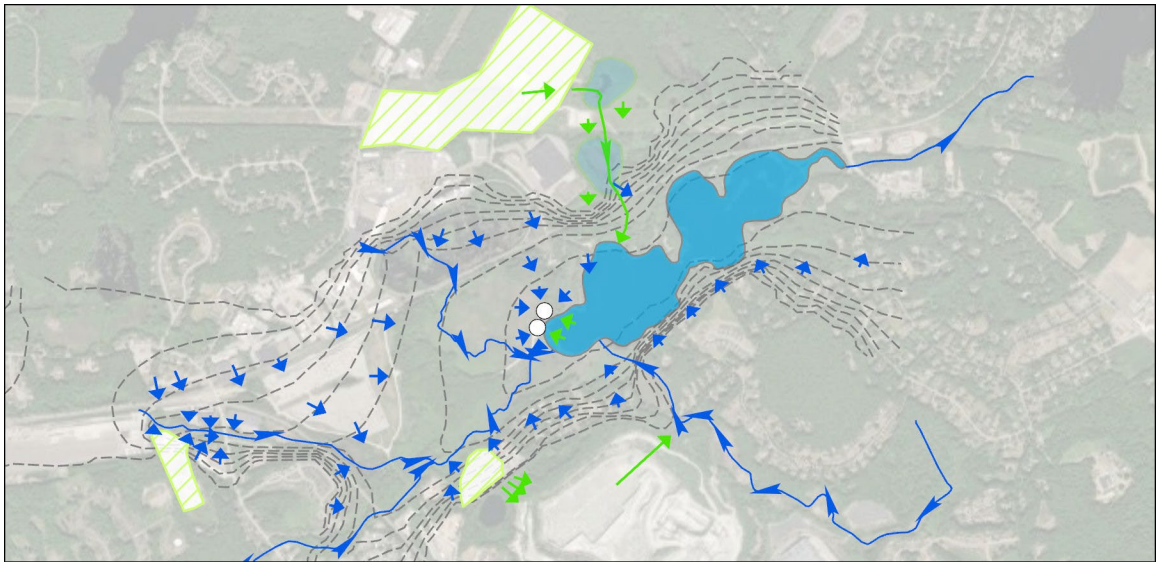
Hodge.WaterResources

Historical Groundwater Reconstruction Study Transport of PFAS to the Spectacle Pond Wellfield

Ayer, Massachusetts



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TABLE OF CONTENTS

SECTION **PAGE**

Executive Summary 4
1.0 Introduction 5
1.1 Project Objectives and Scope 5
1.2 PFAS in General 6
1.3 Previous and Ongoing Studies 6
2.0 Site Description and History 8
2.1 Site Description 8
2.2 Historical PFAS Contamination 8
2.2.1 FIBA Technologies 8
2.2.2 National Grid Properties 8
2.2.3 Routhier's 10
2.2.4 Littleton Spectacle Pond Road Landfill 11
2.3 PFAS Source Summary 12
2.4 Ayer Water Distribution System 12
2.4.1 Spectacle Pond Pumping History 13
2.4.2 PFAS Contamination at the Spectacle Pond Wellfield 17
2.5 Summary 19
3.0 Hydrogeological Setting 20
3.1 Topography and Hydrology 20
3.2 Geology 23
3.3 Hydrogeology 27
4.0 Conceptual Site Model 34
4.1 Potential Transport Pathways 34
4.2 Well and Pond PFAS Sampling 36
4.3 Source-Specific PFAS Sampling 38
4.3.1 Routhier's 38
4.3.2 Littleton Landfill 43
4.3.3 National Grid Properties 52
4.4 Interaction Between Wells 54
4.5 CSM Summary 54
5.0 Estimate of pfas concentrations at Spectacle Pond Wellfield 57
5.1 Determination of Relative Contribution of Sources 59
5.1.1 Relative Contributions in Bennetts Brook 60
5.1.2 Relative Contributions in Spectacle Pond 63
5.1.3 Relative Contributions in PWS Wells 66
5.2 Estimated PFAS Concentrations at Active Wells 73
5.3 Estimated PFAS Concentrations at Decommissioned Wells 76
6.0 References 78

TABLES

Table 1-1: Previous Investigations Related to Spectacle Pond Wellfield 7
Table 4-1: Spectacle Pond Wellfield PFA6+2 Concentrations 36
Table 4-2: PFHxS and PFOS Concentrations at LLF-SW-1 and LLF-SW-2 40
Table 5-1: Spectacle Pond Wellfield PFAS Concentration Variability and Trend 58
Table 5-2: Relative Contribution Calculation for PFAS in Bennetts Brook 62
Table 5-3: Relative Contribution Percentages at Bennetts Brook 63
Table 5-4: Relative Contribution Calculation for PFAS in Spectacle Pond 65
Table 5-5: Relative Contribution Percentages Spectacle Pond 66
Table 5-6: Relative Contribution Calculation for PFAS in SP-01A 68
Table 5-7: Relative Contribution Calculation for PFAS in SP-01B 69
Table 5-8: Relative Contribution Calculation for PFAS in SP-02A 70
Table 5-9: Relative Contribution Percentages SP-01A 71
Table 5-10: Relative Contribution Percentages SP-01B 71
Table 5-11: Relative Contribution Percentages SP-02A 71

FIGURES

Figure 2-1: Locus Map and Site Layout 9
Figure 2-2: Routhier's Firefighting Response Photos (reference) 11
Figure 2-3: Spectacle Pond Zone II Limits 14
Figure 2-4: Spectacle Pond Wellfield Individual Well Locations 14
Figure 2-5: Interpreted Annual Groundwater Pumping 15
Figure 2-6: Spectacle Pond Individual Well Pumping (Monthly Average) 16
Figure 2-7: Spectacle Pond Individual Well Pumping (Annual Average) 16
Figure 2-8: PFAS6+2 Time Series at Spectacle Pond Wells 17
Figure 2-9: Concentrations of Individual PFAS at SP-01A Over Time 18
Figure 2-10: Concentrations of Individual PFAS at SP-01B Over Time 18
Figure 2-11: Concentration of Individual PFAS at SP-02A Over Time 19
Figure 3-1: Topography in Vicinity of Spectacle Pond Wellfield (MassGIS, 2024a) 21
Figure 3-2: Spectacle Pond Bathymetric Contours 22
Figure 3-3: Surficial Geology in Vicinity of Spectacle Pond Wellfield (MassGIS, 2024b) 24
Figure 3-4: Regional Bedrock Elevation (Moore, 1993, pg. 3-47) 25
Figure 3-5: Bedrock Elevation in Vicinity of Spectacle Pond Wellfield 26
Figure 3-6: Groundwater Surface Elevation 1990 (US EPA, 1993, pg. 3-50) 28
Figure 3-7: Groundwater Surface Elevation 1990 in Vicinity of Spectacle Pond Wellfield 29
Figure 3-8: USGS Groundwater Availability (Brackley and Hansen, 1985) 30
Figure 3-9: Hydraulic Conductivity Based on Well Tests 31
Figure 3-10: Quarry Aerial Review (2008) 33
Figure 4-1: CSM Flow Direction Diagram 35
Figure 4-2: SP-01A Radar Chart 36
Figure 4-3: SP-01B Radar Chart 37
Figure 4-4: SP-02A Radar Chart 37
Figure 4-5: Spectacle Pond Radar Chart 38
Figure 4-6: Routhier's Groundwater Sampling Results 39
Figure 4-7: Bennetts Brook Surface Water Sampling Results 40
Figure 4-8: Radar Plots Along Bennetts Brook 42
Figure 4-9: Littleton Landfill Sampling Locations 43
Figure 4-10: PFAS6+2 Concentrations at the Littleton Landfill Over Time 44
Figure 4-11: Radar Plots at the Littleton Landfill 45

Figure 4-12: PFAS6+2 Concentrations at Downgradient Wells (LLF-MW-5, LLF-MW-6, and LLF-MW-7) Over Time 46
Figure 4-13: Radar Plots for Downgradient Wells (LLF-MW-5, LLF-MW-6, and LLF-MW-7) 46
Figure 4-14: PFAS6+2 Concentrations at LLF-MW-1 Over Time 47
Figure 4-15: Radar Plots for LLF-MW-1 47
Figure 4-16: Quarry Sampling Locations 48
Figure 4-17: PFAS6+2 Concentrations at Quarry Sampling Locations Over Time 49
Figure 4-18: Radar Plots for Quarry Sampling Locations 49
Figure 4-19: Radar Plot for Samples at Locations QuaSt and SV-5 50
Figure 4-20: PFAS6+2 Concentrations at LLF-SW-6 Over Time 51
Figure 4-21: Radar Plot for LLF-SW-6 51
Figure 4-22: National Grid Sampling Locations 53
Figure 4-23: Radar Plot for Surface Water Samples at National Grid Properties 53
Figure 4-24: Radar Plot for Groundwater Samples at National Grid Properties 54
Figure 4-25: Flow Chart of Transport Pathways from Sources to Wells 56
Figure 5-1: PFHxA and PFHxS at SP-02A 59
Figure 5-2: Radar Plot for Comparison of Observed PFAS and Estimated PFAS in Bennetts Brook 63
Figure 5-3: Radar Plot for Comparison of Observed PFAS and Estimated PFAS in Spectacle Pond 66
Figure 5-4: Radar Plot for Comparison of Observed PFAS and Estimated PFAS at SP-01A 72
Figure 5-5: Radar Plot for Comparison of Observed PFAS and Estimated PFAS at SP-01B 72
Figure 5-6: Radar Plot for Comparison of Observed PFAS and Estimated PFAS at SP-02A 73
Figure 5-7: Estimated PFOA Concentration at SP-02A, 2000-2020 74
Figure 5-8: Estimated PFAS6+2 Concentration at Spectacle Pond Wellfield, 2000-2020 74

ATTACHMENTS

Attachment 1: Estimated PFAS Concentrations at Spectacle Pond Wellfield

EXECUTIVE SUMMARY

Hodge.WaterResources, LLC, HydroPredictions, LLC, and HydroAnalysis LLC (the Project Team) have completed a historical reconstruction of per- and polyfluoroalkyl substance (PFAS) concentrations at the Spectacle Pond wellfield in Ayer, Massachusetts. The aquifer that feeds the Spectacle Pond wellfield has been investigated for multiple purposes in the past, including as part of a wellhead protection area study (WPA) (Tata & Howard, 1999), an energy facility siting study (GHR, 1989), and PFAS source determination study (Tighe & Bond, 2020a). The Project Team used these studies to inform the historical reconstruction of PFAS concentrations in the aquifer and at the wellfield.

The Spectacle Pond wellfield includes Well 1 and Well 2. Well 1 has been replaced twice, and Well 2 has been replaced once. A total of five separate wells (i.e., SP-01, SP-01A, SP-01B, SP-02, and SP-02A) have been developed at the wellfield over time. SP-01 was decommissioned in 2010. SP-01A was decommissioned in 2021. SP-02 was decommissioned in 2018. PFAS sampling at the Spectacle Pond wellfield began in 2018. Sampling at SP-01A, SP-01B, and SP-02A indicate that all three wells have elevated levels of PFAS.

The Project Team developed a conceptual site model (CSM) that identifies three sources of PFAS at the Spectacle Pond wellfield. Based on the available historical information, our current understanding is that the Littleton Spectacle Pond Road Landfill (Littleton Landfill) is leaching PFAS to groundwater. The landfill was closed in 1988 and is unlined. The release of PFAS began potentially decades before the landfill closure. PFAS from the landfill is reaching the Spectacle Pond wellfield via groundwater and reaching Spectacle Pond via surface water. Firefighting occurred at Routhier's (a tire recycling facility west of Spectacle Pond) in 1994, 2010, and 2012. An unknown amount of aqueous film-forming foam (AFFF) was used in 1994, and approximately 500 gallons of AFFF were used at Routhier's in 2010. There is no record of AFFF use for the 2012 fire. The Routhier’s property has elevated concentrations of PFAS in groundwater, soil, and surface water. PFAS-contaminated groundwater from Routhier’s is reaching Spectacle Pond via surface water. Approximately 10 gallons of AFFF were used each year from 2007 through 2017 as a part of annual training at a National Grid property north of Spectacle Pond. Onsite and downgradient groundwater sampling and downstream surface water sampling from the property show elevated levels of PFAS. PFAS from the National Grid properties is reaching the Spectacle Pond wellfield via groundwater and reaching Spectacle Pond via surface water.

PFAS sampling at the Spectacle Pond wellfield indicates stable PFAS concentrations since 2018 at each well. The Project Team estimated historical PFAS concentrations based on the average concentration at each active well and the available information about the dates of each source release. The Project Team estimated PFAS concentrations for years 2000-2022 for each of four individual PFAS compounds. These estimates are included as Attachment 1 to this report.

1.0 INTRODUCTION

Silent Spring Institute (SSI) asked Hodge.WaterResources, LLC to conduct a historical reconstruction of per- and polyfluoroalkyl substances (PFAS) concentrations at the Spectacle Pond wellfield in Ayer, Massachusetts. Hodge.WaterResources, LLC collaborated with HydroPredictions, LLC and HydroAnalysis LLC to complete this work. References to the Project Team indicate the collective work of these three organizations.

This historical reconstruction of PFAS is part of the Agency for Toxic Substances and Disease Registry (ATSDR) PFAS Multi-site Study (MSS). The PFAS MSS aims to better understand the health impacts of exposure to PFAS through drinking water. The PFAS MSS builds off of the Pease Study (ATSDR, 2024), a prior study of the former Pease Air Force Base in New Hampshire. The PFAS MSS includes sites in seven different states. Within Massachusetts, the PFAS MSS is focused on two communities: Ayer and Hyannis. This historical reconstruction focuses on the Spectacle Pond wellfield, one of two public water supply wellfields that supply drinking water to the Ayer water distribution system.

The PFAS MSS sites jointly established the study period to be the years 2000 through 2023. PFAS sampling at the Spectacle Pond wellfield began in 2018, and Ayer began treating the pumped water to remove PFAS in 2022. An estimate of PFAS concentrations in the groundwater for the years 2000 through 2022 is necessary to achieve the PFAS MSS goals at the Ayer site.

1.1 Project Objectives and Scope

The study objective was to estimate PFAS concentrations in the Spectacle Pond public water supply wells from 2000 through 2022. The following four PFAS compounds were included in this objective:

- perfluorooctane sulfonic acid (PFOS),
- perfluorooctanoic acid (PFOA),
- perfluorohexane sulfonic acid (PFHxS), and
- perfluorononanoic acid (PFNA).

For the purposes of analysis, the Project Team expanded the list of PFAS evaluated in this report to include:

- perfluoroheptanoic acid (PFHpA),
- perfluorodecanoic acid (PFDA),
- perfluorohexanoic acid (PFHxA), and
- perfluorobutane sulfonic acid (PFBS).

The Project Team's analysis is based on sampling results from multiple sampling programs. This set of eight PFAS are the PFAS that the sampling programs have in common, thus allowing for direct comparison of sampling results across programs. PFAS6 refers to the six compounds regulated by the Commonwealth of Massachusetts (i.e., PFOS, PFOA, PFHxS, PFNA, PFHpA, and PFDA), and the full set of eight PFAS compounds is referenced as PFAS6+2 in this report.

The Project Team set out to estimate annual PFAS concentrations in groundwater at the wells by identifying potential PFAS sources, investigating available information about the aquifer, and evaluating the Spectacle Pond wellfield pumping history. The Project Team used this information to develop a conceptual site model (CSM) to understand the timeline and transport pathways that have led to elevated PFAS concentrations at the Ayer public water supply (PWS) wells.

The state of the science related to PFAS is evolving. In contrast to many other contaminants, the chemical and physical processes involved in PFAS fate and transport are more complex and not fully understood. These limitations result in PFAS fate and transport uncertainty. For the Spectacle Pond wellfield, PFAS transport uncertainty is coupled with site-specific uncertainty. For at least one of the potential PFAS sources, the Littleton Landfill, there is a lack of sufficient information to characterize the timeline and amount of PFAS being released to the environment.

1.2 PFAS in General

PFAS are a category of synthetic chemicals that include carbon-fluorine bonds. Thousands of different PFAS chemicals have been created since the 1950s (US EPA, 2024). PFAS have been ubiquitous in manufacturing for many decades. Some of the most common uses include as a surfactant in aqueous film-forming foam (AFFF), as a water/grease repellant for textiles, and as component materials for a wide range of industrial products.

PFAS are commonly called “forever chemicals” due to their persistence in the environment. The properties that make PFAS useful also make them resistant to biodegradation. PFAS are found in water, soil, and air around the world. Some of the most common sources of PFAS in the environment are applications of AFFF, wastewater treatment plants (WWTP), and landfills. These common sources are not an exhaustive list. The ubiquitous nature of PFAS in industrial operations means that any industrial activity has the potential to be a source of PFAS in the environment.

The behavior of PFAS in the environment is different from conventional contaminants. Most of the PFAS that have been detected in the environment have a chemical structure that consists of a hydrophobic (not attracted to water) head and a hydrophilic (attracted to water) tail (ITRC, 2024a). This structure leads PFAS to accumulate at the interface between different media. These interfaces include the groundwater surface (i.e., the interface between air and water) and the interface between soil and groundwater. The accumulated PFAS are typically in the aqueous phase because most PFAS have high aqueous solubility (ITRC, 2024a). The occurrence of pure phase PFAS in the environment is rare (ITRC, 2024a).

Partitioning at the soil-water interface is thought to be primarily controlled by sorption through electrostatic interactions and sorption to organic matter via hydrophobic interactions (ITRC, 2024a). The vast number and variable chemical structure of PFAS mean that the partitioning behavior of PFAS has not been fully determined. Conventional approaches to fate and transport modeling may not be as conceptually correct as for conventional contaminants, but these approaches remain the best way to evaluate PFAS fate and transport.

1.3 Previous and Ongoing Studies

The aquifer that feeds the Spectacle Pond wellfield has been investigated for multiple purposes in the past. Table 1-1 lists five previous studies and describes the type of work completed. These studies serve as the foundation for much of the work described in this report. Digital copies of these documents are included with this report as Digital Attachment 1.

Table 1-1: Previous Investigations Related to Spectacle Pond Wellfield

Study Title	Reference	Description
Patriot Energy Project, Ayer, Massachusetts, Baseline Hydrogeological Evaluation	GHR, 1989	The purpose of this study was to characterize the surface water and groundwater of the area immediately west of Spectacle Pond including Bennetts Brook. The study reviewed available hydrogeological information, and the study included on-site investigations including soil borings, installation of monitoring wells, peat probing, and hydraulic conductivity testing. The study also developed a steady-state groundwater flow model of the area west of Spectacle Pond.
Case Studies in Wellhead Protection Area Delineation and Monitoring	Moore, 1993	This report prepared for the US EPA includes four case studies that described the establishment of wellhead protection areas (WPAs). One of the case studies is the development of the WPA for the Town of Littleton whose PWS well is located on the eastern end of Spectacle Pond. The case study summarizes work that included the collection of available geologic and hydrogeologic information, groundwater quality sampling, peat probing, and the development of a steady-state groundwater flow model.
Conceptual Zone II Delineation for the Spectacle Pond Wells, Ayer Massachusetts	Tata & Howard, 1999	This study established a WPA for the Town of Ayer Spectacle Pond wellfield located on the western end of Spectacle Pond. This study collected available geologic and hydrogeologic information about the aquifer that feeds the Spectacle Pond wellfield. The study used this information to establish a WPA based on a downgradient stagnation point and upgradient geologic boundaries of saturated surficial deposits.
Immediate Response Action Plan Modification & Status Report No. 10, 43 Willow Road, Ayer, Massachusetts, RTN 2-17951.	Weston & Sampson, 2024	This report provides a summary of the environmental impacts associated with the release of contaminants during and after fires that occurred at the property located at 43 Willow Road in Ayer. The site is a tire recycling center. Fires occurred at this site in 1994, 2010, and 2012. The firefighting response to the 2010 fire included the use of as much as 500 gallons of AFFF. The report describes details of the response to the fire as well as surface water, groundwater, and soil sampling that have occurred at and near the site.
Spectacle Pond Watershed, Ayer and Littleton, Massachusetts, PFAS Distribution and Source Evaluation	Tighe & Bond, 2020	Water from both the Littleton PWS well and the Ayer PWS wells have been shown to have elevated PFAS concentrations. This study evaluated available PFAS sampling in groundwater and surface water in order to determine the likely source of PFAS at the PWS wells. The study concluded that the PWS wells do not have a single source, and there are likely multiple sources contributing PFAS to the PWS wells.

2.0 SITE DESCRIPTION AND HISTORY

2.1 Site Description

The town of Ayer is located in eastern Massachusetts approximately 40 miles northwest of Boston. The town provides drinking water to most of its residents through a water distribution system. The source waters for the town's distribution system are the Grove Pond wellfield and Spectacle Pond wellfield with each wellfield located adjacent to their respective ponds. Figure 2-1 shows the location of Spectacle Pond. Bennetts Brook flows from west to east and drains into the western end of Spectacle Pond. Bennetts Brook includes two unnamed tributaries. A second stream colloquially known as the Quarry Stream flows from the south and drains to the western end of Spectacle Pond. The outlet for Spectacle Pond is Gilson Brook on the east, which carries water eastward towards Forge Pond. Aggregate Industries owns an active quarry that is located approximately 1,000 feet (ft) south of Spectacle Pond. The quarry and the area south of Bennetts Brook are located within the neighboring town of Littleton.

2.2 Historical PFAS Contamination

The region of interest for this study is the area surrounding the western half of Spectacle Pond. Aerial imagery, as shown in Figure 2-1, shows a mixture of land use with approximately 50% developed (i.e., industrial, commercial, or residential) and 50% undeveloped. Tighe & Bond (2020a) identified four potential PFAS sources within the Spectacle Pond watershed. These sources are FIBA Technologies, National Grid High Voltage Direct Current (HVDC) converter terminal and substation, a tire recycling center known as Routhier's, and the Littleton Spectacle Pond Road Landfill. The location of each potential source is shown in Figure 2-1 and described below.

2.2.1 FIBA Technologies

FIBA Technologies, Inc. (FIBA) owns a property located at 53 Ayer Road in Littleton. The property location is shown in Figure 2-1. FIBA is an industrial company that provides "gas containment equipment" for various uses (FIBA, 2024). FIBA received a Request for Information from the Massachusetts Department of Environmental Protection (DEP), and FIBA responded in July of 2020 (Tighe & Bond, 2020a, pg. 2-4). FIBA indicated that they had no knowledge of PFAS use at their property in their response to DEP (Finn, 2020). Multiple town-owned groundwater monitoring wells located at the property were sampled for PFAS as a part of the Tighe & Bond study. Two wells (MX-4 and MX-6) showed elevated concentrations of PFOS and N-Ethyl-N-[(heptadecafluorooctyl)sulphonyl]glycine (NEtFOSAA). Tighe & Bond (2020, pg. 5-3) eliminated the site as a potential source of PFAS at the PWS wells because the property is outside of the Zone II area for both the Ayer and Littleton PWS wells. The presence of the quarry and related bedrock outcropping limits the potential for transport via groundwater to the Spectacle Pond wellfield. There is no surface water pathway evident that would connect FIBA to Spectacle Pond. None of the Ayer PWS wells have ever shown elevated concentrations of NEtFOSAA. The Project Team agrees with the conclusion made by Tighe & Bond.

2.2.2 National Grid Properties

National Grid owns two properties located north of Spectacle Pond. The facility at 55 Raddison Road in Ayer is an HVDC converter terminal, and the facility at 65 Westford Road in Ayer is an electrical substation (Tighe & Bond, 2020a, pg. 2-2). The individual addresses are shown in Figure 2-1. As much as 10 gallons of AFFF were sprayed on to the ground at the Raddison Road property as a part of annual testing of the on-site fire suppression system from 2007 to 2017, and as much as five gallons of AFFF was used in August 2018 to extinguish a fire at the property (Callanan, 2020). AFFF may have been used at the Westford Road

property in 1995 in fighting a fire (Tighe & Bond, 2020a, pg. 2-3). The Tighe & Bond study included surface water sampling and groundwater sampling at multiple locations between the National Grid properties and Spectacle Pond.

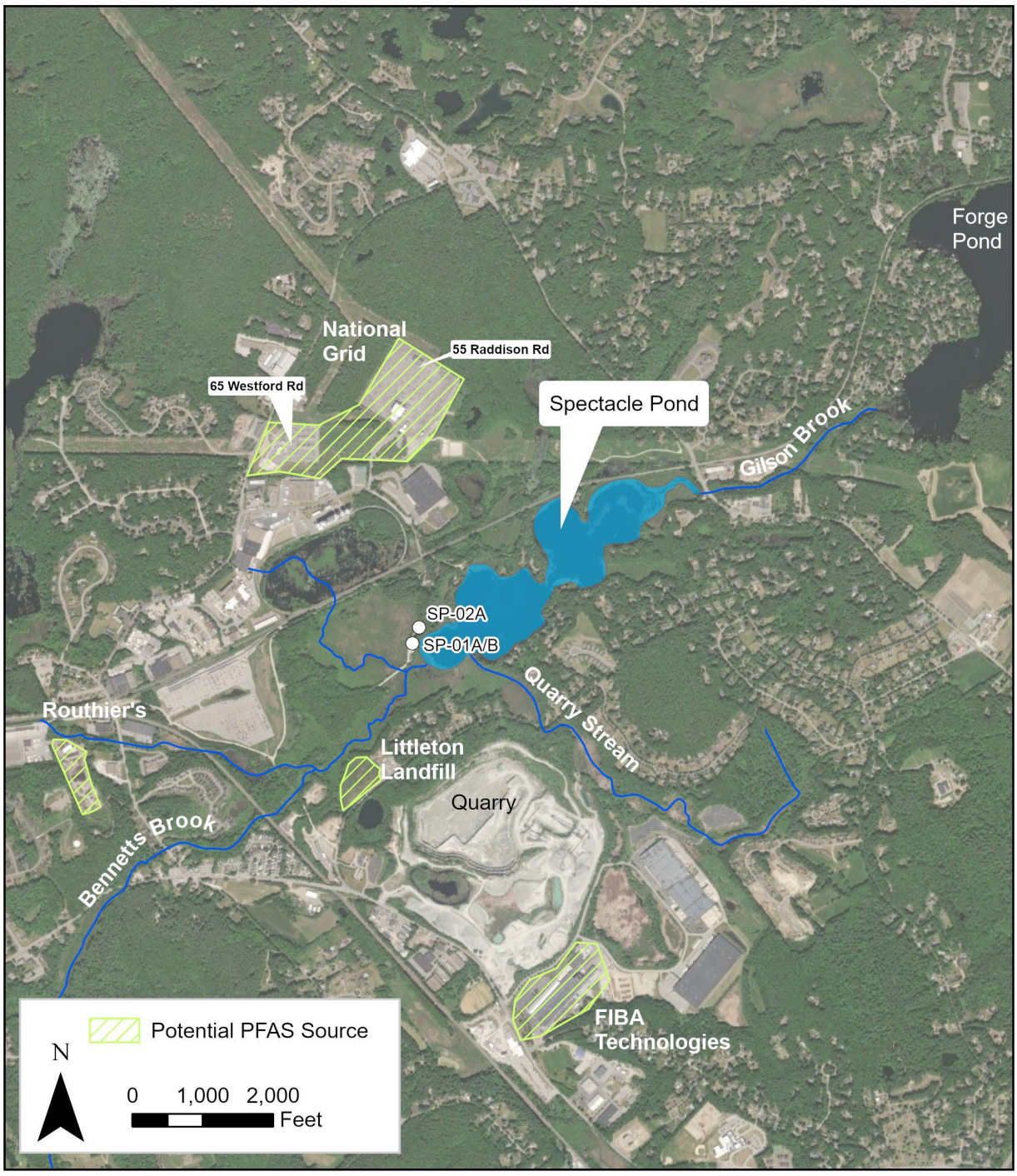


Figure 2-1: Locus Map and Site Layout

Surface water samples and groundwater samples indicated elevated levels of PFAS. The PFAS compounds with the highest concentrations included perfluoropentanoic acid (PFPeA), PFHxA, and perfluorobutanoic acid (PFBA) (Tighe & Bond, 2020a, pg. 5-3). The surface water samples also had elevated levels of 6:2-fluorotelomersulfonic acid (6:2 FTS) (Tighe & Bond, 2020a, pg. 5-3). The elevated concentrations in both surface and groundwater suggest an upgradient/upstream source north of Spectacle Pond (i.e., the National Grid properties).

