FINAL

United States Army Corps of Engineers
New England District

Performance Monitoring Work Plan

Shepley's Hill Landfill

Former Fort Devens Army Installation

Devens, Massachusetts

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August 2023

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Devens, Massachusetts

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Prepared By:
SERES-Arcadis 8(a) JV 2, LLC
669 Marina Drive, Suite B-7
Charleston, South Carolina 29492
Tel 843 216 8531

Prepared For:
United States Army Corps of Engineers,
New England District

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.

Reviewed By:

____

Andy Vitolins, PG
Project Manager

Heather Levesque
____

Heather Levesque, PMP
Deputy Project Manager

Received By:

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Penelope Reddy
USACE Project Manager

Contents

Tables

Figures

Appendices

Acronyms and Abbreviations

%	percent
µg/L	microgram per liter
3PE	three-point estimation
AOC	Area of Contamination
Army	U.S. Army
ATP	Arsenic Treatment Plant
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	contaminant of concern
CSM	conceptual site model
Devens	Former Fort Devens Army Installation
DO	dissolved oxygen
DOC	dissolved organic carbon
EDMS	Environmental Data Management System
FFA	Federal Facility Agreement
FFS	focused feasibility study
gpm	gallons per minute
HAZWOPER	Hazardous Waste Operations and Emergency Response
IDW	investigation-derived waste
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
MEC	munitions and explosives of concern
MCL	Maximum Contaminant Levels
NAD	North American Datum
NAVD 88	North American Vertical Datum of 1988
NIA	North Impact Area
O&M	operations and maintenance

ORP	oxidation-reduction potential
PVC	polyvinyl chloride
QAPP	quality assurance project plan
RI	remedial investigation
ROD	record of decision
SHL	Shepley's Hill Landfill
SOP	standard operating procedure
SOW	scope of work
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
USEPA	United States Environmental Protection Agency
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 performance monitoring work plan (WP) on behalf of the United States (U.S.) Army Corps of Engineers – New England District (USACE) to assess the changes in the capture zone and groundwater chemistry provided by the addition of a third extraction well to the existing two extraction well groundwater treatment system at Shepley's Hill Landfill (SHL; Area of Contamination [AOC] 5) at the former Fort Devens Army Installation (Devens) located in Devens, Massachusetts.

1.1. Purpose

This WP has been prepared to address concerns expressed by the United States Environmental Protection Agency (USEPA) and Massachusetts Department of Environmental Protection (MassDEP) that groundwater migrating northward from the SHL is not consistently captured by the existing groundwater extraction and treatment system, which is collectively referred to as the Arsenic Treatment Plant (ATP). Although the Army believes that adequate capture of groundwater exiting the landfill is achieved by the current two well groundwater extraction system configuration, the Army plans to assess whether the installation and operation of an additional groundwater extraction well can 1) provide greater assurance to the USEPA of containment of groundwater leaving the landfill, and 2) demonstrate whether additional groundwater extraction from the east side of the landfill reduces the concentrations of arsenic in groundwater downgradient of the ATP.

The Army submitted a proposal for the pilot test and performance monitoring of the third extraction well to EPA on November 16, 2022. The Army requested comments from USEPA in accordance with the Federal Facilities Agreement Secondary Document Review Process by January 16, 2023. During the Project Managers' Meeting conference call on January 23, 2023, USEPA stated that USEPA will not review or provide comments on any work plans associated with the pilot test of the third well, but that the USEPA did not object to Army's proposal to proceed with the work. The Army sent a letter to USEPA on March 9, 2023 indicating that they were proceeding with the pilot test and performance monitoring.

This WP presents the methods proposed to evaluate the elements described in the *Proposed Installation and Pilot Testing of Third Extraction Well at the Shepley's Hill Landfill Treatment Plant* memorandum submitted to USEPA on November 16, 2022 (USACE 2022). Specifically, the goals and elements of the WP include:

- An assessment of the hydrogeological performance of the three well system using three-point estimation (3PE) vector analyses for various pumping scenarios. Groundwater modeling using the approved model may also be conducted to assess performance and eventually select optimal pumping rates.
- An assessment of the influent and effluent characteristics for the ATP under different pumping scenarios in comparison to the current system operation.

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

1.2. Regulatory Requirements

Devens was placed on the National Priorities List (NPL) in December 1989. Activities completed under this WP are subject to, and consistent with, the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) as amended (42 United States Code § 9601 et seq.), and the National Oil and Hazardous Substances Pollution Contingency Plan (40 Code of Federal Regulations Part 300), with regulatory coordination from MassDEP, USEPA, and Army policies and guidance.

Since 1991, operable units (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.

1.3. Site Background

1.3.1. Site Setting

Fort Devens is located approximately 35 miles northwest of the city of Boston, within the towns of Ayer and Shirley in Middlesex County and Harvard and Lancaster in Worcester County. Fort Devens was established in 1917 for military training and logistical support during World War I and operated as a permanent base from 1931 until closure by the Base Realignment and Closure Committee in 1996.

SHL encompasses approximately 84 acres in the northeast corner of the Main Post of Fort Devens (**Figure 1-1**). The landfill is bordered to the east by Plow Shop Pond and land formerly containing a railroad roundhouse, to the west by Shepley's Hill, to the south by recent commercial development, and to the north by wooded and residential areas. Plow Show Pond to the east drains to Nonacoicus Brook to the north, which flows north/northwest and discharges to the Nashua River. Nonacoicus Brook is located north of the landfill in the North Impact Area (NIA; **Figure 1-2**).

1.3.2. Site History

The Army reportedly began operating SHL by the early 1940s; however, evidence from test pits within the landfill suggests earlier usage, possibly as early as the mid-19th century. SHL contains a variety of waste materials (more than 1.5 million cubic yards) that extend to a depth of approximately 40 feet below the current ground surface (bgs) in the central portion of the landfill. Approximately 160,000 cubic yards (11 percent [%] of the total waste mass) appear to have been emplaced below the water table in a former wetland, and peat deposits have been identified below the waste (Harding ESE 2003; Sovereign 2011).

The MassDEP approved the landfill closure plan for SHL in 1985. The landfill was closed in five phases between 1987 and 1993 in accordance with 310 Code of Massachusetts Regulations 19.000. Closure consisted of capping the landfill, covering the cap with soil and vegetation, installing gas vents and groundwater monitoring wells, and constructing drainage swales. The MassDEP issued a Landfill Capping Compliance Letter approving the closure in February 1996 (Harding ESE 2003; Sovereign 2011).

After closure of SHL, the Army completed remedial investigations (RIs) under CERCLA to characterize soil, sediment, surface water, and groundwater. RIs confirmed the presence of various contaminants at the site, the most predominant of which is arsenic dissolved in groundwater. A subsequent feasibility study and ROD (USACE 1995) resulted in a remedial action, which included long-term operations and maintenance (O&M) of the landfill cap, groundwater monitoring, and a contingent remedial component requiring the design and construction of a groundwater extraction and treatment system if the landfill cap did not result in a reduction of groundwater contaminant concentrations (primarily arsenic) below risk-based cleanup goals by 2008. The remedial action objectives listed in the ROD for SHL are to:

- Protect potential residential receptors from exposure to impacted groundwater migrating from the landfill that contains chemicals in excess of USEPA Maximum Contaminant Levels (MCLs)
- Prevent impacted groundwater from contributing to the contamination of Plow Shop Pond sediments in excess of human health and ecological risk-based concentrations.

Table 1-1, below, lists the contaminants of concern (COCs) identified in the ROD and their current target cleanup levels. Of the COCs listed below, only arsenic, iron, and manganese are currently sampled as part of the long-term monitoring (LTM) program, in accordance with the *Long-Term Monitoring and Maintenance Plan Update, Shepley's Hill Landfill* (SHL LTMMP Update; Sovereign 2015) which includes the site-specific *Uniform Federal Policy for Quality Assurance Project Plan* (SHL QAPP) and the SHL LTMMP Addendum (KOMAN Government Solutions, LLC [KGS] 2018).

Table 1-1 ROD-Specified Contaminants of Concern and Current Cleanup Levels

COC	Current Cleanup Level (µg/L)	Selection Basis
Arsenic	10	MCL[a]
Manganese	1,715	Background[b]
Iron	9,100	Background
Chromium	100	MCL
1,2-Dichlorobenzene	600	MCL
1,4-Dichlorobenzene	5	MCL
1,2-Dichloroethane	5	MCL
Lead	15	Action level
Nickel	100	MCL
Sodium	20,000	Health advisory
Aluminum	6,870	Background

Notes:
[a] In accordance with the 2005 Five-Year Review Report, data are screened against the updated standard of 10 µg/L (USACE 2005) rather than the original standard of 50 µg/L from the ROD (USACE 1995).
[b] Revised from ROD (USACE 1995) cleanup level based on background evaluation.
µg/L = microgram per liter

In March 2006, the Army installed two extraction wells (EW-01 and EW-04) and constructed a groundwater extraction and treatment system in accordance with the requirements of the contingency remedy listed in the ROD. The system started with an initial pumping rate of 25 gallons per minute (gpm), which was gradually increased to a combined extraction rate of at least 50 gpm by 2014. In 2022, the ATP average online extraction flow rate was 54.73 gpm, with an average effective flow rate (including downtime) of 48.05 gpm. During 2022, the system had an uptime of approximately 88%, with downtime due to routine O&M as well as periodic non-routine maintenance and repairs.

In 2011, the Army investigated Red Cove/Plow Shop Pond (known as AOC 72) located east of SHL. The AOC 72 RI (AMEC 2011) concluded that the SHL remedy in place in 2011 (landfill capping and groundwater extraction) did not eliminate groundwater flow and arsenic migration from SHL to Red Cove/Plow Shop Pond, and that groundwater discharge was contributing arsenic to sediment that could accumulate to levels that posed unacceptable risk to receptors. As a result, in August and September 2012, the Army installed an in-situ barrier wall between SHL and AOC 72 as a non-time critical removal action. Documentation of the barrier wall installation was provided in the *Removal Action Completion Report for Shepley's Hill Landfill Barrier Wall* (Sovereign 2013a).

In addition to LTM and O&M activities, land use controls were established for the NIA in 2013 (Sovereign 2013b), and the Army subsequently issued the *Land Use Control Implementation Plan Restriction of Groundwater Use, Shepley's Hill Landfill* (Sovereign 2014).

1.4. Work Plan Organization

This performance monitoring WP includes:

- Project objectives;
- Project approach;
- SHL Conceptual Site Model (CSM) summary;
- Performance monitoring design and rationale;
- Discussion of deliverables; and
- Project schedule.

This 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 SHL LTMMP and QAPP (Sovereign 2015) and the SHL LTMMP Addendum (KGS 2018)

This WP is organized as follows:

- **Section** 1 – Introduction: Presents the purpose of the WP, the site history and physical characteristics, the project background, and summarizes the previous CERCLA decision documents and remedial actions at SHL.
- **Section 2** – Project Approach and Objectives: Presents the regulatory approach and overall objectives of the WP.
- **Section 3** – CSM Summary
- **Section 4** – WP Implementation: Summarizes the planned performance monitoring activities, including installation of monitoring wells to support the assessment and associated field methodologies.
- **Section 5** – Deliverables: Identifies the deliverables that will be generated for the project.
- **Section 6** – Project Schedule: Presents the WP schedule.
- **Section 7** – References: Provides a list of references used in preparing the WP.

2. Project Approach and Objectives

This WP details the proposed performance monitoring of the three well extraction system at SHL. This section discusses the WP approach and the objectives for the project.

2.1. Project Approach

To support the assessment of the hydrogeological performance of the three well extraction system at SHL, five new groundwater monitoring well clusters will be installed. Each well cluster will include one shallow well drilled to a maximum of 40 feet bgs (most likely screened from 20 to 30 feet bgs or 25 to 35 feet bgs), and one deep well drilled to the top of bedrock (anticipated to be no more than 100 feet bgs but most likely screened from 70 to 80 feet bgs). These screen intervals are similar to those of the piezometers installed by the USEPA in 2012.

After installation of the third extraction well (and a concurrent upgrade to the ATP treatment process), a pilot test will be conducted with the ATP system operating with a total online extraction rate of up to 55 gpm balanced between the three wells. Although the upgraded ATP may be able to process more extracted groundwater, a higher total extraction rate would result in greater sludge production and therefore greater waste generation and waste disposal costs. Therefore, the three-well system will be operated at a total extraction flow rate no less than an average of 50 gpm to ensure that there is no negative impact to the ROD-selected remedy.

Performance monitoring will be conducted over 12 months after installation of the 10 new wells. The performance monitoring will include the following activities:

- The 10 new wells and a subset of existing wells (eight listed wells, plus as many other wells as can be gauged in one day of field work for a two-person team) will be gauged during up to 10 events conducted over 12 months, with emphasis placed on gauging the deeper wells where the highest concentration of arsenic exists; however, several shallow wells will also be gauged to confirm vertical gradients. The 10 new wells will also be equipped with data logging transducers to record changes in water level throughout the monitoring period. The timing and frequency of the gauging events will correlate with changes made to ATP extraction well flowrates during the first year of operation.
- The 10 new wells will be sampled during the regularly scheduled SHL LTM events in the fall of 2023 and spring of 2024 for dissolved metals (arsenic, iron, and manganese) and geochemical parameters (alkalinity, chloride, dissolved organic carbon, and sulfate) and measured field parameters.
- The three extraction wells will be sampled during the regularly scheduled SHL LTM events in the fall of 2023 and spring of 2024 for total metals (arsenic, iron, and manganese).
- The ATP influent and effluent lines will be sampled during the regularly scheduled SHL LTM events in fall 2023 and spring 2024 from existing sampling ports. Additional samples may be collected from the influent and effluent to see the impact of pumping rates changes throughout the test. Influent samples will be analyzed for metals (arsenic, iron, and manganese), and dissolved gases (methane and ethane). Effluent samples will be analyzed in accordance with requirements of Landfill Discharge Permit Number 020 (Massachusetts Development and Finance Agency [MassDevelopment] 2022).
- No field quality control samples will be collected.

