

# **Draft Interim Conceptual Site Model Site Investigation Report: Bennington, Vermont**

Prepared for  
Saint-Gobain Performance Plastics

December 2017

**12/15/2017 DRAFT [to be updated upon completion of  
bedrock investigation]**



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## Certifications

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Ray Wuolo	date
PE #: add PE number	Date

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## Acronyms and Abbreviations

<b>Abbreviation/ Acronym</b>	<b>Description</b>
AHC	Agglomerative Hierarchical Cluster analysis
bgs	below ground surface
CAAI	Corrective Action Area II
CAAs	Corrective Action Areas
CSM	conceptual site model
ELLE	Eurofins Lancaster Laboratories Environmental, LLC
EPA	U.S. Environmental Protection Agency
ES	Environmental Standards
$f_{oc}$	fraction of organic carbon
FSP	Field Sampling Plan
IDL	instrument detection limit
IDW	investigation derived waste
K	hydraulic conductivity
$K_{oc}$	organic carbon partitioning coefficient
$K_d$	distribution coefficient
MDL	method detection limit
MVA	multivariate analysis
NAVD88	North American Vertical Datum of 1988
ng/g	nanograms per gram
ng/L	nanograms per liter
PCBs	polychlorinated biphenyls
PFAS	per- and polyfluoroalkyl substances
PFBA	perfluorobutanoic acid
PFBS	perfluorobutanesulfonic acid
PFHxA	perfluorohexanoic acid
PFHxS	perfluorohexanesulfonic acid
PFHpA	perfluoroheptanoic acid
PFNA	perfluorononanoic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctanesulfonic acid
PFPeA	perfluoropentanoic acid
PFTeDA	perfluorotetradecanoic acid
PID	photoionization detector
POET	point-of-entry treatment system
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion

PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
SM	silty sand
SC	clayey sand
SP	poorly graded sand
SVOC	semivolatile organic compound
TAL	target-analyte-list
TOC	total organic carbon
TOP	total oxidizable precursor
VGS	Vermont Geological Survey
VOC	volatile organic compound
VTANR	Vermont Agency of Natural Resources
VTDEC	Vermont Department of Environmental Conservation
WWTP	wastewater treatment plant

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## Executive Summary

An investigation was conducted on behalf of Saint-Gobain Performance Plastics (Saint-Gobain) to further assess the distribution of per- and polyfluoroalkyl substances (PFAS) in soil and groundwater in an investigation area in and near the Town of Bennington and the Village of North Bennington, Vermont. Specific investigation objectives included:

- assessment of site hydrogeologic conditions;
- evaluation of the relationships and trends in PFAS concentrations;
- evaluation of potential impacts from the former Bennington Landfill;
- identification of some of the other potential sources of PFAS in the investigation area and measurement of background levels of PFAS present in soil and groundwater within the Corrective Action Areas (CAAs); and
- assessment of the measured distribution of PFAS in soil and groundwater against the predicted distribution based upon modeling of air emissions at the former Chemfab facilities.

The investigation was completed in accordance with the requirements of the Consent Order between the State of Vermont Agency of Natural Resources (VTANR) and Saint-Gobain dated October 2, 2017 and the *Revised Work Plan – CSM Site Investigation: Bennington, Vermont* (Work Plan; Barr, 2017a) approved by the Vermont Department of Environmental Conservation (VTDEC) as amended (VTDEC, 2017a; Barr, 2017b), with the following exception: investigation of groundwater conditions in the bedrock aquifer in the vicinity of the former Bennington Landfill is ongoing, and this report will be supplemented as data from that investigation are collected.

The investigation area includes two CAAs. As identified in the Consent Order, Corrective Action Area I generally consists of a bounded area west of Route 7 (Harwood Hill Road), and Corrective Action Area II (CAAII) generally consists of a bounded area east of Route 7. PFAS has been detected in groundwater at varying concentrations and in various locations, including some residential water wells, within both CAAs. Investigation activities described in this report were performed at locations primarily within the CAAs, but also at some locations beyond the CAA borders (e.g., background sample locations).

The investigation activities conducted to date have included installation of shallow and deep soil borings in unconsolidated materials located along transects between Bennington Landfill and the two former Chemfab facilities and in each cardinal direction from the former Chemfab Water Street facility. Four bedrock borings also were advanced into bedrock at or near Bennington Landfill, and will be completed as permanent monitoring wells. A total of 568 soil samples were collected from the borings and analyzed for PFAS, total organic carbon, soil pH, and moisture content. Soil samples from the deep soil borings and bedrock monitoring wells were also analyzed for metals and cations. Temporary wells were installed in 16 shallow soil borings and screened at or across the water table and permanent monitoring wells were completed in the unconsolidated aquifer at eight deep soil borings. All groundwater samples were analyzed for PFAS, metal/cations (excluding cyanide and mercury), anions, ammonia, orthophosphate, and total Kjeldahl nitrogen. Groundwater samples collected within the Bennington Landfill area were also analyzed for cyanide, mercury, volatile organic compounds, and 1,4-dioxane to assess the presence of

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landfill leachate impacts. Bedrock groundwater elevations were monitored by installing data-logging pressure transducers in existing bedrock monitoring wells at Bennington Landfill and in seven residential water wells completed in bedrock near the landfill. Slug testing was conducted to obtain estimates of hydraulic conductivity in seven permanent monitoring wells installed for the investigation. Hydraulic conductivity estimates were also obtained from analysis of grain-size distribution data for samples collected from investigation soil borings.

Findings associated with the investigation objectives include the following:

- hydrogeologic conditions are similar to those used in the conceptual site model (CSM);
- relationships and trends in current PFAS concentrations in CAAII soil and groundwater are not indicative of historical impacts from the former Chemfab facilities; and
- the measured soil concentrations across the investigation area are generally consistent with background concentrations and may also be indicative of localized sources of PFAS.

After accounting for background sources, the data collected as part of this investigation are consistent with the CSM. While measured PFAS concentrations were higher in some areas of CAAII than the model-predicted values, such differences may be largely attributed to the fact that the model did not account for background local, regional, and global sources of PFAS other than the former Chemfab facilities, some of which are identified in this report. For the purposes of assessing the effects of air emissions from the former Chemfab facilities, an evaluation of the site data indicate that additional investigations within the CAAs are not warranted. However, additional investigation by the appropriate regulatory agency to evaluate other potential local or regional sources, such as those identified in this report, may be appropriate.

# 1.0 Introduction

The investigation activities described herein were conducted on behalf of Saint-Gobain Performance Plastics (Saint-Gobain) and were completed in accordance with the requirements of the Consent Order between the State of Vermont, Agency of Natural Resources (VTANR) and Saint-Gobain dated October 2, 2017 (Consent Order) and the *Revised Work Plan – CSM Site Investigation: Bennington, Vermont* (Work Plan; Barr, 2017a) approved by the Vermont Department of Environmental Conservation (VTDEC) as amended (VTDEC, 2017a; Barr, 2017b). The work was performed by consulting staff from Barr Engineering Co., C.T. Male Associates, and Golder Associates.

The purpose of this investigation was to further assess the distribution of per- and polyfluoroalkyl substances (PFAS) in soil and groundwater in an investigation area encompassing the Village of North Bennington and portions of the Towns of Bennington and Shaftsbury, Vermont (Figure 1.1) to meet the following site-specific objectives:

- assess hydrogeologic conditions;
- evaluate relationships and trends in PFAS distribution, specifically in relation to perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS);
- evaluate potential impacts from the former Bennington Landfill;
- identify some of the other potential sources of PFAS within the investigation area and measure background levels of PFAS present in soil and groundwater within the Corrective Action Areas (CAAs); and
- assess the measured distribution of PFAS concentrations in soil and groundwater against the predicted distribution based upon modeling of air emissions from the former Chemfab facilities.

Data collected as part of this investigation were used to further refine the conceptual site model (CSM) of PFAS fate and transport developed for the area. The CSM is described in the *Draft Conceptual Modeling of PFOA Fate and Transport: North Bennington, Vermont* (Draft CSM Report; Barr, 2017c), and was developed using site data available prior to January 2017; chemical characteristics of PFAS; and modeling studies of processes important to PFAS fate and transport.

For the purposes of this investigation, the specific areas of interest within the investigation area included the former Bennington Landfill and the former Chemfab facilities on Water Street in North Bennington and on Northside Drive in Bennington (Figure 1.1). While there are other likely sources that have contributed to PFAS concentrations within the CAAs, some of which are identified in this report, the detailed investigation of such potential sources was beyond the scope of this report.

While investigation activities were completed at Bennington Landfill prior to submission of this interim report, additional investigation of the bedrock aquifer is ongoing, and this report will be supplemented after such data are collected. Access to the former Chemfab facilities was not available at the time of Work Plan development and approval, and therefore, no investigation activities were completed at these facilities as part of this investigation. However, additional investigation activities will be completed at these locations, pending access, and following the development and approval of associated investigation

work plans. Results from these additional investigation activities at the former Chemfab facilities will be reported separately, and submitted to VTDEC in accordance with the schedule presented in the Consent Order.

## 1.1 Investigation Objectives

As stated above, the purpose of this investigation was to further assess the distribution of PFAS in soil and groundwater at the site. These data were collected to meet the following site-specific investigation objectives identified in the Work Plan:

- **Assess site hydrogeologic conditions.** Additional information regarding the hydrogeologic conditions was collected in areas with limited or no available data, specifically for bedrock in the Bennington Landfill area.
- **Evaluate relationships and trends in PFAS concentrations.** Soil analytical results were evaluated to enhance the understanding of geochemical relationships for PFAS and determine what, if any, relationship exists between total organic carbon (TOC), metals, and PFAS concentrations. Soil and groundwater analytical results were evaluated for distributional relationships, such as spatial (depth or distance) or lithological (unconsolidated or bedrock).
- **Evaluate potential impacts from Bennington Landfill.** Monitoring wells were installed at the landfill to characterize groundwater flow directions in this area relative to nearby residential wells and to further assess the role of Bennington Landfill as a potential source of PFAS.
- **Identify other potential sources of PFAS within the investigation area and evaluate background conditions.** A preliminary evaluation of other potential PFAS sources in the investigation area was performed using available public records and data available prior to this investigation. In addition, samples were collected from areas alleged to not have been impacted by air deposition of PFAS from the former Chemfab facilities for the purpose of establishing background concentrations of PFAS in soil and groundwater resulting from regional and global sources.
- **Assess measured distribution of PFAS in soil and groundwater against the expected distribution.** For purposes of this report, soil analytical results from the upper unsaturated zone soils (O horizon and C horizon mineral zone beneath the root zone) and at depths to bedrock or the water table were used for comparison against the air deposition and unsaturated zone models. Similarly, groundwater results were evaluated against the modeled concentrations.

## 1.2 Report Organization

The remainder of this report is organized into the following sections:

- **Section 2.0 Background** – discussion of the site history; physical setting; characteristics of PFOA, PFOS, and associated compounds; and the PFOA fate and transport conceptual modeling approach and results.

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- **Section 3.0 Work Plan Implementation Activities and Results** – summary of the investigation activities and methods, including sample collection and analyses and deviations from the Work Plan; and discussion of the results of soil and groundwater sampling (including Quality Assurance/Quality Control (QA/QC), hydrogeologic investigation activities, and bedrock evaluation, including results from drilling, desktop and outcrop studies, and geophysical logging.
  - **Section 4.0 Analysis** – summary of the interpretation and analysis of the investigation data with respect to hydrogeologic conditions, geochemical relationships of PFAS in the soil and groundwater, potential additional PFAS sources, and the observed distribution of PFAS in soil and groundwater.
  - **Section 5.0 Summary** – discussion of findings as related to the objectives of the investigation.

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## 2.0 Background

The following discussion of background information relevant to this investigation is drawn primarily from the Draft CSM Report (Barr, 2017c). Additional detail not included in this section may be found in that document.

### 2.1 Site Description and History

For the purposes of this investigation, the site is an area of approximately 35 square miles in southwestern Vermont (Figure 1.1), encompassing the Village of North Bennington and portions of the Towns of Bennington and Shaftsbury. While it is likely that there are countless sources of PFAS within the investigation area, this investigation primarily focused upon the two former Chemfab facilities and Bennington Landfill. Background information and history for each of these is included below.

#### 2.1.1 Former Chemfab Facilities

The former Chemfab facilities are located on Northside Drive in Bennington and on Water Street in North Bennington (Figure 1.1). The Northside Drive facility operated from 1969 until mid-1978 when operations were transferred to the Water Street facility. The Water Street facility operated from mid-1978 until February 2002, when the plant closed. The facilities applied polytetrafluoroethylene (PTFE) coatings to some fiberglass fabrics. During drying and curing of certain fabrics, a small portion of the PFOA driven off the fabric may have been emitted from the facilities' stacks. PFOA is understood to be the only PFAS compound in the air emissions from the former Chemfab facilities. Modeling results presented in the Draft CSM Report (Barr, 2017c) suggest that air emissions of PFOA from the former Chemfab facilities contributed some PFOA, in varying amounts, to groundwater in certain portions of the investigation area.