2.2.3 Routhier's

JP Routhier & Sons, Inc. (Routhier's) is located at 43 Willow Road in Ayer. Routhier's has been a tire recycling center since 1991 and a tire storage facility since 1985 (Weston & Sampson, 2024, pg. 2). The property is located approximately 3,500 ft west of the Spectacle Pond wellfield and adjacent to a tributary of Bennetts Brook. Tighe & Bond (2020a, pg. 2-4) state that tire fires occurred at Routhier's in 1994, 2010, and 2012. At the time of the 1994 fire, the Times Free Press Public Spirit, a local newspaper, reported that a foam-spraying truck from Fort Devens was used to battle the fire (Gordon, 1994). The Project Team did not find any additional information about the 1994 fire in the documents that we reviewed. The 2010 fire occurred on August 2. Approximately 500 gallons of Class B AFFF was used to extinguish the fire (Sanborn Head, 2020, pg. 1). Figure 2-2 shows two photos taken during the firefighting response in 2010. White foam is clearly present at the presumed fire location and in stormwater detention basins on site. The Ayer Fire Department notified the DEP of a potential release of oily water, but not the foam, and DEP assigned the site release tracking number (RTN) 2-0017951. The 2012 fire occurred on September 15. AFFF may have been used, but the Project Team did not find any additional information in the documents that we reviewed.

Initial spill response actions at Routhier's focused on the release of oily water, but in September of 2019 DEP issued a notice of audit (NOA) to Routhier's. DEP sampled soils, groundwater, and surface water for the presence of PFAS in relation to DEP's investigation of PFAS sources for the Spectacle Pond wellfield (Weston & Sampson, 2024, pg. 4). DEP's investigation found elevated PFAS concentrations in all three media. Routhier's has been engaged in response actions since that time and has conducted additional sampling of PFAS at the property and at downstream or downgradient locations.

More recent sampling, by Routhier's and its contractors, indicates very elevated concentrations (i.e., more than 1,000 nanograms per liter (ng/L)) of PFAS6+2 in on-site groundwater monitoring wells and elevated PFAS concentrations in the tributary that flows along the property boundary.





Figure 2-2: Routhier's Firefighting Response Photos (DEP, 2023)

2.2.4 Littleton Spectacle Pond Road Landfill

The land to the south of the Spectacle Pond wellfield is part of the neighboring town of Littleton. The Littleton Spectacle Pond Road Landfill (or Littleton Landfill) is located approximately 1,500 ft southwest of the Spectacle Pond wellfield. Its location is shown in Figure 2-1. Very little information is available about the history of the landfill. Weston & Sampson (1989a) report that the landfill began operations before the 1970s as an open burning dump. It ceased operations in September 1988 and closure plans were prepared in 1989 (Weston & Sampson, 1989b). The closure plans called for an "impervious cap" but without detailed specifications other than that it was to consist of two 6-inch lifts of clay. Tata & Howard (1999) report that

the landfill was capped in the early 1990s. DEP also reports that the landfill ceased accepting solid waste in 1988 and that it is unlined (DEP, 2017). GHR (1989) reports that the town kept a storage pile for road salt approximately 800 ft southwest and upgradient of the landfill on the opposite side of Route 2A. The Project Team met with the Littleton Department of Public Works to request additional information. The town was able to confirm that the landfill was closed and capped but could not provide any additional information about the history of operation or construction. The town began monitoring groundwater quality for conventional and organic constituents (but not PFAS) around the landfill in 1982 (GHR, 1989, pg. 2-8). GHR used the landfill groundwater sample results in conjunction with sample results for the Spectacle Pond wellfield to develop Stiff diagrams of inorganic water quality from the landfill monitoring wells and the PWS wells. GHR drew the following conclusion. “It is clear that the presence of the landfill and the salt storage pile (when it was uncovered) have influenced the water quality of PW-1 [SP-01] and to a lesser extent PW-2 [SP-02]” (GHR, 1989, pg. 6-7).

According to Littleton, quarterly sampling at the landfill monitoring wells now includes sampling for PFAS. Tighe & Bond used sampling from February 2020 as a part of their investigation of PFAS sources in the vicinity of Spectacle Pond. Four of the five wells that ring the boundary of the landfill had elevated levels of PFAS6 (Tighe & Bond, 2020a, Table 3).

2.3 PFAS Source Summary

DEP initiated an investigation of PFAS at the Ayer and Littleton PWS wells located adjacent to Spectacle Pond in 2019. They issued 17 requests for information (RFIs) (Tighe & Bond, 2020a, pg. 2-2). Tighe & Bond narrowed the list of potential sources down to four properties (i.e., Routhier’s, Littleton Landfill, FIBA Technologies, and the National Grid properties). After Tighe & Bond (2020a) eliminated FIBA as a potential source, three potential sources of PFAS remained. The Project Team conducted additional analysis of these three sources in order to support our estimate of PFAS at the Ayer PWS wells.

2.4 Ayer Water Distribution System

The only source of drinking water in Ayer is groundwater. The water distribution system includes two wellfields: the Grove Pond wellfield and the Spectacle Pond wellfield. Both wellfields pump from sand and gravel aquifers. The Grove Pond wellfield aquifer is unconfined, and the Spectacle Pond wellfield aquifer is semi-confined. The first Spectacle Pond well was developed in 1975 and a second well was completed in 1985 (Tata & Howard, 1999, pg. 3-4).

The town of Ayer completed a Zone II study for the Spectacle Pond wellfield in 1999 (Tata & Howard, 1999). A Zone II study is an investigation that establishes the WPA (the wellhead protection area that should be protected from groundwater contamination) to prevent drinking water contamination. The Spectacle Pond Zone II study delineated the WPA based on a review of existing aquifer test data, test well and monitoring well logs, and publicly available hydrogeologic information (Tata & Howard, 1999). No new sampling or modeling was collected as a part of this study, and the study relied heavily on the Zone II delineation by Moore (1993) for the Littleton PWS wells. The Zone II boundary for the Spectacle Pond wellfield is shown in Figure 2-3. Only the landfill is wholly within the Zone II boundary. Routhier’s is partially within the Zone II boundary. Surface water streams that flow adjacent to or nearby Routhier’s and the National Grid properties drain to Spectacle Pond. Spectacle Pond itself is not within the Zone II boundary. The interaction between the pond and the wellfield is discussed in Section 3.3 of this report.

2.4.1 Spectacle Pond Pumping History

Spectacle Pond Well 1 (SP-01) and Spectacle Pond Well 2 (SP-02) were in service when the Zone II study was completed. Since that time, both wells have been replaced by new wells in close horizontal proximity to the wells they replaced. SP-01 was replaced by Well 1A (SP-01A) which has since been replaced by Well 1B (SP-01B). SP-01 stopped pumping in January 2010, and SP-01A stopped pumping in April 2021. SP-02 was replaced by Well 2A (SP-02A) in January 2018. Figure 2-4 shows the location of each well and the screen depths for active and decommissioned wells. SP-01 had two screened intervals. Ayer was not able to provide as-built information for well SP-01A. The wells that are active today (i.e., SP-01B and SP-02A) have a single screened interval with SP-01B screened approximately 15 ft deeper than SP-02A.

The Spectacle Pond wells have been pumped at different rates based on capacity, demand, and maintenance over the years. In addition to the variability of pumping at the Spectacle Pond wellfield, the Town of Ayer made significant changes to their pumping operations over the years, again in response to capacity, demand, and maintenance. The Project Team collected all available pumping records from the DEP. These records date back to 1986. The Project Team relied on annual pumping estimates included in the town's annual reports to understand the intensity of pumping at both the Spectacle Pond and Grove Pond wellfields prior to 1986. Figure 2-5 shows the interpreted annual average pumping rate at both wellfields. The Spectacle Pond wellfield came online in 1977, and the Grove Pond wellfield was rarely used from then until 1998. From that year forward, both wellfields supplied water for the town.

Individual well pumping at Spectacle Pond is available from 1986 onward with the exception of 1995. For the period after 1986, monthly pumping records are available for each well. Figure 2-6 shows the monthly average pumping rates, and Figure 2-7 shows the annual average pumping rates. These figures show that the town routinely varied pumping from well to well.

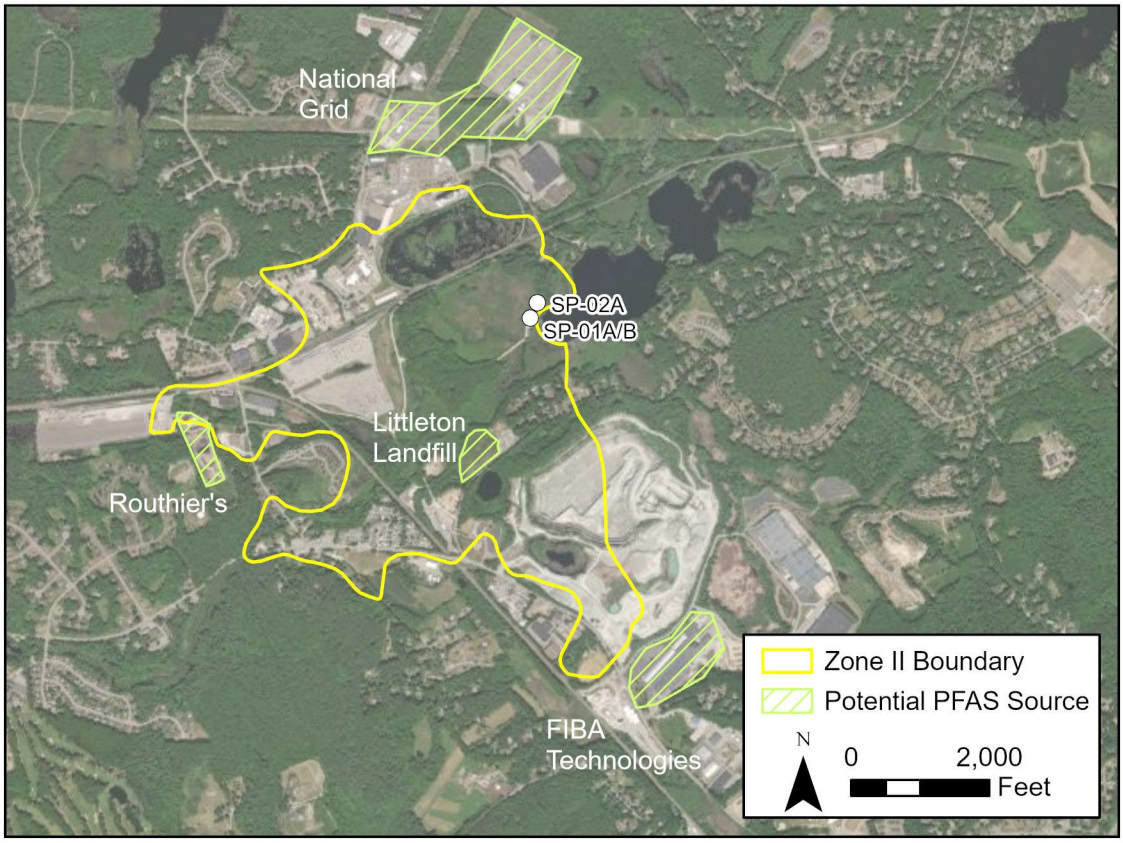


Figure 2-3: Spectacle Pond Zone II Limits

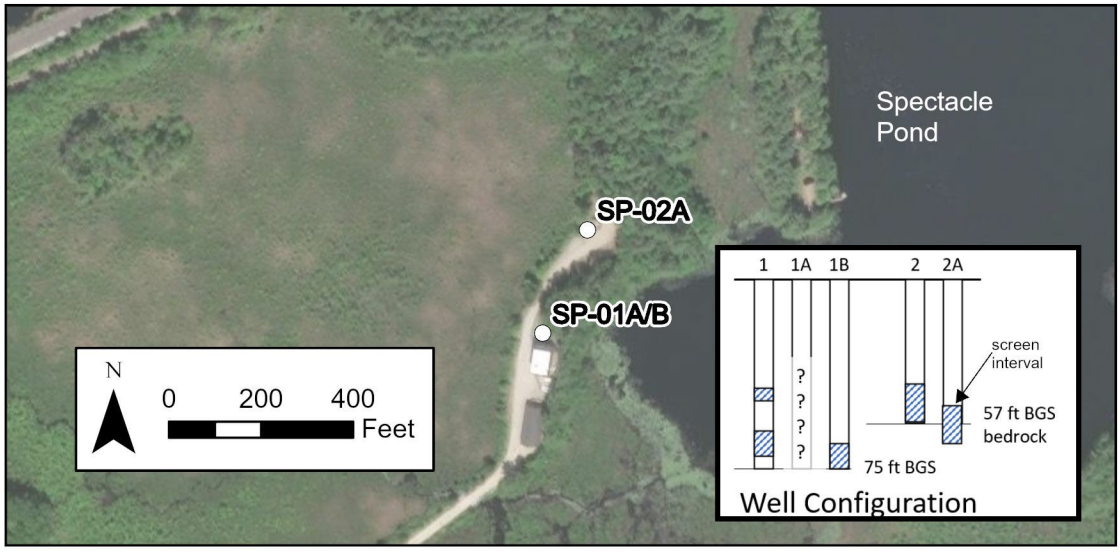


Figure 2-4: Spectacle Pond Wellfield Individual Well Locations

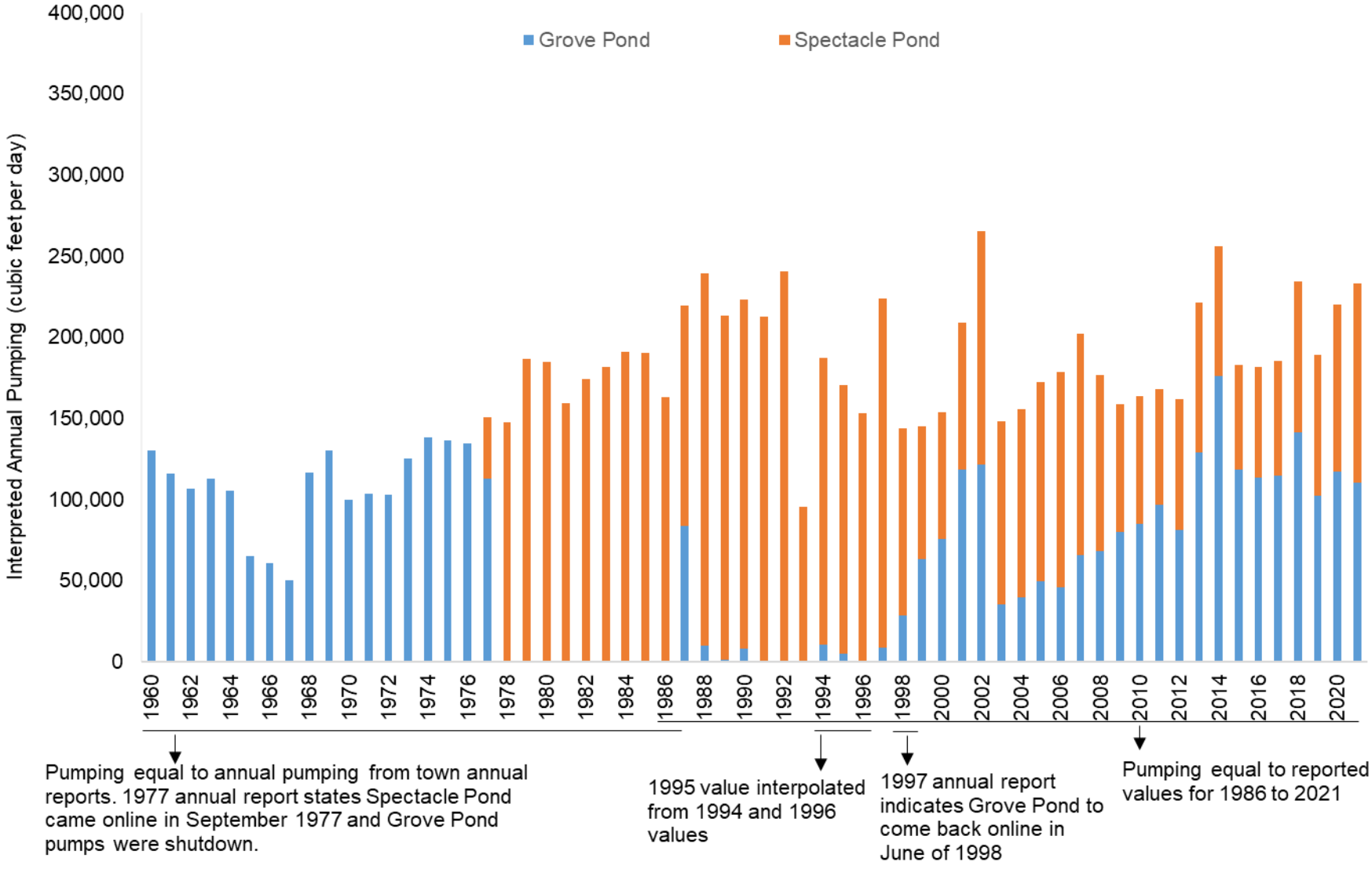


Figure 2-5: Interpreted Annual Groundwater Pumping

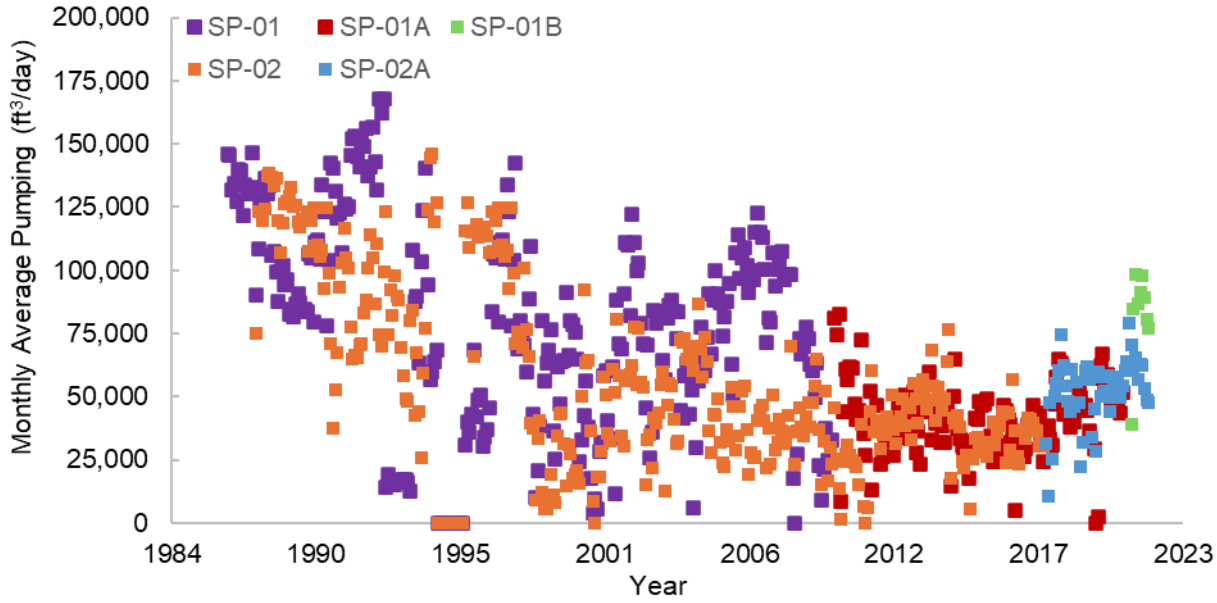


Figure 2-6: Spectacle Pond Individual Well Pumping (Monthly Average)

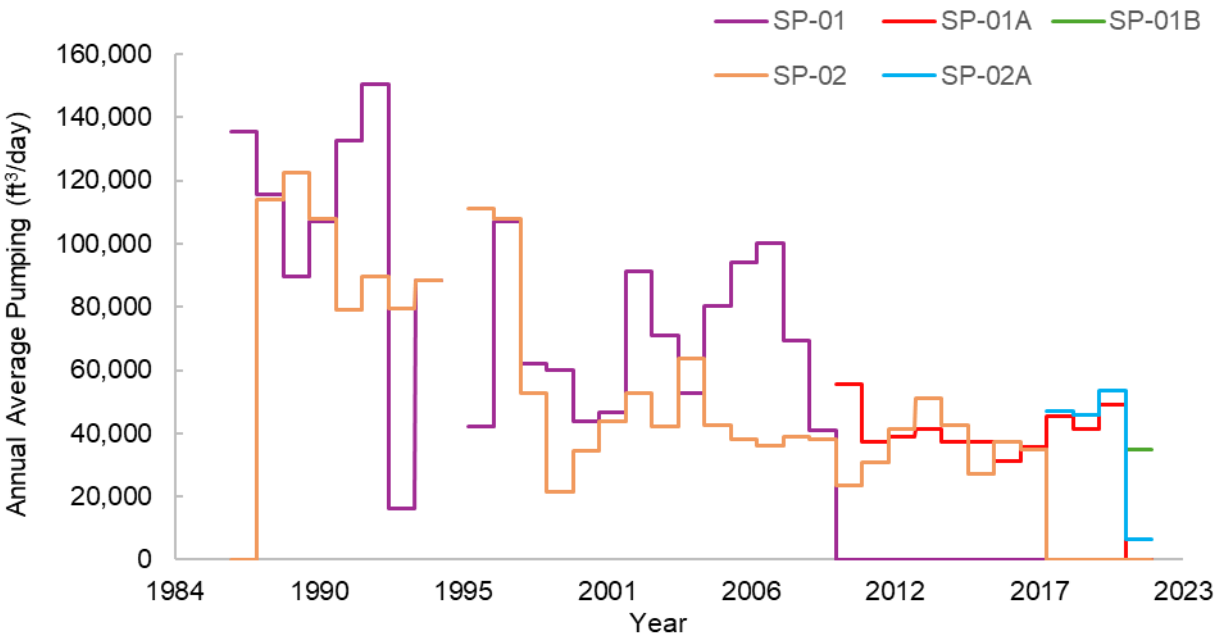


Figure 2-7: Spectacle Pond Individual Well Pumping (Annual Average)

2.4.2 PFAS Contamination at the Spectacle Pond Wellfield

Ayer first detected PFAS in drinking water at the Grove Pond wellfield in 2016 (Ayer, 2019), and PFAS was subsequently detected at the Spectacle Pond wellfield in 2018. Since that time, Ayer has regularly monitored PFAS concentrations in both the raw (prior to treatment) and finished (after treatment) drinking water. Figure 2-8 shows the PFAS6+2 concentrations recorded at the Spectacle Pond wellfield between mid-2018 and mid 2024 as reported to the state (EEA, 2024). SP-01B has the highest single sample, but SP-01A has the highest average concentration. All of the samples are the same order of magnitude with values between 20 and 60 ng/L. Figure 2-9 through Figure 2-11 show the concentrations of individual PFAS compounds that makes up PFAS6+2 concentrations.

The sample profiles show subtle variations at the different wells, a characteristic that we attribute to different potential sources as discussed in Sections 4 and 5 of this report. Samples from SP-01A show PFOS as the highest concentration PFAS, samples from SP-01B show PFOA as the highest concentration PFAS. Samples from SP-02A show PFHxA as the highest concentration PFAS. PFNA and PFDA have the lowest concentrations at all three wells. During the time period of PFAS sampling, SP-01A and SP-02A were both actively pumped. SP-01B was not actively pumped until April 2021. After SP-01B came online, pumping at SP-01A stopped.

Not all PFAS compounds were sampled during each sampling event. For example, PFHxA was not sampled at SP-02A for the first two sampling events on March 1, 2018 and April 23, 2018. If an individual compound was not measured as a part of a sampling event, the entire sampling event is excluded from Figure 2-8. Sample results that are non-detect[1] and do not include a detection limit or a reporting limit are excluded from the graphs.

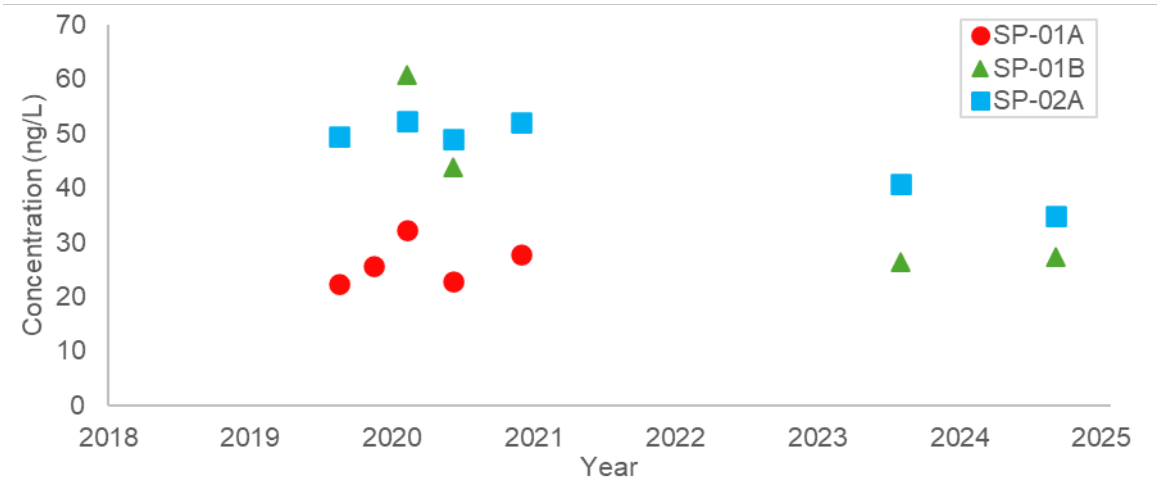


Figure 2-8: PFAS6+2 Time Series at Spectacle Pond Wells

[1] The sampling results presented in this report include results from multiple sampling programs. The Project Team elected to assign a concentration of half the detection limit for all non-detect sample results. All qualified (e.g., J-qualified) sampling results were assigned the qualified concentration. Not all of the PWS sample results include a lab-specified detection limit. If no detection limit was available for a non-detect value, the Project Team assigned a concentration of half of the reporting limit. If a non-detect sample result included neither a detection limit nor a reporting limit, the Project Team excluded the non-detect from analysis.