2.2. Objectives

The objectives of the WP are to assess the changes in the ATP capture zone associated with the installation and operation of a third extraction well to address concerns expressed by the USEPA that groundwater exiting the landfill is bypassing the system in the area to the northeast of the landfill footprint. Specifically, the goals of the performance monitoring WP are to:

- Collect sufficient site-specific data to conduct 3PE analyses for various pumping scenarios.
- Evaluate hydrogeological performance of the three well system.
- Assess influent and effluent characteristics for the ATP under different pumping scenarios and compare them with current system operation.

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. 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. This step is not applicable to this WP because influent samples will be collected at various flow rates and prior data will be used to make decisions regarding future well extraction rates.

2.2.1. Problem Statement

Historically, the USEPA has expressed concern that groundwater migrating northward from the landfill through the eastern edge of the landfill (i.e., between monitoring wells SHM-10-06 and SHL-21) is not consistently captured by the ATP system (i.e., may "bypass" the ATP). To address the USEPA's concerns, the Army is installing a third extraction well to the east of the current extraction wells EW-01 and EW-04 to evaluate the impact of the additional well on capture of water flowing along the eastern edge of the landfill.

The location of the third extraction well (EW-03) and potential flow rates were modeled to establish a location and a starting point for the revised pumping scheme (USACE 2022). The total extraction rate for all three wells was limited to 53.1 gpm in the model, which represents the long-term average annual pumping rate (Geosyntec 2020). Flow rates for EW-03 ranged from 17.7 to 21.2 gpm. With EW-04 pumping at a reduced rate (20% of the total extraction rate) and EW-01 and EW-03 each pumping at 40% of the total ATP pumping rate, model results indicate full capture of particles along the east-west transect across the northern portion of the landfill, and a more westerly direction of the pathlines east of the landfill in the area of the inferred "bypass" (S-A JV 2021a)-.

2.2.2. Project Goals

Performance monitoring will be conducted in accordance with this WP to evaluate the ATP capture zone with an additional third extraction well pumping. Data collected from new and existing wells will be used to assess the capture zone provided by a three extraction well system and evaluate whether this configuration addresses the concern expressed by USEPA and MassDEP. While the main objective of this performance monitoring is to assess the impacts on capture from the newly installed extraction well (EW-03), a secondary objective is to evaluate if changes to the extraction well network have an impact on downgradient dissolved arsenic concentrations and, by so doing, help clarify whether the source of the arsenic is primarily geogenic or anthropogenic. The influent groundwater quality of the extraction wells as a function of the groundwater extraction rate may be used to optimize pumping rates.

2.2.3. Information Inputs / Data Needs

The information inputs required to accomplish the project goals are:

- Historical geologic, hydrogeologic/hydraulic, and chemical data required to evaluate performance/operations of the ATP.
- Current geologic, hydrogeologic/hydraulic, and chemical data required to evaluate changes to performance/operations of the ATP.
- Water levels for hydrogeologic/hydraulic evaluation.
- Field Parameters for evaluating temporal trends in general water quality conditions that affect stability and solubility of arsenic:
    - Dissolved oxygen (DO)
    - Oxidation-reduction potential (ORP)
    - Specific conductance
    - Temperature
    - Turbidity
    - pH

- Laboratory Analyses for extraction wells:
  - Arsenic (total)
  - Iron (total)
  - Manganese (total)
- Laboratory Analyses of monitoring wells for geochemical evaluation:
  - Arsenic (dissolved)
  - Iron and Manganese (dissolved) – Used to evaluate redox status and capacity for arsenic natural attenuation via coprecipitation.
  - Dissolved organic carbon (DOC) – Used to evaluate residual reducing potential in the aquifer (specifically, potential for ongoing dissolved oxygen consumption, limiting the rate of arsenic natural attenuation).
  - Alkalinity
  - Chloride
  - Sulfate – Used as secondary line of evidence for aquifer reducing potential.

Historical site conditions at SHL are well documented with LTM data collected between 1996 and 2022.

2.2.4. Boundaries of Study

The general areal boundaries for the WP are primarily the Nearfield Area of SHL (**Figure 1-2**).

The temporal boundaries of the study are the 12 months following startup of the third extraction well at SHL.

2.2.5. Decision Rules

The data will be utilized to evaluate the impact of a third extraction well on the capture of groundwater leaving the SHL and, as a secondary goal, to evaluate the associated effect on downgradient dissolved arsenic concentrations in groundwater. The influent groundwater quality of the extraction wells as a function of the groundwater extraction rate may be used to optimize pumping rates. Decisions regarding further actions will be determined after review of the data by Army, USEPA, and MassDEP.

2.2.6. Specify Limits on Decision Errors

Errors may be associated with transducer malfunctions or manual measurements deviating significantly from the transducer readings. If the error is greater than 0.5 feet (i.e., the difference between manual measurements and transducer readings), then the data and actions will be discussed between the JV and Army.

3. Conceptual Site Model Summary

This section presents a summary of the CSM for SHL. A more comprehensive discussion of the CSM appears in the *Focused Feasibility Study Report, Shepley's Hill Landfill (AOC 5)* (FFS; S-A JV 2023).

3.1. Geology

The overburden deposits beneath SHL consist of glacially deposited, well-graded to poorly graded sands with silts and gravel. The saturated soil is predominantly medium and fine to medium sands with little variability. A discontinuous layer of glacial till is present at the base of the sands directly overlying bedrock. The overburden ranges from 65 to 95 feet thick. To the west of the landfill lies Shepley's Hill, which consists almost entirely of bedrock with little to no overburden.

The bedrock formations beneath SHL and Nonacoicus Brook are the Ayer Granite (also referred to as the Ayer Granodiorite) and the Chelmsford Granite. The Ayer Granite, which is part of a larger assemblage of intrusive rocks in eastern Massachusetts, is characterized as gneissic-biotite granite and granodiorite, approximately late Silurian to early Devonian in age, and has been significantly deformed by subsequent metamorphism and intrusion (Wones and Goldsmith 1991; Kopera 2008). Analyses of core samples indicate that silicate minerals (primarily quartz, feldspars, and mica group minerals), iron and manganese oxides/oxyhydroxides, clay minerals, and carbonates are present in the bedrock, which is consistent with Ayer Granite mineralogy (Gannett Fleming 2012). Though less prevalent than the Ayer Granite, the Chelmsford Granite is also present in parts of SHL. This formation is a well foliated quartz-microcline-plagioclase monzonite that intrudes the Ayer Granite. Naturally occurring arsenic is present in the bedrock at SHL as arsenic sulfide minerals, including arsenopyrite, as well as the ferric arsenate mineral scorodite (a common weathering product of arsenopyrite; Gannett Fleming 2012).

3.2. Hydrogeology

Groundwater beneath SHL originates from two primary recharge areas:

- Precipitation on Shepley's Hill (to the west of SHL) recharges bedrock groundwater, which flows east and up into overburden (seasonally, when the hydraulic gradient between bedrock and overlying overburden is upward); and precipitation on the north end of Shepley's Hill flows north/northeast and up into the overburden.
- Groundwater within the overburden flows from south to north under SHL, receiving additional recharge from an area of stormwater retention located along the southern boundary of SHL.

Groundwater at SHL consistently flows northwest from Plow Shop Pond toward the NIA, north of the extraction wells (S-A JV 2021b). This is likely driven by direct recharge along the northwest shore of Plow Shop Pond. The Plow Shop Pond dam is located approximately 800 feet east of the ATP and is approximately 4 feet above the surface of Nonacoicus Brook. The difference in surface water elevation created by the dam is approximately 4 feet, as indicated by historical measurements from staff gages SWEL-107 (below the dam) and SWEL-106 at the dam. A review of the potentiometric maps shows that the groundwater contours wrap around the active extraction wells EW-01 and EW-04 (located on the north end of SHL) and are driven by recharge from Shepley's Hill and Plow Shop Pond. In the absence of groundwater pumping at the extraction wells, groundwater flows generally from the southwest to the north toward

Nonacoicus Brook. Without the barrier wall between SHL and Plow Shop Pond (installed in 2012; see Figure 1-2 for the location), groundwater flow would be predominantly to the east/northeast.

An analysis of groundwater gradients based on potentiometric maps and three-point estimation analysis (i.e., 3PE) indicates that the groundwater flow direction varies in the northern portion of SHL (S-A JV 2021b). The influence of Shepley's Hill and its underlying bedrock aquifer creates a northeasterly flow along the western edge of SHL southwest of the ATP, while Plow Shop Pond creates an elevated hydraulic head that induces a flow to the northwest. These two hydraulic gradients create a funnel-like flow system in the northern portion and area north of SHL. Groundwater flow from the western and eastern portions of SHL migrate toward the extraction wells north of the toe of SHL (S-A JV 2021b). Groundwater from areas east of the landfill footprint flows toward the area north of SHL, with some flow toward the extraction wells and some to the north or northwest toward Nonacoicus Brook and the NIA.

Seasonal changes in the direction of vertical groundwater flow between the bedrock and overburden have been observed at SHL. During periods of high recharge and low evapotranspiration (generally winter and spring), the direction of groundwater flow is upward from the bedrock to the overburden beneath SHL, primarily due to precipitation recharge on Shepley's Hill. During periods of low recharge and high evapotranspiration (generally summer and fall), the direction of groundwater flow is downward from the overburden sands to the underlying bedrock, but with a lesser gradient than the upward gradient observed in the winter and spring (Gannett Fleming 2012). For example, groundwater flow from the bedrock aquifer at Shepley's Hill is evident in the groundwater elevations measured at well cluster SHP-2016-06 (on the western side of the landfill), which shows a consistent upward gradient from the deeper wells (SHP-2016-06B/C) to the shallow well (SHP-2016-06A). Other locations show upward gradients from deeper wells seasonally, with upward gradients occurring most often in the spring when recharge is higher (e.g., SHP-2016-3A/B).

3.3. Nature and Extent of Arsenic

The nature and extent of arsenic in groundwater (the primary COC at SHL) is described in detail in the SHL FFS (S-A JV 2023). The Army monitors the groundwater within and around SHL semi-annually. The S-A JV sampled the monitoring well network at SHL in October and November 2021 as part of the semi-annual LTM program (S-A JV 2022). The extent of dissolved metals in groundwater based on the October and November 2021 sampling is shown on **Figure 3-1**. The locations of two cross sections are also shown on this figure, one north to south and one west to east. The extent of dissolved metals in groundwater is shown on **Figure 3-2** for the north to south cross section and **Figure 3-3** for the west to east cross section.

Arsenic in groundwater beneath and adjacent to SHL is derived from a combination of geogenic sources in the bedrock, glacial till, and overburden sands, as well as from anthropogenic sources in the landfill waste. However, there is disagreement between Army, USEPA, and MassDEP on the relative contribution of these arsenic sources to current concentrations of arsenic in groundwater. Data and investigations supporting anthropogenic and geogenic sources of arsenic present in groundwater at SHL are described in the SHL FFS (S-A JV 2023).

4. Performance Monitoring Implementation

This section presents the approach, methods, and operational procedures to be used for the performance monitoring that will support the evaluation of the expanded groundwater extraction network. The sections below detail the activities proposed to address the study questions presented in **Section 2.2.1**, and to meet the WP objectives. As noted previously, to better assess capture of groundwater leaving the landfill with the addition of extraction well EW-03, the Army proposes the installation of five nested well pairings (five shallow wells drilled to approximately 40 feet bgs (most likely screened 20 to 30 feet bgs or 25 to 35 feet bgs), and five deep wells drilled to the top of bedrock (anticipated to be no more than 100 feet bgs but most likely screened 70 to 80 feet bgs) for a total of ten wells. The proposed monitoring well locations are summarized in **Table 4-1** and presented on **Figure 4-1.**

4.1. Proposed Activities

The capture zone evaluation will be performed using the USEPA guidance document *A Systematic Approach for Evaluation of Capture Zones at Pump and Treat Systems* (USEPA 2008) (Capture Guidance). The six steps to systematically evaluate capture zones, as included in the Capture Guidance, are:

1) Review site data, site conceptual model, and remedy objectives
2) Define site-specific Target Capture Zone(s)
3) Interpret water levels
4) Perform calculations
5) Evaluate concentration trends
6) Interpret actual capture based on Steps 1 through 5, compare to Target Capture Zone(s), assess uncertainties and data gaps

Details for each of these steps, and how they will be completed, are outlined in the sections below.

4.1.1. Step 1: Review Site Data, Site Conceptual Model, and Remedy Objectives

Prerequisites for a capture zone evaluation include delineation of the plume in three directions, adequate hydrogeologic information, a conceptual site model, and clear remedial objectives (USEPA 2008). These items are summarized in detail in the SHL FFS (S-A JV 2023).

Descriptions of plume delineation as well as significant hydrogeologic information are also summarized in the SHL FFS (S-A JV 2023). From a CSM perspective, arsenic in groundwater beneath, and adjacent to, SHL is derived from geogenic sources in the bedrock, glacial till, and overburden sands, as well as from anthropogenic sources in the landfill waste. However, there is disagreement on the relative contributions of these sources to the current arsenic concentrations in groundwater. While the main objective of this performance monitoring is to assess the impacts on capture from the newly installed extraction well EW-03, a secondary objective is to evaluate if changes to the extraction well network have an impact on downgradient dissolved arsenic concentrations and, by so doing, clarify whether the source of the arsenic is primarily geogenic or anthropogenic.

The objective of the groundwater extraction and ATP remedy is to provide downgradient receptor protection through hydraulic control and mass removal, resulting in reduced mass flux from the SHL. The design objective of the system is capture of groundwater with arsenic concentrations exceeding 10 micrograms per liter (µg/L) as defined in the ROD (USACE 1995). The locations of ten proposed wells were selected to better assess changes to the capture zone following the installation of EW-03 on the eastern portion of the landfill (**Table 4-1** and **Figure 4-1**).