#### 2.1.2 Bennington Landfill

Bennington Landfill, shown on Figure 1.1, is a closed landfill that received municipal sanitary waste from the Town of Bennington from 1969 until 1987 (U.S. EPA, 2004). Historical records indicate that polychlorinated biphenyls (PCBs), volatile organic compounds (VOCs), and lead were disposed of in the landfill. Several industries in the Bennington area dumped liquid wastes into an unlined lagoon at the landfill from 1969 to 1975. An underdrain was installed in 1976 to dewater the unlined lagoon (McLaren/Hart, 1997). This underdrain was extended to the north in 1979-1980 as waste was disposed of in that area. A treatment system was eventually installed to treat leachate collected by the underdrain. The treated leachate was infiltrated on site. The landfill was graded and capped by 1999 and other measures were taken to reduce production of leachate. The leachate treatment system was decommissioned in 2008. Since 2008, untreated leachate has been collected in a storage vault, pumped out of the vault when leachate levels are high, and treated and disposed of off site (VTANR, 2016).

Leachate from Bennington Landfill has been shown to have contaminated surface water and groundwater with PCBs and VOCs. The facility was listed as a Superfund site in 1989 for this reason (U.S. EPA, 2004). Constituents monitored in the landfill leachate and monitoring wells include PCBs and VOCs. Monitoring for PFOA and other PFAS compounds was not undertaken until an investigation in March and April of



2016 (Weston Solutions, Inc., 2016), during which PFOA was measured at concentrations ranging from 5,300 parts per trillion (ppt) in the leachate vault to non-detect (< 2 ppt) in the two bedrock wells sampled (B-2-3 and B-6-3). A subsequent monitoring event at non-bedrock monitoring wells was performed on behalf of the U.S. Environmental Protection Agency (EPA) in 2017 as part of a larger investigation, and included completion of soil borings and monitoring wells and collection of soil and groundwater samples in the southwestern portion of the landfill area (Weston Solutions, Inc., 2017). Sample splits were collected by Saint-Gobain representatives during this monitoring well sampling event. The results of that investigation are discussed in this report.

## **2.2 Physical Setting**

The regional and site geology and hydrogeology are described in the following sections. Additional data related to the physical setting were collected during this investigation and an interpretation of the geology and hydrogeology within the investigation area is presented in Section 4.1 and Section 4.2, respectively.

### **2.2.1 Regional Geology and Hydrogeology**

The investigation area is located in the Northeastern Appalachians groundwater region (Randall et al., 1988). The following regional geology and hydrogeology summary is condensed from that resource.

The Northeastern Appalachians groundwater region is characterized by rolling topography that primarily reflects the weathered bedrock surface with glacial and fluvial landforms mantling the bedrock. The bedrock consists of folded and faulted metamorphosed sedimentary rocks with low primary porosity. Water is conducted in the bedrock through secondary porosity. In some rock types, such as those in the North Bennington area, the secondary porosity is enhanced and enlarged by dissolution. The frequency and permeability of secondary porosity typically decreases with depth. Most bedrock wells in the region are between 200 and 400 feet deep.

Glacial erosion and deposition produced changes in drainage and topography and deposited a nearly continuous layer of unconsolidated till over the bedrock. Stratified drift units, chiefly sand and gravel, are associated with the larger valleys such as those of the Walloomsac River.

Recharge to the bedrock is controlled by the permeability and thickness of the overlying glacial deposits and overburden. Runoff in upland areas is focused to seasonal streams that typically lose discharge in areas in which they flow over stratified drift at the margins of the larger valleys. Bedrock wells that are pumped continuously may receive pumping-induced recharge from adjacent stratified drift aquifers. Discharge is primarily from the bedrock to wells and to the stratified drift in the large valleys. Inter-basin flow systems with significant discharge have not been discovered in the bedrock.

In addition to discharge to the stratified drift filling the larger valleys from minor upland streams, recharge to these units is from direct infiltration of precipitation, and discharge from bedrock. Recharge from the larger rivers may take place in the case of localized pumping from the stratified drift or higher-than-

normal river stage. Discharge from the stratified drift is via pumping wells, evapotranspiration, and to the larger rivers when their stage is at or below typical levels.

## 2.2.2 Groundwater Use in the Investigation Area

Groundwater use in the investigation area is primarily from private wells. No high-capacity industrial or commercial wells were identified from available information on water use and well construction. The municipal water sources for the Town of Bennington are Morgan Spring and Bolles Brook, which are spring and stream source types, respectively (Town of Bennington, 2016). The municipal water sources for the Village of North Bennington are supply wells near the surface-water intake on Basin Brook, which is located in Shaftsbury (VTDEC, 2016). PFOA has not been detected in these municipal water supplies (Barr, 2017c).

## 2.3 Characteristics of PFOA, PFOS, and Associated Compounds

PFOA is one of a class of fluorinated hydrocarbon compounds associated with fluoropolymers – most commonly recognized as Teflon®. Like PFOA, PFOS is a “C8” PFAS, possessing eight carbon atoms, each attached to two fluorine atoms. PFOA was manufactured by 3M and DuPont in the United States until its production was phased out between 2002 and 2006. PFOS was manufactured by 3M using an electrochemical fluorination process until 2002. Since that time, shorter-chain PFAS have been used.

PFOA and PFOS were used in the manufacture of many commercial materials for industrial and residential use, including stain-resistant carpeting/furniture/upholstery, non-stick cookware, food package coatings, aqueous film-forming foams, moisture-resistant breathable fabrics, concrete and rock sealants, electrical capacitors, dyes, paints and coatings, ski wax, batteries, photographic films, printing inks, herbicide and pesticide formulations, car wash surfactants, and as a vapor suppressor in metal plating processes (Kissa, 2001; 3M, 1999; Knepper and Langué, 2012; Olsen, 2015). They are a ubiquitous presence in most households and consequently are found in municipal waste streams and in most landfills (Busch et al., 2009; MPCA, 2009). In some manufacturing processes, PFOA is used and may be released to the environment through air emissions. They are also found in biosolids, in part from municipal sewer sludge used as amendments to soil in agricultural and landscaping applications, including gravel pit reclamation (Sepulvado et al., 2011; NEBRA, 2014).

PFOA and PFOS are highly soluble in water and are resistant to degradation. They adsorb poorly to material with low organic material content, and where they bond, it is to surfaces of organic material. In saturated, unconsolidated deposits and fractured rock media, they are mobile and migrate as an unattenuated solute in flowing groundwater. In general, they are considered “conservative” solutes because the compounds’ conservation of mass is confined to the dissolved phase and the compound is not substantially converted to other forms. Very small sources of PFOA and PFOS can result in detections in groundwater in the ppt and parts per billion (ppb) range.

Perfluoroalkyl carboxylates, the class of PFAS containing PFOA, are stable in water, sediment, and soil under natural conditions (Kissa, 2001). As a result, longer-chained perfluoroalkyl carboxylates are not known to degrade into PFOA in these media in the environment. PFOA is itself a degradation product of

perfluoro alcohols. The perfluoro alcohols that degrade to PFOA are volatile and may be emitted into the atmosphere as part of various chemical manufacturing processes. Consequently, PFOA is found worldwide at low levels (Strynar et al., 2012; Rankin et al., 2016).

Several studies have quantified the structure-activity relationships between the length of linear PFAS and transport potential through soil columns (Higgins and Luthy, 2006; Zhang et al., 2013; Gellrich et al., 2012; Hirata-Koizumi et al., 2015). Perfluorotetradecanoic acid (PFTeDA) and other longer-chained fluorocarbons also have a much higher partition coefficient with respect to organic carbon, resulting in very low mobility in the soil column which prevents them from migrating to groundwater (which likely explains why they are not detected in deeper soils or groundwater where they were detected in shallow soils). Thus, compared to PFOA, PFTeDA and other long-chain linear PFAS found in organic soils are less likely to affect groundwater because of their inability to percolate through soil columns.

## **2.4 PFOA Fate and Transport Conceptual Modeling Approach and Results**

For purposes of the Draft CSM Report (Barr, 2017c), numerical models were developed to simulate PFOA transport and migration from points of release at the former Chemfab facilities to the groundwater-flow system and private wells. Given the limited amount of hydrogeologic data and some uncertainties in sources of PFOA, the modeling approach constituted a conservative, regional evaluation. The simulations allowed for a quantitative and physically-based assessment of the mechanisms that could potentially result in detectable PFOA concentrations in soils and groundwater in areas at distance from the release points.

For purposes of the Draft CSM Report (Barr, 2017c), the complete PFOA transport pathway was simulated to assess the possibility of transport from source to potential receptors. As indicated above, these transport paths are through air, unsaturated soil and other unconsolidated materials, and saturated aquifer materials. No single model in standard practice exists that can account for transport through these different media. Therefore, transport was simulated by a series of distinct models, with the output of one or more models serving as input for the model simulating the next segment of the transport pathway. Each of these individual models is a widely accepted tool for the transport pathway for which it was applied. Assumptions and limitations in the modeling approach are described in the Draft CSM Report (Barr, 2017c). For purposes of the Draft CSM Report (Barr, 2017c), the only sources of PFOA that were evaluated were air emissions from the two former Chemfab facilities—other local sources and regional or worldwide deposition sources were not part of the modeling evaluation.

The primary findings of the conceptual modeling were that the distribution of PFOA measured in private wells could not be explained solely by air emissions from the former Chemfab facilities, and that such emissions would not have potentially produced PFAS concentrations above 20 ppt in private wells in Corrective Action Area II (CAAI).

## 3.0 Work Plan Implementation Activities and Results

The Work Plan (Barr, 2017a) was implemented through soil and bedrock boring advancement, temporary and permanent monitoring well installation, collection and laboratory analysis of soil and groundwater samples, groundwater elevation monitoring, and hydraulic conductivity testing. In addition, a bedrock study in the vicinity of Bennington Landfill is underway and this interim report will be supplemented once such study is completed. The work was performed to assist in meeting the following study objectives:

- Assess site hydrogeologic conditions.
- Evaluate relationships and trends in PFAS concentrations.
- Evaluate potential impacts from the former Bennington Landfill.
- Identify other potential sources of PFAS in the investigation area and measure background levels of PFAS present in soil and groundwater.
- Assess the measured distribution of PFAS in soil and groundwater against the expected distribution.

Investigative activities commenced on August 12, 2017, following approval of the Work Plan by VTDEC (VTDEC, 2017a). The field activities were performed between August 14 and *[Date to be updated upon completion of scope of work]*, and the field methods were generally consistent with the Work Plan with the exception of minor deviations described in Appendix A and discussed in Section 3.6.

A summary of the investigation locations, soil samples collected, and well construction details are provided in Table 3.1, Table 3.2, and Table 3.3, respectively. Field investigation documentation including soil boring logs, field notes, well construction logs, and photographs from the investigation are provided in Appendix A. Analytical methods are summarized in Table 3.4. Laboratory reports are included in Appendix B, and a summary of QA/QC results is provided in Appendix C. Statistical evaluation of the soil and groundwater analytical data was conducted as part of this investigation and is included in Appendix D.

### 3.1 Unconsolidated Soil Characterization

Locations of background and shallow unconsolidated investigation borings are shown on Figure 3.1. Locations of deep unconsolidated investigation borings are shown on Figure 3.2. When considering the shallow and deep soil borings together, borings were placed in an approximate grid pattern across the investigation area. The grid sampling concept was proposed to allow the greatest flexibility in interpreting results as a function of distance in any direction from a feature of interest. Access restrictions resulted in minor deviations to this approach.

Soil samples were collected from each soil boring for geologic characterization, field screening, and laboratory analysis. Geologic characterization included classifying material using the visual and manual test methods described in ASTM D-2488, Standard Practice for Description and Identification of Soils (Visual/Manual). Field screening included classification of soils in accordance with the methods in the Field Sampling Plan (FSP) included as part of the Work Plan (Barr, 2017a), and visually examining the soil

samples; recording observations of moisture, odor, and discoloration; and determining the presence of organic vapors with a photoionization detector (PID) equipped with a 10.6-electron-volts lamp. Laboratory analysis of soil samples was completed at the locations and for the parameters identified in Table 3.2 and was completed in accordance with the Quality Assurance Project Plan (QAPP; CT Male, 2016) and QAPP Addendum included as part of the Work Plan (Barr, 2017a).

Soil samples were collected for laboratory analysis in general accordance with the Work Plan. In general, soil samples were collected for laboratory analysis from investigation borings at selected intervals: 0-0.5 feet below ground surface (bgs), 0.5-1 feet bgs, 1-1.5 feet bgs, 3-4 feet bgs, 8-9 feet bgs, and at 10-foot intervals to the terminus of the boring at the water table or bedrock, whichever was shallower. If saturated soil was encountered at a depth of less than 8 feet, a sample was collected from just above the observed groundwater level. If refusal was encountered at a depth of less than 8 feet, a sample was collected at the terminus of the boring, unless refusal was encountered at depths less than 4 feet bgs, in which case additional attempts were made within the vicinity of the originally proposed location. Additional soil samples were also collected if highly organic soils were encountered or if field screening identified signs of obvious environmental impacts.