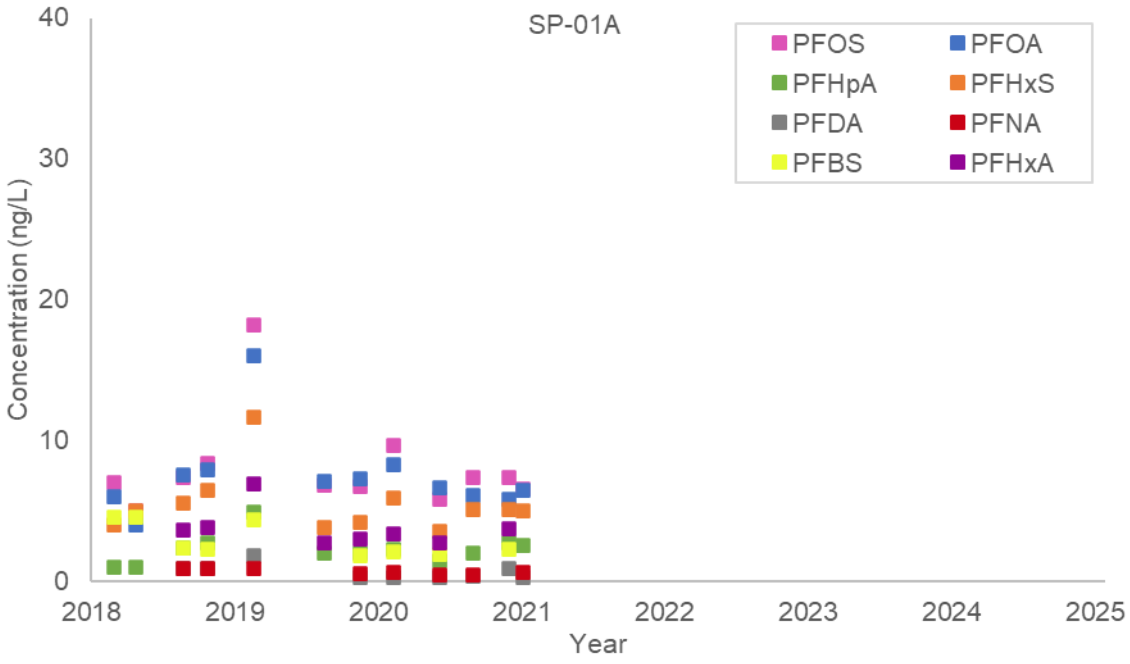


Figure 2-9: Concentrations of Individual PFAS at SP-01A Over Time

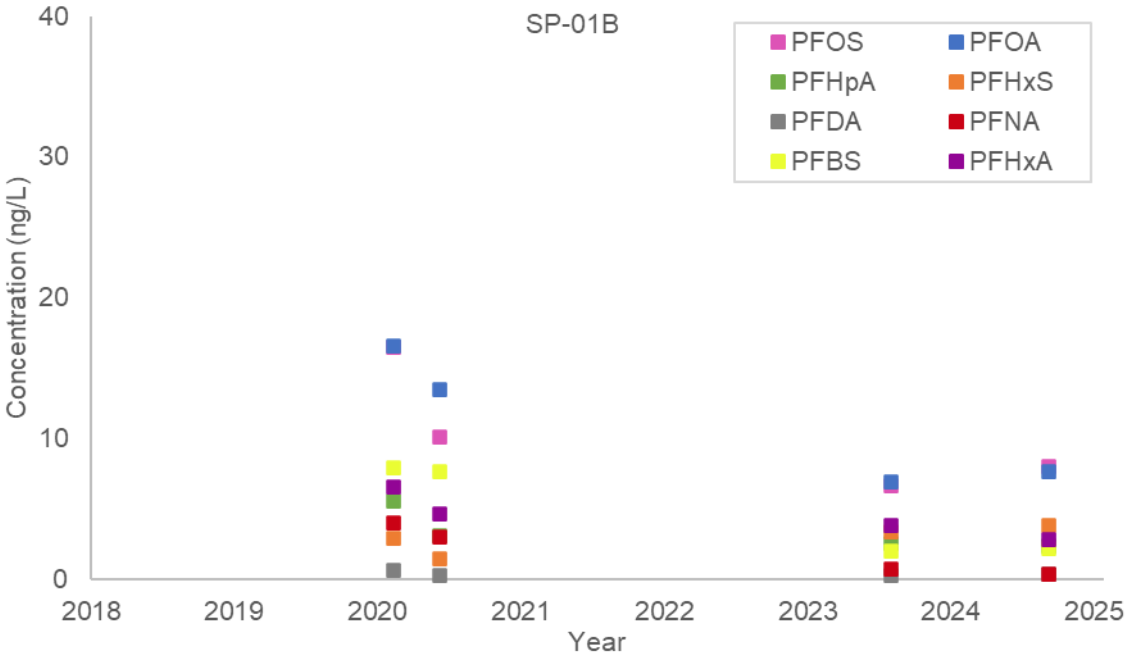


Figure 2-10: Concentrations of Individual PFAS at SP-01B Over Time

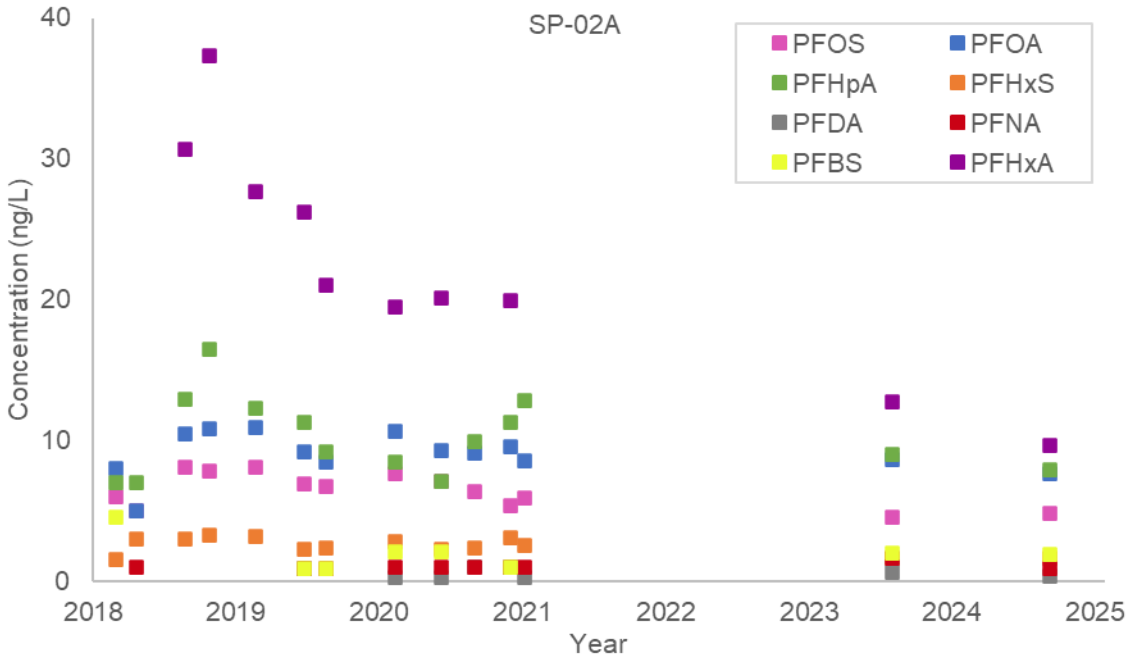


Figure 2-11: Concentration of Individual PFAS at SP-02A Over Time

2.5 Summary

The town of Ayer has been pumping groundwater from the Spectacle Pond wellfield since 1977. From 1978 to 1998, the Spectacle Pond wellfield was the primary source of drinking water for the town. Since then, both the Spectacle Pond wellfield and the Grove Pond wellfield have been providing water to Ayer, and the Spectacle Pond wellfield contribution has decreased in relation to the Grove Pond contribution since 2003. Measurements of PFAS contamination in the Spectacle Pond wells date back to 2018, but many of the potential PFAS sources are older than that. In the next section of the report, we present the hydrogeologic setting for the Spectacle Pond wellfield. We then evaluate the available groundwater quality and surface water quality data in the context of the source histories and the geologic setting to develop a conceptual site model for use in estimating historical PFAS concentrations at the Ayer PWS wells.

3.0 HYDROGEOLOGICAL SETTING

Previous investigations provide a substantial amount of information to aid our understanding of the Spectacle Pond aquifer's hydrogeology. Littleton's Spectacle Pond Zone II study (US EPA, 1993) and the Patriot Energy Project study (GHR, 1989) included sub-surface investigations including observation well drilling, groundwater sampling, aquifer tests, and groundwater modeling. Ayer's Zone II study (Tata & Howard, 1999) provide additional context to the two earlier investigations.

3.1 Topography and Hydrology

The topography near Spectacle Pond forms a valley with the ground sloping towards the pond from the west, south, and north. Figure 3-1 shows ground surface contours in feet referenced to the North American Vertical Datum 1988 (NAVD88). The figure also shows the primary surface water features. Bennetts Brook flows from the west towards Spectacle Pond with two unnamed tributaries joining the brook within the Spectacle Pond Zone II Boundary. The informally named Quarry Stream flows into Spectacle Pond approximately 500 ft southeast of the Spectacle Pond wellfield. The outlet to Spectacle Pond is located at the eastern end of the pond where Gilson Brook flows east towards Forge Pond.

Spectacle Pond has a western lobe and an eastern lobe. The western lobe has a maximum depth of 32 ft while the eastern lobe is shallower with a maximum depth of approximately 14 ft. Figure 3-2 shows bathymetric contours of the pond based on measurements of water depth by GHR (1989, pg. 5-3).

Both GHR (1989) and the Town of Littleton (Moore, 1993) discuss the presence of a peat layer underneath and surrounding Spectacle Pond. GHR measured the thickness of the peat layer along Bennetts Brook from approximately 1,500 ft upstream of the pond to beneath the pond itself and in the wetlands north of Bennetts Brook. The average thickness of the peat layer along the brook is 2 ft, and the thickness underneath the pond ranges from 3 to 6 ft (GHR, 1989, pg. 4-16). GHR (1989, pg. 4-14) describe the peat as "loosely packed." Littleton measured peat layer thicknesses in the eastern lobe of Spectacle Pond and the thickness ranged from less than 1 ft to more than 34 ft with an average thickness of 5 ft (Moore, 1993, pg. 3-36, 3-48). Littleton also noted that the peat was loosely packed.

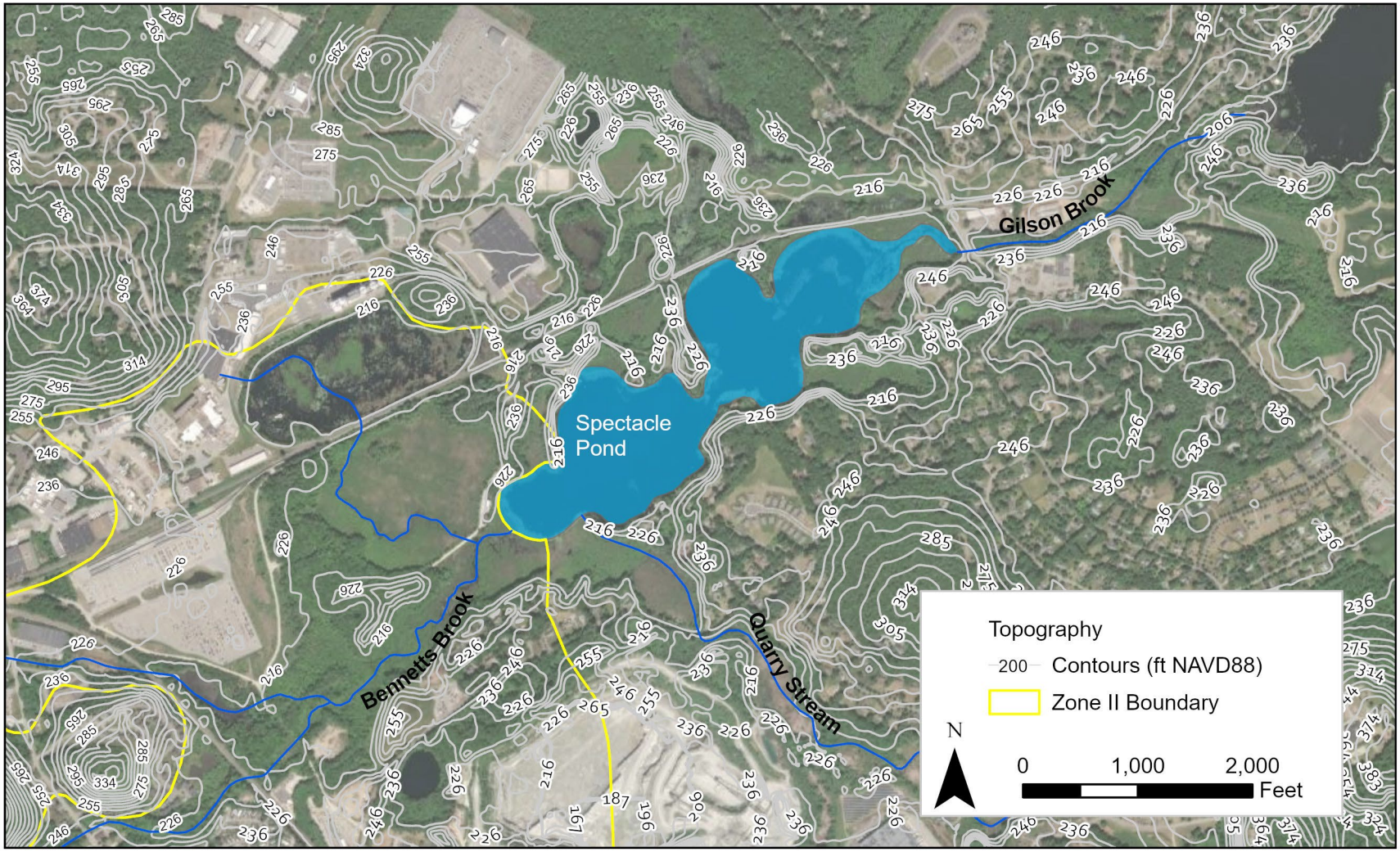


Figure 3-1: Topography in Vicinity of Spectacle Pond Wellfield (MassGIS, 2024a)

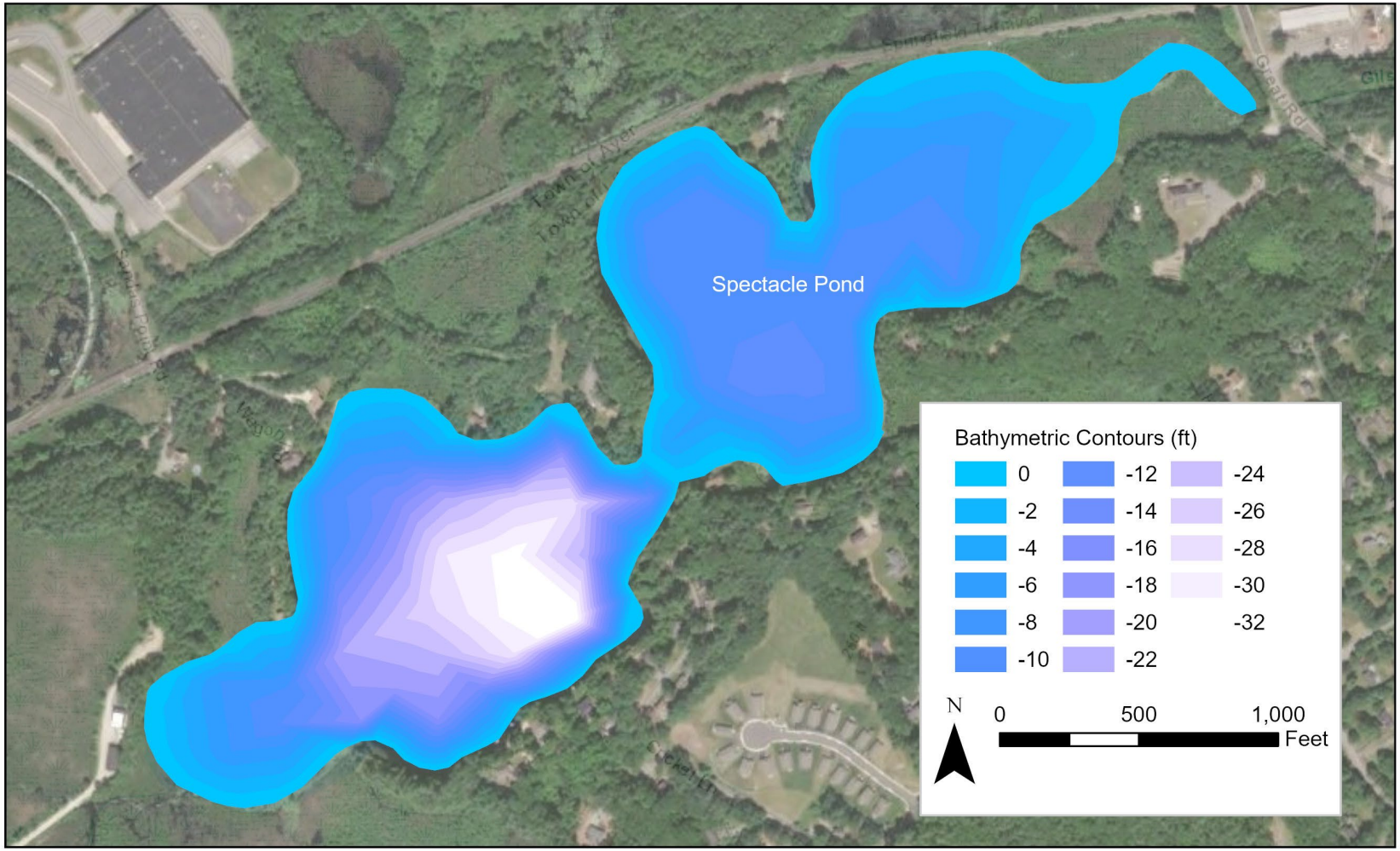


Figure 3-2: Spectacle Pond Bathymetric Contours

3.2 Geology

Tata & Howard (1999, pg. 2-2) describe the surficial geology near Spectacle Pond as glacial drift with stratified layers of fine to coarse sands and gravels. The Spectacle Pond wellfield is located within an esker composed of a mixture of pebbles, boulder gravel, and fine to coarse sand. Figure 3-3 shows the surficial geology as mapped by the United States Geological Survey (USGS) (Jahns, 1953; MassGIS, 2024b). The USGS surficial geology zones include many swamp deposits (shown as purple in Figure 3-3). These swamp deposits roughly align with the peat layer boundaries as identified in other studies. Spectacle Pond itself is shown aligning with a small region of thick till. The well logs for SP-01 and SP-02 indicate coarse granular soils up to depths of 70 ft below the ground surface (Tata & Howard, 1999, pg. 2-2) and do not show a confining/semi-confining till layer.

As mapped by Moore (1993, pg. 3-47), bedrock elevations mirror the valley seen in the surface topography. The valley centerline west of Spectacle Pond approximately aligns with Bennetts Brook. Along the brook, the depth to bedrock ranges from 0 to more than 100 ft (Moore, 1993, pg. 3-4). Figure 3-4 shows a bedrock elevation map from the Littleton Zone II study (Moore, 1993), and Figure 3-5 shows the same contours, relative to mean sea level (MSL), in the area surrounding the Spectacle Pond wellfield. Tata & Howard (1999, pg. 2-6) identify the bedrock underlying Spectacle Pond as granitic. Both Tata & Howard (1999) and Littleton (Moore, 1993) characterize the bedrock as impermeable relative to the overburden.

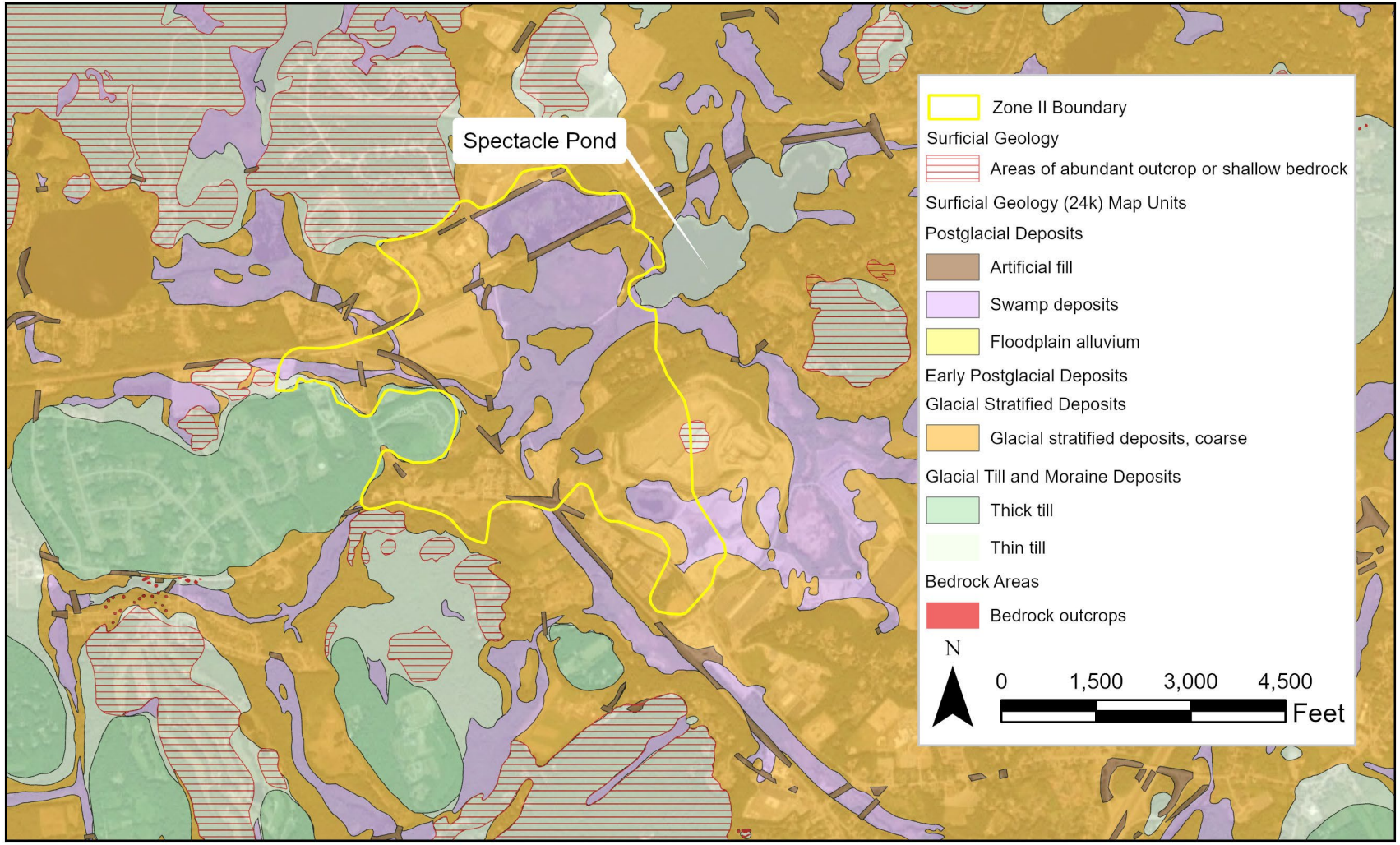


Figure 3-3: Surficial Geology in Vicinity of Spectacle Pond Wellfield (MassGIS, 2024b)

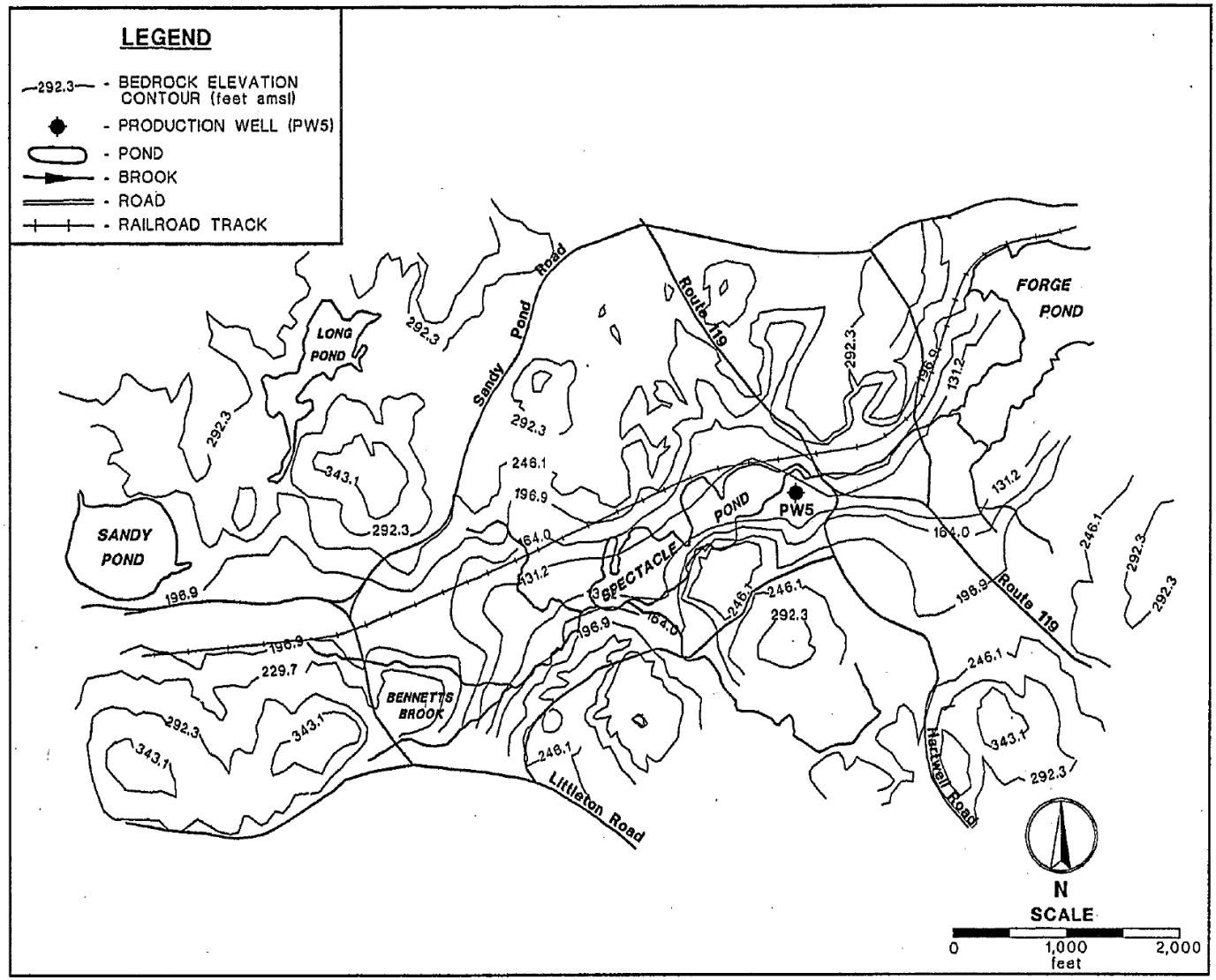


Figure 3-4: Regional Bedrock Elevation (Moore, 1993, pg. 3-47)

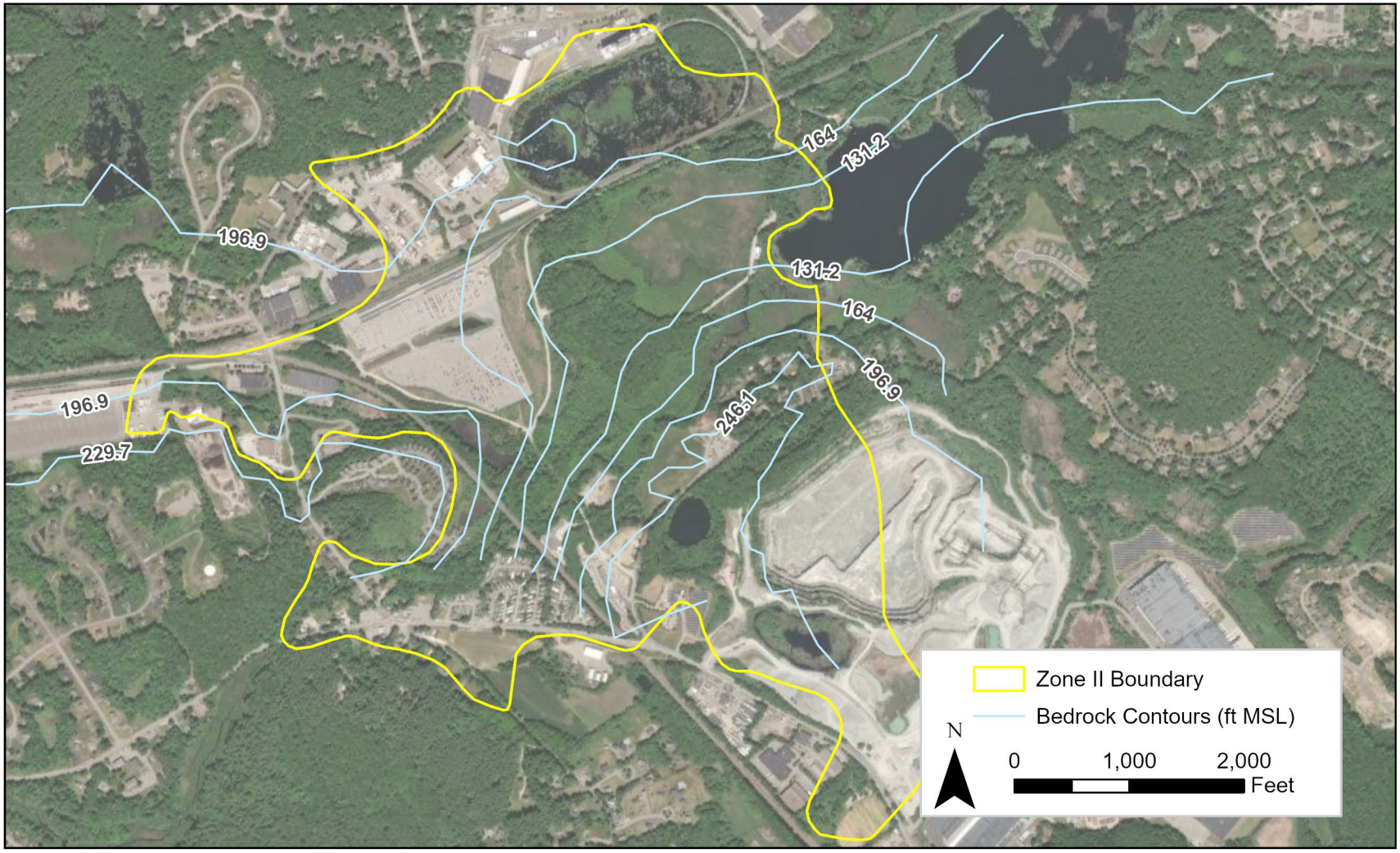


Figure 3-5: Bedrock Elevation in Vicinity of Spectacle Pond Wellfield

3.3 Hydrogeology

According to Tata & Howard (1999, pg. 2-7), groundwater flows from the southwest toward Spectacle Pond, and the depth to the water table ranges from 0 to 25 ft below ground surface. The saturated thickness of the aquifer ranges from 25 to 70 ft (Tata & Howard, 1999, pg. 4-3). The regional aquifer is unconfined, but the peat layer/swamp deposits around and underneath Spectacle Pond create semi-confined conditions in the immediate vicinity of Spectacle Pond (Moore, 1993, pg. 3-36). Littleton collected piezometric head measurements on all sides of Spectacle Pond in 1990, and they used those measurements to calibrate a two-dimensional groundwater model of the regional aquifer (Moore, 1993). Figure 3-6 is an excerpt from Littleton's report that shows both the observed groundwater levels and the modeled groundwater contours (Moore, 1993, pg. 3-50). Figure 3-7 shows the same contours but zooms into the western portion of Spectacle Pond. Littleton characterized the aquifer as semi-confined but modeled the aquifer as unconfined. The Project Team concludes that these contours are representative of the regional aquifer but may not capture the complex interaction between Spectacle Pond and the wellfields.

