

Prepared in Cooperation with the Letterkenny Army Depot

**Baseline Environmental Monitoring of Groundwater,
Surface Water, and Soil at the Ammonium Perchlorate
Rocket Motor Destruction Facility at the Letterkenny
Army Depot, Chambersburg, Pennsylvania, 2016**

Open-File Report 2019–1094

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By Daniel G. Galeone

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**U.S. Department of the Interior
U.S. Geological Survey**

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Contents

Abstract.....	1
Introduction.....	2
Purpose and Scope	2
Study Area.....	2
Study Design and Methods	3
Quality Assurance and Quality Control	13
Groundwater.....	13
Surface Water	17
Soil.....	17
Baseline Characterization Data	19
Groundwater.....	19
Surface Water	21
Soil.....	24
Summary and Conclusions.....	25
References Cited.....	29
Appendix 1. Description of wells and constituent concentrations in groundwater samples from four wells at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.....	32
Appendix 2. Monthly ranges of volatile organic compounds in matrix-spike samples analyzed internally at ALS laboratory for soil samples submitted from the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016	32
Appendix 3. Description of surface-water sites and constituents in surface-water samples collected near the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.....	32
Appendix 4. Description of soil sites and constituent concentrations in soil samples collected at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.....	32

Figures

1. Photo of the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot in Chambersburg, Pennsylvania, during construction, summer 2016.....	3
2. Map showing underlying geology and locations of well and surface-water sampling sites at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, 2016	4
3. Map showing location of surface-water, storm-runoff, and soil sampling sites and groundwater monitoring wells at the Ammonium Perchlorate Rocket Motor Destruction Facility, Letterkenny Army Depot, Pennsylvania, 2016	9
4. Photo of well MW-3 at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, June 9, 2016.....	10
5. Photo of surface-water site SW-U at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September 13, 2016	11

Figures—Continued

6.	Photo of dry conditions at surface-water site SW-1D taken at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, December 7, 2016.....	12
7.	Photo of a retention basin that captures runoff water from areas adjacent to the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, June 9, 2016.....	13
8.	Photo of a culvert at storm-runoff site ST-B at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September 27, 2016.....	13
9.	Photo of soil sampling site SO-4 at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, June 9, 2016.....	14
10.	Photo of soil sampling site SO-5 at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, June 9, 2016.....	15
11.	Graphs showing measured and mean values of water temperature, dissolved oxygen, pH, specific conductance, water level, and turbidity for water samples collected at the four monitoring wells at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.....	20
12.	Graphs showing measured and mean concentrations of dissolved iron, molybdenum, barium, arsenic, chromium, and bismuth in water samples collected from four monitoring wells at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.....	21
13.	Graphs showing measured and mean concentrations of chloride, sulfate, fluoride, phosphorus, dissolved silica, and dissolved potassium concentrations in water samples collected from four monitoring wells at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.....	22
14.	Map showing drainage area for surface-water site SW-U at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, 2016	23
15.	Graphs showing measured and mean concentrations of arsenic, lead, chromium, copper, mercury, and selenium in soil samples collected from the nine soil sites at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016	26
16.	Graphs showing measured and mean concentrations of iron, molybdenum, barium, bismuth, aluminum, and zirconium concentrations in soil samples collected from the nine soil sites at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.....	27
17.	Graphs showing measured and mean concentrations of chloride, sulfate, potassium, silica, fluoride, and phosphorus in soil samples collected from the nine soil sites at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016	28

Tables

1. Constituents, Reporting Detection Levels, and methods of analysis for water and soil samples collected at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.....	6
2. Description of wells drilled at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, May 16–17, 2016	10
3. Lithology at four wells at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania	11
4. Descriptions of nine soil sampling sites at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, 2016.....	14
5. Relative percent differences for selected constituents between routine and replicate groundwater samples from four wells at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, 2016	16
6. Relative percent differences for selected constituents between routine and replicate soil samples collected at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.....	18
7. Minimum, mean, and maximum values for selected constituents in surface-water samples collected at site SW-U near the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.....	24

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m ²)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km ²)
square foot (ft ²)	929.0	square centimeter (cm ²)
square foot (ft ²)	0.09290	square meter (m ²)
square mile (mi ²)	259.0	hectare (ha)
square mile (mi ²)	2.590	square kilometer (km ²)
Volume		
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m ³)

Conversion Factors—Continued

U.S. customary units to International System of Units

Multiply	By	To obtain
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m ³ /s)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32.$$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter ($\mu\text{g}/\text{L}$).

Abbreviations

ARMD	Ammonium Perchlorate Rocket Motor Destruction
CFR	Code of Federal Regulations
DO	Dissolved oxygen
EPA	U.S. Environmental Protection Agency
LEAD	Letterkenny Army Depot
MCL	Maximum Contaminant Level
MSC	Medium-specific concentrations
MS/MSD	Matrix-spike and matrix-spike duplicate
MTBE	Methyl tert-butyl ether

Abbreviations—Continued

NTUs	Nephelometric Turbidity Units
PADEP	Pennsylvania Department of Environmental Protection
QA/QC	Quality assurance and quality control
RDLs	Reporting Detection Levels
RPD	Relative percent difference
SC	Specific conductance
SMCL	Secondary Maximum Contaminant Level
SSL	Soil screening level
USGS	U.S. Geological Survey
VOCs	Volatile organic compounds

Baseline Environmental Monitoring of Groundwater, Surface Water, and Soil at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Chambersburg, Pennsylvania, 2016

By Daniel G. Galeone

Abstract

Letterkenny Army Depot in Chambersburg, Pennsylvania, built an Ammonium Perchlorate Rocket Motor Destruction (ARMD) facility in 2016. The ARMD Facility was designed to centralize rocket motor destruction and contain or capture all waste during the destruction process. Ideally, there would be no contaminant transport to air, soil, or water from the facility, but the Code of Federal Regulations requires that any hazardous waste disposal facility have an environmental monitoring program in place. In a study by the U.S. Geological Survey, in cooperation with the Letterkenny Army Depot, baseline characterization of constituents in groundwater, surface water, and soil was conducted from September to December 2016 to document site conditions prior to the beginning of operations at the facility in January 2017. Groundwater wells, surface water, and soils were sampled monthly during the baseline characterization period. No sediment transport from the site occurred on days when samples were collected from surface-water sites, so no sediment was collected from the retention basin at the facility during the baseline period. Data collected during the baseline period can be compared to data collected in future years to determine whether there is any contaminant transport from the ARMD Facility to the surrounding environment.

During the baseline characterization period, monthly samples were collected from 4 groundwater wells and 9 soil sites near the ARMD Facility. The only surface-water site sampled monthly during the baseline period was upgradient from the facility. There was no streamflow at surface-water sites downgradient from the facility on days when surface-water samples were collected during the baseline characterization period.

Groundwater results for the four wells sampled near the ARMD Facility during the baseline period did not show any major water-quality issues. Mean specific conductance (SC) and pH in groundwater ranged from 220 to 771 microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$) and 6.45 to 6.98, respectively. No constituents in groundwater samples

exceeded any U.S. Environmental Protection Agency (EPA) Maximum Contaminant Level (MCL). Dissolved iron (Fe) was the only groundwater constituent that exceeded a Secondary Maximum Contaminant Level (SMCL) established by the EPA. The SMCL for Fe is 300 micrograms per liter ($\mu\text{g}/\text{L}$); samples from three wells had mean dissolved Fe concentrations ranging from 1,100 to 2,600 $\mu\text{g}/\text{L}$. The only volatile organic compounds (VOCs) detected in groundwater samples were bromomethane, acetone, and chloromethane. All VOC detections in groundwater samples were less than the Reporting Detection Levels (RDLs). These three compounds also were detected in blank samples submitted for groundwater samples. Perchlorate was not detected in any groundwater sample collected during the baseline period.

Surface-water data collected during the baseline period were strictly representative of a stream reach upgradient from the ARMD Facility. Stream discharge ranged from 0.03 to 0.08 cubic feet per second during sample collection. The mean SC and pH were 310 $\mu\text{S}/\text{cm}$ and 7.6, respectively. No EPA established MCLs or SMCLs were exceeded for any constituents in samples collected from this upgradient stream. Some VOCs were detected in surface water at less than the RDLs. The VOCs detected in surface water were generally the same VOCs as those detected at less than the RDLs for groundwater. Perchlorate was detected in each sample collected from the stream; the mean concentration was 0.07 $\mu\text{g}/\text{L}$. All perchlorate results were less than the RDL of 0.2 $\mu\text{g}/\text{L}$.

Soil samples collected during the baseline period did not have any constituent concentrations that exceeded any medium-specific concentrations (MSC) or soil screening levels (SSL) established by either the Commonwealth of Pennsylvania or the EPA. The Commonwealth of Pennsylvania calculates MSCs based on either a function of acceptable concentrations in groundwater or based on health concerns if the soil is directly contacted. The EPA derives acceptable concentrations of constituents (SSLs) in soil based on standardized equations combining exposure information assumptions with EPA toxicity data. The EPA calculates SSLs for residential and industrial sites. Soil sites at the ARMD Facility were

2 Baseline Environmental Monitoring at the Letterkenny Army Depot, Chambersburg, Pennsylvania, 2016

considered “industrial” for comparative purposes. There was at least one order of magnitude difference between any inorganic constituent concentration detected in soil and the MSC and (or) SSL for that constituent. Four VOCs were detected in soil samples collected during the baseline period. None of the VOCs detected in the soils were within three orders of magnitude of any established MSCs or SSLs. The VOCs detected in soil were dichloromethane (also known as methylene chloride), methyl tert-butyl ether (MTBE), tetrachloroethene, and acetone (only detected once). Dichloromethane was the only VOC detected at greater than the RDLs; concentrations in all soil samples were greater than the RDLs. Dichloromethane concentrations ranged from 1.9 to 50.1 micrograms per kilogram ($\mu\text{g}/\text{kg}$). MTBE was detected in 50 percent of samples collected but all results were less than the RDLs of 1.7 to 2.6 $\mu\text{g}/\text{kg}$. Tetrachloroethene was detected in 20 percent of soil samples collected, with a maximum estimated value of 1.5 $\mu\text{g}/\text{kg}$. Inorganic constituents with the highest concentrations in soil were Fe and aluminum (Al); mean Fe and Al concentrations ranged from 28,700 to 52,400 and 10,300 to 19,800 milligrams per kilogram (mg/kg), respectively. Data collected during the baseline period in 2016 can be compared to future data to determine whether concentrations in water and soils surrounding the facility have shown any changes that could be caused by the facility operation.

Introduction

Letterkenny Army Depot (LEAD), located near Chambersburg, Pennsylvania, is a Federal government facility that provides supply and maintenance support to the U.S. Armed Forces. LEAD overhauls, rebuilds, modifies, tests, and repairs a wide variety of missile systems ranging from air-launched missiles to large ground-based air defense missile systems. LEAD also receives, stores, issues, renovates, and demilitarizes conventional ammunition (Redhorse Corporation, 2016). In 2016, LEAD completed a new destruction facility, the Ammonium Perchlorate Rocket Motor Destruction (ARMD) Facility, which uses confined burning with emissions control to treat solid propellant rocket motors that were previously treated at uncontained outdoor grounds at LEAD. The ARMD Facility conducts static firing of full motors and containment and capture of the exhaust for treatment in a pollution abatement system. The structures at the facility include the confined burn unit and two buildings that will be used for processing and de-segmenting the rocket motors. The ARMD Facility is a contained burn treatment facility for demilitarization of rocket motors, the byproduct of which is a non-hazardous solid waste, with no planned releases to surface water, groundwater, soils, stormwater runoff, or runoff sediment. However, 40 Code of Federal Regulations (CFR) Part 264 (Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities), Subpart F (Releases from Solid Waste Management Units) requires monitoring and response

programs (Code of Federal Regulations, 2018; Redhorse Corporation, 2016).

To meet the CFR requirements for monitoring, an environmental sampling plan was developed by Redhorse Corporation (2016) in coordination with LEAD and the Pennsylvania Department of Environmental Protection (PADEP). The U.S. Geological Survey (USGS), in cooperation with Letterkenny Army Depot, conducted a study to measure the characteristics and constituents in groundwater, surface water, and soil during a baseline period from September to December 2016. The environmental monitoring conducted prior to the operation of the ARMD Facility was needed to establish baseline concentrations of indicator compounds that could result from unplanned releases to soil, surface water, groundwater, stormwater runoff, or runoff sediment, from the ARMD Facility. The beginning of facility operation in January 2017 terminated the baseline characterization period; therefore, no baseline samples were collected in spring and summer. Data collected during the baseline period in 2016 can be compared to subsequent sampling data to determine whether operations at the ARMD Facility are adversely affecting the surrounding environment.

Purpose and Scope

This report presents the results for baseline sampling and analysis to characterize groundwater, surface water, and soils at the ARMD Facility at the Letterkenny Army Depot from September 2016 through December 2016, prior to the beginning of facility operation in January 2017. The findings for constituent concentrations in groundwater, surface water, and soil during the baseline period are summarized in this report. Quality-assurance and quality-control (QA/QC) sample analysis results and soil sample analysis results presented in this report are available online at <https://doi.org/10.5066/P973YRPL>.

Study Area

The ARMD Facility (fig. 1) is in a remote area of LEAD that is used for a variety of purposes including missile maintenance, ammunition storage, and the Open Burning and Open Detonation grounds. Some fallow/forage land surrounds the immediate vicinity of the facility. Land to the west (approximately 4,000 feet from ARMD) is primarily forested and slopes upward to Broad Mountain. Elevations at LEAD range from approximately 600 to 800 feet above the North American Vertical Datum of 1988 (NAVD 88) in the valley below Broad Mountain.

The LEAD facility is in the Cumberland Valley part of the Great Valley in the easternmost section of the Ridge and Valley Province of the Appalachian Mountains, approximately 3.5 miles southwest of Upper Strasburg, Pennsylvania. The Ordovician-aged bedrock underlying the ARMD Facility and surrounding landscape varies moving from west to east. The



Figure 1. Photo of the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot in Chambersburg, Pennsylvania, during construction, summer 2016.

facility itself is underlain by shales of the Martinsburg Formation. Adjacent land to the west is underlain by argillaceous limestone of the Chambersburg Formation, and a bit further to the west land is underlain by limestone of the St. Paul Group (fig. 2). Precipitation in the area averages about 42 inches per year, and the mean annual temperature is about 11 degrees Celsius ($^{\circ}\text{C}$; Pennsylvania State Climatologist, 2018).

Native soils in the vicinity of the ARMD Facility are channery silt loams or silt loams, typically well drained. The building and immediate vicinity consist of soils identified as Weikert channery silt loam. This silt loam typically forms on the side slopes of ridges and is well drained. Depth to bedrock is about 20 inches. The soil is derived from weathered shale and siltstone (U.S. Department of Agriculture, 2018a). Other soils surrounding the facility are found in settings from mountain slopes to depressions and flood plains. The soils in flood plain/depression land forms (Melvin silt loam and

Brinkerton silt loam) are poorly drained and are either alluvium or colluvium derived from sedimentary rocks. The soils typically formed on hillslopes (Berks channery silt loam and Swanpond-Edom complex) are well drained and derived from residuum weathered from limestone, shale, or siltstone (U.S. Department of Agriculture, 2018a).

