals such as “phenol-like” odor or “BTEX” odor.
- Structure
- Bedding planes (laminated, banded, geologic contacts).
- Presence of roots, root holes, organic material, man-made materials, minerals, etc.
- Mineralogy

- Cementation
- NAPL presence/characteristics, including sheen (based on client-specific guidance).
- Reaction with HCl - typically only used for special soil conditions, such as caliche environments.
- Origin, if known (Lacustrine; Fill; etc.).

8.3 Example of Soil Descriptions

The standard generic description order is presented below.

- Depth
- PRIMARY TEXTURE
- Principal and Minor Components with Descriptors
    - % Modifiers and grain size fraction
    - Angularity for very coarse sand and larger particles
    - Consistency or Density
    - Plasticity for silt and clay
    - Dilatancy for silt and silt-sand mixtures
- Sorting
- Moisture Content
- Color
- Notes

10-15 feet CLAY, trace silt, trace small to very large pebbles, subround to subangular up to 2" diameter; medium to high plasticity, stiff, moist, dark grayish brown (10YR 4/2). NOTE: Lacustrine; laminated 0.1 to 0.2" thick, laminations brownish yellow (10YR 4/3).

10 -15 feet SAND, medium to very coarse, little granules to medium pebbles, subround to subangular, trace silt; poorly sorted, wet, grayish brown (10YR5/2).

Unlike the first example where a density of cohesive soils could be estimated, this rotary-sonic sand and pebble sample was disturbed during drilling (due to vibrations in a loose sand and pebble matrix) so no density description could be provided. Neither sample had noticeable odor so odor comments were not included.

9 Waste Management

Project-specific requirements should be identified and followed. The following procedures, or similar waste management procedures are generally required.

Water generated during cleaning procedures will be collected and contained onsite in appropriate containers for future analysis and appropriate disposal. PPE (such as gloves, disposable clothing, and other disposable equipment) resulting from personnel cleaning procedures and soil sampling/handling activities will be placed in plastic bags. These bags will be transferred into appropriately labeled 55-gallon drums or a covered roll-off box for appropriate disposal.

Soil materials will be placed in sealed 55-gallon steel drums or covered roll-off boxes and stored in a secured area. Once full, the material will be analyzed to determine the appropriate disposal method.

10 Data Recording and Management

10.1 Digital Data Collection Process Overview

Digital data collection is the Arcadis standard using available FieldNow® applications that enable real-time, paperless data collection, entry, and automated reporting. Paper forms should only be used as backup to FieldNow® digital data collection and/or as necessary to collect data not captured by available FieldNow® applications. The Field Now® digital form applications follow a standardized approach, correlate to most TGIs and are available to all projects accessible with a PC or capable mobile device. Once the digital forms are saved within FieldNow®, the data is instantly available for review on a web interface. This facilitates review by project management team members and SMEs enabling error or anomalous data detection for correction while the staff are still in the field. Continual improvements of FieldNow® applications are ongoing, and revisions are made as necessary in response to feedback from users and subject matter experts.

10.2 Digital Data Collection Tools for Soil Descriptions

Arcadis is transitioning from the use of paper forms to a digital soil description logging process using web-based FieldNow applications accessible on field tablets and smart phones. Company-wide roll out of a FieldNow application for soil descriptions is targeted by the end of 2022.

Paper forms are included in Revision 3 (April 2022) of this Soil Description TGI. Specifically, a blank boring log and completed boring log are provided in **Attachment D** and **Attachment E**. Additional guidance and examples of the digital data collection tools for soil descriptions will be provided in the next revision to this TGI.

10.3 Additional Guidance

The general logging scheme for soil descriptions is described in this document. Depending on project data quality objectives, specific soil description parameters that are not applicable to project goals may be omitted at the project manager’s discretion. In any case, use of consistent procedures is required.

Completed logs and/or logbook will be maintained in the task/project field records file. Digital photographs of typical soil types observed at the site and any unusual features should be obtained whenever possible. Photographs should include a ruler or common object for scale. Photo location, depth and orientation must be recorded in the daily log or logbook and a label showing this information in the photo is useful.

For projects involving soil logging and soil sampling, the soil sample should be recorded on the Arcadis boring log form and the field logbook based on Data Quality Objectives for the task/project.

11 Quality Assurance

Soil descriptions should be completed only by appropriately trained personnel. Descriptions should be reviewed by an experienced field geologist for content, format and consistency. Edited boring logs should be reviewed by the original author to assure that content has not changed.

12 References

ASTM D-1586, Test Method for Penetration Test and Split-Barrel Sampling of Soils.

ASTM D-2488-00, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)

ASTM D422, 63rd Edition, 1972 - Standard Test Method for Particle-Size Analysis of Soils.

Devlin, J.F. 2015. HydroGeoSieve XL: an Excel-based tool to estimate hydraulic conductivity from grain-size analysis. Hydrogeology Journal, DOI 10.1007/s10040-015-1255-0.

Folk, Robert L. 1980. Petrology of Sedimentary Rocks, p. 1-48.

Payne, F. C., Quinnan, J. A., & Potter, S. T. 2008. Remediation Hydraulics. Boca Raton: FL: CRC Press.

United States Bureau of Reclamation. Engineering Geology Field Manual. United States Department of Interior, Bureau of Reclamation. http://www.usbr.gov/pmts/geology/fieldmap.htm.

Munsell® Color Chart – available from Forestry Suppliers, Inc.- Item 77341 “Munsell® Color Soil Color Charts.

Field Gauge Card that Shows Udden-Wentworth scale – available from Forestry Suppliers, Inc. – Item 77332 “Sand Grain Sizing Folder.”

NIOSH Pocket Guide to Chemical Hazards.

Attachment A

Soil Field Reference Guide

The purpose of this attachment is to present a field reference guide for use during soil logging. Field staff are encouraged to bring a laminated copy of this reference guide into the job site.

ON THE ORIGINAL DRAWING.
USE TO VERIFY FIGURE
REPRODUCTION SCALE

SOIL DESCRIPTION FIELD GUIDE (APRIL, 2022; REV. 3.0)

ARCADIS
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for natural and
built assets

FINE-GRAINED SOILS

Description	Criteria
	Descriptor - Plasticity
Nonplastic	A 1/8-inch (3 mm) thread cannot be rolled at any water content.
Low	The thread can barely be rolled, and the lump cannot be formed when drier than the plastic limit.
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.
	Descriptor - Dilatancy
No Dilatancy	No visible change when shaken or squeezed.
Slow	Water appears slowly on the surface of soil during shaking and does not disappear or disappears slowly when squeezed.
Rapid	Water appears quickly on surface of soil during shaking and disappears quickly when squeezed.
Minor Components with Descriptors	
	Moisture
Dry	Absence of moisture, dry to touch, dusty.
Moist	Damp but no visible water.
Wet	Visible free water; soil is usually below the water table. (Saturated)
	Consistency
Very soft	N-value < 2 or easily penetrated several inches by thumb.
Soft	N-value 2-4 or easily penetrated 1 inch by thumb.
Medium stiff	N-value 5-8 or indented about 1/2 inch by thumb with great effort.
Stiff	N-value 9-15 or indented about 1/4 inch by thumb with great effort.
Very stiff	N-value 16-30 or readily indented by thumb nail.
Hard	N-value > than 30 or indented by thumbnail with difficulty.
Color using Munsell	
Geologic Origin (if known)	
Other	

EXAMPLE OF SOIL DESCRIPTION AND PHOTO

10-15 feet CLAY, trace silt, trace small to very large pebbles, subround to subangular up to 2" diameter; medium to high plasticity, stiff, moist, dark grayish brown (10YR 4/2). NOTE: Lacustrine; laminated 0.1 to 0.2" thick, laminations brownish yellow (10YR 4/3).

DESCRIPTION ORDER

Depth Interval
PRIMARY TEXTURE (e.g., SAND)
Principal and Minor Components with Descriptors:
- % Modifiers and grain size fraction
- Angularity coarse sand and larger
- Consistency or Density
- Plasticity for silt and clay
- Dilatancy for silt and silt-sand

Sorting for granular sediments
Moisture Content
Color
Other NOTES

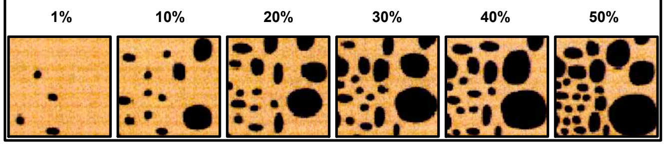
MINOR COMPONENTS % MODIFIERS

Modifier	Percent of Total Sample (by volume)
and	36 - 50
some	21 - 35
little	10 - 20
trace	<10

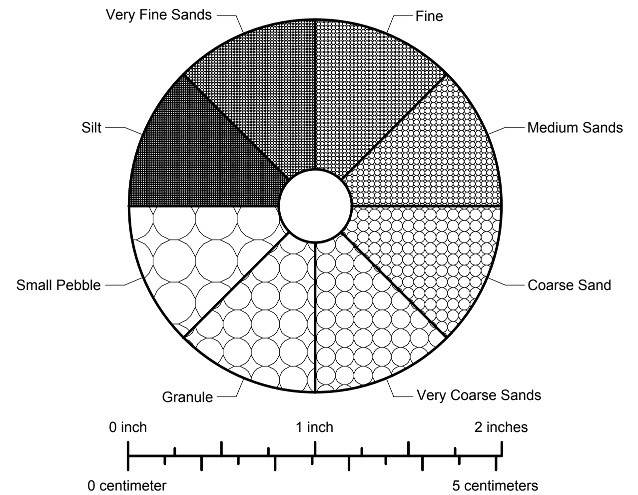
UDDEN-WENTWORTH SCALE

Fraction	Sieve Size	Grain Size	Approximate Scale
Boulder		256 - 4096 mm	Larger than volleyball
Large Cobble		128 - 256 mm	Softball to volleyball
Small Cobble		64 - 128 mm	Pool ball to softball
Very Large Pebble		32 - 64 mm	Pinball to pool ball
Large Pebble		16 - 32 mm	Dime size to pinball
Medium Pebble		8 - 16 mm	Pencil eraser to dime size
Small Pebble	No. 5+	4 - 8 mm	Pea size to pencil eraser
Granule	No. 10 - 5	2 - 4 mm	Rock salt to pea size
Very Coarse Sand	No. 18 - 10	1 - 2 mm	See field gauge card
Coarse Sand	No. 35 -18	0.5 - 1 mm	See field gauge card
Medium Sand	No. 60 - 35	0.25 - 0.5 mm	See field gauge card
Fine Sand	No. 120 - 60	0.125 - 0.25 mm	See field gauge card
Very Fine Sand	No. 230 - 120	0.0625 - 0.125 mm	See field gauge card
Silt and Clay. See SOP for description of fines	Not Applicable	<0.0625 mm	Analyze by pipette or hydrometer

PARTICLE PERCENT COMPOSITION ESTIMATION



GRAPH FOR DETERMINING SIZE OF PARTICLES



FOR COARSE-GRAINED SOILS

Description	Criteria
	Descriptor - Angularity
Angular	Particles have sharp edges and relatively planar sides withunpolished surfaces.
Subangular	Particles are similar to angular but have rounded edges.
Subround	Particles have nearly planar sides but have well-roundedcorners and edges.
Round	Particles have smoothly curved sides and no edges.
Minor Components with Descriptors	
	Sorting **Cu= d60/d10**
Well Sorted	Near uniform grain-size distribution Cu= 1 to 3.
Poorly Sorted	Wide range of grain size Cu= 4 to 6.
	Moisture
Dry	Absence of moisture, dry to touch, dusty.
Moist	Damp but no visible water.
Wet	Visible free water; soil is usually below the water table. (Saturated)
	Density
Very loose	N-value 1 - 4
Loose	N-value 5 - 10
Medium Dense	N-value 11 - 30
Dense	N-value 31 - 50
Very dense	N-value >50
Color using Munsell	
Geologic Origin (if known)	
Other	
	Cementation
Weak Cementation	Crumbles or breaks with handling or little finger pressure.
Moderate Cementation	Crumbles or breaks with considerable finger pressure.
Strong Cementation	Will not crumble with finger pressure.
	Reaction with Dilute HCl Solution (10%)
No Reaction	No visible reaction.
Weak Reaction	Some reaction, with bubbles forming slowly.
Strong Reaction	Violent reaction, with bubbles forming immediately.

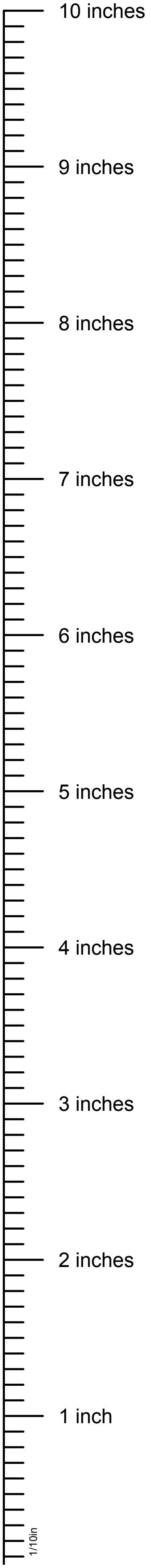
EXAMPLE OF SOIL DESCRIPTION AND PHOTO

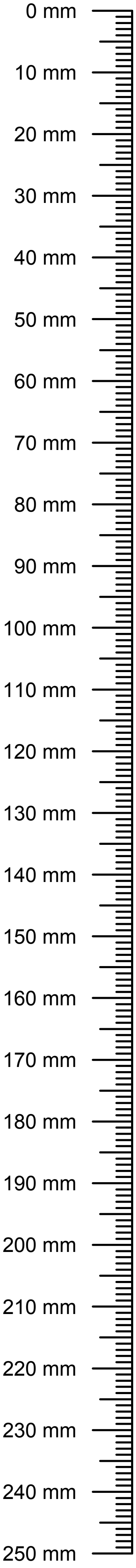
10 -15 feet SAND, medium to very coarse, little granules to medium pebbles, subround to subangular, trace silt; poorly sorted, wet, grayish brown (10YR 5/2).

ON THE ORIGINAL DRAWING.
USE TO VERIFY FIGURE
REPRODUCTION SCALE

SOIL DESCRIPTION FIELD GUIDE (APRIL, 2022; REV. 3.0)

ARCADIS Design & Consultancy for natural and built assets





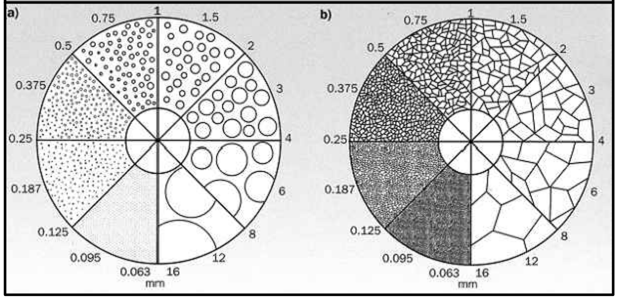
VARIATIONS IN SOIL STRATIGRAPHY

Term	Thickness of Configuration
Parting	0 - to 1/16-inch thickness.
Seam	1/16 - to 1/2-inch thickness.
Layer	1/2 - to 12-inch thickness.
Stratum	> 12-inch thickness.
Pocket	Small erratic deposit, usually less than 1 foot in size.
Varved Clay	Alternating seams or layers of sand, silt, and clay (laminated).
Occasional	≤ 1 foot thick.
Frequent	> 1 foot thick.

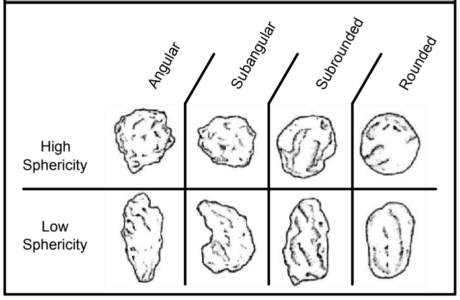
SOIL STRUCTURE DESCRIPTIONS

Term	Description
Homogeneous	Same color and appearance throughout.
Laminated	Alternating layers < 1/4 inch thick.
Stratified	Alternating layers ≥ 1/4 inch thick.
Lensed	Inclusions of small pockets of different materials, such as lenses of sand scattered through a mass of clay; note thickness.
Blocky	Cohesive soil can be broken down into small angular lumps, which resist further breakdown.
Fissured	Breaks along definite planes of fracture with little resistance to fracturing.
Slickensided	Fracture planes appear to be polished or glossy, sometimes striated.

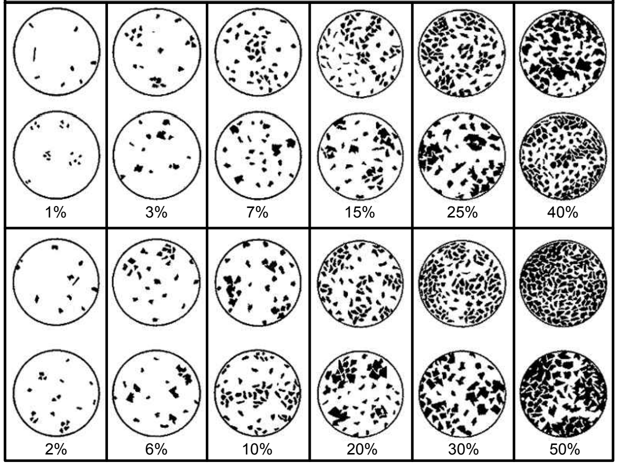
GRAPH FOR DETERMINING SIZE OF PARTICLES



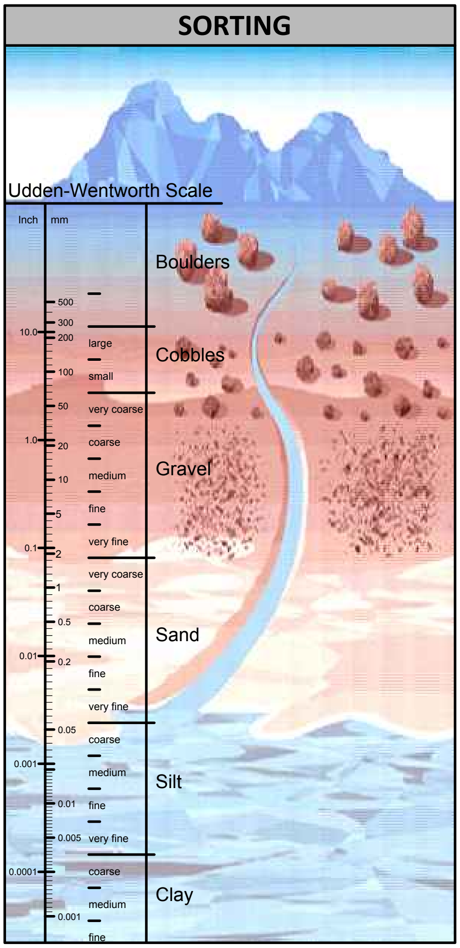
ANGULARITY CHART



PARTICLE PERCENT COMPOSITION ESTIMATION



SORTING



SETTLING TABLE (SILT/CLAY)

Diameter of Particle (mm)	<0.625	<0.031	<0.016	<0.008	<0.004	<0.002	<0.0005
Depth of Withdrawal (cm)	10	10	10	10	5	5	3
Time of Withdrawal	hr:min:sec	hr:min:sec	hr:min:sec	hr:min:sec	hr:min:sec	hr:min:sec	hr:min:sec
Temperature (Celsius)							
20	00:00:29	00:01:55	00:07:40	00:30:40	00:61:19	04:05:00	37:21:00
21	00:00:28	00:01:52	00:07:29	00:29:58	00:59:50	04:00:00	
22	00:00:27	00:01:50	00:07:18	00:29:13	00:58:22	03:54:00	
23	00:00:27	00:01:47	00:07:08	00:28:34	00:57:05	03:48:00	
24	00:00:26	00:01:45	00:06:58	00:27:52	00:55:41	03:43:00	33:56:00
25	00:00:25	00:01:42	00:06:48	00:27:14	00:54:25	03:38:00	
26	00:00:25	00:01:40	00:06:39	00:26:38	00:53:12	03:33:00	
27	00:00:24	00:01:38	00:06:31	00:26:02	00:52:02	03:28:00	
28	00:00:24	00:01:35	00:06:22	00:25:28	00:50:52	03:24:00	31:00:00
29	00:00:23	00:01:33	00:06:13	00:24:53	00:49:42	03:10:00	
30	00:00:23	00:01:31	00:06:06	00:24:22	00:48:42	03:05:00	

Attachment B

Particle Size System Comparison

The purpose of this attachment is to illustrate how the Udden-Wentworth particle sizes and descriptive terms compares to other particle size systems.

When in the field, it is a customary practice to compare current soil descriptions to historical soil boring logs for reference purposes. When reviewing boring logs prepared by others, field staff should first note the particle size system used and recognize these particle size systems may differ. This will avoid confusion when cross referencing between historical and new boring logs and when reviewing existing geologic cross-sections.

For example, a well-sorted sand with grain sizes ranging from 1 to 2 mm should be classified as a very coarse sand by the Udden-Wentworth system. As shown in this attachment, the same particle size would be classified as a medium sand by the United Soil Classification System. The later system has fewer particle size grades and in general, is less descriptive than the Udden-Wentworth system.

PARTICLE SIZE SYSTEM COMPARISON

System Name | **Used By** | **Grain size distribution in millimeters (mm)**

Udden-Wentworth
Remediation Geologists and Engineers

								Pebbles				Cobbles	
		V. Fine	Fine	Medium	Coarse	V. Coarse	Granule	Small	Medium	Large	V. Large	Small	Large
CLAY	SILT	SAND					GRAVEL						
0.039	0.065	0.125	0.25	0.5	1	2	4	8	16	32	64	128	256
	1/16	1/8	1/4	1/2									

United Soil Classification System
Geotechnical Engineers

		Fine	Medium	Coarse	Fine	Coarse	
CLAY	SILT	SAND			GRAVEL		COBBLE
	0.074	0.42	2	4.75	19	75	300

U.S. Dept. of Agriculture
Soil Scientists

		V. Fine	Fine	Medium	Coarse	V. Coarse	
CLAY	SILT	SAND					GRAVEL
0.002	0.05	0.10	0.25	0.5	1	2	75

Remediation Hydraulics 2008, page 195): The Udden-Wentworth scale is preferred "...because the geometric progression of grain-size diameter also reflects relationships that are important when considering the erosion and deposition of sediments during the depositional process. The correlation between increasing grain size and degree of sorting and permeability is the most important, as permeability structure is responsible for the mobile and immobile porosity within aquifer systems. "

Attachment C

Description of Soil Logging Terms

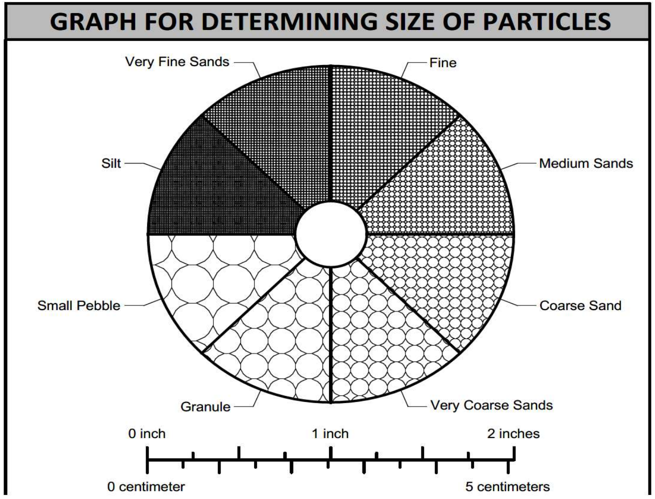
The purpose of this attachment is to concisely define the soil logging terms used when filling out boring logs. During report preparation, project staff could use this sheet as an index placed in front of the completed boring logs. Also, it can serve as a supplemental reference sheet during field activities.

Description of Logging Terms

Note: Soil descriptions based on Arcadis Technical Guidance and Instructions (TGI) procedures. Key terms defined below.

Udden Wentworth Soil Sizes

Boulder	> 256 mm
Large Cobble	128 to 256 mm
Small Cobble	64 to 128 mm
Very Large Pebble	32 to 64 mm
Large Pebble	16 to 32 mm
Medium Pebble	8 to 16 mm
Small Pebble	4 to 8 mm
Granule	2 to 4 mm
Very Coarse Sand	1 to 2 mm
Coarse Sand	0.5 to 1 mm
Medium Sand	0.25 to 0.5 mm
Fine Sand	0.125 to 0.25 mm
Very Fine Sand	0.062 to 0.12 mm
Silt/Clay	<0.065 mm



GRAPH FOR DETERMINING SIZE OF PARTICLES

Primary Texture *(e.g. CLAY, SILT, SAND, GRANULE, PEAT, MUCK, FILL, etc.)*

List particle size with the highest percentage per sample interval (e.g. SAND)
Always CAPITALIZE the primary texture
Follow primary texture with a comma followed by grain-size descriptors, etc.

Minor Texture

And	(36 to 50%)
Some	(21 to 35%)
Little	(10 to 20%)
Trace	(>10%)

Angularity

Angular	Sharp edges
Sub-Angular	Rounded edges
Sub-Rounded	Well-rounded
Rounded	Smooth curved edges

Sand Density (Blow Counts/ft)

Very Loose	0-4
Loose	5-10
Medium Dense	11-30
Dense	31-50
Very Dense	<50

Silt/Clay Consistency (Blow Counts/ft)

Very Soft	0-2,	thumb easily penetrates several inches
Soft	3-4,	thumb easily penetrates one inch
Medium Stiff	5-8,	thumb indents 0.5 in. with much effort
Stiff	9-15,	thumb indents 0.25 in. with great effort
Very Stiff	16-30,	thumbnail is readily intended

Sorting

Well Sorted	1 to 3 Particle Sizes
Poorly Sorted	4+ Particle Sizes

Moisture Content

Dry	Dry to touch
Moist	No visible water
Wet	Visible free water

Plasticity (for silts and clays)

Non-Plastic	3 mm thread can not be rolled
Low Plasticity	3 mm thread can barely be rolled
Medium Plasticity	3 mm thread can easily and quickly rolled, but not rerolled
High Plasticity	3 mm thread can be rolled slowly, but can be rerolled

Dilatancy (for silts and silt-sand mixtures)

None	No visible change in the specimen
Slow	Water appears slowly during shaking / disappears slowly or not at all upon squeezing
Rapid	Water appears quickly during shaking / disappears quickly upon squeezing

Example Description

10 -15 feet SAND, medium to very coarse, little granules to medium pebbles, subround to subangular, trace silt; poorly sorted, wet, grayish brown (10YR5/2).

Attachment D

Blank Boring Log

The purpose of this attachment is to present a blank field form for use during soil logging. A digital version (Microsoft Excel) of this field form is available from the authors (upon request). If project specific modifications to this boring log template are warranted, please contact the Site Investigation Community of Practice leader for further assistance.

BORING LOG

Boring ID: ____________________

Permit ID: ____________________

Site Address: ____________________

City, State: ____________________

Drilling Co: ____________________

Driller: ____________________

Drilling Method: ____________________

Boring Status: ____________________

Project Name: ____________________

Date Started: ____________________

Date Completed: ____________________

Total Depth: ____________________

Depth to Water: ____________________

Hole Diameter: ____________________

Core Device: ____________________

Drilling Fluid: ____________________

Page: ________ / ________

Ground Elevation: ____________________

Vertical Datum: ____________________

Northing: ____________________

Easting: ____________________

Horizontal Datum: ____________________

Prepared by: ____________________

Reviewed by: ____________________

Drilling Information				Graphical Log for Primary Texture											Soil Description (Udden-Wentworth System)	Field Notes
				Fines		Sand					Gravel					
Drilling Depth (ft bgs)	Core Interval (ft)	Core Recovery (inches)	Vapor Reading (ppm)	clay	silt	very fine	fine	medium	coarse	very coarse	granule	pebble	cobble	boulder	Depth Interval (ft), PRIMARY TEXTURE, Principal and Minor Components with Descriptors (% modifiers and grain size fraction, angularity for coarse sand and larger, consistency/density, plasticity for silt and clay, dilatancy for silt/silt-sand); Sorting, Moisture Content, Color. NOTES: *Texture Modifiers: Trace (<10%), Little (10 to 20%), Some (21 to 35%), And (36 to 50%)*	Driller's Observations, Geologic Formation, Field Screening Results, Sample Interval etc.

BORING LOG

ARCADIS

Boring ID: ____________________

Project Name: ________________________________

Page: ______ / ______

Drilling Information				Graphical Log for Primary Texture											Soil Description (Udden-Wentworth System)	Field Notes
				Fines		Sand					Gravel					
Drilling Depth (ft bgs)	Core Interval (ft)	Core Recovery (inches)	Vapor Reading (ppm)	clay	silt	very fine	fine	medium	coarse	very coarse	granule	pebble	cobble	boulder	Depth Interval (ft), PRIMARY TEXTURE, Principal and Minor Components with Descriptors (% modifiers and grain size fraction, angularity for coarse sand and larger, consistency/density, plasticity for silt and clay, dilatancy for silt/silt-sand); Sorting, Moisture Content, Color. NOTES: *Texture Modifiers: Trace (<10%), Little (10 to 20%), Some (21 to 35%), And (36 to 50%)*	Driller's Observations, Geologic Formation, Field Screening Results, Sample Interval etc.

Attachment E

Completed Boring Log

The purpose of this attachment is to provide an example of a completed boring log for reference purposes to field staff. The example provided is for a soil boring completed outside the waste mass of a closed municipal landfill near Baltimore, Maryland. The objective of the drilling program was to determine the depth to groundwater to determine the appropriate depth interval to install a soil gas monitoring well and groundwater monitoring well across the first water-bearing zone. The site geology consists of unconsolidated sediments of the Mid-Atlantic Coastal Plain, specifically the Upper Patapsco formation. These sediments were deposited in a moderate gradient fluvial environment during the Cretaceous period. The landfill was constructed into a regional clay confining unit.