The direction of groundwater flow is perpendicular to groundwater contours (i.e., lines of constant head) in unconsolidated media like glacial drift. The direction of groundwater flow is generally radially inward to Spectacle Pond flowing from the north in the north, from the west in the west, and from the south in south. The rate of groundwater flow is a function of the hydraulic gradient (i.e., head differential along a flow path between two points) and the hydraulic conductivity of the porous medium. Hydraulic conductivity is a coefficient, with units of length per time, that is used in Darcy's law to represent the ease with which water passes through a given porous medium (Freeze and Cherry, 1979).

GHR and Littleton both developed estimates of hydraulic conductivity in the regional aquifer. They both used groundwater availability mapping completed by the USGS (Brackley and Hansen, 1985) supplemented by well-specific tests (e.g., aquifer tests and slug tests). Figure 3-8 shows an excerpt from the groundwater availability mapping. The USGS map delineates regions based on transmissivity. Transmissivity is the hydraulic conductivity multiplied by the aquifer thickness (Freeze and Cherry, 1979). The zone of highest transmissivity underlies Spectacle Pond and extends eastward to Forge Pond. Transmissivity decreases in all directions as you move away from the ponds.

Littleton focused their hydraulic conductivity testing on the eastern end of Spectacle Pond, but did calibrate the regional groundwater model by adjusting hydraulic conductivity values throughout the model domain. Littleton stated "Calibrated hydraulic conductivities range from 26 to 230 ft/d [feet per day], with the lowest values occurring in the topographically-high areas within the model domain. The greatest values occur around Spectacle Pond and Forge Pond and along the Bennetts Brook valley" (Moore, 1993, pg. 3-49).

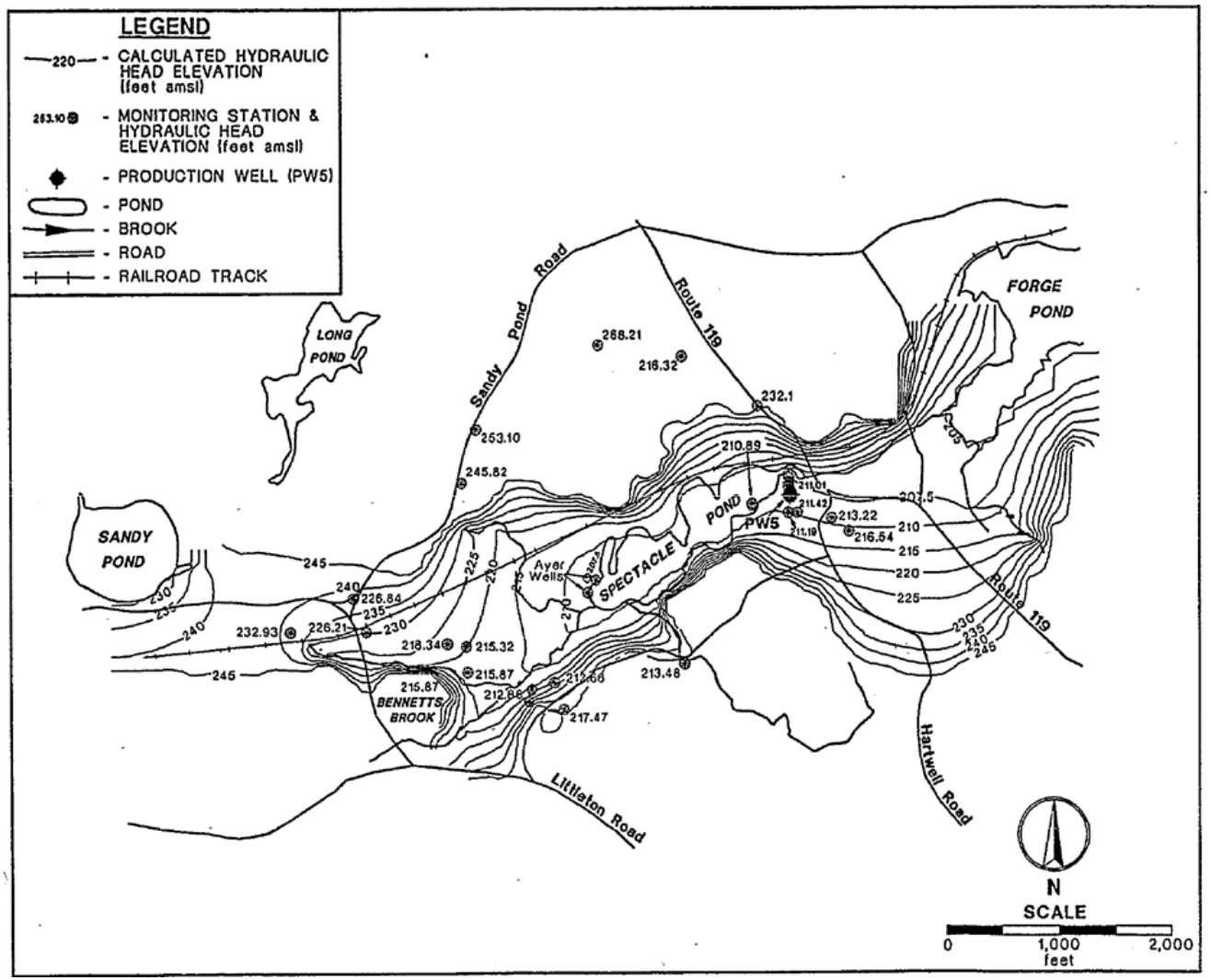


Figure 3-6: Groundwater Surface Elevation 1990 (US EPA, 1993, pg. 3-50)

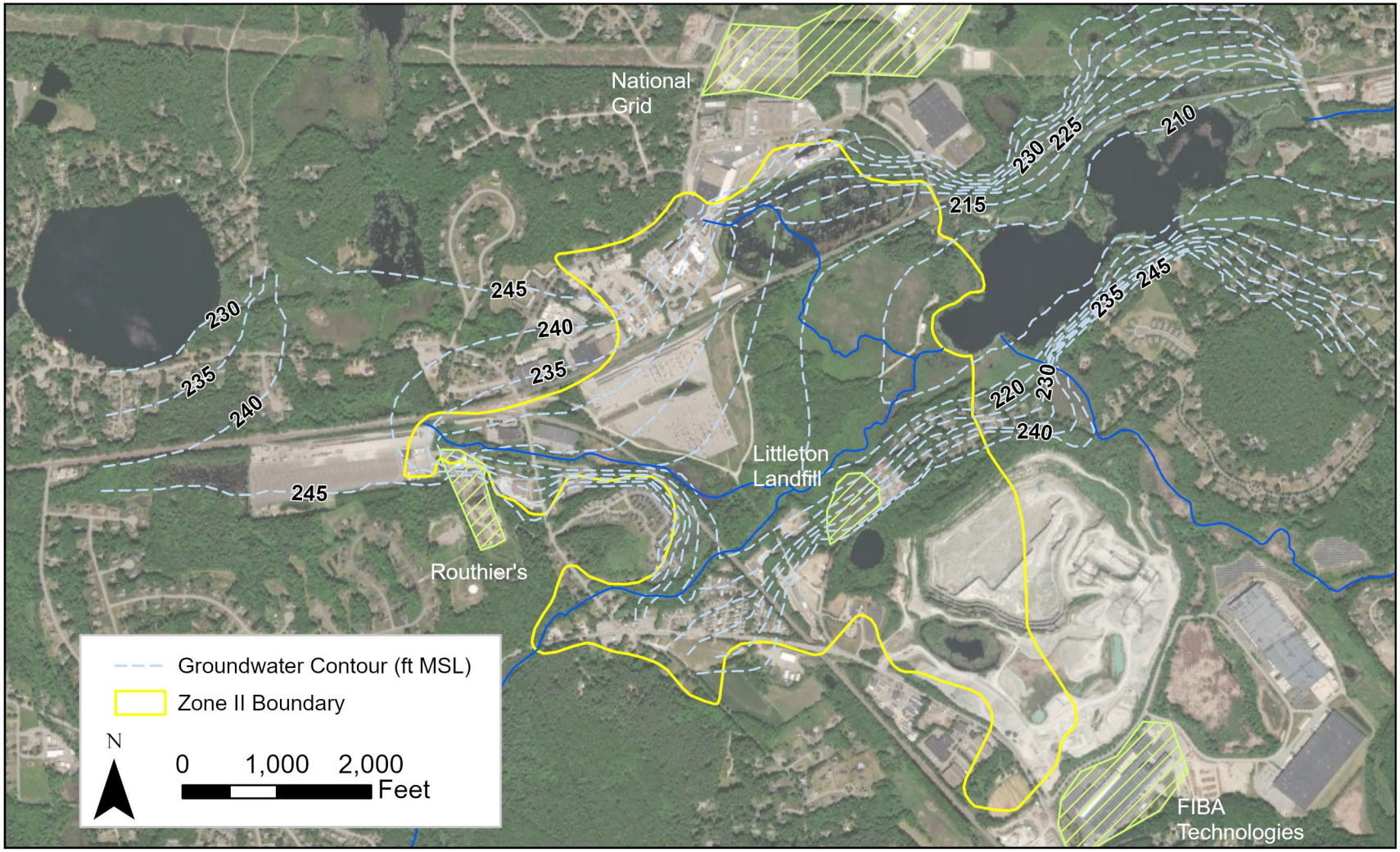


Figure 3-7: Groundwater Surface Elevation 1990 in Vicinity of Spectacle Pond Wellfield

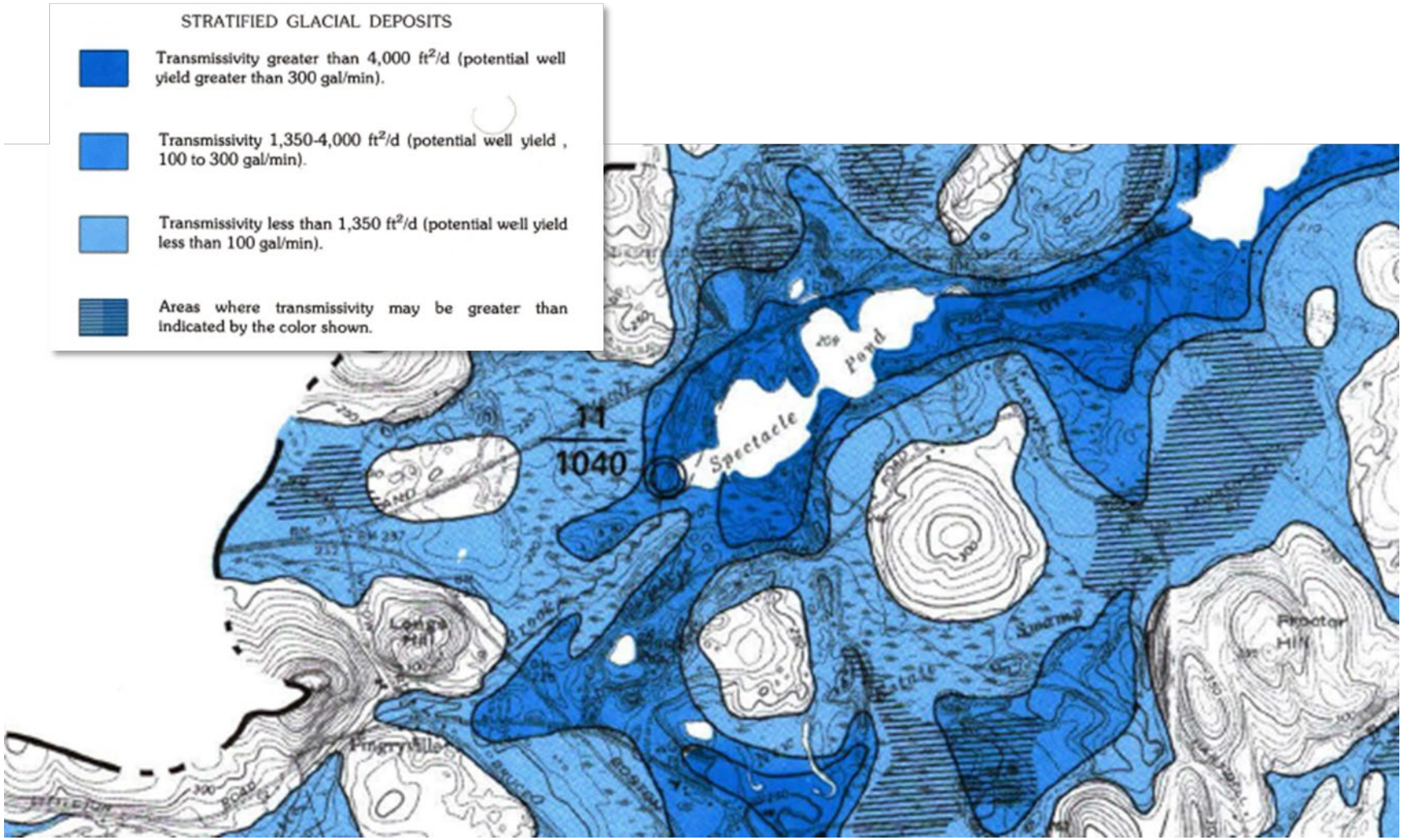


Figure 3-8: USGS Groundwater Availability (Brackley and Hansen, 1985)

Hydraulic conductivity information around the western end of Spectacle Pond includes estimates from drawdown tests at the Spectacle Pond wellfield and slug tests at multiple locations west of Spectacle Pond and north of Bennetts Brook. Tata & Howard (1999, pg. 3-5) determined the hydraulic conductivity at the Ayer PWS wells by re-analyzing aquifer test results from 1974 and 1985. They estimated the hydraulic conductivity to be 600 ft/d at SP-01 and 487 ft/d at SP-02. GHR analyzed slug tests at 11 monitoring wells to estimate hydraulic conductivity (GHR, 1989, pg. 3-3). Nine of those wells are relevant to this investigation. Figure 3-9 shows the location of each slug test and the estimated hydraulic conductivity.

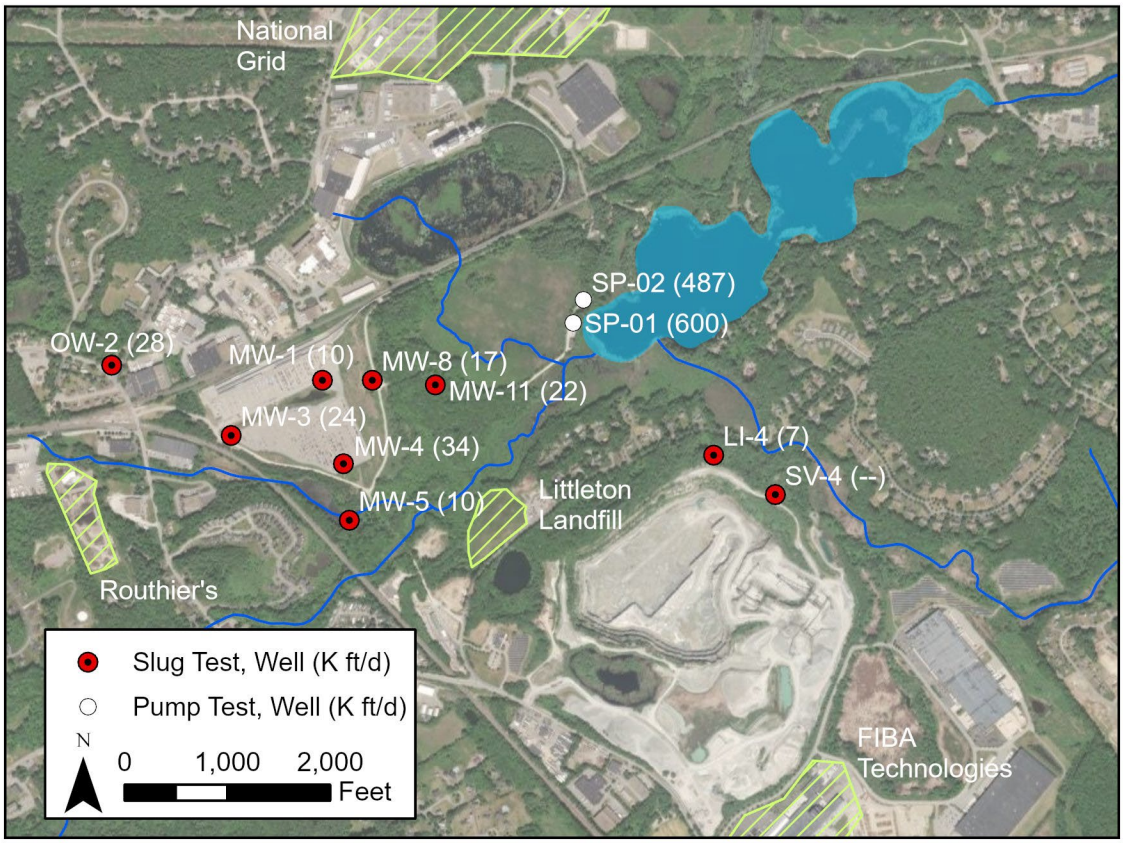


Figure 3-9: Hydraulic Conductivity Based on Well Tests

Wells located more than 1,000 ft from Spectacle Pond have hydraulic conductivities that range from 7 to 34 ft/d. The PWS wells are located in material with hydraulic conductivity that is more than an order of magnitude higher than the surrounding area. This high yield zone is at least partially separated from the pond by the swamp deposits/peat layer, but all three previous studies indicate that a hydraulic connection exists between the pond and wells.

Prior studies have also addressed the potential for the supply wells to induce infiltration from Spectacle Pond. GHR (1989, pg. 7-2) states "Model results indicate that, at current pumping rates [1,190 gallons per minute (gpm)], approximately 83% of the water extracted from the Town of Ayer's Spectacle Pond wellfield comes from induced infiltration." The Zone II study for the Littleton Spectacle Pond well, states "… approximately 20% to 25% of the water recharging PW-5 is believed to be derived from Spectacle Pond" (Moore, 1993, pg. 3-42). Finally, Tata & Howard (1999, pg. 4-3) state "Spectacle Pond and associated wetlands and ponds are conceptualized as partially penetrating water bodies that probably contribute some induced recharge to the sand and gravel aquifer under maximum pumping conditions used to establish the Zone II. No estimate of the percentage attributable to induced recharge was made for this study…"

A hydraulic connection between the pond and the Ayer PWS wells exists, but the proportion of water entering the wells from the pond as opposed to the aquifer is unknown. The previous studies cited above suggest a range of anywhere between 20% and 83% of the total water being pumped is coming from the pond. Induced infiltration from Spectacle Pond into the PWS wells creates the possibility that the PFAS at the wells may be originating from a surface water source that is discharging to the pond.

The Quarry Stream may be one such source. Holcim–NER, Inc. (previously Aggregate Industries) owns and operates a quarry located south of Spectacle Pond and immediately east of the Littleton Landfill (Figure 2-1). Groundwater elevations around the landfill are roughly 210 ft MSL (Moore, 1993, pg. 3-50). Topographic contours of the quarry from the 1990s indicate that the bottom of the quarry had an elevation of approximately 170 ft MSL (MassGIS, 2025a) and more recent Lidar data indicates the bottom of the quarry is now at an elevation of approximately 80 ft NAVD88 (MassGIS, 2025b).

The quarry operators keep the quarry dry by dewatering the quarry. Water is pumped from the bottom of the quarry to a settling pond (Pond 3) where water infiltrates into the ground, and overflow from this pond flows into another pond (Pond 2) that discharges surface water to the adjacent wetland/Quarry Stream (Brown and Caldwell, 2021, pg. 4-1). Figure 3-10 shows the quarry in 2008. The locations of Pond 3 and Pond 2 are identified in the figure, and the hoses that connect the sump pond to the settling ponds are identified with white arrows. The Project Team confirmed that Pond 3 and Pond 2 were constructed some time between 2001 and 2005, but the site has been an active quarry since the 1940s (Brown and Caldwell, 2021, pg. 3-1). Brown and Caldwell (2021, pg. 3-1) characterize the quarry as a "major drainage point for groundwater." They also report the monthly average discharge as 895,777 gallons per day (gpd) (Brown and Caldwell, 2021, pg. 3-2). Dewatering operations at the quarry mean that the quarry is downgradient from the landfill and that groundwater from the landfill is being transported via the quarry to the Quarry Stream.

The quarry was required by DEP to install PFAS treatment of effluent from Pond 3 and Pond 2 prior to discharge into the wetland as a part of their Immediate Response Action (IRA) plan (Brown and Caldwell, 2021, pg. 6-1). Ultimately, treatment was found to be infeasible by the quarry operators and DEP agreed to allow the operators to continue with assessment efforts (e.g., sampling) of PFAS without treatment (Brown and Caldwell, 2025, pg. 1-1).

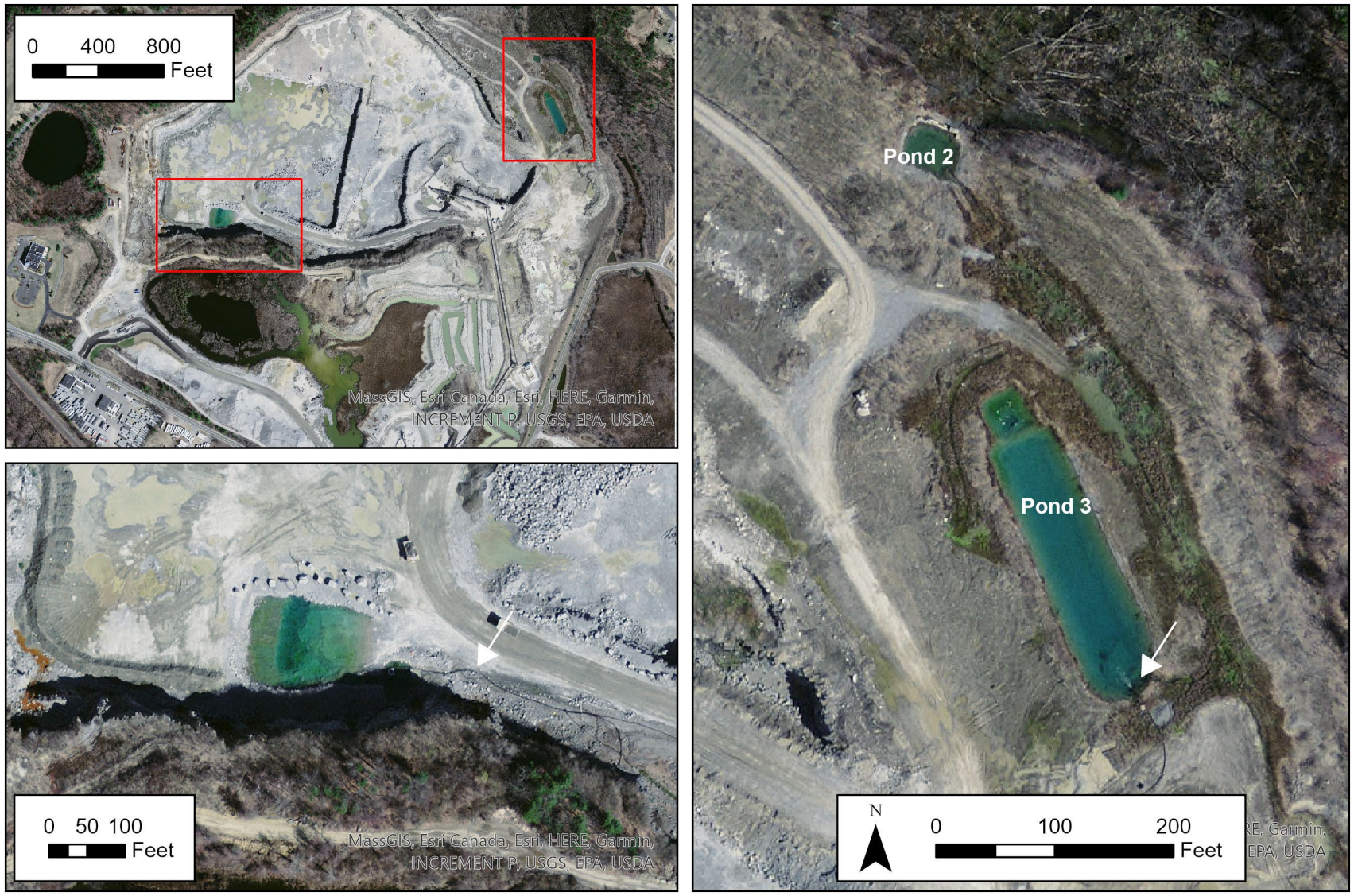


Figure 3-10: Quarry Aerial Review (2008)

4.0 CONCEPTUAL SITE MODEL

The Project Team reviewed the site, the history of PFAS release, groundwater sampling results, surface water sampling results, and the hydrogeology of the aquifer in order to develop a conceptual site model (CSM). The CSM represents our understanding of the transport and sources of PFAS that drive the PFAS concentrations at the Spectacle Pond wellfield.