Study Design and Methods

The ARMD is a fully contained unit for demilitarization of rocket motors, the byproduct of which is a non-hazardous solid waste, with no planned releases to surface water, groundwater, soils, or stormwater runoff catchments. The monitoring program approach was designed to establish baseline concentrations of indicator compounds that could result from unplanned releases to soil, surface water, groundwater, or

4 Baseline Environmental Monitoring at the Letterkenny Army Depot, Chambersburg, Pennsylvania, 2016

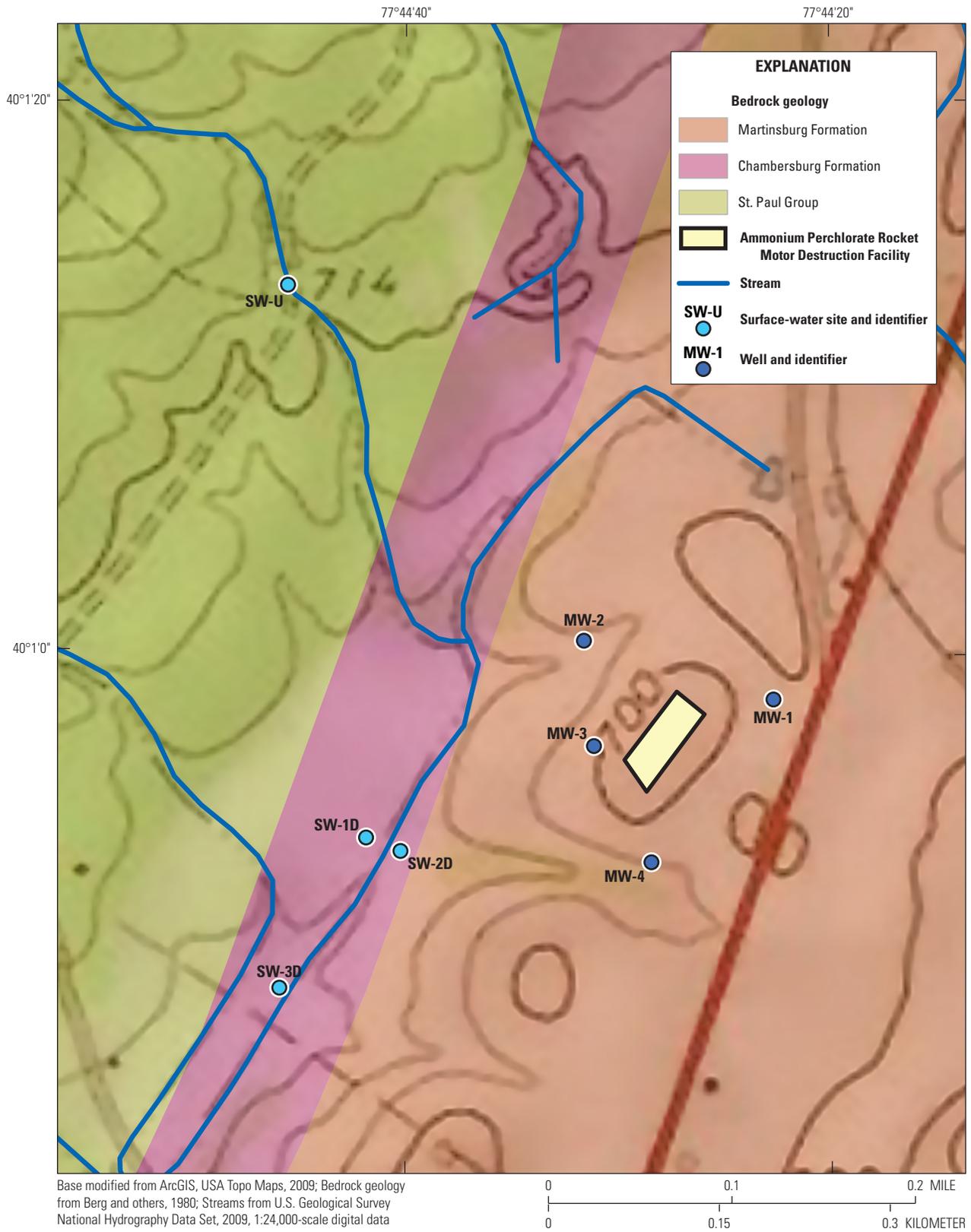


Figure 2. Underlying geology and locations of well and surface-water sampling sites at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, 2016.

stormwater runoff from the ARMD Facility (Redhorse Corporation, 2016). Once baseline conditions are established during 2016 prior to the beginning of the facility operation, the monitoring program would transition to annual sampling in 2017 when the facility became operational. An increase in indicator compound concentration or other change from baseline concentrations or a change from downgradient versus upgradient concentrations in soil, surface water, groundwater, or stormwater runoff could indicate a release has occurred at the ARMD Facility. The baseline characterization period was from September to December 2016. Monthly samples were collected from wells, streams, and soils during this period.

Field characteristics for water samples were measured using a multiparameter sonde. The sonde was used to measure water temperature, pH, specific conductance (SC), dissolved oxygen (DO), and Eh. Eh is a measure of the oxidation reduction potential in millivolts. A portable turbidimeter was used to measure turbidity. The sonde was calibrated each morning prior to sample collection. Calibration of the turbidimeter is checked semiannually.

Constituents for environmental monitoring were selected at the request of PADEP. The initial constituent list was determined on the basis of the system design information, controls, rocket motor combustion byproducts, proximal facility operations, characteristics of liquid and solid waste at the site, materials used, material storage, and material handling methods. Samples were collected from water and soils according to standard USGS field methods (U.S. Geological Survey, variously dated), unless otherwise noted, and were analyzed for total (unfiltered) nutrients, dissolved trace metals, major ions, total volatile organic compounds (VOCs), total perchlorate, and dissolved zirconium (Zr; see table 1 for a complete listing).

The sample sites (fig. 3) for this project were determined by PADEP in collaboration with Letterkenny staff and private consultants working for LEAD. Surface-water sites and groundwater-monitoring wells were identified upgradient and downgradient from the ARMD Facility. Two storm-runoff sites and nine soil sampling sites in the vicinity of the ARMD Facility and associated parking areas were identified.

Four groundwater monitoring wells are in the study area, one upgradient (MW-1) and three downgradient (MW-2, MW-3, and MW-4) from the facility (figs. 3). The four monitoring wells were completed (air rotary drill technique) in the Ordovician-aged Martinsburg Formation and range in depth from 22 to 81 feet (table 2). A photo of MW-3 is provided in figure 4. The Martinsburg Formation, which is present at the site of well MW-3, is predominantly composed of black carbonaceous shale with a thin basal unit of platy limestone (Becher and Taylor, 1982). The lithology described by Steven Read (Read and Associates, written commun., 2016) is representative of wells completed in the Martinsburg Formation (table 3). These four wells are relatively shallow with 6-inch casings at depths of 3–18 feet below land surface. The 6-inch steel casing protects the inner 2-inch polyvinyl chloride casing that extends to the depth of the slotted screened interval.

Wells were grouted from land surface to above the slotted screened interval. Bentonite plugs of 1–4 feet in length above the screened interval protect the screen from surface water traveling down the annulus; sand packing surrounds the slotted screen below the bentonite plug to the bottom of the well (Steven Read, Read and Associates, written commun., 2016).

Dedicated bladder pumps (and Teflon-lined tubing) were installed in each well in August 2016 to promote low-flow sampling at flow rates less than 1 gallon per minute (gal/min). Pumps were positioned at varying heights above the bottom of the well hole. Bladder pumps were positioned at approximately the center of the slotted screened interval for each well (table 2). Static water levels were recorded prior to purging. Flow rates during sampling ranged from 0.1 to 0.8 gal/min (appendix 1). Samples for analysis were collected after field characteristics (pH, DO, Eh, SC, water temperature, and turbidity) were stable. Field characteristics were recorded every 5 minutes. Typically, wells were purged for 30–40 minutes before samples were collected for analyses. The number of well volumes purged prior to sampling ranged from 0.4 to 10.4, with an average purge of about 4 well volumes. Only samples collected for metals and Zr were filtered through a 0.45-micron capsule filter (table 1). All other analyses were conducted on unfiltered water. All groundwater samples were placed on ice immediately after sample collection and delivered to the ALS laboratory in Middletown, Pa., the day of sample collection.

The four surface-water sampling sites are near the ARMD Facility, one upgradient (SW-U) and three downgradient (SW-1D, SW-2D, and SW-3D) from the facility (fig. 3). Only one of these stream locations (SW-U) is perennial (fig. 5). The stream sampling sites downgradient from the facility were not flowing when the samples were collected from September to December 2016 (fig. 6). In addition to the field characteristics measured in groundwater samples, stream discharge was measured at the time of sample collection. Stream discharge was measured either volumetrically or with an acoustic doppler velocity flow meter. A volumetric measurement was made if the stream depth was less than 0.3 feet at the culvert outflow at SW-U. A volumetric measurement involved placing a container immediately below the culvert pipe at SW-U for a specified time (less than 10 seconds), then measuring the volume.

The width of SW-U at the time of sample collection was approximately 3 feet, so samples bottles were simply dipped into the stream and filled. Only samples collected for metals and Zr were filtered through a 0.45-micron capsule filter (table 1). All other analyses were conducted on unfiltered water. All surface-water samples were placed on ice immediately after sample collection and delivered to the ALS laboratory the day of sample collection.

6 Baseline Environmental Monitoring at the Letterkenny Army Depot, Chambersburg, Pennsylvania, 2016

Table 1. Constituents, Reporting Detection Levels, and methods of analysis for water and soil samples collected at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.

[RDL, Reporting Detection Level; µg/L, micrograms per liter; µg/kg, micrograms per kilogram; mg/L, milligrams per liter; mg/kg, milligrams per kilogram; diss, dissolved; N, nitrogen; %, percent]

Constituent	Water			Soil		
	Unit	RDL Range	Method	Unit	RDL Range	Method
Volatile Organic Compounds						
Acetone	µg/L	10	SW846 8260B ¹	µg/kg	8.4–12.8	SW846 8260B
Benzene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Bromochloromethane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Bromodichloromethane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Bromoform	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Bromomethane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
2-Butanone	µg/L	10	SW846 8260B	µg/kg	8.4–12.8	SW846 8260B
Carbon Disulfide	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Carbon Tetrachloride	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Chlorobenzene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Chlorodibromomethane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Chloroethane	µg/L	1	SW846 8260B	µg/kg	4.2–6.4	SW846 8260B
Chloromethane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Cyclohexane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
1,2-Dibromo-3- chloropropane	µg/L	7	SW846 8260B	µg/kg	4.2–6.4	SW846 8260B
1,2-Dibromoethane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
1,2-Dichlorobenzene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
1,3-Dichlorobenzene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
1,4-Dichlorobenzene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Dichlorodifluoromethane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
1,1-Dichloroethane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
1,2-Dichloroethane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
1,1-Dichloroethene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
cis-1,2-Dichloroethene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
trans-1,2-Dichloroethene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
1,2-Dichloropropane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
cis-1,3-Dichloropropene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
trans-1,3-Dichloropropene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
1,4-Dioxane	µg/L	320	SW846 8260B	µg/kg	63.2–96.3	SW846 8260B
Ethylbenzene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Freon 113	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B

Table 1. Constituents, Reporting Detection Levels, and methods of analysis for water and soil samples collected at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.—Continued

[RDL, Reporting Detection Level; µg/L, micrograms per liter; µg/kg, micrograms per kilogram; mg/L, milligrams per liter; mg/kg, milligrams per kilogram; diss, dissolved; N, nitrogen; %, percent]

Constituent	Water			Soil		
	Unit	RDL Range	Method	Unit	RDL Range	Method
Volatile Organic Compounds—Continued						
2-Hexanone	µg/L	5	SW846 8260B	µg/kg	8.4–12.8	SW846 8260B
Isopropylbenzene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Methyl acetate	µg/L	2	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Methyl cyclohexane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Methyl t-Butyl Ether	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
4-Methyl-2- Pentanone (MIBK)	µg/L	5	SW846 8260B	µg/kg	8.4–12.8	SW846 8260B
Methylene Chloride	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Styrene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
1,1,2,2-Tetrachloroethane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Tetrachloroethene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Trichloromethane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Toluene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Total Xylenes	µg/L	3	SW846 8260B	µg/kg	5.1–7.7	SW846 8260B
1,2,3-Trichlorobenzene	µg/L	2	SW846 8260B	µg/kg	4.2–6.4	SW846 8260B
1,2,4-Trichlorobenzene	µg/L	2	SW846 8260B	µg/kg	4.2–6.4	SW846 8260B
1,1,1-Trichloroethane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
1,1,2-Trichloroethane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Trichloroethene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Trichlorofluoromethane	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
Vinyl Chloride	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
o-Xylene	µg/L	1	SW846 8260B	µg/kg	1.7–2.6	SW846 8260B
mp-Xylene	µg/L	2	SW846 8260B	µg/kg	3.4–5.1	SW846 8260B
Semivolatile Organic Compound						
Perchlorate	µg/L	0.2	² 6850	µg/kg	0.32–3.1	6850
Major Ions						
Chloride	mg/L	1.0–2.0	³ EPA 300.0	mg/kg	109–131	EPA 300.0
Fluoride	mg/L	0.20	EPA 300.0	mg/kg	2.2–2.6	EPA 300.0
Potassium (diss-water; total-soil)	mg/L	0.10	SW846 6020A	mg/kg	48.9–65.6	SW846 6020A
Sulfate	mg/L	1.0–2.0	EPA 300.0	mg/kg	109–131	EPA 300.0
Silica	mg/L	0.24	SW846 6010C ⁴	mg/kg	9.8–26.2	SW846 6010C
Sulfur				mg/kg	9.8–26.2	SW846 6010C

8 Baseline Environmental Monitoring at the Letterkenny Army Depot, Chambersburg, Pennsylvania, 2016

Table 1. Constituents, Reporting Detection Levels, and methods of analysis for water and soil samples collected at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.—Continued

[RDL, Reporting Detection Level; µg/L, micrograms per liter; µg/kg, micrograms per kilogram; mg/L, milligrams per liter; mg/kg, milligrams per kilogram; diss, dissolved; N, nitrogen; %, percent]

Constituent	Water			Soil		
	Unit	RDL Range	Method	Unit	RDL Range	Method
Nutrients						
Nitrate/Nitrite-N	mg/L	0.1–0.2	EPA 300.0	mg/kg	10.9–13.1	EPA 300.0
Phosphorus	mg/L	0.10	⁵ EPA 365.1	mg/kg	2.7–143	EPA 365.1
Trace ions						
Aluminum (diss-water; total-soil)	mg/L	0.080	SW846 6020A ⁶	mg/kg	39.1–262	SW846 6020A
Arsenic (diss-water; total-soil)	mg/L	0.0030	SW846 6020A	mg/kg	1.5–2.0	SW846 6020A
Barium (diss-water; total-soil)	mg/L	0.0050	SW846 6020A	mg/kg	2.4–3.3	SW846 6020A
Bismuth (diss-water; total-soil)	mg/L	0.050	SW846 6010C	mg/kg	4.9–13.1	SW846 6010C
Cadmium (diss-water; total-soil)	mg/L	0.0010	SW846 6020A	mg/kg	0.49–0.66	SW846 6020A
Chromium (diss-water; total-soil)	mg/L	0.0020	SW846 6020A	mg/kg	0.98–1.3	SW846 6020A
Copper (diss-water; total-soil)	mg/L	0.0050	SW846 6020A	mg/kg	2.4–3.3	SW846 6020A
Iron (diss-water; total-soil)	mg/L	0.050	SW846 6020A	mg/kg	24.5–164	SW846 6020A
Lead (diss-water; total-soil)	mg/L	0.0020	SW846 6020A	mg/kg	0.98–1.3	SW846 6020A
Mercury (diss-water; total-soil)	mg/L	0.00050	SW846 7470A ⁷	mg/kg	0.049–0.064	SW846 7471B ⁸
Molybdenum (diss-water; total-soil)	mg/L	0.0020	SW846 6020A	mg/kg	0.98–1.3	SW846 6020A
Selenium (diss-water; total-soil)	mg/L	0.0050	SW846 6020A	mg/kg	2.4–3.3	SW846 6020A
Silver (diss-water; total-soil)	mg/L	0.0020	SW846 6020A	mg/kg	0.98–1.3	SW846 6020A
Tin (diss-water; total-soil)	mg/L	0.0050	SW846 6020A	mg/kg	2.4–3.3	SW846 6020A
Zirconium (diss-water; total-soil)	mg/L	0.0121	SW846 6010C	mg/kg	3.33–25.2	SW846 6010B ⁹
Miscellaneous						
Acidity, total	mg/L	5	¹⁰ S2310B-97			
Soil moisture				%	0.1	¹¹ S2540G-11
Total solids				%	0.1	S2540G-11

¹Environmental Protection Agency (1996a).