4.1.2. Step 2: Define Site-Specific Target Capture Zone

A target capture zone is defined as the three-dimensional zone of groundwater that must be captured by the remedy extraction wells for the hydraulic containment portion of the remedy to be considered successful (USEPA 2008). At SHL the target capture zone of the ATP is defined as the extent of groundwater that must be captured to intercept overburden groundwater discharging from the SHL that contains arsenic at concentrations exceeding the cleanup goal established in the ROD (USACE 1995). This area is shown in planar view in **Figure 4-1**.

4.1.3. Step 3: Interpret Water Levels

Groundwater elevation measurements will be used to evaluate changes in horizontal and vertical flow directions within the SHL while EW-03 is operational. Water level interpretations will include potentiometric surface maps drawn using groundwater elevation data collected semi-annually, as well as monthly vertical gradient analysis between nested monitoring well pairs. Installation of five nested well pairs (**Figure 4-1**) is proposed to supplement the existing well network. Four of the well pairs are proposed for the eastern side of the SHP to assess the effects of EW-03 on the capture zone and evaluate whether this configuration addresses the concern expressed by the USEPA that groundwater migrating northward from the landfill between monitoring wells SHM-10-06 and SHL-21 is not consistently captured by the ATP system. The fifth well pair is proposed for the western edge of the SHL to help assess the effects that decreased flow rates in EW-01 and EW-04 will have on plume capture (if any) in that area. A summary of wells in the SHL monitoring well network including the proposed and existing wells is shown in **Table 4-2**.

Water level information will be collected in two ways: through dedicated transducers at the newly proposed monitoring wells, and through manual gauging of the larger well network. The 10 new wells will be equipped with data logging pressure transducers to record changes in water level and vertical gradients throughout the monitoring period. The pressure transducers will be set to collect a measurement once every 5 minutes for the duration of the monitoring period. The 10 new wells and a subset of existing wells (eight listed wells, plus as many other wells as can be gauged in 1 day of field work for a two-person team) will be manually gauged during 10 events conducted over 12 months starting after activation of EW-03 (expected in Fall 2023). These locations are noted in the hydraulic control performance monitoring **Table 4-2** and are shown on **Figure 4-1**.

A network of hydraulic control points will be established consisting of proposed and existing monitoring wells. This network will consist of nested well pairs which will be used to calculate the magnitude and direction of the vertical gradient between the upper and lower sand units. This well network will be measured manually during the 10 gauging events and will be used to calculate the gradient between control points. The vertical gradient between each well pairing will be calculated semi-annually (in the Spring and Fall). **Table 4-2** shows the list of wells including each gradient control well pairing.

4.1.4. Step 4: Perform Calculations

Specific calculations will be performed to add additional lines of evidence regarding the extent of capture. 3PE analyses will be performed on the expanded well network. In a 3PE analysis, vector gradients are calculated for triangular areas of the flow field using groundwater elevations measured in a group of three wells pairs located within a well array. The well array used for the 3PE analysis at SHL is a subset of the wells used to develop potentiometric surface maps. The wells that best define the potential capture zone of the extraction wells are those screened within the lower sands of the glacial aquifer overlying the bedrock.

The proposed wells will supplement the current network by increasing the density of the 3PE triangles around the newly operational EW-03 as well as expand the analysis area along the eastern and western edge of the plume. **Figure 4-2** shows the updated 3PE triangles from the proposed monitoring wells and **Table 4-1** describes the rationale for the location of each proposed well as well as the purpose that the well will serve in furthering the 3PE analysis. **Table 4-2** presents the subset of wells that will be monitored for the 3PE analysis.

4.1.5. Step 5: Evaluate Concentration Trends

Evaluation of concentration trends will be employed to assess the degree of hydraulic and arsenic mass capture. Per the Capture Guidance (USEPA 2008), contaminant concentrations can be monitored at two types of wells downgradient of the Target Capture Zone to interpret capture:

- Sentinel wells that are located downgradient of the Target Capture Zone
- Performance monitoring wells that are located within the Target Capture Zone and are currently impacted above background concentrations

As shown in **Table 4-2**, sentinel wells, as defined above, include: EPA-PZ-2012-2A, EPA-PZ-2012-2B, EPA-PZ-2012-5A, EPA-PZ-2012-5B, EPA-PZ-2012-7A, EPA-PZ-2012-7B, SHL-5, SHL-8S, SHL-8D,, SHL-22, SHM-05-41C, SHM-05-42B, SHM-10-16, SHM-93-22B, SHM-93-22C, SHM-96-5B, SHM-96-5C, SHP-2016-2B, SHP-2016-3B. Monitoring wells located downgradient of the target groundwater capture zone were selected to serve as downgradient ATP performance monitoring wells. The ATP performance monitoring wells include: EPA-PZ-2012-1A, EPA-PZ-2012-1B, EPA-PZ-2012-3A, EPA-PZ-2012-3B, EPA-PZ-2012-4A, EPA-PZ-2012-4B, EPA-PZ-2012-6A, EPA-PZ-2012-6B, SHM-10-06, SHM-10-06A, SHP-05-45B, SHP-05-46B, SHL-9, SHL-21, SHL-23, SHP-2016-1B, SHP-2016-4B, SHP-2016-5B, SHP-2016-6A, SHP-2016-6B, and SHP-2016-6C. Successful capture should result in declining contaminant concentrations at these monitoring wells over time if an anthropogenic source of arsenic is present in the landfill. In addition to the sentinel wells, the extraction wells, and key wells with arsenic concentrations exceeding 10 µg/L within the capture zone (performance monitoring wells) will also be monitored. Capture zone and downgradient contaminant concentration performance monitoring wells are identified on **Figure 4-1**.

Mann-Kendall statistical trend analyses are commonly used to evaluate if remedial measures are decreasing contaminant concentrations in groundwater at landfills and other cleanup sites and indicate whether the concentration trend over time is increasing, decreasing, or if there is insufficient evidence of a statistically significant trend for each dataset. Concentration trends for the 56 monitoring wells/piezometers within the NIA and Nearfield Area used for trend analysis in the *Final Phase I EPA SOW – Demonstrate Plume Capture Technical Memorandum Phase I Subtask 5.e* (S-A JV 2021a) will be updated with the information gathered as part of this study and the most recent LTM data where it is available.

It is important to note that arsenic trends in the NIA are not necessarily a good indicator of "plume capture," and, therefore, the objective of understanding extent of capture based on these trends is unlikely to be met, whereas 3PE is more definitive of hydraulic capture, and excludes geochemistry. More specifically, a lack of a decreasing arsenic trend in the NIA does not in itself imply that water emanating from the landfill has not been prevented from entering the NIA. The NIA comprises a naturally reducing zone with influence from wetland and natural organic matter deposits. This reducing condition is expected to prevent attenuation and/or contribute to release of arsenic derived from geogenic sources; this is in addition to the desorption of adsorbed arsenic in equilibrium with the aqueous phase, which also serves to replenish dissolved arsenic and extend the timeframe for washout of arsenic via advection. Accordingly, arsenic concentrations are likely to remain elevated as the reducing condition is sustained, even as the NIA receives groundwater inflow from areas other than the landfill.

4.1.6. Step 6: Interpret Actual Capture Based on Steps 1-5, Compare to Target Capture Zone(s), Assess Uncertainties and Data Gaps

Once water level data, calculations, and contaminant concentration trends have been evaluated, the results of the separate evaluations will be reviewed holistically to evaluate if the interpreted capture zone is in line with the Target Capture Zone (**Figure 4-1**). It is important to perform the above evaluations without them being influenced by knowledge of the Target Capture Zone boundaries; they should only be compared once independent conclusions have been reached in Steps 3, 4, and 5 (USEPA 2008). If conducted, results of particle tracking using the existing approved groundwater model (conducted to compare the measured capture zone to the model simulate capture zone) will be included as part of the evaluation of the system.

The Capture Guidance recommends the following steps be completed after performing the independent analyses described above:

1. Compare the interpreted capture zone to the Target Capture Zone. *Does the current system achieve remedy objectives with respect to plume capture, both horizontally and vertically?*

2. Assess uncertainties in the interpretation of the actual capture zone. *Are alternative interpretations possible that would change the conclusions as to whether or not sufficient capture is achieved?*

3. Assess the need for additional characterization and/or monitoring. *Is there a need for additional plume delineation or additional piezometer locations to determine convincingly whether or not actual capture is sufficient?*

4. Evaluate the need to reduce or increase extraction rates. *Should extraction rates, number of extraction wells, and/or locations be modified based on the results of the capture zone analysis?*

The evaluation of the above criteria and results with any recommendations will be included in the 12-month report.

4.2. Methodology

Field activities will be conducted in accordance with the following Technical Guidance Instructions (TGIs) and Standard Operating Procedures (SOPs):

- TGI – Utility Location

- TGI – Manual Water-Level Monitoring (Rev #0, May 2020)
- TGI – In-Situ and Ex-Situ Water Quality Parameters (Rev #0, October 2018)
- TGI – Sample Chain of Custody (Rev #2, April 2020)
- TGI – Investigation-Derived Waste Handling and Storage (Rev #0, February 2017)
- TGI – Groundwater and Soil Sampling Equipment Decontamination (Rev #1, May 2020)
- TGI – Low Stress (low flow) Purging and Sampling Procedure for the Collection of Groundwater Samples from Monitoring Wells (Rev #4, September 2017)

These TGIs are included in the SHL LTMMP Update and QAPP (Sovereign 2015) and the SHL LTMMP Addendum (KGS 2018). Additional details concerning field activities are provided below. An additional TGI for water level monitoring using data logging instruments is attached as **Appendix A**.

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 using a private utility locator. The S-A JV will utilize a subcontractor for this task, who will utilize their own TGIs/SOPs.
- 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. Monitoring Well Installation

The proposed monitoring wells will be drilled using 4.25-inch hollow stem augers or drive-and-wash drilling methods. Each well cluster will include one shallow well drilled to approximately 40 feet bgs (most likely screened 20 to 30 feet bgs or 25 to 35 feet bgs), and one deep well drilled to the top of bedrock (anticipated to be no more than 100 feet bgs but most likely screened 70 to 80 feet bgs). If the depth of bedrock is deeper than 100 feet bgs, the screen interval will be adjusted after consultation with the USACE. Each well will be installed using 2-inch diameter schedule 40 polyvinyl chloride (PVC). PVC wells will be constructed using 10-foot long, 0.010-inch slotted screens. A grade #0 silica sand pack will be installed from the bottom of the screen to approximately 2 feet above the top of the screens. Two-foot hydrated bentonite seals will be installed above the sand packs, and the remaining annular space at each well will be tremie-grouted to approximately 1 foot below grade. Each well will be finished with a 4-inch, locking steel stick-up protective casing. All drilling will be completed by a licensed Massachusetts driller under the oversight of an S-A JV geologist and will be conducted in accordance with all promulgated state and federal laws.

Each overburden 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. Where drive-and-wash drilling methods are used (and drilling water is introduced into the formation), well development will also recover any drilling fluids added. Groundwater will be pumped from the well until at least three well volumes, plus the amount of drilling water introduced to the formation, have been purged and the water runs clear.

4.2.3. Groundwater Sampling and Water Level Measurements

The 10 new wells and a subset of existing wells (eight listed wells, plus as many other wells as can be gauged in one day of field work for a two-person team) will be gauged during 10 gauging events conducted over a 1-year period. The 10 new wells will also be equipped with data logging transducers to record changes in water level throughout the monitoring period. Groundwater samples will be collected from new and existing monitoring wells, as described in **Table 4-3**. Samples will be collected in accordance with the TGI. The new and existing monitoring wells will be sampled twice for dissolved metals (arsenic, iron, and manganese) and geochemical parameters (alkalinity, chloride, dissolved organic carbon, and sulfate) and measured field parameters in accordance with the SHL LTMMP Update and QAPP (Sovereign 2015) and SHL LTMMP Addendum (KGS 2018). It is assumed that this sampling will be conducted during regularly scheduled SHL LTM events in the fall of 2023 and spring of 2024. It is anticipated that the Fall 2023 event will be baseline conditions prior to the operation of EW-03. If there is a significant time difference between the installation of the new monitoring wells and the Fall 2023 sampling event, the new wells would be sampled after installation. In addition, groundwater samples will be collected from the three extraction wells and sampled for total metals (arsenic, iron, and manganese). The samples will be collected from the existing sampling ports on the ATP influent lines and no field quality control samples will be collected.

4.2.4. Transducers

Transducers will be deployed in the 10 new monitoring wells. The transducers will be deployed approximately two-thirds to three-quarters down the well screen such that changes in water levels from extraction can be monitored. Non-vented transducers will be used since they require less maintenance. Non-vented transducers require a separate barometric pressure logger such that barometric corrections can be made to the recorded water levels on the transducers. The barometric pressure logger will be deployed at SHL in a location that is protected from the weather (e.g., precipitation and sun) in an open atmosphere setting. Transducer data will be downloaded during the 10 gauging events conducted during the one-year monitoring period. The transducers should not need to be removed during groundwater sampling; however detailed field notes will note when sampling takes place.

4.2.5. 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 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. Groundwater generated (including drilling water and rinsate water) will be discharged to the ground surface at the site of generation. If sheens or other evidence of potential contamination are observed in 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.

4.2.6. Surveying

All well locations will be surveyed for the location and elevation of the ground surface. Locations will be marked and/or staked after drilling activities have been completed to ensure the accuracy of the survey. Surveying will be measured to the nearest 0.1 foot horizontally and 0.01 foot vertically. A Massachusetts-licensed surveyor will be contracted to perform surveying in accordance with the Massachusetts State Plane Coordinate System of the North American Datum (NAD) 1983 and vertically on the North American Vertical Datum of 1988 (NAVD 88). The surveyor will utilize their own SOPs to complete the field activities.

4.2.7. Database

The Former Fort Devens Environmental Data Management System (EDMS) is an online database that provides information access to project team members within the USACE, contractor, laboratory, and validation organizations. The well construction data, physical parameters, survey/location data, water levels, and chemistry data collected in accordance with this WP will be loaded into the EDMS database (ftdevens.org) on an on-going basis during event planning, sample collection, and data analysis activities.