BORING LOG

Boring ID:	MW-08	**Project Name:**	Acme Landfill	**Page:**	1 / 1
Permit ID:	MD-PG-100	**Date Started:**	7/18/2018	**Ground Elevation:**	50.5 ft
Site Address:	100 Landfill Road	**Date Completed:**	7/18/2018	**Vertical Datum:**	NAVD 88, feet
City, State:	Baltimore, Maryland	**Total Depth:**	35 ft below ground	**Northing:**	123456.79
Drilling Co:	Earth Matters	**Depth to Water:**	19 ft below ground	**Easting:**	123456.79
Driller:	Rod E. Piper	**Hole Diameter:**	2-inch	**Horizontal Datum:**	NAD 83 feet, MD State
Drilling Method:	Direct-push/hollow-stem	**Core Device:**	5-foot macrocore sampler	**Prepared by:**	Sandy Pebbles
Boring Status:	completed as well	**Drilling Fluid:**	none	**Reviewed by:**	Clay Brown

Drilling Information				Graphical Log for Primary Texture											Soil Description (Udden-Wentworth System)	Field Notes
				Fines		Sand					Gravel					
Drilling Depth (ft bgs)	Core Interval (ft)	Core Recovery (inches)	VOC Vapor Reading (ppm)	clay	silt	very fine	fine	medium	coarse	very coarse	granule	pebble	cobble	boulder	Depth Interval (ft), PRIMARY TEXTURE, Principal and Minor Components with Descriptors (% modifiers and grain size fraction, angularity for coarse sand and larger, consistency/density, plasticity for silt and clay, dilatancy for silt/silt-sand); Sorting, Moisture Content, Color. NOTES: *Texture Modifiers: Trace (<10%), Little (10 to 20%), Some (21 to 35%), And (36 to 50%)*	Driller's Observations, Geologic Formation, Field Screening Results, Sample Interval etc.
0 to 1	0-5	43.2/60	< 1												0-0.5 ft, topsoil with organics	Grass covered area
1 to 2			< 1				X								0.5-5 ft, SAND, fine, trace silt, trace pebble, round; poorly sorted, moist, yellowish brown (7.5 YR 5/8). NOTE: some cementation, does not react with HCl	continuous macro-core logging
2 to 3			< 1				X									
3 to 4			< 1				X									cemented sand @3.6-4 ft
4 to 5			< 1				X									
5 to 6	5-10	40.8/60	< 1				X	X	X						5-10 ft, SAND, fine to coarse, round to subround; well sorted, moist, light to strong brown (7.5 YR 6/4 to 7.5 YR 5/6).	
6 to 7			< 1				X	X	X							
7 to 8			< 1				X	X	X							
8 to 9			< 1				X	X	X							
9 to 10			< 1				X	X	X							
10 to 11	10-15	36/60	< 1				X	X	X						10-12.5 ft, same as above with trace silt	
11 to 12			< 1				X	X	X							
12 to 13			< 1				X	X	X							
13 to 14			< 1				X	X	X						12.5 to 15 ft, same as above, color change to pink (7.5 YR 7/3) and reddish yellow (7.5YR 6/8)	
14 to 15			< 1				X	X	X							
15 to 16	15-20	55.2/60	< 1						X	X					15-18.9 ft, SAND, coarse to very coarse, round to subround; well sorted, moist, strong brown (7.5YR 5/6) to reddish yellow (7.5YR 6/6)	
16 to 17			< 1						X	X						
17 to 18			< 1						X	X						
18 to 19			< 1		X	X	X								18.9-22.7 ft, SAND, very fine to fine, and SILT, coarse to very coarse, poorly sorted, wet, light gray (7.5YR 7/1)	water table encountered @ 18.9 ft
19 to 20			< 1		X	X	X									
20 to 21	20-25	36/60	< 1		X	X	X									
21 to 22			< 1		X	X	X									
21 to 23			< 1		X	X	X									
23 to 24			< 1	X	X										22.7-25 ft, CLAY and SILT, high plasticity, soft to stiff at 25 ft, dry to moist, light gray (2/5YR 7/1) w/ red mottling (2.5YR 4/6)	Middle Patapsco Confining Unit
24 to 25			< 1	X	X											
25 to 26	25-30	30/60	< 1	X	X										25-31.1 ft, CLAY and SILT, high plasticity, stiff; dry to moist, light gray (2/5YR 7/1) with red mottling (2.5YR 4/6)	
26 to 27			< 1	X	X											
27 to 28			< 1	X	X											
28 to 29			< 1	X	X											
29 to 30			< 1	X	X											
30 to 31	30-35 ft	60/60	< 1	X	X											
31 to 32			< 1		X											
32 to 33			< 1		X											
33 to 34			< 1		X										31.1-35 ft, SILT, low plasticity, high dilatancy; wet, gray (7.5YR 7/1)	End of direct-push boring @ 35 ft
34 to 35			< 1		X											

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TGI - MONITORING WELL INSTALLATION

Rev #: 0

Rev Date: April 24, 2017

VERSION CONTROL

Revision No	Revision Date	Page No(s)	Description	Reviewed by
0	4/24/2017	All	Re-written as a TGI	Marc Killingstad Peter C. Frederick

APPROVAL SIGNATURES

Prepared by: 4/20/17
Jay Erickson Date:

Technical Expert Reviewed by: 4/24/17
Marc Killingstad Date:

1 INTRODUCTION

This document describes general and/or specific procedures, methods, actions, steps, and considerations to be used and observed by Arcadis staff when performing work, tasks, or actions under the scope and relevancy of this document. This document may describe expectations, requirements, guidance, recommendations, and/or instructions pertinent to the service, work task, or activity it covers.

It is the responsibility of the Arcadis Certified Project Manager (CPM) to provide this document to the persons conducting services that fall under the scope and purpose of this procedure, instruction, and/or guidance. The Arcadis CPM will also ensure that the persons conducting the work falling under this document are appropriately trained and familiar with its content. The persons conducting the work under this document are required to meet the minimum competency requirements outlined herein, and inquire to the CPM regarding any questions, misunderstanding, or discrepancy related to the work under this document.

This document is not considered to be all inclusive nor does it apply to any and all projects. It is the CPM's responsibility to determine the proper scope and personnel required for each project. There may be project- and/or client- and/or state-specific requirements that may be more or less stringent than what is described herein. The CPM is responsible for informing Arcadis and/or Subcontractor personnel of omissions and/or deviations from this document that may be required for the project. In turn, project staff are required to inform the CPM if or when there is a deviation or omission from work performed as compared to what is described herein.

In following this document to execute the scope of work for a project, it may be necessary for staff to make professional judgment decisions to meet the project's scope of work based upon site conditions, staffing expertise, state-specific requirements, health and safety concerns, etc. Staff are required to consult with the CPM when or if a deviation or omission from this document is required that has not already been previously approved by the CPM. Upon approval by the CPM, the staff can perform the deviation or omission as confirmed by the CPM.

2 SCOPE AND APPLICATION

This Technical Guidance Instruction (TGI) describes methods used to install groundwater monitoring wells in granular aquifers. It is assumed that the monitoring well has been properly designed, including sizing of the filter pack and screen, the length of the screen, total depth of the well, material strength and compatibility and surface completion. Typical monitoring wells are constructed of manufactured screen and engineered filter pack and are generally suitable for formations with granular materials having a grain size distribution with up to 50% passing a #200 sieve and up to 20% clay-sized material. Monitoring wells installed in formations finer than this may not be able to produce turbidity free water.

The monitoring well installation procedures set forth herein are consistent with the approach and methods presented in the American Society of Testing and Materials (ASTM) D5092 – *Standard Practice for Design and Installation of Groundwater Monitoring Wells* (ASTM D5092). As such, following this TGI in combination with proper well design (see appropriate TGI), well development (see appropriate TGI), groundwater sampling procedures (see appropriate TGI), and well maintenance and rehabilitation (see appropriate TGI), will result in a monitoring well suitable for: (1) collection of groundwater samples representative of the surrounding formation and free of artificial turbidity; (2) measurement of accurate groundwater levels; and (3) hydraulic conductivity testing of formation sediments immediately adjacent to the open interval of the well (e.g., slug testing).

Monitoring well boreholes in unconsolidated (overburden) materials are typically drilled using the hollow-stem auger drilling method. Other drilling methods that are also suitable for installing overburden monitoring wells, and are sometimes necessary due to site-specific geologic conditions or project objectives, include: drive-and-wash, spun casing, Rotasonic, dual-rotary (Barber Rig), and fluid/mud rotary with core barrel or roller bit. Direct-push techniques (e.g., Geoprobe or cone penetrometer) and driven well points may also be used in some cases within the overburden. Monitoring wells to be installed within consolidated materials such as fractured bedrock are commonly drilled using water-rotary (coring or tri-cone roller bit), air rotary or Rotasonic methods. For guidance when installing monitoring wells in consolidated materials, please refer to the appropriate document. The drilling method to be used at a given site will be selected based on site-specific consideration of anticipated drilling/well depths, site or regional geologic knowledge, type of monitoring to be conducted using the installed well, project objectives, and cost.

No oils or grease will be used on equipment introduced into the boring (e.g., drill rod, casing, or sampling tools). No polyvinyl chloride (PVC) glue/cement will be used in constructing or retrofitting monitoring wells that will be used for water-quality monitoring. No coated bentonite pellets will be used in the well drilling or construction process. Specifications of materials to be installed in the borehole will be obtained prior to mobilizing onsite; these materials generally include:

- Well casing (length, material, and diameter);
- Well screen (length, material, diameter, and slot size);
- Bentonite (type, as applicable, chips, non-coated and granular bentonite are acceptable);
- Filter pack (filter pack type and fine sand seal type, as applicable); and
- Grout (type, as applicable).

Well materials will be inspected and, if needed, cleaned or replaced prior to installation.

3 PERSONNEL QUALIFICATIONS

Monitoring well installation activities will be performed by persons who have been trained in proper well installation procedures under the guidance of an experienced field geologist, engineer, or technician. Where field sampling is performed for soil or bedrock characterization, field personnel will have undergone in-field training in soil or bedrock description methods, as described in the appropriate Standard Operating Procedures (SOPs) and/or TGIs for those activities.

4 EQUIPMENT LIST

The following materials will be available during soil boring and monitoring well installation activities, as required:

- Site Plan with proposed soil boring/well locations;

- Work Plan (or equivalent), Field Sampling Plan (FSP), and site-specific Health and Safety Plan (HASP);
- Personal protective equipment (PPE), as required by the HASP;
- Traffic cones, delineators, caution tape, and/or fencing as appropriate for securing the work area, if such are not provided by drillers;
- Appropriate soil sampling equipment (e.g., stainless steel spatulas, knife);
- Soil and/or bedrock logging equipment as specified in the appropriate project documents;
- Appropriate sample containers and labels;
- Drum labels as required for investigation derived waste handling;
- Chain-of-custody forms;
- Insulated coolers with ice, when collecting samples requiring preservation by chilling;
- Photoionization detector (PID) or flame ionization detector (FID);
- Ziplock style bags;
- Water level or oil/water interface meter;
- Locks and keys for securing the well after installation;
- Decontamination equipment (bucket, distilled or deionized water, cleansers appropriate for removing expected chemicals of concern, paper towels);
- Engineer’s tape/measuring wheel;
- Weighted tape;
- Disposable bailers;
- Digital camera (or phone with camera)
- Field notebook or Personal Digital Assistant (PDA); and
- Appropriate field forms, consider including a photo of the well head and a Google Earth map showing the well location.

Prior to mobilizing to the site, Arcadis personnel will contact the drilling subcontractor or in-house driller (as appropriate) to confirm that appropriate sampling and well installation equipment will be provided. Specifications of the sampling and well installation equipment are expected to vary by project, and so communication with the driller is necessary to ensure that the materials provided will meet the project objectives. Equipment/materials typically provided by the driller could include:

- Drilling equipment required by the ASTM standard guidance document D1586, when performing split-spoon sampling;
- Disposable plastic liners (when drilling with direct-push equipment);
- Drums for investigation derived waste;

- Drilling and sampling equipment decontamination materials;
- Decontamination pad materials, if required; and
- Well construction materials.

5 CAUTIONS

Prior to beginning field work, underground utilities in the vicinity of the drilling areas will be delineated by the drilling contractor or an independent underground utility locator service. See appropriate guidance for proper utility clearance protocol.

Prior to beginning field work, contact the project technical team to ensure that all field logistics (e.g., access issues, health and safety issues, communication network, schedules, etc.) and task objectives are clearly understood by all team members.

Some regulatory agencies require a minimum annular space between the well or permanent casing and the borehole wall. When specified, the minimum clearance is typically 2 inches on all sides (e.g., a 2-inch diameter well requires a 6-inch diameter borehole). In addition, some regulatory agencies have specific requirements regarding grout mixtures. Determine whether the oversight agency has any such requirements prior to finalizing the drilling and well installation plan.

If dense non-aqueous phase liquids (DNAPL) are known or expected to exist at the site, refer to the project specific documents for additional details regarding drilling and well installation to reduce the potential for inadvertent DNAPL remobilization.

Similarly, if light non-aqueous phase liquids (LNAPLs) are known or expected to be present as “perched” layers above the water table, refer to the DNAPL Contingency Plan. Follow the general provisions and concepts in the DNAPL contingency plan during drilling above the water table at known or expected LNAPL sites.

Avoid using drilling fluids or materials that could impact groundwater or soil quality, or could be incompatible with the subsurface conditions.

Similarly, consider the compatibility between the well materials and the surrounding environment. For example, PVC well materials are not preferred when DNAPL is present. In addition, some groundwater conditions leach metals from stainless steel or are corrosive to metal well materials. If questions arise, contact the CPM and/or project technical lead to discuss.

Water used for drilling and sampling of soil or bedrock, decontamination of drilling/sampling equipment, or grouting boreholes upon completion will be of a quality acceptable for project objectives. Testing of water supply should be considered.

Specifications of materials used for backfilling the borehole will be obtained, reviewed and approved to meet project quality objectives. Bentonite is not recommended where DNAPLs are likely to be present or in groundwater with high salinity. In these situations, neat cement grout is preferred.

As noted above, coated bentonite pellets will not be used in monitoring well construction, as the coating could impact the water quality in the completed well.

Heat of hydration during neat cement grout curing must be considered to avoid damage to PVC well materials. The annular space for a typical monitoring well is small enough that heat of hydration should not create excessive temperature increases which may damage PVC well material. However, washouts in the borehole can lead to thick accumulations of grout which can produce enough heat during curing to weaken and potentially damage PVC casing. If heat of hydration is a concern, contact the project technical lead to address the issue.

6 HEALTH AND SAFETY CONSIDERATIONS

Field activities associated with monitoring well installation will be performed in accordance with a site-specific HASP, a copy of which will be present on site during such activities.

7 PROCEDURE

The procedures for installing groundwater monitoring wells are presented below:

Hollow-Stem Auger, Drive-and-Wash, Spun Casing, Fluid/Mud Rotary, Rotasonic, and Dual-Rotary Drilling Methods

1. Prior to monitoring well installation, determine the expected volumes of filter pack and seal materials including bentonite (if applicable) and grout (neat cement or cement-bentonite).
2. Locate boring/well location, establish work zone, and set up sampling equipment decontamination area.
3. Advance boring to desired depth. Collect soil and/or bedrock samples at appropriate interval as specified in the Work Plan (or equivalent) and/or FSP. Collect, document, and store samples for laboratory analysis as specified in the Work Plan and/or FSP. Decontaminate equipment between samples in accordance with the Work Plan (or equivalent) and/or FSP. A common sampling method that produces high-quality soil samples with relatively little soil disturbance is described in ASTM D1586 – *Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils* (ASTM D1586). Split-spoon samples are obtained during drilling using hollow-stem auger, drive-and-wash, spun casing, and fluid/mud rotary. Rotasonic drilling produces soil cores that, for the most part, are relatively undisturbed, but note that when drilling in consolidated or finer-grained sediment the vibratory action during core barrel advancement may create secondary fractures or breaks. Dual-rotary removes cuttings by compressed air or water/mud and allow only a general assessment of geology.
4. Describe each soil sample as outlined in the appropriate project records. Record descriptions in the field notebook and/or personal digital assistant (PDA). It is also beneficial to photo document the samples. It should be noted that PDA logs must be electronically backed up and transferred to a location accessible to other project team members as soon as feasible to retain and protect the field data. During soil boring advancement, document all drilling events in field notebook, including blow counts (number of blows required to advance split-spoon sampler in 6-inch increments) and work stoppages. Blow counts will not be available if Rotasonic, dual-rotary, or direct-push methods are used.

5. If it is necessary to install a monitor well into a permeable zone below a confining layer, particularly if the deeper zone is believed to have water quality that differs significantly from the zone above the confining layer, then a telescopic well construction should be considered. In this case, the borehole is advanced approximately 3 to 5 feet into the top of the confining layer, and a permanent casing (typically PVC, black steel or stainless steel) is installed into the socket drilled into the top of the confining layer. The casing is then grouted in place. The preferred methods of grouting telescoping casings include: pressure-injection grouting using an inflatable packer installed temporarily into the base of the casing, such that grout is injected out the bottom of the casing until it is observed at ground surface outside the casing; displacement-method grouting (also known as the Halliburton method), which entails filling the casing with grout and displacing the grout out the bottom of the casing by pushing a drillable plug, typically made of wood to the bottom of the casing, following by tremie grouting the remainder of the annulus outside the casing; or tremie grouting the annulus surrounding the casing using a tremie pipe installed to the base of the borehole. In all three cases, the casing is grouted to the ground surface, and the grout is allowed to set prior to drilling deeper through the casing. Site-specific criteria and work plans should be created for the completion of non-standard monitoring wells, including telescopic wells.

6. Before installing a screened, it is important to confirm that the borehole has been advanced into the targeted saturated zone. This is particularly important for wells installed to monitor the water table and/or the shallow saturated zone, as the capillary fringe may cause soils above the water table to appear saturated. If one or more previously installed monitoring wells exist nearby, use the depth to water at such well(s) to estimate the water-table depth at the new borehole location.

   To verify that the borehole has been advanced into the saturated zone, it is necessary to measure the water level in the borehole. For boreholes drilled without using water (e.g., hollow-stem auger, cable-tool, air rotary, air hammer), verify the presence of groundwater (and /or LNAPL, if applicable) in the borehole using an electronic water level probe, oil-water interface probe, or a new or decontaminated bailer. For boreholes drilled using water (e.g., drive and wash, spun-casing with roller-bit wash, Rotasonic, or water rotary with core or roller bit), monitor the water level in the borehole as it re-equilibrates to the static level. In low-permeability units like clay, fine-grained glacial tills, shale and other bedrock formations, it may be necessary to wait overnight to allow the water level to equilibrate. Document depth to water in the borehole on the appropriate field forms and field notebook. If there are questions concerning the depth of the well/screen interval, consult with the project technical lead prior to finalizing well depth/screen interval. To the extent practicable, ensure that the depth of the well below the apparent water table is deep enough so that the installed well can monitor groundwater year-round, accounting for seasonal water-table fluctuations. When in doubt, err on the side of slightly deeper well installation.

7. Upon completing the borehole to the desired depth, if a screened well construction is desired, install the monitoring well by lowering the screen and casing assembly with sump through the augers or casing. Monitoring wells typically will be constructed of 2-inch-diameter (although sometimes 4-inch), flush-threaded PVC or stainless steel slotted or wire wrapped well screen and blank riser casing. Smaller diameters may be used if wells are installed using direct-push methodology or if multiple wells are to be installed in a single borehole. The screen length will be specified in the Work Plan (or equivalent) or FSP based on regulatory requirements and specific monitoring objectives. Monitoring well screens are usually 5 to 10 feet long, but may be up to 25 feet long in very low permeability, thick

geologic formations. The screen length will depend on the purpose for the well and the objectives of the groundwater investigation and will (in most cases) be determined prior to the field mobilization.

The slot size and filter pack gradation should be predetermined in the Work Plan (or equivalent) or FSP and based on site-specific grain-size analysis (sieve analysis) or other geologic considerations or monitoring objectives. Typically, slot sizes for monitoring wells will range from 0.010 inches to 0.020 inches while the filter pack will be 20-40, Morie No. 0, or equivalent. In very fine-grained formations where sample turbidity needs to be minimized, it may be preferred to use a 0.006-inch slot size and 30-65, Morie No. 00, or equivalent filter pack. Alternatively, where monitoring wells are installed in coarse-grained deposits and higher well yield is required, a 0.020-inch slot size and 10-20, Morie No. 1, or equivalent filter pack may be preferred. If the screen slot size and filter pack have not been based on site-specific grain-size analysis, consider collecting soil samples during well installation so future wells can be properly designed.

A blank sump may be attached below the well screen if the well is being installed for DNAPL recovery/monitoring purposes. If so, the annular space around the sump may be backfilled with neat cement grout using a tremie to the bottom of the well screen prior to placing the filter pack around the screen. A blank riser will extend from the top of the screen to approximately 2.5 feet above grade or, if necessary, just below grade where conditions warrant a flush-mounted monitoring well. For wells greater than 50 feet deep, centralizers may be desired to assist in centering the monitoring well in the borehole during construction.

8. When the monitoring well assembly has been set in place and the grout has been placed around the sump (if any), place a washed silica filter pack in the annular space from the bottom of the boring to a height of 1 to 2 feet above the top of the well screen (following specifications in the Work Plan) using a tremie. The filter pack is placed and drilling equipment extracted in increments until the top of the sand pack is at the appropriate depth. Verify that the expected volume of filter pack matches with the actual amount installed. There can be differences due to irregularities in the borehole. Washout of the borehole will result in the need for greater than calculated well materials. If a difference of more than 10% is noted, consult with the project technical team. The filter pack will be consistent with the screen slot size and the soil particle size in the screened interval, as specified in the Work Plan (or equivalent) or FSP. The well should be gently surged to prevent filter pack material bridging and to settled the filter pack prior to well seal installation.
9. A hydrated bentonite seal (a minimum of 2 feet thick) will then be placed in the annular space above the sand pack (alternatively, in some cases a fine sand seal may be installed instead of bentonite—follow the specifications in the Work Plan). If non-hydrated bentonite is used, the bentonite should be permitted to hydrate in place for a minimum of 30 minutes before proceeding. *No coated bentonite pellets will be used in monitoring well drilling or construction*. Potable water may be added to hydrate the bentonite if the seal is above the water table. Monitor the placement of the sand pack and bentonite with a weighted tape measure.
10. During the extraction of the augers or casing, a cement/bentonite or neat cement grout will be placed in the annular space from the bentonite seal to a depth approximately 2 ft. below groundwater surface (bgs) or as specified in the Work Plan (or equivalent). As with the filter pack, it is recommended that seal material be placed with a tremie pipe. Ensure that seal materials are mixed at the proper ratios with water following manufacturer’s recommendations.

11. Install the monitoring well completion as specified Work Plan (or equivalent). Typical completions are a locking, steel protective casing (extended at least 1.5 feet below grade and 2 feet above grade) over the riser casing and secure with a neat cement seal. Alternatively, for flush-mount completions, place a steel curb box with a bolt-down lid over the riser casing and secure with a neat cement seal. In either case, the cement seal will extend approximately 1.5 to 2.0 feet below grade and laterally at least 1 foot in all directions from the protective casing, and should slope gently away to promote drainage away from the well.
12. Monitoring wells should be labeled using indelible ink or paint with the appropriate designation on both the inner and outer well casings or inside of the curb box lid.
13. When an above-grade completion is used, the riser will be sealed using an expandable locking plug and the top of the well will be vented by drilling a small-diameter (1/8 inch) hole near the top of the well casing or through the locking plug, or by cutting a vertical slot in the top of the well casing. When a flush-mount installation is used, the riser will be sealed using an unvented, expandable locking plug.
14. During well installation, record construction details and actual measurements relayed by the drilling contractor and tabulate materials used (e.g., screen and riser footages; bags of bentonite, cement, and sand) in the field notebook as well as appropriate field forms.
15. After completing the well installation, lock the well, clean the area, and dispose of materials in accordance with the procedures outlined in Section 7 below.

Direct-Push Method

The direct-push drilling method may also be used to complete soil borings and install monitoring wells. Examples of this technique include the Diedrich ESP vibratory probe system, GeoProbe®, or AMS Power Probe® dual-tube system. Environmental probe systems typically use a hydraulically operated percussion hammer. Depending on the equipment used, the hammer delivers 140- to 350-foot pounds of energy with each blow. The hammer provides the force needed to penetrate very stiff to medium dense soil formations. The hammer simultaneously advances an outer steel casing that contains a dual-tube liner for sampling soil. The outside diameter (OD) of the outer casing ranges from 1.75 to 2.4 inches and the OD of the inner sampling tube ranges from 1.1 to 1.8 inches. The outer casing isolates shallow layers and permits the unit to continue to probe at depth. The double-rod system provides a borehole that may be tremie-grouted from the bottom up. Alternatively, the inside diameter (ID) of the steel casing provides clearance for the installation of small-diameter (e.g., 0.75- to 1-inch ID) micro-wells. The procedures for installing monitoring wells in soil using the direct-push method are described below.

1. Locate boring/well location, establish work zone, and set up sample equipment decontamination area.
2. Advance soil boring to designated depth, collecting samples at intervals specified in the Work Plan (or equivalent). Samples will be collected using dedicated, disposable, plastic liners. Describe samples in accordance with the procedures outlined in Step 3 above. Collect samples for laboratory analysis as specified in the Work Plan (or equivalent) and/or FSP.
3. Upon advancing the borehole to the desired depth, install the micro-well through the inner drill casing. The micro-well will consist of approximately 1-inch ID PVC or stainless steel slotted screen and blank riser. The sand pack, bentonite seal, and cement/bentonite grout will be installed as described, where applicable, in Steps 9 through 11 above.

4. Install protective steel casing or flush-mount, as appropriate, as described in Step 12 above. During well installation, record construction details and tabulate materials used in field notebook as well as appropriate field forms.
5. After completing the well installation, lock the well, clean the area, and dispose of materials in accordance with the procedures outlined in Section 8 below.

Driven Well Point Installation

Well points will be installed by pushing or driving using a drilling rig or direct-push rig, or hand-driven where possible. The well point construction materials will consist of a 1- to 2-inch-diameter threaded steel casing with either 0.010- or 0.020-inch slotted stainless steel screen. The screen length will vary depending on the hydrogeologic conditions of the site. The casings will be joined together with threaded couplings and the terminal end will consist of a steel well point. Because they are driven or pushed to the desired depth, well points do not have annular backfill materials such as sand pack or grout.

8 WASTE MANAGEMENT

Investigation-derived wastes (IDW), including soil cuttings and excess drilling fluids (if used), decontamination liquids, and disposable materials (well material packages, PPE, etc.), will be placed in clearly labeled, appropriate containers, or managed as otherwise specified in the Work Plan (or equivalent), FSP, and/or IDW management guidance document.

9 DATA RECORDING AND MANAGEMENT

Drilling activities should be documented on appropriate field/log forms as well as in a proper field notebook and/or PDA. Additionally, all documents (and photographs) should be scanned and electronically filed in the appropriate project directory for easy access. Pertinent information will include personnel present on site, times of arrival and departure, significant weather conditions, timing of well installation activities, soil descriptions, well construction specifications (screen and riser material and diameter, sump length, screen length and slot size, riser length, sand pack type), and quantities of materials used. In addition, the locations of newly-installed wells will be documented photographically or in a site sketch. If appropriate, a measuring wheel or engineer’s tape will be used to determine approximate distances between important site features.

The well location, ground surface elevation, and inner and outer casing elevations will be surveyed using the method specified in the site Work Plan (or equivalent). Generally, a local baseline control will be set up. This local baseline control can then be tied into the appropriate vertical and horizontal datum, such as the National Geodetic Vertical Datum of 1929 or 1988 and the State Plane Coordinate System. At a minimum, the elevation of the top of the inner casing used for water-level measurements should be measured to the nearest 0.01 foot. Elevations will be established in relation to the National Geodetic Vertical Datum of 1929. A permanent mark will be placed on top of the inner casing to mark the point for water-level measurements.

10 QUALITY ASSURANCE

All drilling equipment and associated tools (including augers, drill rods, sampling equipment, wrenches, and any other equipment or tools) that may have come in contact with soil will be cleaned in accordance with the procedures outlined in the appropriate SOP. Well materials will also be cleaned prior to well installation.

11 REFERENCES

American Society for Testing Materials (ASTM) D5092 - *Standard Practice for Design and Installation of Ground Water Monitoring Wells*. American Society for Testing Materials. West Conshohocken, Pennsylvania.

American Society of Testing and Materials (ASTM) D1586 - *Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils*. American Society for Testing Materials. West Conshohocken, Pennsylvania.

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TGI – Monitoring Well Development

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Reviewed by:		4/12/2022
	Marc Killingstad (Subject Matter Expert)	Date

1 Introduction

This Technical Guidance Instruction (TGI) covers the development of screened wells used for obtaining representative groundwater information and samples from granular aquifers (i.e., monitoring wells).

Note: This TGI only applies to monitoring well development and not remediation (injection/extraction) well development.

2 Intended Use and Responsibilities

This document describes general and/or specific procedures, methods, actions, steps, and considerations to be used and observed by Arcadis staff when performing work, tasks, or actions under the scope and relevancy of this document. This document may describe expectations, requirements, guidance, recommendations, and/or instructions pertinent to the service, work task, or activity it covers.

It is the responsibility of the Arcadis Certified Project Manager (CPM) to provide this document to the persons conducting services that fall under the scope and purpose of this procedure, instruction, and/or guidance. The Arcadis CPM will also ensure that the persons conducting the work falling under this document are appropriately trained and familiar with its content. The persons conducting the work under this document are required to meet the minimum competency requirements outlined herein, and inquire to the CPM regarding any questions, misunderstanding, or discrepancy related to the work under this document.

This document is not considered to be all inclusive nor does it apply to all projects. It is the CPM's responsibility to determine the proper scope and personnel required for each project. There may be project- and/or client- and/or state-specific requirements that may be more or less stringent than what is described herein. The CPM is responsible for informing Arcadis and/or Subcontractor personnel of omissions and/or deviations from this document that may be required for the project. In turn, project staff are required to inform the CPM if or when there is a deviation or omission from work performed as compared to what is described herein.

In following this document to execute the scope of work for a project, it may be necessary for staff to make professional judgment decisions to meet the project's scope of work based upon site conditions, staffing expertise, regulation-specific requirements, health and safety concerns, etc. Staff are required to consult with the CPM when or if a deviation or omission from this document is required that has not already been previously approved by the CPM. Upon approval by the CPM, the staff can perform the deviation or omission as confirmed by the CPM.

3 Scope and Application

The objectives of monitoring well development are:

1. Repair damage to the borehole wall from drilling that can include clogging, smearing or compaction of aquifer materials;
2. Remove fine-grained sediment from the formation and filter pack that may result in high turbidity levels in groundwater samples;
3. To re-sort formation and filter pack material adjacent to the well screen;

4. To recover any drilling fluids (if used) that may affect the permeability of the formation and filter pack or alter the water quality around the well; and
5. To optimize the well efficiency and hydraulic communication between the well screen and the formation.

Successful monitoring well development is dependent on the following:

1. Hydrostratigraphy – Permeable formations containing primarily sand and gravel are more easily developed due to lower percentages of silt and clay material. Water in permeable formations can be moved in and out of the screen and/or through the formation easier than in less permeable deposits.
2. Well Diameter – Development tooling including brushes, surge blocks, pumps and jetting tools are more readily available for wells 4 inches in diameter and greater.
3. Well Design – Wells with filter packs and screens designed to match the formation through the analysis of formation sieve samples are easier to develop. An important aspect to well design is to minimize the size of the annular space between the formation and well screen. Adequate room must be allowed for the proper installation of well materials, but not too large as to prevent/reduce communication with the surrounding formation.
4. Drilling Methods – Different drilling methods result in varying amount of borehole damage and, therefore, impact the degree to which development will be successful.

Well development methods for monitoring wells include the following:

1. Bailing – Use of a bailer to remove water and sediment from the well casing. This technique does little to remove fines from the filter pack and may lead to bridging of sediment since the flow is in only one direction, toward the well screen. The most effective use of bailing during monitoring well development is in conjunction with other methods (e.g., surging/swabbing) to remove fines accumulated in the monitoring well between cycles of other development methods.
2. Pumping/over pumping – Use of a pump to remove water and sediment from the well casing, over pumping involves pumping the well at a rate that exceeds the design capacity of the well. Similar to bailing, this technique does little to remove fines from the filter pack and may lead to bridging of sediment since the flow is in only one direction, toward the well screen. Small diameter monitoring wells have the additional constraint on pump size and flow rates which further limit the effectiveness of this methodology.
3. Backwashing (rawhiding) – Consists of starting and stopping a pump intermittently to produce rapid pressure changes in a well. This method can produce better results than pumping alone since the procedure involves movement of the water in and out of the screen and formation. However, in many cases the surging action is not rigorous enough to fully develop the well and might be considered the final phase of development after a more rigorous method has been used. Again, small diameter monitoring wells have the additional constraint on pump size and flow rates which further limit the effectiveness of this methodology.
4. Surging/swabbing – Use of a mechanical surge block or swabbing tool to operate like a piston with an up and down motion. The downstroke causes a backwash action that breaks up bridged sediment and the upstroke pulls the dislodged sediment into the well. This method works well for both small and large diameter monitoring wells. Care should be taken on the downstroke so as not to force fines back into the formation, frequent pumping/purging during surging help to keep fines out of the well. Double surge blocks are recommended, and this is typically the most effective method for development of monitoring wells.

5. Jetting – Use of a tool fitted with nozzles that direct streams of water horizontally into well screens at high velocity. Due to the size of the tooling, this method is better suited for wells 4 inches in diameter and larger. The method is also more effective with wire-wrapped/continuous slot screens due to the increased open area. Jetting requires specialized equipment and concurrent pumping to prevent reintroducing fines into the filter pack. Additionally, depending on the configuration of the tool, jetting may require subsequent surging/pumping to remove fines dislodged in the filter pack and formation. Typically, jetting is not a preferred option for new well development but may be effective as part of a re-development/rehabilitation effort.