²Environmental Protection Agency (2007b).

³Pfaff (1993).

⁴Environmental Protection Agency (2007a).

⁵O'Dell (1993).

⁶Environmental Protection Agency (1998a).

⁷Environmental Protection Agency (1994).

⁸Environmental Protection Agency (1998b).

⁹Environmental Protection Agency (1996a).

¹⁰Greenburg and others (1992a).

¹¹Greenburg and others (1992b).

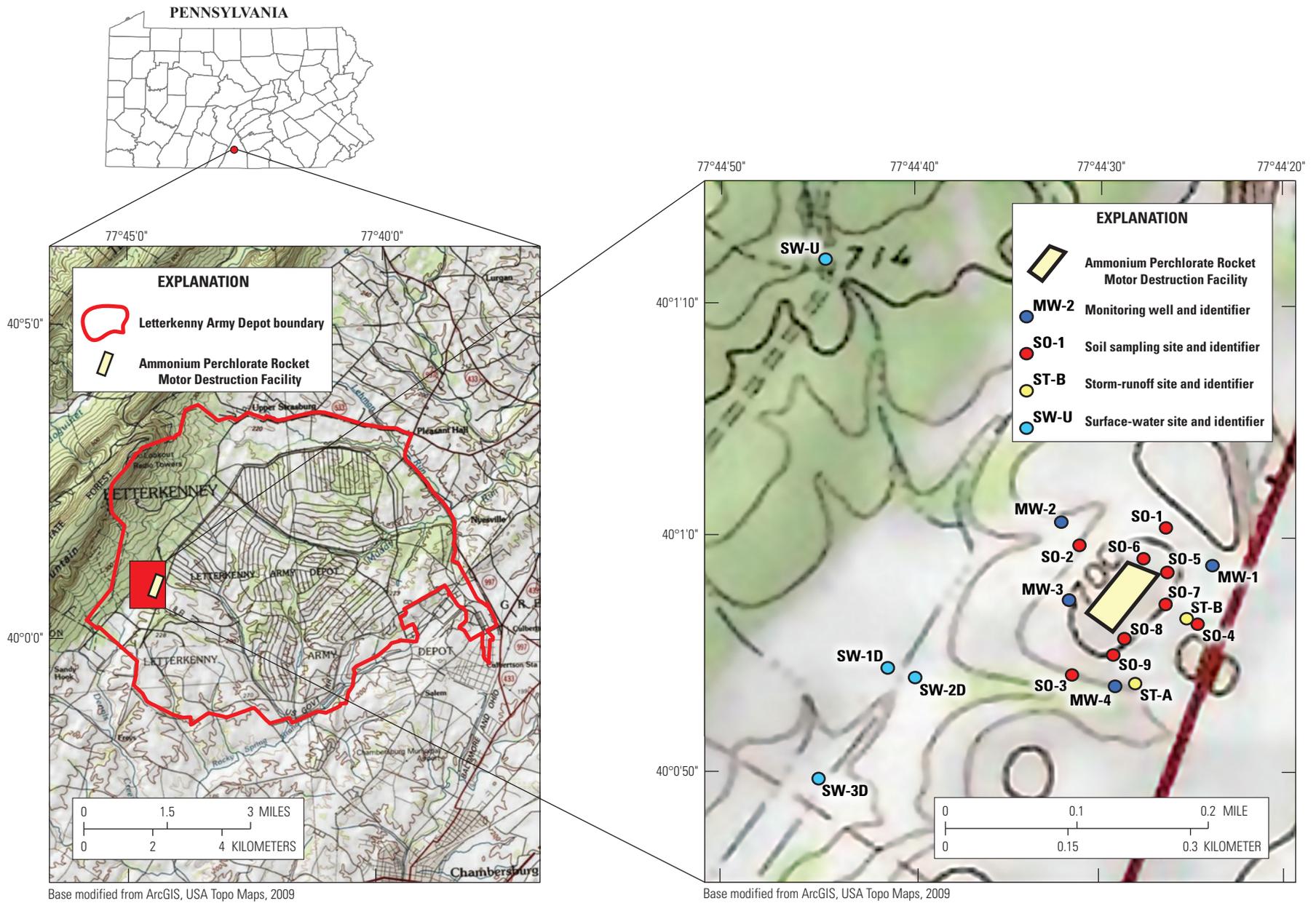


Figure 3. Location of surface-water, storm-runoff, and soil sampling sites and groundwater monitoring wells at the Ammonium Perchlorate Rocket Motor Destruction Facility, Letterkenny Army Depot, Pennsylvania, 2016.

10 Baseline Environmental Monitoring at the Letterkenny Army Depot, Chambersburg, Pennsylvania, 2016

Table 2. Description of wells drilled at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, May 16–17, 2016.

[ft, foot; NAVD 88, North American Vertical Datum of 1988; gal/min, gallons per minute]

Station identifier	Local well number	Local name	Latitude, in decimal degrees	Longitude, in decimal degrees	Ground elevation, in ft above NAVD 88	Well depth, in ft	Measuring point, height above land surface, in ft	Six-inch casing depth below land surface, in ft	Slotted screen depth below land surface, in ft	Pump depth below land surface, in ft	Well yield, in gal/min ¹
400058077442501	FR 838	MW-1	40.01624	77.74022	697.81	41.3	1.15	18	16–41	28	5.3
400101077443201	FR 839	MW-2	40.01682	77.74236	678.88	22	1.57	3	5–22	13	2.9
400057077443201	FR 840	MW-3	40.01589	77.74229	702.60	81	1.24	14.5	36–81	58	1.6
400053077443001	FR 841	MW-4	40.01485	77.74168	682.85	41	1.25	12.3	31–41	36	5.2

¹Well yields measured by Steven Read (Read and Associates, written commun., 2016).



Figure 4. Photo of well MW-3 at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, June 9, 2016.

Table 3. Lithology at four wells at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania. Modified from Steven Read, Read and Associates, written commun. (2016).

[Depth is feet below land surface]

Well							
MW-1		MW-2		MW-3		MW-4	
Depth, in feet	Lithology	Depth, in feet	Lithology	Depth, in feet	Lithology	Depth, in feet	Lithology
0–3	Topsoil → subsoil	0–6	Topsoil → subsoil	0–0.5	Topsoil → subsoil	0–3	Topsoil → subsoil
3–15	Grayish black silty shale	6–10	Mudstone	0.5–27	Dark-gray silty limestone	3–21	Dark-gray silty shale
15–22	Dark-gray silty shale grades to siltstone	10–20	Carbonaceous, black shale with platy quartz fragments	27–32	Dary-gray siltstone	21–41	Dark-grey siltstone
22–35	Dark-gray siltstone grades to shale	20–22	Dary-gray limestone	32–81	Dark-gray silty limestone	41	Bottom of well
35–41.3	Grayish-black shale	22	Bottom of well	81	Bottom of well		
41.3	Bottom of well						



Figure 5. Photo of surface-water site SW-U at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September 13, 2016.

Two storm-runoff sites were identified at the ARMD Facility. The two storm-runoff sites (ST-A and ST-B) drain parking areas and buildings (less than 1 acre in total surface area for either sampling site) associated with the facility (fig. 3). The storm-runoff sites were to be sampled the same day as the surface-water sites. Runoff from the parking areas and buildings drains to culverts that discharge to a retention basin (fig. 7). No runoff was evident in the culverts or the retention basin on any day that surface-water samples were collected. No sediment was evident in either the culverts (fig. 8) or the retention basin on the days when the surface-water sites were sampled from September to December 2016. Surface-water samples were collected Sept. 15, Oct. 12, Nov. 7, and Dec. 5, 2016. Based on daily radar estimates and records at two National Oceanic and Atmospheric Administration weather stations near LEAD, there was no measurable precipitation from Sept. 13 through Sept. 15, 2016, and from Oct. 10 through Oct. 12, 2016. There was no precipitation during Nov. 7–8, 2016, but light precipitation did occur at the time of sample collection on Nov. 9, 2016. Approximately

an inch of precipitation fell during Dec. 5–6, 2016, prior to sampling on Dec. 7, 2016 (National Oceanic and Atmospheric Administration, 2018a and 2018b). There was no evidence of any sediment transport from the areas around the ARMD Facility to the culverts, and subsequently the retention basin, during the entire baseline characterization period (Sept. to Dec. 2016). The culverts and retention basin showed no signs of any sediment deposition; however, it is likely that small amounts of suspended sediment were transported via surface runoff through the culverts.

Nine soil sampling sites (SO-1 to SO-9) were identified in and around the ARMD Facility (table 4 and fig. 3). Soil sampling sites SO-1, SO-2, SO-3, SO-4 (fig. 9), SO-7, and SO-8 were either along a fence line or in an open-field setting. Soil sampling sites SO-5 (fig. 10), SO-6, and SO-9 were initially sited in parking areas at the time environmental monitoring began but were not suitable for soil sampling. SO-6 and SO-9 were moved to the nearest area where a representative soil sample could be collected. Soil site SO-5 was not near any other suitable location, so soil samples were collected below



Figure 6. Photo of dry conditions at surface-water site SW-1D taken at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, December 7, 2016.



Figure 7. Photo of a retention basin that captures runoff water from areas adjacent to the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, June 9, 2016.

the shale layer that had been deposited to support vehicle loads.

Soil samples were collected to a depth of approximately 6 inches. A stainless-steel trowel was used to remove the top organic layer with roots and vegetation. After removing the top organic layer, subsamples were collected with the trowel for all constituents except VOCs. The sample area ranged from 2 to 12 square feet per soil site, and the number of subsamples ranged from 5 to 12 per soil site. Subsamples were placed on a plastic sheet, mixed, and then placed in the sample jars using the trowel. Any rocks that were gravel size or larger were removed from the subsamples before the soil was placed in four glass jars (two 8-ounce and two 16-ounce containers) using the sampling trowel. Soil samples for VOC analyses were collected with an En Core sampler instead of a trowel. En Core samplers (25-gram capacity) are constructed from an inert composite polymer and are easily sealed after extraction from soil profile, immediately becoming an air-tight transportation vessel. Three En Core samples were collected at each sample location for each sampling event. All soil samples were placed on ice immediately after sample collection and delivered to the ALS laboratory in Middletown, Pa., the day of sample collection.

Quality Assurance and Quality Control

QA/QC samples were collected for each sampling event and sample media. USGS personnel submitted replicate and blank samples for groundwater and surface-water samples for analysis; only replicate samples were submitted for soil samples. ALS laboratory also analyzed matrix-spike and matrix-spike duplicate (MS/MSD) samples for all sampling events and sample media. Three types of blank samples were analyzed at ALS laboratory: equipment, trip, and internal



Figure 8. Photo of a culvert at storm-runoff site ST-B at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September 27, 2016.

laboratory. An equipment blank is used to determine potential contamination from equipment and supplies (Francy and others, 1998). Trip blanks were prepared by ALS laboratory and shipped to USGS with the sample bottles provided by ALS laboratory. The trip blank was placed in a cooler the morning of sampling and was returned to ALS laboratory when samples were delivered later that day. The purpose of a trip blank is to identify VOC contaminants introduced into samples during transit to and from the laboratory. Internal laboratory blanks are used to quantify any laboratory bias from contamination. Replicate samples are used to determine the precision and variability of sample collection and processing (Francy and others, 1998). Matrix-spike and matrix-spike duplicate (MS/MSD) samples are environmental samples spiked in the laboratory to verify percent recoveries. MS/MSD samples are primarily used to check sample matrix interferences. MS/MSD samples that fall outside the acceptable range for a constituent could indicate a negative (recovering less than the acceptable range) or positive (recovery greater than the acceptable range) bias. All QA/QC data for this study are available online at <https://doi.org/10.5066/P973YRPL>.

Groundwater

Three trip blanks, one equipment blank, and multiple internal blanks were analyzed for groundwater samples. The trip blank submitted Oct. 11, 2016, was the only trip blank associated with groundwater samples that had any detectable VOC concentrations. Fifty-three VOCs were analyzed in each groundwater sample. Acetone and bromomethane were detected at concentrations of 5.2 and 0.40 micrograms per liter ($\mu\text{g/L}$), respectively, in the Oct. 11, 2016, trip blank. The Reporting Detection Levels (RDLs) for acetone and bromomethane were 10 and 1.0 $\mu\text{g/L}$, respectively, so both

14 Baseline Environmental Monitoring at the Letterkenny Army Depot, Chambersburg, Pennsylvania, 2016

Table 4. Descriptions of nine soil sampling sites at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, 2016.

Station identifier	Local name	Latitude, in decimal degrees	Longitude, in decimal degrees	Description
400100077442701	SO-1	40.01671	77.74086	Fence line, typical A horizon
400060077443201	SO-2	40.01654	77.74211	Fence line, typical A horizon
400054077443201	SO-3	40.015	77.74229	Fence line, typical A horizon
400056077442601	SO-4	40.01555	77.74046	Open field, typical A horizon
400058077442701	SO-5	40.01618	77.74087	Paved area, compact shale layer at surface
400059077442901	SO-6	40.01628	77.74139	Paved area, compact shale layer at surface
400057077442701	SO-7	40.0158	77.74091	Open field, typical A horizon
400055077442901	SO-8	40.01541	77.74152	Open field, typical A horizon
400055077443101	SO-9	40.01531	77.74207	Paved area, compact shale layer at surface



Figure 9. Photo of soil sampling site SO-4 at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, June 9, 2016.



Figure 10. Photo of soil sampling site S0-5 at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, June 9, 2016.

were flagged as estimated values. Four other constituents were detected at less than their respective RDLs in the equipment blank submitted Dec. 5, 2016: chloride (Cl; 0.18 milligrams per liter [mg/L]), bromomethane (0.50 $\mu\text{g/L}$), acetone (5.8 $\mu\text{g/L}$), and chloromethane (0.55 $\mu\text{g/L}$). Internal blanks for groundwater were analyzed by ALS laboratory; concentrations of seven constituents were detected at less than the RDLs. Total Cl was detected consistently in internal blanks analyzed from October to December 2016. Nineteen internal blanks were analyzed for total Cl by ALS laboratory from October to December 2016; Cl was detected in each blank (values ranged from 0.20 to 0.33 mg/L). Total sulfate was detected in only four internal blanks analyzed during October 2016 at 0.07–0.08 mg/L. Trichloromethane (also known as chloroform; 0.24, 0.29, and 0.57 $\mu\text{g/L}$) and total phosphorus (P; 0.014 and 0.019 mg/L) were detected in internal blanks analyzed in September and November 2016. Chloromethane was detected (0.50 and 0.43 $\mu\text{g/L}$) in internal blanks analyzed in November and December 2016. Bromomethane was detected (0.41 and 0.65 $\mu\text{g/L}$) in internal blanks analyzed in

October and December 2016. Dichloromethane was detected only at 0.54 $\mu\text{g/L}$ in the internal blank analyzed in October 2016.

Five replicate samples from groundwater wells were submitted for analyses from September to December 2016. Three of the replicate samples had one or more constituents with a relative percent difference (RPD) greater than 10 (table 5). Most of the RPDs were less than 5 percent. VOC results for replicate samples are not presented in table 5 because most VOC results were nondetects. There were five results for VOCs (3 for acetone and 1 each for chloromethane and bromomethane) in the paired routine-replicate samples in which one pair had a nondetect and the other had a detection of less than the RDL. These results indicate that replication of groundwater samples can be conducted with fairly good precision.

MS/MSD samples were analyzed by ALS laboratory for each groundwater sampling event. The only inorganic constituent to fall outside the acceptable range for groundwater MS/MSD samples was silicon dioxide (SiO_2). The

Table 5. Relative percent differences for selected constituents between routine and replicate groundwater samples from four wells at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, 2016.