5. Deliverables

While the pilot test is being conducted, monthly updates of the ATP operations performance monitoring will be prepared to present the data collected to date. The monthly reports will include results of the laboratory analyses, vertical gradient, and 3PE evaluation.

In addition, two technical memoranda will be prepared that summarize and compare pilot test results of the three well system:

- A 6-month memorandum will be prepared to provide a summary of the first six months of the performance monitoring period.
- A 12-month memorandum will be prepared to provide overall findings.

An assessment of the influent and effluent characteristics for the ATP under different pumping scenarios, comparing them with current system operation, will be included in one or both of the memoranda. If conducted, results of particle tracking using the existing approved groundwater model (conducted to compare the measured capture zone to the model simulate capture zone) will be included as part of the evaluation of the system.

The memoranda will also include the following:

- Description of the field activities completed to date (i.e., groundwater sample collection).
- Results of the field activities including synoptic gauging event maps, seasonal groundwater fluctuations, groundwater gradient (horizontal/vertical), 3PE analyses, target and measured capture zones, Mann-Kendall trends, etc.
- 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 attachments to the memoranda, and as discussed in **Section 4.2.6**, uploaded to the project database.

6. Schedule

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

The extraction well is currently scheduled for installation the week of September 5, 2023, and the performance monitoring wells will be installed after that event, depending on the logistics and progress of the plant upgrade activities.

Table 6-1 Anticipated Project Schedule

Task	Date
Field Work (anticipated)	Fall 2023 – Fall 2024
Submit Draft 6-Month Memorandum (pending field work start)	Spring 2024
Submit Draft 12-Month Memorandum (pending field work start)	December 2024

7. References

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Tables

Table 4-1
Proposed Monitoring Well Locations Rationale

Performance Monitoring Work Plan
USACE New England District
Shepley's Hill Landfill - Former Fort Devens Army Installation
Devens, Massachusetts

SERES Engineering & Services, LLC
ARCADIS
a joint venture

Well ID	Location Type	Rationale for Proposed Location
SHP-2023-1A	Proposed Nested Well Pair	Expand density of gradient control points, 3PE triangles, and concentration trend analysis points to assess impacts on capture on the western side of SHL from decreased pumping rates at EW-01 and EW-04
SHP-2023-1B		
SHP-2023-2A		Expand density of gradient control points, 3PE triangles, and concentration trend analysis points to assess capture on the eastern side of SHL from installation of EW-03
SHP-2023-2B		
SHP-2023-3A		Expand density of gradient control points, 3PE triangles, and concentration trend analysis points to assess capture on the eastern side of SHL from installation of EW-03
SHP-2023-3B		
SHP-2023-4A		Expand density of gradient control points, 3PE triangles, and concentration trend analysis points to assess capture on the eastern side of SHL from installation of EW-03
SHP-2023-4B		
SHP-2023-5A		Expand density of gradient control points, 3PE triangles, and concentration trend analysis points to assess EPA concen that groundwater migrating northward from the eastern side of the landfill is not consistantly captured by the ATP system
SHP-2023-5B		
EPA-PZ-2012-1A	Existing Monitoring Well	Existing Monitoring Wells
EPA-PZ-2012-1B		
EPA-PZ-2012-2A		
EPA-PZ-2012-2B		
EPA-PZ-2012-3A		
EPA-PZ-2012-3B		
EPA-PZ-2012-4A		
EPA-PZ-2012-4B		
EPA-PZ-2012-5A		
EPA-PZ-2012-5B		
EPA-PZ-2012-6A		
EPA-PZ-2012-6B		
EPA-PZ-2012-7A		
EPA-PZ-2012-7B		
SHL-5		
SHL-8S		
SHL-8D		
SHL-9		
SHL-21		
SHL-22		
SHL-23		
SHM-05-41C		
SHM-05-42B		
SHM-10-06		
SHM-10-06A		
SHM-10-16		
SHM-93-22B		
SHM-93-22C		
SHM-96-5B		
SHM-96-5C		
SHP-05-45B		
SHP-05-46B		
SHP-2016-1B		
SHP-2016-2B		
SHP-2016-3B		
SHP-2016-4B		
SHP-2016-5B		
SHP-2016-6A		
SHP-2016-6B		
SHP-2016-6C		

Notes:

Table 4-2
Performance Monitoring Capture Zone Analysis

Performance Monitoring Work Plan
USACE New England District
Shepley's Hill Landfill - Former Fort Devens Army Installation
Devens, Massachusetts

SERES Engineering & Services, LLC
ARCADIS
a joint venture

Well ID	Location Type	Analysis				
		Manually Gauged Wells During Synoptic Events	Vertical Gradient Control Points	3PE Triangle Analysis	Sentinel Wells in Concentration Trend Analysis	Performance Monitoring Wells in Concentration Trend Analysis
SHP-2023-1A	Proposed Nested Well Pair	X	X	X		X
SHP-2023-1B		X	X			X
SHP-2023-2A		X	X	X		X
SHP-2023-2B		X	X			X
SHP-2023-3A		X	X	X		X
SHP-2023-3B		X	X			X
SHP-2023-4A		X	X	X	X	
SHP-2023-4B		X	X		X	
SHP-2023-5A		X	X	X	X	
SHP-2023-5B		X	X		X	
EPA-PZ-2012-1A	Existing Monitoring Well		X			X
EPA-PZ-2012-1B		X	X	X		X
EPA-PZ-2012-2A			X		X	
EPA-PZ-2012-2B			X	X	X	
EPA-PZ-2012-3A			X			X
EPA-PZ-2012-3B		X	X	X		X
EPA-PZ-2012-4A			X			X
EPA-PZ-2012-4B			X	X		X
EPA-PZ-2012-5A			X		X	
EPA-PZ-2012-5B			X	X	X	
EPA-PZ-2012-6A			X			X
EPA-PZ-2012-6B			X	X		X
EPA-PZ-2012-7A			X		X	
EPA-PZ-2012-7B		X	X	X	X	
SHL-5					X	
SHL-8S			X		X	
SHL-8D			X		X	
SHL-9		X				X
SHL-21						X
SHL-22					X	
SHL-23						X
SHM-05-41C					X	
SHM-05-42B				X	X	
SHM-10-06				X		X
SHM-10-06A				X		X
SHM-10-16					X	
SHM-93-22B					X	
SHM-93-22C					X	
SHM-96-5B		X		X	X	
SHM-96-5C					X	
SHP-05-45B				X		X
SHP-05-46B				X		X
SHP-2016-1B				X		X
SHP-2016-2B				X	X	
SHP-2016-3B		X		X	X	
SHP-2016-4B		X		X		X
SHP-2016-5B				X		X
SHP-2016-6A			X			X
SHP-2016-6B		X	X			X
SHP-2016-6C						X

Notes:

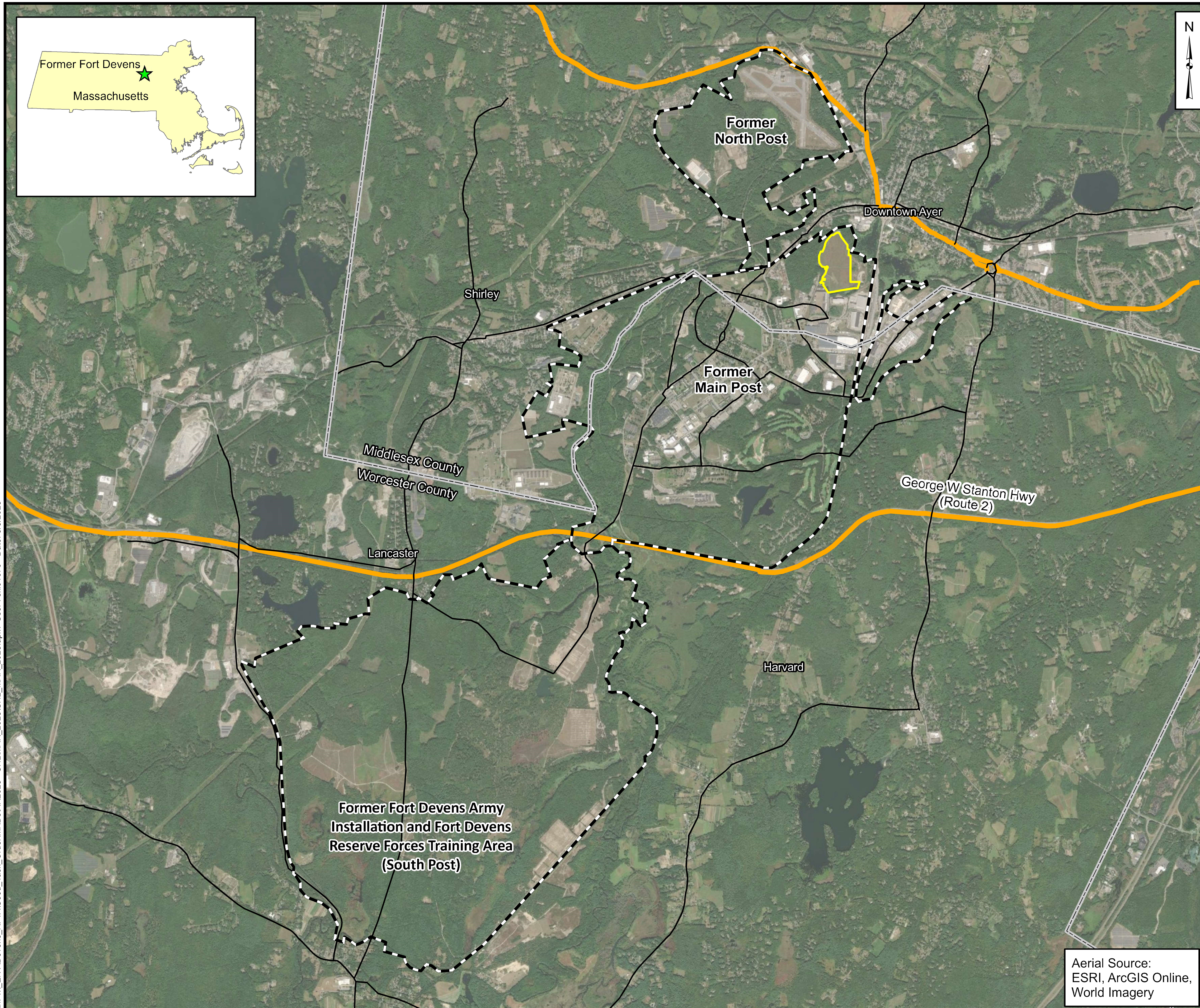
Table 4-3
Proposed Groundwater Sampling Analysis

Performance Monitoring Work Plan
USACE New England District
Shepley's Hill Landfill - Former Fort Devens Army Installation
Devens, Massachusetts

Well ID	Location Type	Laboratory Analysis					
		Dissolved Arsenic	Dissolved Iron and Manganese	Dissolved Organic Carbon	Alkalinity	Chloride	Sulfate
SHP-2023-1A	Proposed Nested Well Pair	X	X	X	X	X	X
SHP-2023-1B		X	X	X	X	X	X
SHP-2023-2A		X	X	X	X	X	X
SHP-2023-2B		X	X	X	X	X	X
SHP-2023-3A		X	X	X	X	X	X
SHP-2023-3B		X	X	X	X	X	X
SHP-2023-4A		X	X	X	X	X	X
SHP-2023-4B		X	X	X	X	X	X
SHP-2023-5A		X	X	X	X	X	X
SHP-2023-5B		X	X	X	X	X	X
EPA-PZ-2012-1A	Existing Monitoring Well	X	X	X	X	X	X
EPA-PZ-2012-1B		X	X	X	X	X	X
EPA-PZ-2012-2A		X	X	X	X	X	X
EPA-PZ-2012-2B		X	X	X	X	X	X
EPA-PZ-2012-3A		X	X	X	X	X	X
EPA-PZ-2012-3B		X	X	X	X	X	X
EPA-PZ-2012-4A		X	X	X	X	X	X
EPA-PZ-2012-4B		X	X	X	X	X	X
EPA-PZ-2012-5A		X	X	X	X	X	X
EPA-PZ-2012-5B		X	X	X	X	X	X
EPA-PZ-2012-6A		X	X	X	X	X	X
EPA-PZ-2012-6B		X	X	X	X	X	X
EPA-PZ-2012-7A		X	X	X	X	X	X
EPA-PZ-2012-7B		X	X	X	X	X	X
SHL-5		X	X	X	X	X	X
SHL-8S		X	X	X	X	X	X
SHL-8D		X	X	X	X	X	X
SHL-9		X	X	X	X	X	X
SHL-21		X	X	X	X	X	X
SHL-22		X	X	X	X	X	X
SHL-23		X	X	X	X	X	X
SHM-05-41C		X	X	X	X	X	X
SHM-05-42B		X	X	X	X	X	X
SHM-10-06		X	X	X	X	X	X
SHM-10-06A		X	X	X	X	X	X
SHM-10-16		X	X	X	X	X	X
SHM-93-22B		X	X	X	X	X	X
SHM-93-22C		X	X	X	X	X	X
SHM-96-5B		X	X	X	X	X	X
SHM-96-5C		X	X	X	X	X	X
SHP-05-45B		X	X	X	X	X	X
SHP-05-46B		X	X	X	X	X	X
SHP-2016-1B		X	X	X	X	X	X
SHP-2016-2B		X	X	X	X	X	X
SHP-2016-3B		X	X	X	X	X	X
SHP-2016-4B		X	X	X	X	X	X
SHP-2016-5B		X	X	X	X	X	X
SHP-2016-6A		X	X	X	X	X	X
SHP-2016-6B		X	X	X	X	X	X
SHP-2016-6C		X	X	X	X	X	X

Notes:
1. Dissolved Fe/Mn samples will be field filtered.
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. Ferrous iron samples will be collected with a Hach field kit (or similar).