The CSM does not consider vadose zone transport, but we acknowledge that vadose zone transport did, and potentially continues to, occur at each PFAS source. We have incomplete information about the type, quantity, and duration of the release of PFAS at each site. There is little to no information about the vadose zone at each site. But, we have measurements of groundwater concentrations at each site. Transport through the vadose zone leads to the presence of PFAS in groundwater. The Project Team concluded that it is appropriate to exclude vadose zone transport from the CSM because our most reliable information (i.e., groundwater sampling) characterizes conditions after vadose zone transport has occurred.

4.1 Potential Transport Pathways

One transport pathway for PFAS is to be advected with groundwater as it flows toward the Spectacle Pond wellfield. To the west of the Spectacle Pond wellfield, groundwater flows towards Bennetts Brook and then flows east toward, under, and beyond Spectacle Pond flowing to Forge Pond. Bedrock outcrops and thick till establish a western limit to the aquifer. North and south of Spectacle Pond, groundwater flows toward the pond. In the immediate vicinity of the pond, the aquifer is approximately 70 ft thick with hydraulic conductivity as high as 600 ft/d, which is very high relative to the surrounding area.

A layer of swamp deposits/peat separates the aquifer from the pond, but that layer has variable thickness and is discontinuous. Somewhere between 20% and 83% of the water that is pumped at the Spectacle Pond wellfield comes from Spectacle Pond. This hydraulic connection between the pond and the wells creates a second transport pathway. In this pathway, PFAS is present in surface water in the upstream reaches of the basin and flows through streams and into Spectacle Pond. The pond water is then drawn through the bottom of the pond and into the wells.

Figure 4-1 shows the direction of groundwater flow and surface water flow in the area immediately surrounding the western half of Spectacle Pond. Blue arrows indicate confirmed flow directions while green arrows indicate probable flow directions. In the next section of this report, we evaluate PFAS sampling specific to each potential source in the context of these transport pathways to understand how PFAS from each source is or is not being transported to the Spectacle Pond wellfield.

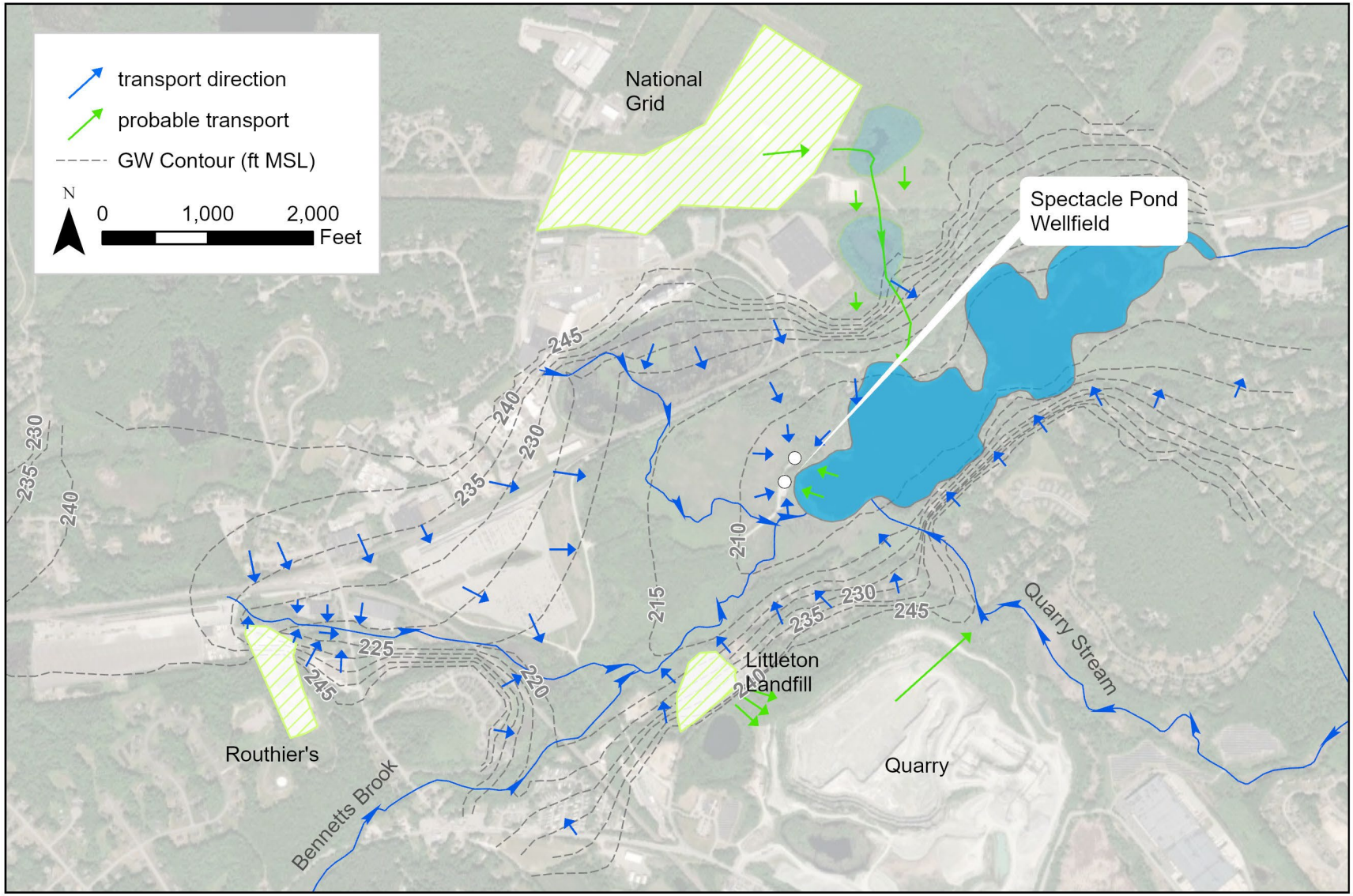


Figure 4-1: CSM Flow Direction Diagram

4.2 Well and Pond PFAS Sampling

The Project Team reviewed PFAS sampling results in surface water and groundwater at multiple locations. We compared the magnitude of individual PFAS concentrations as well as the relative concentration of each individual PFAS for a given sample. Our primary tool in evaluating the relative concentrations is a radar chart (also called a star chart or spider chart). The radar charts in this report plot each individual PFAS concentration divided by the sum of all plotted PFAS concentrations. A radar chart is a cross between a bar chart and a pie chart. It is particularly helpful in showing the similarity between different samples (ITRC, 2024b).

Table 4-1 presents the average and standard deviation for PFAS6+2 concentrations at each of the Ayer PWS wells. Figure 4-2 and Figure 4-3 show the radar chart for SP-01A and SP-01B. Figure 4-4 shows the radar chart for SP-02A. The SP-01A and SP-01B plots show a pattern that is dominated by PFOS, PFOA, and PFHxS. This pattern is consistent across multiple samples. It appears on the chart as an upper left dominated shape. SP-02A shows a pattern that is dominated by PFHxA with some indication of PFOS, PFOA, and PFHpA. The pattern is also consistent across multiple samples. The chart is an upper right dominated shape.

Table 4-1: Spectacle Pond Wellfield PFA6+2 Concentrations

	PFAS6+2 (ng/L)		
Well	Average	Standard Deviation	Sample Count
SP-01A	26.2	4.1	7
SP-01B	39.6	16.2	4
SP-02A	46.5	7.1	10

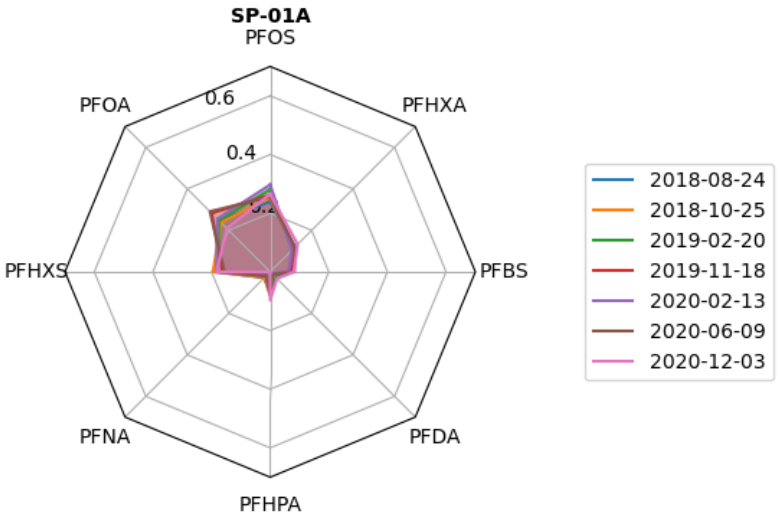


Figure 4-2: SP-01A Radar Chart

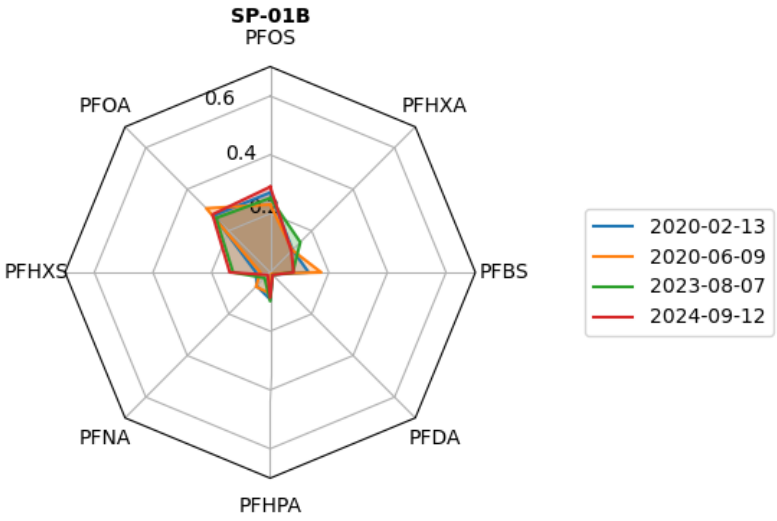


Figure 4-3: SP-01B Radar Chart

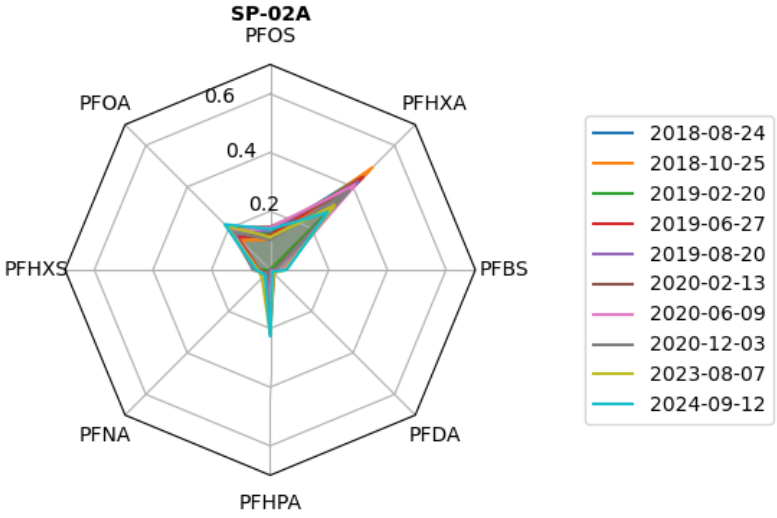


Figure 4-4: SP-02A Radar Chart

As a part of their investigation of PFAS sources, Littleton collected multiple surface water samples in Spectacle Pond on March 31, 2020 (Tighe & Bond, 2020a). Figure 4-5 shows the radar chart for these samples, which include shallow (identified with the suffix S) and deep (identified with the suffix D) samples from nine different locations. Most of the pond samples show the same pattern with roughly equal parts PFHxA, PFOS, PFOA, and PFHxS. One sample (SPSW-7S) shows a spike of PFOS, and another sample (SPSW-6S) shows a spike of PFHpA. In general, the pond samples show an equally distributed pattern. The pond radar chart pattern contains elements of both the SP-01 pattern and the SP-02 pattern.

The pond PFAS6+2 concentrations average approximately 28.5 ng/L with a standard deviation of 2.3 ng/L. The standard deviation for the pond samples is an indication of spatial variability and is not directly comparable to the standard deviation for the wells because the well values represent temporal variability.

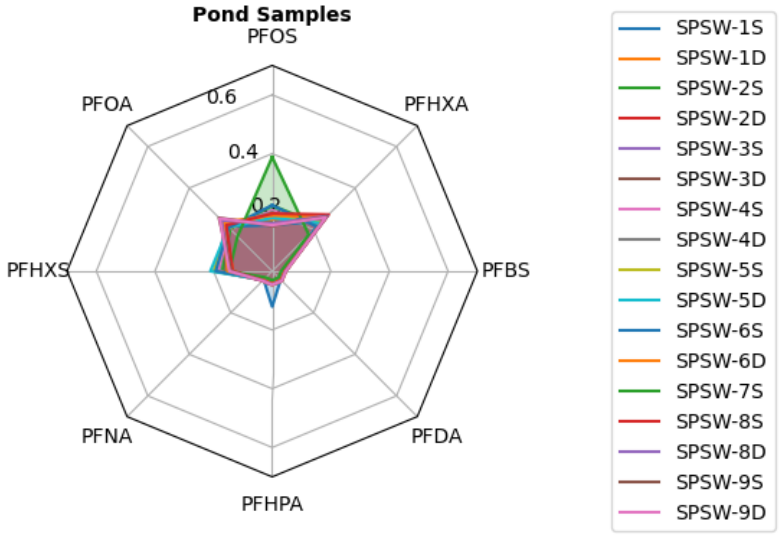


Figure 4-5: Spectacle Pond Radar Chart

In the CSM, we consider the wells and the pond to be receptors of PFAS that is being transported to them via groundwater and surface water from the three PFAS sources.

4.3 Source-Specific PFAS Sampling

4.3.1 Routhier's

Routhier's is currently conducting a monitoring program for PFAS at their property as well as at downgradient groundwater and downstream surface water locations (Weston & Sampson, 2024). Figure 4-6 presents the CSM flow pattern overlaid by the relevant groundwater sampling results from the most recent IRA Status Report (Weston & Sampson, 2024) based on samples collected on April 5, 2022. PFAS6+2 concentrations in groundwater on and immediately adjacent to the property are consistently greater than 500 ng/L with multiple samples greater than 1,500 ng/L. However, the downgradient monitoring locations have substantially lower PFAS6+2 concentrations. Monitoring well SB-204 had a PFAS6+2 concentration of 14 ng/L, and SB-205 had a concentration of 7 ng/L. The results depicted in Figure 4-6 suggest that PFAS contamination in the groundwater has migrated less than 500 ft from the property. The downgradient wells are positioned between Routhier's and the Spectacle Pond wellfield. Low concentrations at the downgradient wells are a clear demonstration that PFAS from Routhier's is not being transported to the Spectacle Pond wellfield via groundwater.

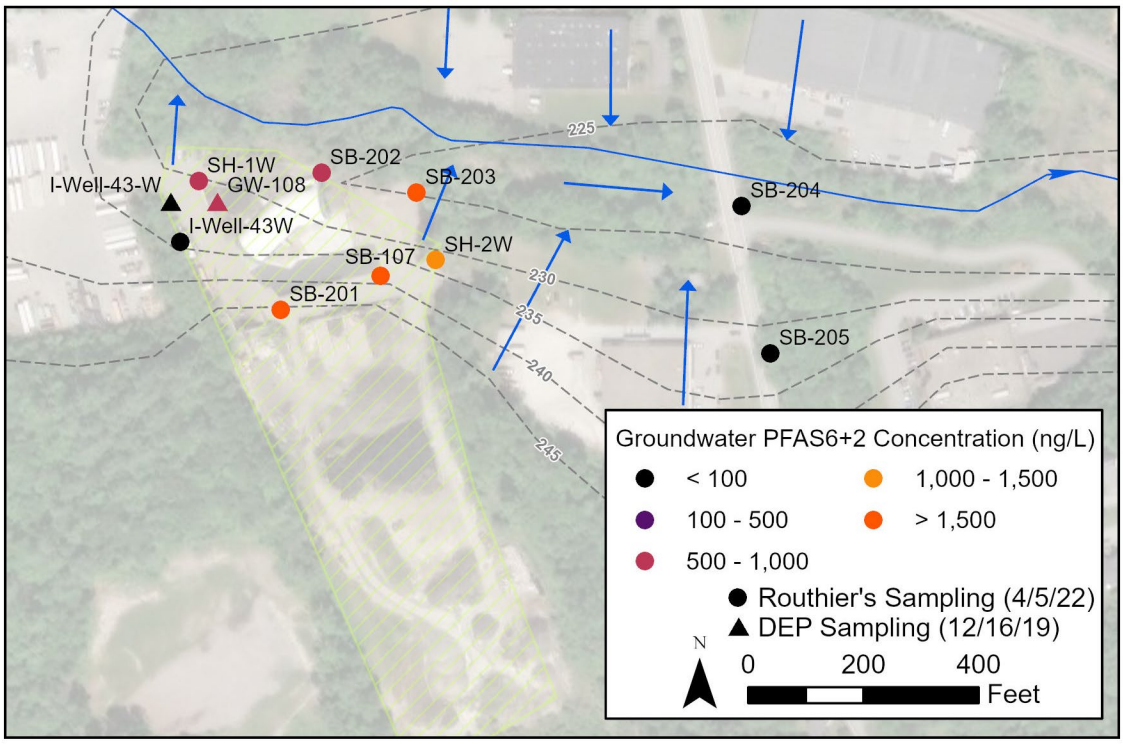


Figure 4-6: Routhier's Groundwater Sampling Results

While the groundwater sampling results suggest limited groundwater transport of PFAS away from the property, the surface water sampling results suggest the opposite. Figure 4-7 again presents the CSM flow pattern but includes relevant surface water sampling results from the IRA and surface water sampling results from Littleton's PFAS study (Tighe & Bond, 2020a). Sampling station SW-7 is located in the unnamed tributary that flows to Bennetts Brook and is upstream of the property. The PFAS6+2 concentration at SW-7 on April 5, 2022 was approximately 11 ng/L. Downstream of the property PFAS6+2 jumped to above 100 ng/L with concentrations at SW-5 of 218 ng/L and 124 ng/L at SW-6.

There are two mechanisms that are releasing PFAS from Routhier's into the unnamed tributary. GHR (1989, pg. 4-12) identified the unnamed tributary as a gaining stream. This means that groundwater at the site is flowing into the stream. This groundwater likely includes PFAS. Water quality sampling in Routhier's stormwater management system (i.e., at SW-1 and SW-2) also indicates the presence of PFAS. Runoff from the site during precipitation flows into the unnamed tributary and likely includes PFAS.

Routhier's IRA sampling locations stop at SW-6, but additional downstream sampling results are available from the Littleton PFAS study. These sampling locations are also shown in Figure 4-7. The Littleton PFAS study dataset includes sampling from September 2020. These downstream measurements are from approximately two years earlier than Routhier's most recent sampling, and the two datasets are not directly comparable. Routhier's sampling location SW-6 is co-located with Littleton's sampling location LLF-SW-2, and PFAS6+2 sampling results from the two surveys show similar relative concentrations of individual PFAS (see Figure 4-8). The Littleton PFAS study included sampling upstream of the confluence of Bennetts Brooks and the unnamed tributary (LLF-SW-1). The PFAS6+2 concentration was 16 ng/L at LLF-SW-1 and 200 ng/L at LLF-SW-2. The main branch of Bennetts Brook concentration was approximately one-tenth of the unnamed tributary, but the difference between the two branches is more apparent for the concentrations

for PFOS and PFHxS. Table 4-2 shows the PFHxS and PFOS concentrations for LLF-SW-1 and LLF-SW-2. The concentrations at LLF-SW-1 are mostly non-detects whereas the concentrations at LLF-SW-2 are consistently above 60 ng/L. The Project Team concludes that the main branch is not a significant source of PFAS relative to the unnamed tributary based on this information.

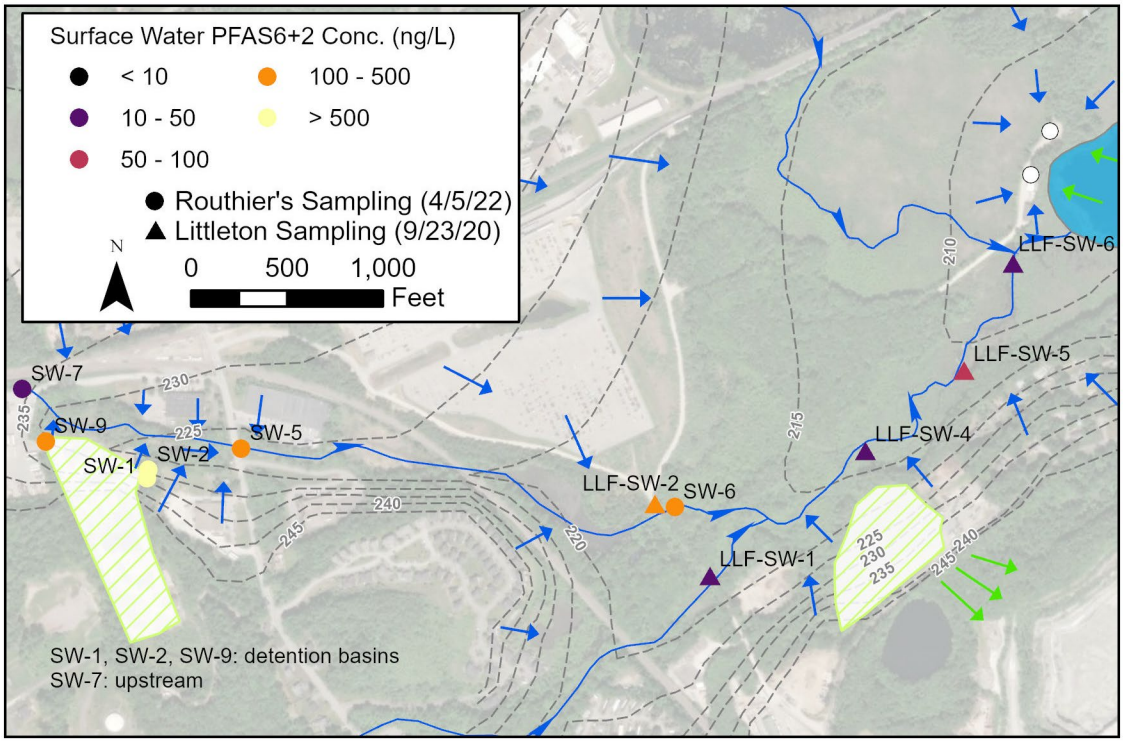


Figure 4-7: Bennetts Brook Surface Water Sampling Results

Table 4-2: PFHxS and PFOS Concentrations at LLF-SW-1 and LLF-SW-2

	PFHxS (ng/L)		PFOS (ng/L)	
Location	9/23/2020	11/19/2020	9/23/2020	11/19/2020
LLF-SW-1	ND	ND	6.6	ND
LLF-SW-2	69	68	65	62

The Project Team investigated the relative contribution of individual PFAS as well as the total PFAS6+2 concentrations for the surface water sampling stations shown in Figure 4-7. Figure 4-8 represents the same information but includes radar plots for relevant sampling locations. The radar plot format (i.e., individual PFAS position on the plot) is the same as previous radar plots presented in this report, but the axis labels have been removed from the figure to more effectively communicate the radar plot patterns. Figure 4-8 shows that the sampling results for locations from Routhier's up to the confluence of the unnamed tributary and Bennetts Brook have a consistent "signature." This signature appears in the radar plots as a backwards L shape.

The signature disappears downstream of the landfill, and the radar plots of sampling locations in Bennetts Brook show a different shape. The most downstream sampling location (LLF-SW-6) has a very different shape than the surface water samples immediately next to Routhier's. The most downstream sampling location has a pattern that is much more similar to the pond samples than to the Routhier's samples.

The Project Team concludes that PFAS from Routhier's has not migrated to the Spectacle Pond wellfield via groundwater transport because the downgradient wells have low PFAS concentrations, but PFAS from Routhier's has reached Spectacle Pond via surface water transport. There are two sources that are contributing PFAS to Spectacle Pond via Bennetts Brook. The PFAS from Routhier's is entering the unnamed tributary (either from surface water discharge or from groundwater entering the stream) and flowing into Bennetts Brook. PFAS from Routhier's is mixing with PFAS from the landfill in Bennetts Brook, and the combined PFAS is flowing into Spectacle Pond.

Routhier's is a source of PFAS, but there are two documented instances of AFFF being used at the site (i.e., 1994 fire and the 2010 fire). The Project Team looked at the full list of PFAS sampled at Routhier's to understand which fire resulted in the release of PFAS at the property. Both groundwater and surface water samples at Routhier's are dominated by PFOS and PFHxS. Most of the groundwater samples and surface water samples at Routhier's are non-detect for fluorotelomer PFAS (e.g., 6:2 FTS) (Weston & Sampson, 2024). All of the groundwater and surface water samples have low fluorotelomer concentrations relative to PFOS and PFHxS (Weston & Sampson, 2024).

Non-fluorotelomer manufacturing of AFFF was discontinued in 2002 (ITRC, 2025). The lack of fluorotelomer PFAS at Routhier's strongly suggests that the PFAS at Routhier's has been there since 1994.