For most situations, surging/swabbing coupled with bailing or pumping to remove dislodged materials is recommended.

Final well development for properly designed and constructed monitoring wells may begin after the annular seal materials have been installed and allowed to cure, since these wells are designed to retain approximately 90% of the filter pack material. This cure time is typically at least 24 to 48 hours after the sealing materials have been installed.

This TGI is meant to provide a general guide for proper development of newly installed monitoring wells.

A site-specific field implementation plan (FIP) for well installation and development detailing the specific methods and tools is strongly recommended to provide site-specific instruction and guidance.

4 Personnel Qualifications

Generally, Arcadis field personnel will have completed or are in the process of completing site-specific training as well as having current health and safety training as required by Arcadis, client, and/or state/federal regulations, such as 40-hour HAZWOPER training and/or OSHA HAZWOPER site supervisor training. Arcadis personnel will also have current training as specified in the Health and Safety Plan (HASP) which may include first aid, cardiopulmonary resuscitation (CPR), Blood Borne Pathogens (BBP) as needed. In addition, Arcadis field sampling personnel will be knowledgeable in the relevant processes, procedures, and TGIs and possess the demonstrated required skills and experience necessary to successfully complete the desired field work. The HASP and other documents will identify other training requirements and access control requirements.

The designated Field Manager is responsible for periodic observation of field activities and review of field generated documentation associated with this TGI. The Field Manager is also responsible for implementation of corrective action if problems occur (e.g., retraining personnel, additional review of work plans and TGIs, variances to QC sampling requirements, issuing non-conformances, etc.).

Prior to mobilizing to the field, personnel will review and be thoroughly familiar with relevant site-specific documents including but not limited to the task-specific work plan or field implementation plan (FIP)/field sampling plan/work plan, Quality Assurance Project Plan (QAPP), HASP, historical information, and other relevant site documents.

Field personnel assigned to install and develop monitoring wells are responsible for completing their tasks in accordance with the specifications outlined in this TGI and other appropriate and relevant guidelines.

Monitoring well development activities will be performed by persons who have been trained in proper well development procedures under the guidance of an experienced field geologist, engineer, or technician.

5 Equipment List

Required equipment depends on the selected method and should be detailed in the site-specific FIP; however, the following are typically required.

- Approved site-specific Health and Safety Plan (HASP)
- Approved site-specific FIP which will include site map, well construction information/borehole information, and development plan
- Personal protective equipment (PPE) and health and safety equipment, as required by the HASP
- Field notebook and/or smart device (phone or tablet)
- Cleaning/decontamination equipment
  - Non-phosphate laboratory soap (Alconox or equivalent), brushes, clean buckets or clean wash tubs—new buckets or tubs will be purchased if it cannot be determined if the presentitems are clean
  - Distilled or de-ionized water for equipment decontamination
- Monitoring well keys
- Water-level meter
- Down-hole multiparameter water quality sonde (e.g., YSI)
- Plastic sheeting (e.g., Weatherall Visqueen) to protect all down-hole sampling equipment fromcontact with potential sources of contamination
- Well development forms/logs
- Well construction logs/diagrams
- Weighted tape (of sufficient length for maximum site depth)
- Turbidity meter
- Camera
- Watch/timing device

6 Cautions

Different USEPA regions and/or state regulatory agencies may stipulate deviations from this document. It is the responsibility of the Project Team (Project Manager and Technical Lead) to be fully aware of the requirements from the applicable regulatory framework.

Prior to beginning field work, the project technical team will ensure that all field logistics (e.g., access issues, health and safety issues, communication network, schedules, etc.) and task objectives are clearly understood by all team members. An internal call with the project technical team to review the FIP/field sampling plan/work plan scope and objectives is strongly recommended prior to mobilization to ensure that the field work will be effectively and efficiently executed.

Where surging is performed to assist in removing fine-grained material from the sand pack, surging must be performed in a gentle manner. Excessive suction could promote fine-grained sediment entry into the outside of the sand pack from the formation.

Avoid using development fluids or materials that could impact groundwater or soil quality or could be incompatible with the subsurface conditions.

In some cases, it may be necessary to add potable water to a well to allow surging and development, especially for new monitoring wells installed in low permeability formations. Before adding potable water to a well, the Certified Project Manager (CPM) and/or Project Hydrogeologist must be notified, and the CPM shall make the decision regarding the appropriateness and applicability of adding potable water to a well during well development procedures. If potable water is to be added to a well as part of development, the potable water source should be sampled and analyzed for constituents of concern, and the results evaluated by the CPM prior to adding the potable water to the well. If potable water is added to a well for development purposes, at the end of development the well will be purged dry to remove the potable water, or if the well no longer goes dry then the well will be purged to remove at least three times the volume of potable water that was added

7 Health and Safety Considerations

Field activities associated with monitoring well development will be performed in accordance with a site-specific HASP, a copy of which will be present on site during such activities.

Appropriate PPE will be worn at all times in line with the task and the site-specific HASP.

Review all site-specific and procedural hazards as they are provided in the HASP, and review Job Safety Analysis (JSA) documents in the field each day prior to beginning work.

Access to well locations may expose field personnel to hazardous materials such as contaminated groundwater or NAPL (e.g., petroleum hydrocarbons, chlorinated solvents). Other potential hazards include pressurized wells, stinging insects that may inhabit well heads, other biological hazards (e.g., ticks in long grass/weeds around wellhead), and potentially the use of sharp cutting tools (scissors, knife). Open well caps slowly and keep face and body away while allowing to vent any built-up pressure to vent. Only use non-toxic peppermint oil spray for stinging insect nests. Review client-specific health and safety requirements, which may preclude the use of fixed/folding-blade knives and use appropriate hand protection.

Do not enter confined spaces unless following appropriate confined space entry procedures specified in the HASP.

If thunder or lightning is present, discontinue sampling until 30 minutes have passed after the last occurrence of thunder or lightning.

8 Procedure

As indicated above, for most monitoring wells, gentle surging coupled with bailing or pumping to remove dislodged sediment is recommended.

8.1 Preliminary Well Development

After installation of the primary filter pack around the monitoring well screen, preliminary well development is recommended be performed to ensure that the filter pack settles and does not bridge within the annular space. The preliminary well development steps are as follows:

1. Measure and record depth to water, total depth of well, and depth to top of the sand pack in the annulus.
2. Use steel or weighted bailer to remove any fines that have accumulated in the bottom of the well.
3. Lower an appropriately sized double-surge block into the screened portion of the well on a rigid pipe or high-density tubing and gently cycle up and down to force water in and out of the screen slots and formation. A two-foot throw is recommended (use tape or chalk marks on the pipe or tubing); however, the entire length of well screen must be gently surged.
4. Start above the screen and gently surge over two-foot intervals while working down to the screen bottom.

NOTE: Care must be taken not to surge the well too aggressively at this point as the casing is not well-supported and damage could occur. The objective is to create enough surging action to settle the primary filter pack and provide some preliminary removal of accumulated materials before final development.

NOTE: If possible, ensure that the developer surges the block upward faster than downward to pull the fines out of the filter pack, instead of forcing them back in (and allowing for proper settlement).

5. Monitor the total depth of the well periodically during surging to ensure that we are not pulling excessive amounts of filter pack through the screen and remove any debris accumulated in the well with a weighted bailer or pump.
6. Re-measure the top of the sand in the annulus to see if more sand pack is necessary. Remove any fines that have accumulated out of the well using a submersible pump or weighted bailer.

NOTE: If the monitoring well was drilled using mud rotary drilling methodology or if significant fines were encountered during the well installation, consider adding a commercially available 'mud' dispersant (e.g., AQUA-CLEAR PFD, Nu Well 220, etc.) as part of the preliminary development. This will help to break up the 'skin' along the borehole wall created by either the drilling fluid or smearing during drilling and assist in final development. Follow manufacturer's directions for dosing, and the mixture should be worked through the entire saturated screen interval by gently surging or brushing.

8.2 Final Well Development

After sufficient time has passed to allow for proper curing of the well seal/grout (i.e., 24 to 48 hours), final well development can be performed. Final well development steps are as follows:

1. Don appropriate PPE (as required by the site-specific HASP).
2. Place plastic sheeting around the well.
3. Clean all equipment entering each monitoring well, except for new, disposable materials that have not been previously used.
4. Open the well cover while standing upwind of the well, remove well cap. Insert PID probe approximately 4 to 6 inches into the casing or the well headspace and cover with gloved hand. Record the PID reading in

the field notebook. If the well headspace reading is less than 5 PID units, proceed; if the headspace reading is greater than 5 PID units, screen the air within the breathing zone. If the PID reading in the breathing zone is below 5 PID units, proceed. If the PID reading is above 5 PID units, move upwind from well for 5 minutes to allow the volatiles to dissipate. Repeat the breathing zone test. If the reading is still above 5 PID units, don the appropriate respiratory protection in accordance with the requirements of the HASP. Record all PID readings.

5. Obtain an initial measurement of the depth to water and the total well depth from the reference point at the top of the well casing. Record these measurements in the field logbook. It is recommended to use a weighted tape for the total well depth measurement.
6. The depth to the bottom of the well should be sounded and then compared to the completion form or construction diagram for the well. Any discrepancies should be reported immediately to the CPM and/or Project Hydrogeologist. If sand or sediment is present inside the well, it should first be removed by bailing. Do not insert bailers, pumps, or surge blocks into the well if obstructions, parting of the casing, or other damage to the well is suspected. Instead report the conditions to the CPM and/or Project Hydrogeologist and obtain approval to continue or cease well development activities.

NOTE: If the monitoring well was drilled using mud rotary drilling methodology or if significant fines were encountered during the well installation, it is recommended that a commercially available 'mud' dispersant (e.g., AQUA-CLEAR PFD, Nu Well 220, etc.) be included as part of the final well development to effectively break up the 'skin' along the borehole wall created by either the drilling fluid or smearing during drilling.

Per manufacturer's instructions, the general procedure for adding dispersant is as follows:

- i. *Determine volume of water in screen area and double the calculated volume to account for water in gravel pack and formation interface*
- ii. *Once the water volume is determined, calculate the required treatment volume of dispersant need per manufacturer's recommendations*
- iii. *Mix thoroughly before introducing into well*
- iv. *The preferable application method utilizes a tremie line with the product applied into the screened area*
- v. *Mixture should be thoroughly blended in well, then agitated via surging/swabbing/brushing repeatedly (e.g., every two hours) for a period of up to 24 hours*
- vi. *The dispersant should sit for at least 6 to 8 hours or overnight before continuing well development activities*

7. After allowing the dispersant to sit for the required time (if dispersant is used), start the mechanical development by lowering an appropriately sized double-surge block (or similar) into the well on a rigid pipe or high-density tubing.
    - i. Surging should start above the screen to reduce the possibility of "sand-locking" the surge block. Initial surging should be with a long stroke and at a slow rate (20 to 25 strokes per minute)
    - ii. After surging above the screen, the well should be cleaned via bottom-loading bailer, submersible pump, or inertia pump tubing with check valve to the bottom of the well

    iii. Begin surging at the lower end of the screen, gradually working upward, surging in 2-ft intervals until the entire screen has been developed.
    iv. Surge the well a minimum of 10 throws per 2-ft screen interval.
    v. Each interval may require several surge cycles to achieve the best development.
    vi. The entire length of well screen must be surged.
    vii. Ensure that the developer surges the block upward faster than downward to pull the fines out of the filter pack, instead of forcing them back in (and allowing for proper settlement)
    viii. measure total depth of the well periodically during surging to ensure that excessive amounts of sediment are not being pulled through the screen. Remove any debris accumulated in the well via simultaneous airlifting (if a combined tool is available) or with bailing/pumping.

8. After completing a cycle of surging, lower a bottom-loading bailer, submersible pump, or inertia pump tubing with check valve to the bottom of the well and gently bounce on the bottom of the well to collect/remove accumulated sediment, if any. Remove and empty the bailer, if used. Repeat until the bailed/pumped water is free of excessive sediment and contact at the bottom of the well feels solid. Alternatively, measurement of the well depth with a weighted tape can be used to verify that sediment and/or silt has been removed to the extent practicable, based on a comparison with the well installation log or previous measurement of total well depth.
9. After surging the well for a minimum of two cycles and removing excess accumulated sediment from the bottom of the well, re-measure the depth-to-water and the total well depth from the reference point at the top of the well casing. Record these measurements in the field log book.
10. Remove formation water by pumping/bailing.
    i. Where pumping is used, measure and record the pre-pumping water level.
    ii. Operate the pump at a relatively constant rate
    iii. Measure the pumping rate using a calibrated container and stopwatch, and record the pumping rate in the field log book
    iv. Measure and record the water level in the well at least once every 5 minutes during pumping
    v. Record any relevant observations in terms of color, visual level of turbidity, sheen, odors, etc.
    vi. Pump or bail until termination criteria specified in the site-specific FIP are reached
    vii. Record the total volume of water purged from the well

NOTE: The FIP may also specify a maximum turbidity requirement for completion of development. Unless otherwise specified the maximum turbidity should be 50 NTUs or less

11. While developing, take periodic water level measurements (at least one every five minutes) to determine if drawdown is occurring and record the measurements on the Well Development Log.
12. While developing, calculate the rate at which water is being removed from the well. Record the volume on the Well Development Log.
13. While developing, water is also periodically collected directly from the well or bailer discharge and readings taken of the indicator parameters: pH, specific conductance, and temperature. Development is

considered complete when the indicator parameters have stabilized (i.e., three consecutive pH, specific conductance, and temperature readings are within tolerances specified in the project work plans or within 10% if not otherwise specified), the extracted water is clear and free of fine sediment and most importantly, when acceptable volume of water has been removed and/or a sufficient amount of surging has been performed.

14. In certain instances, for slow recharging wells, the parameters may not stabilize. In this case, well development is considered complete when minimal amounts of fine-grained sediments are recovered, and an acceptable volume of water has been removed.
15. If the well goes dry, stop pumping or bailing. Note the time that the well went dry. After allowing the well to recover, note the time and depth to water. Resume pumping or bailing when sufficient water has recharged the well.
16. Contain all development water in appropriate containers.
17. When complete, secure the lid back on the well.
18. Place disposable materials in plastic bags for appropriate disposal and decontaminate reusable, downhole pump components and/or bailer

9 Waste Management

Investigation-Derived Waste (IDW), including purge water and decontamination liquids, will be stored on site in appropriately labeled containers and disposed of properly. Disposable materials will be stored and disposed of separately. Containers must be labeled at the time of collection and will include date, location(s), site name, city, state, and description of matrix contained (e.g., water, PPE). Waste will be managed in accordance with the *TGI – Investigation-Derived Waste Handling and Storage*, the procedures identified in the FIP/field sampling plan/work plan or QAPP as well as state-, federal- or client-specific requirements. Be certain that waste containers are properly labeled and documented in the field log.

10 Data Recording and Management

Digital data collection is the Arcadis standard using available FieldNow® applications that enable real-time, paperless data collection, entry, and automated reporting. Paper forms should only be used as backup to FieldNow® digital data collection and/or as necessary to collect data not captured by available FieldNow® applications. The Field Now® digital form applications follow a standardized approach, correlate to most TGIs and are available to all projects accessible with a PC or capable mobile device. Once the digital forms are saved within FieldNow®, the data is instantly available for review on a web interface. This facilitates review by project management team members and SMEs enabling error or anomalous data detection for correction while the staff are still in the field. Continual improvements of FieldNow® applications are ongoing, and revisions are made as necessary in response to feedback from users and subject matter experts.

All well development activities will be documented on appropriate log forms as well as in a proper field notebook and/or PDA. Additionally, all documents (and photographs) should be scanned and electronically filed in the appropriate project directory for easy access. Pertinent information will include personnel present on site; times of arrival and departure; significant weather conditions; timing of well development activities; development method(s); observations of purge water color, turbidity, odor, sheen, etc.; purge rate; and water levels before, during, and after pumping.

Management of the original documents from the field will be completed in accordance with the site-specific QAPP. Records generated as a result of this TGI will be controlled and maintained in the project record files in accordance with project requirements.

Development activities will be documented on appropriate field logs as well as in a proper field notebook. All field data will be recorded digitally or with indelible ink. Field forms, logs/notes (including daily field and calibration logs), digital records, and chain-of-custody records will be maintained by the field team lead. Any deviations or omissions from this TGI should be documented.

Initial field logs and forms will be transmitted to the Arcadis CPM and/or Technical Lead at the end of each day unless otherwise directed by the CPM. The field team leader retains copies of the field documentation.

11 Quality Assurance

Quality assurance procedures will be conducted in accordance with the Arcadis Quality ManagementSystem or the site-specific QAPP. Refer to the QAPP or FIP/sampling plan/work plan for specific requirements.

12 References

American Society for Testing Materials (ASTM), Designation D5521-05. *Standard Guide for Development of Ground-Water Monitoring Wells in Granular Aquifers*. American Society for Testing Materials. West Conshohocken, Pennsylvania.

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ATTACHMENT B

LAB SAMPLING SOPs
(FERROUS IRON AND PHOSPHATE)

Iron, Ferrous

DOC316.53.01049

1,10-Phenanthroline Method[1]

Method 8146

0.02 to 3.00 mg/L Fe^{2+}

Powder Pillows

Scope and application: For water, wastewater, seawater, brine solutions, produced waters and hydraulic fracturing waters.

[1] Adapted from Standard Methods for the Examination of Water and Wastewater, 15th ed. 201 (1980).

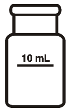
Test preparation

Instrument-specific information

Table 1 shows all of the instruments that have the program for this test. The table also shows sample cell and orientation requirements for reagent addition tests, such as powder pillow or bulk reagent tests.

To use the table, select an instrument, then read across to find the applicable information for this test.

Table 1 Instrument-specific information

Instrument	Sample cell orientation	Sample cell
DR6000 DR3800 DR2800 DR2700 DR1900	The fill line is to the right.	2495402 
DR5000 DR3900	The fill line is toward the user.	
DR900	The orientation mark is toward the user.	2401906 

Before starting

Samples must be analyzed immediately after collection and cannot be preserved for later analysis.

Install the instrument cap on the DR900 cell holder before ZERO or READ is pushed.

For the best results, measure the reagent blank value for each new lot of reagent. Replace the sample with deionized water in the test procedure to determine the reagent blank value. Subtract the reagent blank value from the sample results automatically with the reagent blank adjust option.

Review the Safety Data Sheets (MSDS/SDS) for the chemicals that are used. Use the recommended personal protective equipment.

Dispose of reacted solutions according to local, state and federal regulations. Refer to the Safety Data Sheets for disposal information for unused reagents. Refer to the environmental, health and safety staff for your facility and/or local regulatory agencies for further disposal information.

Items to collect

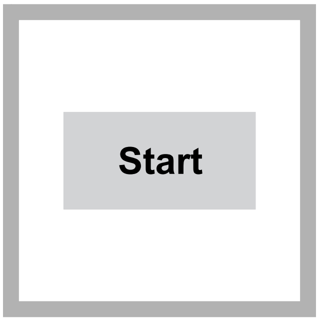
Description	Quantity
Ferrous Iron Reagent Powder Pillows, 25 mL	1
Sample cells. (For information about sample cells, adapters or light shields, refer to Instrument-specific information on page 1.)	2

Refer to Consumables and replacement items on page 4 for order information.

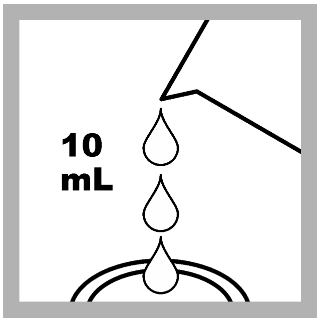
Sample collection

- Analyze the samples immediately. The samples cannot be preserved for later analysis.
- Collect samples in clean glass or plastic bottles with tight-fitting caps. Completely fill the bottle and immediately tighten the cap.
- Prevent agitation of the sample and exposure to air.

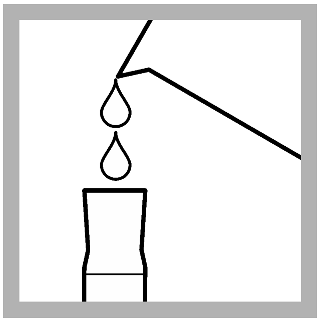
Test procedure



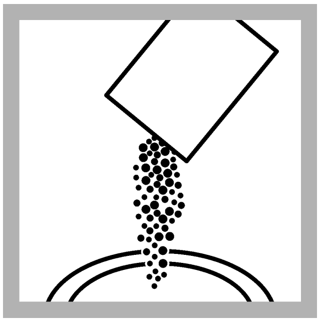
1. Start program **255 Iron, Ferrous**. For information about sample cells, adapters or light shields, refer to Instrument-specific information on page 1.



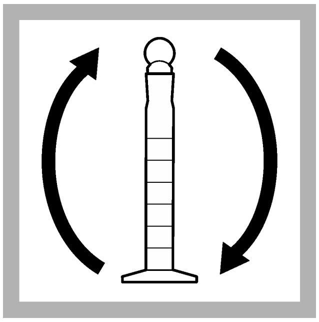
2. Prepare the blank: Fill the sample cell with 10 mL of sample.



3. Prepare the sample: Fill a mixing cylinder to the 25-mL line with sample.

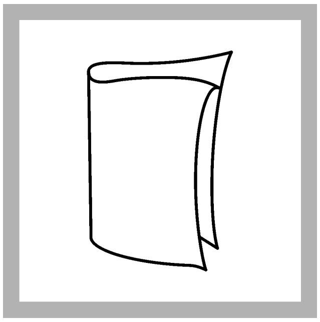


4. Add the contents of one Ferrous Iron Reagent Powder Pillow to the mixing cylinder.
An orange color shows if ferrous iron is present in the sample.

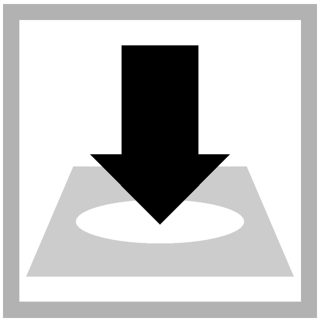


5. Put the stopper on the mixing cylinder. Invert the mixing cylinder several times to mix.
Undissolved powder does not affect accuracy.

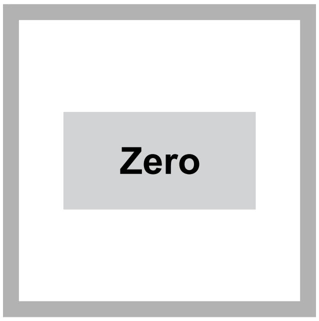
6. Start the instrument timer. A 3-minute reaction time starts.



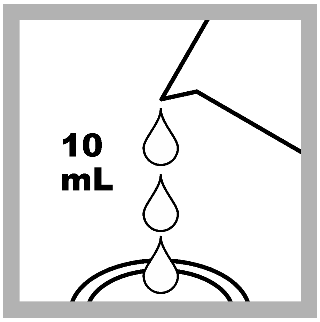
7. When the timer expires, clean the blank sample cell.



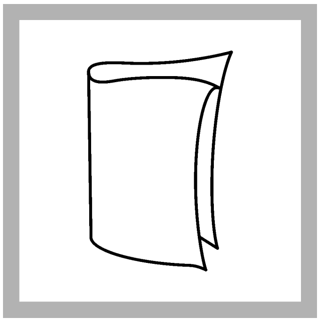
8. Insert the blank into the cell holder.



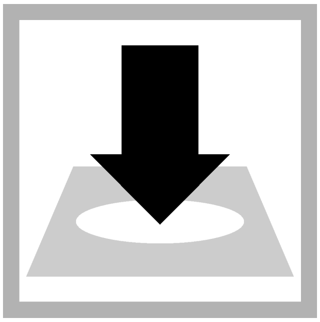
9. Push **ZERO**. The display shows 0.00 mg/L Fe^{2+}.



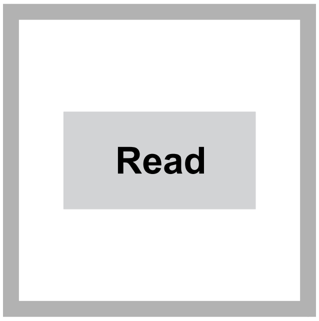
10. Fill a second sample cell with 10 mL of the reacted prepared sample.



11. Clean the prepared sample cell.



12. Insert the prepared sample into the cell holder.



13. Push **READ**. Results show in mg/L Fe^{2+}.

Accuracy check

Standard solution method

Use the standard solution method to validate the test procedure, the reagents and the instrument.

Items to collect:

- Ferrous Ammonium Sulfate, hexahydrate
- 1-L volumetric flask, Class A
- 100-mL volumetric flask, Class A
- 2-mL volumetric pipet, Class A and pipet filler
- Deionized water

1. Prepare a 100-mg/L Fe^{2+} ferrous iron stock solution as follows:
    a. Add 0.7022 g of ferrous ammonium sulfate, hexahydrate into a 1-L volumetric flask.
    b. Dilute to the mark with deionized water. Mix well.
2. Prepare a 2-mg/L ferrous iron standard solution as follows:
    a. Use a pipet to add 2.00 mL of the 100-mg/L Fe^{2+} ferrous iron stock solution into a 100-mL volumetric flask.
    b. Dilute to the mark with deionized water. Mix well. Prepare the standard solution immediately before use.
3. Use the test procedure to measure the concentration of the prepared standard solution.
4. Compare the expected result to the actual result.

    Note: *The factory calibration can be adjusted slightly with the standard calibration adjust option so that the instrument shows the expected value of the standard solution. The adjusted calibration is then used for all test results. This adjustment can increase the test accuracy when there are small variations in the reagents or instruments.*

Method performance

The method performance data that follows was derived from laboratory tests that were measured on a spectrophotometer during ideal test conditions. Users can get different results under different test conditions.

Program	Standard	Precision (95% confidence interval)	Sensitivity Concentration change per 0.010 Abs change
255	2.00 mg/L Fe^{2+}	1.99–2.01 mg/L Fe^{2+}	0.021 mg/L Fe^{2+}

Summary of method

The 1,10-phenanthroline indicator in the Ferrous Iron Reagent reacts with ferrous iron (Fe^{2+}) in the sample to form an orange color in proportion to the iron concentration. Ferric iron (Fe^{3+}) does not react. The ferric iron concentration can be determined by subtracting the ferrous iron concentration from the results of a total iron test. The measurement wavelength is 510 nm for spectrophotometers or 520 nm for colorimeters.

Consumables and replacement items

Required reagents

Description	Quantity/test	Unit	Item no.
Ferrous Iron Reagent Powder Pillow, 25 mL	1	100/pkg	103769

Recommended standards and apparatus

Description	Unit	Item no.
Balance, analytical, 80 g x 0.1 mg 100–240 VAC	each	2936701
Ferrous Ammonium Sulfate, hexahydrate, ACS	113 g	1125614
Flask, volumetric, Class A, 1000 mL glass	each	1457453
Pipet filler, safety bulb	each	1465100
Pipet, volumetric, Class A, 1.00 mL	each	1451535
Water, deionized	4 L	27256
Wipes, disposable	280/pkg	2097000

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08/2019, Edition 11

MEASUREMENT OF ANALYTES USING THE KONELAB ANALYZER

(Methods: Various)

Approvals (Signature/Date):

08/16/2022

Adriana Geiger | Date
Department Manager

Kimberly Chamberlain

08/16/2022

Kimberly Chamberlain | Date
Quality Assurance Manager / Environmental Health and Safety Coordinator

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1.0 Scope and Application

This SOP gives the procedures for the determination of various analytes in water and soil samples using the Konelab Autoanalyzer. The following analytes may be determined:

Analyte	Reference Method	SOP Summary
Ammonia	EPA 350.1 SM4500-NH3 B (AQ prep) COE 3-154 (SO Prep) SM4500-NH3 G (analysis)	Attachment 1a
Chloride	EPA 325.2 EPA 9251 SM4500-Cl$^-$ E	Attachment 1b
Total Chlorine	EPA 5050 / EPA 9251	Attachment 1b
Ferrous iron	SM3500-Fe D (SM 21st Edition) SM3500-Fe B (SM On-Line Edition)	Attachment 1c
Ferric Iron	SM3500-Fe B (Calculation)	Attachment 1c
Hexavalent Chromium	EPA 7196A SM3500-Cr D (SM 21st Edition) SM3500-Cr B (SM On-Line Edition)	Attachment 1d
Trivalent Chromium	EPA 7196A SM3500-Cr B (Calculation)	Attachment 1d
Ortho-Phosphate	EPA 365.1 SM4500-P F	Attachment 1e
Sulfate	EPA 375.4 EPA 9038	Attachment 1f
Total Sulfur	EPA 5050 / EPA 9038	Attachment 1f
BTU	ASTM D240-87	Attachment 1f

The reporting limits (RL), the method detection limits (MDL), and the accuracy and precision criteria associated with each method are provided in the TALS Method Limit Groups (MLGs).

This SOP was written by and for Eurofins Savannah laboratory.

2.0 Summary of Method

Samples and reagents are dispensed into disposable, acrylic multi-cell cuvettes that hold 12 separate analyses. During the incubation period(s), the sample cuvettes are maintained at 37°C. The measurement system is a single channel interference filter photometer with beam splitting reference. The color wheel can be configured with up to 15 different filters. Fiber optic cabling transfers the light signal from the source to the detector. The lamp is a halogen lamp.

The SOP Attachments contain the method parameters required to perform each analysis, a summary of the "chemistries" (reagents, standards, procedures, wavelengths, etc.) used to measure each target analyte, sample preparation information, as well as any method-specific information, requirements, and/or criteria. Method-specific requirements contained in the Attachments supersede the requirements outlined within the body of this SOP.

This SOP is based on the methods listed in Section 1.0 and written for Eurofins Savannah.

3.0 Definitions

Refer to the Glossary Section of the *Quality Assurance Manual* (QAM) for a complete listing of applicable definitions and acronyms.

4.0 Interferences

4.1 Procedural Interferences

4.1.1 Interferences may be caused by contaminants in solvents, reagents, glassware, and other sample processing apparatus and can make identification and/or quantification of the target analytes difficult.

4.1.2 All sample collection containers are single-use disposable containers which limits the potential for contamination. All non-disposable labware must be scrupulously cleaned in accordance with the posted Labware Cleaning Instructions to ensure it is free from contaminants and does not contribute artifacts.

4.1.3 High purity reagents and solvents are used to help minimize interference problems. Acetone, hydrochloric acid, methanol, nitric acid, and sulfuric acid must be verified prior to use in accordance with the Eurofins Environment Testing Solvent Lot Testing Program.

4.1.4 Instrument and/or method blanks are routinely used to demonstrate all reagents and apparatus are free from interferences under the conditions of the analysis.

4.1.5 Refer to the appropriate SOP Attachment, as listed in Section 1, for any method-specific procedural interference information.

4.2 Matrix Interferences

4.2.1 Matrix interferences may be caused by contaminants that are co-extracted from the sample matrix. The sample may require cleanup or dilution prior to analysis to reduce or eliminate the interferences. For this procedure, the only cleanup procedure available is filtration through a 0.45um filter. This filtration step will remove turbidity that is present that may interfere with analysis.

4.2.2 Interfering contamination may occur when a sample containing low concentrations of analytes is analyzed immediately following a sample containing relatively high concentrations of analytes. As such, samples known to be clean should be analyzed first. To prevent carryover into subsequent samples, analysis of reagent blanks may be needed after the analysis of a sample containing high concentrations of analytes.

4.2.3 Refer to the appropriate SOP Attachment, as listed in Section 1, for any method-specific matrix interference information.

5.0 Safety

Employees must abide by the policies and procedures in the Eurofins Environment Testing Environmental Health and Safety Manual (EHSM), the Eurofins Savannah Addendum to the EHSM, and this document.