Laboratory analytical services were provided for soil samples, grain-size distribution samples, and water samples by Eurofins Lancaster Laboratories Environmental, LLC (ELLE) of Lancaster, Pennsylvania in accordance with the QAPP (CT Male, 2016) and the QAPP Addendum attached to the Work Plan (Barr, 2017a). Laboratory reports are included in Appendix B. The analytical data QA/QC reviews are in Appendix C. As requested by VTDEC in comments on the revised Work Plan (VTDEC, 2017a), additional soil samples were analyzed for grain-size distribution using ASTM D422 (Standard Test Method for Particle-Size Analysis of Soils) to allow interpretation of soil type and estimation of hydraulic conductivity. The sample intervals for grain-size distribution analysis were selected to represent the range of lithologies observed in the soil borings.

### **3.1.1 Background Soil Borings**

Background soil borings were completed to evaluate local background concentrations of PFAS in soil. The boring locations were selected in consultation with VTDEC and were placed near sampling locations previously completed by VTDEC during a statewide study of the background concentrations of polycyclic aromatic hydrocarbons (PAHs), arsenic, and lead in surface soils (VTDEC, 2017b). The borings were placed in Shaftsbury State Park, Woodford State Park, Molly Stark State Park, and at the Lake Raponda boat launch area (Figure 3.1).

Four shallow soil borings (BG1 to BG4) were installed using direct-push drilling methods (i.e., Geoprobe®) within the unconsolidated materials and continuously logged to depths ranging from 3.5 to 10 feet bgs. The Work Plan specified collection of an analytical soil sample at a depth of 8 feet bgs or groundwater (whichever was shallower). Background soil borings BG1 and BG2 were advanced to 10 feet bgs to obtain a sufficient volume of soil for analysis; boring BG3 encountered refusal at 3.5 feet bgs and multiple additional attempts in the vicinity were unsuccessful; and BG4 encountered groundwater at 8 feet bgs.

No odor, sheen, or discolored soil was observed during field screening. Headspace readings were measured below background at all locations.

A total of 18 soil samples were collected and analyzed for PFAS, TOC, soil moisture, and soil pH (Table 3.5). Soil analytical results from samples collected at background locations are shown on Figure 3.3, Figure 3.4, and Figure 3.5 for PFOA, PFOS, and TOC, respectively. PFOA was detected above the method detection limit (MDL) in ten samples at concentrations ranging from 0.37 to 7.2 nanograms per gram (ng/g), and PFOS was detected above the MDL in four samples at concentrations ranging from 0.42 to 1.1 ng/g. The highest concentrations of PFOA and PFOS (7.2 and 1.1 ng/g, respectively) were detected in a sample collected from surface soils in boring BG2 located near a hiking/skiing trail in Woodford State Park, approximately 7 miles east of the investigation area (Figure 3.3 and Figure 3.4). As shown on Figure 3.6, PFOA and perfluorobutanoic acid (PFBA) were the most frequently detected of the PFAS compounds in samples from background locations.

The concentrations of PFOA and TOC from the four background soil borings were compared to background soil concentrations collected from across North America. The purpose of this evaluation was to assess whether the background samples collected during this investigation were representative of known background conditions in North America. The results of this evaluation are provided in Appendix D and an interpretation of the background soil analytical evaluation is in Section 4.4.1.

### **3.1.2 Shallow Soil Borings**

As shown on Figure 3.1, a total of 46 shallow soil borings (S1 to S14, S11-2, S16, S18, S20 to S22, S24 to S49) were installed within the unconsolidated materials using hand auger or direct-push drilling methods (i.e., Geoprobe®) along an approximate grid across the site (when taking into account deep borings and access issues). In general, shallow borings were planned to be advanced to depths of 8 feet bgs or until reaching saturated conditions, whichever was shallower; however, because the Work Plan specified collection of an analytical soil sample at a depth of 8 feet bgs from each shallow boring, final boring depths of up to 10 feet bgs were common in order to obtain a sufficient volume of soil for analysis.

No odor, sheen, or discolored soil was observed during field screening at these borings with the exception of boring S02, where both a sheen and odor were noted at a depth of 1.5 feet bgs. Headspace readings were measured above background in soils from seven borings (S02, S11, S11-2, S14, S21, S27, and S38) and PID readings in these borings ranged from 5.3 to 35 parts per million (ppm). Elevated headspace readings at borings S11 and S14 appear to have been sourced by equipment interference (i.e., elevated ambient air readings inside empty headspace bags) and are likely not representative of actual conditions.

A total of 214 soil samples were collected from shallow borings and analyzed for PFAS, TOC, soil moisture, and soil pH (Table 3.6). Due to elevated organic vapor concentrations, petroleum odors, and potential staining in samples from S02 (0.5-1 feet bgs) and S02 (1-1.5 feet bgs), location S02 was resampled and analyzed for volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), PCBs, and pesticides. Results of these additional analyses show no elevated concentrations to suggest an environmental impact (Table 3.7). Soil analytical results for shallow soil borings are shown on Figure 3.7,

Figure 3.8, and Figure 3.9 for site-wide PFOA, PFOS, and TOC, respectively, and on Figure 3.10, Figure 3.11, and Figure 3.12 for Bennington Landfill-specific PFOA, PFOS, and TOC, respectively.

PFOA was detected above the MDL in 120 shallow soil boring samples at concentrations ranging from 0.17 to 130 ng/g, and PFOS was detected above the MDL in 73 samples at concentrations ranging from 0.32 to 17 ng/g. The highest PFOA and PFOS concentrations were detected in samples collected from shallow soils in borings S20 and S29. The samples from these borings were collected from the organic soil and peat in a wetland area east of Bennington Landfill. The TOC concentrations in these samples were also the highest measured during this investigation, with measured concentrations up to 512,000 mg/kg (Figure 3.9). As shown on Figure 3.13, PFOA and PFOS were the most frequently detected of the PFAS compounds in shallow soil borings, but only just over half of the samples had a detected PFAS compound.

### 3.1.3 Deep Soil Borings

Deep soil borings were located along transects between Bennington Landfill and the former Chemfab facilities and in each cardinal direction from the Water Street facility (Figure 3.2). The locations were intended to target areas that have been undisturbed since the late 1960s; were away from potential PFAS sources that may have been associated with the former Chemfab facilities; and for which access could be obtained. Access restrictions resulted in the majority of soil borings being placed within public rights-of-way along roadways, where disturbance of the shallow soil layers may have occurred since the late 1960s.

A total of 25 deep soil borings (D01 to D03 and D05 to D26) were advanced within the unconsolidated materials to bedrock or the water table (whichever was shallower) using rotosonic drilling methods and logged continuously to depths ranging from 10 to 200 feet bgs. Four of the scoped deep borings (D06, D08, D14, D19) were completed to shallow depths (between 10 and 20 feet bgs) after groundwater and/or bedrock was encountered.

No odor, sheen, or discolored soil was observed during field screening for these borings. Headspace readings were measured above background (i.e., 5.0 ppm) in soils from seven borings (D03, D05, D06, D07, D10, D11, D20, and D23) and PID readings in these borings ranged from 5.3 to 23 ppm. Elevated headspace readings at borings D03 and D05 appear to have been sourced by equipment interference (i.e., elevated ambient air readings inside empty headspace bags) and are likely not representative of actual conditions.

A total of 336 soil samples were collected from deep soil borings and analyzed for PFAS, TOC, soil moisture, and soil pH (Table 3.8). Of these 336 soil samples, 190 samples from deep borings were also analyzed for target-analyte-list (TAL) metals. Due to elevated organic vapor concentration and potential staining in sample D20 (78 to 79'), this sample was also analyzed for VOCs, SVOCs, PCBs, and pesticides (Table 3.7). Soil analytical results from samples collected from deep borings are shown on Figure 3.7, Figure 3.8, and Figure 3.9 for site-wide PFOA, PFOS and TOC, respectively and on Figure 3.10, Figure 3.11 and Figure 3.12 for Bennington Landfill-specific PFOA, PFOS and TOC, respectively.

PFOA was detected above the MDL in 80 samples at concentrations ranging from 0.16 to 7.2 ng/g and PFOS was detected above the MDL in 34 samples at concentrations ranging from 0.28 to 16 ng/g. The

highest PFOA concentrations were detected in samples collected from shallow soils in boring D05 located approximately 0.7 miles north of the former Water Street facility. The highest PFOS concentrations were detected in samples collected from shallow soils in borings D08 and D10 located at Bennington Landfill. The detection frequency plots on Figure 3.14 show that while PFOA and PFOS were the most frequently detected of the PFAS compounds in samples from deep soil borings, approximately two-thirds of samples had no detected PFAS parameters. This high proportion of non-detects relative to the shallow soil borings is a result of the greater depths of sample collection; the vertical distribution of PFAS is evaluated and discussed in more detail in Section 4.3.1.2.

### **3.1.4 Comparison of Landfill to Non-Landfill Results**

Shallow and deep unconsolidated borings completed in Bennington Landfill and outside the landfill were sampled and analyzed as described above. Analytical data discussed above and summarized on Table 3.6 and Table 3.8 for shallow and deep soil borings, respectively, are also presented in Table 3.9 and Table 3.10 for non-landfill and landfill locations, respectively.

A total of 318 soil samples were collected from outside the landfill and analyzed for PFAS, TOC, and soil pH (Table 3.9). Of these 318 soil samples, 126 samples from deep soil borings were also analyzed for TAL metals. Soil analytical results are shown on Figure 3.7, Figure 3.8, and Figure 3.9 for PFOA, PFOS and TOC, respectively. PFOA was detected above the MDL in 151 samples at concentrations ranging from 0.18 to 12 ng/g. PFOS was detected above the MDL in 71 samples at concentrations ranging from 0.28 to 4.4 ng/g. The highest PFOA concentrations were detected in samples collected from shallow soils in boring S33 located along Harwood Hill Road (Route 7), approximately 1.7 miles east of the former Chemfab Water Street facility (Figure 3.7) and ranged from 10 to 12 ng/g. The highest PFOS concentration (4.4 ng/g) was detected in a sample collected from surface soils in boring S46, located in the southern portion of the investigation area (Figure 3.8). PFOA and PFOS were the most frequently detected of the PFAS compounds in samples from non-landfill locations.

A total of 232 soil samples were collected from the landfill and analyzed for PFAS, TOC, and soil pH (Table 3.10). Of these 232 soil samples, 175 samples from deep soil borings and bedrock monitoring well borings were also analyzed for TAL metals. Soil analytical results from samples collected at the landfill are shown on Figure 3.10, Figure 3.11, and Figure 3.12 for PFOA, PFOS and TOC, respectively. PFOA was detected above the MDL in 54 samples at concentrations ranging from 0.16 to 130 ng/g and PFOS was detected above the MDL in 39 samples at concentrations ranging from 0.28 to 17 ng/g. The highest PFOA and PFOS concentrations were detected in samples collected from shallow soils in borings S20 and S29. The samples from these borings were collected from the organic soil and peat in a wetland area east of the landfill. The TOC concentrations in these samples were also the highest measured during this investigation. PFOA and PFOS were the most frequently detected of the PFAS compounds in samples from the landfill.

## **3.2 Bedrock Characterization**

Characterization of the bedrock is ongoing. This report will be supplemented once the bedrock investigation has been completed.



### 3.2.1 Bedrock Borings

*[This section will be finalized once the bedrock investigation has been completed.]*

### 3.2.2 Borehole Geophysics

*[This section will be finalized once the bedrock investigation has been completed.]*

### 3.2.3 Bedrock Desktop Review and Outcrop Study

A desktop review of available information regarding the bedrock geology, an outcrop mapping analysis, and a photo lineament analysis were performed for the area around Bennington Landfill. The discussion below is a summary of the study methods and results that are discussed in detail in Appendix E. The objectives of this work were to guide placement of bedrock borings and monitoring wells near the landfill along any potential preferential groundwater flow paths, to verify recent Vermont Geological Survey (VGS) geologic mapping of the area, to collect geologic, hydrogeologic, and rock mass discontinuity data at the outcrop-level scale, and to collect lineament trend data at a larger scale.

Candidate outcrop locations were identified through the desktop review of the recent geologic mapping by VGS (e.g., Kim, 2017), the Remedial Investigation Report documents for Bennington Landfill (McLaren/Hart, 1997), and other regional geologic reports. Candidate outcrop locations were further screened using Google Earth's Street View to identify outcrop locations that were publicly accessible. Outcrops of the Cambrian Cheshire Formation quartzite were identified and quartz veins filling joints were noted at the outcrops. Ogden (1969) described quartz veins in the Cheshire Formation quartzite associated with the kaolin deposits in the Cheshire Formation near Monkton, VT. Ogden (1969) also noted that several kaolin deposits have been identified along the western base of the Green Mountains from Bennington to East Monkton. All of the deposits are in a zone of faulting. Kaolin in the Cheshire Formation quartzite arising from hydrothermal alteration appears to be consistent with available information regarding the stratigraphic position and chemical composition of these deposits. Previous work at Bennington Landfill indicated weathering as the source of alteration of bedrock beneath the landfill. For example, McLaren/Hart (1997) described a weathered zone on the bedrock ranging from 0 to greater than 150 feet in thickness and classified it as a saprolite (clay-rich rock formed by chemical weathering of igneous or metamorphic rock; AGI, 1976).