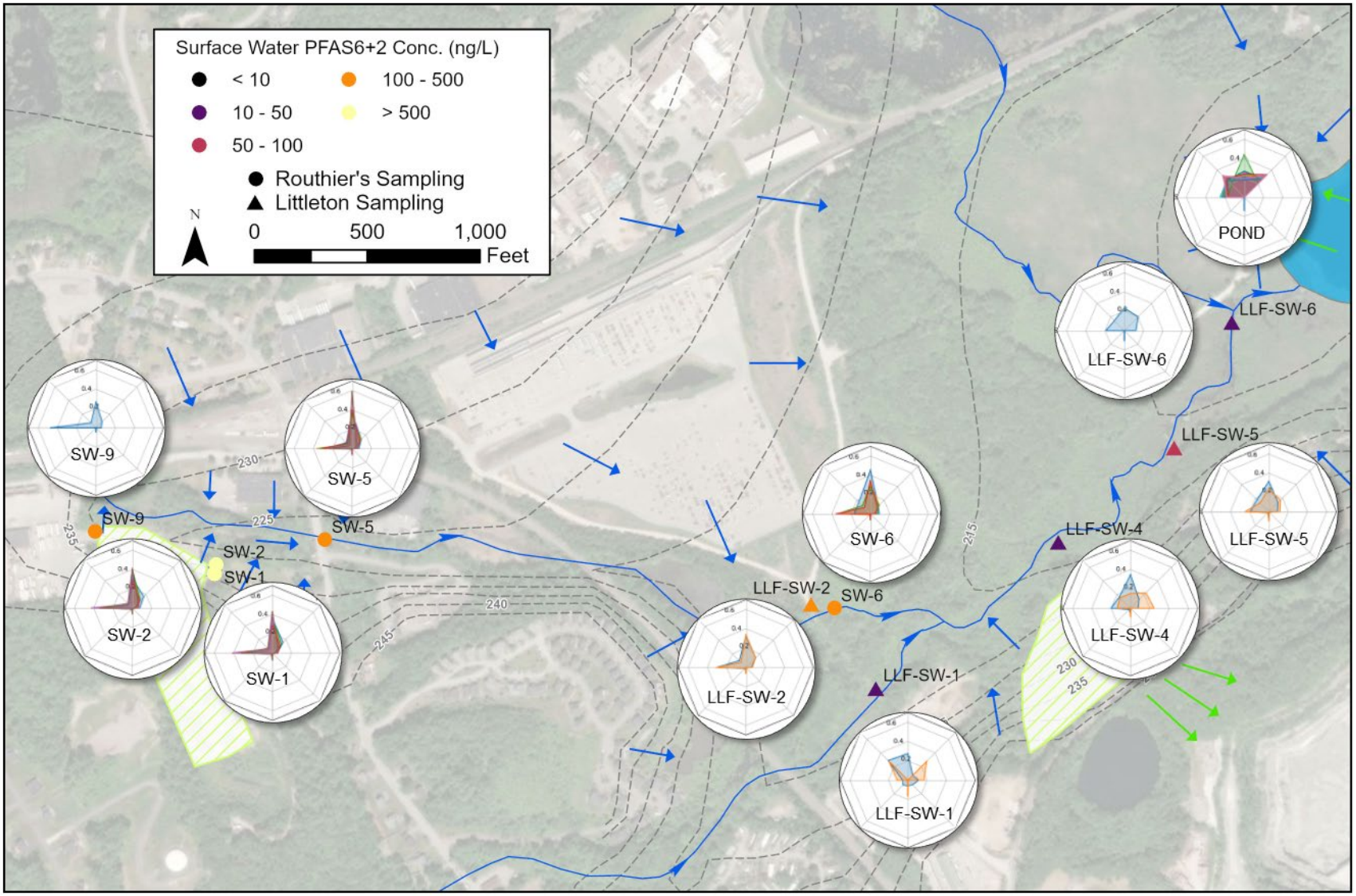


Figure 4-8: Radar Plots Along Bennetts Brook

4.3.2 Littleton Landfill

The CSM includes groundwater flow from the Littleton Landfill northeast toward Bennetts Brook, Spectacle Pond, and the PWS wells. The CSM also includes groundwater flow from the Littleton Landfill southeast toward the quarry. Littleton conducts quarterly sampling of both groundwater and surface water in the vicinity of the landfill and along Bennetts Brook. The most recent sampling results that the Project Team was able to acquire come from the 2023 Q3 sampling report (Tighe & Bond, 2024). This sampling report includes PFAS sampling from September 2020 through October 2023. The sampling results available in the quarterly report and the sampling results from Littleton's PFAS study (Tighe & Bond, 2020a) characterize PFAS originating from the landfill. Figure 4-9 shows the location of a subset of surface water and groundwater sampling locations that are located along transport pathways between the landfill and the Spectacle Pond wellfield.

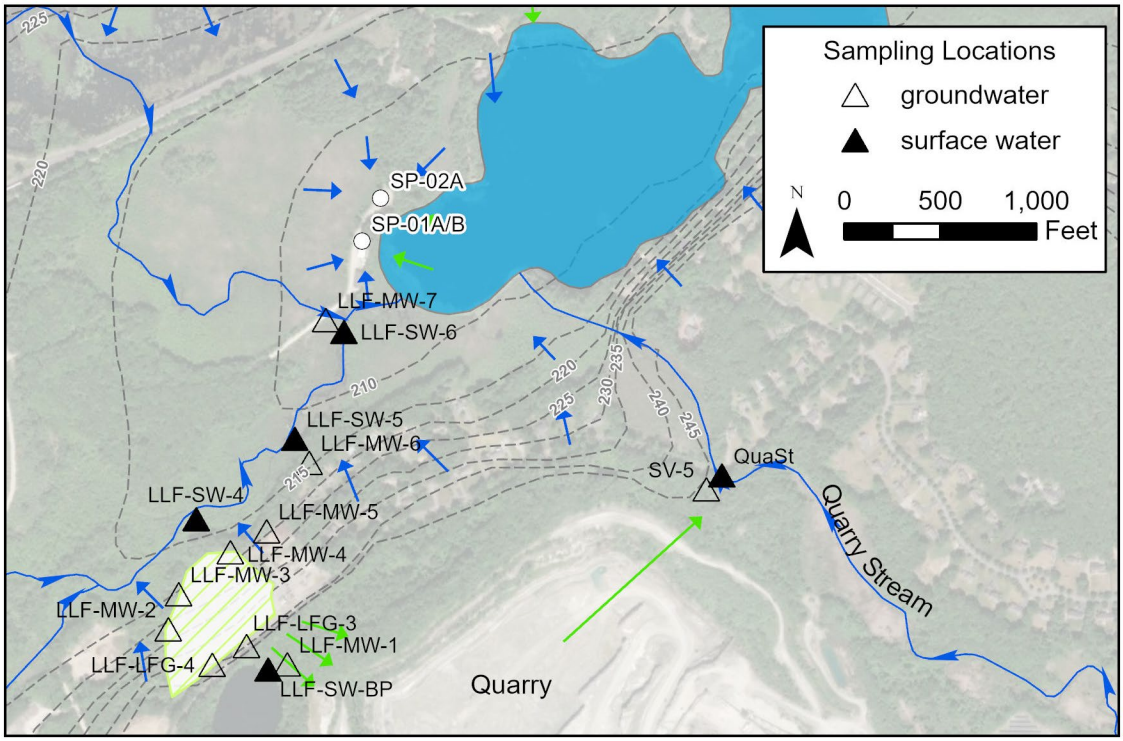


Figure 4-9: Littleton Landfill Sampling Locations

A set of five groundwater monitoring wells ring the landfill on all sides. PFAS sampling at these wells (i.e., LLF-MW-2 through LLF-MW-4, LLF-LFG-3, and LLF-LFG-4) characterize PFAS at the source. LLF-MW-4 is definitively downgradient of the landfill and has the highest concentrations of the four wells with PFAS6+2 concentrations ranging from 50 to 240 ng/L. LLF-LFG-3 and LLF-LFG-4 are likely also downgradient assuming groundwater is drawn eastward by pumping at the quarry. PFAS6+2 concentrations at these wells are lower with ranges of 6 to 14 ng/L for LLF-LFG-3 and 24 to 74 ng/L for LLF-LFG-4. Monitoring wells LLF-MW-2 and LLF-MW-3 are cross-gradient to the landfill and have lower and more stable PFAS6+2 concentrations. Sample results at LLF-MW-2 range from approximately 10 to 40 ng/L, and results at LLF-MW-3 range from approximately 20 to 40 ng/L. Figure 4-10 shows the PFAS6+2 concentrations at each well over time, and Figure 4-11 shows radar plots for each of the five monitoring wells. The radar plots are arranged consistent with each well's location in relation to the other wells (e.g., LLF-MW-3 top left/northwest).

The radar plots show variability in the composition of PFAS6+2 at the landfill. All of the wells that ring the landfill are dominated by PFOA and PFOS with the exception of LLF-LFG-3. Sampling at LLF-LFG-3 typically includes non-detects for between four and eight of the compounds included in PFAS6+2.

LLF-MW-4 includes the signature dominance of PFOA and PFOS and adds PFHxA in equal proportion to PFOA/PFOS results. The samples from the wells that ring the landfill are not uniform, but the Project Team believes the heterogeneity is inherent in the nature of a municipal waste landfill. That is to say, it is what would be expected at a landfill where various materials were dumped at different locations over time. In general, the landfill sample results are dominated by carboxylate PFAS, and this contrasts sharply with the sulfonate-dominated PFAS from Routhier's.

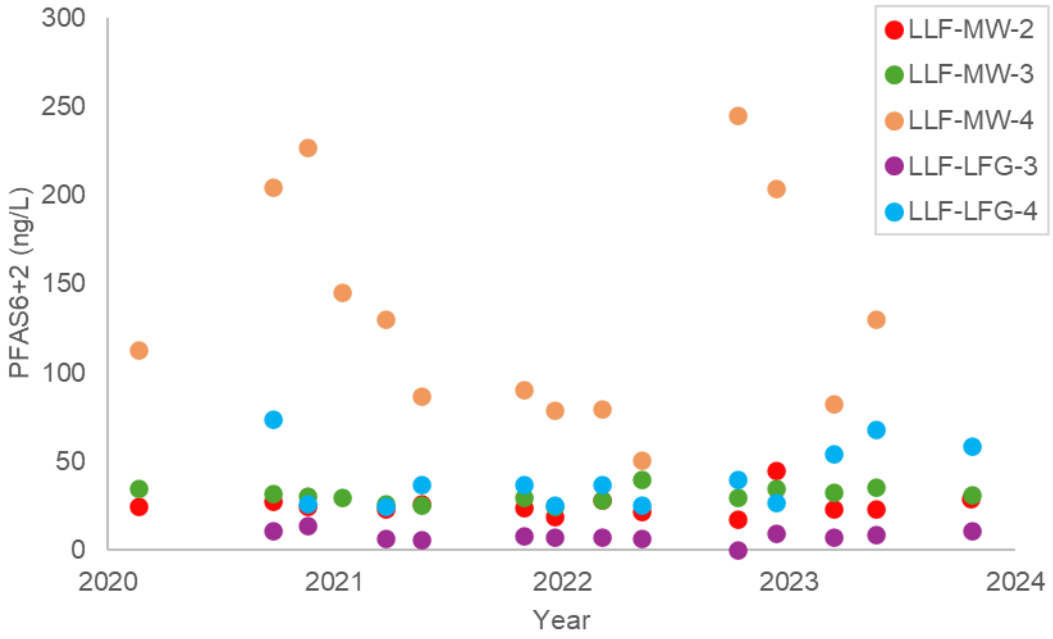


Figure 4-10: PFAS6+2 Concentrations at the Littleton Landfill Over Time

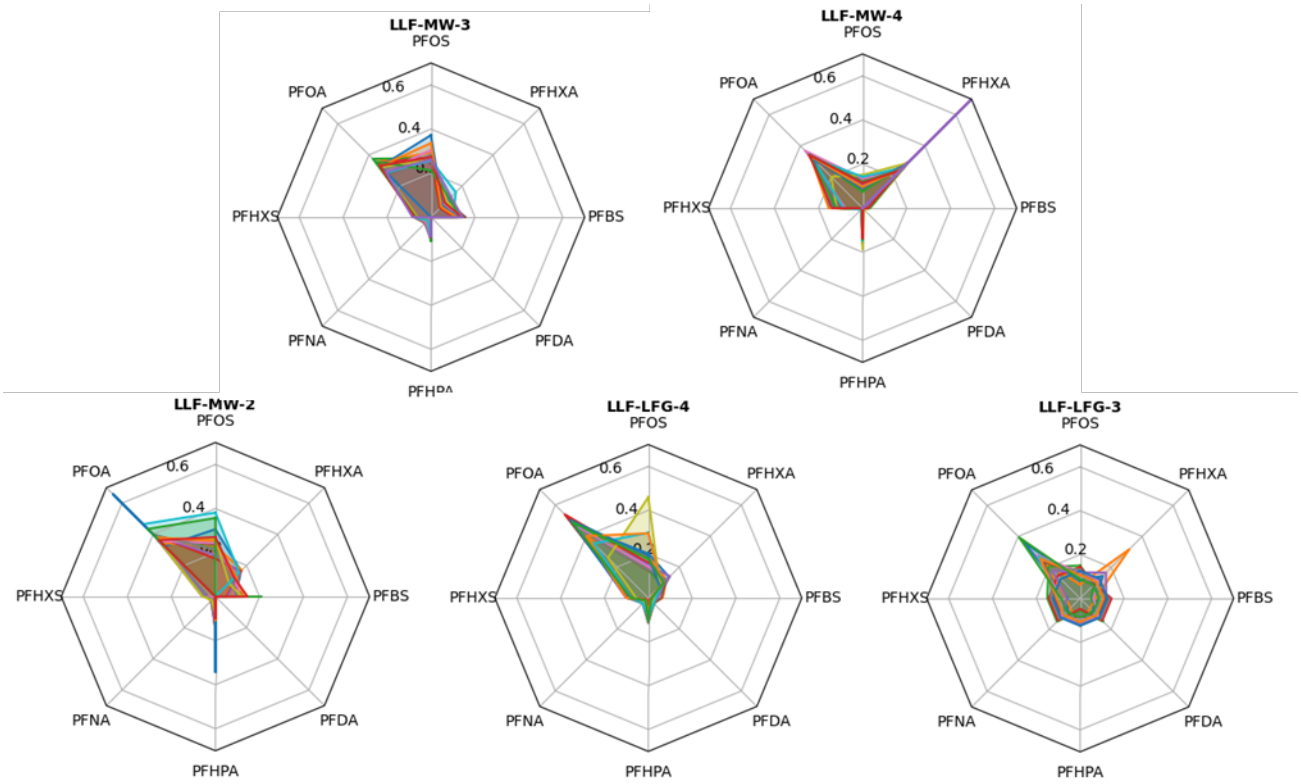


Figure 4-11: Radar Plots at the Littleton Landfill

Concentrations at the landfill boundary are relevant to this study, but do not account for environmental processes (e.g., retardation) that influence PFAS transport between the Littleton Landfill and the PWS wells. The sampling results closer to the Spectacle Pond wellfield are of the most value in estimating historical concentrations. Groundwater monitoring for the landfill includes three downgradient wells. These wells (LLF-MW-5, LLF-MW-6, and LLF-MW-7) are all located between the landfill and the Ayer PWS wells. LLF-MW-5 is approximately 200 ft east of the landfill, and LLF-MW-6 is approximately 600 ft northeast of the landfill. The Project Team notes that these wells are characterized as directly downgradient by Tighe & Bond (2024, Figure 4) but are not directly downgradient based on the water table contours developed by Moore (1993) as shown in Figure 4-9.

LLF-MW-7 is the closest monitoring well to the Ayer PWS wells. LLF-MW-7 is 400 ft southwest and upgradient of SP-01A and SP-01B. LLF-MW-7 is downgradient of the landfill based on the work of both Tighe & Bond (2024) and Moore (1993). PFAS sampling at this monitoring well provides a characterization of the PFAS migrating toward the PWS wells via groundwater from the landfill.

Figure 4-12 shows the PFAS6+2 concentration at each of these three wells over time, and Figure 4-13 shows the radar plots. The PFAS6+2 concentration at LLF-MW-5 and LLF-MW-6 varies over time. The PFAS6+2 concentration range at LLF-MW-5 is 26 to 103 ng/L, and the PFAS6+2 concentration range at LLF-MW-6 is 8 to 63 ng/L. The PFAS6+2 concentration at LLF-MW-7 is by comparison stable with a range of 18 to 32 ng/L.

The radar plots for the sampling locations that ring the landfill show a pattern that is dominated by PFOA and PFOS. That pattern is also present in the radar plots for LLF-MW-5, LLF-MW-6 and LLF-MW-7.

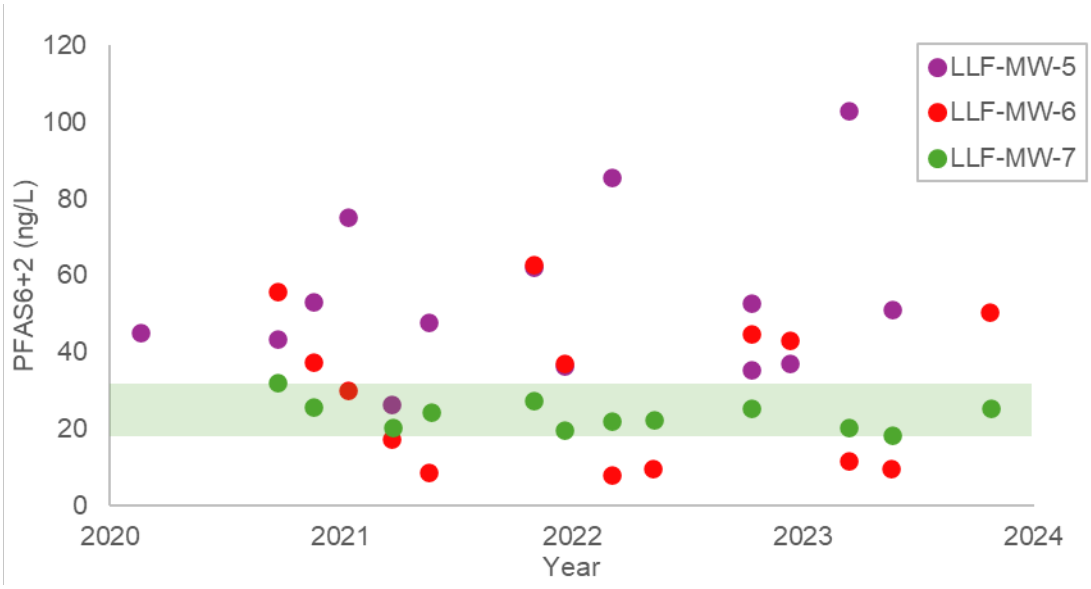


Figure 4-12: PFAS6+2 Concentrations at Downgradient Wells (LLF-MW-5, LLF-MW-6, and LLF-MW-7) Over Time

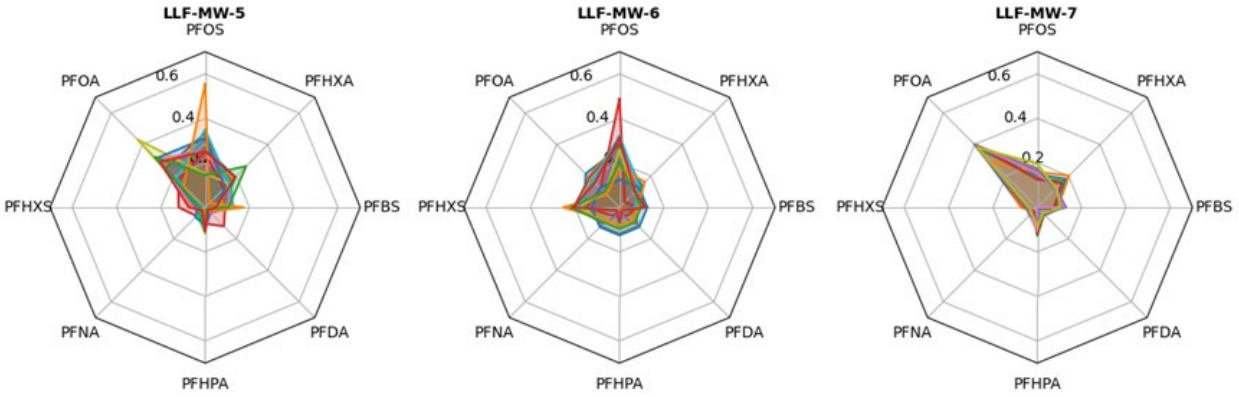


Figure 4-13: Radar Plots for Downgradient Wells (LLF-MW-5, LLF-MW-6, and LLF-MW-7)

The foregoing discussion focuses on PFAS migration from the Littleton Landfill to the northeast. The Project Team considers it likely that PFAS-contaminated groundwater from the landfill is also migrating southeast, entering the quarry, being pumped to the settling basins, and entering surface water (i.e., Quarry Stream) and groundwater east of the quarry. The Project Team evaluated PFAS sampling along this transport pathway to investigate whether the sampling results showed evidence of PFAS from the landfill.

Southeast of the landfill is a small pond called Black Pond. Black Pond is not part of the transport pathway of PFAS through the quarry and not a PFAS source. Weston & Sampson (2024) have sampled surface water (LLF-SW-BP) from the pond since September 2020 and the results are non-detect for all compounds within PFAS6+2 except for PFOA. PFOA concentrations in Black Pond are low (1 to 3 ng/L).

Tighe & Bond consider LLF-MW-1 to be an upgradient well (Tighe & Bond, 2020a), but LLF-MW-1 is in fact downgradient of the landfill given that the quarry is a “major groundwater drainage point for groundwater”

(Brown and Caldwell, 2021, pg. 3-1). Figure 4-14 shows PFAS6+2 concentrations over time and Figure 4-15 shows the radar plot for LLF-MW-1. PFAS6+2 concentrations at LLF-MW-1 are elevated with an average concentration of approximately 80 ng/L. The radar plot is distinct from the other landfill radar plots in that it lacks the presence of any PFOS.

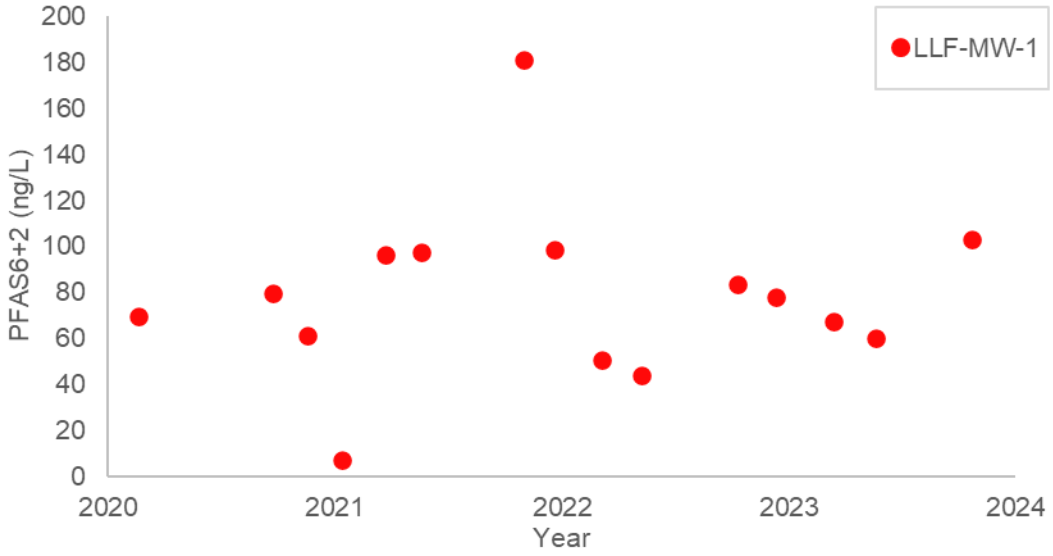


Figure 4-14: PFAS6+2 Concentrations at LLF-MW-1 Over Time

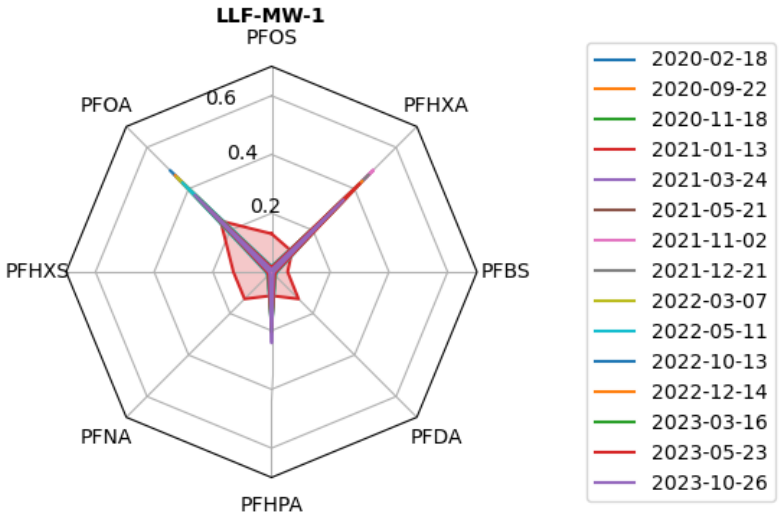


Figure 4-15: Radar Plots for LLF-MW-1

The groundwater that flows from the landfill toward the quarry seeps out of the quarry walls and becomes surface water that collects in a sump pond at the bottom of the quarry and is then pumped to Pond 3 and Pond 2. The quarry began sampling for PFAS in 2020. That sampling program is ongoing as part of their IRA (Brown and Caldwell, 2025). The initial round of sampling included sampling at multiple locations within the active quarry area as well as in Pond 3, Pond 2, and the Quarry Stream. Figure 4-16 shows the sampling

locations along the transport pathway through the quarry: the sump pond (QUARRY-2), Pond 3 (POND-3), Pond 2 (POND-2), and the Quarry Stream (STREAM-1). The sampling program includes surface water sampling at other locations and sampling in groundwater. None of the results from this sampling suggests a source of PFAS other than the landfill.

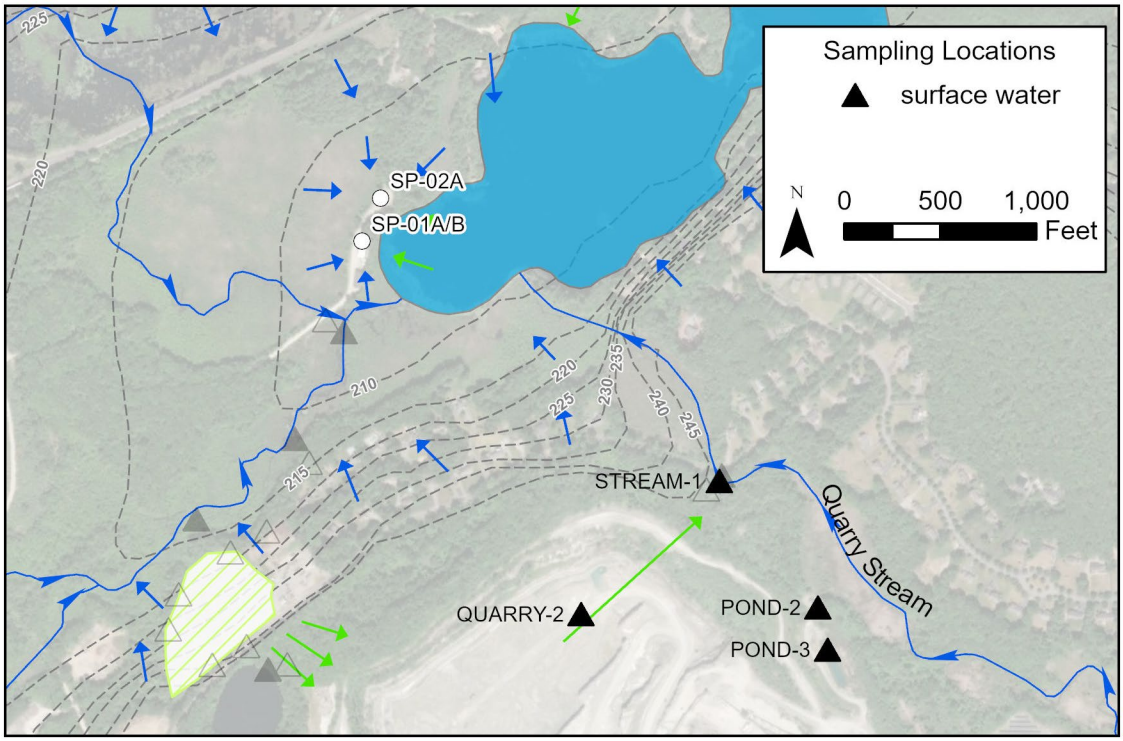


Figure 4-16: Quarry Sampling Locations

Figure 4-17 shows the PFAS6+2 concentrations at each of the quarry sampling locations over time. Figure 4-18 shows radar plots for the same sampling locations. The approximate range is 20 to 40 ng/L with sample results at Pond 3/Pond 2 and the Quarry Stream being similar. The radar plots show that the sample results are dominated by PFOA, PFOS, and PFHxA similar to the sampling results from the monitoring wells that ring the landfill.