This procedure may involve hazardous materials, operations, and equipment. This SOP does not purport to address all of the safety problems associated with its use. It is the responsibility of the user to follow appropriate safety, waste disposal, and health practices under the assumption that all samples and reagents are potentially hazardous.

The analyst must protect himself/herself from exposure to the sample matrix. Many of the samples that are tested may contain hazardous chemical compounds or biological organisms. The analyst must, at a minimum, wear protective clothing (lab coat), eye protection (safety glasses or face shield), disposable nitrile gloves, or equivalent, and closed-toe, nonabsorbent shoes when handling samples.

5.1 Specific Safety Concerns or Requirements

The toxicity or carcinogenicity of chemicals used in this method has not been precisely defined. Each chemical should be treated as a potential health hazard, and exposure to these chemicals should be minimized.

Mercuric thiocyanate will give off hydrogen cyanide (HCN) gas if combined with strong acids. Inhalation of CN gas can cause irritation, dizziness, nausea, unconsciousness and potentially death.

Sulfuric acid is a strong oxidizer and is a corrosive. It will react violently when combined with organic compounds, possibly producing fire. Inhalation can cause irritation of the nose, throat, mucus membranes, and upper respiratory tract. Contact with the eyes can cause blurred vision, redness, pain, and even blindness.

Acetic acid is a corrosive. Contact with concentrated acetic acid can cause damage to the skin and eyes. Inhalation of concentrated vapors may cause damage to the lining of the nose, throat, and lungs.

Acetone is a flammable solvent. It can cause irritation to the respiratory tract. Overexposure can cause fatigue, lightheadedness, headache, dizziness, and blurred vision.

Nitric and hydrochloric acids are extremely hazardous as oxidizers, corrosives, poisons, and are reactive. Inhalation of the vapors can cause coughing, choking, irritation of the nose, throat, and respiratory tract, breathing difficulties, and lead to pneumonia and pulmonary edema. Contact with the skin can cause severe burns, redness, and pain. Nitric acid can cause deep ulcers, and staining of the skin to a yellow or yellow-brown color. These acid vapors are irritating and can cause damage to the eyes. Contact with the eyes can cause permanent damage.

Methanol is a flammable solvent. It can cause irritation to the respiratory tract. Overexposure can cause fatigue, confusion, headache, dizziness, and drowsiness.

5.2 Primary Materials Used

The following is a list of the materials used in this procedure, which have a serious or significant hazard rating, and a summary of the primary hazards listed in their MSDS/SDS.

Note: **This list does not include all materials used in the procedure.** A complete list of materials used in this procedure can be found in the Reagents and Standards Section and the Equipment and Supplies Section of this SOP

Employees must review the information in the MSDS/SDS for each material before using it for the first time or when there are major changes to the MSDS/SDS. Electronic copies of MSDS/SDS can be found using the “MSDS” link on the Oasis homepage, on the EH&S webpage on Oasis, and via TALS File System Shares.

Material	Hazards	Exposure Limit[1]	Signs and Symptoms of Exposure
Acetic Acid	Corrosive Poison Flammable	10ppm TWA	Contact with concentrated solution may cause serious damage to the skin and eyes. Inhalation of concentrated vapors may cause serious damage to the lining of the nose, throat, and lungs. Breathing difficulties may occur.
Acetone	Flammable	1000ppm TWA	Inhalation of vapors irritates the respiratory tract. May cause coughing, dizziness, dullness, and headache.
Barium Chloride	Poison Irritant	0.5mg/m^3 TWA	May be fatal if swallowed. Harmful if inhaled. Avoid contact with eyes, skin, and clothing. Avoid breathing dust. Keep container closed and when in use adequate ventilation.
Ferric Nitrate	Oxidizer	None	Causes irritation to the respiratory tract. Causes irritation, redness, and pain to the skin and eyes.
Hydrochloric Acid[2]	Corrosive Poison	5ppm Ceiling	Inhalation of vapors can cause coughing, choking, inflammation of the nose, throat, and upper respiratory tract, and in severe cases, pulmonary edema, circulatory failure, and death. Can cause redness, pain, and severe skin burns. Vapors are irritating and may cause damage to the eyes. Contact may cause severe burns and permanent eye damage.
Mercuric Thiocyanate	Poison	0.1 mg/m^3 Ceiling (Mercury Compounds)	Extremely Toxic. Causes irritation to the respiratory tract. **May produce Hydrogen Cyanide gas if combined with strong acids.** Causes irritation. Symptoms include redness and pain. May cause burns. May cause sensitization. Can be absorbed through the skin with symptoms to parallel ingestion. **May affect the central nervous system.** Causes irritation and burns to eyes. Symptoms include redness, pain, and blurred vision; may cause serious and permanent eye damage.
Methanol	Flammable Poison Irritant	200ppm TWA	A slight irritant to the mucous membranes. Toxic effects exerted upon nervous system, particularly the optic nerve. Symptoms of overexposure may include headache, drowsiness and dizziness. Methyl alcohol is a defatting agent and may cause skin to become dry and cracked. Skin absorption can occur; symptoms may parallel inhalation exposure. Irritant to the eyes.

Material	Hazards	Exposure Limit[1]	Signs and Symptoms of Exposure
Nitric Acid[2]	Corrosive Oxidizer Poison	2ppm TWA 4ppm STEL	Nitric acid is extremely hazardous; it is corrosive, reactive, an oxidizer, and a poison. Inhalation of vapors can cause breathing difficulties and lead to pneumonia and pulmonary edema, which may be fatal. Other symptoms may include coughing, choking, and irritation of the nose, throat, and respiratory tract. Can cause redness, pain, and severe skin burns. Concentrated solutions cause deep ulcers and stain skin a yellow or yellow-brown color. Vapors are irritating and may cause damage to the eyes. Contact may cause severe burns and permanent eye damage.
Phenol	Corrosive	5ppm TWA	Breathing vapor, dust or mist results in digestive disturbances. Will irritate and possibly burn respiratory tract. Rapidly absorbed through the skin with systemic poisoning effects to follow. Discoloration and severe burns may occur, but may be disguised by a loss in pain sensation. Eye burns with redness, pain, blurred vision may occur. May cause severe damage and blindness.
Phosphoric Acid	Corrosive	1mg/m^3 TWA	Inhalation is not an expected hazard unless misted or heated to high temperatures. May cause redness, pain, and severe skin burns. May cause redness, pain, blurred vision, eye burns, and permanent eye damage.
Sodium Hydroxide	Corrosive Poison	2mg/m^3 TWA	This material will cause burns if comes into contact with the skin or eyes. Inhalation of Sodium Hydroxide dust will cause irritation of the nasal and respiratory system.
Sulfuric Acid[2]	Corrosive Oxidizer Dehydrator Poison Carcinogen	1mg/m^3 TWA	Inhalation produces damaging effects on the mucous membranes and upper respiratory tract. Symptoms may include irritation of the nose and throat, and labored breathing. Symptoms of redness, pain, and severe burn can occur. Contact can cause blurred vision, redness, pain and severe tissue burns. Can cause blindness.
[1]Exposure limit refers to the OSHA regulatory exposure limit.			
[2]Always add acid to water to prevent violent reactions.			

6.0 Equipment and Supplies

All applicable laboratory support equipment and supplies (including balances; thermometers; and volumetric containers, used to determine quantitative measurements, such as mechanical pipettes, disposable graduated pipettes, gas-tight syringes, etc.) must be verified in accordance with SOP SA-AN-100: *Laboratory Support Equipment (Verification and Use)*.

6.1 Equipment and Instrumentation

- Top-loading Balance
- Tumbler
- MicroDist Apparatus
- Konelab Model 20 Autoanalyzer, or equivalent
- Data System: The software system is based on the Windows NT operating system. The hardware interface can be either RS232 or an Ethernet connection and can be integrated to both transmit and receive information from a TALS.

6.2 Analytical Data System/ Software / Hardware

The Quality Assurance Department maintains the Master Equipment Listing for the laboratory. This is a listing of all instrumentation utilized by the laboratory and includes details about the instrumentation including the software or firmware.

6.3 Volumetric Containers and Dispensers

All volumetric labware must be verified in accordance with SOP SA-AN-100: *Laboratory Support Equipment (Verification and Use).* Refer to Attachment 6 for Labware Cleaning Procedures.

Volumetric Labware	**Volume**	**Type (Quantitative / Qualitative)**	**Use**	**Verification Frequency**	**Laboratory Verification Criteria**
Plastic Transfer Pipettes	Various	Qualitative	pH checks, transferring sample or reagents	None	None
Disposable Medicine Cups	Various	Qualitative	Used to contain sample aliquot for pH measurement	None	None
Disposable Konelab Sample Cups	2mL	Qualitative	Holding sample on instrument	None	None
Eppendorf-Style Mechanical Pipettes	Various	QUANTITATIVE	Preparing Dilutions, Standard and Reagent Preparation and Spiking	Initially, prior to first use, then quarterly thereafter (Daily for DOD)	Accuracy = 2% Precision = 1%
Volumetric Flasks (Class A)	Various	QUANTITATIVE	Preparing Dilutions, Standard and Reagent Preparation	None (Class A)	None (Class A)
Graduated Cylinders (Class A)	Various	QUANTITATIVE	Preparing Dilutions, Standard and Reagent Preparation	None (Class A)	None (Class A)
Disposable Round Bottom Test Tubes	8mL	Qualitative	Holding sample on instrument	None	None

6.4 Lab Supplies

- pH paper (narrow and wide range)
- Residual Chlorine Check Strips – starch iodide strips or DPD pillow pops
- Detergent – Nochromix, or equivalent, used for washing non-disposable labware.
- Hengar Granules
- Magnetic Stir Bars
- Teflon Chips – used as soil blank matrix

6.5 Sample Collection Containers

All sample collection containers are single-use disposable containers which limits the potential for contamination. The routine sample collection containers supplied by the laboratory are purchased with Certificate of Analysis attesting to purity.

Refer to Attachment 2 for a cross-reference of containers to methods.

7.0 Reagents and Standards

7.1 Expiration Dates

Expiration dates (time from initial use or receipt to final use) for standard and reagent materials must be set according to the guidance in this SOP. Note: These are maximum expiration dates and are not to be considered an absolute guarantee of standard or reagent quality. Sound judgment must be used when deciding whether to use a standard or reagent. If there is doubt about the quality of a standard or reagent material, a new material must be obtained or the standard or reagent material verified. Data quality must not be compromised to extend a standard's life.

The expiration date of any standard or reagent must not exceed the expiration date of the standard or reagent that was used to prepare it.

Unless noted elsewhere in this SOP, the following expiration date requirements and storage conditions apply:

Purchased Unopened = Manufacturer's Expiration Date
Purchased Opened = 5 years from Open Date
Prepared = 3 months from Preparation Date
Storage = Room Temperature

7.2 Reagents

Reagents must be prepared and documented in accordance with SOP SA-AN-041: *Reagent and Standard Materials Procedures.* Certificates of analysis or purity must be received with all purchased reagents, and scanned and attached to the standard in TALS. Unless otherwise stated in the method-specific attachments, reagents should be stored in a cool, dry, ventilated storage area away from incompatible materials.

Refer to the appropriate SOP Attachment, as listed in Section 1, for the method-specific reagents associated with each analysis.

Acetone, hydrochloric acid, methanol, nitric acid, and sulfuric acid must be verified prior to use in accordance with the Eurofins Environment Testing Solvent Lot Testing Program.

Blank Matrix – Ottawa Sand or Teflon Chips (see associated Attachment). Used for the preparation of soil QC samples.

Laboratory Reagent Water – ASTM Type II (also referred to as DI Water)

7.3 Standards

Standards must be prepared and documented in accordance with SOP SA-AN-041: *Reagent and Standard Materials Procedures.* Certificates of analysis or purity must be received with all purchased standards, and scanned and attached to the standard in TALS.

Refer to the appropriate SOP Attachment, as listed in Section 1, for the method-specific standards associated with each analysis. Other standard concentrations may be used provided they support the reporting limit and are fully documented in accordance with SOP SA-AN-041.

8.0 Sample Collection, Preservation, Shipment, and Storage

Refer to Attachment 2 for the method-specific sample collection, preservation, shipment, and storage information.

9.0 Quality Control

SOP SA-QA-017: *Evaluation of Batch QC Data* and the SOP Summary in Attachment 3 provide requirements for evaluating QC data. Refer to the appropriate SOP Attachment, as listed in Section 1, for any method-specific quality control information associated with each analysis.

9.1 Batch QC

A preparation/analysis batch consists of up to 20 environmental samples and the associated QC items analyzed together within a 24 hour period. Refer to the Table in Attachment 3 for a summary of the method-specific batch QC items.

If there is insufficient sample volume to perform the required matrix spike(s), an NCM must be initiated on all affected samples to denote this situation. Insufficient sample volume is defined as receiving less than a total of 20mL.

If insufficient sample volume is provided to perform the Sample duplicate (SD) or matrix spike/ matrix spike duplicate (MS/MSD), the Laboratory control sample (LCS) must be prepared in duplicate (LCS/LCSD). An NCM must be initiated on all samples within the batch to denote this situation.

Note: Unless the client has specified which sample to use as the matrix spike, the matrix spike must be selected at random from the samples in the batch. Field QC (e.g., equipment blanks, trip blanks, and field blanks) must not be used for MS/MSD unless specifically requested to do so by the client or unless there is insufficient sample available for performing MS/MSD using an actual field sample.

MRL LCS for DW

The EPA Manual for the Certification of Laboratories Analyzing Drinking Water requires a Laboratory fortified blank (LFB) at the MRL to be performed each day. Therefore, if analyzing drinking water samples, a Laboratory Control Sample (LCS) at the Reporting Limit (RL) must also be included in the required batch QC.

9.2 Instrument QC

9.2.1 Initial Calibration (ICAL)

The instrument must be calibrated in accordance with SOP SA-QA-016: *Evaluation of Calibration Curves.* This SOP provides requirements for establishing the calibration curve and gives the applicable formulas.

Instrument calibration is performed by analyzing a series of known standards. The calibration curve must consist of a minimum of 3 standards and a blank. The lowest level calibration standard must be at or below the reporting limit, and the remaining standards will define the working range of the analytical system.

The regression coefficient (r^2) of the regression curve must be greater than or equal to 0.995 for the initial calibration curve to be acceptable.

Readback Criteria: Each point on the curve must be within +/- 10% of true value.

9.2.2 Second Source Initial Calibration Verification (ICV)

The calibration curve must be verified initially – prior to any sample analyses – in accordance with SOP SA-QA-016 with a standard obtained from a second source.

The ICV must be within 10% to be acceptable.

9.2.3 Initial Calibration Blank (ICB) / Continuing Calibration Blank (CCB)/ Method Blank (MB)

The instrument must be shown to be free from contamination by the analysis of calibration blanks. Initial calibration blanks are analyzed at the beginning of each analysis run. Continuing calibration blanks are analyzed following each CCV.

SM3500-Fe B, SM3500 Fe-D SM3500-Cr B: Blanks must be < MDL
Other methods: Blanks must be < ½ RL.

9.2.4 Continuing Calibration Verification (CCV)

Unless noted elsewhere in this SOP, the initial calibration curve must be verified every 10 analyses and at the end of the analysis run with a mid-level standard.

The CCV must be within 10% to be acceptable.

9.2.5 Linear Calibration Range / Linear Dynamic Range

The linear calibration range (LCR), also known as the Linear Dynamic Range (LDR), must be determined initially for the following methods:

SM3500-Fe B
SM3500-Cr B
SM4500-NH_3 G
SM4500-P F
SM4500-Cl^- E
EPA 350.1
EPA 365.1

The initial demonstration of linearity uses as many standards as necessary to ensure the curve is linear. The standards should cover the low and high ends of the calibration range. Each standard must be within +/- 10% of the true value.

The LCR/LDR must be verified every 6 months for the following methods:

EPA 350.1
EPA 365.1

The continued demonstration of linearity consists of a minimum of 3 standards and a blank. For the linearity to be verified, the standards must be within +/-10% of the initial value to be acceptable. If this criterion is not met, the initial demonstration of linearity must be performed.

> Note: This study is not meant to extend the linear range of the calibration. If an analyte is measured at a concentration greater than the highest calibration standard, the sample must be analyzed at a dilution to bring the target analyte into the range of the initial calibration.

9.3 Corrective Action for Out-of-Control Data

When the quality control parameters do not meet the criteria set forth in this SOP, corrective action must be taken in accordance with SOP SA-QA-005: *Preventive and Corrective Action Procedure* and the QC Summary Table in Attachment 3. SOP SA-QA-005 provides contingencies for out-of-control data and gives guidance for exceptionally permitting departures from approved policies and procedures. Nonconformance Memos must be initiated to document all instances where QC criteria are not met and all departures from approved policies and procedures.

10.0 **Procedure**

10.1 Sample Preparation

Remove the samples or extracts from the refrigerator and allow them to come to room temperature.

Soil samples must be homogenized prior to preparation in accordance with SOP SA-QA-015: *Compositing, Homogenization, and Segregation of Samples*. Note: If a sample or extract is filtered, the associated QC must also be filtered.

The sample preparation procedures are summarized below. Refer to appropriate SOP Attachment for the method-specific procedures.

Analyte	**Aqueous Prep**	**Soil Prep**
Ammonia	Distillation* (EPA 350.1 / SM4500-NH$_3$ B) Undistilled (No Prep)*	Soil Leachate
Chloride	No Prep	Soil Leachate
Total Chlorine	EPA 5050 (SOP SA-GE-010)	EPA 5050 (SOP SA-GE-010)
Ferrous Iron (Ferric Iron calc)	Filter	▨
Hexavalent Chromium (Trivalent Chromium calc)	Filter**	N/A
Ortho-Phosphate	Filter **	Soil Leachate
Sulfate	No Prep	Soil Leachate
Total Sulfur	EPA 5050 (SOP SA-GE-010)	EPA 5050 (SOP SA-GE-010)
BTU	ASTM D270-87	ASTM D240-87

*Ammonia samples are distilled upon client request.
** Samples should be field filtered.

10.2 QC Sample Preparation

Refer to appropriate SOP Attachment, as listed in Section 1, for the method-specific QC sample preparation instruction associated with each procedure.

10.3 Analysis

10.3.1 Instrument Operating Conditions

The instrument conditions listed in this SOP are provided for guidance purposes. The actual conditions used by the laboratory may be slightly different from those listed here and must be documented in the instrument maintenance log, data system, and/or run log.

Instrument maintenance must be performed in accordance with Attachment 4 of this SOP.

Data System
Programmable instrument parameters include:

Volume of sample (maximum of 125uL)
Wavelength
Type and order of reagent(s) addition
Background absorbance
Time of sample/reagent mixing
Timing of absorbance readings
Dilutions
Reagents lot numbers/expiration dates

QC checks can be programmed into the methods as needed, including initial and continuing control standards, blanks, and upper and lower limits on absorbance. If samples or standards exceed these control limits, the data are flagged.

Operation
The instrument utilizes the following process:

- Sample is dispensed into the cuvettes according to the test method (maximum sample volume is 125uL)
- The reagents are added to the sample and mixed.
- The sample is incubated.
- The sample absorbance is measured (if absorbance exceeds calibration range, sample is diluted as defined in the test method and reanalyzed. If the dilution exceeds the maximum range, the data are flagged and the analyst must prepare dilution for sample).

10.3.2 Initial and Continuing Calibration

The instrument is calibrated using the standards and criteria described in the appropriate SOP Attachment, as listed in Section 1. Once the calibration has been established and verified with an ICV in accordance with Section 9.2.2, sample analysis may proceed.

Verify the calibration curve with a continuing calibration verification using the standards and criteria described given in Section 9.2.4 and the appropriate SOP Attachment, as listed in Section 1.

10.3.3 Sample Analysis

Remove the samples or extracts from the refrigerator and allow them to come to room temperature.

Samples are loaded into racks that hold 14 samples each. The autosampler holds up to 6 racks of 14 samples. The racks can be fitted to hold sample containers from 0.5mL up to 10mL. Two separate wash stations are used to minimize sampler carryover. The probe is flow-through and externally rinsed.

The sample/extract must be analyzed using the same volume used for the calibration standards. The default procedure is to include QC items (method blank, LCS, MS/MSD, and SD) in determining the maximum number of samples in the analysis.

10.3.4 Example Analytical Sequence

Refer to the appropriate SOP Attachment, as listed in Section 1, for any changes to the sequence listed below.

Description	**Comments**
Blank	
Initial Calibration	
ICV	Second Source
ICB	
Samples & Batch QC Items	Up to 10 analyses. Not to exceed 2 hours.
CCV	
CCB	
Samples & Batch QC Items	Up to 10 analyses. Not to exceed 2 hours.
CCV	
CCB	

11.0 Calculations / Data Reduction

11.1 Data Reduction

Data must be evaluated in accordance with SOP SA-QA-002: *Data Review and Reporting*.

11.1.1 MS/MSD Evaluation

If the concentration of a target analyte in the un-spiked (native) sample is more than four times the theoretical concentration of the matrix spike, the recovery is not reported and the data is flagged.

11.1.2 Historical Data

Many of the laboratory's clients submit samples for repeat monitoring purposes. Prior to analysis, verify TALS Worksheet Notes and/or use the TALS Historical Data Tracker Feature to determine if historical data is available for review.

11.1.3 Chemical Relationships

When available, the following chemical relationships must be evaluated for each sample. If these relationships are not met the Department Manager must be contacted immediately.

- Total Results ≥ Dissolved Results
- TKN ≥ Ammonia
- Total Phosphorus ≥ Ortho-phosphate
- TDS ≥ Individual Anions
- Ferrous Iron ≤ Total Iron

11.1.4 Drinking Water Compliance Evaluation

Public water suppliers (PWS) are governed by EPA-specified Maximum Contaminant Levels (MCL) above which indicates noncompliance. The MCLs associated with this procedure are given in Attachment 5. Notify the PM immediately via a Nonconformance Memo if any sample contains detection above these levels.

11.2 Calculations

11.2.1 The calculations associated with batch QC determinations are given in SOP SA-QA-017. Applicable calculations include accuracy (% recovery) and precision (%RPD).

11.2.2 The calculations associated with initial and continuing calibrations and are given in SOP SA-QA-016. Applicable calculations include determination for: calibration factor, standard deviation, relative response factor, and relative standard deviation.

11.2.3 The calculation to determine final concentration is given as follows:

$$FinalConcentration = CONC_{Sample} \otimes \frac{F}{I \times dw} \otimes D$$

Where:

$CONC_{Sample}$= Concentration of the sample
F = Final volume/weight
I = Initial volume/weight
dw = % Solids decimal equivalent
D = Dilution factor

Note: All dry weight corrections are performed automatically in TALS.

12.0 Method Performance

12.1 Reporting Limit Verification (RLV/ LOQ)

At a minimum, RLVs must be performed initially upon method set-up in accordance with SOP SA-QA-007: *Determination and Verification of Detection and Reporting Limits*.

For analytes and methods certified RLVs must be performed quarterly thereafter.

12.2 Method Detection Limit (MDL) Study

The method detection limits (MDL) is defined as the minimum measure concentration of a substance that can be reported with 99% confidence that the measured concentration is distinguishable from the method blank results. MDLs reflect a calculated (statistical) value determined under ideal laboratory conditions in a clean matrix and may not be achievable in all environmental matrices. The current MDLs associated with this procedure are given in the Method Limit Group (MLG) in TALS.

At a minimum, MDL Studies must be performed initially upon method set-up in accordance with SOP SA-QA-007: *Determination and Verification of Detection and Reporting Limits*.

Note: MDL Studies are not required for non-routine analytes provided results are not reported below the RL (i.e., MDL equals RL in TALS).

12.3 Method Detection Limit Verification (MDLV/ LOD)

At a minimum, MDLVs must be performed initially upon method set-up in accordance with SOP SA-QA-007: *Determination and Verification of Detection and Reporting Limits*.

The MDLV must be verified quarterly for methods certified by DOD ELAP.

12.4 QC Limit Generation, Control Charting, and Trend Analysis

The control limits for the batch QC items (LCS, MS/MSD, SD) for this procedure are specified in the reference method and cannot be broadened; therefore, the laboratory defaults to the method-defined limits and does not utilize in-house or laboratory-derived limits for the evaluation of batch QC items.

Although the laboratory must default to the method-defined QC limits, control charting is a useful tool and is performed to assess analyte recoveries over time to evaluate trends. Control charting must be performed periodically (at a minimum annually) in accordance with SOP SA-QA-017: *Evaluation of Batch QC Data.*

12.5 Demonstrations of Capability

Initial and continuing demonstration of capability must be performed in accordance with SOP SA-QA-006*: Training Procedures.*
Prior to performing this procedure unsupervised, each new analyst who performs this analysis must demonstrate proficiency per method/analyte combination by successful completion of an initial demonstration of capability. The IDOC is performed by the analysis of 4 consecutive LCSs that meet the method criteria for accuracy and precision. The IDOC must be documented and routed to the QA Department for filing.

Annual continuing demonstrations of capability (CDOCs) are also required per analyst per method/analyte combination. The CDOC requirement may be met by the consecutive analysis of four LCS all in the same batch, by the analysis of four LCS analyzed in four consecutive batches (in different batches on different days), via acceptable results on a PT study, or analysis of client samples with statistically indistinguishable results when compared to another certified analyst. The CDOC must be documented and routed to the QA Department for filing.

12.6 Training Requirements

All training must be performed and documented in accordance with SOP SA-QA-006: *Training Procedures*.

Note: The SOPs listed in the Reference/Cross-Reference Section are applicable to this procedure. All employees performing this procedure must also be trained on these SOPs.

13.0 Pollution Control

It is Eurofins Savannah’s policy to evaluate each method and look for opportunities to minimize waste generated (e.g., examining recycling options, ordering chemicals based on quantity needed, preparing reagents based on anticipated usage and reagent stability, etc.). Employees must abide by the policies in Section 13 of the Environmental Health and Safety Manual.

This procedure has been evaluated for opportunities to minimize the waste generated. Where reasonably feasible, pollution control procedures have been incorporated.

14.0 Waste Management

Waste management practices must be conducted consistent with all applicable federal, state, and local rules and regulations. All waste (i.e., excess reagents, samples, and method process wastes) must be disposed of in accordance with Section 9 of the Eurofins Savannah Addendum to the EHSM. Waste description rules and land disposal restrictions must be followed.

14.1 Waste Streams Produced by the Method

The following waste streams are produced when this method is carried out:

- Excess aqueous samples – Dispose according to characterization by the disposal program. Neutralize non-hazardous samples before disposal into drain/sewer. Transfer hazardous samples to the waste department for disposal.

- Excess soil and solid samples – Dispose according to characterization by the disposal program. Transfer hazardous and non-hazardous samples to the yardbox in the waste storage area for disposal via incineration. Samples classified as PCB or Foreign Soil hazardous must be transferred to the waste coordinator for drumming.

- Non-hazardous acidic and alkaline wastewater and samples must be neutralized before disposal into the sewer system.

15.0 References / Cross-References

- SOP SA-AN-100: *Laboratory Support Equipment (Verification and Use)*
- SOP SA-AN-041: *Reagent and Standard Materials Procedures*
- SOP SA-ME-021: *Digestion Procedures for Solids for Hexavalent Chromium*
- SOP SA-QA-002: *Data Review and Reporting*
- SOP SA-QA-005: *Preventive and Corrective Action Procedures*
- SOP SA-QA-006*: Training Procedures*
- SOP SA-QA-007: *Determination and Verification of Detection and Reporting Limits (RLs, MDLs, and IDLs)*
- SOP SA-QA-015: *Homogenization, Compositing, and Segregation of Samples*
- SOP SA-QA-016: *Evaluation of Calibration Curves*
- SOP SA-QA-017: *Evaluation of Batch QC Data*
- Eurofins Savannah Quality Assurance Manual
- Eurofins Environmental Health and Safety Manual (CW-E-M-001)
- Eurofins Savannah Addendum to the Environmental Health and Safety Manual
- *Standard Methods for the Examination of Water and Wastewater*; American Public Health Association: Washington, DC
    - SM1020: *Quality Assurance*; 20th Edition
    - SM3020: *Quality Assurance/Quality Control*; 2005
    - SM3500-Cr B: *Chromium, Colorimetric Method*; 2001
    - SM3500-Fe B: *Ferrous Iron, Phenanthroline Method*; 1997
    - SM4020: *Quality Assurance/Quality Control*
    - SM4500-Cl^- E: *Chloride, Automated Ferricyanide Method*; (Approved 1997; Editorial Revision 2011)
    - SM4500-NH_3 B: *Nitrogen (Ammonia), Preliminary Distillation Step*; 1997
    - SM4500-P F: *Phosphorous, Automated Ascorbic Acid Reduction Method*; 1999
    - SM4500-NH_3 G: *Nitrogen (Ammonia), Automated Phenate Method*; 1997

  - SM5020: *Quality Assurance/Quality Control*
- *Methods for Chemical Analysis of Water and Wastes*; U.S. EPA Office of Research and Development: Cincinnati, OH, March, 1983
  - EPA 325.2: *Chloride (Colorimetric, Automated Ferricyanide AAII)*; 1978
  - EPA 350.1: *Determination of Ammonia Nitrogen by Semi-Automated Colorimetry*; Revision 2.0, August 1993
  - EPA 365.1: *Determination of Phosphorus by Semi-Automated Colorimetry*; Revision 2.0, August 1993
  - EPA 375.4: *Sulfate (Turbidimetric)*; 1978
- *Test Methods for Evaluating Solid Waste, Third Edition On-line*; U.S. EPA Office of Solid Waste and Emergency Response: Washington, DC
  - EPA 5050: *Bomb Preparation Method for Solid Waste; Revision 0, September 1994*
  - EPA 7196A: *Chromium, Hexavalent (Colorimetric)*; Revision 1, July 1992
  - EPA 9038: *Sulfate (Turbidimetric)*; Revision 0, September 1986
  - EPA 9251: *Chloride (Colorimetric, Automated Ferricyanide AAII)* ; Revision 0, September 1986
- *Annual Book of ASTM Standards Section 5, Volume 05.01;* American Society of Testing and Materials: Philadelphia, 1992.
  - D240-87: *Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter*; May 1991

16.0 Method Modifications and Clarifications

16.1 Many of the reference methods were written specifically for drinking water and source water samples; however, the laboratory may perform other types of water samples using these procedures. These procedures may be modified to analyze other matrices (e.g., wipe samples) based on the needs of the client. This will need to be arranged by the Project Manager at the initiation of the project. Wipe, waste, and tissue matrices are non-routine, and the laboratory is not currently NELAC certified for these matrices. The laboratory uses its routine soil RLs and MDLs (converted for initial and final volumes, etc.), and soil QC limits to evaluate wipe, waste, and tissue samples. Soil DOCs can be used to satisfy analyst demonstrations of capability for these types of non-routine matrices. Ottawa sand is used as the blank matrix for tissue samples unless a “true” tissue matrix is required by the project.

16.2 The EPA Manual for the Certification of Laboratories Analyzing Drinking Water requires a LFB at the MRL to be performed each day. The laboratory meets this requirement by preparing an LCS at the RL in each batch of drinking water samples.

16.3 Refer to appropriate SOP Attachment, as listed in Section 1, for any method-specific modifications and/or clarifications associated with each procedure.

16.4 The default procedure for the ammonia analysis is to analyze samples undistilled. An equivalency study has been conducted using a variety of sample matrices and shows similar results were obtained for undistilled versus distilled samples. Distillation for ammonia samples can be performed upon client request.

16.5 EPA Method 350.1 requires the ammonia calibration to be analyzed in **decreasing** order. However, due to software limitations of the KONE analyzer, calibration standards are unable to be analyzed in this manner. The instrument is classified as a true automated discrete analyzer where sample analysis is performed in single use discrete cells which decreases the risk for contamination between sample analyses.