The outcrop mapping analysis consisted of photographing the outcrops studied, compiling lithologic descriptions, taking representative lithologic samples, and mapping discontinuities in the rock masses. Discontinuity types included bedding-plane fractures, joints, faults, and mineralized veins. Discontinuity characteristics that were documented include the type, orientation, persistence, aperture, infilling material (if present), shear strength of infilling material, surface roughness, shape, presence of water, and spacing. The outcrop study identified one bedding plane discontinuity set and two primary joint sets. Bedding-plane strikes are predominantly northeasterly, with dips both toward the southeast and northwest at angles ranging from 3 to 32 degrees. A broad, open anticline was mapped with its axis located west of the landfill. Joint sets J1 and J2 have azimuths of approximately 21 and 306 degrees azimuth. Joint and bedding-plane discontinuity spacing ranges from 0.04 feet to 5 feet. Joint and bedding-plane persistence

(lateral and vertical continuity) on the outcrops examined ranges up to 50 feet. Bedding-plane apertures average 0.3 inches and the apertures of joint sets J1 and J2 average 0.7 and 1.2 inches, respectively.

The photo lineament analysis identified possible joint sets at the regional level and compared their orientations with those measured in the outcrop study with the results of a similar study conducted for the investigation of the landfill (McLaren/Hart, 1997). An area around Bennington Landfill with an approximate radius of 12,500 feet was studied as part of the desktop review and outcrop study. The photo lineament analysis identified two predominant lineament directions: 44 and 311 degrees azimuth. These lineaments correspond with the J1 and J2 joint sets identified in the outcrop study. Spacing between these lineaments ranges from 100 to 1,400 feet and 300 to 4,000 feet, respectively. Representative orientations, based on combined information from the outcrop and lineament analyses for the J1 and J2 joint sets, are 33 and 310 degrees azimuth. These orientations are projected from the limits of the capped portion of Bennington Landfill in Figure 3.15 to show alignment of the joint sets relative to investigation locations in the landfill area.

The results of the outcrop study and lineament analysis support the simulation of the bedrock using an equivalent porous medium approach for the purposes of the conceptual modeling described in the Draft CSM Report (Barr, 2017c). These results include near-vertical joint and near-horizontal bedding-plane discontinuities which are interconnected, have average apertures ranging from 0.3 to 1.2 inches, and have spacings that are small, relative to the extent of the model domain (142 square miles).

### **3.3 Groundwater Characterization**

Groundwater characterization is ongoing, and this report will be supplemented once the investigation of the bedrock aquifer has been completed.

To date, groundwater samples have been collected from permanent and temporary unconsolidated monitoring wells and existing Bennington Landfill monitoring wells. A leachate sample also was collected from the Bennington Landfill leachate vault. A summary of the groundwater sampling locations, including well construction details, is provided in Table 3.3. Locations of shallow (temporary) and deep (temporary and permanent) monitoring wells are shown on Figure 3.1 and Figure 3.2 and locations of bedrock monitoring wells (including those still to be completed and sampled) are provided on Figure 3.15. Additional supporting information associated with the monitoring well installation is included in Appendix A. Permanent monitoring wells installed during this investigation were installed by a Vermont-licensed well contractor and were constructed in accordance with VTDEC well code. Prior to sampling, monitoring wells were developed using a combination of surging and pumping to remove fines from the well screen.

Groundwater samples were collected following methods described in the FSP. Groundwater samples were analyzed for PFAS, TAL metals/cations (excluding cyanide and mercury), anions, ammonia, orthophosphate, and total Kjeldahl nitrogen. Groundwater samples collected within the Bennington Landfill area were also analyzed for cyanide, mercury, VOCs, and 1,4-dioxane. The analytical methods for each of the analyte groups for groundwater were consistent with those listed in the Work Plan and

Table 3.4. The analytical method for PFAS was a modified version of EPA Method 537, to allow for the analysis of other matrices.

Following installation and sampling of wells completed as part of this investigation, hydraulic conductivity testing was completed and the groundwater elevation was measured. Hydraulic conductivity testing consisted of slug testing and an evaluation of grain-size distribution samples. Groundwater elevations were collected using manual measurements and data-recording pressure transducers.

Groundwater analytical results for groundwater samples collected outside of Bennington Landfill and at Bennington Landfill can be found in Table 3.11 and Table 3.12, respectively. Non-landfill groundwater analytical data are shown on Figure 3.16 and Figure 3.17 for PFOA and PFOS, respectively, and Bennington Landfill groundwater data are shown on Figure 3.18 and Figure 3.19 for PFOA and PFOS, respectively.

### **3.3.1 Shallow Unconsolidated Groundwater Sampling**

One groundwater sample was collected from a temporary well installed at a background location (BG4). Groundwater was not encountered at any of the other three background locations over the depth of the shallow soil boring. Only PFOA and perfluoroheptanoic acid (PFHpA) were detected in the temporary monitoring well installed in boring BG4, at concentrations of 6 and 0.9 J nanograms per liter (ng/L), respectively (Table 3.11).

Groundwater analytical results for the shallow unconsolidated samples are summarized in Table 3.11 and Table 3.12 for non-landfill and landfill locations, respectively. Temporary wells were installed in 14 shallow soil borings (S01, S03, S04, S08, S10, S16, S21, S24, S28, S34, S37, S41, S42, and S49) and groundwater samples were collected from each well screened at or across the water table. PFOA was detected in all samples from shallow boring temporary wells at concentrations ranging from 5 to 850 ng/L. PFOS was detected in eight samples at concentrations ranging from 2 to 23 ng/L. The highest groundwater concentration of PFOA was detected in temporary well S34 located on the eastern side of CAII, along the Walloomsac River and north of VT 279 (Figure 3.1). The highest groundwater concentration of PFOS was detected in temporary monitoring well S03 located beyond the northern boundary of CAII, near Shaftsbury (Figure 3.1). Detection frequency plots show that PFOA, PFHpA, and perfluorohexanoic acid (PFHxA) were the most frequently detected PFAS compounds in groundwater samples collected from shallow wells (Figure 3.20).

### **3.3.2 Deep Unconsolidated Groundwater Sampling**

Groundwater samples were collected from the deep unconsolidated groundwater at temporary wells installed in two borings (D03, D13) and from eight deep soil borings after they were converted into permanent monitoring wells (SG3-MW17-01 to SG3-MW17-07, SG3-MW17-WWTP). The eight permanent monitoring wells completed in deep soil borings were screened at or across the water table. Note that for purposes of this report, the soil borings in which permanent monitoring wells were installed typically have a different name than their associated monitoring well. For example, monitoring well SG3-MW17-01 was constructed in soil boring D06. The relationship between soil boring and monitoring well names is summarized in Table 3.1.

Groundwater analytical results for the deep unconsolidated samples are summarized in Table 3.11 and Table 3.12, for non-landfill and landfill, respectively. PFOA was detected in samples from all of the deep unconsolidated groundwater wells at concentrations ranging from 8 to 240 ng/L. PFOS was detected in seven of the deep unconsolidated groundwater wells at concentrations ranging from 2 to 10 ng/L.

The highest concentrations of PFOA and PFOS in the deep unconsolidated groundwater (240 and 10 ng/L, respectively) were at temporary well D03, located 1.2 miles north of the former Chemfab Water Street facility. Detection frequency plots show that PFOA, PFHxA, PFHpA, and perfluoropentanoic acid (PFPeA) were the most frequently detected PFAS compounds in samples from deep wells (Figure 3.21).

### 3.3.3 Bedrock Groundwater

[This section will be completed once the bedrock investigation has been completed.]

### 3.3.4 Bennington Landfill Groundwater Split Sampling

Groundwater samples from a subset of existing Bennington Landfill monitoring wells were obtained by Saint-Gobain representatives as sample splits during a groundwater sampling event performed by VTDEC/EPA representatives on May 24 and 25, 2017. This monitoring round is described in the *Final Technical Report for the Bennington Municipal Sanitary Landfill Site* (Weston Solutions, 2017). Purging and stabilization of each monitoring well was performed by the VTDEC/EPA representative, and laboratory sample containers were filled by Saint-Gobain representatives and shipped to the appropriate laboratory for analysis (ELLE or Test America). Groundwater samples were analyzed for the parameters listed in Table 3.4 and were also analyzed for PFAS precursors using the Total Oxidizable Precursor (TOP) Assay methodology (Appendix F).

Samples were collected from non-bedrock monitoring wells at the landfill and from the leachate vault (VLT-01). Sample identification and sampling rationale are presented below, and sample locations are shown on Figure 3.15.

- B-2-1: shallow well adjacent to vault
- B-2-2: intermediate depth well adjacent to leachate vault
- B-12: previously sampled in 2016, with elevated results
- MW-7: not previously sampled well west of landfill
- MW-100S: shallow monitoring well completed by VTDEC/EPA in 2017
- VLT-01: leachate vault

Attempts to collect a sample from monitoring well B-6-1, located beneath the landfill cap, were unsuccessful, due to an insufficient volume of water for sample collection.

### 3.3.5 Hydraulic Conductivity

Hydraulic conductivity testing was performed to provide a data set to improve the understanding of hydrogeologic conditions in the investigation area and to compare against values of hydraulic conductivity that were used in the conceptual modeling, as described in the Draft CSM Report (Barr, 2017c). For purposes of this investigation, hydraulic conductivity testing methods included slug testing of

the new monitoring wells completed as part of the investigation and analysis of grain-size distribution data for soil samples. Hydraulic conductivity testing and data analysis procedures for the two methods employed for purposes of this investigation are described in Appendix G. A summary of hydraulic conductivity results is provided in Table 3.13.

Slug testing was conducted in the new monitoring wells SG3-MW17-01, SG3-MW17-02, SG3-MW17-03, SG3-MW17-04, SG3-MW17-06, SG3-MW17-07, and SG3-MW17-WWTP. The process involves rapidly raising or lowering the water level in a well by inserting or removing a solid “slug”, monitoring the water-level recovery to equilibrium conditions, and fitting a theoretical model to the field data. Hydraulic conductivity (K) values estimated from slug tests performed in wells ranged from 0.01 to 230 feet/day. The highest hydraulic conductivity values (86 – 230 feet/day) were calculated from slug tests performed in the three wells located near the former leachate infiltration area at Bennington Landfill (SG3-MW17-01, SG3-MW17-02, and SG3-MW17-06).

Hydraulic conductivity estimates were also obtained from analysis of grain-size distribution data for samples collected from investigation soil borings (Table 3.13). Most of the K values estimated from the grain-size distribution data are low (< 0.1 feet/day), which reflects the high percentage of fine-grained materials in the unconsolidated deposits.

### **3.3.6 Groundwater Elevations**

Groundwater elevations in the unconsolidated aquifer were measured in the permanent monitoring wells installed to date as part of this investigation during a monitoring event on November 2, 2017. Groundwater elevations from this monitoring event are summarized in Table 3.14 and shown on Figure 3.22. Field sheets from the manual measurements are included in Appendix A.

Groundwater elevations were also monitored in existing monitoring wells at Bennington Landfill and residential wells near Bennington Landfill using manual depth-to-water measurements and inferred from the transducer records. Field sheets from the manual measurements are included in Appendix A, and available well construction records for residential water wells and the landfill monitoring wells are included in Appendix E.

Bedrock groundwater elevations were monitored by installing data-logging pressure transducers (i.e., In-Situ Level TROLLs) in existing bedrock monitoring wells at Bennington Landfill and in seven residential water wells completed in bedrock near the landfill. The wells in which transducers were installed are shown on Figure 3.23 and include:

- B-2-3
- B-4-3
- B-6-3
- 32 Cortland Lane
- 49 Michaels Drive
- 54 Cortland Lane
- 901 Rocky Lane

- 1102 Rocky Lane
- 1371 Harwood Hill Road
- 1400 Becks Drive

Field sheets from the manual measurements are included in Appendix A, and available well construction records for residential water wells and the landfill monitoring wells are included in Appendix E.

The residential water wells were identified from candidate locations in consultation with VTDEC and contingent on gaining access from well owners. In addition to the wells listed above, access was also provided to the residential well at 1152 Harwood Hill Road; however, this well did not have sufficient water column height to allow for transducer installation.

The transducers were installed in the residential water wells in a 1-inch-diameter polyvinyl chloride (PVC) stilling pipe to a depth of approximately 20-30 feet below the water level at the time of stilling pipe installation. Due to pumping in several of the residential wells during the transducer installation, a true static water level could not be measured for those wells (well pumps were not pulled to complete transducer installation). Transducer installation at the landfill monitoring wells was more straightforward, as there were no pumps and associated riser pipe and cables obstructing access to the water column. Transducer installation occurred between October 20, 2017 and October 31, 2017. As of the date of this report, the transducers are still deployed in the wells and are collecting additional water-level data.