Figures



Legend

- Former Fort Devens Boundary
- Shepley's Hill Landfill Boundary
- County Line
- Highway
- Major Road

0 1 2
Miles

Shepley's Hill Landfill
Former Fort Devens Army Installation
Devens, Massachusetts
Performance Monitoring Work Plan

Site Location

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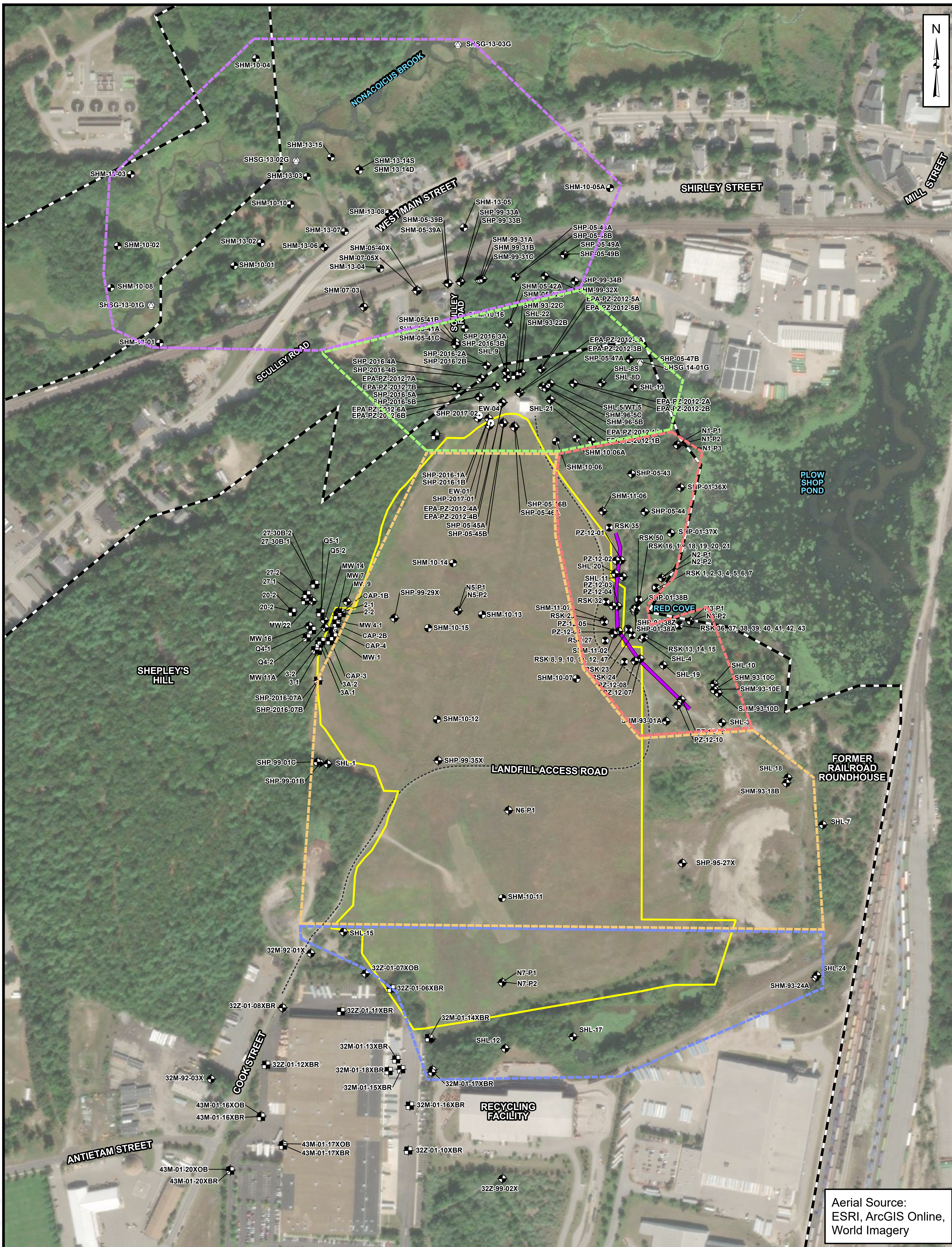
Figure 1-1

Path: T:_ENV\Devens_RFTA\Seed_Task_Order\MXDs\AR2023 - SHL\MAR_2023\SHL_MAR_2023.aprx User: ski01076 Date: 3/3/2023



Legend
- Former Fort Devens Boundary
- Shepley's Hill Landfill Boundary
- Overburden Monitoring Well/Piezometer
- Groundwater Profiling Location/Monitoring Well
- Monitoring Well
- Bedrock Monitoring Well
- Extraction Well
- Stream Gauge
- Barrier Wall
- Landfill Access Road
- Barrier Wall Area Wells
- Landfill Area Wells
- Nearfield Area Wells
- North Impact Area Wells
- Upgradient Area Wells

Shepley's Hill Landfill
Former Fort Devens Army Installation
Devens, Massachusetts
Performance Monitoring Work Plan

Site Plan

SERES Engineering & Services, LLC
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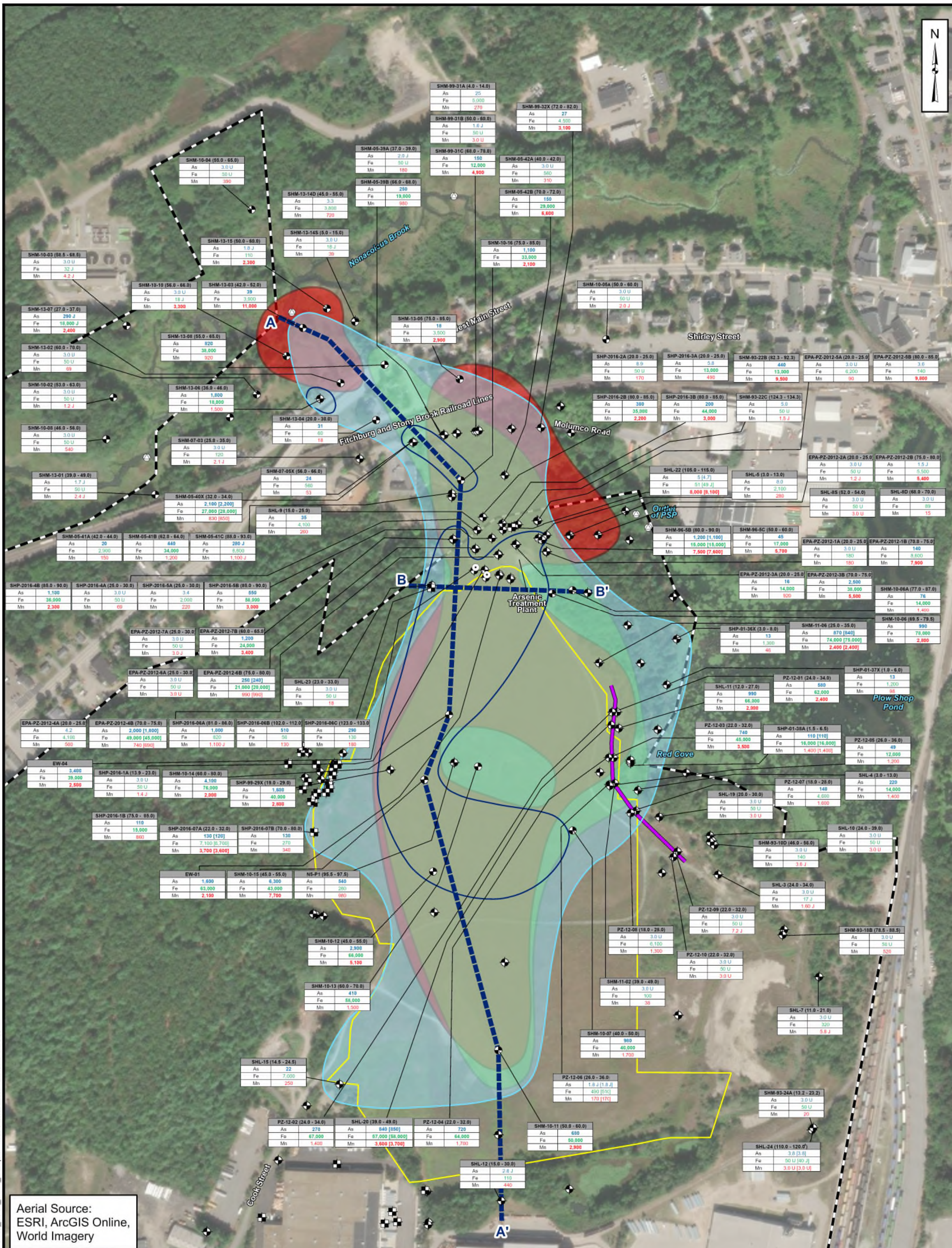
a joint venture

Figure
1-2

Path: T:_ENV\Devens_RFTA\Seed_Task_Order\MXDs\AR2023 - SHL\MAR_2023\SHL_MAR_2023.aprx User : ski01076 Date: 3/3/2023

File: SHL_MAR_2023.mxd



Legend

- Former Fort Devens Boundary
- Shepley's Hill Landfill Boundary
- Overburden Monitoring Well/Piezometer
- Groundwater Profiling Location/Monitoring Well
- Bedrock Monitoring Well
- Extraction Well
- Stream Gauge
- Barrier Wall
- Interpreted Area of Arsenic >10 ug/L
- Interpreted Area of Arsenic > 1,000 ug/L
- Interpreted Area of Arsenic > CL of 10 µg/L
- Interpreted Area of Iron > CL of 9,100 µg/L
- Interpreted Area of Manganese > CL of 1,715 µg/L
- Cross-Section Location

Notes:
1. All concentrations are in µg/L
2. As = arsenic
3. Fe = iron
4. Mn = manganese
5. J = Estimated result
6. U = Analyte was below detection limit
7. As concentrations are presented in blue
8. Fe concentrations are presented in green
9. Mn concentrations are presented in red
10. Duplicate results are presented in brackets following the sample results
11. **Bold** values indicate an exceedance of the CLs
12. µg/L = micrograms per liter
13. CL = Cleanup Level
14. > = greater than

0 200 400
Feet

Shepley's Hill Landfill
Former Fort Devens Army Installation
Devens, Massachusetts
Performance Monitoring Work Plan

Extent of Dissolved Metals in Groundwater October/November 2021

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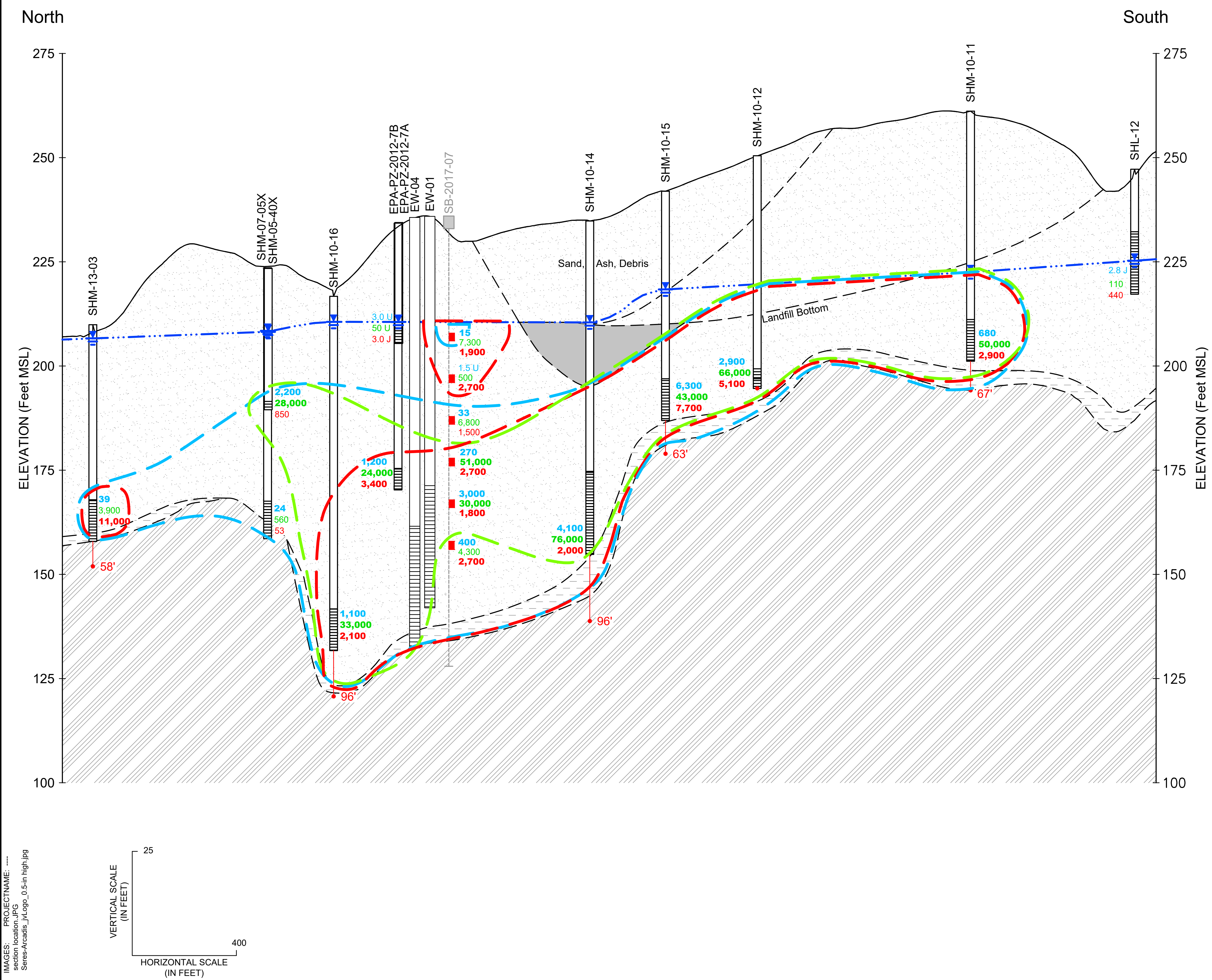
Figure 3-1

Path: T:_ENV\Devens_RFTA\Seed_Task_Order\MXDs\AR2023 - SHL\MAR_2023\SHL_MAR_2023_V1.aprx User: vmn1306 Date: 3/9/2023

File: SHL_MAR_2023_V1.mxd



Legend

EPA-PZ-2012-7A

Monitoring Well

430 Arsenic Concentration (µg/L)
47,000 Iron Concentration (µg/L)
1,900 Manganese Concentration (µg/L)
U, J = Laboratory Qualifiers

Results shown for monitoring wells are from October/November 2021 or most recent sampling event for that well as specified.