[Green shading denotes relative percent difference above 10 percent; NA, not applicable]

Selected constituent	Well and sample collection date				
	MW-1 September 13, 2016	MW-2 October 11, 2016	MW-3 November 7, 2016	MW-1 November 7, 2016	MW-4 December 5, 2016
Dissolved potassium	0.00	1.51	0.00	0.00	0.00
Acidity	2.70	4.35	0.00	0.00	18.18
Chloride	0.00	0.00	0.00	2.60	0.00
Fluoride	0.00	0.00	4.88	0.00	0.00
Dissolved silica	0.91	0.30	0.00	0.64	1.30
Sulfate	1.29	0.00	0.77	0.00	0.00
Nitrate plus nitrite	0.00	0.00	0.00	0.00	0.00
Phosphorus	7.41	5.26	NA ¹	4.88	4.88
Dissolved aluminum	0.00	0.00	0.00	0.00	0.00
Dissolved barium	0.99	0.99	1.65	0.93	0.00
Dissolved bismuth	0.00	0.00	1.79	0.00	0.00
Dissolved cadmium	0.00	0.00	0.00	0.00	0.00
Dissolved chromium	0.00	17.50	5.71	9.76	9.76
Dissolved copper	0.00	0.00	0.00	0.00	0.00
Dissolved iron	0.00	0.00	0.00	0.00	0.00
Dissolved lead	0.00	0.00	0.00	0.00	0.00
Dissolved mercury	0.00	0.00	0.00	0.00	0.00
Dissolved molybdenum	13.64	50.00	0.00	0.00	0.00
Dissolved silver	0.00	0.00	0.00	0.00	0.00
Dissolved tin	0.00	0.00	0.00	0.00	0.00
Dissolved zirconium	0.00	0.00	0.00	0.00	0.00
Dissolved arsenic	3.88	2.53	0.00	0.00	0.00
Perchlorate	0.00	0.00	0.00	0.00	0.00
Dissolved selenium	0.00	0.00	0.00	0.00	0.00

¹Regular sample had estimated value of 0.071 milligrams per liter (mg/L) (below the reporting detection level of 0.1 mg/L). The replicate value was less than 0.1 mg/L.

acceptable MS/MSD recovery range for dissolved SiO₂ was 75–125 percent. The MS/MSD recoveries for the Sept. 2016 and Nov. 2016 samples were 27–30 and 230–300 percent, respectively.

Results for nine VOCs fell outside the acceptable MS/MSD recovery range for at least one groundwater MS/MSD sample. Both 1,1,2-trichloro-1,2,2-trifluoroethane (also known as freon-113) and 1,2,3-trichlorobenzene had four MS/MSD samples (of eight total MS/MSD samples) with percent recoveries outside the acceptable range. The acceptable ranges for 1,1,2-trichloro-1,2,2-trifluoroethane and 1,2,3-trichlorobenzene were 50–130 and 61–126 percent, respectively. MS/MSD recoveries of 1,1,2-trichloro-1,2,2-trifluoroethane from Oct. to Dec. 2016 were 131–159 percent for samples outside the acceptable range. MS/MSD results for 1,2,3-trichlorobenzene ranged from 40.2 to 49.9 percent for samples outside the acceptable recovery range that were internally analyzed at ALS laboratory from Sept. to

Nov. 2016. Three MS/MSD samples for 1,1-dichloroethene had values greater than the acceptable high recovery rate of 128 percent; percent recoveries for these Oct. and Dec. 2016 samples ranged from 133 to 137 percent. Four constituents (1,2,4-trichlorobenzene, carbon disulfide, cyclohexane, and trichlorofluoromethane) each had two MS/MSD results outside the acceptable ranges. Two MS/MSD samples for 1,2,4-trichlorobenzene had values (63.5 percent in Sept. 2016 and 63.9 percent in Nov. 2016) of less than the acceptable low recovery rate of 67 percent. Carbon disulfide, trichlorofluoromethane, and cyclohexane, each had two MS/MSD samples with values greater than the acceptable high recovery rates. The acceptable high-end recovery rates for carbon disulfide, trichlorofluoromethane, and cyclohexane were 131, 123, and 130 percent, respectively. These MS/MSD samples for carbon disulfide (132 percent recovery for two samples) and trichlorofluoromethane (138 and 133 percent recoveries) were analyzed in Oct. 2016. The

high-end exceedances for cyclohexane (136 and 140 percent recoveries) were for MS/MSD samples analyzed in Nov. 2016. Trans-1,2-dichloroethene and tribromomethane (also called bromoform) in one MS/MSD sample each were outside the acceptable ranges. Trans-1,2-dichloroethene in one MS/MSD sample in Oct. 2016 exceeded the acceptable high-end value (122 percent) by 1 percent; in contrast, tribromomethane, in one MS/MSD sample in Sept. 2016 was less than the acceptable low-end value (70 percent) by 3.5 percent. All QA/QC data for this report are available online at <https://doi.org/10.5066/P973YRPL>.

Surface Water

Blank samples submitted for surface water QA/QC included 3 trip blanks, 1 equipment blank, and multiple internal blanks. Acetone was detected at an estimated value of 6.6 µg/L (RDL = 10 µg/L) in the trip blank submitted on Oct. 12, 2016. Five VOCs were detected at concentrations less than the RDLs in the trip blank submitted on Nov. 9, 2016: 1,4-dichlorobenzene (0.28 µg/L, RDL=1 µg/L), bromomethane (0.45 µg/L, RDL=1 µg/L), 1,2,4-trichlorobenzene (0.86 µg/L, RDL=2 µg/L), acetone (3.6 µg/L, RDL=10 µg/L), and chloromethane (0.45 µg/L, RDL=1 µg/L). Four constituents were detected at less than their respective RDLs in the equipment blank submitted Dec. 7, 2016: total Cl (0.49 mg/L), dissolved iron (Fe; 22 µg/L), dissolved molybdenum (1.7 µg/L), and bromomethane (0.69 µg/L). Note that for all the groundwater and surface-water samples collected from Sept. to Dec. 2016, hydrochloric acid (HCl) was added by ALS laboratory at the time the bottles were prepared for shipment to the USGS office in New Cumberland, Pa.; subsequently, the HCl added by ALS remained in the sample bottle until sample collection. It was brought to the attention of USGS by another laboratory that HCl can interact with a bottle septum and release VOCs, primarily acetone (Ray Martrano, Seewald Laboratories, oral commun., 2017). The problem was corrected for water samples collected after December 2016 by adding HCl at the time of VOC sample collection.

In internal blanks submitted for surface water and analyzed by ALS laboratory, numerous constituents were detected, all at less than the RDLs. Eight VOCs were detected in internal blank samples during the baseline characterization period, Sept.–Dec. 2016. Trichloromethane was detected at concentrations ranging from 0.30 to 0.61 µg/L in internal blanks analyzed in Sept., Oct., and Dec. 2016. Bromomethane was detected in the Nov. 2016 internal blank (0.51 µg/L) and Dec. 2016 (0.66 µg/L). Carbon disulfide (0.33 µg/L), chloromethane (0.40 µg/L), 1,3-dichlorobenzene (0.27 µg/L), 1,4-dichlorobenzene (0.32 µg/L), and 1,2,4-trichlorobenzene (0.83 µg/L) were detected in the Nov. 2016 internal blank, and dichloromethane (0.47 µg/L) was detected in the Dec. 2016 internal blank. Four inorganic constituents were detected at concentrations less than the RDLs for internal blanks. Total Cl was detected at less than the RDL (1 mg/L) in Oct., Nov.,

and Dec. 2016 blanks. ALS analyzed numerous blanks to verify the Cl results. Cl was detected in 4 blanks in Oct. 2016 at concentrations ranging from 0.19 to 0.27 mg/L; 5 blanks in Nov. 2016 at concentrations ranging from 0.25 to 0.29 mg/L; and 8 blanks in Dec. 2016 at concentrations ranging from 0.23 to 0.36 mg/L. The other inorganic constituents detected in internal samples were total P (0.033 mg/L in Nov. 2016), dissolved molybdenum (0.00069 mg/L in Dec. 2016), and dissolved selenium (Se; 0.0016 mg/L in Dec. 2016).

One replicate sample was collected in Oct. 2016. Concentrations of only eight constituents differed between the routine and replicate samples. Total Cl, total nitrate plus nitrite, dissolved SiO₂, dissolved barium (Ba), and dissolved chromium (Cr) had RPDs of less than 5 percent between the routine and replicate samples. The three constituents with RPDs greater than 5 percent were perchlorate (9 percent), dissolved potassium (K; 12 percent), and fluoride (F; 29 percent). The measured concentrations of F were 0.04 and 0.06 mg/L. No VOCs were detected in either the routine or replicate sample in Oct. 2016.

MS/MSD samples were analyzed by ALS laboratory for each surface-water sampling event, but most MS/MSD samples were analyzed in association with the Nov. 2016 surface-water sampling. The only two inorganic constituents to fall outside the acceptable range for a surface-water MS/MSD sample were dissolved SiO₂ and Se. The acceptable MS/MSD recovery range for both constituents was 75–125 percent. The MS/MSD recoveries for dissolved SiO₂ in two Nov. 2016 samples were 223 and 220 percent. The MS/MSD recoveries for dissolved Se in two Nov. 2016 samples were 129 and 130 percent.

MS/MSD sample results from ALS laboratory for VOCs were provided only for the Nov. 2016 samples. Three VOCs fell outside the acceptable MS/MSD recovery range for at least one surface-water MS/MSD sample. Two MS/MSD samples for 1,1,2-trichloro-1,2,2-trifluoroethane and methylcyclohexane had recoveries of 142 and 158 percent, respectively, which are greater than the acceptable high end of 130 percent for both VOCs. Two MS/MSD samples for chloroethane had recoveries of 46 and 49 percent, which are less than the acceptable low end of 51 percent recovery.

Soil

Only internal laboratory blanks were analyzed in coordination with soil samples. Internal blanks for soil samples were analyzed by ALS laboratory for each soil sampling event. Cl was detected in each blank analyzed for soil samples at concentrations much less than the RDL of 50 milligrams per kilogram (mg/kg). The range of total Cl concentrations in internal blanks was 1.6 to 5.3 mg/kg. F and sulfate (SO₄) were detected at less than the RDLs in blanks submitted for Sept.–Nov. 2016 samples; concentrations ranged from 0.3 to 0.6 mg/kg and 13.6 to 18.0 mg/kg, respectively. The RDLs for F and SO₄ were 1.0 and 50 mg/kg, respectively. P was detected in two internal blanks submitted in Sept. and Nov. 2016

at concentrations of 0.92 and 4.1 mg/kg, respectively. The RDLs for P in Sept. and Nov. 2016 were 2.5 and 9.7 mg/kg, respectively.

Only two constituents had internal blank results that exceeded RDLs. Dichloromethane (RDL = 2 micrograms per kilogram [$\mu\text{g}/\text{kg}$]) was detected at concentrations of 4.5 and 2.5 $\mu\text{g}/\text{kg}$ in blanks submitted for analysis in Sept. and Nov. 2016, respectively. Sulfur (RDL = 10 $\mu\text{g}/\text{kg}$) was detected at 10.4 $\mu\text{g}/\text{kg}$ in the internal blank submitted in Nov. 2016.

Four replicate soil samples were submitted for analyses from Sept. to Dec. 2016. Replicate data show higher variability for soil samples than for water samples collected for this study. Replicate variability for the Oct. 2016 soil samples was less than the variability detected in other months (table 6). Only three VOCs were detected in the routine and replicate soil samples. Perchlorate, silver (Ag), and tin (Sn) were not

detected in the routine and replicate samples. Most constituents listed in table 6 had RPDs greater than 20 percent. The constituents that showed the least amount of variability in replicate samples were total solids, Cl, soil moisture, Zr, and P. These constituents had a mean RPD between routine and replicate samples of less than 10 percent.

MS/MSD samples were analyzed by ALS laboratory for each soil sampling event. MS/MSD results show more laboratory bias for soil samples than for water samples collected for this study. Twelve inorganic constituents (out of 22 inorganic constituents) were outside the acceptable ranges for at least one MS/MSD soil sample analyzed from Sept. to Dec. 2016. Aluminum (Al), iron (Fe), and SiO_2 in four MS/MSD samples had relative percent recoveries outside of the acceptable range of 75–125 percent. MS/MSD data for Al and Fe are available only for Sept. and Nov. 2016; both constituents

Table 6. Relative percent differences for selected constituents between routine and replicate soil samples collected at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.

[NA, not applicable]

Selected constituent	Soil sampling site and sample collection date			
	S0-4 September 14, 2016	S0-2 October 13, 2016	S0-7 November 8, 2016	S0-9 December 8, 2016
Aluminum	30.77	7.44	45.60	44.13
Arsenic	24.67	10.00	25.81	19.78
Barium	24.80	2.88	26.42	45.84
Bismuth	25.00	15.22	NA	42.00
Cadmium	51.55	NA ¹	NA	NA
Chloride	5.16	3.65	9.35	0.00
Chromium	28.04	7.69	35.46	39.23
Copper	23.86	7.14	28.57	31.81
Dichloromethane	7.04	86.96	41.51	19.88
Fluoride	8.99	0.00	36.84	2.99
Iron	15.72	7.33	25.20	50.51
Lead	19.69	9.71	22.92	41.82
Mercury	5.99	13.45	7.33	29.31
Methyl tert-butyl ether	16.67	NA	NA	5.56
Molybdenum	22.81	3.85	28.91	29.79
Nitrate plus nitrite as nitrogen	NA	NA	69.88	NA
Phosphorus	11.64	2.74	0.56	24.49
Potassium	35.01	7.10	50.84	44.96
Selenium	21.59	NA	26.92	36.62
Silica	37.30	1.49	4.11	22.14
Soil moisture	1.31	0.00	7.09	11.74
Sulfate	NA	26.53	18.18	11.43
Sulfur	25.08	9.48	23.97	60.30
Tetrachloroethene	NA	NA	NA	14.29
Total Solids	0.15	0.00	1.16	2.61
Zirconium	21.17	1.33	10.58	5.71

¹If either the regular or replicate sample was a nondetection (less than value), then a relative percent difference could not be determined.

had 2 samples at much less than and 2 samples at much greater than the acceptable range limits. For SiO_2 , 3 MS/MSD samples were less than the acceptable lower end, and 1 sample was greater than the acceptable high end from a total of 8 MS/MSD samples analyzed from Sept. to Nov. 2016. For copper (Cu), Cr, and Zr, three MS/MSD samples were outside of the acceptable recovery range of 75–125 percent. Relative percent recoveries for Cu, Cr, and Zr were 68–210, 63–157, and 21–109 percent, respectively. Other inorganic constituents with one or two MS/MSD samples outside relative percent recovery ranges were arsenic (As), Ba, F, lead (Pb), P, and K.

Of the 53 VOCs analyzed, 39 were outside the acceptable relative recovery percent range for at least one soil MS/MSD sample (74 percent; appendix 2). Acceptable relative percent recoveries varied by VOC. Seven MS/MSD samples were analyzed internally at ALS laboratory for each VOC. All MS/MSD samples for methyl acetate collected from September to December 2016 had relative percent recoveries greater than the high end of the range of 130 percent (ranging from 132 to 267 percent). The relative percent recoveries for 1,2,3-trichlorobenzene, 1,2,4-trichlorobenzene, 1,3-dichlorobenzene, 1,4-dichlorobenzene, and trans-1,3-dichloropropene in six MS/MSD samples were less than the acceptable low end values. These VOCs were present in only one MS/MSD sample in the acceptable range for MS/MSD samples collected in either Nov. or Dec. 2016. The acceptable low-end recovery for 1,2,3-trichlorobenzene, 1,2,4-trichlorobenzene, 1,3-dichlorobenzene, 1,4-dichlorobenzene, and trans-1,3-dichloropropene ranged from 63 to 77 percent. The range of percent recoveries below the acceptable low-end values for 1,2,3-trichlorobenzene, 1,2,4-trichlorobenzene, 1,3-dichlorobenzene, 1,4-dichlorobenzene, and trans-1,3-dichloropropene ranged from 18–62, 21–60, 34–71, 33–71, and 43–72 percent, respectively. Fourteen VOCs had 5 MS/MSD samples outside of acceptable ranges, with the 2 in-range samples for each analyzed in November 2016. An additional 20 VOCs had 1 to 4 MS/MSD samples that fell outside of the acceptable ranges (appendix 2; refer to Galeone (2019) at <https://doi.org/10.5066/P973YRPL>).