The transducers were programmed to record pressure measurements at consistent one-hour intervals. The downloaded pressure measurements were converted to water elevations by first correcting the pressure measurement to manual depth to water measurements made at the time of transducer installation and then converting the depths to water to elevations based on the surveyed elevation of the measurement point at the top of the stilling pipe.

Due to detections of PFAS in rinsate blanks of the In-Situ transducer cables that allow use of vented transducers and live display of transducer readings, unvented (i.e., absolute pressure) transducers were used instead and were suspended in the wells with fishing line. To allow removal of the barometric pressure component of the absolute pressure readings (barometric compensation), a data-logging barometer (i.e., In-Situ BaroTROLL) was deployed at the landfill to measure barometric pressure on the consistent hourly monitoring schedule.

Figure 3.24 shows a hydrograph of the groundwater-elevation data collected by transducers installed in the seven domestic water supply wells completed in bedrock and the three existing bedrock monitoring wells at Bennington Landfill (B-2-3, B-4-3, and B-6-3), shown on Figure 3.23. Hydrographs of individual wells are included in Appendix G. A representative groundwater elevation at each transducer monitoring point is summarized in the table on Figure 3.24, and well logs from the domestic wells and a construction summary for the existing landfill bedrock wells are included in Appendix E.

*[This section will be expanded with groundwater elevations from the bedrock wells being completed at Bennington Landfill.]*

## 3.4 Desktop Review of Other Potential PFAS Sources

A preliminary evaluation of other potential PFAS sources in the investigation area was performed using available public records and groundwater analytical data collected prior to this investigation. A memorandum describing the evaluation methods and findings is provided in Appendix H. This memo may be updated once the site investigation is completed.

## 3.5 Implementation Logistics

Logistics associated with implementing the Work Plan are described below and include: sampling and analysis QA/QC; management of investigation derived waste (IDW); coordination of property access; and surveying investigation locations.

### 3.5.1 Sampling and Analysis QA/QC

#### 3.5.1.1 Field Quality Control

As a check on the potential for cross contamination, quality-control samples were collected and analyzed for PFAS from source materials and equipment used in the investigation. Equipment and source materials with PFAS detections that posed a risk of cross-contamination or of otherwise affecting sample results were not used in the investigation. Source materials sampled included water used by the drilling contractor for drilling and equipment decontamination and water used as final decontamination rinse water. Equipment sampled included: casing, rods, core barrels, macro core samplers, totes, tanks, and submersible pumps used by the drilling contractor; water-level pressure transducers and associated stilling tubes, suspending cables, rope, and wire; downhole equipment used by the geophysical logging contractor; and monitoring well construction materials. When possible, equipment/rinsate blanks were collected and analytical results reviewed prior to mobilization of the equipment to the site. To the extent practical, source equipment was segregated and not used for any other purpose by the drilling and geophysical logging contractors from the time that field quality control samples were collected to the time that the equipment was mobilized to the site for the investigation.

The water used by the drilling contractor was obtained from the potable water supply for the City of Troy, New York (City Water) and then treated to reduce levels of PFAS to below the associated MDLs or to concentrations not expected to cross-contaminate environmental samples. The City Water was delivered by tanker truck to the former Chemfab facility on Water Street for storage and treatment. Samples of City Water were collected for PFAS analysis from the truck's pump; the end of the truck's discharge hose; and from the storage tank into which the City Water was pumped. The City Water was then pumped through a point-of-entry treatment (POET) system and into another storage tank for the treated water. Samples for PFAS analysis were collected from the discharge of the POET system before the treated water went into the storage tank and, once the treated water tank was full, samples were collected from the treated water tank for laboratory analysis. Treated water sample results are presented in Appendix C.

Field quality-control samples included equipment blanks, field blanks, and duplicates. Quality-control samples were taken for each media type at a ratio of one (1) set of quality control samples per 20 media samples. Laboratory-prepared trip blanks were submitted with aqueous samples requiring analysis for

Target Compound List VOCs or PFAS. The types of field quality-control samples collected and the sampling method and rationale were detailed in the Field Sampling Plan of the Work Plan (Barr, 2017a). Quality-control samples for the TOP Assay were limited to duplicate collection. Equipment blank and duplicate results are presented in Appendix C.

### 3.5.1.2 Data Validation

All laboratory analytical data were evaluated by Environmental Standards (ES) using standard operating procedures based on guidance documents and/or method documentation. In the case of PFAS analyses, ES developed a document based on the raw data they received from ELLE.

Data were evaluated at different levels of review as part of the validation process. A Level IIA data review confirms that analytical methods, analytes, and reporting levels are consistent with project objectives and applicable state and federal regulations. Additionally, this level of review verifies that supporting QA/QC are of a level of quality necessary to support sample results. Level IV data validation consists of a full review and evaluation of all summaries and raw data associated with the data package, and ensures the highest level of defensibility.

In general, the level of validation/review effort for this investigation was as follows:

- soils undergo 90% Level IIA review, 10% Level IV validation;
- new investigative media (groundwater, surface water, sediment) undergo 100% Level IV validation; and
- as determined by the project team (i.e., additional samples may be selected for Level IV validation).

Assessments of QA/QC results, including a description of any potential impacts on the usability of project sample results, are provided in the individual data validation reports prepared by ES for each Sample Delivery Group. Validation reports and additional information on Level IIA and Level IV evaluation are included in Appendix C.

### 3.5.1 IDW Management and Disposal

IDW consisted of soil cuttings from boring activities and water from equipment decontamination and monitoring-well development and sampling. Handling and disposal of IDW was consistent with the approach described in the Work Plan and approved by VTDEC in the conditional approval and comment letter dated August 12, 2017 (VTDEC, 2017a). Handling and disposal of IDW differed by the media type and by the location of IDW generation (either at Bennington Landfill or elsewhere). Handling of IDW at the landfill differed from handling at other locations due to the presence of hazardous, non-PFAS contaminants (primarily PCBs), in the landfill area. A table summarizing how IDW was managed is provided in Appendix A.

Soil cuttings generated from the investigation activities were either thin-spread at each respective boring location or containerized for waste characterization and disposal. Soil cuttings from borings at Bennington Landfill were containerized in 55-gallon drums and are presently stored at the landfill, pending waste



characterization and disposal. Results of the waste characterization will determine the nature of the IDW material, which will in turn dictate whether disposal of the cuttings is by thin-spreading in the vicinity of the soil boring or is in a facility permitted to receive the waste material. Outside of the landfill, soil cuttings from borings were thin-spread in the vicinity of each soil boring to the extent practicable. Excess soil cuttings from deep borings were containerized in 55-gallon drums, transported to the Chemfab Water Street facility, and transferred into a covered 20-cubic-yard roll-off container. Waste characterization sampling for soil from the roll-off container will be completed prior to future off-site disposal.

Water generated during monitoring well development, sampling, and equipment decontamination at Bennington Landfill was discharged to the ground surface. Outside of the landfill, water generated from well development and equipment decontamination was containerized in a frac tank that was staged at the former Chemfab Water Street facility. Treatment of the containerized water to remove PFAS will be completed prior to discharge at an approved location and in a manner consistent with the plan provided to and approved by VTDEC in response to the 1272 Order. The appropriate documentation requested in the 1272 Order will be provided to VTDEC prior to any treated water discharge.

### **3.5.2 Property Access**

Investigation activities completed on public and private property included investigative drilling, monitoring well installation, transducer installation and download, and slug testing. Access to municipal rights-of-way was obtained by contacting the respective municipality (Town of Bennington, Village of North Bennington, or the Town of Shaftsbury) in which the particular investigation activity was planned. Access to the William H. Morse State Airport was obtained by contacting the Vermont Agency of Transportation and access to Vermont State Parks property was obtained through a Special Use Permit from the VTANR.

Access to private properties was obtained by individual Access and Maintenance Agreements signed by each property owner. Prior to investigation activities on private property, at least 24-hour advance notice was provided by telephone or email, as preferred by each property owner or unless agreed to in advance by the property owner. Environmental activities generally were undertaken between 9:00 am and 6:00 pm, Monday through Friday, unless prior permission from the property owner had been obtained.

### **3.5.3 Surveying**

Investigative borings and monitoring well locations were surveyed in the field using Real-Time Kinematic Global Positioning System (GPS) methods. The survey information for each investigation location is summarized in Table 3.1. In addition, the elevation of the top of riser and/or casing and the ground elevation for each well were measured to the nearest 0.01 foot using typical survey methods. Elevations were surveyed relative to the North American Vertical Datum of 1988 (NAVD88). These elevation data are listed in Table 3.3.

## **3.6 Deviations from Work Plan**

*[This section will be finalized once the bedrock investigation has been completed.]*

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Investigation and sampling activities were conducted in general accordance with the Work Plan. Minor deviations and modifications from the Work Plan are summarized in Appendix A. Deviations included minor adjustments to proposed boring locations and changes to sample collection methodology. The following modifications to the Work Plan represent investigation activities beyond the initial scope of work defined in the Work Plan, several of which were performed at the request of VTDEC (VTDEC, 2017a):

- Existing Bennington Landfill bedrock monitoring well B-4-3 was developed and sampled.
- Existing Bennington Landfill bedrock monitoring wells B-2-3, B-4-3, and B-6-3 were surveyed.
- Soil samples from deep borings were analyzed for TAL metals to provide a better understanding of the adsorption and attenuation of PFAS compounds in the unsaturated zone.
- Grain-size distribution analysis was completed to further assist in evaluating values of hydraulic conductivity and to compare against the assumed values that were used in the conceptual modeling described in the Draft CSM Report (Barr, 2017c). Soil samples were selected from investigation locations across the site and analyzed for grain-size distribution analysis.
- Slug testing of the permanent monitoring wells was completed to calculate the values of hydraulic conductivity across the investigation area and to compare the calculated values to the assumed values used in the conceptual modeling described in the Draft CSM Report (Barr, 2017c). Slug testing was completed at the permanent monitoring wells after sampling the well.
- Preliminary desktop evaluation of other potential PFAS sources in the investigation area.

None of the additions or deviations were deemed to have had a negative impact on the investigation results.

## 4.0 Analysis

This section synthesizes the investigation results presented in Section 3.0 to address the primary objectives of the study. References to results of previous studies are made only to the extent necessary for analysis of the investigation results. The discussion does not reflect or address all available information related to the CSM.

### 4.1 Site Geology

The available background information on site geology, which is described in the Draft CSM Report (Barr, 2017c), indicates that the geology of the investigation area generally consists of sandy glacial till deposits of varying thickness overlying bedrock that has been folded and faulted in a compressional structural setting. Bedrock across the site is almost entirely composed of various metamorphosed sedimentary rock formations. A series of thrust faults have been previously mapped in a northeast to southwest orientation across the investigation area, with Cambrian rocks being thrust from the east over Ordovician rocks (Kim, 2017). The thrust rocks have formed topographic highs. General bedrock orientation and associated structure was inferred from Kim (2017) and based on mapping described in Appendix E.

The materials encountered in borings completed as part of this investigation are consistent with previous interpretations of site geology. Three cross sections of the subsurface materials encountered during the investigation have been constructed along transects shown on Figure 4.1. The cross sections are shown on Figure 4.2, Figure 4.3, and Figure 4.4. A contour map showing an interpreted elevation of the upper bedrock surface is shown on Figure 4.5. Photos of the geologic units described below are provided in a photo log in Appendix A and referenced throughout this section.

#### 4.1.1 Unconsolidated Materials

The unconsolidated materials encountered as part of this investigation largely consisted of sandy glacial till (photo #12, Appendix A) with some outwash and alluvial deposits. Thickness of till units ranged significantly from several feet to over one hundred feet thick, with till thinner on hilltops and thicker in valleys. Till was typically classified as a sandy lean clay with gravel and some cobbles. The till was typically yellowish brown to deep reddish brown. Though till was typically massive, layers and laminations that are indicative of glaciolacustrine deposition were observed in some borings. Potential lodgement till was observed in the eastern portion of the site near Bennington Landfill, where increased density and hardness made advancement difficult during drilling.

Cobbles and boulders were present within the till, with one quartzite boulder measuring over five feet thick. Wherever possible, deep borings were advanced five to ten feet into rock to confirm the presence of bedrock, rather than a large boulder. Gravel and cobbles found in till were typically locally sourced (e.g., Cheshire Formation quartzite, Dunham Formation dolomite and marble, as well as other metamorphosed sedimentary rocks) and their angularity ranged from angular to rounded.

Some sandy outwash units were observed in thin intervals (typically 0.25 to 5 feet thick), randomly distributed within till. Outwash units were typically classified as silty sand or silty sand with gravel.

Outwash units were saturated when encountered below the water table, whereas till units were typically quite dry, but classified as “moist” via *ASTM 2488-09a Visual-Manual Soil Classification* standards.