Well Casing

Screened Interval

90' Depth to Bottom of Boring (feet)

SB-16-09

2017 Soil Boring

430 Arsenic Concentration (µg/L)
47,000 Iron Concentration (µg/L)
1,900 Manganese Concentration (µg/L)
U, J = Laboratory Qualifiers

Sample Interval (1 Foot)

Boring to Refusal

Interpreted Area of Arsenic > CL of 10 µg/L

Interpreted Area of Iron > CL of 9,100 µg/L

Interpreted Area of Manganese > CL of 1,715 µg/L

Water Table Elevations for Monitoring Wells are from October 2021 Well Hydraulic Gauging Event

Sand

Peat

Till

Bedrock

Notes:

1. MSL = mean seal level
2. µg/L = microgram per liter
3. J = Estimated result 2023
4. U = Analyte was below detection limit
5. CL = cleanup levels
6. > = greater than
5. **Bold** values indicate an exceedance of the CLs
8. Cross sections and data included in the August 2011 Shepley's Hill Landfill Supplemental Groundwater and Landfill Cap Assessment for Long-Term Monitoring anda Maintenance - Addendum Report by Sovereign Consulting, Inc. were referenced in development of this cross section.
9. Geologic and depth to bottom information shown for SB-2017-07 is based on notes during installation of SB-16-07.
10. Depth to bottom of boring not available for SHM-05-40X, SHM-07-05X, EPA-PZ-2012-7A, EPA-PZ-2012-7B, and SHL-12.

Shepley's Hill Landfill
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Devens, Massachusetts
Performance Monitoring Work Plan

DISSOLVED METALS IN GROUNDWATER - NORTH TO SOUTH CROSS SECTION

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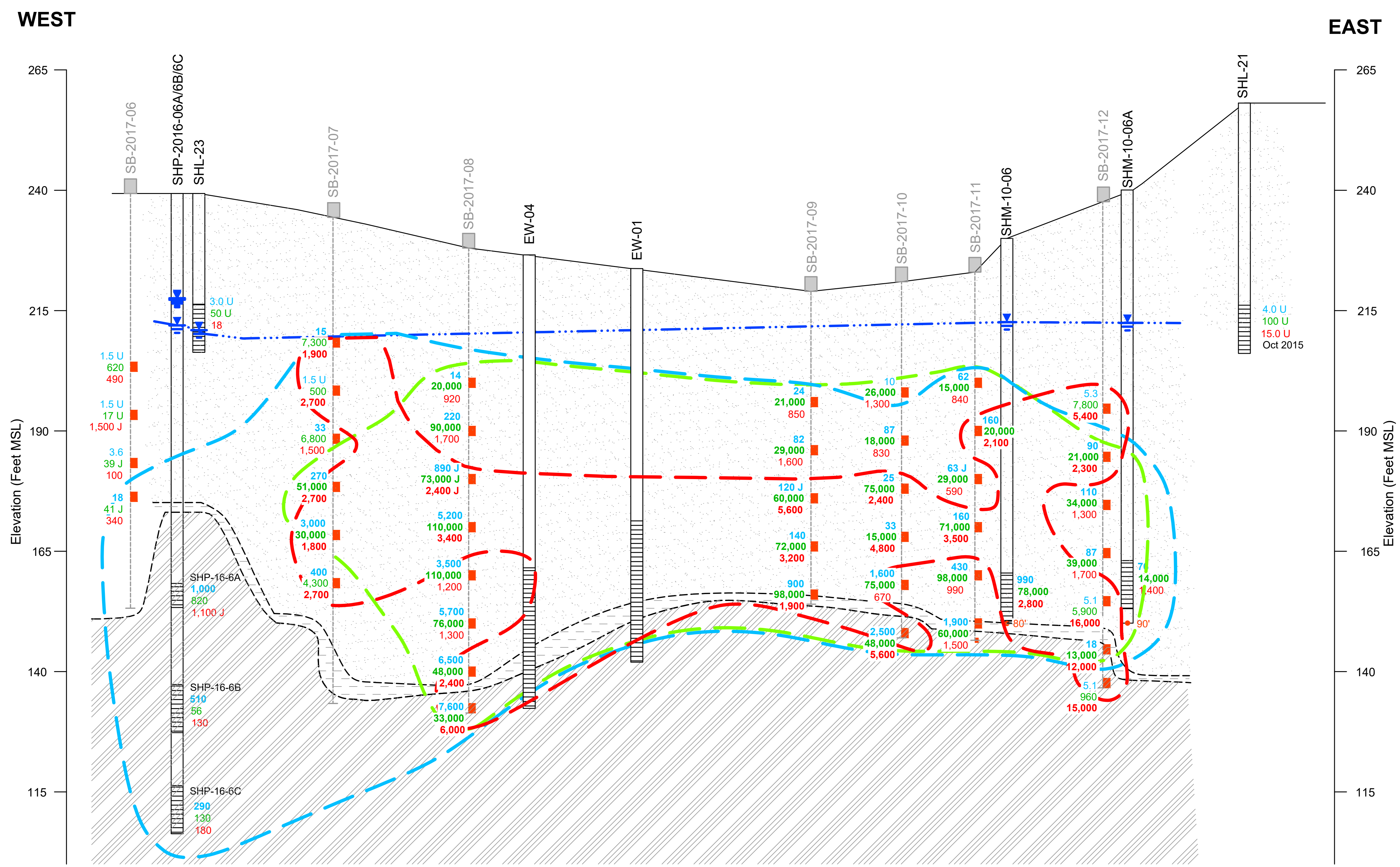
Figure

3-2



VERTICAL SCALE (IN FEET) 25

HORIZONTAL SCALE (IN FEET) 75

Legend

- Monitoring Well (SHL-21)
  - 4.0 U Arsenic Concentration (µg/L)
  - 100 U Iron Concentration (µg/L)
  - 15.0 U Manganese Concentration (µg/L)
  - U, J = Laboratory Qualifiers
  - Results shown for monitoring wells are from October/November 2021 or most recent sampling event for that well as specified.
- Well Casing
- Screened Interval
- 90' Depth to Refusal (feet)
- 2017 Soil Boring (SB-16-09)
  - 25 Arsenic Concentration (µg/L)
  - 75,000 Iron Concentration (µg/L)
  - 2,400 Manganese Concentration (µg/L)
  - U, J = Laboratory Qualifiers
- Sample Interval (1 Foot)
- Boring to Refusal
- Interpreted Area of Arsenic > CL of 10 µg/L
- Interpreted Area of Iron > CL of 9,100 µg/L
- Interpreted Area of Manganese > CL of 1,715 µg/L
- Water Table Elevations for Monitoring Wells are from October 2021 Well Hydraulic Gauging Event
- Sand
- Bedrock
- Till

Notes:

1. MSL = mean seal level
2. µg/L = microgram per liter
3. J = Estimated result 2023
4. U = Analyte was below detection limit
5. CL = cleanup levels
6. > = greater than
7. **Bold** values indicate an exceedance of the CLs
8. Depth to bottom of boring not available for SHL-21 and SHL-23.
9. Strata data shown on Figure 5-8 of the September 2020 Area 2 Preliminary Site Characterization Summary Per- and Polyfluoroalkyl Substances (PFAS) Remedial Investigation by KOMAN Government Solutions, LLC were used to develop this figure.

Shepley's Hill Landfill
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Devens, Massachusetts
Performance Monitoring Work Plan

DISSOLVED METALS IN GROUNDWATER - WEST TO EAST CROSS SECTION

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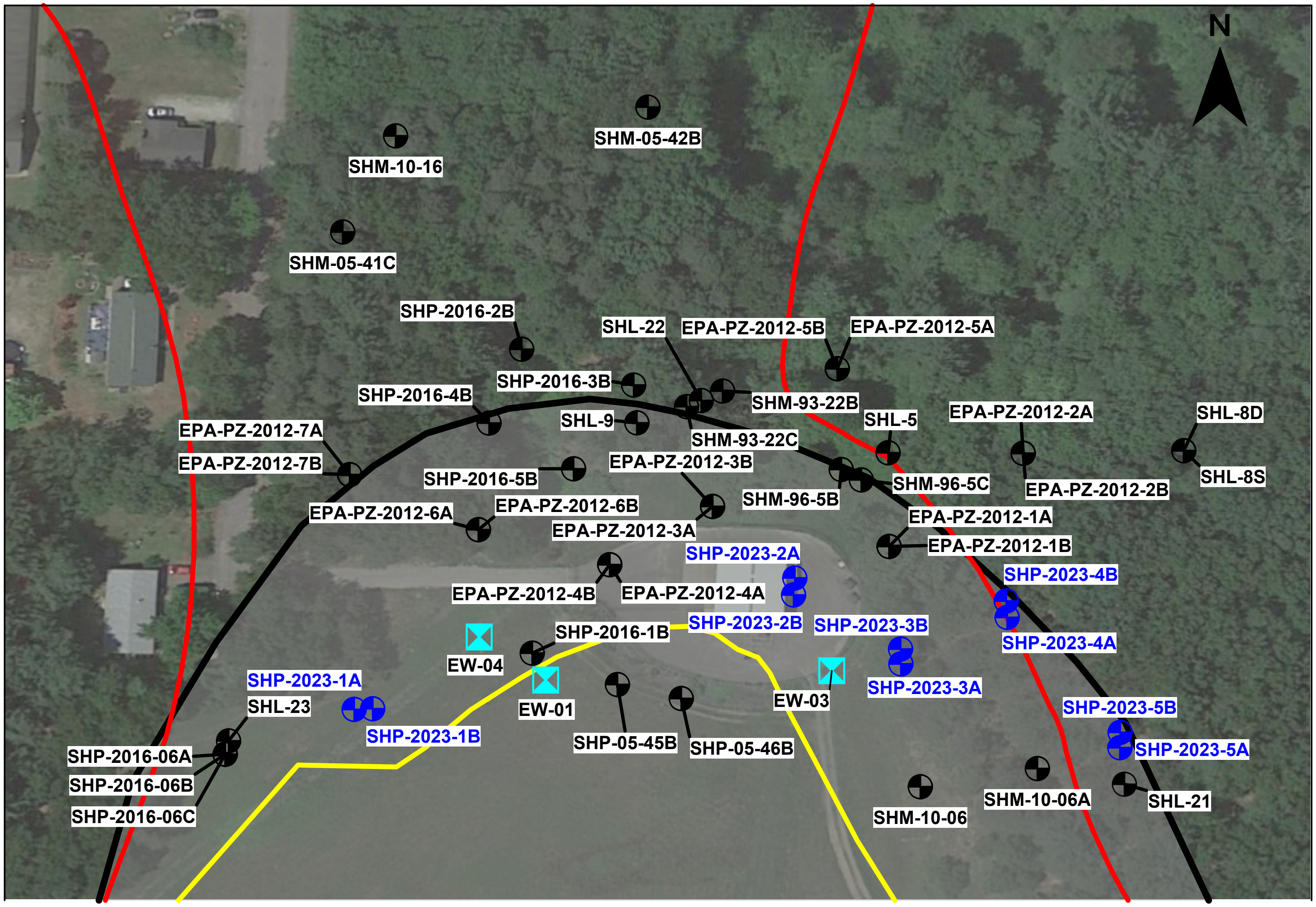
Figure 3-3



Note:
1. Proposed monitoring well locations are approximate and subject to change based on field conditions

Legend

- Extraction Wells
- Existing Monitoring Wells
- Proposed Monitoring Wells
- Target Groundwater Capture Zone
- Shepley's Hill Landfill Boundary
- Approximate Extent of Dissolved Arsenic Exceeding 10 ug/L