The Littleton PFAS study (Tighe & Bond, 2020a) also sampled the Quarry Stream (QuaSt) and groundwater at the same location (SV-5) downstream/downgradient of the settling basins. These locations are co-located with STREAM-1 and shown in Figure 4-9. The Quarry Stream was sampled on February 3, 2020 and had a PFAS6+2 concentration of 18.4 ng/L. Groundwater at SV-5 was sampled on April 14, 2020 and had a PFAS6+2 concentration 11.3 ng/L. Figure 4-19 shows a radar plot for QuaSt and SV-5. QuaSt and SV-5 are similar to each other suggesting a common source. Both samples are primarily composed of PFOA and PFOS with PFOA dominant between the two. This is consistent with PFAS from the quarry sampling program and the landfill.

The available information about operations at the quarry strongly suggests that groundwater flows from the landfill to the quarry. That water is then pumped to the Quarry Stream. PFAS samples along this pathway, while not dispositive, are consistent with a transport pathway from the landfill into the quarry. The one inconsistency is the groundwater sampling results at LLF-MW-1, but the Project Team believes the lack of PFOS in these results is likely due to variability of PFAS within the landfill.

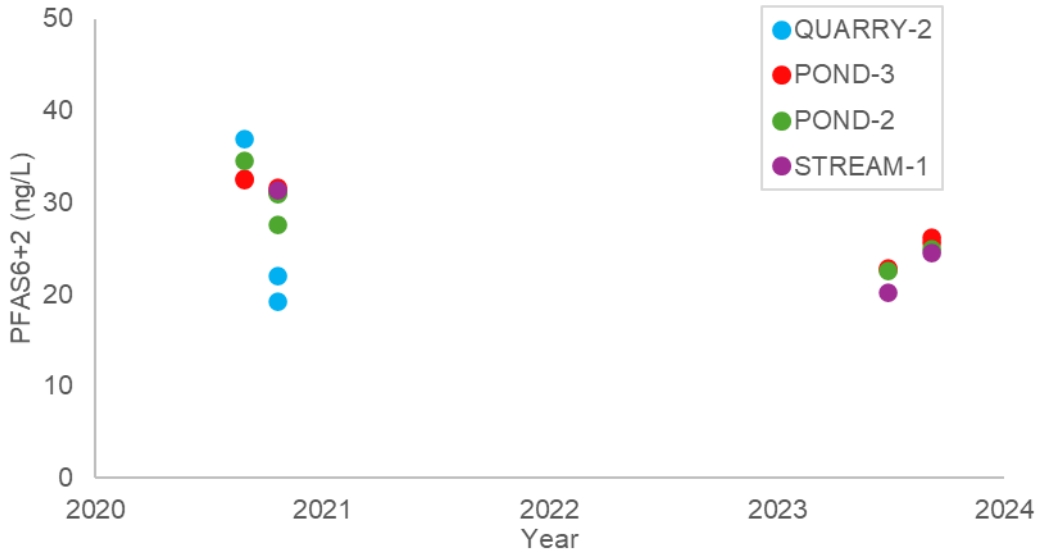


Figure 4-17: PFAS6+2 Concentrations at Quarry Sampling Locations Over Time

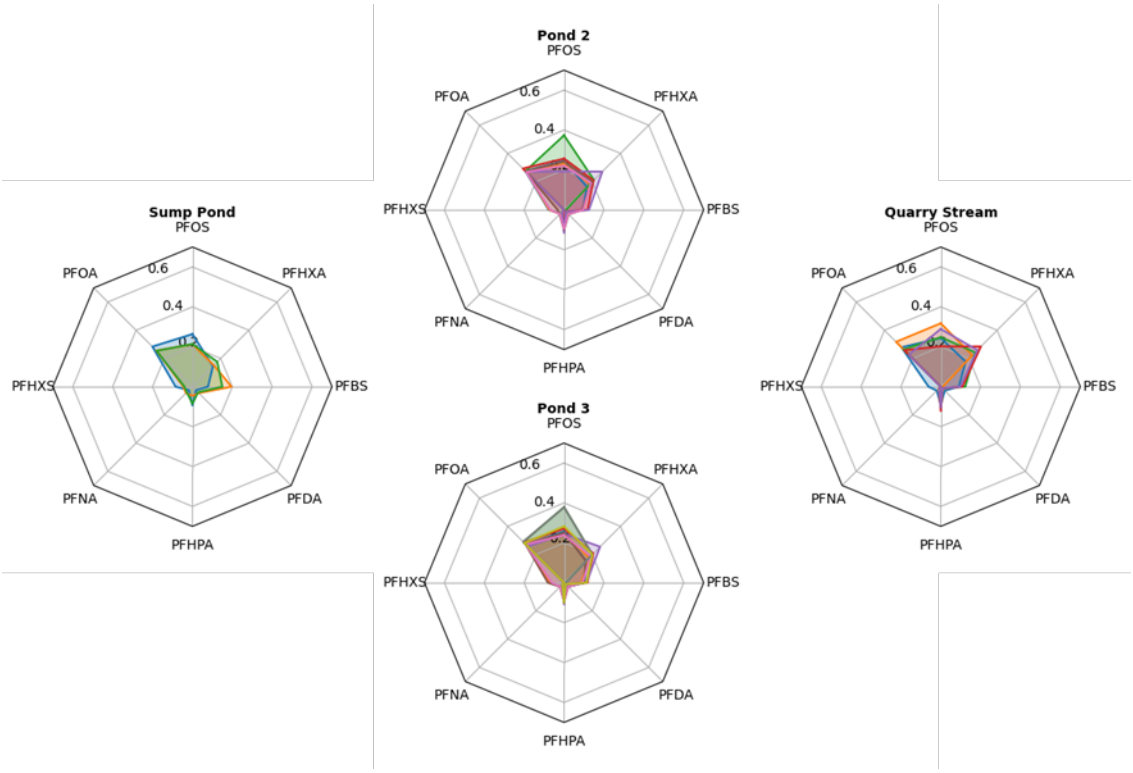


Figure 4-18: Radar Plots for Quarry Sampling Locations

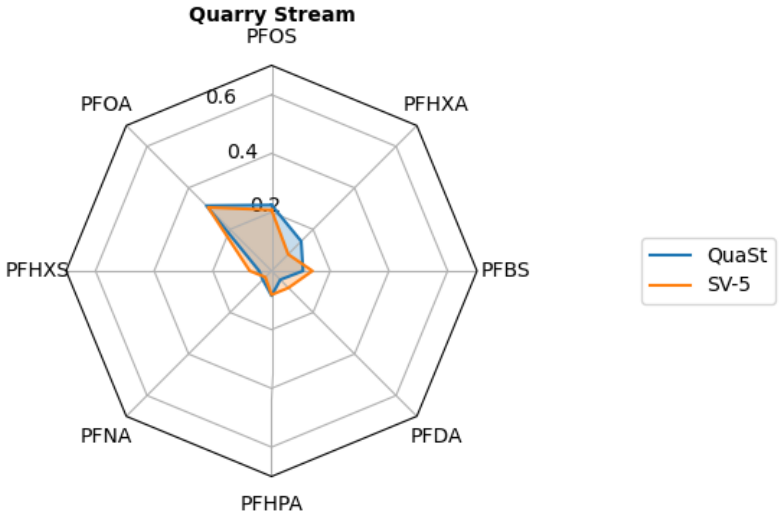


Figure 4-19: Radar Plot for Samples at Locations QuaSt and SV-5

In the previous section of this report (Section 4.3.1), we discussed how the PFAS that is present in Bennetts Brook is a combination of PFAS from Routhier's and from the landfill. Surface water monitoring location LLF-SW-6 is located in Bennetts Brook just before the brook flows into Spectacle Pond. Bennetts Brook is the primary source of surface water flowing into Spectacle Pond. Figure 4-14 shows the PFAS6+2 concentrations at LLF-SW-6 over time. There is no clear trend over time and concentrations range from approximately 14 to 40 ng/L. Figure 4-20 also shows the average PFAS6+2 concentration in Spectacle Pond from the Littleton Study. The average pond concentration falls within the range of concentrations measured at LLF-SW-6.

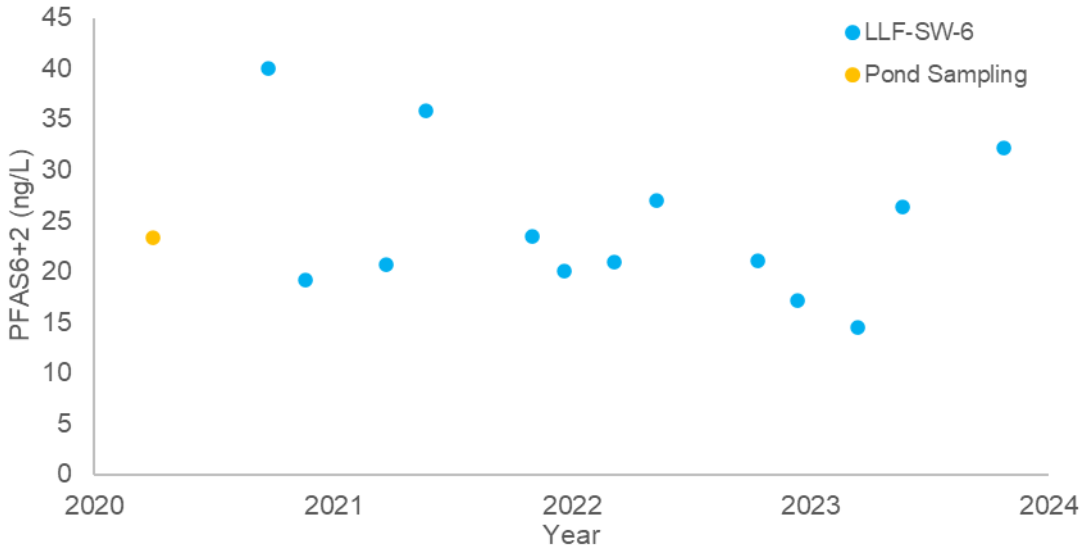


Figure 4-20: PFAS6+2 Concentrations at LLF-SW-6 Over Time

Figure 4-21 shows the radar plot of all PFAS sampling at LLF-SW-6 over time. The shape of the PFAS sampling is much more variable with some samples being PFOA dominant (i.e., October 14 and December 15 in 2022) while others show more equal distribution of PFAS between PFHxS, PFOA, PFOS, and PFHxA. The radar plots for LLF-SW-6 and Spectacle Pond are similar (see Figure 4-5).

The sampling results at LLF-MW-7 and at LLF-SW-6 in conjunction with the radar plots shown in Figure 4-8 indicate that PFAS from the landfill is reaching the Spectacle Pond wellfield through groundwater and Spectacle Pond through Bennetts Brook.

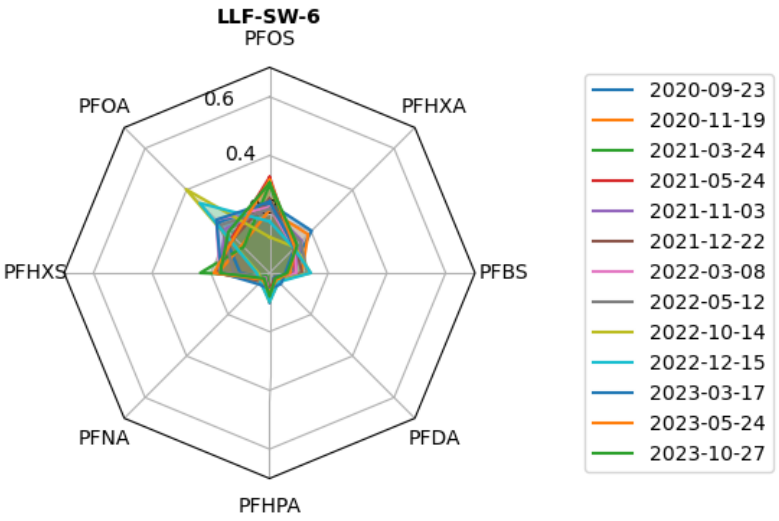


Figure 4-21: Radar Plot for LLF-SW-6

4.3.3 National Grid Properties

It is the Project Team's understanding that the only PFAS sampling near the National Grid properties is the PFAS sampling that was a part of Littleton's PFAS study (Tighe & Bond, 2020a). National Grid conducted on-site sampling in October of 2020 at the request of DEP (Coneco, 2020). Documentation of National Grid's sampling includes the approximate location of the annual AFFF testing at the property. That location and the sampling locations from both the Littleton PFAS study and National Grid's investigation are shown in Figure 4-22. Surface water sampling results are available from seven locations spanning from west to east. Three private drinking water wells were sampled along Sandas Pond Road as well as four groundwater samples collected on the property.

The groundwater concentrations are highest immediately next to the location of the annual AFFF fire suppression system testing. The PFAS6+2 concentration at CMW-104 was 503 ng/L in October 2020. According to Coneco (2020, Figure 2) monitoring well CMW-103 is downgradient to the testing location and CMW-104. The PFAS6+2 concentration at CMW-103 in October 2020 was 482 ng/L. Sample results from February 2020 include PFAS6+2 of concentrations at 2 Sandas Point Road and 3 Sandas Point Road of 169 ng/L and 245 ng/L respectively. The concentrations at 1 Sandas Point Road are low with a concentration of 9.0 ng/L for PFAS6+2.

The surface water sampling concentrations indicate concentrations below 50 ng/L everywhere except for the samples identified as SURFACE WATER-1 (66.8 ng/L), Bousquet Pond (169 ng/L), and Bousquet1 (Bousquet Brook) (80 ng/L). All sample results at SURFACE WATER-1 were non-detects, but the reporting limit for this sample was 16.7 ng/L. Neither Bousquet Pond nor Bousquet Brook are identified on USGS maps. The Project Team assumes that Bousquet Pond and Bousquet Brook are the wetland area located immediately east of the National Grid properties, and that Bousquet Brook drains to Spectacle Pond.

Elevated groundwater concentrations on the east end of the National Grid properties indicate that the annual AFFF testing is a source of PFAS. Elevated groundwater concentrations at downgradient locations and elevated surface concentrations in Bousquet Pond and Bousquet Brook all demonstrate that PFAS is migrating toward Spectacle Pond in both groundwater and surface water. The aquifer underlying Spectacle Pond is semi-confined (see Section 3.1). The Project Team assumes that PFAS in groundwater bypasses the pond and flow to the Ayer PWS wells, and the PFAS in surface water enters Spectacle Pond.

The radar plots for the surface water samples are shown in Figure 4-23, and the radar plots for the groundwater samples are shown in Figure 4-24. These figures show a consistent pattern along the transport pathway from the on-site groundwater samples to the Bousquet surface water samples and the Sandas Point Road groundwater samples. All samples are dominated by the presence of PFHxA and PFHpA with only PFOA present at a significant level relative to other PFAS. The consistency in shape across these samples demonstrates the connection between the National Grid properties and PFAS reaching Spectacle Pond.

Surface water samples east of the properties show much lower PFAS concentrations than Bousquet Pond suggesting that the source of PFAS in Bousquet Pond is groundwater flowing into the Pond.

Based on the available PFAS sampling for the National Grid properties, the Project Team concludes that PFAS is being transported via surface water to Spectacle Pond and via groundwater to the Spectacle Pond wellfield and Spectacle Pond.

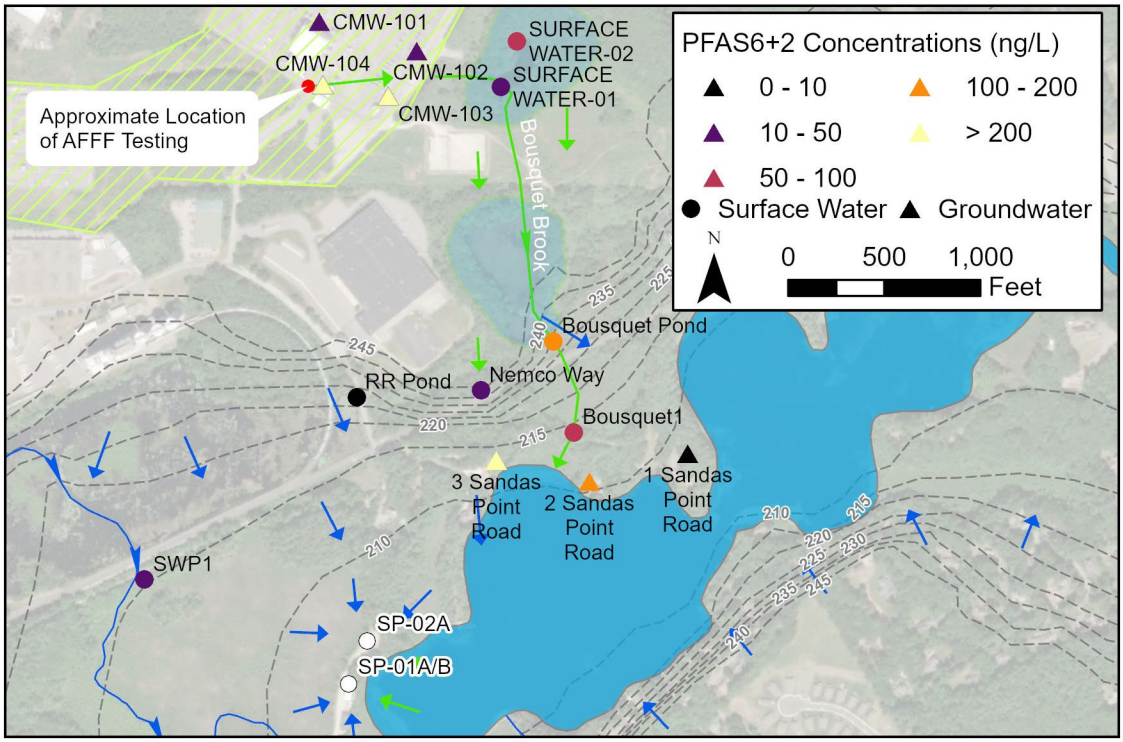


Figure 4-22: National Grid Sampling Locations

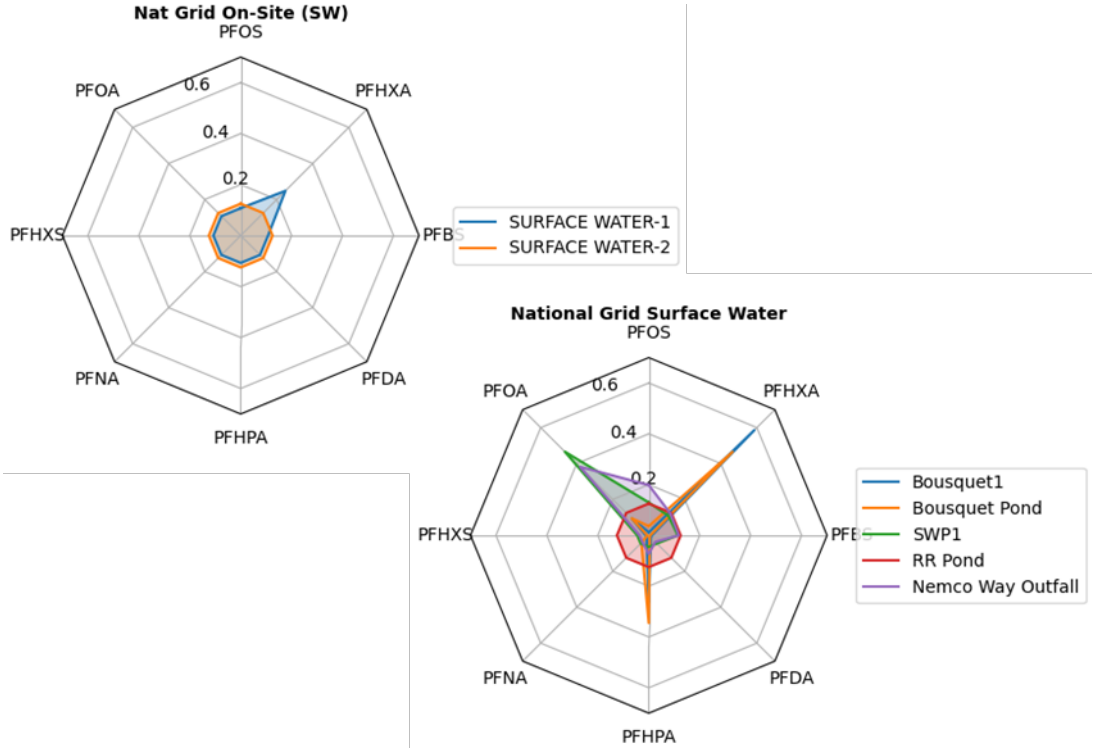


Figure 4-23: Radar Plot for Surface Water Samples at National Grid Properties

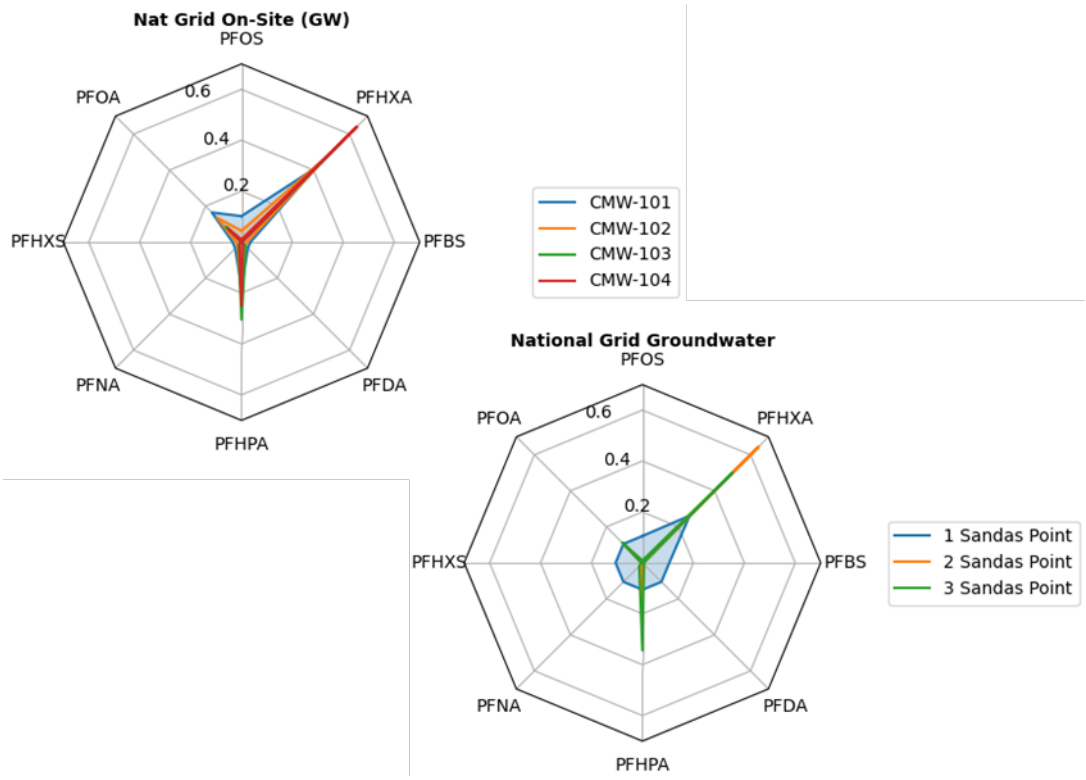


Figure 4-24: Radar Plot for Groundwater Samples at National Grid Properties

4.4 Interaction Between Wells

The CSM includes PFAS migrating southwest to the wells via groundwater from the National Grid properties towards the wells and PFAS migrating northeast to the wells via groundwater from the Littleton Landfill. Wells SP-01, SP-01A, and SP-01B are southwest of wells SP-02 and SP-02A, and historical pumping records indicate that both well locations are active each month (see Figure 2-6). Pumping rates were reported monthly. It is not possible for the Project Team to know whether the wells were pumping simultaneously or according to an alternating pump schedule. Regardless of the actual pumping schedule, the regular activity of both pumps suggests that PFAS migrating southwest is less likely to get past SP-02/A and reach SP-01/A/B. The reverse is also true. PFAS migrating northeast is less likely to get past SP-01/A/B and reach SP-02/A. The Project Team incorporates this into the CSM by assuming that PFAS from the National Grid properties predominantly reach the SP-02/A well and PFAS from the landfill predominantly reach the SP-01/A/B well.

4.5 CSM Summary

The hydrology and hydrogeology around the western half of Spectacle Pond provides multiple pathways for PFAS to be transported to the Spectacle Pond wellfield. The Project Team conducted a review of PFAS sampling at each source and between the sources and Spectacle Pond to understand which pathways are actively transporting PFAS to the Spectacle Pond wellfield.

PFAS from Routhier's reaches Spectacle Pond via Bennetts Brook. PFAS from National Grid reaches Spectacle Pond via Bousquet Brook. PFAS from the Littleton Landfill reaches Spectacle Pond via Bennetts Brook and via the Quarry Stream. Previous studies have concluded that pumping at the Ayer PWS wells induces infiltration of pond water into the wells. Between 20% and 83% of the water pumped at the

Spectacle Pond wellfield has been estimated to originate in Spectacle Pond. PFAS in Spectacle Pond enters the Ayer water supply system through the Spectacle Pond wellfield.

Multiple previous studies have confirmed the presence of a highly transmissive zone that underlies Spectacle Pond. Groundwater sampling in or at the edges of this zone (i.e., LLF-MW-7, 2 Sandas Point Road, and 3 Sandas Point Road) indicate that PFAS from both the landfill and National Grid are present in the aquifer that feeds the Spectacle Pond wellfield. PFAS from the landfill reaches the Well 1 location (i.e., SP-01, SP-01A, and SP-01B) via groundwater. PFAS from the National Grid properties reaches the Well 2 location (i.e., SP-02 and SP-02A) via groundwater. All three PFAS sources have at least one pathway to at least one of the Ayer PWS wells. Both the National Grid properties and the landfill have multiple pathways. Figure 4-25 presents a flow chart indicating transport pathways and how PFAS arrives at the Spectacle Pond wellfield.

The CSM identifies the sources and transport pathways of PFAS at the Ayer PWS wells. There are key elements of each transport pathway that are not sufficiently understood to warrant a numerical groundwater model of PFAS transport to the Spectacle Pond wellfield. The missing key elements include:

- an understanding of the height of fill and filling history at the Littleton Landfill,
- an understanding of the soil characteristics at Routhier's and National Grid related to vadose zone transport at those locations,
- a reliable estimate of infiltration from Spectacle Pond to the wells,
- a reliable estimate of PFAS concentrations in Spectacle Pond over time,
- flow rates in Bennetts Brook,
- an understanding of the hydraulic connection between wetlands areas and the underlying aquifer, and
- sufficient sampling to delineate the groundwater plume originating from each source, to understand differential retardation across PFAS compounds, and to evaluate precursor transformation.

Given these missing elements, the Project Team made estimates of historical PFAS concentrations based on the information that we have been able to collect and analyze.