Baseline Characterization Data

The following sections characterize baseline data from samples that were collected monthly from September to December 2016 (baseline period prior to operation of the ARMD Facility) at 4 groundwater wells, 1 surface-water site, and 9 soil sites at the ARMD Facility.

Groundwater

Groundwater samples from the four monitoring wells around the ARMD Facility were collected monthly from Sept. to Dec. 2016. Static water levels prior to pumping the wells were fairly consistent from month to month (fig. 11 and

appendix 1). The range of water levels measured at the time of sampling in any well did not exceed 2.3 feet. Sampled water was shallowest at MW-2 (average was 6.36 feet below land surface) and deepest at MW-3 (average was 29.83 ft below land surface). Land-surface elevations relative to the NAVD 88 at MW-2 and MW-3 are 678.88 and 702.60 feet, respectively.

Field characteristic for the four wells were relatively consistent from Sept. to Dec. 2016. Dissolved oxygen for the wells was less than 3.0 mg/L in all samples collected. The SC measured at each well was stable from sample to sample, with the lowest mean SC measured at MW-1 (220 $\mu\text{S}/\text{cm}$) and highest at MW-3 (771 $\mu\text{S}/\text{cm}$). Mean pH ranged from 6.45 at MW-1 to 6.98 at MW-3 (fig. 11). All the wells were completed in the Martinsburg Formation; however, the western edge of the well field where MW-2 and MW-3 are sited is near the contact with the Martinsburg Formation (shale) and the Chambersburg Formation, which is composed of argillaceous limestone (fig. 2). The proximity to the limestone formation could contribute dissolved ions to the water that flows to MW-3. MW-3 had the highest SC followed by MW-2. MW-3 is 59 feet deeper than MW-2, and it is likely the flow path to MW-3 is in greater contact with the Chambersburg Formation than the more shallow MW-2. Water temperatures were highest in MW-2 (mean = 14.7 °C), with the other three wells having mean water temperatures ranging from 12.1 to 12.7 °C. The well depth of MW-2 is 22 ft; it's the shallowest well in the well network at the ARMD Facility (table 2).

Inorganic analytical results showed no inorganic constituents that exceeded any U.S. Environmental Protection Agency (EPA) Maximum Contaminant Levels (MCLs) (U.S. Environmental Protection Agency, 2009). Dissolved As was detected only in samples from two wells, MW-1 and MW-2, at mean concentrations of 2.8 and 5.2 $\mu\text{g}/\text{L}$, respectively (fig. 12). The MCL for As is 10 $\mu\text{g}/\text{L}$. Similar to some other constituents, some concentrations of dissolved As were less than nondetect values. This occurred because RDLs can vary by sample and by date. Values less than the RDL are considered to be estimated values; if no detection occurs, then the result is reported as “less than.” Total nitrate was not detected in any groundwater sample (appendix 1) and had an RDL of 0.2 mg/L. The maximum total phosphorus (P) concentration in any groundwater sample was 0.15 mg/L for MW-1 (fig. 13). The deepest well, MW-3, had the lowest total P concentration of the four wells. Mean total Cl and total SO_4 concentrations for MW-3 (56 and 86.8 mg/L, respectively) were higher than for the other wells; the total Cl concentration in MW-3 was more than a magnitude greater than that of any other well. The higher concentrations of total Cl and total SO_4 for MW-3 are reflected in the higher SC for this well. Higher dissolved ion concentrations typically are expected in deeper wells compared to more shallow wells completed in the same recharge area (Freeze and Cherry, 1979, p. 241).

Dissolved Fe was the only inorganic constituent measured at greater than a Secondary Maximum Contaminant Level (SMCL; fig. 12). All samples collected at MW-1,

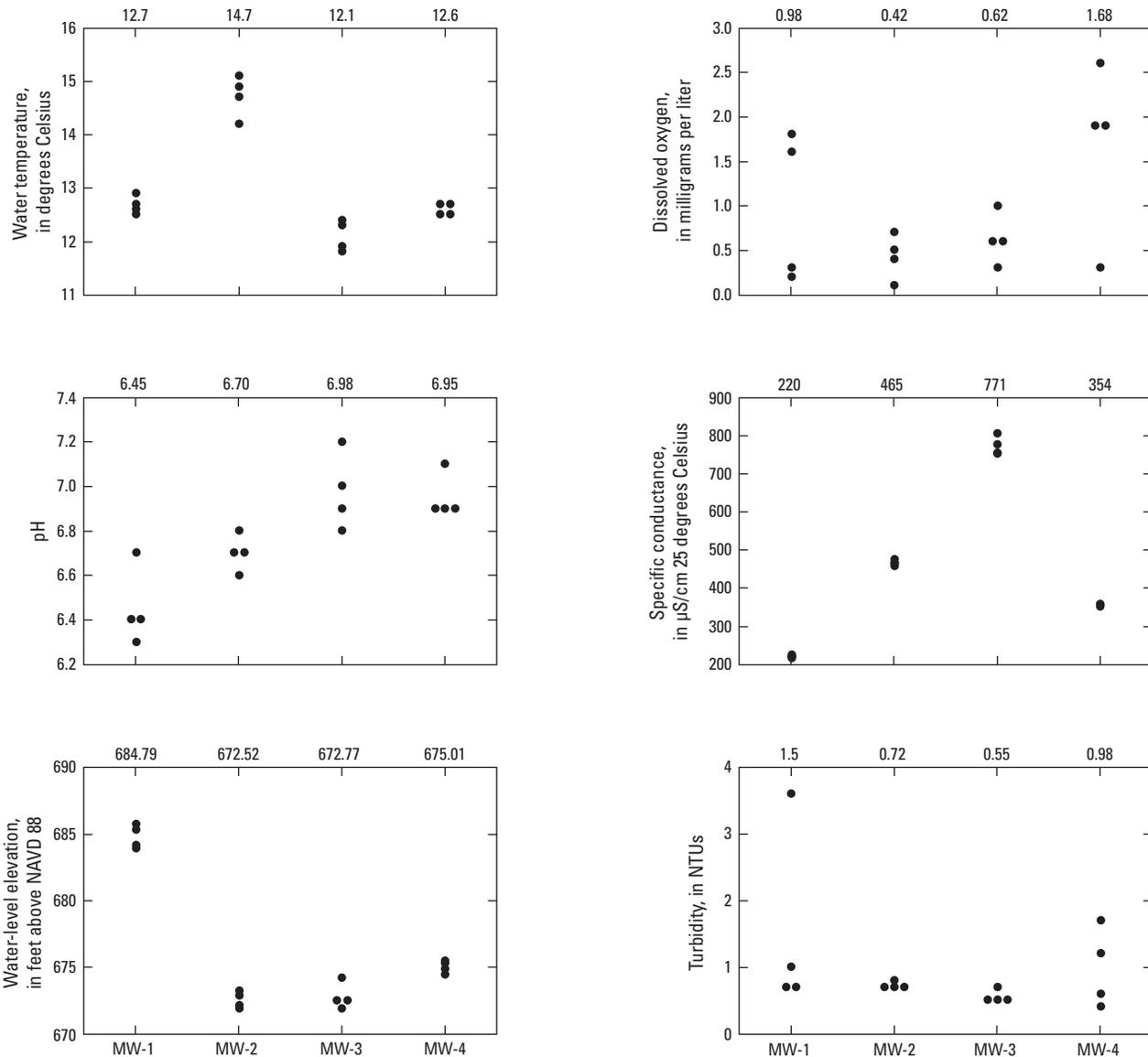


Figure 11. Measured and mean values of water temperature, dissolved oxygen, pH, specific conductance, water level, and turbidity for water samples collected at the four monitoring wells at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.

(Mean values are given above the graphs; µS/cm, microsiemens per centimeter; NTUs, Nephelometric Turbidity Units; NAVD 88, North American Vertical Datum of 1988)

MW-2, and MW-4 exceeded the SMCL for Fe of 300 µg/L (U.S. Environmental Protection Agency, 2009). Mean dissolved Fe concentrations for MW-1, MW-2, and MW-4 were 2,600, 1,100, and 1,300 µg/L, respectively; in contrast, the mean dissolved Fe concentration for MW-3 was 100 µg/L. Exceedance of the SMCL for Fe can cause discoloration of materials. No health effects are related to any SMCL exceedance. There were no detections in any of the ARMD groundwater samples of dissolved Al (RDL = 80 µg/L), dissolved cadmium (Cd) (RDL = 1 µg/L), dissolved Cu (RDL = 5 µg/L), dissolved Pb (RDL = 2 µg/L), dissolved mercury (Hg; RDL = 0.5 µg/L), dissolved Ag (RDL = 2 µg/L), dissolved

Sn (RDL = 5 µg/L), dissolved Zr (RDL = 10 µg/L), or perchlorate (RDL = 0.2 µg/L) (appendix 1).

Only three VOCs were detected in samples collected from the ARMD wells from October to December 2016. No VOCs were detected in Sept. 2016 samples, and only one VOC (bromomethane) was detected in an Oct. 2016 sample. Bromomethane was detected four times at less than the RDL of 1 µg/L at concentrations ranging from 0.41 to 0.67 µg/L (appendix 1). Bromomethane was detected at MW-2 in Oct. and Dec. 2016 and in MW-1 and MW-4 in Dec. 2016. Acetone was detected less than the RDL of 10 µg/L in two samples collected in Nov. 2016 from MW-2 (3.4 µg/L) and MW-4 (5.4 µg/L). Chloromethane was detected at less than

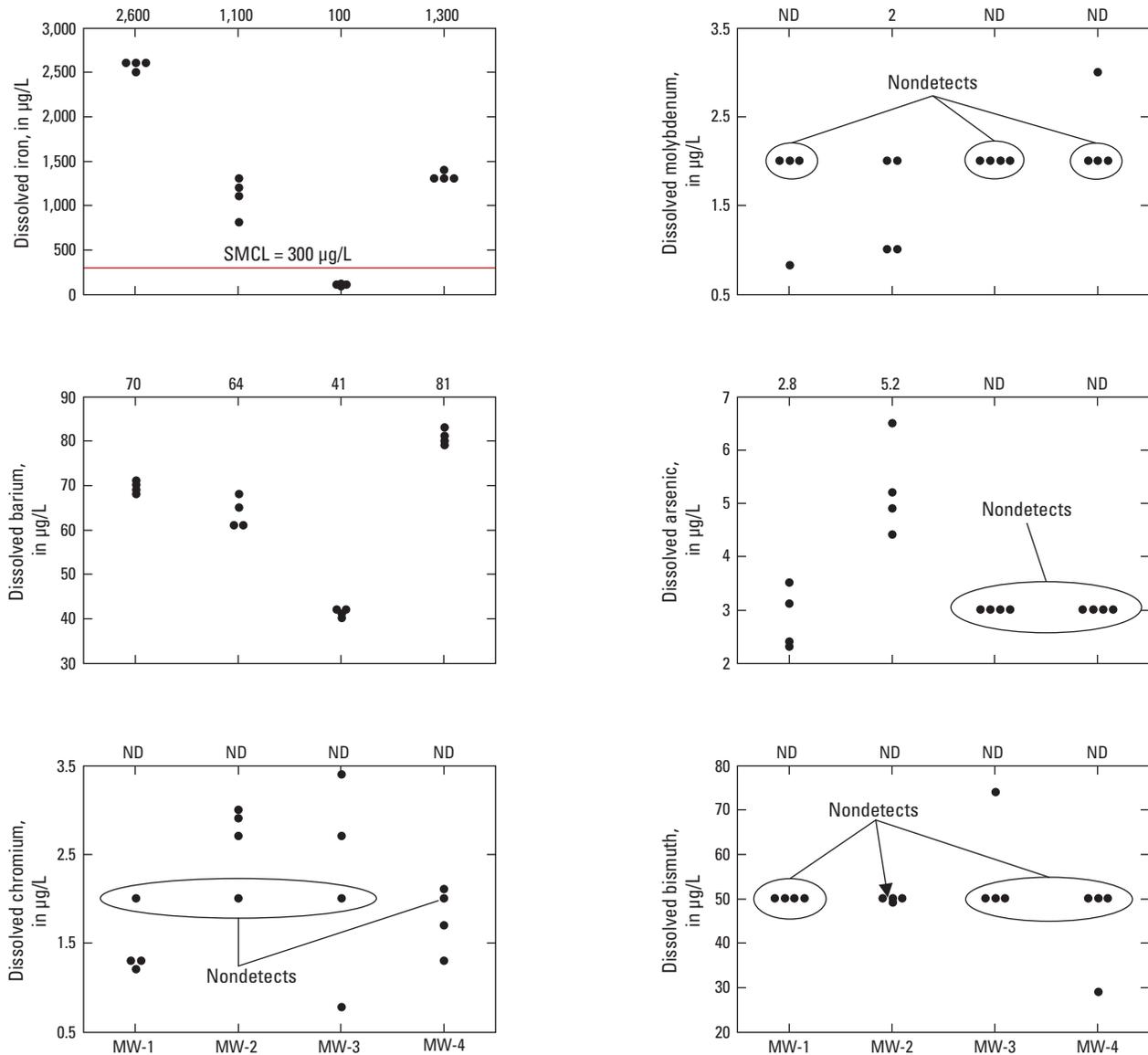


Figure 12. Measured and mean concentrations of dissolved iron, molybdenum, barium, arsenic, chromium, and bismuth in water samples collected from four monitoring wells at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.

(Mean values are given above plot; ND, not determined; µg/L, micrograms per liter; SMCL, secondary maximum contaminant level)

the RDL of 1 µg/L in one sample collected in Nov. 2016 from MW-4 (0.44 µg/L) and one sample collected in Dec. 2016 from MW-2 (0.46 µg/L). Each of the VOCs detected in groundwater samples were also detected in blank samples. Bromomethane, acetone, and chloromethane were detected in blanks with values ranging from 0.40 to 0.65 µg/L, 5.2 to 5.8 µg/L, and 0.43 to 0.55 µg/L, respectively.