17.0 Attachments

The following Tables, Diagrams, and/or Validation Data are included as Attachments:

Attachment 1a: SOP Summary – Ammonia
Attachment 1b: SOP Summary – Chloride and Total Chlorine
Attachment 1c: SOP Summary – Ferrous Iron and Ferric Iron
Attachment 1d: SOP Summary – Hexavalent Chromium and Trivalent Chromium
Attachment 1e: SOP Summary – Ortho-phosphate
Attachment 1f: SOP Summary – Sulfate, Total Sulfur, and BTU
Attachment 2: Sample Collection, Preservation, and Holding Time Table
Attachment 3a: Batch QC Frequency
Attachment 3b: QC Summary
Attachment 4: Instrument Maintenance and Troubleshooting
Attachment 5: Maximum Contaminant Levels (MCL) Table
Attachment 6: Glassware Cleaning Procedures

Attachment 1a
SOP Summary
Ammonia

1.0 Summary

Ammonia reacts with hypochlorite and alkaline phenol to form indophenol blue. The blue color produced is intensified with sodium nitroprusside and measured at 660nm.

2.0 Interferences

Extreme sample pH values may interfere. Proper sample preservation and adjustment just prior to analysis should alleviate this problem. Turbidity and color in samples must be filtered and/or diluted prior to analysis. Residual chlorine should be removed at the time of sampling by the addition of sodium thiosulfate.

3.0 Reagents and Standards

3.1 Purchased Reagents
Sodium Thiosulfate ($Na_2S_2O_3{\bullet}5H_2O$) Dechlorination Reagent – reagent grade

Sulfuric Acid (H_2SO_4) – concentrated, reagent grade
Storage: Area with acid resistant floors. Store away from direct sunlight, heat, and water.

Sodium Hydroxide (NaOH) – pellets, reagent grade
Storage: Isolate from moisture and heat sources.

Potassium Chloride (KCl) – reagent grade

Phenol – solution must be ≥89% pure
Storage: Isolate from heat or ignition sources.

Sodium Tetraborate ($Na_2B_4O_7$) – reagent grade

Bleach/Sodium Hypochlorite – must contain 6.15% sodium hypochlorite (NaOCl)
Storage: Protect from heat and light.
Expiration: Unopened: 1 year; Opened: 6 months

Disodium Ethylenediamine Tetraacetate (EDTA) – reagent grade

Sodium Nitroprusside ($Na_2(NO)Fe(CN)_5{\bullet}2H_2O$) – reagent grade
Storage: Away from moisture and incompatibles

3.2 Prepared Reagents

Sodium Phenate Solution
Dissolve 9.3mL liquid (≥89%) phenol in 50mL ammonia free water, slowly add 3.2g NaOH and mix thoroughly and dilute to 100mL with DI Water. **CAUTION**: Wear gloves and eye protection when preparing this solution.
Expiration: Daily

Sodium Hypochlorite Solution
Dilute 25mL of 5.25% NaOCl with 50mL DI Water. (Note: If “concentrated” bleach is used (8.25% NaOCl), measure 16mL and dilute to 50mL with DI Water.)
Expiration: Daily

EDTA Buffer
Dissolve 50g of disodium ethylenediamine tetraacetate and 5.5g of NaOH in 1000mL of DI water.
Expiration: 1 year

Sodium Nitroprusside Solution
Dissolve 0.5g of $Na_2(NO)FE(CN)_5.2H_2O$ in 1000mL of DI Water.
Expiration: 1 year

5% Sulfuric Acid Solution
Add 50mL of concentrated sulfuric acid to a 1L volumetric flask containing 500mL DI water. Bring to volume with DI water.

Sulfuric Acid Solution (0.01M) – NH3_Diluent
Add 2.08mL of concentrated sulfuric acid to 1.0 gallon of water (0.56mL of concentrated H2SO4 per liter of water). The pH of this solution is 2.0. Verify the pH before use.
Expiration: 1 year

2N Sodium Hydroxide Solution
In a 1L volumetric flask add 500mL of DI water. Add 80 grams of sodium hydroxide pellets and let dissolve. Bring to volume with DI water after the pellets have dissolved. Mix well.
Expiration: 1 year

Sodium Hydroxide Solution (15N)
Add 250mL DI Water to a 500mL volumetric flask. Add a stir bar and place on stir plate. In small increments and with constant stirring, slowly add 300g NaOH to the flask. Allow to cool and dilute to volume with DI water. Transfer to a labeled storage container.
Expiration: 1 year

Potassium Chloride (1M)
Dilute 148g of potassium chloride to with 1800mL DI Water. Add 1.12mL concentrated sulfuric acid. Dilute to 2000mL and mix thoroughly.
Expiration: 1 year

O-Cresolphthalein Indicator Solution 0.2% w/v alcoholic solution.
Expiration: Manufacturer's expiration date

MicroDist Trapping Solution
Add 3.3mL of concentrated sulfuric acid to 1.0L of water.
Expiration: 1 year

Borate Buffer (MicroDist)
Add 5.0g of sodium borate decahydrate and 22g sodium hydroxide to 600mL of DI Water in a 1L volumetric flask. Stir to dissolve then add 10mL o-cresolphthalein indicator solution. Dilute to mark with DI Water. Buffer should be a deep purple color.
Expiration: 1 year

3.3 Standards

Ammonia Stock Standard (100mg/L) Purchased
Expiration: Manufacturer's expiration date

Ammonia Calibration Standards
Prepare calibration standards in 0.01M Sulfuric Acid (NH3 Diluent) according to the following table.

Standard Level	Parent Standard	Volume Intermediate (mL)	Final Volume (mL)	Final Concentration (mg/L)
1	Ammonia Stock Standard	2.0	100	2.0
2 (LCS)	Ammonia Stock Standard	10	1000	1.0
3	Ammonia Stock Standard	0.50	100	0.50
4	Ammonia Stock Standard	0.25	100	0.25
5	Ammonia Stock Standard	0.10	100	0.10
6	Cal 2	5.0	100	0.050
7	Cal 2	2.5	100	0.025

Note: EPA Method 350.1 requires the ammonia calibration to be analyzed in **decreasing** order. However, due to software limitations of the KONE analyzer, calibration standards are unable to be analyzed in this manner. The instrument is classified as a true automated discrete analyzer where sample analysis is performed in single use discrete cells which decreases the risk for contamination between sample analyses.

Initial Calibration Verification (ICV) – 1.0mg/L standard from NCL Labs. Adjust to pH 2 with a weak solution of H_2SO_4.
Expiration: manufacturer's date (1 month if no date given)

4.0 Sample Preparation

4.1 Aqueous Samples

Aqueous samples are routinely analyzed with no sample preparation. The samples can be distilled upon request.

NOTE: All compliance samples originating from South Carolina must be distilled prior to analysis.

Residual Chlorine Check (for Ammonia analyses only)

For each sample,
- Place a piece of starch-iodide paper in a disposable medicine cup.
- Pour a few drops of sample into the medicine cup and note the color change of the paper.
- If the paper turns blue or black, residual chlorine is present. Initiate a Nonconformance Memo and dechlorinate the sample with sodium thiosulfate.

pH Verification (for Ammonia analyses only)

For each sample,
- Create a preservation batch in LIMS (preserv_chk)
- Place a piece of pH paper in a disposable medicine cup. Use narrow range 1.0-2.5 pH paper.
- Pour a few drops of sample into the medicine cup and note the color change of the pH paper.
- If the pH is greater than 2, initiate a Nonconformance Memo. Adjust the sample pH to 2 or less, targeting a value near pH 2, using sulfuric acid. The volume of sulfuric acid must not exceed 1% of the volume of the container or sample; e.g., no more than 2.5mL of sulfuric acid per 250mL container or sample.

Note: To avoid cross-contamination, use a separate medicine cup, pH strip, and residual chlorine strip per sample. Do not dip the strip into the sample container.

Prepare QC samples in the same manner as field samples as follows:
- Laboratory Control Sample (LCS) – Prepared in same manner as Cal Level 2.
- Low-Level Laboratory Control Sample- (LLCS) (Drinking Water only) – Performed at the RL (0.25mg/L) for routine DW samples. Performed at 0.05mg/L for FP
- Matrix Spike / Matrix Spike Duplicate (MS/MSD) – Add 0.1mL of the 100mg/L Ammonia Stock Standard to 10mL of the sample selected for MS/MSD.

  Note: SM4500-NH3 G recommends the MS/MSD spike concentration to be varied periodically.

4.1.1 Ammonia Micro-Distillation Preparation

Create a Distill_Ammonia batch in LIMS.

Set controller to 120°C and turn on the heater block to warm up (~40 min). Verify the temperature of the micro-distillation apparatus with an IR gun. The temperature must be within 115-125°C. Record the corrected and uncorrected temperature in the Batch Data Types in TALS.

Determine the number of collector tubes needed and align with “M” end in the up position by placing them into a collector tube rack.

Label and fill each collector tube with 1mL of trapping solution (0.016M Sulfuric Acid). At the end of the distillation, once diluted to 6mL final volume, the final concentration will be 0.003M Sulfuric Acid.

Place the same number of sample tubes into the sample tube rack.

Label each tube and place 6mL of sample into each sample tube.

Add 1mL of 0.55M Borate Buffer to each tube. Ensure the sample plus buffer remains purple (pH >9.8). If purple color fades when the buffer is added, add additional NaOH Solution to bring the pH up until the purple color returns.

Immediately push the “D” end of the collector tube over the open end of the sample tube to start the seal.

Place the tube assembly in the press by putting the sample tube through the hole in the base.

Before pressing, place one hand at the breakaway point located on the collector tube to stabilize the assembly.

Apply pressure to the assembly with a smooth motion until the stop ring on the sample tube hits the “D” end of the collector tube.

Once complete, put on heat resistant gloves and add the tube assemblies to the pre-heated block by placing the sample tube and “D” end of the collector tube into the block.

Set the timer for 30 minutes. Document the start time in the LIMs batch.

Once time is up remove the assemblies from the block one at a time and immediately remove the sample tube from the collector tube and invert so the D side is facing up. Note: this should be done within 4 seconds to prevent “suck-back” of the sample.

Document the end time, uncorrected temperature and corrected temperature in the batch information.

Once all of the tubes have been removed and disassembled, seal with Parafilm at the “I” end of the tube and allow the tubes to cool for 10 minutes.

Hold the tube horizontally and roll the tube with your fingers to gather the droplets that are stuck to the walls. The tube can be flicked with your finger as well.

With the “D” end still up, grasp the tube and break it at the breakaway point by pulling the “D” end towards your body and twisting the tube. Discard the “D” end of the tube.

Perform a pH check of samples to ensure they are still at a pH of 2. If not, adjust with Sulfuric Acid prior to diluting up to 6mLs. Use narrow range pH paper with a range of 1-2.5 for this check.

Dilute the distillate up to the 6 mL mark with NH3 Diluent and cover the tube with Parafilm until ready for analysis.

4.2 Soil Samples

- Weigh approximately 20g of sample into a 125mL screw-cap plastic bottle. Record the weight to the nearest 0.1g. Add 100mL of 2M potassium chloride to each sample container and place in the tumbler.
- Rotate for 30-45 minutes. Remove the containers from the extractor and allow the leachates to settle.
- Filter the extract using a syringe filter with a 0.45um pore size filter and analyze the extracts as liquid samples.

Prepare QC samples in the same manner as field samples as follows:

- Method Blank – Weigh approximately 20g of Teflon chips into a 125mL screw-cap plastic bottle. Record the weight to the nearest 0.1g.
- Laboratory Control Sample – Weigh approximately 20g of Teflon chips into a 125mL screw-cap plastic bottle. Record the weight to the nearest 0.1g. Add 1mL of 100mg/L Ammonia Intermediate Standard to the extraction bottle. Spike soil prior to adding 99ml of 2M potassium chloride.
- MS/MSD – Weigh additional 20g aliquots of one of the samples for the MS/MSD. Add 1mL of 100mg/L Ammonia Intermediate Standard Ammonia Matrix Spike Solution to the sample. Spike soil prior to adding 99ml of 2M potassium chloride.

5.0 Method-Specific QC Requirements

5.1 Linear Calibration Range
EPA 350.1 – Performed initially; verified every 6 months.
SM4500-NH_3 G – Performed initially.

5.2 Method Detection Limit Studies
EPA 350.1 – Requires MDL Studies every 6 months.
SM4500-NH_3 G – Requires MDL Study to be analyzed over 3-5 days.

6.0 Method-Specific Modifications and/or Clarifications

The ammonia distillation sample volumes have been adjusted to compensate for current lab restrictions of glassware and volume of sample submitted. All reagent volumes have been adjusted accordingly.

The reference methods state to adjust sample pH with 1N NaOH. The sample is preserved with H_2SO_4 to a pH of <2. To adjust the pH with such a weak solution would require adding >5% volume and therefore diluting the sample. As such, the laboratory uses 15N NaOH to adjust the sample pH.

The default procedure for the ammonia analysis is to analyze samples undistilled. An equivalency study has been conducted using a variety of sample matrices and shows similar results were obtained for undistilled versus distilled samples. Distillation for ammonia samples can be performed upon client request.

EPA Method 350.1 requires the ammonia calibration to be analyzed in **decreasing** order. However, due to software limitations of the KONE analyzer, calibration standards are unable to be analyzed in this manner. The instrument is classified as a true automated discrete analyzer where sample analysis is performed in single use discrete cells which decreases the risk for contamination between sample analyses.

Attachment 1b
SOP Summary
Chloride & Total Chlorine

1.0 Summary

Chloride reacts with mercuric thiocyanate forming a mercuric chloride complex. Released thiocyanate reacts with iron (III) forming a red ferric thiocyanate complex the color produced, measured at 480nm, is proportional to the chloride concentration.

Refer to SOP SA-GE-010 for information on the preparation procedures for Total Chlorine. The attached Work Instruction provides the procedural and calculation information.

2.0 Interferences

Highly colored samples can positively interfere. Turbid samples should be filtered.

3.0 Reagents and Standards

3.1 Purchased Reagents

Mercuric Thiocyanate [$Hg(SCN)_2$] – reagent grade
Storage: Protected from light.

Methanol – HPLC or P&T grade
Storage: Protect from heat, sparks, and flame in a flammable storage area.

Ferric Nitrate [$Fe(NO_3)_3.9H_2O$] – reagent grade
Storage: Away from sources of heat and moisture. Avoid storage on wooden floors.
Expiration: 1 year

Nitric Acid, concentrated – A.C.S. grade
Storage: acid resistant floors and good drainage; away from sunlight, heat, and water.

3.2 Prepared Reagents

Ferric Nitrate Solution (20.2%) – Dissolve 202g $Fe(NO_3)_3.9H_2O$ into 500mL reagent water. Carefully add 44.4mL of concentrated nitric acid. Mix and dilute to 1L with reagent water. Store in an amber bottle away from light.
Expiration: 1 Year

Mercuric Thiocyanate Solution (Saturated) – Dissolve 4.16g $Hg(SCN)_2$ into 500mL of methanol. Dilute to 1L with methanol, mix, and filter. Dispose if reagent becomes discolored or cloudy.
Storage: Protected from light.
Expiration: 1 year

Color Reagent – Add 75mL of Mercuric Thiocyanate Solution to 75mL Ferric Nitrate Solution. Mix and dilute to 500mL with reagent water. Dispose if reagent becomes discolored or cloudy.
Storage: Tightly closed-light resistant container. Protect from light.
Expiration: 3 months

3.3 Standards

Sodium Chloride (NaCl) – reagent grade

Chloride Calibration Stock (1000mg/L) – Purchased from Inorganic Ventures.
Expiration: manufacturer's expiration date or one year, whichever is shorter.

Chloride Calibration Standards

Standard Level	TALS Reagent Name	Parent Standard	Aliquot (mL)	Final Volume (mL)	Final Concentration (mg/L)
1	Cl CAL10	Cl Cal Stk	0.1	100	1
2	Cl CAL6	Cl Cal Stk	1.0	100	10
3	Cl CAL5	Cl Cal Stk	2.0	100	20
4	Cl CAL4	Cl Cal Stk	4.0	100	40
5	Cl CAL12	Cl Cal Stk	5.0	100	50

Dilute to volume in reagent water.

Chloride Laboratory Control Sample (LCS) (25mg/L) – Add 6.25mL Chloride Calibration Stock to a 250mL volumetric. Dilute to volume with reagent water. This standard is also used as the CCV.

Chloride ICV Stock (1000mg/L) – Purchased from NSI.
Expiration: manufacturer's expiration date or one year, whichever is shorter.

Chloride ICV (25mg/L) – Add 2.5mL of Chloride ICV Stock to a 100mL volumetric flask. Dilute to volume with reagent water.

4.0 Sample Preparation

4.1 Aqueous Samples
Aqueous samples are routinely analyzed with no sample preparation.

Prepare QC samples in the same manner as field samples as follows:

- Laboratory Control Sample (LCS) – prepared as described above
- Low-Level Laboratory Control Sample (LLCS) (Drinking Water only) – Lowest level standard of the initial calibration
- MS/MSD – Add 0.25mL of Chloride Calibration Stock to 10mL of the sample selected for MS/MSD. Note: SM4500-Cl^- E recommends the MS/MSD spike concentration to be varied periodically.
- Sample Duplicate (SD) – Prepare an additional aliquot of the chosen sample.

4.2 Soil Samples

- Create a preparation batch in LIMS
- Weigh approximately 5g of sample into a 125mL screw-cap plastic bottle. Record the weight to the nearest 0.1g. Add 100mL of reagent water to each sample container and place in the tumbler.
- Rotate for 15minutes.
- Remove the containers from the extractor and allow the leachates to settle. Filter the extract using a chloride-free 25mm PTFE syringe filter with a 0.20µm pore size and analyze the extracts as liquid samples.

Prepare QC samples in the same manner as field samples as follows:

- Method Blank – Weigh approximately 5g of Teflon Chips into a 125mL screw-cap plastic bottle. Record the weight to the nearest 0.1g.
- Laboratory Control Sample – Weigh approximately 5g of Teflon Chips into a 125mL screw-cap plastic bottle. Record the weight to the nearest 0.1g. Add 2.5mL of the Chloride Cal Stock (1000mg/L) Solution and 97.5mL of DI water.
- MS/MSD – Weigh 2 additional 5g aliquots of one of the samples for the MS/MSD. Add 2.5mL of the Chloride Cal Stock (1000mg/L) Solution and 97.5mL of DI water to each bottle.

5.0 Method-Specific QC Requirements

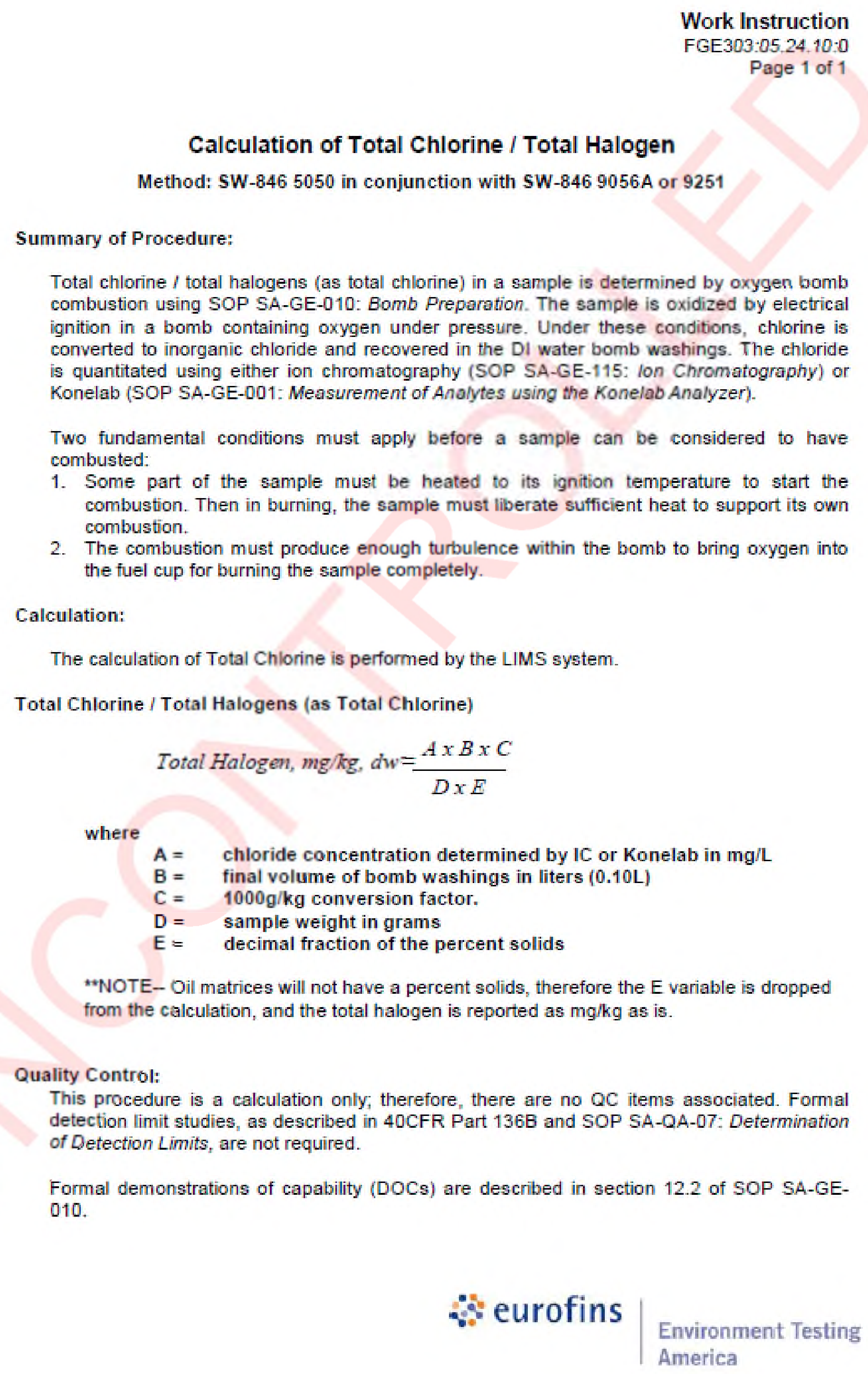
5.1 Linear Calibration Range
SM4500-Cl^- E – Performed initially.

5.2 Method Detection Limit Studies
SM4500-Cl^- E – Requires MDL Study to be analyzed over 3-5 days.

6.0 Method-Specific Modifications and/or Clarifications

6.1 The SM4500-Cl^- E reference method specifies to use 21mL nitric acid to prepare the ferric nitrate solution. The EPA 325.2 and EPA 9251 reference methods specify 31.5mL. The laboratory utilizes 44.4mL as outlined in the Konelab application notes.

6.2 The SM4500-Cl^- E reference method includes the addition of polyoxyethylene 23 lauryl ether to the color reagent. This is not required by the other methods and has been omitted from the laboratory's procedure.



Work Instruction
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Calculation of Total Chlorine / Total Halogen

Method: SW-846 5050 in conjunction with SW-846 9056A or 9251

Summary of Procedure:

Total chlorine / total halogens (as total chlorine) in a sample is determined by oxygen bomb combustion using SOP SA-GE-010: *Bomb Preparation*. The sample is oxidized by electrical ignition in a bomb containing oxygen under pressure. Under these conditions, chlorine is converted to inorganic chloride and recovered in the DI water bomb washings. The chloride is quantitated using either ion chromatography (SOP SA-GE-115: *Ion Chromatography*) or Konelab (SOP SA-GE-001: *Measurement of Analytes using the Konelab Analyzer*).

Two fundamental conditions must apply before a sample can be considered to have combusted:

1. Some part of the sample must be heated to its ignition temperature to start the combustion. Then in burning, the sample must liberate sufficient heat to support its own combustion.
2. The combustion must produce enough turbulence within the bomb to bring oxygen into the fuel cup for burning the sample completely.

Calculation:

The calculation of Total Chlorine is performed by the LIMS system.

Total Chlorine / Total Halogens (as Total Chlorine)

$$\text{Total Halogen, mg/kg, dw} = \frac{A \times B \times C}{D \times E}$$

where

A = chloride concentration determined by IC or Konelab in mg/L
B = final volume of bomb washings in liters (0.10L)
C = 1000g/kg conversion factor.
D = sample weight in grams
E = decimal fraction of the percent solids

**NOTE-- Oil matrices will not have a percent solids, therefore the E variable is dropped from the calculation, and the total halogen is reported as mg/kg as is.

Quality Control:

This procedure is a calculation only; therefore, there are no QC items associated. Formal detection limit studies, as described in 40CFR Part 136B and SOP SA-QA-07: *Determination of Detection Limits*, are not required.

Formal demonstrations of capability (DOCs) are described in section 12.2 of SOP SA-GE-010.

Attachment 1c
SOP Summary
Ferrous Iron and Ferric Iron

1.0 Summary

Ferrous iron is determined by reaction with phenanthroline in acid solution producing an orange color with a maximum absorbance of 510nm.

Ferric iron is performed via the calculation below. The Total Iron result is obtained via ICP and/or ICP/MS analysis in accordance with SOP SA-ME-070 or SA-ME-074.

Ferric Iron = Total Iron – Ferrous Iron

2.0 Interferences

The reaction of ferrous iron with 1,10-phenanthroline is free from common interferences. Long storage times or exposure of samples to light must be avoided. Protect from light and analyze as soon as possible.

3.0 Standards and Reagents

3.1 Purchased Reagents

Hydrochloric Acid (HCl) – concentrated, A.C.S. grade
Storage: Acid resistant floors and good drainage. Store away from sunlight, heat and water.

Glacial Acetic Acid (CH_3COOH) – concentrated, A.C.S. grade
Storage: Acid resistant floors and good drainage. Protect from freezing. Store away from sunlight, heat, and ignition sources.

Ammonium Acetate ($NH_4C_2H_3O_2$) – reagent grade

1,10-phenanthroline monohydrate ($C_{12}H_8N_2 \cdot H_2O$) – reagent grade

3.2 Prepared Reagents

Hydrochloric Acid (1:1) – Slowly add 500mL concentrated HCl to about 400mL DI Water in a 1-L volumetric flask, cool and dilute to volume with DI water. This solution must be prepared in a hood.
Expiration: parent's expiration date or within 1 year of preparation, whichever comes first

Ammonium Acetate Buffer Solution – Dissolve 150g $NH_4C_2H_3O_2$ into 150mL DI Water. Add 700mL concentrated glacial acetic acid. Note: Because $NH_4C_2H_3O_2$ contains a significant amount of iron, new reference standards must be made with each buffer preparation.
Expiration: 5 years (not to exceed expiration of parent reagents).

Phenanthroline Solution (Color Reagent) – Dissolve 100mg $C_{12}H_8N_2 \bullet H_2O$ into 100mL of reagent water. Add 2 drops of concentrated HCl. Discard this solution if it darkens.
Expiration 1 year.

Diluent – 30ml of reagent water acidified to pH <2.0 with 1:1 HCl. For use in Kone instrument.

3.3 Standards

Ferrous Ammonium Sulfate [$Fe(NH_4)_2(SO_4)_2 \bullet 6H_2O$] – reagent grade; Note: The laboratory utilizes two independent lots of ferrous ammonium sulfate. One lot (Mallinckrodt) is utilized as the primary source for calibration standards, laboratory control samples, and matrix spikes. The second lot (Hach) is utilized as the secondary source for the initial calibration verification (ICV).

Ferrous Iron Solution (1000mg/L) – Dissolve 0.7022g $Fe(NH_4)_2(SO_4)_2 \bullet 6H_2O$ (primary source) into 50mL of reagent water in a 100mL volumetric flask. Acidify to pH <2 with 1:1 HCl and dilute to volume with reagent water.

Ferrous Iron Calibration Standards

Standard Level	TALS Reagent Name	Parent Standard	Aliquot (mL)	Final Volume (mL)	Final Concentration (mg/L)
1	FeCal7	1000mg/L	0.0050	100	0.050
2	FeCal6	1000mg/L	0.010	100	0.10
3	FeCal5	1000mg/L	0.030	100	0.30
4	FeCal4	1000mg/L	0.050	100	0.50
5	FeCal3	1000mg/L	0.10	100	1.0
6	FeCal2	1000mg/L	0.30	100	3.0
7	FeCal1	1000mg/L	0.50	100	5.0

Dilute to volume in reagent water.
Expiration: one month.

Ferrous Iron Matrix Spike Solution (40mg/L) – Dilute 4mL of the 1000mg/L Fe+2 Cal Stk to a final volume of 100mL with DI water.
Expiration: one month.

Ferrous Iron Laboratory Control Sample (2.0mg/L) – Dilute 5.0 mL of the 40mg/L matrix spike solution to a final volume of 100mL with DI water.
Expiration: one month.

Ferrous Iron ICV Stock Solution (1000mg/L) – Dissolve 0.7022g $Fe(NH_4)_2(SO_4)_2 \bullet 6H_2O$ (secondary source) into 50mL of reagent water in a 100mL volumetric flask. Acidify to pH <2 with 1:1 HCl and dilute to volume with reagent water.

Ferrous Iron Initial Calibration Verification (ICV) (3.0 mg/L) – Dilute 0.30mL of the 1000mg/L Fe+2 ICVSTK to a final volume of 100mL with DI water.
Expiration: one month.

4.0 Sample Preparation

4.1 Aqueous Samples
10mL of sample are filtered through a 0.45 micron filter prior to analysis. Add approximately 0.05mL (1 drop) of 1:1 HCl to adjust the sample to a pH 1.5–2.5. Use narrow range pH paper during adjustment to verify the proper pH is achieved.

Prepare QC samples in the same manner as field samples as follows:

- Continuing Calibration Verification- prepared as described above.
- Continuing Calibration Blank- reagent water acidified to a PH <2.0 with 1:1 HCl
- Method Blank- reagent water acidified to a PH <2.0 with 1:1 HCl
- Laboratory Control Sample – prepared as described above.
- Low-Level Laboratory Control Sample (Drinking Water only) – Lowest level standard of the initial calibration.
- Matrix Spike/Matrix Spike Duplicate – Add 0.50mL of Ferrous Iron Matrix Spike Solution to 10mL of the chosen sample
- .

4.2 Soil samples are not performed for this analysis.

5.0 Method-Specific QC Requirements

5.1 Linear Calibration Range required to be performed initially.

5.2 Reporting limit verification required for every batch. An RL check standard must be analyzed at the beginning of each sequence.

5.3 Analyze CCV immediately after ICAL (in addition to the ICV). Recovery must be within 5% of true value.

5.4 Any sample containing detection greater than 90% of the determined LDR must be diluted to until the raw result is less than 90% of the determined LDR.

6.0 Method-specific Modifications and/or Clarifications

6.1 The preparation of the Ferrous Iron Solution (1000mg/L) has been revised from the reference method to correspond to that outlined in the Konelab Application Notes.

Attachment 1d
SOP Summary
Hexavalent Chromium and Trivalent Chromium

1.0 Summary

The sample is acidified to pH 2 (+/-0.5) and 1,5-diphenylcarbazide (a color reagent) is added. The intensity of the purple color, measured at 540nm, is proportional to the concentration of hexavalent chromium present in the sample.

Trivalent Chromium is performed via the calculation below. The Total Chromium result is obtained via ICP and/or ICP/MS analysis in accordance with SOP SA-ME-070 or SA-ME-074.

Trivalent Chromium = Total Chromium – Hexavalent Chromium

2.0 Interferences

Iron in concentrations of greater than 1mg/L may produce a yellow color, but this is usually not significant when measured at 540nm. Hexavalent molybdenum and mercury salts react to form colored complexes with the color reagent, but the intensities of the colors produced are much lower than for chromium at the specified pH. Mercury and molybdenum concentrations of up to 200mg/L can be tolerated. Vanadium interferes more strongly, but concentrations of up to 10 times that of chromium can be tolerated.

All samples analyzed must be adjusted to a pH range of 1.5-2.5 with sulfuric acid prior to analysis to minimize interference and allow proper color development.