## 4.1.2 Bedrock

*[This section will be finalized once the bedrock investigation has been completed.]*

### 4.1.2.1 Altered Bedrock

*[This section will be finalized once the bedrock investigation has been completed.]*

Hydrothermally altered bedrock, also referred to as “kaolin” or “ocher”, was encountered in the eastern half of the site at bedrock monitoring wells SG3-MW17-BR1, SG3-MW17-BR2, and SG3-MW17-BR4 at or near Bennington Landfill and at deep soil boring D07 along Chapel Road. Hydrothermally altered bedrock was also encountered at one location (deep soil boring D24) in the southwestern area of the site near William H. Morse State Airport (Figure 3.1). The altered bedrock typically consisted of altered rocks of the Cheshire Formation or the Dunham Formation (Ogden, 1969). The hydrothermally altered rock was usually observed as a residual soil of clay or silt-sized material with minor sandy intervals, formed when silicates were leached from the parent rock. Previous investigations in the area have referred to these deposits as saprolite (McLaren/Hart, 1997).

Ocher consists of sandy lean clay or gravelly lean clay with some quartz precipitate nodules (photo #16, Appendix A) and is typically associated with hydrothermal alteration of the Cheshire Formation, Dunham Formation or Monkton Formation (Ogden, 1969). The material exhibits a distinct dark reddish-brown iron oxidation color. A five- to ten-foot-thick layer of ocher (photos #13 and 15, Appendix A) was typically present overlying kaolin in investigation borings completed near Bennington Landfill. Ocher was also encountered at deep soil boring D24 near William H. Morse State Airport (Figure 4.1). This boring was terminated after penetrating 17 feet of ocher and it is unknown if kaolin was present below it. The Clarendon Springs Formation has been mapped (Kim, 2017) as the uppermost bedrock just to north of D24 and is inferred to be the parent material of the ocher observed in this boring.

Kaolin (photos #14 and 17, Appendix A) was observed as a clayey or silty, friable, residual soil resulting from hydrothermal alteration of the Cheshire or Dunham Formations. Kaolin was observed at SG3-MW17-BR1, SG3-MW17-BR2, and SG3-MW17-BR4 and deep soil boring D07 in thicknesses of 150 to 300 feet (Figure 4.3 and Figure 4.4). Coloration of kaolin typically ranged from a white to yellowish powdery material to earthy reddish-brown. Intervals of argillaceous phyllite and quartz sericite phyllite-schist were observed within intervals of kaolin.

The parent rock of hydrothermally altered material such as kaolin and ocher was typically inferred by the presence of interbedded subfacies and from previous geologic investigations in the area that mapped the bedrock geology (e.g., Kim, 2017). Altered rock derived from the Dunham and Monkton Formations typically contained interbeds of carbonate rock such as limestone, dolomite, and marble. Altered rock derived from the Cheshire Formation was typically more homogenous and massive, which is indicative of Cheshire Formation quartzite parent rock.

### 4.1.2.2 Competent Bedrock

*[This section will be finalized once the bedrock investigation has been completed.]*

For purposes of this report, competent bedrock refers to bedrock that has not been hydrothermally altered, and may include rock that has been metamorphosed or mechanically altered. Competent bedrock was encountered across the site at depths ranging from surficial exposure to nearly 400 feet bgs where significant hydrothermally altered bedrock was present. Competent bedrock was generally very hard, metamorphosed sedimentary rocks.

Cambrian bedrock encountered during drilling consisted of a very hard, white quartzite (photo #20, Appendix A) associated with the Cheshire Formation or as various interbedded metamorphic rocks of the overlying Dunham Formation, which is primarily dolomitic quartzite, marble (photo #18, Appendix A), and limestone. Cambrian formations mapped by others in the area include the Clarendon Springs, Winooski, and Monkton Formations (listed youngest to oldest). All of these formations are stratigraphically above the Dunham Formation. These formations, which have been mapped as limestones and dolostones with varying degrees of metamorphism (Kim, 2017), were not observed during this investigation.

Ordovician bedrock was encountered as a suite of foliated metamorphic rocks such as slate and phyllite that was typically highly weathered at the contact with unconsolidated material. The Ordovician bedrock units at the site are members of the Walloomsac, Bascom, and Shelburne Formations (listed youngest to oldest), all of which are made up of chemical sedimentary rocks or fine-grained detrital sedimentary rocks that have undergone varying degrees of metamorphism (Kim, 2017). Ordovician bedrock was only observed west of the Silk Road Fault (Figure 4.4).

## 4.2 Hydrogeologic Conditions

This section compares the hydraulic conductivity (K) values calculated from data collected as part of this investigation and the K values used in the groundwater model of the site (Barr, 2017c). Water-level data collected from new unconsolidated monitoring wells at Bennington Landfill and from the wells instrumented with transducers are also discussed. A more complete analysis of groundwater elevations and flow directions will follow once all bedrock water-level data are available.

### 4.2.1 Hydraulic Conductivity Values

#### 4.2.1.1 Comparison to Published Values

The estimated K values vary over six orders of magnitude and are consistent with published values associated with the types of geologic materials tested. Hydraulic conductivity can vary over orders of magnitude even within a given material type (Freeze and Cherry, 1979), though hydraulic conductivity generally increases with increasing grain size. For the following general groups of materials, hydraulic conductivity values estimated from slug tests and grain-size distributions ranged from: clay, 0.00053 – 0.51 feet/day; silt, 0.0013 – 7.6 feet/day; sand, 0.0021 – 820 feet/day; and gravel, 0.1 – 230 feet/day. The overlapping ranges are to be expected given that the screened intervals/grain-size distribution samples tested are not homogenous, and the presence of an appreciable fine-grained fraction can significantly

influence the hydraulic conductivity of a predominantly coarse-grained material (e.g.,  $K = 0.1$  feet/day for clayey gravel).

#### **4.2.1.2 Comparison of Field and Model Values**

Hydraulic conductivity values estimated from field data are consistent with values used in the groundwater flow model for the conceptual modeling described in the Draft CSM Report (Barr, 2017c). The conceptual modeling used horizontal hydraulic conductivity values for unconsolidated deposits that range from 0.49 feet/day for fine-grained sediments to 197 feet/day for sand and gravel. The values estimated from slug tests and grain-size distributions range from 0.00053 feet/day for clay to 820 feet/day for sand, and are consistent with the values for unconsolidated materials in the model which all fall within the range of measured values. Bedrock hydraulic conductivity estimates obtained to date are also consistent with model values, with the model value of 1.0 feet/day for quartzite agreeing with the value of 2.3 feet/day estimated from the slug test at monitoring well SG3-MW17-WWTP and the value of 5.3 feet/day from grain-size distribution analysis at deep boring D02 (Table 3.13).

### **4.2.2 Groundwater Level Monitoring**

#### **4.2.2.1 Unconsolidated Aquifer near Bennington Landfill**

Water levels collected at five wells completed in the unconsolidated aquifer at Bennington Landfill are shown on Figure 3.22. Wells SG3-MW17-01, SG3-MW17-02, and SG3-MW17-06 are located near existing shallow monitoring wells B-2-1 and B-2-2. Groundwater elevations measured at B-2-1 in 30 sampling events from December 1992 through July 1997 ranged from 907.87 to 912.87 feet above mean sea level and groundwater elevations measured at B-2-2 in 22 sampling events from April 1993 through July 1997 ranged from 907.88 to 912.89 feet above mean sea level (McLaren/Hart, 1997). Though the specific datum used (NGVD29 or NAVD88) for these historical measurements is unknown, the November 2, 2017 groundwater elevations at SG3-MW17-01, SG3-MW17-02, and SG3-MW17-06, which range from 908.07 to 908.14 feet above NAVD88, appear to be consistent with the historical measurements at B-2-1 and B-2-2. No comparisons to existing data are possible for SG3-MW17-03 and SG3-MW17-04, the former because no wells were installed in this area as part of previous investigations at Bennington Landfill and the latter because no existing unconsolidated monitoring wells near SG3-MW17-04 are completed over a similar depth interval.

#### **4.2.2.2 Wells Equipped with Transducers**

Water-level variations due to pumping are evident in the data from domestic wells at 32 Cortland Lane, 54 Cortland Lane, and 1400 Becks Drive shown on Figure 3.24. Apparent water-level variations due to pumping are also observed on the individual hydrographs for 49 Michaels Drive, 1102 Rocky Lane, and 1371 Harwood Hill Road (Appendix G). Though pumping rates at these wells are not known, the smaller drawdowns observed for the latter group of wells may suggest that the bedrock aquifer is more permeable at these locations.

Water levels in nearly all wells appeared to increase in response to a precipitation event on October 29-30. Other small increases in water levels from October 30 to November 10, seen most clearly in the data from B-6-3 and 49 Michaels Drive, also appear to correlate with precipitation events. While the

October 29-30 precipitation event produced clear water-level rises in several wells, the smaller precipitation events within the monitoring period (e.g., October 26 and November 6) do not result in clear water-level responses. This suggests that precipitation events must be of sufficient magnitude and/or duration to produce a measurable change in bedrock groundwater levels.

#### 4.2.2.3 Bedrock Aquifer near Bennington Landfill

*[This section will be finalized once the bedrock investigation has been completed.]*

### 4.3 Relationships and Trends in PFAS Concentrations

#### 4.3.1 Soil

##### 4.3.1.1 Relationship of Soil PFAS to TOC, Metals, and pH

As stated in Section 1.1, a primary objective of soil sampling was to determine what, if any, relationships exist between PFAS concentrations and soil geochemistry. Specifically, the relationship between PFAS concentrations and soil TOC, metals concentrations, and pH was evaluated as a possible explanation of the observed distribution of PFAS concentrations in soil. The data analysis addresses a central aspect of the CSM (Barr, 2017c), which is that TOC is the primary control on PFAS sorption to subsurface materials. The relationships between PFAS concentrations and soil TOC, metals concentrations, and pH were assessed statistically. Details of the statistical methods and results are included in Appendix D.1a; a summary is provided below.

The statistical analysis of soil data focused on evaluating the differences in concentrations of PFAS, TOC, and metals among groupings that might potentially affect the attenuation of PFAS compounds in soils and on the correlations between these parameters. Correlations were assessed between concentrations of the various chemical parameters (e.g., metals, TOC, and PFOA).

The statistical analyses assessing geochemical relationships in the investigation soil data show that:

- **PFOA and TOC in soil are significantly positively correlated.** The relationship between PFOA and TOC concentrations in soil is shown on Figure 4.6. The significant correlation between PFOA and TOC suggests a better retention of PFAS by organic material. Significantly higher concentrations of both TOC and PFOA were observed at shallower depths.
- **PFOA in soil is not significantly correlated with metals expected to control PFOA sorption.** No significant correlation (positive or negative) was found between concentrations of PFOA and calcium and iron. A significant correlation existed only for silver (positive), but this result was likely affected by a high proportion of non-detect values. Correlation values and scatter plots for each metal parameter are provided in Appendix D.1a.
- **PFOA in soil and soil pH are significantly negatively correlated.** This relationship may be due to a lesser ability for acidic soils to adsorb or otherwise retain PFAS.

##### 4.3.1.2 Spatial Trends in Soil PFAS

Similar to the statistical analysis described in the previous section, spatial trends in PFAS concentrations were identified through statistical analyses. Details of the statistical methods and results are included in

Appendix D.1a; a summary is provided below. For purposes of this report, analysis of the soil data through multivariate analysis was not performed because the chemical signature from air emissions from Chemfab no longer appeared to be present and distinguishable in soils in the investigation area, which precludes an analysis to distinguish that source from others. Additionally, preliminary multivariate analyses did not yield results from which distinct signatures of any potential sources could be readily identified, which is consistent with the finding that current soil concentrations in the CAAs are consistent with background concentrations (Section 4.4.1).

The spatial trends focused on differences in the distribution of PFOA concentrations in samples collected at different depth intervals in the soil profile, and at increasing distances from known PFAS sources, including the former Water Street facility and Bennington Landfill. For purposes of this report, groupings included depth intervals (surface, 0 to 1.5 feet bgs; shallow, 1.5 to 5.0 feet bgs; and deep samples, greater than 5 feet bgs) and geographic areas (the four background sampling locations, Bennington Landfill, and the non-landfill investigation area). The statistical analyses assessing spatial trends in the investigation soil data show that:

- **PFAS and other parameters vary significantly with soil depth.** Organic parameters (PFAS and TOC) and several major cations (e.g., calcium and magnesium) were notably higher in concentration in the surface soils than in the deep soils, whereas iron and trace metals increased in concentration with depth. Concentrations of PFOA are higher in surface soils relative to deep soils (Figure 4.7), which is consistent with PFAS sources at the ground surface. Higher concentrations of TOC are also measured in surface soils, which is consistent with a soil weathering profile where the highest TOC is found in the uppermost soil horizons.
- **PFOA concentrations in surface soils at the landfill were significantly different from concentrations elsewhere in the investigation area.** The box-and-whisker plots on Figure 4.7 show distinct differences in the distribution of PFOA concentrations in soil between Bennington Landfill and the background and non-landfill locations. The associated p-values (both <0.001) indicate that the difference is statistically significant. However, when PFOA concentrations are normalized to TOC concentrations (which requires that non-detect values be removed from the analysis), landfill samples are significantly different from only non-landfill samples.
- **PFOA concentrations were not significantly different between background soils and non-landfill soils.** The box-and-whisker plots on Figure 4.7 show visually similar distributions in PFOA values concentrations between background and non-landfill soils. The associated p-value (0.997) indicates that there is no statistically significant difference in median concentrations between the areas. When PFOA concentrations are normalized to TOC concentrations, there is no statistically significant difference in median concentrations between the background and non-landfill soils.
- **PFOA concentrations are significantly correlated to distance from the former Water Street facility and Bennington Landfill, but the distance trend predicts the data poorly.** A statistically significant correlation was found between PFOA concentration in surface soils (up to 1.5 feet bgs) and distance from two locations of interest in the investigation area: the former Water Street facility and Bennington Landfill. The trends are decreasing or increasing concentration with distance from the former Water Street facility and from Bennington Landfill,



respectively, as shown on Figure 4.8 and Figure 4.9. While the correlation is significant, the agreement between the measured concentrations and the best-fit model is poor, as reflected by relatively low  $R^2$  values. This means that the statistically significant distance trend is only a weak predictor of soil PFOA concentrations, even when the PFOA concentration is normalized to account for the effect of another statistically significant predictor of PFOA: TOC.