Surface Water

Surface-water samples were collected at SW-U from September to December 2016. The downgradient streams did not have any flow on the days when SW-U was sampled, so

there are no data for any of the upgradient surface-water sites. Therefore, the surface-water data collected during the baseline characterization period are only representative of the environment upgradient from the ARMD Facility. SW-U drains 0.44 square miles of forested land (fig. 14). The drainage basin extends to the top of Broad Mountain with an approximate elevation at the top of 2,250 feet above the NAVD 88. The elevation at SW-U is about 715 feet above the NAVD 88. This steep gradient limits recharge water interaction with the deeper groundwater system, and this is reflected in the field and analytical data for SW-U. Mean total Cl and total SO₄ concentrations at SW-U were 1.8 and 8.4 mg/L, respectively (table 7). These concentrations are evidence of relatively short flow paths through the shallow groundwater system (Freeze and

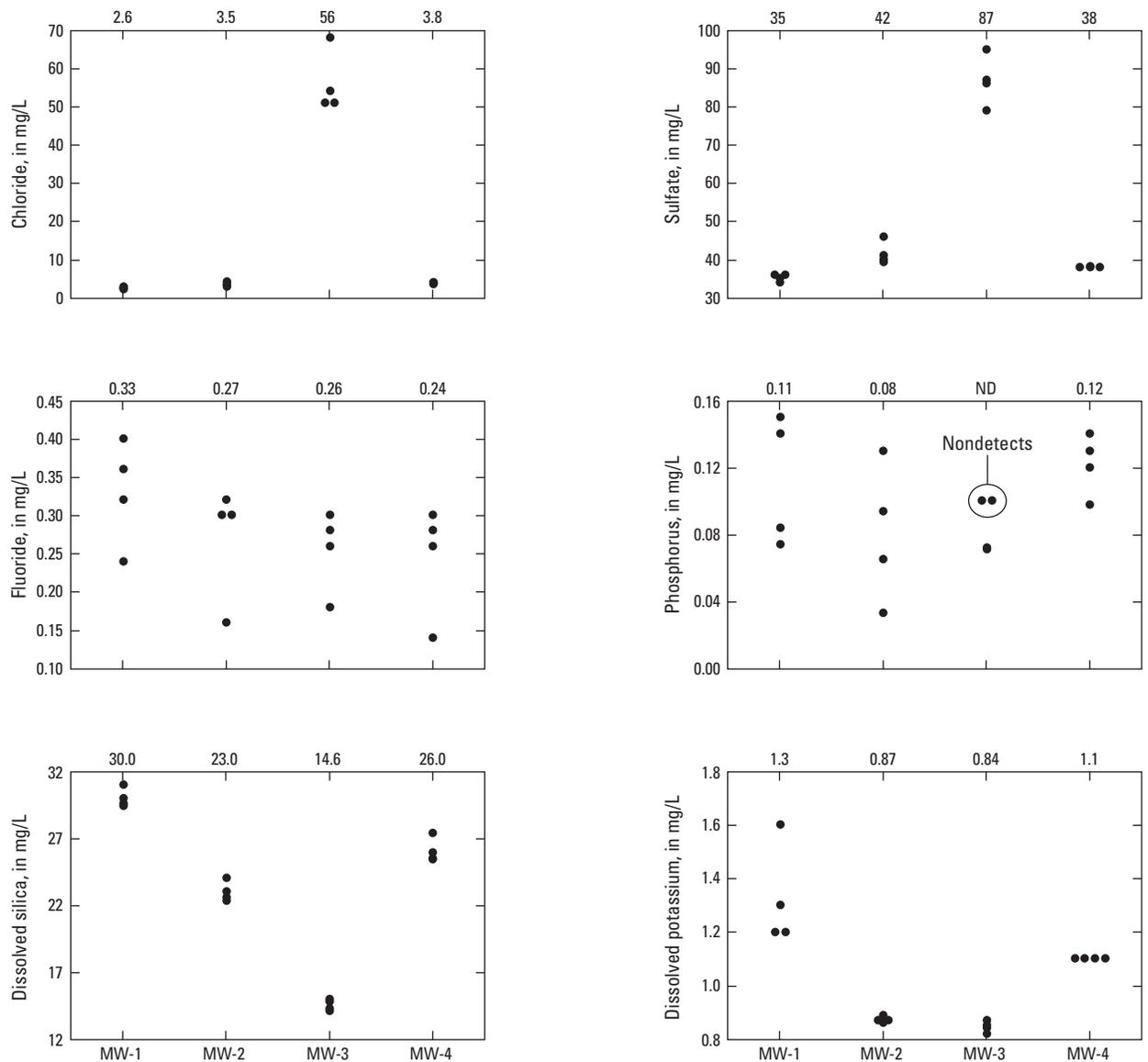


Figure 13. Measured and mean concentrations of chloride, sulfate, fluoride, phosphorus, dissolved silica, and dissolved potassium concentrations in water samples collected from four monitoring wells at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.

(Mean values are given above plot; ND, not determined; mg/L, milligrams per liter)

Cherry, 1979, p. 241). Note that Cl⁻ was detected in QA/QC blank samples at a range of 0.19–0.36 mg/L for surface-water samples. The mean SC of 292 μ S/cm is somewhat high for a small forested basin, but the underlying bedrock at SW-U is limestone of the St. Paul Group. This bedrock can contribute to the SC through dissolution of calcium and magnesium. The mean pH for samples collected at SW-U was 7.6, and this slightly alkaline pH is also reflective of the underlying limestone formation.

There were no apparent water-quality issues for the water sampled at SW-U. Samples were collected during base-flow conditions. No storm events were sampled. Stream discharge ranged from 0.03 to 0.08 cubic feet per second (ft³/s). The turbidity measured in Sept. 2016 was 23 nephelometric turbidity

units (NTUs), but this sediment was grayish-white in color and not due to storm movement of soil particles. No total P was detected at an RDL equal to 0.10 mg/L. The maximum total nitrate plus nitrite as N concentration detected was 0.20 mg/L (appendix 3). No MCLs or SMCLs were exceeded for any constituents. There were no detections in any of the dissolved forms of Al (RDL = 80 μ g/L), bismuth (Bi; RDL = 50 μ g/L), Cd (RDL = 1 μ g/L), Cu (RDL = 5 μ g/L), Fe (RDL = 50 μ g/L), Pb (RDL = 2 μ g/L), Hg (RDL = 0.5 μ g/L), Ag (RDL = 2 μ g/L), Sn (RDL = 5 μ g/L), Zr (RDL = 10 μ g/L), As (RDL = 3 μ g/L), and Se (RDL = 5 μ g/L).

VOCs were detected in the samples collected at SW-U in Nov. and Dec. 2016. All the VOC detections were less than the RDL. Bromomethane was detected in Nov. and Dec. at

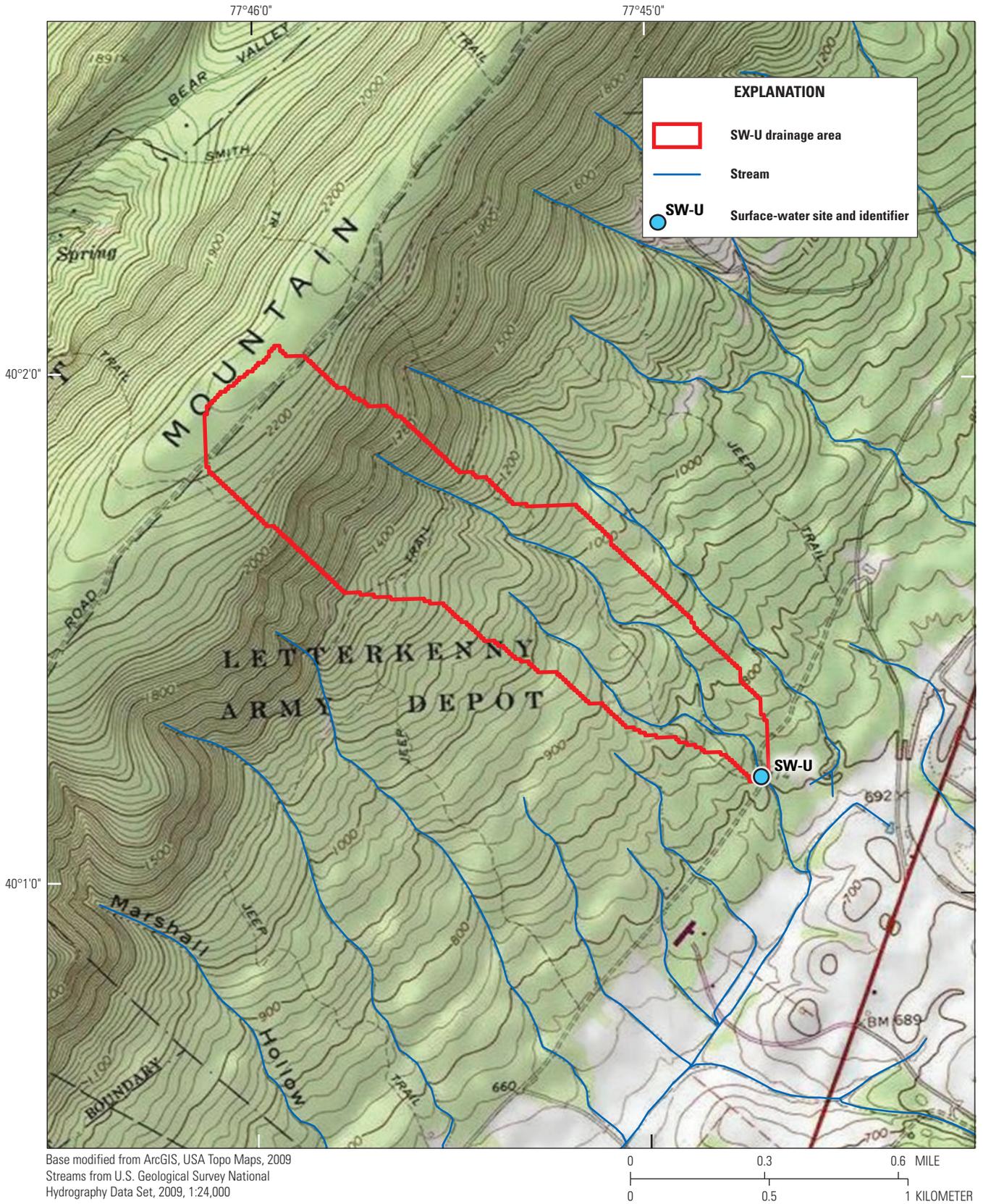


Figure 14. Drainage area for surface-water site SW-U at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, 2016.

Table 7. Minimum, mean, and maximum values for selected constituents in surface-water samples collected at site SW-U near the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.

[ft³/s, cubic foot per second; mg/L, milligrams per liter; μ S/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, Nephelometric Turbidity Units; μ g/L, micrograms per liter; <, less than; ND, not determined]

Constituent	Unit	Minimum	Mean	Maximum
Discharge	ft ³ /s	0.03	0.06	0.08
Dissolved oxygen	mg/L	8.4	9.6	11.5
Eh	millivolts	143	315	383
pH		7.2	7.6	8.1
Specific conductance	μ S/cm at 25 °C	232	292	315
Turbidity	NTU	3	8	23
Water temperature	°C	7	11.6	16.7
Dissolved barium	μ g/L	51	66	72
Dissolved chromium	μ g/L	< 2	ND	2.5
Dissolved molybdenum	μ g/L	< 2	ND	2
Dissolved potassium	mg/L	0.84	1.3	2.2
Dissolved silica	mg/L	8.1	8.8	9.5
Total chloride	mg/L	1.6	1.8	2.1
Total fluoride	mg/L	0.04	0.1	0.18
Total perchlorate	μ g/L	0.06	0.07	0.09
Total sulfate	mg/L	6.8	8.4	11

0.41 and 0.80 μ g/L, respectively; acetone and chloromethane were detected at 7.2 mg/L (acetone RDL = 10 μ g/L) and 0.35 μ g/L, respectively, in November; and dichloromethane was detected at 0.87 μ g/L in December. The RDLs for bromomethane, chloromethane, and dichloromethane are 1.0 μ g/L (appendix 3). Note that bromomethane was detected in blank samples for surface water at concentrations ranging from 0.51 to 0.66 μ g/L. Acetone was detected in blank samples for groundwater but not surface water. Chloromethane was detected at 0.40 μ g/L in a blank sample submitted in November 2016 for surface water. Dichloromethane was detected at 0.47 μ g/L in a blank sample submitted in Dec. 2016 for surface water. Perchlorate, a semi-volatile organic compound, was detected at less than the RDL (RDL = 0.2 μ g/L) in each sample collected at SW-U with a mean total concentration of 0.07 μ g/L (table 7) for the four samples collected.

Soil

Soil samples from the nine soil sampling sites were collected from September to December 2016. Soil sites SO-5 and SO-6 were not sampled in December 2016 because asphalt had been spread over the sites in early December 2016. Four sites (SO-1, SO-4, SO-7, and SO-8) had typical A grading into E horizons down to a 6-inch depth. A horizons are below the organic layer (O horizon) of roots and organic debris and contain only some organic matter. The E horizon contains only limited organic matter. Both A and E horizons are mineral horizons where all parent rock material has been

obliterated (U.S. Department of Agriculture, 2018b). The other soil sites sampled appear to have been affected by activities at LEAD. Sites SO-2 and SO-3 have very compact soils. SO-2 appeared to have fill material near the surface, but it did not have significant shale fragments. SO-3 has rock/cobble in the 0- to 6-inch depth below the surface, and this also appeared to be fill material. Sites SO-5, SO-6, and SO-9 have shale fill at the surface down to a depth of 6 inches. The shale is interspersed with finer particles of sand and silt.

Analytical results for soils show that only one constituent, As, exceeded acceptable limits established by the Commonwealth of Pennsylvania (Pennsylvania Department of Environmental Protection, 2018) or the U.S. Environmental Protection Agency (2015). The Commonwealth of Pennsylvania has established medium-specific concentrations (MSCs) for soil that vary depending on the method used in calculating the MSC. The Commonwealth of Pennsylvania calculates MSCs based on health concerns if the soil is directly contacted. The EPA derives acceptable concentrations of constituents in soil (referred to as soil screening levels [SSLs]) based on standardized equations combining exposure information assumptions with EPA toxicity data. The EPA calculates SSLs for residential and industrial sites (U.S. Environmental Protection Agency, 2015). The soils at the ARMD site are considered “industrial” or “nonresidential” for comparative purposes. None of the As concentrations in soil exceeded the Pennsylvania MSC; however, all the As concentrations in soil exceeded the EPA SSL for As. Arsenic concentrations in soil ranged from 5.2 to 20.8 mg/kg (fig. 15 and appendix 4). The EPA SSL for As is 3 mg/kg. According to the Commonwealth

of Pennsylvania, the surface soil (0–2 feet) nonresidential MSC for As is 61 mg/kg. The Pennsylvania MSC for As is based on direct human contact, whereas the EPA SSL is based on assumptions made for exposure and toxicity. EPA (2018) notes that some SSL values may be less than background concentrations because the SSLs are purely risk based and that “Arsenic, aluminum, iron and manganese are common elements in soils that have background levels that may exceed risk-based SLs. This does not mean that these metals cannot be site-related, or that these metals should automatically be attributed to background.”

The inorganic constituents with the highest concentrations in soil samples were Fe and Al (fig. 16). Mean Fe concentrations ranged from 28,700 mg/kg for SO-7 to 52,400 mg/kg for SO-9. Mean Al concentrations ranged from 10,300 mg/kg for SO-7 to 19,800 mg/kg for SO-9.

Another element found at relatively high concentrations in soils was SiO₂. The mean SiO₂ concentrations ranged from 841 mg/kg for SO-2 to 1,550 mg/kg for SO-9 (fig. 17). Site SO-9 had been filled with shale in the past. SiO₂ is the primary element in shale, followed by aluminum (Schultz and others, 1980). Native soils also are highly concentrated with these elements as shown in figures 16 and 17; however, it is likely that the shale fill at SO-9 contributed to the high concentrations of SiO₂ and Al at this site. Mean concentrations of SiO₂ and Al were highest at SO-9. The lowest P concentrations were detected at the shale-filled sites (SO-5, SO-6, and SO-9); the lowest mean concentration of 245 mg/kg was detected at SO-5 (fig. 17).

Some trace elements that were detected in soil but at low concentrations were As, Pb, Hg, and Se. The lowest mean concentrations for As, Pb, and Hg were detected in samples from site SO-6, at concentrations of 6.2, 16.4, and 0.029 mg/kg, respectively. The highest mean concentrations for As and Pb were detected in samples from site SO-2, at concentrations of 12.6 and 31.2 mg/kg, respectively (fig. 15). The mean Se concentration for all soil samples collected was 1.5 mg/kg, with nine nondetects at RDLs ranging from 2.4 to 3.3 mg/kg.

Inorganic constituents with very limited detection in any soil samples were Cd, Ag, and Sn. All values for Cd and Sn were either estimated values less than the RDLs or nondetects. The RDLs for Cd and Sn were about 0.5–0.6 and 2.5–3.0 mg/kg, respectively. There were no Ag detections in any soil sample; the RDL for Ag is about 1.0 mg/kg (appendix 4).