After acidification, soil digestates should be purged with helium to eliminate excess carbon dioxide gas. Bubble formation in the cuvettes can interfere with readings.

The recovery of soluble forms of hexavalent chromium may be low where the sample matrix contains substances that are readily oxidized by hexavalent chromium (a reducing matrix). The measurement pH and oxidation-reduction potential may provide information about the ability of hexavalent chromium to persist in the sample.

3.0 Standards and Reagents

3.1 Purchased Reagents

Phosphoric acid (H_3PO_4) – concentrated, A.C.S. grade
Storage: Acid resistant floors and good drainage; away from sunlight, heat and water.

Sulfuric Acid (H_2SO_4) – concentrated, A.C.S. grade
Storage: Acid resistant floors and good drainage; away from sunlight, heat, and water.

Acetone – concentrated, A.C.S. grade
Storage: Protect from heat, sparks, and flame in a flammable storage area.

1,5-diphenylcarbazide – reagent grade
Storage: Protect from light and store in desiccator.

3.2 Prepared Reagents

Sulfuric Acid (50% v/v) – Slowly add 50mL concentrated H_2SO_4 to about 40mL reagent water in a 100mL volumetric flask, cool and dilute to volume with reagent water. This solution must be prepared in a hood.
Record ID within the Reagent Program
Expiration: 3 months from date prepared.

Color Reagent – Transfer 0.1250g of 1,5-diphenylcarbazide to 25mL volumetric flask. Add 10mL acetone; swirl to dissolve. Dilute to volume with acetone. Discard if reagent becomes discolored.
Storage: Store in the dark in a tightly capped.
Expiration: 1 Week from date prepared

Diluent: 30mL of reagent water acidified to a pH <2.0 with 1:1 H_2SO_4. For use in KONE instrument.
Expiration: 1 month from date prepared

3.3 Standards

Hexavalent Chromium Initial Calibration Verification Stock (1000mg/L) – Purchased from Sigma Aldrich.
Expiration: Opened: 1 year or the manufacturer’s expiration date, whichever is shorter

Hexavalent Chromium Solution (10mg/L) – Purchased from CPI. Used to prepare calibration standards and matrix spike/ matrix spike duplicates (MS/MSD)
Storage: Opened: 1 year or the manufacturer’s expiration date, whichever is shorter

Hexavalent Chromium Calibration Standards

Standard Level	TALS Reagent Name	Parent Standard	Aliquot (mL)	Final Volume (mL)	Final Concentration (mg/L)
1	CR6 CAL 6	10mg/L Cr6 Solution	0.10	100	0.010
2	CR6 CAL 5	10mg/L Cr6 Solution	0.25	100	0.025
3	CR6 CAL 4	10mg/L Cr6 Solution	0.50	100	0.050
4	CR6 CAL 3	10mg/L Cr6 Solution	1.0	100	0.10
5	CR6 CAL 2	10mg/L Cr6 Solution	3.0	100	0.30
6	CR6 CAL 1	10mg/L Cr6 Solution	5.0	100	0.50

Dilute to volume in reagent water. Expiration: 1 month from preparation

Hexavalent Chromium Laboratory Control Sample (LCS) (0.20mg/L) – Dilute 2mL of the 10mg/L Hexavalent Chromium Solution to 100mL with DI water. (Used as CCV and LCS)
Expiration: 1 month from preparation

Hexavalent Chromium ICV Intermediate Standard (10mg/L) – Dilute 1mL of the 1000mg/L CR6 ICV Stock standard to 100 mL with DI water.
Expiration: 1 month from preparation

Hexavalent Chromium Initial Calibration Verification (0.30mg/L) – Dilute 3mL of the 10mg/L CR6 ICV Intermediate standard to 100 mL with DI water.
Expiration: 1 month from preparation

4.0 Sample Preparation

4.1 Aqueous Samples
Approximately 20mL of aqueous samples are filtered through a 0.45 micron filter prior to analysis. Add approximately 0.05mL (1 drop) of concentrated H_3PO_4. And adjust the pH of 20mL of sample to pH 1.5–2.5 with 50% H_2SO_4.

pH Verification and adjustment
For each sample,

- Create a preservation batch in LIMS (preserv_chk)
- Place a piece of wide range pH paper in a disposable medicine cup. .
- Pour a few drops of sample into the medicine cup and note the color change of the pH paper. Record the pH as “initial pH” in the batch.
- Filter 20mL of sample and add 0.005mL of concentrated Phosphoric Acid. Adjust pH to 1.5-2.5 with 50% Sulfuric Acid.
- Using a transfer pipette and narrow range pH paper (1-2.5) add a drop of the adjusted sample to the pH paper and record pH as “final pH’ in the batch. pH must be within 1.5-2.5.

Note: Make sure to record all reagent and filter IDs in the batch information.
Note: To avoid cross-contamination, use a separate medicine cup and pH strip per sample. Do not dip the strip into the sample container

Prepare QC samples in the same manner as field samples as follows:

- Continuing Calibration Verification- prepared as described above
- Continuing Calibration verification Blank – reagent water
- Method Blank – reagent water
- Laboratory Control Sample (LLCS) – prepared as described above.
- Low-Level Laboratory Control Sample (drinking water) – Lowest level standard of the initial calibration
- Matrix Spike/Matrix Spike Duplicate – Add 0.20mL of Hexavalent Chromium Solution (10mg/L) to 10mL of the chosen sample.

5.0 Method-Specific QC Requirements

SM3500-Cr B – Linear Dynamic Range (LDR) study initially. Reporting limit verification per batch. Any sample containing a detection greater than 90% of the determined LDR must be diluted to until the raw result is less than 90% of the determined LDR.

A CCV must be analyzed immediately following the initial calibration (in addition to the ICV). This CCV must recover within 5% of the true value.

An RL check sample must be analyzed at the beginning of each sequence.

6.0 Method-Specific Modifications and Clarifications

6.1 The SM3500-Cr B reference method states to adjust sample pH to 2 +/-0.5 with 0.2N sulfuric acid. The EPA 7196A reference method states to adjust sample pH to 2 +/-0.5 with 10%sulfuric acid. Adjusting the pH with such a weak solution requires adding >5% volume and therefore diluting the sample. As such, the laboratory has chosen to use 50% sulfuric to adjust the sample pH.

6.2 The EPA 7196A reference method states to add the color reagent, then adjust the sample pH to 1.5-2.5. The Konelab instrument automatically adds the color reagent; therefore, the order of these steps is reversed (i.e., the laboratory adjusts the pH then adds the color reagent). Correspondence with EPA indicates this is an acceptable modification to the method.

Attachment 1e
SOP Summary
Ortho-phosphate

1.0 Summary

Orthophosphate reacts with ammonium molybdate and antimony potassium tartrate under acidic conditions to form a complex which, when reduced with ascorbic acid, produces an intense blue color. The color is measured photometrically at 880nm and the absorbance is proportionate to the amount of orthophosphate in the sample.

2.0 Interferences

Samples that are blue in color may interfere. Samples with high concentrations of arsenic may interfere.

3.0 Reagents and Standards

3.1 Purchased Reagents

Antimony Potassium Tartrate [$K(SbO)C_4H_4O_6 \bullet ½ H_2O$] – reagent grade

Ammonium Molybdate [$(NH_4)_6Mo_7O_{24} \bullet 4H_2O$] – reagent grade. Storage: Isolated from sources of heat and moisture.

Sulfuric Acid (H_2SO_4) – concentrated, A.C.S. grade
Storage: Acid resistant floors and good drainage. Away from sunlight, heat, and water.

Ascorbic Acid – reagent grade
Storage: Isolate from sources of heat and fire.

3.2 Prepared Reagents

Sulfuric acid solution 5N: Slowly add 70mL of concentrated H_2SO_4 to approximately 400mL of reagent water. Cool to room temperature and dilute to 500mL with reagent water.

Antimony Potassium Tartrate Solution – Dissolve 3.0g $K(SbO)C_4H_4O_6 \bullet ½ H_2O$ in approximately 500mL of reagent water. Dilute to 1000mL with reagent water.
Storage: Store at 4°C in a dark, glass-stoppered bottle.

Ammonium Molybdate Solution – Dissolve 40g $(NH_4)_6Mo_7O_{24} \bullet 4H_2O$ in approximately 800mL of reagent water. Dilute to 1L with reagent water.
Storage: Store at 4°C in a plastic bottle.

Color Reagent 2 – Ascorbic Acid Solution (0.1M) – Dissolve 1.76g ascorbic acid in approximately 50mL of reagent water. Dilute to 100mL with reagent water.
Expiration: Prepare fresh daily.

Color Reagent 1 – Add 75mL Ammonium Molybdate Solution to 250mL 5N sulfuric acid. Mix well. Add 25mL Antimony Potassium Tartrate Solution to this solution and mix well.
Expiration: 6 months

Combined Color Reagent – Add 14mL of Color Reagent 1 to 6mL of Color Reagent 2. Mix well.
Expiration: Solution is only good for 4 hours from time of prep.

3.3 Standards

Phosphate Calibration Standard (1000mg/L) – Purchased from NSI Lab Solutions.
Storage: Away from sunlight.
Expiration: Opened: 1 year or the manufacturer's expiration date, whichever is shorter.

Ortho-phosphate Initial Calibration Verification (ICV) Stock (1000mg/L) – Purchased from Inorganic Ventures.
Storage: Away from sunlight.
Expiration: Opened: 1 year or the manufacturer's expiration date, whichever is shorter.

Ortho-phosphate Calibration Standards:

Standard Level	TALS Reagent Name	Parent Standard	Volume of Parent Standard (mL)	Final Volume (mL)	Final Concentration (mg/L)
7	PO4 CAL 1	PO4 100ppm	2	100	2.0
6	PO4 CAL 2	PO4 100ppm	1.6	100	1.6
5	PO4 LCS	PO4 100ppm	1.2	100	1.2
4	PO4 CAL 3	PO4 100ppm	0.8	100	0.80
3	PO4 CAL 4	PO4 100ppm	0.4	100	0.40
2	PO4 CAL 5	PO4 100ppm	0.2	100	0.20
1	PO4 CAL 1 PO4 RL	PO4 100ppm	0.050	100	0.050

Dilute to volume in reagent water.

Ortho-phosphate Laboratory Control Sample (1.2mg/L) – Dilute 1.2mL of 100mg/L Orthophosphate Matrix Spike Solution to a final volume of 100mL with reagent water. (Also used as CCV)
Expiration: 1 month

Ortho-phosphate Initial Calibration Verification (1.0mg/L) – Dilute 1.0mL of the 1000mg/L Ortho-phosphate ICV Stock to a final volume of 1000mL with reagent water.
Expiration: 1 month.

Ortho-phosphate Matrix Spike Solution (100mg/L) – Dilute 10mL of the 1000mg/L Phosphate Calibration Standard to a final volume of 100mL with reagent water.
Expiration: 1 month.

4.0 Sample Preparation

4.1 Aqueous Samples

Aqueous samples are routinely filtered. Filter samples through a 0.45 micron pp filter.

Note: Acidic samples must be neutralized with 1N NaOH prior to analysis.

4.1.1 QC Sample Preparation

- Continuing Calibration Verification – Prepared as described above
- Continuing Calibration Blank – reagent water
- Method Blank – reagent water
- Laboratory Control Sample – Prepared as outlined above
- Low-Level Laboratory Control Sample (Drinking Water only) – Lowest level standard of the initial calibration
- Matrix Spike/Matrix Spike Duplicate – Add 0.10mL of 100mg/L Matrix Spike Solution to 10mL of the chosen sample. The concentration of the MS/MSD must equal the concentration of the LCS.

Prepare all QC in the same manner as samples.

4.2 Soil Samples

Create a DI Leach batch in LIMs.

Weigh approximately 5g of sample into a 125mL screw-cap plastic bottle. Record the weight to the nearest 0.1g. Add 100mL of reagent water to each sample container and place in the tumbler.

Rotate for 2 hours +/- 30 minutes.

Remove the containers from the extractor and allow the leachates to settle. Filter the extract using a syringe filter with a 0.45um pore size filter and analyze the extracts as liquid samples.

Add one drop of phenolphthalein indicator solution to approximately 50mL of leachate. If a red color develops add 10N sulfuric acid dropwise until the color dissipates.

Note: Acidic samples must be neutralized with 1N NaOH prior to analysis.

4.2.1 QC Sample Preparation

Method Blank – Weigh approximately 20g of Teflon chips into a 125mL screw-cap plastic bottle. Record the weight to the nearest 0.1g.

Laboratory Control Sample – Weigh approximately 5g of Teflon chips into a 125mL screw-cap plastic bottle. Record the weight to the nearest 0.1g. Add 1.0mL of 100mg/L Matrix Spike Solution to the extraction bottle.

Matrix Spike – Weigh an additional 5g aliquot of one of the samples for the MS. Add 1.0mL of 100mg/L Matrix Spike Solution to the extraction bottle. One sample must be chosen from samples 1-10 and one sample from samples 11-20. The concentration of the MS must equal the concentration of the LCS.
Sample Duplicate – If precision is required, weigh one additional 20g aliquot of one of the samples for the SD.

Prepare all QC in the same manner as samples.

5.0 Method-Specific QC Requirements

SM4500-P F requires the MDL study to be analyzed over 3-5 days.

SM4500-P F recommends the matrix spike concentration be rotated.

Attachment 1f
SOP Summary
Sulfate, Total Sulfur, and Heat of Combustion (BTU)

1.0 Summary

Sulfate ion is precipitated in a strongly acidic medium with Barium Chloride. The resulting turbidity is measured photometrically at 405nm and compared with appropriate standard solutions.

Refer to SOP SA-GE-010 for information on the preparation procedures for Total Sulfur and Heat of Combustion (BTU). The attached Work Instruction provides the procedural and calculation information.

2.0 Interferences

Silica at a concentration above 500mg/L in the sample will interfere. Color and turbidity due to the sample matrix can cause positive interferences that must be accounted for by the analysis of sample blanks (i.e. samples analyzed without adding reagents). The absorbance or turbidity of the sample blank is subtracted from the absorbance or turbidity of the treated sample, and the concentration is determined from the corrected response.

3.0 Reagents and Standards

3.1 Purchased Reagents

Barium Chloride ($BaCl_2$) – reagent grade
Storage: Store in a cool, dry, ventilated area. Isolate from heat, moisture, and incompatibles.

Sodium Chloride (NaCl) – reagent grade
Storage: Store in a cool, dry, ventilated area.

Gelatin – (TALS – Gelatin)

Hydrochloric Acid (HCl) – concentrated, A.C.S. grade
Storage: Store in a cool, dry, ventilated area with acid resistant floors and good drainage. Store away from sunlight, heat, water, and incompatible materials.

3.2 Prepared Reagents

Precipitating Solution – In a 100mL volumetric flask, dissolve 1.0g $BaCl_2$, 2.0g NaCl, and 0.1g of Gelatin in approximately 30mL reagent water. Stir until completely dissolved. Carefully add 0.5mL concentrated HCl and dilute to volume with reagent water.
Expiration: 3 months

3.3 Purchased Standards

Sulfate Calibration Stock Solution (1000mg/L) – Purchased from Inorganic Ventures.
Expiration: Manufacturer’s expiration date.

Sulfate Calibration Standards

Standard Level	TALS Reagent Name	Parent Standard	Volume of Parent Standard (mL)	Final Volume (mL)	Final Concentration (mg/L)
6	SO4 CAL 6	1000mg/L	3.5	100	35
5	SO4 CAL 5	1000mg/L	3.0	100	30
4	SO4 CAL 4	1000mg/L	2.5	100	25
3	SO4 CAL 3	1000mg/L	1.5	100	15
2	SO4 CAL 2	1000mg/L	1.0	100	10
1	SO4 CAL 1	1000mg/L	0.5	100	5

Dilute to volume in reagent water.

Sulfate Laboratory Control Sample (20mg/L) – Dilute 5mL of the 1000mg/L SO4 Cal stock to 250mL final volume.
Expiration: 3 months

Sulfate ICV Stock (1000 mg/L) – Purchased from NSI.
Expiration: Manufacturer’s expiration date.

Sulfate Initial Calibration Verification (20mg/L) Add 2.0mL Sulfate Calibration Stock Solution to a 100mL volumetric flask. Dilute to mark with DI water.
Expiration: 3 months

Sulfate Matrix Spike Solution (1000mg/L) – This is the same as the SO4 Calibration Stock Solution
Expiration: Manufacturer’s expiration date.

4.0 Sample Preparation

4.1 Aqueous Samples
Aqueous samples are routinely analyzed with no sample preparation.

4.1.1 QC Sample Preparation

Method Blank – reagent water

Laboratory Control Sample – Prepared as outlined above.

Low-Level Laboratory Control Sample (drinking water) – Lowest level standard of the initial calibration

Matrix Spike/Matrix Spike Duplicate – Add 0.2mL of Sulfate Matrix Spike Solution to 10mL of the chosen sample.

Prepare all QC in the same manner as samples

4.2 Soil Samples

Create a DI Leach batch in LIMS.

Weigh approximately 5g of sample into a 125mL screw-cap plastic bottle. Record the weight to the nearest 0.1g. Add 100mL of reagent water to each sample container and place in the tumbler.

Rotate for 2 hours +/- 15 minutes.

Remove the containers from the extractor and allow the leachates to settle. Filter the extract using a syringe filter with a 0.450-um pore size filter and analyze the extracts as liquid samples.

4.2.1 QC Sample Preparation

Method Blank – Weigh approximately 5g of Ottawa sand into a 125mL screw-cap plastic bottle. Record the weight to the nearest 0.1g.

Laboratory Control Sample – Weigh approximately 5g of Ottawa sand into a 125mL screw-cap plastic bottle. Record the weight to the nearest 0.1g. Add 2.0mL of Sulfate Cal Stock (1000mg/L) solution and 98mL of DI water.

Matrix Spike/Matrix Spike Duplicate – Weigh two additional 5g aliquots of one of the samples for the MS and MSD. Add 2.0mL of Sulfate Cal Stock (1000mg/L) solution and 98mL of DI water to each bottle.

Prepare all QC in the same manner as samples.

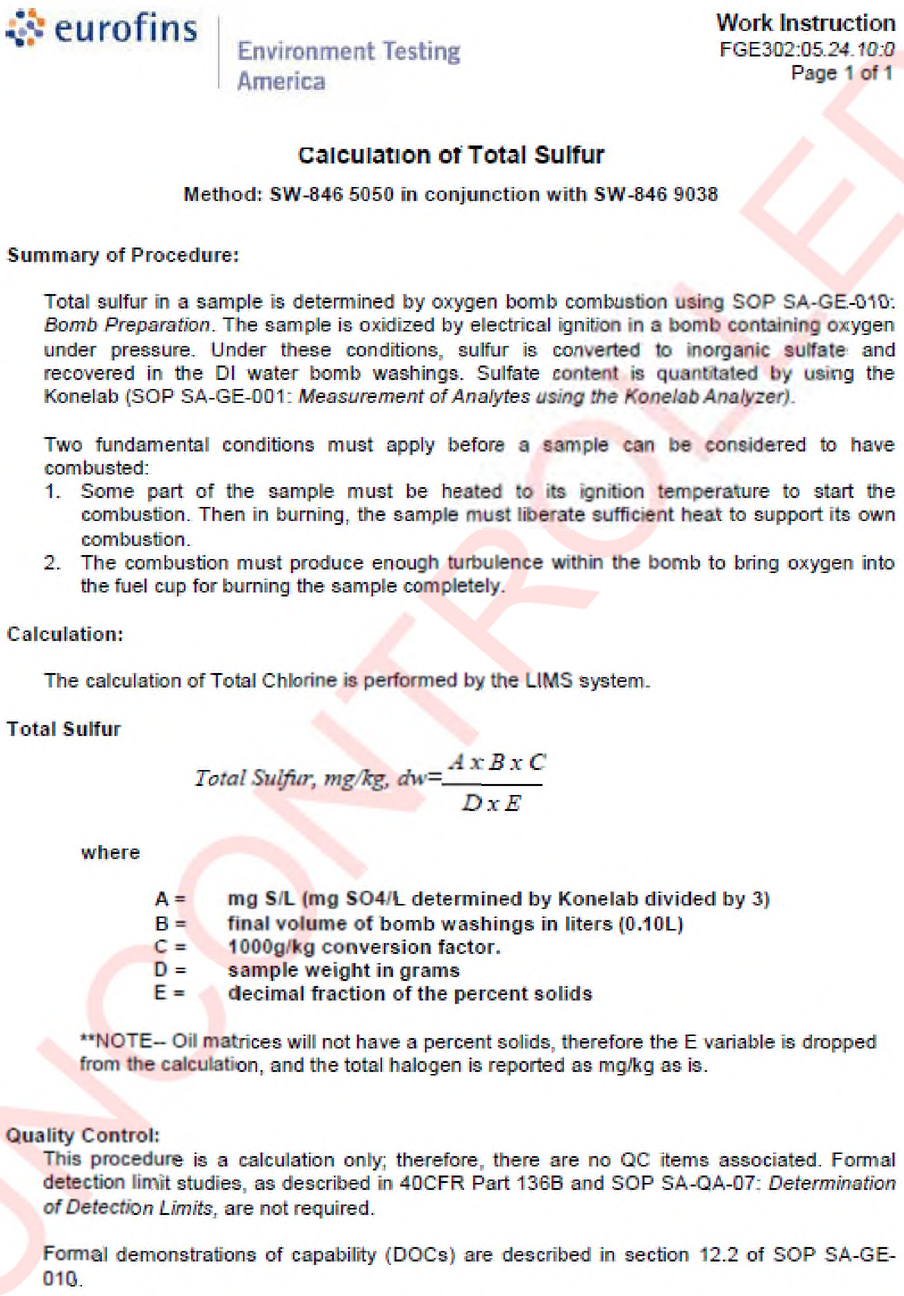
5.0 Method-Specific QC Requirements

A CCV must be analyzed every 3-4 sample analyses (EPA 375.4 Section 6.3.4 and EPA 9038 Section 7.3.4).

6.0 Method-Specific Modifications and Clarifications

6.1 The EPA 375.4 reference method states to measure turbidity every 30 seconds for 1-5 minutes after the addition of barium chloride, with the maximum turbidity reading used for determining the Sulfate concentration. The Konelab instrument performs parallel analyses of each sample - one for performing turbidity measurements and one for sulfate determination. The turbidity measurements are made 200 seconds after the color reagent is added and every 28 seconds after that for 240 seconds. The turbidity absorbances are presented on the raw data to indicate if the sample is settling out but do not affect how the sulfate result is determined. The sulfate determination is made 300 seconds after the color reagent is added. Although the Konelab instrument will allow multiple sulfate readings to be made, the instrument cannot select the result associated with the highest turbidity; rather, it will perform an average of the results obtained. As this instrument configuration cannot be changed to use the sulfate reading taken from the highest turbidity replicate.

6.2 The Sulfate Precipitating Solution is prepared in accordance with the Konelab Application. Notes which differs from the information provided in the reference method.



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Calculation of Total Sulfur

Method: SW-846 5050 in conjunction with SW-846 9038

Summary of Procedure:

Total sulfur in a sample is determined by oxygen bomb combustion using SOP SA-GE-010: *Bomb Preparation*. The sample is oxidized by electrical ignition in a bomb containing oxygen under pressure. Under these conditions, sulfur is converted to inorganic sulfate and recovered in the DI water bomb washings. Sulfate content is quantitated by using the Konelab (SOP SA-GE-001: *Measurement of Analytes using the Konelab Analyzer)*.

Two fundamental conditions must apply before a sample can be considered to have combusted:

1. Some part of the sample must be heated to its ignition temperature to start the combustion. Then in burning, the sample must liberate sufficient heat to support its own combustion.
2. The combustion must produce enough turbulence within the bomb to bring oxygen into the fuel cup for burning the sample completely.

Calculation:

The calculation of Total Chlorine is performed by the LIMS system.

Total Sulfur

$$\textit{Total Sulfur, mg/kg, dw} = \frac{A \times B \times C}{D \times E}$$

where

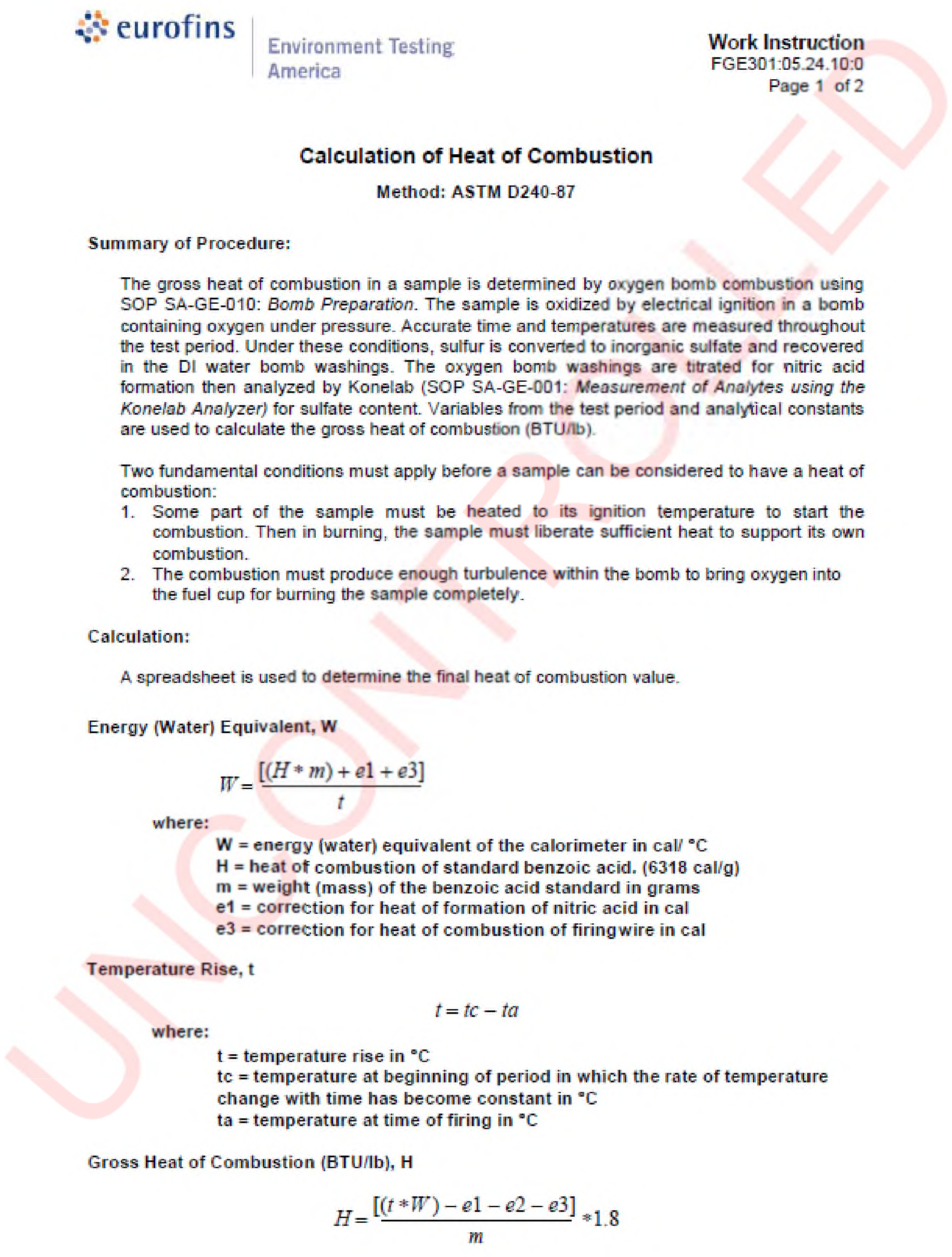
A = **mg S/L (mg SO4/L determined by Konelab divided by 3)**
B = **final volume of bomb washings in liters (0.10L)**
C = **1000g/kg conversion factor.**
D = **sample weight in grams**
E = **decimal fraction of the percent solids**

**NOTE-- Oil matrices will not have a percent solids, therefore the E variable is dropped from the calculation, and the total halogen is reported as mg/kg as is.

Quality Control:

This procedure is a calculation only; therefore, there are no QC items associated. Formal detection limit studies, as described in 40CFR Part 136B and SOP SA-QA-07: *Determination of Detection Limits*, are not required.

Formal demonstrations of capability (DOCs) are described in section 12.2 of SOP SA-GE-010.



Calculation of Heat of Combustion

Method: ASTM D240-87

Summary of Procedure:

The gross heat of combustion in a sample is determined by oxygen bomb combustion using SOP SA-GE-010: *Bomb Preparation*. The sample is oxidized by electrical ignition in a bomb containing oxygen under pressure. Accurate time and temperatures are measured throughout the test period. Under these conditions, sulfur is converted to inorganic sulfate and recovered in the DI water bomb washings. The oxygen bomb washings are titrated for nitric acid formation then analyzed by Konelab (SOP SA-GE-001: *Measurement of Analytes using the Konelab Analyzer)* for sulfate content. Variables from the test period and analytical constants are used to calculate the gross heat of combustion (BTU/lb).

Two fundamental conditions must apply before a sample can be considered to have a heat of combustion:

1. Some part of the sample must be heated to its ignition temperature to start the combustion. Then in burning, the sample must liberate sufficient heat to support its own combustion.
2. The combustion must produce enough turbulence within the bomb to bring oxygen into the fuel cup for burning the sample completely.

Calculation:

A spreadsheet is used to determine the final heat of combustion value.

Energy (Water) Equivalent, W

$$W = \frac{[(H * m) + e1 + e3]}{t}$$

where:

W = energy (water) equivalent of the calorimeter in cal/ °C
H = heat of combustion of standard benzoic acid. (6318 cal/g)
m = weight (mass) of the benzoic acid standard in grams
e1 = correction for heat of formation of nitric acid in cal
e3 = correction for heat of combustion of firingwire in cal

Temperature Rise, t

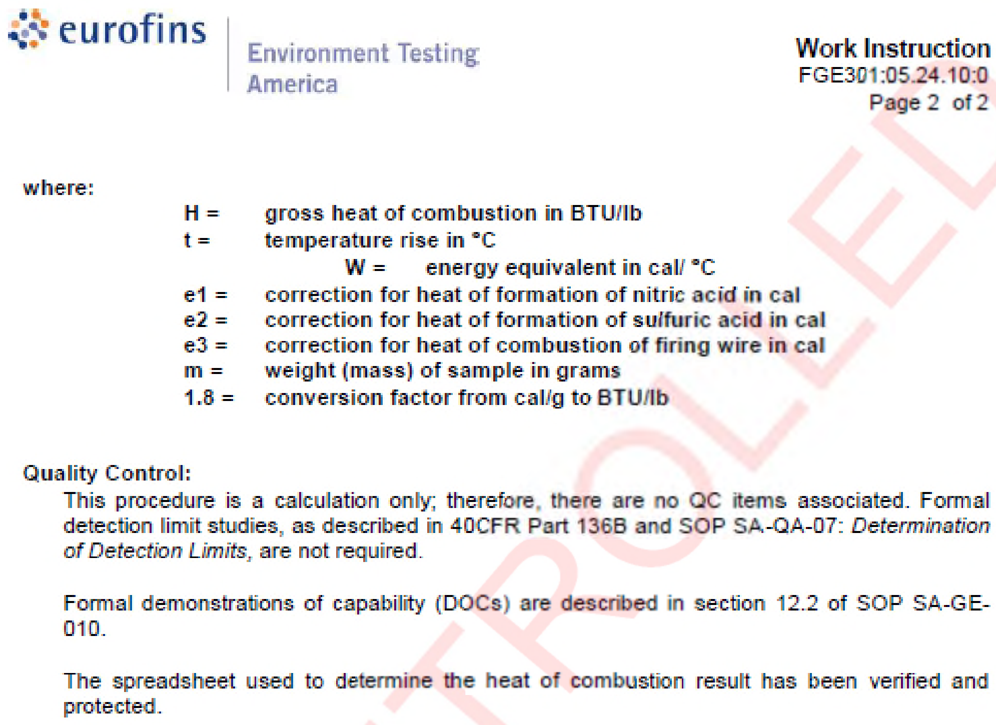
$$t = tc - ta$$

where:

t = temperature rise in °C
tc = temperature at beginning of period in which the rate of temperature change with time has become constant in °C
ta = temperature at time of firing in °C

Gross Heat of Combustion (BTU/lb), H

$$H = \frac{[(t * W) - e1 - e2 - e3]}{m} * 1.8$$



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where:

H = gross heat of combustion in BTU/lb
t = temperature rise in °C
W = energy equivalent in cal/ °C
e1 = correction for heat of formation of nitric acid in cal
e2 = correction for heat of formation of sulfuric acid in cal
e3 = correction for heat of combustion of firing wire in cal
m = weight (mass) of sample in grams
1.8 = conversion factor from cal/g to BTU/lb

Quality Control:

This procedure is a calculation only; therefore, there are no QC items associated. Formal detection limit studies, as described in 40CFR Part 136B and SOP SA-QA-07: *Determination of Detection Limits*, are not required.