The relationship between PFOA and TOC suggests that evaluating these parameters together can assist in the interpretation of PFAS distributions across the investigation area. However, the results of these analyses show that even when PFOA concentrations are normalized to account for variability in TOC, some surface activities, local conditions, or localized sources of PFAS may lead to highly localized variations in soil chemistry that have the potential to confound interpretation of larger-scale patterns.

#### 4.3.1.3 Presence of Sulfonated PFAS Compounds

Given that PFOA is understood to be the only PFAS compound in the air emissions from the former Chemfab facilities, the presence of sulfonated PFAS compounds in soil samples is indicative of a different PFAS source. This is further supported by the presence of sulfonated compounds in four of the background soil samples, at concentrations ranging from 0.42 to 1.1 ng/g (Table 3.5), and at a number of the non-background soil sampling locations (Table 3.4).

#### 4.3.2 Groundwater

As stated in Section 1.1, a primary objective of groundwater sampling was to aid in evaluating the transport of PFAS at the ground surface and deeper soils through the unsaturated zone to the water table and to evaluate the role of Bennington Landfill as a PFAS source. In order to address these objectives, a statistical evaluation of the groundwater quality data collected to date across the investigation area was conducted. The investigation of groundwater conditions in the bedrock aquifer in the vicinity of Bennington Landfill is ongoing, and this report will be supplemented as data from that investigation are collected. Details of this statistical evaluation of investigation data collected to date are in Appendix D.1b, and the preliminary evaluation findings are discussed below.

The statistical analyses of the investigation groundwater data collected to date, which do not include the bedrock groundwater samples that remain to be collected at Bennington Landfill, show that:

- **There was no statistically significant difference in concentrations of PFOA or PFOS in groundwater sampled at Bennington Landfill and at locations outside of the landfill.** PFOS concentrations in groundwater ranged from <0.7 to 12 ng/L in samples collected at the landfill and from <0.8 to 23 ng/L in samples collected outside of the landfill. PFOA concentrations in groundwater ranged from 3 to 160 ng/L in samples collected at the landfill and from 5 to 850 ng/L in samples from outside the landfill.
- **There were no apparent spatial trends in concentrations of PFOA or PFOS across the investigation area.** For PFOS, the highest concentrations (excluding the leachate vault results) appear to be located along the outer edges of the investigation area, with concentrations greater

than 10 ng/L at S03 (north; non-landfill), S41 (south; non-landfill), and S28 (east; Bennington Landfill). These relationships are shown on Figure 3.16, Figure 3.17, Figure 3.18, and Figure 3.19.

#### **4.3.2.1 Multivariate Analysis of Groundwater Data**

For purposes of this report, PFAS data for groundwater that has been collected to date as part of this investigation were statistically processed along with the private well sampling data collected by the VTDEC and POET influent monitoring data collected on behalf of Saint-Gobain. Statistical tools were used to determine if there were patterns outside of spatial considerations that could be used to identify groups or “families” of samples. By using multivariate analysis (MVA) statistical approaches on the available dataset, previously unrecognized relationships between samples may identify potentially separate sources of PFAS, or may potentially identify the likelihood of a common source. The MVA analysis presented herein is an update of the analysis presented in the Draft CSM Report (Barr, 2017c) and reflects the inclusion of data collected to date as part of this investigation.

MVA is a well-established set of statistical methods for evaluating data involving more than one variable. MVA procedures were applied to the data from the investigation area in order to discern any patterns to the data and any relationships between data points, based solely on the composition of the PFAS compounds. For purposes of this report, the statistical add-on tool to Microsoft Excel, XLStat ([www.xlstat.com](http://www.xlstat.com)), was used in the MVA procedures.

Agglomerative Hierarchical Cluster (AHC) analysis was used in the MVA evaluation. AHC involves evaluating the data (i.e., multiple PFAS compounds from many locations) without any consideration to mechanisms, physical processes, trends, or spatial location. AHC analysis seeks to identify which data locations are similar to other locations and groups or “clusters” like-data based on statistical thresholds. AHC is a statistical iterative classification method which produces a dendrogram (clustering tree), representing a hierarchy of objective similarities and dissimilarities. The agglomerative methodology used was Ward’s method using Euclidian distance proximity. Truncation of the AHC was conducted manually and favored fewer groups with larger populations over many groups with smaller (or single) populations.

PFAS data included in the MVA analysis included those PFAS compounds from EPA Method 537 that were found throughout the results and included: perfluorobutanesulfonic acid (PFBS), PFHpA, perfluorohexanesulfonic acid (PFHxS), perfluorononanoic acid (PFNA), PFOS, and PFOA. For purposes of this report, where no value is reported in the private well sampling dataset provided by VTDEC, a value of “no detection” was assumed for all parameters not reported for a sample. The presence of non-detect concentrations required assignment of values to allow analysis. Detection limits may be different for different compounds and for different samples. For purposes of this analysis, a non-detect result was treated as a value of 0 ppt and J-qualified values (i.e., values between the instrument detection limit and the practical reporting limit) were not altered.

PFAS data were selected from the available groundwater and POET influent data and transformed in the following manner prior to analysis:

- The geographic location of the data within the investigation area was not a factor in data selection or statistical analysis.
- Multiple observations made at a single location were treated as separate data points due to the amount of time between sample collections (approximately quarterly).
- Of the 1156 total groundwater samples, 698 data points met the criteria of at least one PFAS compound detected and all six PFAS compounds analyzed for.
- The data set was normalized to convert to fractional concentrations of the sum of PFAS measured and the resultant data was processed with XLStat for AHC. Data processed in this manner allowed for clustering with an emphasis on the total sample profile, diminishing the role played by absolute PFOA concentration and influences on absolute concentrations such as dilution and mixing.

Overall, six sub-groups were identified from the statistical clusters. These sub-groups were combined due to the similarities in the data, forming three statistical groups. The groups are largely divided by contributions of PFOA versus sulfonated compounds, and are as follows;

- Group A – This group contained 651 samples. Members of this group are characterized by the dominance of detections of PFOA and PFHpA, and no sample with total sulfonated compounds greater than 10%. All other PFAS compounds were less than 5% of the total PFAS compounds detected.
- Group B – This group contained 36 samples. Members of this group largely have a sulfonated presence (34 of 36 samples). All PFAS compounds have a presence in this group, but not across all samples. The PFOA contribution ranges from 59 to 86%.
- Group C – This group contained 11 samples. The group is characterized by a relatively small contribution from PFOA, ranging from 0 to 50%. The samples can be considered heavily sulfonated, with contributions from sulfonated compounds ranging from 40 to 75% in the samples where detected.

The three groups identified by the AHC analysis are shown on Figure 4.10. The groups are described as (A) groundwater with PFOA or PFOA/PFHpA and low or no sulfonated PFAS compounds; (B) groundwater with widespread sulfonated compounds, and (C) groundwater with high proportions of sulfonated compounds.

The overall patterns of groupings and characteristics of the groupings for this analysis are very similar to the analysis results presented in the Draft CSM Report (Barr, 2017c). The additional groundwater data collected as part of this investigation reinforce the AHC findings. Wells in the general vicinity of the former Chemfab facilities have PFAS detections that are predominantly PFOA/PFHpA and typically do not have sulfonated PFAS compounds. This profile would generally be consistent with a source of PFAS that would be similar to PFOA-based air dispersion. Wells in the vicinity of Bennington Landfill are statistically grouped together because they generally contain detectable concentrations of sulfonated compounds such as PFOS, PFHxS, and PFBS and are not correlated with PFOA/PFHpA. This profile suggests a mixture of PFAS compounds from a variety of commercial, domestic, and industrial sources other than the former Chemfab facilities. The sporadic presence of wells with sulfonated PFAS compounds throughout the

investigation area indicates a greater statistical commonality with the wells in the Bennington Landfill area than wells in the vicinity of the former Chemfab facilities, again indicating that there are a variety of localized, mixed PFAS sources within the investigation area.

#### **4.3.2.2 Groundwater Type Classification**

The water type, as identified from the relative abundance of major ions in the groundwater sample, does not indicate substantially different water sources for the unconsolidated aquifer. The majority of the groundwater samples collected from the unconsolidated aquifer across the investigation area (Bennington Landfill, non-landfill, and background locations) are characterized as calcium-bicarbonate type water, except for a few samples collected along the edges of the investigation area. These results suggest that the water samples were collected from a chemically similar source of water, such as the same aquifer.

*[This section will be finalized once the bedrock investigation has been completed.]*

### **4.4 Evaluation of PFAS Sources**

As stated in Section 1.1, a primary objective of the investigation was to identify some of the other potential sources of PFAS within the investigation area. The specific PFAS sources evaluated as part of this investigation include background sources, sources related to Bennington Landfill, and PFAS precursors. Other potential PFAS sources in the investigation area were identified as part of a preliminary desktop evaluation. These potential sources are discussed in the following sections.

#### **4.4.1 Background PFOA Soil Concentration**

The concentration of PFOA in soil has two components: the local source contribution and the background contribution. To better understand the magnitude of the local source contribution, the background concentration were subtracted from measured soil concentrations for purposes of this report. A source of background soil concentrations of PFOA is the long-range atmospheric transport and deposition of PFOA and its precursors (Rankin et al., 2016). Background concentrations are also influenced by local water infiltration rates and by the retention of PFOA within the soil column. A soil's TOC content strongly influences PFOA retention (Zareitalabad et al., 2013). A positive correlation between TOC and PFOA concentrations exists for soils in the investigation area (Appendix D). This suggests that for the same background PFOA deposition rate, the background soil PFOA concentration will vary with soil TOC content. Background soil PFOA concentrations can be calculated by multiplying the background PFOA/TOC ratio by the soil's TOC content. A background PFOA/TOC ratio was developed for the investigation area soils.

As described in , background soil samples were collected at four locations north and east of Bennington, at distances ranging from approximately 8 to 22 miles from the former Water Street facility and in locations not alleged to be impacted by emissions from the former Chemfab facilities (Figure 3.1). Samples represented in the background analysis include those from the upper 18 inches of the soil column. PFOA concentrations and TOC-normalized PFOA concentrations from these background sampling locations were evaluated and compared to 33 sampled locations across North America (Rankin et al., 2016). Samples with PFOA/TOC values less than the 95<sup>th</sup> percentile for the 33 North American sites

were regarded as representative of background. Three of the four Bennington background sampling locations had PFOA/TOC ratios below the 95<sup>th</sup> percentile value. The average PFOA/TOC ratio for the three sampling locations was 0.0586 ng PFOA/mg TOC and the standard deviation was 0.0293 ng PFOA/mg TOC. For purposes of this report, the upper limit of the range of background concentrations of PFOA in soil is defined as the 95<sup>th</sup> percentile value of 0.1172 ng PFOA/mg TOC. Thus, the evaluation suggests that the long-range transport, deposition, and retention of PFOA is associated with a background TOC-normalized PFOA concentration of up to 0.1172 ng PFOA/mg TOC for the investigation area.

Soil concentrations of PFOA above the range of background concentrations were calculated for each soil sample, based on the measured TOC concentration in the sample. The TOC-normalized background PFOA concentration for each sample was calculated from the measured TOC concentration and the 95<sup>th</sup> percentile for the TOC-normalized background PFOA concentration of 0.1172 ng PFOA/mg TOC. This sample-specific background PFOA concentration was subtracted from the measured PFOA concentration to provide the above-background PFOA concentrations shown on Figure 4.11 and Figure 4.12. The results on these figures show no clear spatial trend or clustering of concentrations exceeding background values that would suggest potential other current sources in addition to background. Evaluation of current local sources was beyond the scope of this investigation and the potential for current local sources has not been fully evaluated.

Simulations of the fate and transport of PFOA in the vicinity of the former Chemfab facilities, described in the Draft CSM Report (Barr, 2017c), used a TOC concentration of 25,000 mg/kg soil (2.5 percent by weight) to characterize the retention of PFOA in the surficial soil. This investigation shows a positive correlation between TOC and PFOA concentrations in soil samples collected from the Bennington area (Appendix D). Thus, for purposes of this investigation (comparing simulated soil concentrations to those measured in the field), a background PFOA concentration associated with the average background PFOA/TOC ratio of 0.0586 ng PFOA/mg TOC and a TOC of 25,000 mg/kg was calculated to be 1.46 ng PFOA/g soil (i.e., 1.46 ppb). Using the same TOC value and the 95<sup>th</sup> percentile background PFOA/TOC ratio of 0.1172 ng PFOA/mg TOC results in a background PFOA concentration of 2.93 ng PFOA/g soil (i.e., 2.93 ppb).