Of the 53 VOCs analyzed in soil samples collected during Sep.–Dec. 2016, 4 were detected in soil samples (appendix 4). Concentrations of many VOCs in matrix-spike samples were either greater than or less than the acceptable ranges (appendix 4). Similar to inorganic constituents, the Commonwealth of Pennsylvania established MSCs, and the EPA established SSLs for VOCs in soils. None of the VOCs detected in the soils from the ARMD site were within three orders of magnitude of the MSCs or SSLs established. The VOCs detected at the ARMD site were dichloromethane, methyl tert-butyl ether (MTBE), tetrachloroethene, and acetone (appendix 4).

Dichloromethane was detected in each of the 34 soil samples collected, at concentrations ranging from 1.9 to 50.1 µg/kg. All the dichloromethane results were greater than the RDLs. The highest dichloromethane concentration was detected in a sample from SO-7. Note that dichloromethane was detected at concentrations of 4.5 and 2.5 µg/kg in blanks submitted in Sept. and Nov. 2016, respectively. MTBE was detected in 50 percent of the samples collected, but all results were estimated values at less than the RDL (RDLs ranged from 1.7 to 2.6 µg/kg). Note that MS/MSD recoveries for MTBE were less than the acceptable range for samples analyzed in Sept. and Dec. 2016. The maximum estimated MTBE concentration was 1.3 µg/kg for the samples collected at SO-2 and SO-4 in September 2016. Tetrachloroethene was detected at less than the RDL (RDLs ranged from 1.7–2.6 µg/kg) in 20 percent of soil samples collected. Tetrachloroethene was detected only in samples collected in Dec. 2016, and the maximum estimated concentration detected was 1.5 µg/kg from SO-7. Acetone was detected only in one sample. The only detection of acetone was 16.5 µg/kg (RDLs ranged from 8.4 to 12.8 µg/kg) for SO-9 in December 2016 (appendix 4).

Perchlorate was detected at concentrations less than the RDL in 38 percent of the soil samples collected. The RDL range for perchlorate was 0.32–3.1 µg/kg. Perchlorate was detected at three sites (SO-1, SO-2, and SO-9) in 3 of the 4 samples collected at those sites. The maximum estimated concentration of perchlorate detected was 1.4 µg/kg at SO-8. Perchlorate was not detected at SO-3, SO-4, and SO-5 (appendix 4).

Summary and Conclusions

Letterkenny Army Depot (LEAD), located near Chambersburg, Pennsylvania, is a Federal government facility that provides supply and maintenance support to the U.S. Armed Forces. LEAD permitted and built a new destruction facility, which was completed in 2016. The Ammonium Perchlorate Rocket Motor Destruction (ARMD) Facility uses confined burning with emissions control to treat solid propellant rocket motors. The ARMD Facility includes static firing of full motors and containment and capture of the exhaust for treatment in a pollution abatement system. The system was designed so that there would be no waste streams to the external environment. The Code of Federal Regulations requires any hazardous waste disposal facility to have in place an environmental monitoring program. Redhorse Corporation, in coordination with the Pennsylvania Department of Environmental Protection (PADEP) and LEAD, drafted an environmental monitoring plan to implement at the ARMD site. A requirement of the environmental monitoring plan was to establish baseline conditions prior to the beginning of facility operation in January 2017. The U.S. Geological Survey, in cooperation with Letterkenny Army Depot, conducted a study to measure the characteristics and constituents in groundwater,

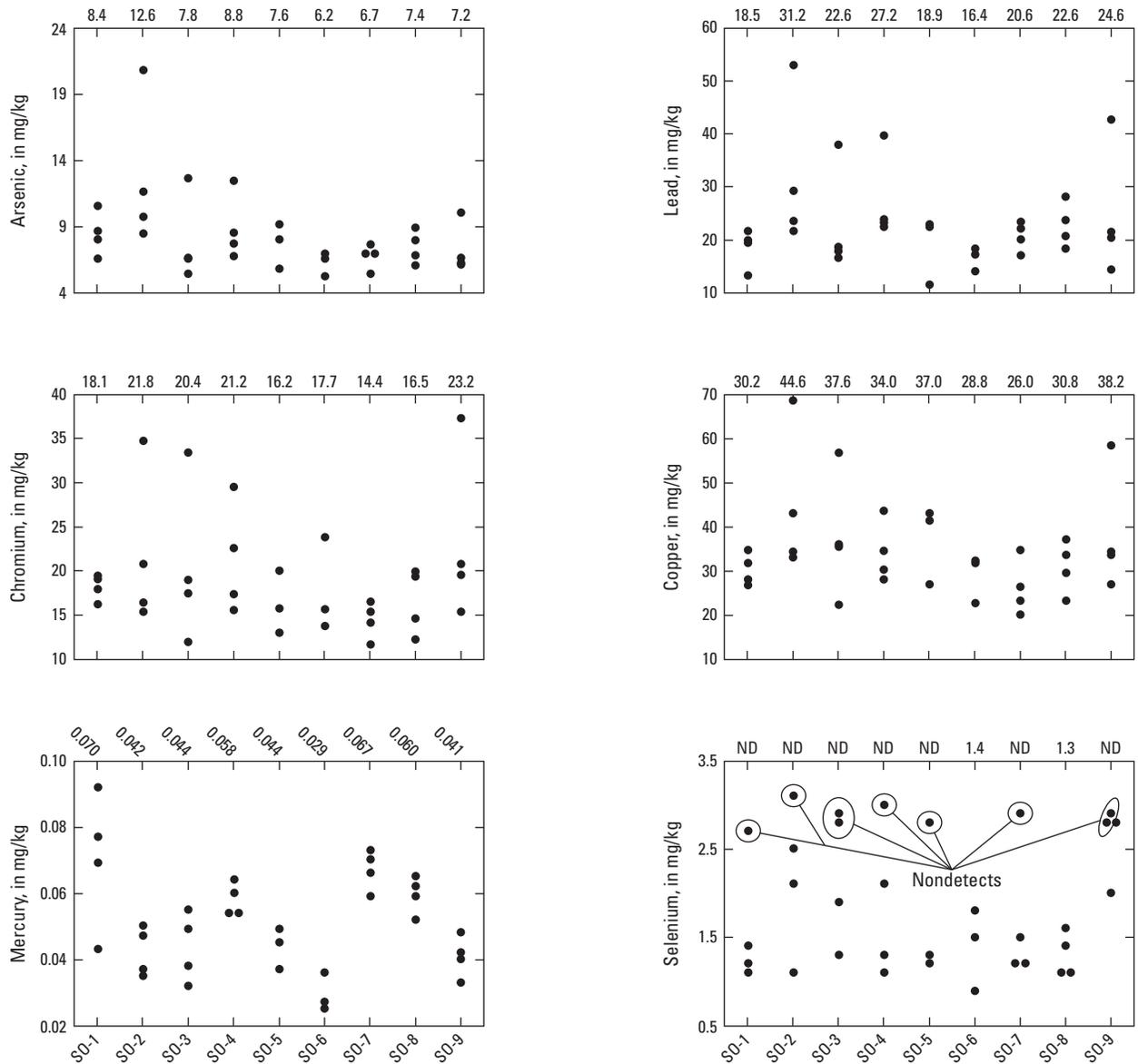


Figure 15. Measured and mean concentrations of arsenic, lead, chromium, copper, mercury, and selenium in soil samples collected from the nine soil sites at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.

(Mean values are given at top of plot; ND, not determined; mg/kg, milligrams per kilogram)

surface water, and soil during a baseline period from Sep. to Dec. 2016. Baseline samples were collected monthly from September to December 2016 prior to facility operation. The monitoring program approach was to establish baseline concentrations of indicator compounds that could result from unplanned releases to soil, surface water, groundwater, stormwater runoff, or runoff sediment from the ARMD Facility; however, since samples were collected only in fall and early winter, any seasonal variability in constituents was not captured.

The sampling sites of the original monitoring plan included 4 groundwater wells, 4 surface-water sites, 9 soil sites, and 2 sediment sampling sites, which were in and

immediately downgradient from culverts that drain the facility. The four monitoring wells, with depths ranging from 41 to 81 feet, were upgradient (one well) and downgradient (three wells) from the facility. The four stream sites were upgradient (one site) and downgradient (three sites) from the facility. The nine soil sites were within a few hundred yards of the facility buildings. The culverts designated for sediment sampling are at the front of the facility grounds, draining parking areas, access roads, and adjacent grounds. During the baseline period, there was no water in the downgradient stream locations, so surface-water samples were collected only at the upgradient site during the baseline period, and this surface water was only representative of the forested environment

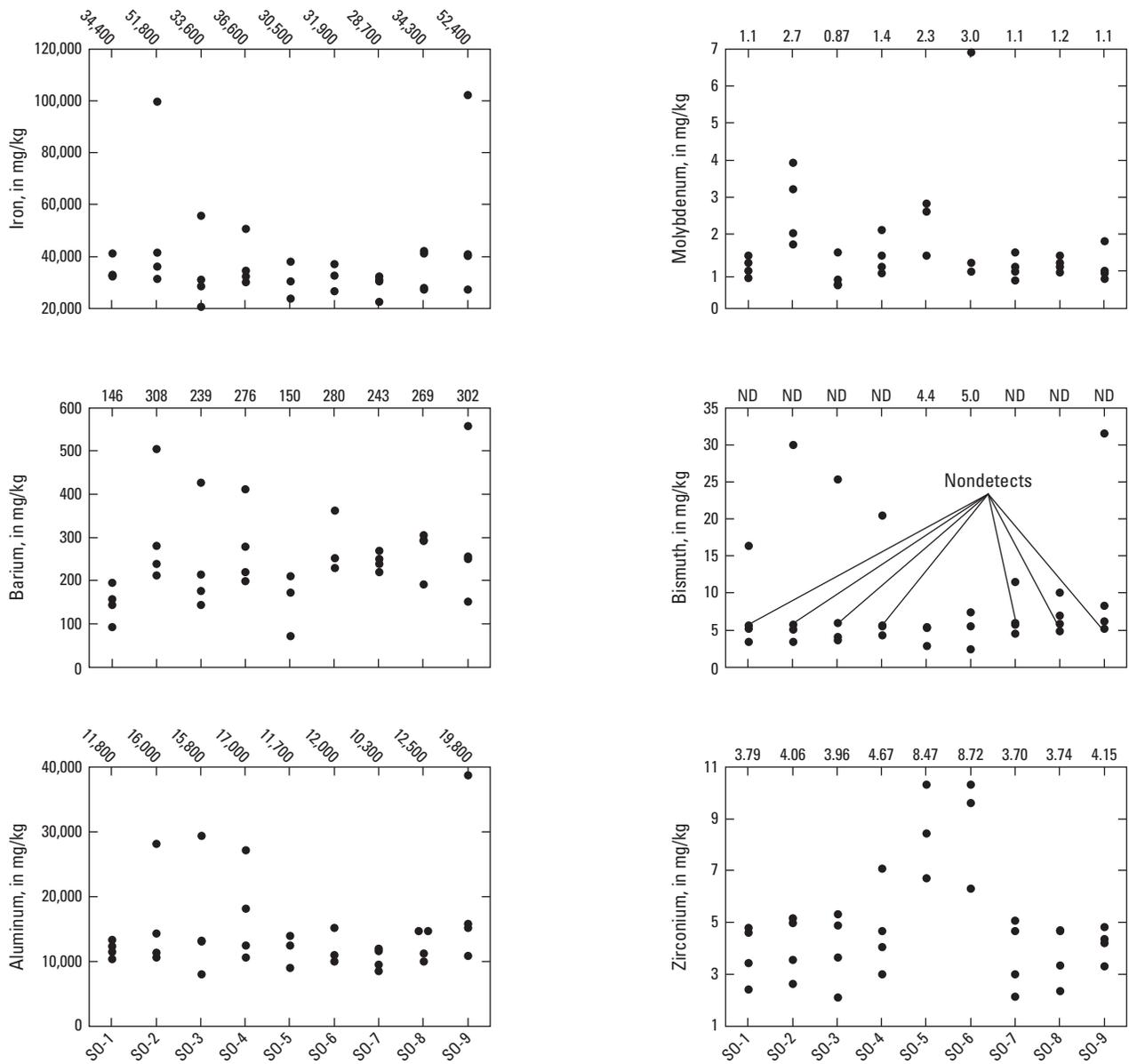


Figure 16. Measured and mean concentrations of iron, molybdenum, barium, bismuth, aluminum, and zirconium concentrations in soil samples collected from the nine soil sites at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.

(Mean values are given at top of plot; ND, not determined; mg/kg, milligrams per kilogram)

upgradient from the ARMD Facility. There also was no sediment in the culverts draining the facility grounds, so no sediment was collected during the baseline period. Water and soil samples were analyzed for trace metals, major ions, volatile organic compounds (VOCs), zirconium, and perchlorate.

Quality assurance and quality control samples collected during the baseline period indicated some sampling and analytical bias based on the results from blank water samples. Analytical results from blanks submitted by sampling personnel to the ALS laboratory and internal blanks analyzed by the ALS laboratory indicated some contamination. All detections in blank water samples were less than the Reporting Detection

Level (RDL) for each constituent. Total chloride (Cl) was detected at less than the RDL with values ranging from 0.18 to 0.49 milligrams per liter (mg/L) in numerous blanks submitted for groundwater and surface-water samples. VOCs detected in blank water samples include acetone, bromomethane, and chloromethane. Acetone, bromomethane, and chloromethane were detected in numerous blanks at concentrations ranging from 3.6 to 6.6, 0.40 to 0.69, and 0.40 to 0.55 micrograms per liter (µg/L), respectively. Internal laboratory blanks submitted for soil samples also had Cl detections (1.6–5.3 milligrams per kilogram [mg/kg]) less than the RDL. Fluoride (F), sulfate (SO₄), and phosphorus (P) were also detected in blank soil

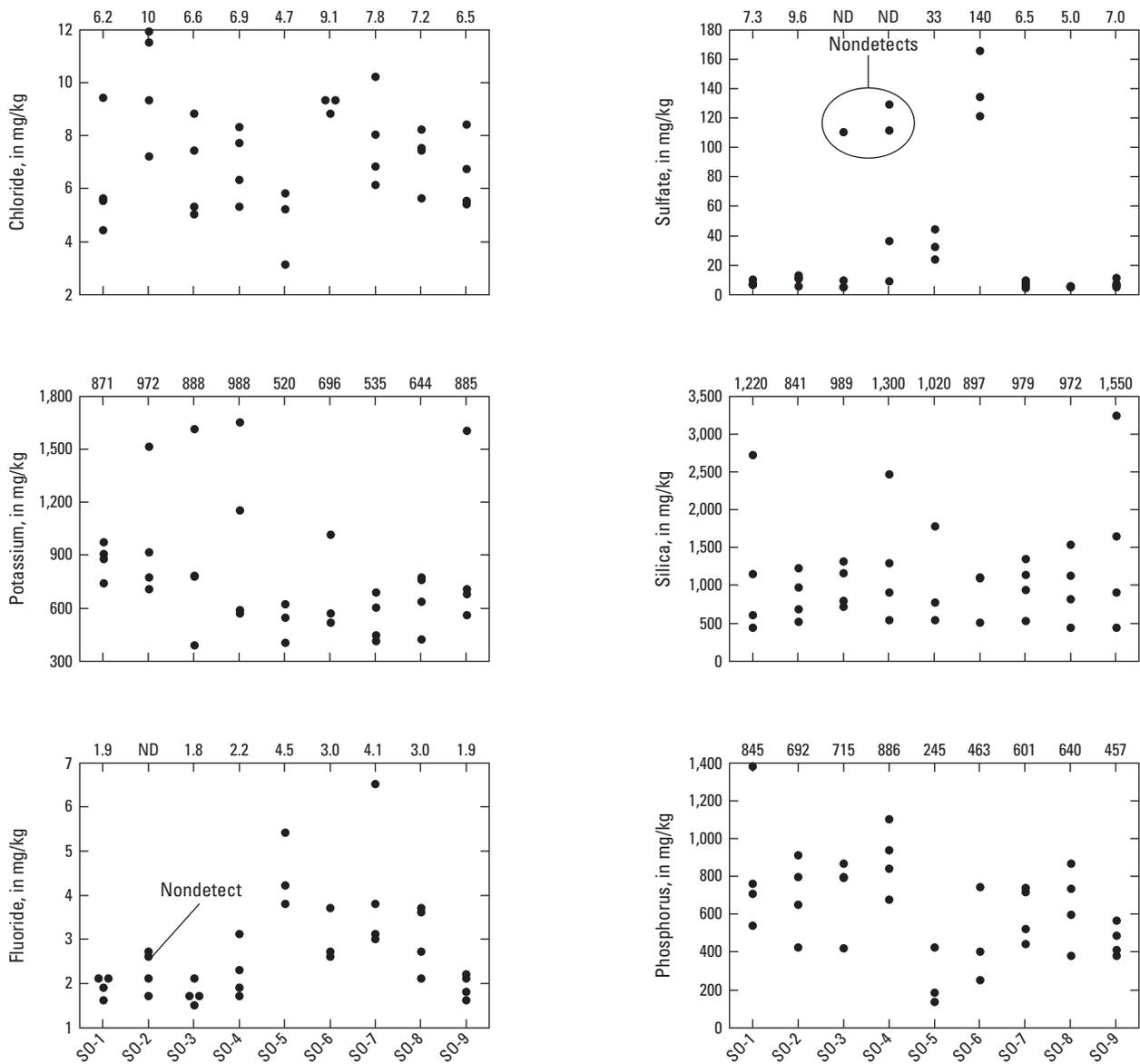


Figure 17. Measured and mean concentrations of chloride, sulfate, potassium, silica, fluoride, and phosphorus in soil samples collected from the nine soil sites at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.