Formal demonstrations of capability (DOCs) are described in section 12.2 of SOP SA-GE-010.

The spreadsheet used to determine the heat of combustion result has been verified and protected.

Attachment 2:
Sample Collection, Preservation, and Holding Time Table

Fraction	Matrix	Routine Sample Container	Routine Sample Size	Chemical Preservation	Thermal Preservation	Dechlorination Agent	Holding Time
Ammonia	Water	250mL plastic	40mL	1mL 1:1 H_2SO_4 pH <2	0-6°C[1]	Sodium Thiosulfate	28 Days
Ammonia	Soil	8oz Plastic	20g	None	0-6°C[1]	None	28 Days[2]
BTU	Water	4oz glass soil jar	1g	None	0-6°C[1]	None	28 Days
BTU	Soil	4oz glass soil jar	1g	None	0-6°C[1]	None	28 Days[2]
Chloride	Water	125mL plastic	10mL	None	0-6°C[1]	None	28 Days
Chloride	Soil	8oz Plastic	5g	None	0-6°C[1]	None	28 Days[2]
Chloride, Total	Water	125mL plastic	1g	None	0-6°C[1]	None	28 Days
Chloride, Total	Soil	8oz Plastic	1g	None	0-6°C[1]	None	28 Days[2]
Ferrous Iron	Water	125mL plastic	10mL	None	0-6°C[1]	None	15 Minutes[3]
Ferric Iron (Calc)	Water	125mL plastic	10mL	None	0-6°C[1]	None	15 Minutes[3]
Hexavalent Chromium	Water	125mL plastic	10mL	None	0-6°C[1]	None	24 Hours[4]

Fraction	Matrix	Routine Sample Container	Minimum Sample Size	Chemical Preservation	Thermal Preservation	Dechlorination Agent	Holding Time
Trivalent Chromium (Calc)	Water	125mL plastic	10mL	None	0-6°C[1]	None	24 Hours
Ortho-Phosphate	Water	125mL plastic	10mL	None	0-6°C[1]	None	48 Hours
Ortho-Phosphate	Soil	8oz Plastic	20g	None	0-6°C[1]	None	48 Hours[2]
Sulfate	Water	125mL plastic	10mL	None	0-6°C[1]	None	28 Days
Sulfate	Soil	8oz Plastic	5g	None	0-6°C[1]	None	28 Days[2]
Sulfur, Total	Water	125mL plastic	1g	None	0-6°C[1]	None	28 Days
Sulfur, Total	Soil	8oz Plastic	1g	None	0-6°C[1]	None	28 Days[2]

[1] Samples must be maintained at 0-6°C, with no frozen samples.

[2] Inclusive of digestion and analysis.

[3] Due to the nature of this analysis, this test is considered a field test. No definitive holding time is specified in the reference methods; however, the Methods Update Rule of 40CFR Part 136 identifies a 15 minute holding time for this method. Although these samples will be outside holding time upon receipt to the laboratory, an effort should be made to analyze as soon as possible after receipt.

[4] Clean Water Act (CWA) sampling requirements state that field filtration must be performed within 15minutes of sampling to prevent interconversion of chromium species. NCMs must be initiated for samples when the COC does not indicate field filtration was performed.

Note: NCMs must be initiated for samples collected in improper containers and containing improper or insufficient preservatives and/or de-chlorination agents.

Attachment 3a: Batch QC Frequency

Fraction	Method	MB Frequency[1]	LCS Frequency[1]	LCSD Frequency[1]	LLCS Frequency[1]	MS Frequency[1]	MSD Frequency[1]	SD Frequency[1]
Ammonia	EPA 350.1	1 per batch	1 per batch	1 per batch[2]	1 per batch[3]	10% of samples	1 per batch	None
Ammonia	SM4500-NH3 G	1 per batch	1 per batch	1 per batch[2]	1 per batch[3]	1 per batch	1 per batch	1 per batch
BTU	ASTM D240-87	None	1 per batch	None	None	None	None	1 per 10
Chloride	EPA 325.2	1 per batch	1 per batch	1 per batch[2]	1 per batch[3]	1 per batch	1 per batch	None
Chloride	EPA 9251	1 per batch	1 per batch	1 per batch[2]	None	10% of samples	10% of samples	None
Chloride	SM4500-Cl E	1 per batch	1 per batch	1 per batch[2]	1 per batch[3]	1 per batch	1 per batch	1 per batch
Chlorine	EPA 5050/EPA 9251	1 per batch	1 per batch	None	None	None	None	1 per 10
Ferrous Iron	SM3500-Fe B	1 per batch	1 per batch	1 per batch[2]	None	1 per batch	1 per batch	None
Ferric Iron (Calc)	SM3500-Fe B	NA	NA	NA	NA	NA	NA	NA
Hexavalent Chromium	SM3500-Cr B	1 per batch	1 per batch	1 per batch[2]	None	1 per batch	1 per batch	None
Hexavalent Chromium	SM3500-Cr D	1 per batch	1 per batch	1 per batch[2]	None	1 per batch	1 per batch	None
Hexavalent Chromium	EPA 7196A	1 per batch	1 per batch	1 per batch[2]	None	10% of samples	1 per batch	None
Ortho-phosphate	EPA 365.1	1 per batch	1 per batch	1 per batch[2]	1 per batch[3]	10% of samples	1 per batch	None
Ortho-phosphate	SM4500-P F	1 per batch	1 per batch	1 per batch[2]	1 per batch[3]	1 per batch	1 per batch	1 per batch
Sulfate	EPA 375.4	1 per batch	1 per batch	1 per batch[2]	1 per batch[3]	1 per batch	1 per batch	None
Sulfate	EPA 9038	1 per batch	1 per batch	1 per batch[2]	None	10% of samples	10% of samples	None
Total Sulfur	EPA 5050/EPA 9038	1 per batch	1 per batch	None	None	None	None	1 per 10
Trivalent Chromium (Calc)	SM3500-Cr B	NA	NA	NA	NA	NA	NA	NA
Trivalent Chromium (Calc)	SM3500-Cr D	NA	NA	NA	NA	NA	NA	NA
Trivalent Chromium (Calc)	EPA 7196A	NA	NA	NA	NA	NA	NA	NA

[1] Batch Definition = Up to 20 field samples prepared and/or analyzed together within 24 hours

[2] If insufficient sample provided for MS/MSD.

[3] For Drinking Water analyses only.

Attachment 3b: QC Summary

QC Item	Frequency	Criteria	Corrective Action
Initial Calibration (ICAL) Multi-point: Minimum 3 standards and 1 blank	Daily	Correlation $\geq$0.995 And each point on curve must be within +/- 10% of true value	Recalibrate Note: SM3500-Fe B and SM3500-Cr B do not allow quadratic curves
Second Source Initial Calibration Verification (ICV)	Immediately following the initial calibration; at a minimum, quarterly	Within ±10% of the true value	Recalibrate
Continuing Calibration Verification (CCV)	SM3500-Fe B, SM3500-Cr B: Immediately following ICAL Sulfate: At the beginning and end of the analysis, and after every 3-4 samples All Others: At the beginning and end of the analysis, and after every 10 samples	SM3500-Fe B, SM3500-Cr B: Within ±5% of the true value All Others: Within ±10% of the true value	Terminate the analysis, fix the problem and reanalyze the previous samples.
Initial Calibration Blank (ICB)	After ICV	SM3500-Fe B, SM3500-Cr B: <MDL Others: < ½ RL	Terminate the analysis, correct problem and reanalyze the previous 10 samples.
Continuing Calibration Blank (CCB)	After every CCV	SM3500-Fe B, SM3500-Cr B: <MDL	Terminate the analysis, correct problem and reanalyze the previous 10 samples.

QC Item	Frequency	Criteria	Corrective Action
		Others: < ½ RL	
Batch Frequency	<=20 field samples or 24 hours	Not Applicable	Not Applicable
Method Blank (MB)	One per batch	SM3500-Fe B, SM3500-Cr B: <MDL Others: < ½ RL	Evaluate according to SOP SA-QA-017
Laboratory Control Sample (LCS)	One per batch	Within limits listed in the MLG	Evaluate according to SOP SA-QA-017
Laboratory Control Sample Duplicate (LCSD)	One per batch, when insufficient sample provided for MS/MSD/SD	Within limits listed in the MLG	Evaluate according to SOP SA-QA-017
Low-Level Laboratory Control Sample (LLCS)	Drinking Water Only: One per batch	Within limits listed in the MLG	Evaluate according to SOP SA-QA-017
Reporting Limit Verification (RLV)	SM3500-Fe B, SM3500-Cr B: One per batch	Within limits listed in the MLG	Evaluate according to SOP SA-QA-017
Matrix Spike (MS)	Refer to QC Frequency Table	Within limits listed in the MLG	Evaluate according to SOP SA-QA-017
Matrix Spike Duplicate (MSD)	Refer to QC Frequency Table	Within limits listed in the MLG	Evaluate according to SOP SA-QA-017
Sample Duplicate (SD)	Refer to QC Frequency Table	Within limits listed in the MLG	Evaluate according to SOP SA-QA-017
Linear Calibration Range (LCR) (Also called Linear Dynamic Range, LDR)	Upon method/instrument set-up, and when LCR verification fails acceptance criteria.	Within ±10% of the true value	This determines the range at which the instrument is considered linear. The highest concentration of the calibration curve can not exceed the highest concentration of the LCR study.

QC Item	Frequency	Criteria	Corrective Action
Linear Calibration Range Verification (LCRV) (Also called Linear Dynamic Range Verification, LDRV)	Every 6 months	Within ±10% of the initial value	Re-perform the LCR study
Initial Demonstration of Capability (IDOC)	Initially, per analyst, per analyte/method combination	Refer to SOP SA-QA-006	Refer to SOP SA-QA-006 (Unsupervised work cannot begin until successful IDOC is obtained.)
Continuing Demonstration of Capability (CDOC)	Annually, per analyst, per analyte/method combination	Refer to SOP SA-QA-006	Refer to SOP SA-QA-006
Reporting Limit Verification (RLV)	Upon method/instrument set-up, per analyte/method/matrix combination. Then quarterly thereafter for DOD ELAP.	Refer to SOP SA-QA-007	Refer to SOP SA-QA-007
Method Detection Limit Study (MDL)	Upon method/instrument set-up, per analyte/method/matrix combination and annually thereafter EPA 365.1: Upon method/instrument set-up, per analyte/method/matrix combination and every 6 months thereafter	Refer to SOP SA-QA-007	Refer to SOP SA-QA-007

QC Item	Frequency	Criteria	Corrective Action
MDL Verification (MDLV)	Upon method/instrument set-up, per analyte/method/matrix combination. Then quarterly thereafter for methods/analytes on DOD ELAP	Refer to SOP SA-QA-007	Refer to SOP SA-QA-007

Attachment 4: Instrument Maintenance and Troubleshooting

Instrument Labeling

Each instrument must be labeled with its name or ID (e.g., MSA, ICP-D, etc.). Additionally, non-operational instruments must be isolated from service or marked as being out of service. Each piece of equipment has an "Operational / Not Operational" sticker that is used for this purpose.

Maintenance Log

A maintenance log must be established for each piece of equipment used in the laboratory. All maintenance that is performed on the instrument must be recorded in the log including:

- Type of maintenance performed (Note: This includes preventative/routine maintenance; non-routine maintenance; maintenance performed by an external vendor; updates to software versions; etc.)
- Analyst or technician performing the maintenance
- Date the maintenance was performed
- Detailed explanation of the reason for the maintenance
- resolution of the problem and return to control
- All service calls from instrument representatives
- Resolution of the problem (i.e., the Return to Control)

Preventive Maintenance

Refer to the instrument manufacturer's guides for troubleshooting items.

LABORATORY EQUIPMENT PREVENTIVE MAINTENANCE SCHEDULE								
EQUIPMENT ITEM	**Service Interval**							**SERVICE LEVEL**
	D	**W**	**M**	**Q**	**SA**	**A**	**AN**	
Sample Probe	X							Clean and inspect daily
Dispenser Rods			X					Clean and lube monthly
Fetcher Rods			X					Clean and lube monthly
Incubator Rods			X					Clean and lube monthly
Water Lines			X					Clean with isopropyl alcohol monthly

D = daily; W = Weekly; M = monthly; Q = Quarterly; SA = semi-annually; A = annually; AN = as needed

Contingency Plan

Maintenance contracts are carried for most instrumentation and close contact is maintained with service personnel to ensure optimal instrument functioning. An extensive spare parts inventory is maintained for routine repairs. Since instrumentation is standardized throughout the laboratory network, spare parts and components can be readily exchanged among the network.

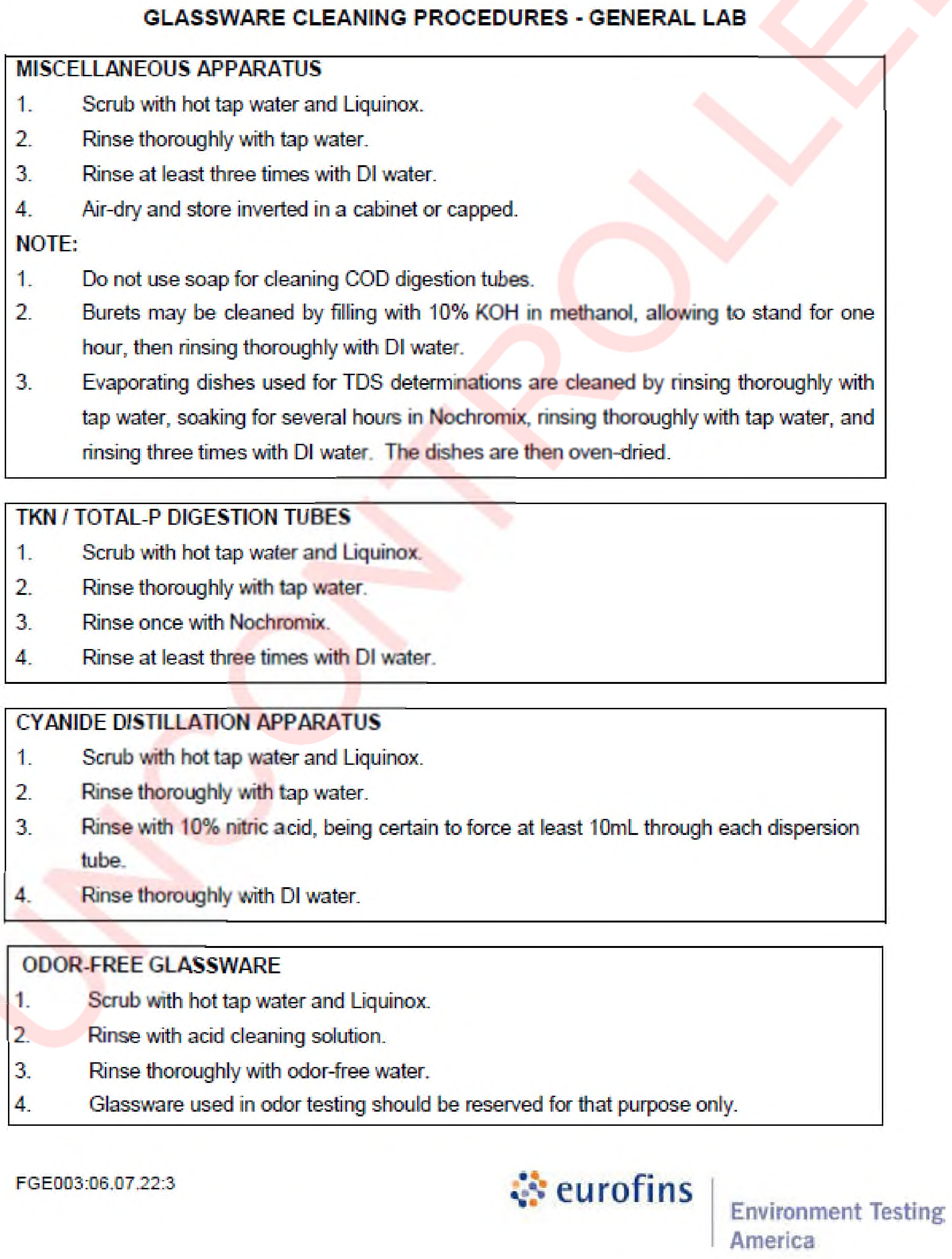
In general, the laboratory has at least one backup unit for each critical unit. In the event of instrument failure, portions of the sample load may be diverted to duplicate instrumentation, the analytical technique switched to an alternate approved technique (such as manual colorimetric determination as opposed to automated colorimetric determination), or samples shipped to another properly certified or approved Eurofins Environment Testing location.

Attachment 5: Maximum Contaminant Levels (MCL) Table

Primary Drinking Water Regulations	
Contaminant	**MCL (mg/L)**
Nitrate (as N)	10
Nitrite (as N)	1

Secondary Drinking Water Regulations	
Contaminant	**MCL (mg/L)**
Chloride	250
Sulfate	250

Attachment 6: Glassware Cleaning Procedures



GLASSWARE CLEANING PROCEDURES - GENERAL LAB

MISCELLANEOUS APPARATUS

1. Scrub with hot tap water and Liquinox.
2. Rinse thoroughly with tap water.
3. Rinse at least three times with DI water.
4. Air-dry and store inverted in a cabinet or capped.

NOTE:

1. Do not use soap for cleaning COD digestion tubes.
2. Burets may be cleaned by filling with 10% KOH in methanol, allowing to stand for one hour, then rinsing thoroughly with DI water.
3. Evaporating dishes used for TDS determinations are cleaned by rinsing thoroughly with tap water, soaking for several hours in Nochromix, rinsing thoroughly with tap water, and rinsing three times with DI water. The dishes are then oven-dried.

TKN / TOTAL-P DIGESTION TUBES

1. Scrub with hot tap water and Liquinox.
2. Rinse thoroughly with tap water.
3. Rinse once with Nochromix.
4. Rinse at least three times with DI water.

CYANIDE DISTILLATION APPARATUS

1. Scrub with hot tap water and Liquinox.
2. Rinse thoroughly with tap water.
3. Rinse with 10% nitric acid, being certain to force at least 10mL through each dispersion tube.
4. Rinse thoroughly with DI water.

ODOR-FREE GLASSWARE

1. Scrub with hot tap water and Liquinox.
2. Rinse with acid cleaning solution.
3. Rinse thoroughly with odor-free water.
4. Glassware used in odor testing should be reserved for that purpose only.

FGE003:06.07.22:3

18.0 Revision History

Summary of Changes for Revision 10:

- Added quarterly MDLV requirement for DOD/ELAP in section 12.3.
- Added method modification for ammonia analysis by EPA method 350.1 regarding ICAL analysis in section 16.5 and Attachment 1a. ANAB Audit 2022
- Removed WV reference in Attachment 1a.
- Included expiration dates for reagents in Attachment 1d for Hexavalent Chromium analysis.
- Included pH verification and adjustment procedures for Hexavalent Chromium prep in Attachment 1d. ANAB Audit 2022

Summary of Changes for Revision 9:

- Removed references to TestAmerica from document.
- Removed references to WV criteria. The laboratory is not certified in WV as of 7/2021.
- Added calibration readback criteria of +/-10% to section 9.2.1.
- Revised blank criteria from <MDL to <1/2RL to be consistent with SM4020. <MDL is the criteria for SM3500 CR –B and Fe-B. Updates to Section 9.2.3 and Attachment 3.
- Updated definition of MDL in section 12.2 to be consistent with SOP SA-QA-007.
- Updated RLV and MDLV requirements.

Summary of Changes for Revision 8:

- Added section 6.2 to reference the Master Equipment Listing Maintained by the QA department.
- Updated section 10.1 that samples for Orthophosphate are filtered prior to analysis.
- Updated section 14.1 that RCRA hazardous and non-hazardous soil samples are disposed via the yardbox for incineration.
- Clarified requirements for Hexavalent Chromium in Attachment 2. Samples must be field filtered within 15minutes of sampling. An NCM must be initiated if no indication on COC of field filtering. WV Audit 2020
- Added pH verification and residual chlorine checks to Attachment 1a for Ammonia.
- Attachment 1c, section 3.3: Updated preparation of Ferrous Iron LCS solution.
- Attachment 1c, section 4.1: Updated sample preparation steps with more details.

Summary of Changes from Previous Revision 7:

- Minor editorial, grammatical, and/or formatting changes made.
- Revised soil sample preparation procedures for chloride. Attachment 1b, Section 4.2
- Revised Company logo and name where applicable

Appendix B

Response to Regulatory Comments on Draft Post–Record of Decision Supplemental Remedial Investigation Work Plan, Area of Contamination 43G, Former Fort Devens, Massachusetts

New England District
696 Virginia Road
Concord, Massachusetts
01742-2751

US Army Corps
of Engineers®

Project Name: Former Fort Devens Army Installation	**Location: Devens, Massachusetts**
Document Name: Post- Record of Decision Supplemental Remedial Investigation Work - AOC 43G (June 2022)	
Prepared By: Seres Arcadis 8(a) JV	

No.	Ref. Page / Para.	COMMENT July/August 2022	RESPONSE October 2022	USEPA COMMENT December 2022	RESPONSE
MAssDEP Comments					
1.	1. Section 1.1, First Paragraph, and Section 2.2.1	The stated objective of the proposed work (confirm groundwater conditions and the future protectiveness of the remedy) does not explicitly address the four five-year requirements that motivated the plan (Section 1.4.4). Presumably, the proposed work is intended to acquire data that can be used to address the first three requirements (respond to technical questions, develop a more aggressive remedy, and revise the LTMMP).	A discussion of the USEPA Additional Work Requirements and the response from Army will be added to the Introduction. The text in Section 1.1 will be revised as follows: As it pertains to this SRI WP and the additional work determined by the USEPA to be necessary to assess protectiveness, the USEPA concluded that the remedy at AOC 43G was not protective in the long-term. The USEPA stated, *"… for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness:* ▪ *respond to the three technical assessment questions specified in EPA's June 2001 FYR guidance, supplemental guidance (see list on Page 4 of EPA's January 20, 2016 Recommended FYR template and more specifically, EPA Region 1's FY2020 Supplemental FYR Template);* ▪ *develop/implement a "more aggressive" remedial action (i.e., soil vapor extraction (SVE) system in the AOC 43G source area) to ensure prompt and effective remediation of all ROD-specified groundwater COCs, attainment of RAOs* [remedial action objectives] *and ensure long-term protection of human health; a draft assessment of proposed remedial alternatives that includes the evaluation of petroleum hydrocarbons in the unsaturated overburden as a continuing source of groundwater contamination shall be prepared and submitted to EPA and MassDEP review and comment in accordance with the Devens FFA;* ▪ *issue draft, revised (2008) LTMMP for each AOC that includes additional sentinel monitoring well locations along the LUC/compliance boundary to more effectively evaluate COC concentration trends, confirm/deny attainment of ROD-specified cleanup goals and RAOs, and more effectively assess/evaluate potential off-site migration of all ROD-specified COCs; and;* ▪ *prepare/submit a draft LUCIP Update for AOC 43G and draft LUCIP for AOC 43J that outlines requirements for implementing, monitoring and*		

No.	Ref. Page / Para.	COMMENT July/August 2022	RESPONSE October 2022	USEPA COMMENT December 2022	RESPONSE
			enforcing ICs/LUCs and includes an Annual LUC Inspection checklist for use during annual LUC inspections and inclusion in the AOCs 43G and 43J Annual LTMMP Reports." The Army disagrees with the USEPA assessment but has agreed to perform additional work to document the protectiveness of the current remedy. The following items listed by the USEPA in the bullets above are not addressed in this SRI for the following reasons: • *"Respond to the three technical assessment questions specified in EPA's June 2001 FYR guidance."* ○ USEPA has determined that Army's updated responses to the three technical assessment questions in its final FYR Report (2020) adequately comply with USEPA guidance and templates, as requested. This task is therefore deemed complete. • *"Prepare/submit a draft LUCIP Update for AOC 43G and draft LUCIP for AOC 43J."* ○ Per USEPA comments on the Draft LUCIP WP received on November 4, 2021, a LUCIP for AOC 43G is no longer required. ○ A LUCIP for AOC 43J will be prepared by the Massachusetts Development Finance Agency (MassDevelopment). This SRI WP details the proposed supplemental investigation of AOC 43G to confirm the Army Protectiveness Statement in the 2020 FYR Report (KGS 2020). To address the USEPA requirement for a revised LTMMP, the Army offered to prepare this SRI WP and an SRI report. Based on the results of the SRI, historical site data, and an updated conceptual site model (CSM), the Army will prepare a focused feasibility study (FFS) to evaluate changes to the remedy, including updates to the LTMMP, if necessary, and prepare any applicable ROD amendments. • The SRI WP will focus on collection of data needed to evaluate remedial alternatives and to estimate remedy timeframes in an FFS, with particular focus on the source area and any continuing sources that are contributing to groundwater contamination.		

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			• Using data collected during the SRI, Army will prepare an SRI report and update the CSM, as necessary. • After approval of the SRI report, Army will prepare an FFS using the results of the SRI, historical site data, and the updated CSM. The FFS will develop and assess a range of remedial alternatives to address any contamination remaining at the site. The FFS will include an evaluation of alternatives for any continuing sources that are contributing to groundwater contamination. • After approval of the FFS, Army will make appropriate changes to the remedy, including updates to the LTMMP, if necessary, and prepare any applicable ROD amendments. In addition, the SRI will use historical and new data to evaluate the ROD-stipulated remedy for possible modification.		
2.	Sections 1.3.2.1 and 1.3.2.2	Sections 1.3.2.1 and 1.3.2.2 should also briefly discuss the second 500-gallon waste oil tank that was removed from the site (Figure 1-2).	Clarification requested. Sections 1.3.2.1 and 1.3.2.2 already discuss the 500-gallon waste oil UST.		
3.	3. Section 2.2.5 and Appendix A, Section 10.5	"Site closure" does not appear to be a potential outcome of the proposed work because LUCs will continue to be necessary to address contaminated soil even if groundwater monitoring is discontinued.	References to "site closure" as a potential outcome of the proposed work will be removed from the text.		
4.	Exhibit 3-3	Results from well XGM-97-12X, discussed in associated text, should be include in the exhibit.	Results from well XGM-97-12X will be added to Exhibit 3-3.		
5.	Exhibit 4-1	To ensure meaningful sample results will be obtained, the six piezometer constructions should be reviewed to determine if screens were placed at depths where site contaminants would be expected to be intercepted if present.	Piezometer construction details are included in Table 3-2. The piezometers are screened across the observed water table in the shallow to deep overburden, which the Army believes is appropriate for confirming the lateral extent of site contaminants.		
6.	Figure 1-2	The Army property line, which serves as a compliance point (Section 1.4), should be added to the figure.	The Army property line is shown on Figure 1-1, but the property line falls outside of the area shown on Figure 1-2. A reference to Figure 1-1 will be added to Section 1.4, and an inset will be added to Figure 1-2 for clarity.		
		USEPA GENERAL COMMENTS			
1.		Consistent with Army's agreement (see 3/14/22 responses to EPA's 1/7/22 comments on the	At USEPA's request, references to the comparison of groundwater data collected during the SRI to MCP / GW-1		

No.	Ref. Page / Para.	COMMENT July/August 2022	RESPONSE October 2022	USEPA COMMENT December 2022	RESPONSE
		November 2021, draft Supplemental Remedial Investigation (RI) Work Plan for AOC 69W) to omit references to Massachusetts Contingency Plan (MCP) standards (i.e., 310 CMR 40) and site cleanup criteria (i.e., GW-1)in the revised draft WP, please remove the same from this WP.	screening criteria were previously removed from the work plan. Remaining references to the MCP are related to previous investigations or to the screening criteria in the current (2015) LTMMP, and thus, remain.		
2.		There is an inconsistency in references to site-specific contaminants in the draft supplemental RI WP and 1996 ROD. Specifically, the ROD does not identify, list, or refer to Contaminants of Concern (COCs) at all. For consistency with the 1996 CERCLA decision document (i.e., ROD), EPA requests that all references to "COCs" in the draft supplemental RI WP be revised to "CPCs" and that the field sampling program include the collection of site-specific data sufficient to address the tasks identified in EPA's 9/29/20 Additional Work letter (i.e., develop/implement a "more aggressive" remedial action and prepare/implement a revised LTMMP that effectively evaluates groundwater conditions/CPC concentrations, confirm/deny possible off-site contaminant migration, and verify attainment of ROD-specified RAOs and cleanup goals(.	The Army disagrees that references to COCs should be changed to CPCs. The USEPA is correct that the 1995 ROD does not specifically reference COCs. The CPCs discussed in the ROD are referenced in an explanation of analytes included in the risk evaluation prepared for the 1996 RI, not as de facto COCs. Based on USEPA guidance, COCs are defined as those COPCs (or CPCs) that contribute to unacceptable risk. USEPA's Risk Assessment Guidance for Superfund (RAGS): Part A establishes criteria to evaluate COPCs to determine which should be retained or eliminated as COCs for the Baseline Risk Assessment. The USEPA Region 4 HHRA Supplemental Guidance (March 2018) succinctly states: *2.6 COPC Selection Process* *All concentrations of each chemical detected in a site sample/media should be compared to the appropriate screening level. … The chemicals selected by this process are retained for further risk evaluation in the BRA.* *6.2 Chemicals of Concern* *COCs are the COPCs that significantly contribute to an exposure pathway for a receptor (e.g. hypothetical future child resident, current youth trespasser, current adult construction worker, etc.) that either (a) exceeds a 1x10-4 cumulative site cancer risk; or (b) exceeds a non-carcinogenic HI of 1. … Chemicals are not considered as significant contributors to risk and therefore are not included as COCs if their individual carcinogenic risk contribution is less than 1x10-6 and their non-carcinogenic HQ is less than 0.1* Based on the USEPA definition, the CPCs arsenic, benzene, manganese, and iron were identified in the ROD as the primary risk contributors for source area groundwater, and arsenic and benzene as the primary risk contributors for downgradient groundwater are, therefore, COCs. However, arsenic was subsequently removed as a COC in the ROD because the MCL exceedance were attributed to high total suspended solids content or the MCL was exceeded in an upgradient sample, and because	As acknowledged in Army's response, although originally identified in the 1995 ROD as a CPC, because arsenic detected in groundwater (above drinking water standards) was attributed to high levels of total suspended solids (TSS), it was subsequently omitted from further evaluation as a site-related contaminant of concern. Since then, however, much has been learned about the correlation between petroleum-related source/released areas and mobilization of naturally occurring inorganics (i.e., arsenic, manganese, and iron) from soils to groundwater and given that the RODs (and associated LTMMPs) for other petroleum-impacted sites/AOCs identify arsenic, manganese, and iron as COCs, it is likely that the elimination of arsenic, manganese and iron as a ROD-specified CPCs due to high TSS levels was premature and ill-advised. For reasons outlined in EPA's original comment, it cannot concur with a draft final work plan that excludes the collection and analysis of data sufficient to accurately define/confirm the existing lateral and vertical extent of site related COCs, including arsenic, manganese and iron.	The site related COCs identified in the EPA-approved ROD for AOC 43G are benzene, xylenes, ethylbenzene, manganese, and iron. The current work plan identifies sample analysis for all the ROD-listed COCs, including iron and manganese; and does not include analytes such as arsenic that are not COCs listed in the EPA approved ROD. However, EPA underlined in its review to Army Response to EPA Specific Comment 5 that EPA cannot concur with a draft final work plan that does not include collection and analysis of groundwater samples for arsenic, manganese, and iron. Thus, to allow the supplemental remedial investigation to progress, the Army has included analysis for total and dissolved arsenic in the work plan.