#### **4.4.2 Bennington Landfill Impacts**

The role of Bennington Landfill as a potential source of PFAS to soil and groundwater in the unconsolidated and bedrock aquifers is illustrated in the available analytical results from this investigation. The available soil and water quality results are provided in Table 3.10 and Table 3.12. Groundwater elevations measured in landfill monitoring wells and nearby private wells are discussed in Section 3.3.6 and Section 4.2.2.2. The data collected to date do not include results from the on-going bedrock investigation at Bennington Landfill; a discussion of Bennington Landfill impacts will be provided upon completion of the bedrock investigation.

#### **4.4.3 PFAS Precursors**

Results of the TOP Assay (Appendix F) for groundwater samples collected at Bennington Landfill suggest that there is a negligible mass of PFAS precursors in the groundwater system. Of the samples subjected to

the TOP Assay, only the landfill leachate sample was shown to have more than a trace amount of PFAS precursors, constituting six percent of the total mass of PFAS in the leachate sample (Table 3.12). The lack of significant PFAS precursor mass suggests that the background soil concentrations described in Section 4.4.1 result from ongoing addition of PFAS from other background sources.

#### **4.4.4 Other Potential PFAS Sources**

The desktop evaluation of other potential PFAS sources in the investigation area described in Appendix H preliminarily identifies local sources other than the former Chemfab facilities and Bennington Landfill that likely existed (and in some cases potentially still exist) in the investigation area. The results of this preliminary evaluation suggest that additional investigation of these potential sources by the appropriate regulatory agency may be warranted.

### **4.5 Evaluation of Expected Distribution of PFAS Concentrations**

As stated in Section 1.1, a primary objective of the investigation was to evaluate the distribution of PFAS in soil and groundwater predicted in the CSM against the concentrations identified during the investigation. As described in the Draft CSM Report (Barr, 2017c), numerical models were developed to simulate potential transport mechanisms of PFOA released by historical air emissions at the former Chemfab facilities that may have resulted in the presence of PFOA in soil and groundwater in the vicinity of these facilities. The results of the simulations were compared to measured PFOA concentrations in soil and groundwater.

This section presents comparisons of PFOA concentrations measured in soil and groundwater during this investigation with simulated values from the models presented in the Draft CSM Report (Barr, 2017c). The comparison does not include the other PFAS parameters measured as part of this investigation, as PFOA was the only PFAS parameter simulated in the conceptual modeling. The fraction organic carbon used in the conceptual modeling is also compared to values measured during this investigation. The results of this analysis are used to update the conceptual model as presented in Barr (2017c).

#### **4.5.1 Saturated Zone Groundwater**

A scatter plot of simulated PFOA concentration in groundwater versus concentrations measured as part of this and previous investigations is presented on Figure 4.13. For purposes of this report, all non-detect values are plotted at their associated detection limit. Overall, there is a slight bias of simulated concentrations being lower than measured concentrations, particularly for higher measured concentrations.

#### **4.5.2 Unsaturated Zone Soils**

As shown on Figure 4.14a, simulated soil concentrations of PFOA are consistently lower than measured values across the investigation area. The model has no lower limit for simulated values and can simulate concentrations much lower than can be quantified by current laboratory methods. Figure 4.14a compares the measured concentrations of PFOA in soil to the model's predictions of soil concentrations for the date the sample was collected at locations and depths of the measured values.

For purposes of the conceptual modeling, sorption of PFOA on organic carbon was simulated using a linear sorption model with a distribution coefficient ( $K_d$ ) based on literature values for the organic carbon partitioning coefficient ( $K_{oc}$ ) and typical values of the fraction of organic carbon ( $f_{oc}$ ) in soils (Barr, 2017b). Values of  $f_{oc}$  assumed in the Draft CSM Report (Barr, 2017c), which decrease with depth below ground surface in soils, are compared with measured values from the current investigation on Figure 4.15.

Measured and modeled  $f_{oc}$  values are compared in Table 4.1 (below) for the depth ranges used in the unsaturated zone model (Appendix C of the Draft CSM Report (Barr, 2017c)). The model input values fall within the observed range for each depth interval. In some cases, the method detection limits exceeded the minimum detected values, therefore non-detect values were not accounted for in geometric mean calculation. Samples with visible organic content were targeted for analysis, therefore, the results may be biased toward higher  $f_{oc}$  values. These results indicate that the  $f_{oc}$  values used to represent the three different depth intervals in the modeling are representative of the available data.

**Table 4.1 Measured and modeled  $f_{oc}$  values for the unsaturated zone model.**

Sample midpoint depth range	Geometric mean of detected values	Minimum detection	Maximum detection	Number of detections	Number of non-detections	Model input
0-10 cm	0.016	0.00041	0.17	129	0	0.025
10-36 cm	0.0094	0.00043	0.48	134	6	0.005
>36 cm	0.0032	0.00012	0.51	475	59	0.0005

### 4.5.3 Comparison to the Conceptual Model

The Draft CSM Report (Barr, 2017c) was reviewed to evaluate if any updates or revisions to the conceptual modeling are necessary in light of additional data collected as part of this investigation. In particular, the numerical models' prediction of groundwater and soil PFOA concentrations below measured values was considered. Background deposition from long-range transport of PFOA and potential contributions from other localized sources like those identified in Appendix H are important contributors that were not included in the Draft CSM Report. The additional background sources and potential additional local sources are believed to be the primary explanation for the model predictions of soil concentrations below measured concentrations.

The model prediction that a signature of emissions from the former Chemfab facilities would no longer be present in soil at the time of this investigation is supported by the finding that the investigation soil data do not show a strong spatial trend with distance from the former Water Street facility (Section 4.3.1.2). The measured PFOA concentrations in soil were higher than the numerical models predict and are consistent with a background source (Section 4.4.1). Figure 4.16 shows a simulated time series of soil concentration of PFOA east of the former Water Street facility resulting from modeled emissions from the former Chemfab facilities that illustrates the predicted attenuation of soil concentrations over the fifteen years since the emissions ceased at the former Water Street facility (2002). Soil concentrations are

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predicted to peak at around 17 ng/g in 1998 and decline rapidly after that, especially after emissions cease in 2002. In certain conditions (e.g., elevated TOC in soil, low infiltration) and certain locations, elevated PFOA concentrations in soil from the former Chemfab emissions may still be present, but overall soil concentrations present today are expected to be more representative of background or other regional sources. The simulated soil concentration for 2017 is 0.3 ng/g, which is only slightly above the detection limit for soil PFOA data collected as part of this study. This illustrates the potential that any signature of emissions from the former Chemfab facilities, in the form of elevated soil concentration, would not be expected 15 years after emissions ceased.

A background source of PFOA was not included in the conceptual modeling, given that the purpose of the modeling was to perform a screening level evaluation of the extent to which emissions from the former Chemfab facilities may have potentially contributed to PFOA concentrations in groundwater. Figure 4.14b is similar to Figure 4.14a, but adds to the model's predicted PFOA concentrations in soil the background soil concentrations of PFOA as a function of the model's TOC values. Because different TOC values were used in the model over three depth intervals (0-10 cm, 10-36 cm, and >36 cm), adding the background contribution results in a clustering of the simulated concentrations with respect to the sampling depth. Figure 4.14b illustrates two considerations: (1) representing more of the measured spatial variability in TOC concentrations in the model would likely produce an even better match between simulated and observed PFOA soil concentrations and (2) including background contributions to soil concentrations is important in assessing the goodness of fit between model-simulated soil concentrations and measured concentrations.

Because long-range transport and deposition is significant and ubiquitous across the modeling domain, simulated PFOA concentrations in both soil and in groundwater are lower than they would be if the background PFOA loading was applied. After accounting for background, model-simulated and measured soil and groundwater concentrations correlate well.



## 5.0 Summary

The following statements summarize the results from the investigation and data analyses conducted thus far and described herein. These summary statements address the overarching investigation objectives of assessing hydrogeologic conditions in the investigation area, evaluating relationships and trends in PFAS concentrations, evaluating some of the other potential additional local PFAS sources, as well as measuring background conditions, and assessing measured PFAS concentrations against the expected distribution.

- Hydrogeologic conditions were found to be very similar to those described in the CSM.
- Relationships and trends in PFAS concentrations indicate that current concentrations of PFOA in soil in CAII are not indicative of historical impacts from the former Chemfab facilities. The measured soil concentrations are generally consistent with background concentrations and may also be indicative of localized sources of PFAS.
- Statistical analysis of available groundwater data from this investigation and monitoring of private wells and POET systems suggests different PFAS sources reflected by groundwater of different PFAS composition, specifically the relative proportion of sulfonated compounds.
- Long-range transport of PFAS from sources outside the investigation area appears to be a significant source of PFAS within the investigation area. A desktop evaluation of area industries identifies additional potential local sources of PFAS within the investigation area.
- After accounting for background sources, the data collected as part of this investigation are consistent with the CSM. The findings do not warrant further investigation for the purposes of assessing the effects of air emissions from the former Chemfab facilities.

This report will be updated upon completion of the bedrock investigation. It is not anticipated that any additional investigation will be required. However, as discussed in the report, other likely local sources contributing to the presence of PFAS exist within the investigation area and may warrant additional investigation by the appropriate regulatory agency.

### 5.1 Hydrogeologic Conditions

- The distribution and values of hydraulic conductivity were found to be similar to conditions described in the Draft CSM Report (Barr, 2017c).
- A comparison of modeled and observed bedrock groundwater-flow directions near Bennington Landfill cannot be completed at this time, but will follow once all bedrock wells have been completed.

### 5.2 Relationships and Trends in PFAS Concentrations

#### 5.2.1 Soil

- A significant, positive correlation exists between soil PFOA and TOC. Higher PFAS concentrations were found in soils with higher TOC, indicating that the organic matter in the soils attenuates PFOA, PFOS and other PFAS compounds relative to the movement of water. A significant,

negative correlation was found between PFOA and soil pH and silver. No other metals were found to significantly correlate with PFOA.

- PFAS concentrations in soil decrease with depth in the soil column, consistent with atmospheric deposition and infiltration from the ground surface. TOC concentrations in soil decrease with depth in the soil column, consistent with a soil-weathering profile. PFAS fractions that are adsorbed to the organic carbon are highest in the shallow soil layers where organic material content is highest. These findings agree with the results and parameterization of the conceptual modeling.
- Normalizing PFOA concentrations by TOC revealed weak spatial trends in the PFAS; specifically, that the PFOA:TOC ratio decreases with increasing distance from the former Chemfab Water Street facility and increases with increasing distance from Bennington Landfill.
- The presence and concentration of sulfonated PFAS compounds in soil was an indicator of impacts from other sources.
- PFOA concentrations measured in background soils and non-landfill soils were not significantly different, but concentrations measured at Bennington Landfill soils were significantly different from background and non-landfill soils. This finding indicates that PFOA concentrations in soil and more specifically, detections of PFOA in soil are not indicative of past impacts from the former Chemfab facilities. In general, PFOA in soils that may have been due to deposition from the former Chemfab facilities appears to have attenuated.

## 5.2.2 Groundwater

- Statistical analyses of groundwater data from this investigation and data from private well sampling and POET influent monitoring indicated distinct groupings of samples based on relative contributions of PFOA and sulfonated compounds. These groupings suggest different PFAS sources to groundwater.
- [Placeholder for bedrock groundwater quality findings]

## 5.3 PFAS Sources

### 5.3.1 Background

- The average PFOA/TOC value for representative background soil samples collected in the Bennington area is 0.0586 ng PFOA/mg TOC, which is within the range of PFOA/TOC values reported for background soil samples located across North America (Rankin et al., 2016). Thus, the evaluation suggests that the long-range transport and deposition of PFOA and its precursors are responsible for measurable background soil concentrations of PFOA in the Bennington area.

### 5.3.2 Bennington Landfill

- A summary of findings related to Bennington Landfill as a PFAS source will be added upon completion of the on-going bedrock investigation.

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### 5.3.3 PFAS Precursors

- Results of the TOP Assay analysis for PFAS precursors show no significant precursor mass in landfill leachate and groundwater in the unconsolidated aquifer at Bennington Landfill.

### 5.3.4 Other Potential PFAS Sources

- Results of a preliminary desktop review of other potential PFAS sources in the investigation area indicate that a number of other potential sources exist. Additional investigation of these potential sources by the appropriate regulatory agency may be warranted.

## 5.4 Expected Distribution of PFAS Concentrations

- Model-simulated and measured concentrations correlate well when background sources are accounted for in the model.
- The organic carbon content of the soil measured for this study confirms that the  $f_{oc}$  values used in the unsaturated zone transport modeling are reasonable and representative of actual conditions. Model values fall in the range of measured values and follow the same general decrease with depth in the soil column.

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