(Mean values are given above plot; ND, not determined; mg/kg, milligrams per kilogram)

samples at concentrations ranging from 0.3 to 0.6, 13.6 to 18.0, and 0.92 to 4.1 mg/kg, respectively. Dichloromethane was the only VOC detected in blank soil samples, and this was detected in two blanks at concentrations (2.5 and 4.5 micrograms per kilogram [$\mu\text{g}/\text{kg}$]) greater than the RDL. Replicate samples collected from water and soil matrices during the baseline period indicated that reproducibility for water samples was fairly high. Relative percent differences for replicated water samples typically were less than 5 percent. In contrast, reproducibility for soil samples was fairly low, with replicated samples showing a relative percent difference of more than 20 percent for most constituents that were detected.

Many VOCs were not detected in either the routine or replicate soil samples.

Groundwater results for the four wells sampled near the ARMD Facility during the baseline period did not show any major water-quality issues. All the wells were completed in the Martinsburg Formation, but mean specific conductance (SC) and pH in the groundwater ranged from 220 to 771 microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$) and 6.45 to 6.98, respectively, indicating that shallow (within 50 feet of land surface) groundwater quality in the western part of the well field was being affected by proximity to the Chambersburg Formation (an argillaceous limestone). No constituents in groundwater samples exceeded any U.S. Environmental

Protection Agency (EPA) Maximum Contaminant Level (MCL). Dissolved iron (Fe) was the only groundwater constituent that exceeded a Secondary Maximum Contaminant Level (SMCL) established by the EPA. The SMCL for Fe is 300 micrograms per liter ($\mu\text{g/L}$), and samples from 3 of 4 wells exceeded this value, with exceedance values ranging from 1,100 to 2,600 $\mu\text{g/L}$. The only VOCs detected in groundwater samples were bromomethane, acetone, and chloromethane. All VOC detections in groundwater samples were less than the RDLs. Detections of bromomethane, acetone, and chloromethane ranged from 0.41 to 0.67, 3.4 to 5.4, and 0.44 to 0.46 $\mu\text{g/L}$, respectively. Bromomethane, acetone, and chloromethane were also detected in blank samples with values ranging from 0.40 to 0.65 $\mu\text{g/L}$, 5.2 to 5.8 $\mu\text{g/L}$, and 0.43 to 0.55 $\mu\text{g/L}$, respectively. Perchlorate was not detected in any groundwater samples collected during the baseline period.

Surface-water data collected during the baseline period were strictly representative of a stream reach upgradient (SW-U) from the ARMD Facility. There was no streamflow evident at the time of sample collection at the three down-gradient surface-water sites. Stream discharge ranged from 0.03 to 0.08 cubic feet per second during sample collection, indicating flows were primarily groundwater in origin and not storm-related subsurface flow or surface runoff. The mean SC and pH for baseline samples collected at SW-U were 315 $\mu\text{S/cm}$ and 7.6, respectively. The relatively high SC for a forested basin and the slightly alkaline pH are reflective of the underlying limestone formation. No EPA established MCLs or SMCLs were exceeded for any constituents in samples collected from SW-U. Similar to groundwater results, some VOCs were detected in surface water at less than the RDLs. The VOCs detected in surface water were generally the same VOCs detected at less than the RDLs for groundwater. These were the same VOCs detected in blank water samples. Perchlorate was detected in each surface-water sample collected at SW-U, with a mean concentration of 0.07 $\mu\text{g/L}$. All perchlorate results were less than the RDL of 0.2 $\mu\text{g/L}$.

Soil samples collected near the ARMD Facility during the baseline period had only one constituent, arsenic (As), that exceeded EPA soil screening levels (SSLs). No soil medium-specific concentrations (MSCs) established by the Commonwealth of Pennsylvania were exceeded. Soil As concentrations ranged from 5.2 to 20.8 mg/kg. The EPA SSL for As is 3 mg/kg; however, EPA acknowledges that "Arsenic, aluminum, iron and manganese are common elements in soils that have background levels that may exceed risk-based SSLs."

The inorganic constituents most commonly detected were Fe and aluminum (Al), with mean Fe and Al concentrations ranging from 28,700 to 52,400 and 10,300 to 19,800 mg/kg, respectively. Four VOCs were detected in soil samples collected during the baseline period. None of the VOCs detected in the soils were within three orders of magnitude of any MSCs or SSLs. The VOCs detected in soil were dichloromethane (also known as methylene chloride), methyl tert-butyl ether (MTBE), tetrachloroethene, and acetone (only detected

once). Dichloromethane was the only VOC detected at greater than the RDL, with concentrations ranging from 1.9 to 50.1 $\mu\text{g/kg}$, all greater than the RDL. Dichloromethane was also detected at concentrations ranging from 2.5 to 4.5 $\mu\text{g/kg}$ in blank samples analyzed for soil samples.

MTBE was detected in 50 percent of soil samples collected, but all results were less than the RDLs of 2–3 $\mu\text{g/kg}$. However, matrix-spike results indicate that MTBE recoveries were less than the acceptable range for Sept. and Dec. 2016 samples. The maximum estimated MTBE value in a soil sample was 1.3 $\mu\text{g/kg}$. Tetrachloroethene was detected at less than the RDL in 20 percent of soil samples collected, with a maximum estimated concentration of 1.5 $\mu\text{g/kg}$.

References Cited

- ArcGIS, 2009, USA Topo Maps, accessed on various dates at <http://www.arcgis.com/home/item.html?id=99cd5fbd98934028802b4f797c4b1732>.
- Becher, A.E., and Taylor, L.E., 1982, Groundwater resources in the Cumberland and Contiguous Valleys of Franklin County, Pennsylvania: Harrisburg, Pa., Pennsylvania Geologic Survey, Water Resource Report 53, Fourth Series, 67 p.
- Berg, T.M., Edmunds, W.E., Geyer, A.R., and others, comps., 1980, Geologic map of Pennsylvania (2d ed.): Pennsylvania Geological Survey, 4th ser., Map 1, scale 1:250,000, 3 sheets, <https://mrdata.usgs.gov/geology/state/map.html>.
- Code of Federal Regulations (CFR), 2018, Title 40 Protection of Environment, Part 264 Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities, Subpart F Releases from Solid Waste Management Units, accessed August 28, 2018 at <http://www.ecfr.gov/cgi-bin/text-idx?SID=f253f25455f4fb6dd5cc40faf9f0cbaf&mc=true&node=sp40.26.264.f&rgn=div6>.
- Francy, D.S., Jones, A.L., Myers, D.N., Rowe, G.L., Eberle, M., and Sarver, K.M., 1998, Quality-assurance/quality-control manual for collection and analysis of water-quality data in the Ohio District: U.S. Geological Survey Water-Resources Investigations Report 98-4057, 71 p.
- Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice-Hall, Inc., 604 p.
- Galeone, D.G., 2019, Quality control and soil quality data in support of baseline environmental monitoring at the Ammonium Perchlorate Rocket Motor Destruction (ARMD) Facility at the Letterkenny Army Depot, Chambersburg, Pennsylvania, 2016: U.S. Geological Survey data release, <https://doi.org/10.5066/P973YRPL>.

- Greenberg, A.E., Clesceri, L.S., and Eaton, A.D., 1992a, Acidity—titration method, *in* Standard methods for the examination of water and wastewater (18th ed.): American Public Health Association, p. 2-23 to 2-25.
- Greenberg, A.E., Clesceri, L.S., and Eaton, A.D., 1992b, Solids, *in* Standard methods for the examination of water and wastewater (18th ed.): American Public Health Association, p. 2-53 to 2-58.
- National Oceanic and Atmospheric Administration, 2018a, NOWData monthly summaries, accessed May 10, 2019, at <http://w2.weather.gov/climate/xmacis.php?wfo=ctp>.
- National Oceanic and Atmospheric Administration, 2018b, National Weather Service Advanced Hydrologic Prediction Service, radar derived precipitation estimates, accessed May 10, 2019, at <https://water.weather.gov/precip/>.
- O'Dell, J.W., ed., 1993, Method 365.1: Determination of phosphorus by semi-automated colorimetry, Revision 2.0: Cincinnati, Ohio, Environmental Monitoring Systems Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, accessed December 13, 2017, at https://www.epa.gov/sites/production/files/2015-08/documents/method_365-1_1993.pdf.
- Pennsylvania Department of Environmental Protection, 2018, Statewide Health Standards, accessed May 15, 2019, at <https://www.dep.pa.gov/Business/Land/LandRecycling/Standards-Guidance-Procedures/Pages/Statewide-Health-Standards.aspx>.
- Pennsylvania State Climatologist, 2018, State wide data, accessed July 10, 2018, at <http://climate.psu.edu/data/state/regional.php#division4>.
- Pfaff, J.D., 1993, Method 300.0: Determination of inorganic ions by ion chromatography, revision 2.1: Cincinnati, Ohio, Environmental Monitoring Systems Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, accessed December 13, 2017, at https://www.epa.gov/sites/production/files/2015-08/documents/method_300-0_rev_2-1_1993.pdf.
- Redhorse Corporation, 2016, Environmental sampling plan—soil, groundwater, and surface water quality monitoring for the Ammonium Perchlorate Rocket Motor Destruction (ARMD) Facility: San Diego, Calif., Redhorse Corporation, prepared for Letterkenny Army Depot, revised May 2016, 58 p.
- Schultz, L.G., Tourtelot, H.A., Gill, J.R., and Boerngen, J.G., 1980, Composition and properties of the Pierre Shale and equivalent rocks, Northern Great Plains Region: U.S. Geological Survey Professional Paper 1064, 114 p. [Also available at <https://pubs.er.usgs.gov/publications/pp1064B>.]
- U. S. Department of Agriculture, 2018a, Natural Resource Conservation Service, Web Soil Survey: U.S. Department of Agriculture, accessed July 11, 2018, at <https://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx>.
- U. S. Department of Agriculture, 2018b, Soil Survey Manual, U.S. Department of Agriculture Handbook No. 18, 603 p.
- U. S. Environmental Protection Agency, 1994, EPA Method 7470A (SW-846)—Mercury in liquid wastes (Manual cold-vapor technique), revision 1: U.S. Environmental Protection Agency, accessed December 12, 2017, at <https://www.epa.gov/homeland-security-research/epa-method-7470a-sw-846-mercury-liquid-wastes-manual-cold-vapor-technique>.
- U. S. Environmental Protection Agency, 1996a, SW-846 Test Method 8260B—Volatile organic compounds by Gas Chromatography/Mass Spectrometry (GC/MS): U.S. Environmental Protection Agency, accessed December 12, 2017, at <https://www.epa.gov/hw-sw846/sw-846-test-method-8260b-volatile-organic-compounds-gas-chromatographymass-spectrometry>.
- U. S. Environmental Protection Agency, 1996b, Method 6010B—Inductively Coupled Plasma-Atomic Emission Spectrometry: U.S. Environmental Protection Agency, accessed December 13, 2017, at <http://www.caslab.com/EPA-Methods/PDF/EPA-Method-6010B.pdf>.
- U. S. Environmental Protection Agency, 1998a, Method 6020A (SW-846)—Inductively Coupled Plasma-Mass Spectrometry, revision 1: U.S. Environmental Protection Agency, accessed December 12, 2017, at <https://www.epa.gov/homeland-security-research/epa-method-6020a-sw-846-inductively-coupled-plasma-mass-spectrometry>.
- U. S. Environmental Protection Agency, 1998b, Method 7471B (SW-846)—Mercury in solid or semisolid waste (Manual cold-vapor technique), revision 2: U.S. Environmental Protection Agency, accessed December 13, 2017, at <https://www.epa.gov/homeland-security-research/epa-method-7471b-sw-846-mercury-solid-or-semisolid-wastes-manual-cold>.
- U. S. Environmental Protection Agency, 2007a, Method 6010C (SW-846)—Inductively Coupled Plasma-Atomic Emission Spectrometry, revision 3: U.S. Environmental Protection Agency, accessed December 12, 2017, at <https://www.epa.gov/homeland-security-research/epa-method-6010c-sw-846-inductively-coupled-plasma-atomic-emission>.

- U. S. Environmental Protection Agency, 2007b, Validated Test Method 6850—Perchlorate in water, soils and solid wastes using High Performance Liquid Chromatography/ Electrospray Ionization/Mass Spectrometry (HPLC/ESI/MS or HPLC/ESI/MS/MS): U.S. Environmental Protection Agency, accessed December 12, 2017, at <https://www.epa.gov/hw-sw846/validated-test-method-6850-perchlorate-water-soils-and-solid-wastes-using-high-performance>.
- U. S. Environmental Protection Agency, 2009, National Primary Drinking Water Regulations: U.S. Environmental Protection Agency, EPA-816-F-09-004, 6 p.
- U. S. Environmental Protection Agency, 2015, Regional screening level (RSL) summary table (TR=1E-06, HQ=1) November 2015: U.S. Environmental Protection Agency, accessed July 13, 2018, at <https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables>.
- U. S. Environmental Protection Agency (EPA), 2018, Regional Screening Level (RSLs) user's guide—November 2018: U.S. Environmental Protection Agency, accessed May 2, 2019, at <https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide>.
- U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A1–A9, accessed Aug. 1, 2016 at <http://pubs.water.usgs.gov/twri9A/>.

Appendix 1. Description of wells and constituent concentrations in groundwater samples from four wells at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.

Appendix_1.xlsx available for download at <https://doi.org/10.3133/ofr20191094>.

Appendix 2. Monthly ranges of volatile organic compounds in matrix-spike samples analyzed internally at ALS laboratory for soil samples submitted from the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.

Appendix_2.xlsx available for download at <https://doi.org/10.3133/ofr20191094>.

Appendix 3. Description of surface-water sites and constituents in surface-water samples collected near the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.

Appendix_3.xlsx available for download at <https://doi.org/10.3133/ofr20191094>.

Appendix 4. Description of soil sites and constituent concentrations in soil samples collected at the Ammonium Perchlorate Rocket Motor Destruction Facility at the Letterkenny Army Depot, Pennsylvania, September–December 2016.

Appendix_4.xlsx available for download at <https://doi.org/10.3133/ofr20191094>.

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