Scale in feet
0 120 240

FORMER FORT DEVENS ARMY INSTALLATION
DEVENS, MASSACHUSETTS
PERFORMANCE MONITORING
WORK PLAN

PROPOSED INVESTIGATION LOCATIONS - AOC 5

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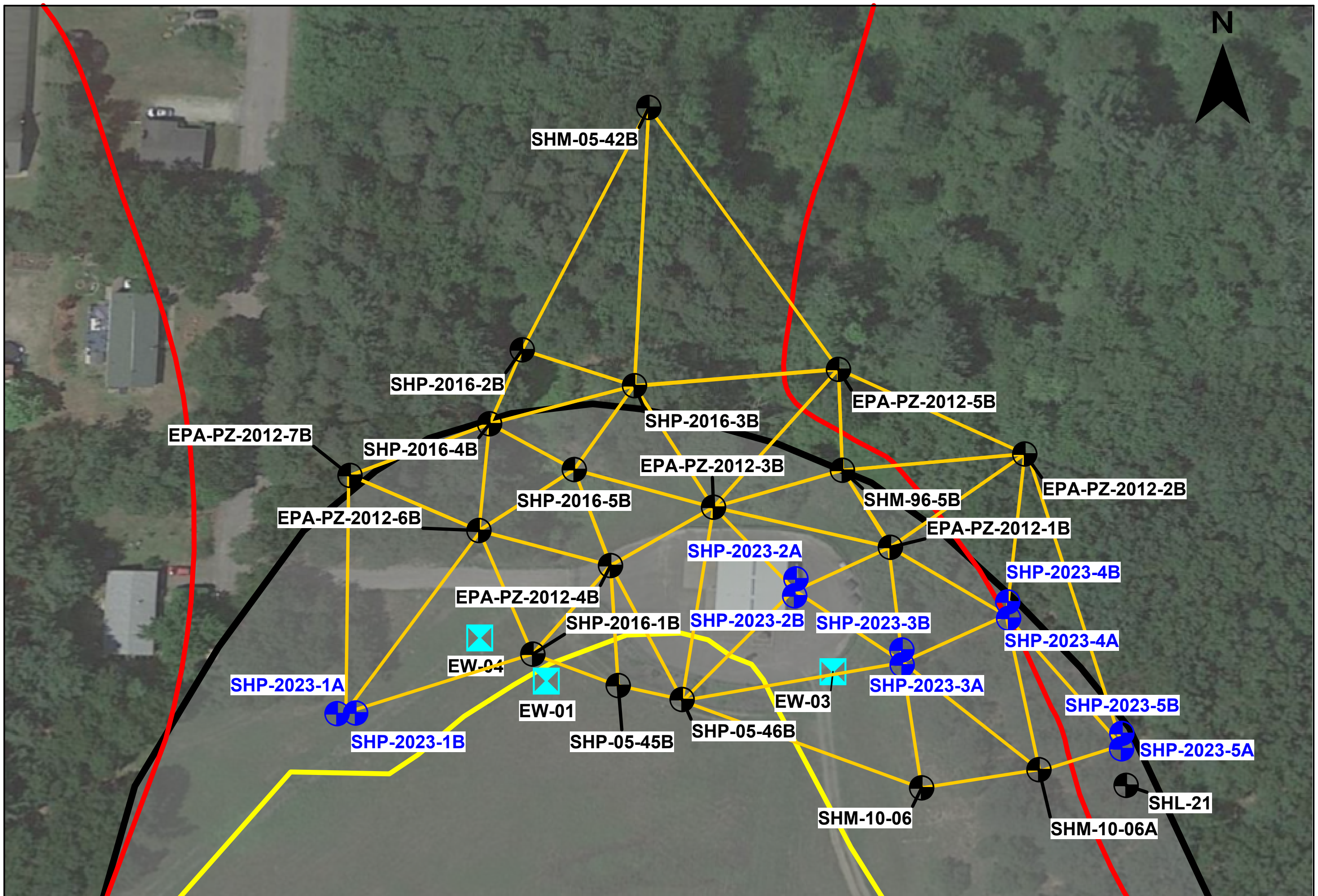
FIGURE
4-1



Note:
1. Proposed monitoring well locations are approximate and subject to change based on field conditions

Legend

- Extraction Wells
- Existing Monitoring Wells
- Proposed Monitoring Wells
- Target Groundwater Capture Zone
- Shepley's Hill Landfill Boundary
- Proposed 3PE Triangle Locations
- Approximate Extent of Dissolved Arsenic Exceeding 10 ug/L

Scale in feet

0 120 240

FORMER FORT DEVENS ARMY INSTALLATION
DEVENS, MASSACHUSETTS
PERFORMANCE MONITORING
WORK PLAN

PROPOSED 3PE TRIANGLE LOCATIONS - AOC 5

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FIGURE
4-2

Appendix A

TGI – Water-Level Monitoring Using Data Logging Instruments

TGI – Water-Level Monitoring Using Data Logging Instruments

Rev: 3

Rev Date: March 1, 2023

Version Control

Issue	Revision No.	Date Issued	Page No.	Description	Reviewed By
0	0	May 15, 2020	All	Initial	Everett H. Fortner III
1	1	March 16, 2022	All	New Template and Minor Revisions	Everett H. Fortner III
1	2	December 22, 2022	All	Data management and minor revisions	
1	3	March 1, 2023	All	Annual review completed by SME. Document revision number and date updated.	

Approval Signatures

Prepared by:

	Christian Seidel (Preparer)	3/1/2023 Date
	Colleen Barton, PG (Preparer)	3/1/2023 Date
Reviewed by:	Everett H. Fortner III, PG	3/1/2023 Date

1 Introduction

Water-level monitoring is essential information for many environmental to engineering projects. The use of data-logging instruments increases the frequency of recording and understanding with time-series analysis.

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 procedures to measure and record groundwater and surface-water levels with data logging instruments such as pressure transducers that are used for several different applications and durations. The high-resolution data acquisition applications include:

- Hydraulic testing and characterization
- Horizontal and vertical hydraulic gradients
- Groundwater/surface-water interaction
- Surface-water, ocean tides, and earth tides
- Remediation, mining, or water supply system performance/operations and maintenance.

Thoughtful planning and proper design combine to form the backbone of high-resolution water-level monitoring via data logging instruments because it is important to ensure that data are acquired to meet the project and data quality objectives. A detailed FIP is essential for execution of the work described in this TGI. Therefore, it is strongly recommended that the project hydrogeologist develop a detailed field implementation plan (FIP) that clearly outlines the objectives, design of the monitoring to be performed, specific steps/procedures to be followed, communication expectations and protocol, and health and safety requirements. This plan will be reviewed with field personnel prior to mobilization to the field.

Design considerations include adequate spatial coverage both laterally (spacing and number of wells or surface points) and vertically (shallow to deep groundwater zones), presence and nature of surface-water and surface-water body sediment point, and collection of background data. The conceptual site model (CSM) drives the design decisions through consideration of key components such as surface topography, changes in geology (i.e., heterogeneity), groundwater zone characteristics (e.g., confined/unconfined, depth, extent, sources of recharge, discharge points, vertical leakage between hydrostratigraphic units, groundwater flow direction), groundwater to surface water interaction zones, and presence of pumping wells and/or injection wells.

Manual water-level measurements, following the *TGI – Manual Water-Level Monitoring*, involves taking an instantaneous measurement of the water level in a well or surface-water body to a known survey point. Knowledge of the vertical datum of the survey is needed to ensure accuracy and consistency. Manual readings are used initially to understand the water column of the system; if historical measurements are available, the historical fluctuation of water levels will be used to determine pressure transducer installation depths. Or, if the monitoring is for a pumping or injection test, the estimated drawdown or mounding will also be considered. Manual water-level measurements are also used to adjust the pressure transducer measurements to an elevation datum either during post-processing or during programming of the pressure transducer with an offset using the instrument software. Additionally, manual water-levels are used to monitor accuracy and potential drift of the instrument readings.

Understanding the instrument type is also critical when planning and designing a water-level monitoring program. Many brands of data logging instruments are available that have different accuracies, sizes, memory capacity, acquisition rates, depth restrictions, warranties, and life spans. All new instruments come with laboratory calibration certificates or are available upon request. If renting an instrument, the rental company must provide the calibration and age to confirm it is within calibration recommendations per the manufacturer. Standard pressure transducers can also record temperature and specific conductance/conductivity depending on the model. More advanced instruments, such as multiparameter probes (sondes), can be customized to provide multiple data types as well (e.g., pH, dissolved oxygen, fluorescence) and requires multi-point calibration.

Other important considerations when planning/designing for a project include:

- Depth required to account for fluctuations and accuracy;
- Density variation;
- Nonaqueous phase liquid (NAPL) monitoring;
- Matching depth with instrument model;
- Choosing absolute (sealed) or vented (gauge);
- Direct read cable or cord requirements;
- Wellhead or surface-water structure connection;

- Acquisition rate needed;
- Available/required memory (acquisition rate and duration); and
- Communication equipment (e.g., direct read cable with laptop, wireless communication).

In general, with most instrument brands, the accuracy of a pressure transducer decreases with increasing head.

Absolute pressure transducers (i.e., non-vented or sealed) do not require a vented tube within the cable or a cable and are cheaper to install; however, a sealed transducer must be coupled with barometric pressure measurements so that compensation of the atmospheric pressure can be subtracted and/or evaluated for characterization (correction, barometric efficiency, or barometric response function). Data-logging barometric pressure transducers are available from most manufacturers.

Gauged pressure transducers (i.e., vented) must have a vented tube within the cable to vent the instrument to the atmosphere, are generally more expensive, and can have complications with the vent tube twisting/bending or collecting moisture. Although vented pressure transducers do not need barometric compensation, barometric pressure measurements are still needed, particularly if aquifer characterization is required for the evaluation (i.e., calculating barometric efficiency). Vented pressure transducers are more frequently used for field programs that require short-term, real-time measurements and evaluation (e.g., slug tests).

Collection and evaluation of weather station data, including rainfall and barometric pressure, will be incorporated into the test design. Precipitation data is necessary to understand and account for recharge response for both surface water and groundwater applications. Site-specific weather station data is preferred; however, the data can also be obtained from local weather stations maintained by third parties (e.g., National Oceanic and Atmospheric Administration or local airport). These third-party datasets, though, should be used with caution; always confirm availability of the data, data resolution, and that the distance from the site is adequate as the distribution of precipitation can be highly variable.

Different brands of pressure transducers may offer different acquisition programming functions and interfaces (e.g., differential, linear, and logarithmic logging of data) and overwriting of memory or slate (i.e., once memory is full, pressure transducers typically stop recording). Additional programming beyond the pressure head of the overlying water column includes setting reference points to measure water level elevation or depth to water. Software is available from the manufacturer (typically free of charge) that provides an interface between a laptop/tablet/mobile device and the particular brand of transducer. Note that the interfacing software is compatible with most laptops and most manufacturers have recently adapted their programs for mobile applications with some brands for use on tablets or smart phones. There are also remote considerations for radio (WiFi or Bluetooth or cellular) telemetry to have direct data feeds to servers or databases. Communication equipment, specific to the brand, are available (e.g., direct connection via cable or by Bluetooth).

Over the last several years, data acquisition rates and memory have been significantly improved by manufacturers with acquisition rates as low as 10 measurements per second and may record in memory more than 350,000 total data points. The selection of a specific brand or model to meet data acquisition needs and data quality objectives (accuracy) is based on the overall project objectives. Compatibility with the geochemistry or contaminant chemistry is also a consideration when selecting an instrument.

4 Personnel Qualifications

Field personnel performing the extraction constant rate tests will have the following qualifications:

- Familiarity and competency with:
  - quantitative hydrogeology,
  - understanding of the Project Site,
  - this TGI, and
  - the scope of work and objectives (i.e., reviewed the FIP with project hydrogeologist).
- Sufficient “hands-on” experience necessary to successfully complete the field work.
- Demonstrated familiarity with equipment required for this testing. Project personnel involved must understand the use, installation, and software required, which will be loaded on the communication device and tested before the event.
- Completed current health and safety training in accordance with the project health and safety plan (HASP) (e.g., 40-hour Hazardous Waste Operations and Emergency Response [HAZWOPER] training and/or Occupational Safety and Health Administration HAZWOPER site supervisor training and/or site-specific training, as appropriate).

5 Equipment List

The following items are required for water level measurements:

- HASP
- Personal protective equipment (PPE) as specified in the HASP
- Decontamination equipment
  - Non-phosphate laboratory soap (Alconox or equivalent), brushes, clean five-gallon buckets or clean wash tubs
  - Distilled or de-ionized (required for sites with metals) water for equipment decontamination
  - Solvent (methanol/acetone) rinse – optional
  - 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
- Photoionization detector (PID) and/or organic vapor analyzer (optional)
- 150-foot measuring tape (or sufficient length for the maximum site depth requirement)
- 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 appropriate field forms (Attachment A); a pressure transducer field form is also available using FieldNow®
- Indelible ink pen
- Digital camera or camera on smart device if photo documentation is necessary

- Electronic water-level indicator, or oil-water level indicator, that is calibrated and graduated in 0.01-foot increments
- Electrical tape
- Pressure transducers, direct-read cables (if applicable), specialized well caps (if necessary), and wire/Kevlar cord to deploy/hang transducers (In-Situ or Solinst® brand equipment is preferred)
- Pressure transducer communication equipment—laptop/tablet/mobile device (smart phone) with associated chargers and loaded with appropriate pressure transducer software
- Barometric pressure transducer, rain logger, tipping bucket, or weather station (if applicable)
- Site-specific details regarding the equipment required and its use will be described in the FIP and discussed during a kick-off meeting prior to the field work. Photographs of common examples of transducers, specialized well caps, and related equipment is included in Attachment B.

6 Cautions

The notes listed below are intended to provide reminders and information for potential issues, particular application notes, or key points:

- Test all equipment with the interface/communication device (laptop/tablet/mobile device) to be used in the field prior to mobilization to ensure functionality.
- Decontaminate each piece of equipment that will be placed into the well, including the pressure transducer, cable/cord, and electronic water-level indicator.
- Instrument equilibration takes time, especially when temperature changes are highly variable during deployment. Allow at least 5 to 10 minutes for equilibration and verify stability with real time data review.
- Direct-read cables may require time to stretch once transducers are deployed especially if they were shipped in tight coils. Allow 10 to 20 minutes following transducer deployment for the cables to equilibrate as well.
- For manual water-level measurements, please refer to TGI – Manual Water-Level Monitoring.
- When taking manual water-level measurements, at least three measurements of the depth to water will be performed to ensure accuracy of measurements and that the pressure transducer will be installed at an appropriate depth.
- When taking total depth measurements, compare the measurements to the well construction log to verify total depth and determine the amount of material accumulation in the well (if any). Evaluate the available water column and depth at which the pressure transducer will be set. This deployment depth will be established in the FIP to understand the fluctuations induced naturally or by hydraulic testing. The depth of deployment will ensure that the water level does not fall below the pressure transducer sensor (dry conditions) or does not rise to a level that exceeds the specified pressure tolerance of the transducer.
- If the presence of a non-aqueous phase liquid (NAPL) is known or suspected at the site or within specific wells, do not use an electronic water-level indicator. Use an oil-water interface meter instead.
- Special considerations are also required for installation of pressure transducers if NAPL or other density-driven situations exist (e.g., zones of increased groundwater density due to reagent injections) and if there are concerns regarding the presence of explosive conditions down-well. Density corrections can be made during post-processing or directly programmed into the pressure transducer. Pressure transducers may be installed below or within light NAPL (LNAPL) or dense NAPL (DNAPL) for specialized testing or monitoring.