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			arsenic was not detected downgradient at a concentration above the MCL. In addition to arsenic, benzene, manganese, and iron, which contributed to unacceptable risk in the risk evaluation, concentrations of xylenes, ethylbenzene, lead, and nickel in groundwater exceeded federal or state drinking water standards and were assigned a preliminary remediation goal. These CPCs, while not contributing to unacceptable risk, are also considered to be COCs. Similar to arsenic, lead was removed as a COC in the ROD because the MCL exceedance was attributed to high total suspended solids content. A discussion of the USEPA Additional Work Requirements and the response from Army will be added to the Introduction. See response to MassDEP Comment #1. Text will be added to Section 2.2 to clarify that the objectives of the SRI are to: ▪ *Collect sufficient and accurate site-specific data needed to accurately define/confirm the lateral and vertical extent of contamination.* ▪ *Evaluate COC concentration trends.* ▪ *Monitor attainment of ROD-specified RAOs and cleanup goals.* ▪ *Assess/evaluate potential off-site migration of all ROD-specified COCs.* ▪ *Assess short- and long-term protectiveness of the selected remedy.*		
3.		While AOC 43G was divided into three areas during the SSI to better focus the investigation, the ROD does not define the site as such. Therefore, with the exception of the Site Background discussion in Section 1.2.3.2, all references to "Areas 2 and 3" should be deleted from the draft supplemental RI WP. If desired, a distinction between "source area groundwater" and "downgradient groundwater" can be made in the draft WP because the ROD identifies separate CPCs for each.	Text will be revised to remove references to Areas 1, 2, or 3.		
		USEPA PAGE-SPECIFIC COMMENTS			
1.	Page 2, § 1.1, ¶ 2	Please identify and discuss the specific tasks identified in EPA's 9/29/20 Additional Work letter (and outlined below) as necessary to ensure protectiveness of the selected AOC 43G remedy:	A discussion of the USEPA Additional Work Requirements and the response from Army will be added to the Introduction. See responses to MassDEP Comment #1 and USEPA General Comment #2.		

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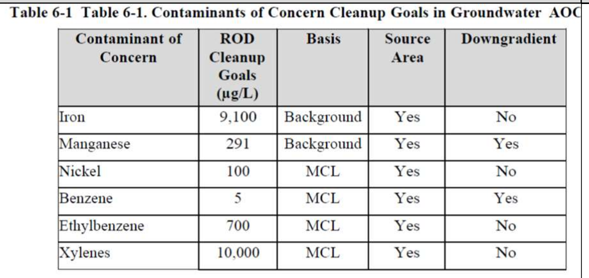
		• develop/implement a "more aggressive" remedial action (i.e., soil vapor extraction (SVE) system in the source area) to ensure prompt and effective remediation of all ROD-specified groundwater COCs; and, • prepare and issue a draft, revised LTMMP that evaluates all known and suspected contaminants of concern and includes a sufficient number of sentinel/monitoring wells along the LUC/compliance boundary to define/evaluate groundwater conditions/contaminant concentrations, confirm/deny possible off-site contaminant migration, and verify progress towards attainment of ROD-specified RAOs and cleanup goals.			
2.	Page 2, § 1.1, ¶¶ 2 and 3	Please amend the text to clarify that performance of a supplemental RI was not a task specified in EPA's 9/29/20 Additional Work letter. This activity was proposed by Army in its 11/18/20 response to EPA's 9/29/20 letter. Specifically, the "preliminary analysis, understanding and proposed path forward" for AOC 43G, stated that Army would prepare a supplemental RI] work plan and "based on these additional investigations, historical site data and updated CSM, prepare a focused FS to evaluate changes to the remedy and any applicable ROD amendments."	Text will be added to clarify that the Army offered to prepare an SRI Work Plan and SRI Report. See response to MassDEP Comment #1.	Army's response states that, "Text will be added to clarify that the Army offered to prepare an SRI Work Plan and SRI Report." Please ensure that this new text is consistent with EPA's comment and the scope and purpose of the SRI Work Plan and SRI Report discussion in Army's 12/11/20 "Scope of Work (SOW) for Additional Work Requirements" (page 4 of 8). EPA's acceptance of this response is contingent upon the text added to the draft final work plan.	The added text is as follows: *"To address the USEPA's requirement for a revised LTMMP, the Army offered to prepare this SRI WP and an SRI report. Based on the results of the SRI, historical site data, and an updated conceptual site model (CSM), the Army will prepare a focused feasibility study (FFS) to evaluate changes to the remedy, including updates to the LTMMP, if necessary, and prepare any applicable ROD amendments."*
3.	Page 5, § 1.4	For consistency with the 1996 ROD, please replace the existing list of ROD-specified RAOs with the following: • Protect potential commercial/industrial receptors, located on Army property, from exposure to contaminated groundwater having chemicals in excess of maximum contaminant levels (MCLs); • Protect potential commercial/industrial receptors located off Army property from exposure to groundwater having chemicals in excess of MCLs; and, • Prevent contaminated groundwater having chemicals in excess of MCLs from migrating off Army property.	Text will be revised to mirror the "remedial response objectives" identified in the ROD.		

No.	Ref. Page / Para.	COMMENT July/August 2022	RESPONSE October 2022	USEPA COMMENT December 2022	RESPONSE
4.	Page 5, § 1.4	To avoid confusion and ensure consistency with the 1996 ROD, please replace the existing list of “Remedial Components identified in the 1996 ROD” with the following and move the description of each component into the subsections that follow: • intrinsic bioremediation; • intrinsic bioremediation assessment data collection and groundwater modeling • installing additional groundwater monitoring wells • long-term groundwater monitoring • annual data reports to USEPA and MADEP • five-year site reviews. Please amend the discussion to clarify that LUCs/ICs were not a component of the selected remedy for AOCs 43G and 43J (because Army owned the property in 1996 and was expected to support Army Reserve activities in the future). In addition, the ROD did require, however, that “Should the Army change the use at either AOC, additional assessment and/or remedial actions may be required based upon the changed risk factors resulting from this change in use. In addition, if the Army transfers either site by lease or deed then an EBS will need to be conducted, and a determination will be made by the Army and USEPA that the selected remedy remains protective of human health and the environment.” (Army performed an EBS and issued the ESD (formally adding LUCs/Ics to the AOC 43J remedy) prior to it being transferred to MassDevelopment in 2006.) To ensure protection of human health at AOC 43G, Army developed and memorialized LUCs/ICs (prohibiting residential use of the property, restricting access to groundwater beneath the site, and requiring that any intrusive work be coordinated with the DPW, the BRAC Environmental Office and the BRAC Clean-up Team (BCT)) in the Real Property Master Plan (RPMP) Long Range Component for Devens Reserve Forces Training Area, Addendum (2007).	The following text will be added to the draft final report to address the comment: The Remedial Components identified in the 1996 ROD to address groundwater contamination at AOC 43G are as follows: • Intrinsic bioremediation (discussed in **Section 1.4.1**). • Intrinsic bioremediation assessment data collection and groundwater modeling. • Installation of additional groundwater monitoring wells. • Long-term groundwater monitoring (discussed in **Section 1.4.2**). • Annual data reports to USEPA and MassDEP. • Five-Year Reviews (discussed in **Section 1.4.4)**. Institutional Controls (i.e., LUCs) were not included in the 1996 ROD Selected Remedy because the Army owned the property in 1996 and expected to support Army Reserve activities on the properties in the future. However, the ROD did require that, “*Should the Army change the use at either AOC, additional assessment and/or remedial actions may be required based upon the changed risk factors resulting from this change in use. In addition, if the Army transfers either site by lease or deed then an EBS* [Environmental Baseline Survey] *will need to be conducted, and a determination will be made by the Army and USEPA that the selected remedy remains protective of human health and the environment.*” Accordingly, prior to AOC 43J being transferred to MassDevelopment in 2006, the Army performed an EBS and issued an ESD, formally adding LUCs to the AOC 43J remedy. To ensure protection of human health at AOC 43G, Army developed and memorialized LUCs to prohibit (1) residential development/use, (2) groundwater usage, and (3) unauthorized soil disturbance or construction. LUCs established for AOC 43G are discussed in more detail in **Section 1.4.3.**		

No.	Ref. Page / Para.	COMMENT July/August 2022	RESPONSE October 2022	USEPA COMMENT December 2022	RESPONSE
5.	Page 5, § 1.4, 2nd full ¶, #4.	While the ROD omitted arsenic (and lead) as CPCs in the 1996 ROD removed arsenic as a COC because MCL exceedances were thought to be associated with high TSS in the samples, much has been learned about arsenic from other LTM sites with similar site/aquifer conditions. Because arsenic was one of the primary risk contributors for source area groundwater s, EPA will continue to push for the identification of arsenic as a CPC at the AOC 43G site.	Noted. No changes to work plan required.	EPA's comment was intended to support its ongoing request that the supplemental RI work plan be amended to include the collection and analysis of site-specific groundwater samples for total and dissolved arsenic. As noted in PSC 1., EPA's Additional Work letter specified that Army must evaluate all known *and suspected* COCs. Despite being omitted from further evaluation in the ROD, because arsenic was a primary risk contributor for source area groundwater and is a long-accepted COC at other petroleum-impacted AOCs/sites, it must be included in the AOC 43G supplemental RI to adequately evaluation groundwater conditions/contaminant concentrations, confirm/deny possible off-site contaminant migration, and verify attainment of ROD-specified cleanup goals for all confirmed COCs/CPCs. *EPA cannot concur with a draft final work plan that does not include the collection and analysis of groundwater samples for arsenic, manganese and iron.*	See response to General Comment 2.
6.	Page 5, § 1.4.1, 2nd	The current discussion inappropriately suggests that results from the 2010 groundwater modeling effort determine whether either or both of the ROD-specified criteria for implementing an additional remedial action (i.e., soil vapor extraction) have been met. As summarized in the draft SRI WP, the ROD specifies that if intrinsic bioremediation assessment data collected during implementation of the long-term groundwater monitoring program indicates that the AOC 43G groundwater contaminant plume has either increased in size on Army property or has remained the same size, but cannot be remediated within 30 years, Army shall implement an additional remedial action (i.e., soil vapor extraction) to ensure protection of human health and the environment. It is Army's refusal (in response to EPA's comment on annual LTM reports and recent FYRs) to update the 2010 groundwater model and perform a comprehensive intrinsic bioremediation assessment that are the basis of EPA's concerns surrounding the continued efficacy of the intrinsic bioremediation component and ongoing protectiveness of the AOC 43G remedy.	The Army is not aware of the existence of a 2010 groundwater model for this site. The Army will update the previous intrinsic bioremediation evaluation through the analysis of additional groundwater parameters at six locations (proposed upgradient well XGM-22-01; existing wells AAFES-2, AAFES-7, XGM-94-04X, XGM-94-07X, and XGM-94-08X) during the baseline sampling event. The additional parameters will include nitrate/nitrite, phosphate, sulfide, alkalinity, and ferrous iron. The Work Plan text will be updated accordingly to state that the data will be used in the latest version of Bioscreen to conduct the evaluation	Army's response states that it "is not aware of the existence of a 2010 groundwater model for this site." For clarification, EPA's comment referred to the "BIOPLUME II modeling" mentioned at the top of the page, that was performed "to estimate remedial duration and contamination migration potential (HydroGeologic [HGL] 2010)." Also, while EPA appreciates Army's offer to "update the previous intrinsic bioremediation evaluation through the analysis of additional groundwater parameters at six locations (proposed upgradient well XGM-22-01; existing wells AAFES-2, AAFES-7, XGM-94-04X, XGM-94-07X, and XGM-94-08X) during the baseline sampling event," EPA recommends that the study be conducted upon conclusion of the supplemental RI. This will allow Army, MassDEP and EPA sufficient time to evaluate current site conditions prior to discussing components of an updated, comprehensive intrinsic bioremediation study (the results of which will support Army's preparation of the draft, revised LTMMP required per EPA's Additional Work letter).	The following text was added per the comments: *"As discussed further in* ***Section 4.2.5****., the Army will update the 1999 intrinsic bioremediation evaluation during the SRI baseline sampling event. A more comprehensive intrinsic bioremediation evaluation may be conducted after evaluation of SRI data by the Army, MassDEP, and the USEPA."*

No.	Ref. Page / Para.	COMMENT July/August 2022	RESPONSE October 2022	USEPA COMMENT December 2022	RESPONSE
7.	Page 6, § 1.4.2	Please amend the discussion to note that EPA did not concur with the changes proposed in the 2000 FYR and 2008 and 2015 revised LTM plans. Army's unilateral implementation of these changes gave rise to concerns surrounding the continued efficacy of the ROD-required long-term groundwater monitoring program and ongoing protectiveness of the selected remedy.	In accordance with the September 29, 2000 letter from Patricia Meaney, the USEPA concurred with the findings of the 2000 FYR. The 2015 LTMMP was finalized in accordance with provisions of the FFA Section 7.8. Text will be revised to indicate that the USEPA does not concur with the 2008 and 2015 LTMMPs.		
8.	Page 6, § 1.4.2–	Please amend the discussion to include the description of the Long-term Monitoring remedial component in the ROD: • Long-term groundwater monitoring is proposed to enable assessment of the intrinsic bioremediation progress and permit detection of any potential migration of contaminants that exceed groundwater cleanup levels beyond Army property. Groundwater monitoring would be conducted on an annual basis until three consecutive sampling rounds indicate that cleanup objectives have been met. The last two years of monitoring (confirmation) would be for only the CPCs. If the data generated from [the modeling or] the long-term groundwater monitoring efforts indicate that groundwater cleanup cannot be met within 30 years, a more aggressive remedial action will take place to enhance the intrinsic bioremediation alternative."	Additional text will be added per the comment. See response to comment 6, which notes that the Army will update the intrinsic bioremediation evaluation as part of this work.	Please see 6. above regarding Army's proposal to update the intrinsic bioremediation evaluation as part of this work. EPA recommends that this work be postponed until the results of the supplemental RI can be evaluated and discussed and a scope of work can be collaboratively developed for performance of this study.	See response to Page-Specific Comment 6.
9.	Page 6, § 1.4.2, ¶ 1, 5th sentence	Please update the sentence to make wording clearer that that VPH is established as a monitoring marker criterion to evaluate intrinsic remediation and VPH does not need to meet MCLs to meet RAOs. This would be helpful for the reader not familiar with the project.	Text will be revised as requested.		
10.	Page 7, Exhibit 1-1	Because it provides a more accurate summary of the ROD-specified CPCs and cleanup goals for source area and downgradient groundwater at AOC 43G, EPA requests that the existing table be replaced with Table 6-1 from the 2020 Devens FYR Report.	Exhibit 1-1 will be updated to mirror Table 6-1.		

<table>
<tr><th>No.</th><th>Ref. Page / Para.</th><th>COMMENT July/August 2022</th><th>RESPONSE October 2022</th><th>USEPA COMMENT December 2022</th><th>RESPONSE</th></tr>
<tr><td></td><td></td><td>
Table 6-1 Table 6-1. Contaminants of Concern Cleanup Goals in Groundwater AOC
<table>
<tr><th>Contaminant of Concern</th><th>ROD Cleanup Goals (µg/L)</th><th>Basis</th><th>Source Area</th><th>Downgradient</th></tr>
<tr><td>Iron</td><td>9,100</td><td>Background</td><td>Yes</td><td>No</td></tr>
<tr><td>Manganese</td><td>291</td><td>Background</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Nickel</td><td>100</td><td>MCL</td><td>Yes</td><td>No</td></tr>
<tr><td>Benzene</td><td>5</td><td>MCL</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Ethylbenzene</td><td>700</td><td>MCL</td><td>Yes</td><td>No</td></tr>
<tr><td>Xylenes</td><td>10,000</td><td>MCL</td><td>Yes</td><td>No</td></tr>
</table></td><td></td><td></td><td></td></tr>
<tr><td>11.</td><td>Page 8, § 1.4.4</td><td>For reasons discussed in PSC 7, the review of “time-concentration trends and Mann-Kendall trend analysis” is inadequate for purposes of assessing ongoing performance of the selected intrinsic bioremediation remedy.</td><td>It is assumed that the comment is meant to refer to PSC 6. See response to PSC 6, which notes that the Army will update the intrinsic bioremediation evaluation as part of this work. However, the Army will also conduct Mann Kendall trend analysis as originally proposed.</td><td></td><td></td></tr>
<tr><td>12.</td><td>Page 11, § 2.0 -</td><td>Please amend this section to identify and discuss the activities necessary to respond to/resolve the Additional Work tasks (i.e., develop/implement a “more aggressive” remedial action and prepare and issue a draft, revised LTMMP that evaluates all known and suspected contaminants of concern and includes a sufficient number of sentinel/monitoring wells along the LUC/compliance boundary to define/evaluate groundwater conditions/contaminant concentrations, confirm/deny possible off-site contaminant migration, and verify progress towards attainment of ROD-specified RAOs and cleanup goals.)</td><td>The following text will be added to the draft final report to resolve the comment:
The objectives of the AOC 43G SRI are to confirm the Army Protectiveness Statement in the 2020 Five-Year Review Report (KGS 2020) and address items specified in the USEPA Additional Work Requirements Table. As discussed in **Section 1.1,** to address the USEPA’s requirement for a revised LTMMP, the Army offered to prepare this SRI WP and an SRI report. Based on the results of the SRI, historical site data, and an updated CSM, the Army would prepare an FFS to evaluate changes to the remedy, including updates to the LTMMP, if necessary, and prepare any applicable ROD amendments.
Therefore, the first step is to prepare an SRI WP. Specifically, the objectives of the SRI are to:
▪ Collect sufficient and accurate site-specific data needed to accurately define/confirm the lateral and vertical extent of contamination.
▪ Evaluate COC concentration trends.
▪ Monitor attainment of ROD-specified RAOs and cleanup goals.
▪ Assess/evaluate potential off-site migration of all ROD-specified COCs.
▪ Assess short- and long-term protectiveness of the selected remedy.
Results of the SRI will be used to evaluate if changes to the AOC 43G ROD or AOC 43G LTM program are necessary.</td><td></td><td></td></tr>
</table>

No.	Ref. Page / Para.	COMMENT July/August 2022	RESPONSE October 2022	USEPA COMMENT December 2022	RESPONSE
13.	Page 13, § 2.2.1, 1st bullet	Provide a reference to the trend plots presented in Section 3.2.5.	A reference to Section 3 will be added to the Problem Statement introduction.		
14.	Page 14, § 2.2.2, ¶ 1, 1st bullet, last sentence	Please indicate why there is no ethylbenzene or xylene data as indicated in Section 3.2.5.1.	As detailed in Section 3.2.5.1, ethylbenzene and xylenes were not detected above RGs historically and results are not included. Benzene and toluene have periodically been detected above RGs; historical data for these two compounds is included in Table 3-3.		
15.	Page 15, § 2.2.5	In general, EPA disagrees with the proposed use of "Decision Rules" to determine if sufficient data exists to confirm the current lateral and vertical extent of the ROD-listed CPCs and VPH in groundwater (and/or establish a stable or decreasing trend of the ROD-listed CPCs and VPH in groundwater which isn't even identified as a task in EPA's 9/29/20 Additional Work letter) and requests that this language be deleted. To adequately satisfy AOC 43G Additional Work requirements, sample data from the supplemental RI should be compiled and presented, with relevant, existing data, in a draft supplemental RI report for regulatory review and comment.	The establishment of Decision Rules is a key component of the DQO process, as specified in Chapter 5 of the USEPA's *Data Quality Objectives Process for Hazardous Waste Site Investigations.* The Decision Rules proposed in the SRI WP present simple "if…then ..." statements to determine if adequate data has been collected during the SRI to meet the goals of the SRI and allow the planning team (including the USEPA) to make decisions. The Decision Rules are not an attempt to pre-empt the review and decision-making process. The Decision Rules will be revised to include collection of data needed to address each of the USEPA's Additional Work requirements and to be more specific as to data required for decision making.	While EPA appreciates Army's response, it's position regarding the use of decision rules to determine if sufficient data exists to confirm the current lateral and vertical extent of ROD-specified CPCs and other suspected COCs in groundwater adequately satisfy AOC 43G Additional Work requirements, remains unchanged.	The Army's position on the use of decision rules, as specified in, and in accordance with, EPA's own published guidance, remains unchanged.
16.	Page 18, 3.2.5	Please amend the discussion to include all ROD-specified CPCs and RGs (see PSC #9.)	Text will be revised to present all AOC 43G COCs and reiterate that VPH is monitored but is not a COC.	As stated above, EPA will not concur with a draft final work plan that does not include the collection and analysis of site-specific groundwater samples for arsenic, manganese, and iron (see RTC 5.)	See response to General Comment 2.
17.	Page 18, § 3.2.5.1	Please include a trend plot showing reductions in benzene concentrations over time.	A trend plot for benzene will be added to the referenced section.		
18.	Page 24, § 4.1	Please amend the discussion to include all ROD-specified CPCs and RGs and address each of the Additional Work requirements identified in EPA's 9/29/20 letter (see PSC #1.)	Text will be revised to include all the ROD-specified COCs with concentrations above MCLs and VPH and to repeat the SRI objectives and SRI study questions developed to address USEPA Additional Work Requirements.		
19.	Page 24, § 4.1, 2nd bullet	Please add information to further describe the new monitoring wells to be installed to define vertical extent. In particular, provide the depth in comparison to existing wells and refer to the section that describes this in more detail.	Additional details regarding the depths of the new monitoring wells are provided in Section 4.2.3; a reference to this subsection will be added to the second study question.		

No.	Ref. Page / Para.	COMMENT July/August 2022	RESPONSE October 2022	USEPA COMMENT December 2022	RESPONSE
20.	Page 25, § 4.1, Exhibit 4-1	Please add VPH + BTEX to the analyte list for MW XGM-94-10X to obtain current data for defining the lateral extent of the specified "Approximate historical extent of Groundwater Contamination in Exceedance of Cleanup Goals".	VPH and BTEX have not been detected above laboratory detection limits historically in monitoring well XGM-94-10X, and the lateral extent of VPH and BTEX is defined at the Site. As described in Section 4, proposed monitoring well XGM-22-01 will be installed to define the upgradient lateral extent, and proposed monitoring wells XGM-22-02 and XGM-22-03 will be installed to define the vertical extent.		
21.	Page 26, § 4.2, 1st sentence	Please clarify which methodologies listed in the bullets are TGIs vs. SOPs because the QAPP addendum refers to both TGIs and SOPs, but they are only defined as TGI's in the bullet list.	The methodology table will be updated. To clarify, the TGIs are internal/developed by the JV, and one external SOP is included (USEPA low flow SOP).		
22.	Page 28, § 4.2.6	Please be sure to submit an Off-Site Rule Compliance package to Carol Keating and Conor O'Brien, EPA Region 1 OSR Coordinator at Obrien.Conor@epa.gov prior to shipping the IDW waste off site to ensure that the receiving facility is operating in compliance and is acceptable to receive CERCLA waste at the time of shipment.	Noted.		
23.	Page 22, Exhibit 3-3	Please include results from well XGM-97-12X (discussed in associated text) in the exhibit.	Results from well XGM-97-12X will be added to the exhibit.		
24.	Page 25, Exhibit 4-1	To ensure meaningful sample results will be obtained, the six piezometer constructions should be reviewed to determine if screens were placed at depths where site contaminants would be expected to be intercepted if present.	Piezometer construction details are included in Table 3-2. The piezometers are screened across the observed water table in the shallow to deep overburden, which the Army believes is appropriate for confirming the lateral extent of site contaminants.		
25.		Appendix A – AOC 43G QAPP Addendum			
a)		Page 2 of Introduction, Project Goals: Add VPH to the first bullet as within the text in Section 2.2.2.	Text will be revised as requested.		
b)		Appendix A within the QAPP – Identify as SOPs and TGIs	Appendix title page will be updated.		
c)		Reconcile the date on the worksheet pages and title page.	Date will be updated.		
d)		Worksheet #10, Section 10.3.1 – reconcile the groundwater flow direction when compared to the main text. The main states the groundwater flow is to the east-southeast.	Section will be updated.		

No.	Ref. Page / Para.	COMMENT July/August 2022	RESPONSE October 2022	USEPA COMMENT December 2022	RESPONSE
e)		Worksheet #10, Section 10.5, 1st paragraph, 4th bullet – the text states that trends for arsenic concentrations will be evaluated, but this is not correct since it is not a COC in accordance with the main text. Please update this bullet so corresponds with main work plan text.	The bullet will be updated to indicate "iron and manganese" instead of "arsenic."	See GC 2. and PSC 5. EPA's comment was intended to distinguish between ROD-specified CPCs and other compounds that were prematurely omitted (based on the limited data available at the time), but should have remained (i.e., arsenic, manganese, and iron). Consistent with other relevant EPA comments, the supplemental RI must include the collection of groundwater samples for arsenic, manganese, and iron analysis.	See response to General Comment 2.
f)		Worksheet #10, Section 10.5, 2nd paragraph, 2nd bullet – see comment 15 above.	See above response.	See 15. above.	See response to Page-Specific Comment 15.
g)		Worksheet #11, Project Goals column. Delete the Number 5 study question.	Number will be deleted.		
h)		Worksheet #11, Performance Criteria column. Identify that Worksheet #12 is in the main LTMMP QAPP.	Reference to the LTMMP QAPP will be added.		
i)		Worksheet #17, Section 17.2 – Confirm that the additional parameters identified in the bullets are identified in the original LTMMP QAPP and that details for these parameters are included in the following worksheets: Measurement Performance Criteria (Worksheet #12); Project Action Limits and Laboratory Detection/Quantification Limits (Worksheet #15); Fixed Laboratory Sampling Containers, Preservation and Hold Times (Worksheet #19); Analytical SOP References (Worksheet #23); Analytical Instrument Calibration (Worksheet #24); Analytical QC Samples and Corrective Action (Worksheet #28) are specified.	All bulleted analytes are included in the LTMMP QAPP in the appropriate Worksheets.		
j)		Worksheet #18– see Comment 19 above. *Please add information to further describe the new monitoring wells to be installed to define vertical extent. In particular, provide the depth in comparison to existing wells and refer to the section that describes this in more detail.*	Worksheet will be revised as requested to describe proposed depths for new monitoring wells in relation to existing wells.		
		END OF COMMENTS			

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE ARMY
OFFICE OF THE DEPUTY CHIEF OF STAFF, G-9
600 ARMY PENTAGON
WASHINGTON, DC 20310-0600

June 2, 2023

SUBJECT: Final Post-Record of Decision (ROD) Supplemental Remedial Investigation Work Plan, Area of Contamination 43G, Former Fort Devens Army Installation, Devens, Massachusetts

Michael Daly
U.S. EPA Region 1
5 Post Office Square
Suite 100 - OSRR7-03
Boston, MA 02109

Dear Mr. Daly:

Thank you for providing your letter dated May 11, 2023, concerning the *Draft Final Post-Record of Decision (ROD) Supplemental Remedial Investigation Work Plan, Area of Contamination 43G*, *Former Fort Devens Army Installation, Devens, Massachusetts* (SRI Work Plan). As noted in your letter, the United States Environmental Protection Agency (USEPA) has approved the SRI Work Plan in the interest of commencing field work and the collection of data necessary to define the nature and extent of known and suspected contaminants of concern, evaluate groundwater conditions/contaminant concentrations, confirm/deny possible off-site contaminant migration, and verify protectiveness of the selected remedy. However, this approval is subject to concurrence by the Army that several unresolved issues will be addressed during the course of the project. These issues, and the Army's subsequent response, are presented below.

1. Sample locations with detections above drinking water standards must have corresponding reducing aquifer (ORP) and dissolved oxygen (DO) data.

    - Army Response: The Army will collect ORP and DO data concurrent with all groundwater samples.

2. Rather than rely on the decision rules in Section 2.2.5 to support post-SRI decisions regarding subsequent data needs, contaminant trends, and necessary changes to the existing remedy and/or LTMMP, EPA will rely upon data in the draft SRI report to determine whether additional data collection is necessary, whether an FFS can be prepared, and whether changes to the remedy and/or updates to the LTMMP, are necessary.

    - Army Response: The Army understands and acknowledges that recommendations and/or activities proposed by the Army based on the data from the SRI will be subject to review and approval by USEPA (and the Massachusetts Department of Environmental Protection ((MassDEP)). However, the Army also believes that the use of Decision Rules established in accordance with USEPA guidance is appropriate and useful to guide the process. Accordingly, the Army has revised the Decision Rules text in Section 2.2.5 to reflect that decisions will be subject to USEPA and MassDEP review. These changes are shown in the attached Red-Line-Strikeout (RLSO) PDF of the text.

3. As specified in the 1996 ROD, the supplemental data shall be used to:
    - Update the intrinsic bioremediation assessment conducted in 1997-1999 to evaluate intrinsic bioremediation performance, assess future intrinsic bioremediation potential, verify if the existing groundwater contaminant plume can be degraded/remediated within 30 years of ROD signature, and if not, develop and implement a more aggressive remedy.
    - Update the fate and transport model (using SRI data and LTM data) to assess the current degradation and migration of contaminants and refine current estimates of intrinsic bioremediation effectiveness.
    - Determine if performance standards stated in the Long Term Monitoring Plan (LTMP) are being achieved.
    - Evaluate contaminant concentration trends using risk-based concentrations, MCLs and/or MMCLs.

    - Army Response: The Army acknowledges these requirements and notes that additional intrinsic bioremediation parameters (nitrate/nitrite, phosphate, sulfate/sulfide, alkalinity, and ferrous iron) were added to Section 4.2.5 of the Draft Final SRI Work Plan to facilitate the required evaluations. The Army has added dissolved methane to the intrinsic bioremediation analyses and increased the number of wells where samples for these parameters will be collected. In addition, the Army has also added analyses of Extractable Petroleum Hydrocarbons (EPH) to the groundwater sampling program (in addition to the existing analysis of Volatile Petroleum Hydrocarbons (VPH) and BTEX) to aid in evaluation of the impact of the remaining petroleum hydrocarbon mass on groundwater conditions. Lastly, the Army has added the collection and analysis of soil samples from new monitoring well soil borings drilled in the former source area to evaluate the degree to which petroleum hydrocarbon source mass remains in this area. These changes are shown in Section 4 of the attached RLSO text PDF.

The Army appreciates the cooperation of the USEPA in moving this investigation forward to facilitate the evaluation of remedy protectiveness. Accordingly, also attached please find an electronic copy of the Final SRI Work Plan.

My point of contact for this action is Jeffrey Dvorak at the US Army Corps of Engineers – New England District (USACE), who can be reached at (978) 318-8464/ Jeffrey.a.dvorak@usace.army.mil; or I can be reached at (703) 545-2487/ Thomas.A.Lineer.civ@army.mil.

Sincerely,

Thomas Lineer
BRAC Program Manager
Army Environmental Division
Installation Services Directorate

Enclosures:

1. RLSO Text (e-copy)
2. Final SRI Work Plan (e-copy)

cc: Shawn Lowry, EPA (e-copy)
Joanne Dearden, MassDEP (e-copy)
Meg Delorier, MassDevelopment (e-copy)
Penny Reddy, USACE (e-copy)
Jeffrey Dvorak, USACE (e-copy)
Andrew Vitolins, SERES-Arcadis JV (e-copy)