- The head space in the well requires venting to the atmosphere for all types of pressure transducers for (1) proper equilibration and (2) so that pressure does not build up in the head space that could affect the instrument readings.
- When using specialized well caps, ensure a measuring point (survey) point offset is recorded by taking a manual depth to water measurement prior to installation and after installation to the known measurement point. The pressure transducer accuracy is reduced when correlating to a known survey point for the elevation calibration (at the accuracy of the manual water-level meter). However, the actual fluctuations evaluated are at the accuracy of the pressure transducer model.
- Special applications may exist that require sealing of the wellhead space. If this is the case, proper planning and an additional pressure transducer may be needed for the sealed head space.
- Understanding instrument drift (vertical movement of transducer due to a variety of reasons) is primarily required for long-term projects (monitoring over a period of months to years). Drift can be evaluated post-processing and by recording the differences between pressure transducer readings and manual measurements (offsets) through time. If drift is excessive (determined by senior technical staff/project hydrogeologist) by the accuracy or continual increasing/decreasing differences of the water-levels, then instrument recalibration by the manufacturer or replacement may be necessary.
- During installation, data download, or operation verification, a manual depth to water measurement is required (see the TGI – Manual Water-Level Monitoring). Manual water levels can be recorded on the form provided in Attachment A or by using FieldNow® electronic data collection.
- Limit handling of the pressure transducers to prevent the need for post-processing shift adjustments.
- If freezing conditions may be encountered, refer to manufacturer guidelines that may include installation with a balloon filled with a nontoxic antifreeze solution.
- If multiple water-level meters will be used, calibrate prior to performing field activities by taking a water-level measurement from one well using all water-level meters to be used on site. Record the well ID, water-level meter ID (e.g., A, B), depth to water, and time measured (see form provided in Attachment A or use FieldNow). Water level meters and transducers will be decontaminated as described in the TGI – Manual Water-Level Monitoring.
- Ensure that pressure transducer wellhead connections are secured according to manufacturer guidelines and using proper equipment. If the pressure transducers need to be redeployed, do so in such a manner to discourage movement/slippage of the line/cable or pressure transducer.
- Barometric pressure transducers require specific conditions for proper operation. Place the barometric pressure transducer in a cool/shaded location that is protected from precipitation and condensation. Desiccants can be used to help with condensation. Often, barometric pressure transducers are placed in a well casing stickup, between the inner and outer casings.
- Pressure transducers (including barometric loggers) require clock synchronization by one device. Most pressure transducer software does not account for daylight savings time.
- Pressure transducer details (serial number, model, programming, deployment, and retrieval information) must be recorded (see Attachment A or use FieldNow®). Also record the date and time of all manual water-level measurements.
- The barometric pressure transducer will always be the first to be deployed. The barometric pressure, rain, or weather station logger/equipment are always last to be downloaded (after all other transducers), following the same protocol as the pressure transducers.

- All time will be recorded in 24-hour format with the time zone indicated. Programming will be required for future start at equal intervals on an even interval (e.g., 14:05:00 start) to facilitate post-processing.
- All data (pressure transducer, barometric pressure, rain, and weather station logger/equipment) will be downloaded and saved as the software raw data file and exported as .csv (comma-separated values) or .xlsx (Excel spreadsheet) file upon download. Filenames will follow the form specified in the FIP. For example, the format may be Well ID_YYYYMMDD (e.g., GW1_20190405) with an additional numeral if multiple daily downloads occur at one well. In addition, cloud services or other networking can be used to transmit data, and remote telemetry systems can be set up to record data in a specified database.
- Communication protocols will be outlined in the FIP. In general, field staff should communicate with the rest of the project team prior to and at the completion of each field visit/monitoring event (before demobilizing from the site). Communication with the project team is critical so informed decisions can be made to address any complications that arise.
- There is a potential for pressure transducer drift or induced error by the instrument or cable if exposed to high/low temperatures or solar radiation. For both these cases, refer to the instrument documentation to ensure that the conditions are met for the expected environment or type of instrument installation.

7 Health and Safety Considerations

Field work will be performed in accordance with the HASP, which includes related Job Safety Analyses (JSA) and safety data sheets (SDS) for site hazards and risks. Arcadis field personnel must review and understand the HASP and sign the appropriate acknowledgement page of the HASP prior to the start of work.

Appropriate PPE, as specified in the HASP, will be worn during these activities. At a minimum, Level D PPE, including hard hat, safety glasses, steel-toe boots, and nitrile gloves, is generally required.

Health and safety tailgate meetings will be conducted at least once daily (in the morning) and at the start of each task to discuss the scope of work, hazards associated with the work, and each person's responsibilities.

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). 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.

8 Procedure

The following procedure will be performed at each wellhead or surface-water point during deployment, download, reset, or retrieval of the pressure transducers.

8.1 Pressure Transducer Setup and Deployment

1. Prior to mobilization, pressure transducers and related equipment will be checked and tested to verify working condition. Each pressure transducer will be accessed with the manufacturer software to ensure proper

connection capabilities with laptop/tablet/smart or Bluetooth device. Pressure transducers will be submerged in a bucket of water at a known depth to verify accuracy and proper operation.

2. Don appropriate PPE (as required by the HASP).
3. Inspect wellhead for damage. Open the well/remove well cap and allow for atmospheric equilibration. If required in the HASP, measure headspace with PID. **Measure the depth to water three times**, and record final measurement, well ID, and date and time on the field form (Attachment A) or using FieldNow®. Measure total depth of well and confirm well construction against well construction log or summary table. Use appropriate length cable or cord to install the pressure transducer. If surface water monitoring is being completed, follow the same procedures for the stilling well or stream gauge.
4. Deploy pressure transducers:
    a. The barometric pressure transducer will be programmed and installed first. The barometric transducer will be installed in an open atmosphere setting protected from weather (sun or rain), such as inside an outer well casing which does not pose a risk of flooding. Use desiccants if excessive condensation is expected.
    b. Prior to deployment, program the pressure transducer following the manufacturer’s instructions and as outlined in the field implementation plan. Information programmed into the transducer will include well identification, parameter to be measured (select Level/Depth, Top-of-Casing, or Elevation, and use appropriate reference elevation, if applicable), recording interval, units, and recording type (e.g., linear, differential, event, logarithmic). Determine start time (following the recommendations stated below) and other options.
    c. All pressure transducers will be synchronized to start after instrumentation is completed at monitoring wells or surface water points. Note that each time a pressure transducer is accessed an option for synchronization to a device can be done. Ensure a consistent device is used or the previous pressure transducer time and new synchronized device differences are recorded. If the programming device is set to a different time zone than the project location, ensure the device and pressure transducers are consistent in time zone.
    d. Pressure transducers will be programmed for a future start date that is consistent with the time interval selected (start time is at even increments using the future start option, with 00 seconds and recording interval, as applicable [e.g., 08:00:00]).
    e. Cables or cords will be pre-measured to match the deployment depth as specified in the field implementation plan Ensure connections are not cross-threaded and sealed. If using a cord, use of a small-diameter Kevlar cord with a bowline knot for connections is recommended. Vented pressure transducers have a top cable connection that will likely have a desiccant connection to inhibit moisture concerns in the vent tube.
    f. Slowly lower the pressure transducer to avoid any sudden disturbance of the water surface. Set to the appropriate depth for the project and data quality objectives as specified in the field plan. If setting the transducer at the base of a well or in a shallow stream, ensure there is at least 6 inches of vertical water column below the transducer to prevent the instrument from coming into contact with sediment. Attach the transducer cable or cord to the well cap and ensure that it is secured to prevent potential movement.
    g. Record all pressure transducer settings on the field form (Attachment A) or using FieldNow®.
    h. Check and record the manual depth to water measurement and initial transducer readings to confirm accuracy of test setup and if anomalies are observed (e.g., depth to water measurement does not match the initial reading and/or transducer readings don’t match manual measurements), consult with Project Hydrogeologist and/or Project Technical Lead.

i. If required, coil excess pressure transducer cable without damaging it and leave inside the protective well casing.
j. Close wellhead and confirm it is vented (do not fully tighten j-plugs or caps) to the atmosphere and not sealed (use specific manufacturer well cap assembly, as necessary).
k. Scan/photograph all paper notes and forms and upload to project directory as specified in the field implementation plan.

8.2 Transducer Retrieval/Download/Reset of Pressure Transducer or Barometric Pressure Logger

5. Follow Steps 1 and 2 in Section 8.1.
6. Retrieve, if applicable, and/or connect to the pressure transducer using appropriate communication equipment and device.
7. Download data following the manufacturer's instructions. Perform an initial qualitative review of the data to identify anomalies and dataset completeness and record the date and time interval.
8. Save data (raw data file and exported .csv or .xls) on communication device (laptop/tablet/mobile device) or using the cloud. When data is uploaded have support staff check for data completeness. Preview saved information to ensure data were saved accurately. Check available memory of the pressure transducer and leave recording or follow the field plan for resetting.
9. Make relevant notes on field form (Attachment A) or FieldNow®.
10. Check and assess remaining memory relative to the recording frequency and recording frequency and clear/reset as necessary to avoid data loss. To reset the transducer, follow programming guidelines presented in Section 8.1.
11. Scan/photograph all paper notes and forms and upload to project directory as specified in the field implementation plan.
12. If the retrieval of a transducer was necessary, reinstall following guidelines outlined in Section 8.1.

Before leaving the site (if possible), confirm that the data are saved on the cloud or server, and communicate the location to the project team.

Additional data download/management is necessary if other site instruments have been deployed (e.g., rain logger, weather station). Follow the same protocol as described above for retrieval/download/reset as needed.

Following final downloading and transducer pull event, decontaminate all transducers and cables as described in the *TGI – Manual Water-Level Monitoring*.

9 Waste Management

Decontamination fluids, PPE, and other disposable equipment will be properly stored on site in labeled containers and disposed of properly. Waste containers must be properly labeled and documented in the field log book. Review the TGI – Investigation-Derived Waste Handling and Storage for additional 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.

Field personnel will complete all applicable field forms for each test (see attached forms and FieldNow® available forms). Forms will include recommended data file naming protocol per the field implementation plan. Data that has been collected must be transmitted at the end of the day (notes/forms/data file). The files must be transmitted to the appropriate project directory (via direct transfer or email to data manager). Work completed that day and any relevant observations noted during the daily activities as well as copies of the data mentioned above should be summarized and provided in an email. The appropriate team member will review the data for accuracy and provide feedback. Field equipment calibration, decontamination activities, and waste management activities will be recorded in the field notebook, appropriate field form, or daily log.

Refer to the Quality Procedure Data Management, QP 4.09, for additional information on data management. .

11 Quality Assurance

The quality items listed below are intended to provide information to ensure that data are collected at highest quality possible based on the field conditions:

- Calibrate the electronic water-level meter prior to use, instead of using an engineer's ruler, to ensure accurate length demarcations on the tape or cable. Record the results.
- Measurements will be conducted three times and the final measurement will be recorded.
- Review the field notes once the field data are delivered.
- Ensure all rental instruments are within calibration warranty dates.
- Do not install the transducer closer than 6 inches from the base of the well to eliminate the possibility of fouling the transducer with sediment accumulated at the bottom of the well or surface-water point.
- To prevent pressure transducer malfunction or damage, do not submerge pressure transducers in excess of the operating range and do not insert objects in the sensor opening unless directed by the manufacturer.
- Test functionality using a bucket or barrel filled with water. Submerge the pressure transducer, measure and estimate the water head above the pressure transducer, and compare the measurement to the reading (recall that absolute [sealed] pressure transducers will have compounded barometric pressure).
- Additional testing of the pressure transducers includes checking the pressure transducer response to changing heads by raising the pressure transducer a known distance, observing the change in head, and measuring the distance manually.
- Check and assess memory prior to deployment and after each download to avoid data loss. Use time interval between download events, sampling frequency, and remaining memory capacity of the transducer to

determine if sufficient memory is available or the transducer requires resetting. Alternatively, remaining memory and sampling frequency can be used to schedule future downloading events.

12 References

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Freeman, L.A., Carpenter, M.C., Rosenberry, D.O., Rousseau, J.P., Unger, R. and McLean, J.S., 2004. Use of submersible pressure transducers in water-resources investigations: US Geological Survey Techniques of Water-Resources Investigations, book 8, chap. A3.

USEPA 2013. SESD Operating Procedure, Groundwater level and Well Depth Measurement. January 29.

Attachment A

Pressure Transducer Log

PRESSURE TRANSDUCER LOG

Personnel: ____________________ Event: ____________________ Weather: ____________________

Pressure Transducers								Manual Depths					Notes
Well or Stilling Point ID	Pressure Transducer Brand/Model	Serial Number	Program Start Date and Time	Initial Recording Interval	Approximate Deployment Depth (ft bTOC)	Transducer Location (above or below pump)	File Name	Water-Level Meter (A,B,C)	Date	Time	DTB (ft bTOC)	DTW (ft bTOC)	

NOTES:

ft bTOC - feet below top of casing.

DTW and DTB - depth-to-water and depth-to-bottom

Attachment B

Photographs of Common Examples of Transducers

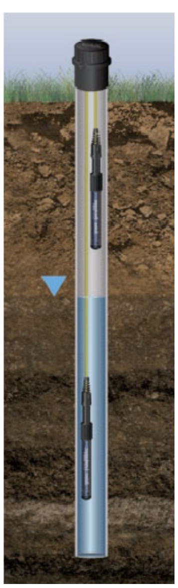
Solinst Levelogger connected to a PC using an optical reader

Solinst Levelogger and direct read cable connected to a PC using a PC interface cable

In-Situ LevelTrolls and BaroTroll

In-Situ vented cable and desiccant pack

Well cap assemblies for transducer deployment



Deployed transducers to measure barometric pressure and water level

Wireless communication equipment

Arcadis U.S., Inc.
630 Plaza Drive, Suite 200
Highlands Ranch
Colorado 80129
Phone: 720 344 3500
Fax: 720 344 3535
www.arcadis.com