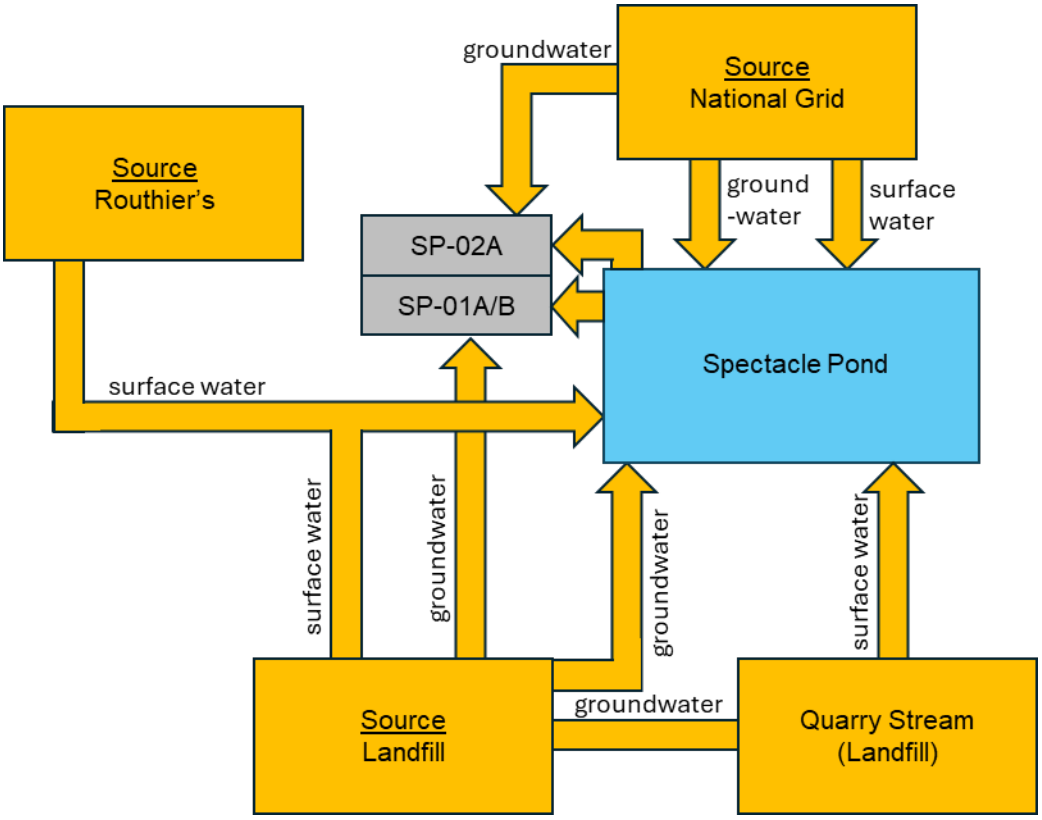


Figure 4-25: Flow Chart of Transport Pathways from Sources to Wells

5.0 ESTIMATE OF PFAS CONCENTRATIONS AT SPECTACLE POND WELLFIELD

Given that there are too many knowledge gaps to reliably apply a groundwater model to estimate historical PFAS concentrations at the Spectacle Pond wellfield, the Project Team considered various analyses that would provide a useful estimate based on the information that is available. The available information includes regular PFAS sampling at SP-01A, SP-01B, and SP-02A from 2018 to 2024, at least one sampling event at some point in each element of the transport pathways that lead to the Spectacle Pond wellfield, and release dates for two of the three PFAS sources.

The PFAS sampling at the Ayer PWS wells (as shown in Section 2.4.2) indicates that PFAS6+2 concentrations are relatively stable. Table 5-1 presents a summary of the sampling concentrations including the average, range, standard deviation, and slope, of a linear trendline, of each individual PFAS in PFAS6+2 for each of the Ayer PWS wells. In most cases the standard deviation is less than 5 ng/L and the slope is less than 1 ng/L/year.

Slope is the least intuitive of the metrics presented in Table 5-1. Figure 5-1 provides a helpful visual of how the slope metric shows trends in the dataset. Figure 5-1 shows concentrations for PFHxA and PFHxS at SP-02A over time. PFHxA concentrations at this well have the clearest trend of any PFAS at any of the wells, and they have a downward slope of 3.6 ng/L/year. In contrast, PFHxS concentrations are essentially unchanged over time with a downward slope of only 0.1 ng/L/year. Figure 5-1 includes an example line indicating a slope of 1.0 ng/L/year. Most of the PFAS sampling results at the Spectacle Pond wellfield have a slope of less than 1.0 ng/L/year. At SP-01A, all eight components of PFAS6+2 have a slope less than 1.0 ng/L/year. At SP-01B, five of the eight components have a slope less than 1.0 ng/L/year. At SP-02A, seven of the eight components have a slope of less than 1.0 ng/L/year. The Project Team considers this information to be an indication of stable PFAS concentrations at the Ayer PWS wells. The presence of stable individual PFAS concentrations at each well suggests that estimating historical concentrations based on the average concentration is a reasonable approach given that two of the three sources (i.e., the Littleton Landfill and Routhier's) became PFAS sources well before the period of estimation (i.e., 2000 – 2022).

The Littleton Landfill operated from sometime before the 1970s to 1988. As early as 1989, GHR (1989, pg. 6-7) noted that inorganic water quality at the Ayer PWS wells had been affected by the landfill. Routhier's became a source of PFAS to Spectacle Pond in approximately 1994. PFAS from Routhier's is transported to Spectacle Pond via surface water. Travel time is measured in hours or days in the context of surface water. Both the Littleton Landfill and Routhier's are already contributing PFAS to the PWS wells at the beginning of the period for estimation (i.e., 2000).

The eastern portion of the National Grid properties became a source of PFAS in approximately 2007. Given that both transport pathways from National Grid have short travel times (i.e., surface water to Spectacle Pond and groundwater migration through a high conductivity aquifer), the Project Team believes that if the relative contribution of National Grid to PFAS concentrations can be determined, they could be removed from the average concentration to establish an estimate of historical concentrations at the Ayer PWS wells that accounts for the introduction of new sources and the presence of long-term sources (i.e., the Littleton Landfill and Routhier's).

Table 5-1: Spectacle Pond Wellfield PFAS Concentration Variability and Trend

	Average ng/L	Range ng/L	St. Dev. ng/L	Slope ng/L/year	Sample Count
		SP-01A			
PFBS	2.9	1.8 – 4.5	1.2	-0.8	9
PFDA	0.7	0.3 – 1.8	0.5	-0.3	9
PFHpA	2.2	1.0 – 4.9	1.0	+0.2	12
PFHxS	5.4	3.6 – 11.7	2.1	-0.4	12
PFHxA	3.7	2.7 – 6.9	1.4	-0.6	8
PFNA	0.7	0.5 – 0.9	0.2	-0.2	8
PFOS	8.0	5.0 – 18.2	3.4	-0.4	12
PFOA	7.4	4.0 – 16.0	2.9	-0.3	12
		SP-01B			
PFBS	**5.0**	**2.0 – 8.0**	**3.3**	**-1.4**	**4**
PFDA	0.4	0.3 – 0.7	0.2	0.0	4
PFHpA	3.4	2.4 – 5.6	1.5	-0.5	4
PFHxS	2.9	1.5 – 3.8	1.0	+0.3	4
PFHxA	4.5	2.8 – 6.6	1.6	-0.6	4
PFNA	2.0	0.3 – 4.0	1.8	-0.8	4
PFOS	**10.3**	**6.7 – 16.5**	**4.4**	**-1.5**	**4**
PFOA	**11.2**	**6.9 – 16.6**	**4.7**	**-1.9**	**4**
		SP-02A			
PFBS	1.9	0.9 – 4.5	1.2	-0.1	8
PFDA	0.6	0.3 – 1.0	0.3	0.0	8
PFHPA	10.2	7.0 – 16.5	2.8	-0.3	14
PFHxS	2.5	1.5 – 3.3	0.6	-0.1	14
PFHxA	**22.5**	**9.7 – 37.3**	**8.2**	**-3.6**	**10**
PFNA	1.0	0.9 – 1.6	0.2	0.0	10
PFOS	6.5	4.6 – 8.1	1.2	-0.4	14
PFOA	9.0	5.0 – 10.9	1.6	-0.1	14

* Bold font indicates PFAS with a slope greater than ±1.0 ng/L/yr

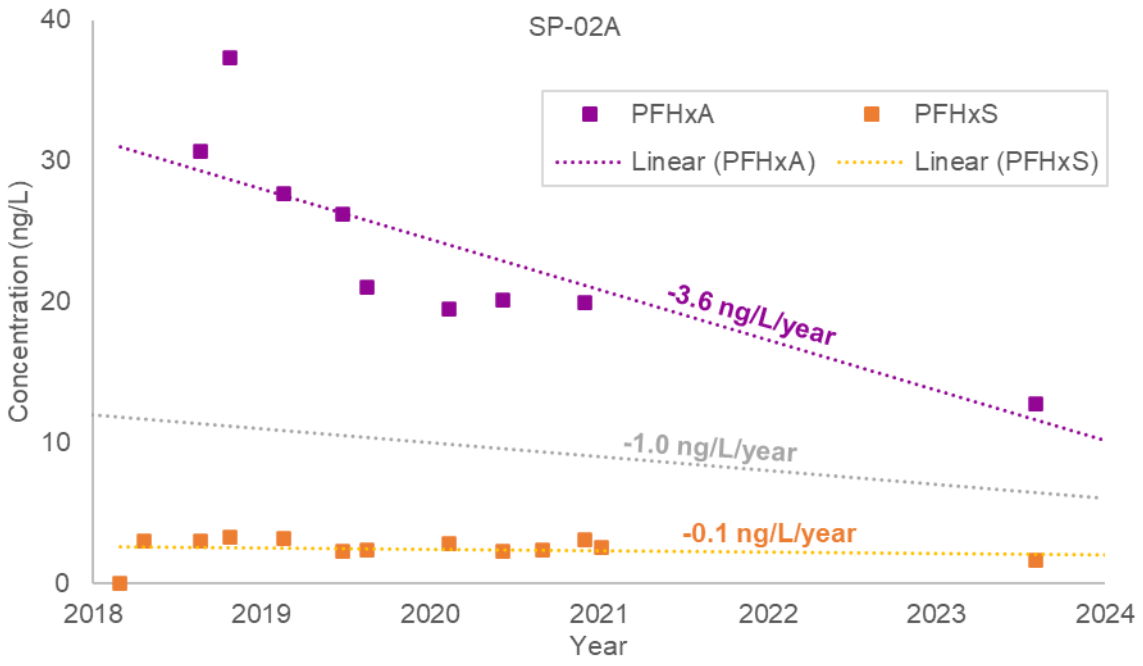


Figure 5-1: PFHxA and PFHxS at SP-02A

5.1 Determination of Relative Contribution of Sources

The Project Team based our estimates of historical PFAS concentrations on the understanding that both the Littleton Landfill and Routhier's were already established sources of PFAS to the Ayer PWS wells in 2000. The introduction of PFAS from National Grid is the only change that occurs during the period for estimation. Different combinations of the three sources mix together prior to reaching the PWS wells. The flow chart shown in Figure 4-25 includes four points in the system where multiple sources combine. These combination points are:

- The mixing of PFAS from Routhier's and the landfill in Bennetts Brook,
- The mixing of PFAS from Bennetts Brook, the Quarry Stream (i.e., the landfill), and Bousquet Brook (i.e., National Grid) in Spectacle Pond,
- The mixing of PFAS from Spectacle Pond and the southern portion of the aquifer (i.e., the landfill) at SP-01A or SP-01B, and
- The mixing of PFAS from Spectacle Pond and the northern portion of the aquifer (i.e., National Grid) at SP-02A.

At each of these points there are chemical and physical processes that control the contribution of each source, but there is insufficient information available to make reliable estimates of each individual process. Given that limitation, the Project Team applied the following methodology to estimate contributions based on water quality sampling results. The steps in this methodology are as follows:

1. Identify dominant PFAS for a sample result that is representative of each relevant source at each combination point (e.g., PFHxS at LLF-SW-2 for Routhier's and PFOA at LLF-MW-5 for the landfill in Bennett's Brook). The dominant PFAS is the PFAS with the highest concentration relative to other PFAS in the same sample (i.e., the biggest spike on the radar plot) and is most unique relative to the other PFAS sources. In the previously mentioned example, PFHxS is selected instead of PFOS for LLF-SW-2 because LLF-MW-5 has a high concentration of PFOS relative to its other concentrations.
2. Identify a representative sample result at the combination point (e.g., LLF-SW-6 in Bennetts Brook).
3. Assume 100% of the dominant PFAS at the combination point is coming from the source associated with that PFAS, and calculate a scaling factor (i.e., combination point concentration divided by source concentration).
4. Apply the scaling factor to all PFAS concentrations from that source (e.g., scaling factor for LLF-SW-2 of 0.0597 applied to seven other PFAS in addition to PFHxS from which it was derived). The scaling factor represents the portion of each PFAS at each source that reaches the combination point.
5. Sum the PFAS concentrations from sources and calculate error relative to the combination point concentrations.
6. Calculate a relative contribution percentage for each source for each PFAS at the combination point.

The scaling factor is a proxy for the physical and chemical processes that are occurring between the source observation and the combination point. The calculated error provides an indication of how closely this approach matches observed conditions, and the relative contribution percentage allows for individual sources to be added to estimated concentrations based on when the release of PFAS occurred. It is important to recognize that this is an approximate method to estimate source contributions. In particular, it rests on the assumption that most or all of the mass of a selected PFAS chemical at a combination point originates solely from a known source. Although PFAS sources and combination points were chosen carefully to conform to this assumption as closely as possible, the assumption is met only approximately in most cases.

5.1.1 Relative Contributions in Bennetts Brook

Two PFAS sources contribute to the concentrations in Bennetts Brook. PFAS from Routhier's is transported to Bennetts Brook via the unnamed tributary that passes the Routhier's property. PFAS from the landfill is entering Bennetts Brook via groundwater flowing into the brook. The Project Team excluded any PFAS from the main branch of Bennetts Brook because observed concentrations at station LLF-SW-1 are approximately 10% of the concentrations at LLF-SW-2. The Littleton PFAS study provides sampling in the unnamed tributary just before it enters Bennetts Brook (LLF-SW-2), at a groundwater monitoring well adjacent to Bennetts Brook (LLF-MW-5), and in Bennetts Brook upstream of Spectacle Pond (LLF-SW-6). LLF-SW-2 and LLF-MW-5 represent sources, and LLF-SW-6 is the combination point for calculating source relative contributions in Bennetts Brook.

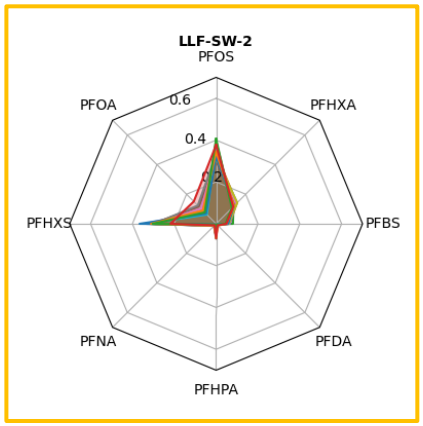
Table 5-2 provides the source concentrations, the combination-point concentrations, the scaling factors, and the difference between the observed concentration and the calculated concentration. Table 5-2 identifies the dominant PFAS with a colored box—PFHxS for LLF-SW-2 and PFOA for LLF-MW-5. The radar chart for each source and for the combination point are shown above the table and are also color coded.

The calculation shown in Table 5-2 results in relative contributions of PFAS from Routhier's and from the landfill to Bennetts Brook. These contributions can be represented as percentages of each individual PFAS concentration at Bennetts Brook. The Project Team calculated the percentages based on the totals estimated by this calculation procedure not the observed totals. Table 5-3 presents the relative contribution percentages.

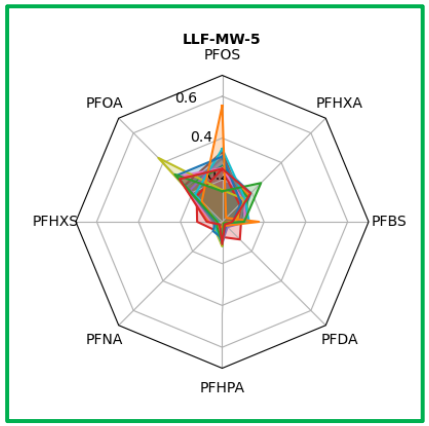
The error values associated with relative contribution calculation provides an indication of how well the calculation matches the observed concentration. The Project Team looked at these error values and at a radar plot that shows the observed PFAS concentrations and the calculated concentrations to make a qualitative assessment of how well the calculation performs.

In the case of Bennetts Brook, the individual PFAS error values are all less than 3 ng/L, and the magnitudes of the error values are all less than the range of measured PFAS concentrations at the combination point. The radar plot comparing observed concentrations and estimated concentrations is shown in Figure 5-2, and indicates that the observed and estimated concentrations are similar. The Project Team concludes that the calculation provides a reasonable estimate of observed concentrations.

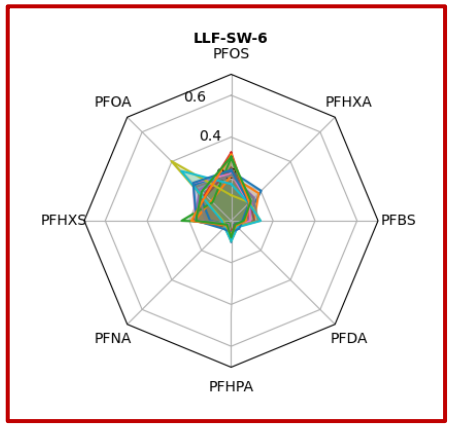
Table 5-2: Relative Contribution Calculation for PFAS in Bennetts Brook



Source 1



Source 2



Combination Point

PFAS (ng/L)	Source 1: Routhier's (LLF-SW-2)	Source 2: Landfill (LLF-MW-5)	Observation Bennetts Brook (LLF-SW-6)		Source 1 based on PFHxS	Source 2 based on PFOA	Total	Error +: over -: under
	11/19/2020	11/18/2020	11/19/2020	Range*	0.0597x	0.2154x		
PFBS	13	6.2	2.3	2.6	0.8	1.3	2.1	-0.2
PFDA	0.9	0.6	0.9	0.2	0.1	0.1	0.2	-0.7
PFHpA	13	6.2	2.0	3.2	0.8	1.3	2.1	+0.1
PFHxA	28	9.0	3.9	6.1	1.7	1.9	3.6	-0.3
PFHxS	62	2.2	3.7	5.9	3.7	0.5	4.2	+0.5
PFNA	2.2	2.1	0.9	0.7	0.1	0.5	0.6	-0.3
PFOA	15	13	2.8	7.3	0.9	2.8	3.7	+0.9
PFOS	68	14	4.5	9.1	4.1	3.0	7.1	+2.6
PFAS6+2	**202**	**53**	**19.2**				**23.5**	

* LLF-SW-6 range calculated based on all samples at that station reported in the landfill's quarterly report (Tighe & Bond, 2024)

Table 5-3: Relative Contribution Percentages at Bennetts Brook

	Routhier's	Landfill
PFBS	37%	63%
PFDA	29%	71%
PFHpA	37%	63%
PFHxA	46%	54%
PFHxS	89%	11%
PFNA	23%	77%
PFOA	24%	76%
PFOS	57%	43%

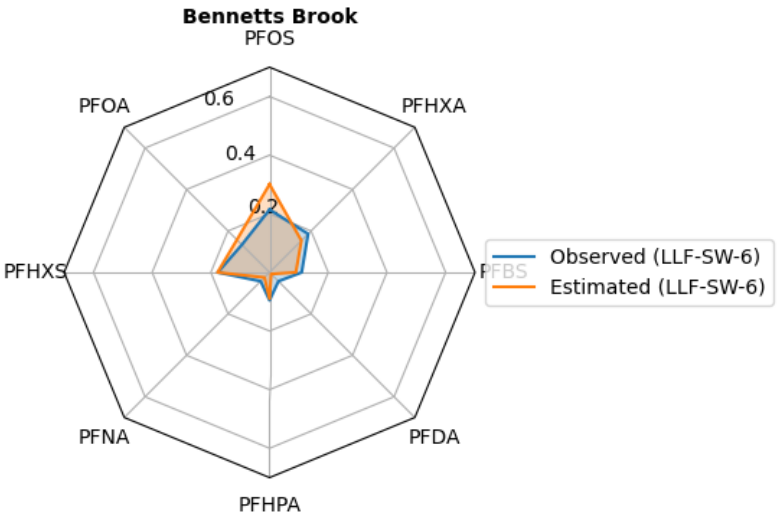


Figure 5-2: Radar Plot for Comparison of Observed PFAS and Estimated PFAS in Bennetts Brook

5.1.2 Relative Contributions in Spectacle Pond

Three PFAS sources contribute to the surface water concentrations in Spectacle Pond. PFAS from Routhier's is transported to Spectacle Pond via Bennetts Brook. PFAS from the Littleton Landfill is entering Spectacle Pond via Bennetts Brook and the Quarry Stream. PFAS from the National Grid properties enters Spectacle Pond via Bousquet Brook. The Littleton PFAS study provides sampling in Bennetts Brook (LLF-SW-6), the Quarry Stream (QuaSt), and Bousquet Brook (Bousquet1) as well as a set of samples collected in Spectacle Pond. LLF-SW-6, QuaSt, and Bousquet1 are sources, and the averaged pond samples are the combination point for calculating relative source contributions in Spectacle Pond.

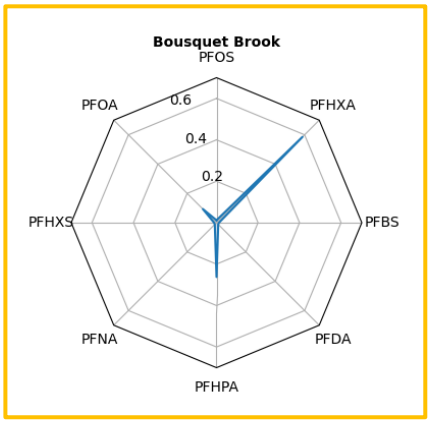
Table 5-4 provides the source concentrations, the combination-point concentrations, the scaling factor, and the difference between the observed concentration and the calculated concentration. Table 5-4 identifies the dominant PFAS with a colored box. The radar chart for each source and for the combination point are shown above the table and are also color coded.

The calculation shown in Table 5-4 results in relative contributions of PFAS from Bennetts Brook, the Quarry Stream, and Bousquet Brook. Table 5-5 presents the relative contribution percentages.

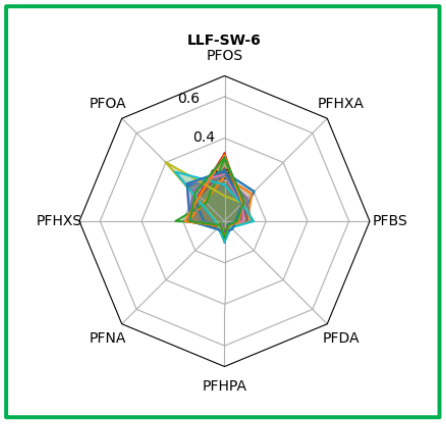
In the case of Spectacle Pond, the individual PFAS error values are all less than or equal to 6 ng/L. The magnitude of the error values for six of the eight PFAS are higher than the range of measured concentrations. The Project Team notes that the range column in Table 5-5 shows the range of concentrations measured at multiple locations within the pond on the same day. This range is different from the range that would be expected from sampling the same location on multiple days as was done for Bennetts Brook. We would expect a larger range if the pond were sampled over a longer period of time across a range of hydrologic conditions.

Figure 5-3 shows the observed and synthetic radar plots for Spectacle Pond. Visual inspection shows that the shapes of both observed and estimated are not markedly dissimilar. Both the comparison of range to error and the radar plot suggest that the results of relative contribution calculation are reasonable.

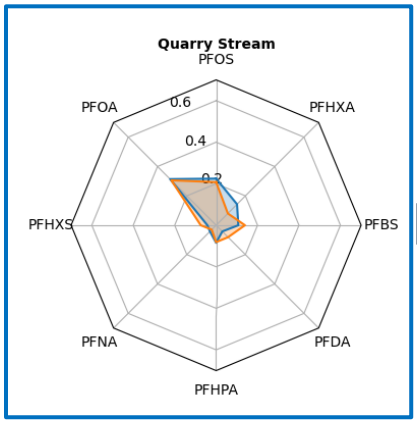
Table 5-4: Relative Contribution Calculation for PFAS in Spectacle Pond



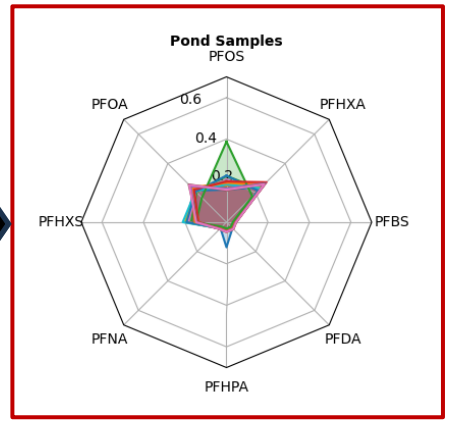
Source 1



Source 2



Source 3



Combination Point

PFAS (ng/L)	Source 1: Bousquet Brook (Bousquet1)	Source 2: Bennetts Brook (LLF-SW-6)	Source 3: Quarry Stream (QuaSt)	Observation Spectacle Pond (Average)		Source 1 based on PFHxA	Source 2 based on PFHxS	Source 3 based on PFOA	Total	Error +: over -: under
	3/2/2020	11/19/2020	2/3/2020	3/31/2020	Range*	0.104x	0.973x	0.725x		
PFBS	1.0	2.3	2.3	0.9	0.1	0.1	2.2	1.6	4.0	+3.1
PFDA	1.0	0.9	0.9	0.9	0.1	0.1	0.9	0.6	1.6	+0.7
PFHpA	22	2.0	1.8	2.8	0.4	2.3	1.9	1.3	5.6	+2.8
PFHxA	50	3.9	3.0	5.2	0.9	5.2	3.8	2.2	11.2	+6.0
PFHxS	1.0	3.7	0.9	3.6	2.0	0.1	3.6	0.6	4.4	+0.8
PFNA	1.0	0.9	0.9	0.9	0.1	0.1	0.9	0.6	1.6	+0.7
PFOA	7.9	2.8	6.6	4.8	0.7	0.8	2.7	4.8	8.4	+3.6
PFOS	1.0	4.5	4.7	4.4	8.3	0.1	4.4	3.4	7.9	+3.5
PFAS6+2	**85**	**21**	**21**	**24**					**45**	

* Spectacle Pond range calculated based on set of 17 samples collected on 3/31/2020.

Table 5-5: Relative Contribution Percentages Spectacle Pond

	Bousquet Brook	Bennetts Brook	Quarry Stream
PFBS	3%	56%	41%
PFDA	6%	54	40%
PFHpA	42%	35%	23%
PFHxA	46%	34%	20%
PFHxS	2%	83%	15%
PFNA	6%	54%	40%
PFOA	10%	33%	57%
PFOS	1%	55%	43%

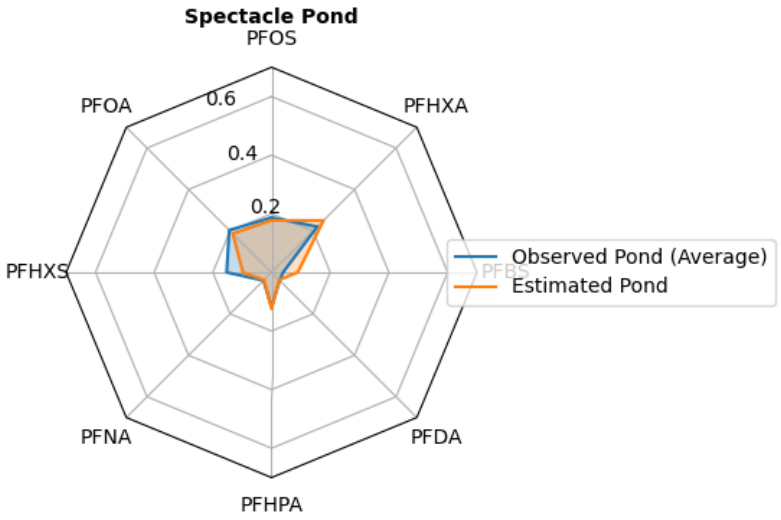


Figure 5-3: Radar Plot for Comparison of Observed PFAS and Estimated PFAS in Spectacle Pond

5.1.3 Relative Contributions in PWS Wells

Two PFAS sources contribute to the concentrations in each of the three PWS wells at Spectacle Pond. PFAS from the landfill is transported to the wells SP-01A and SP-01B via groundwater. PFAS from the National Grid properties is transported to the well SP-02A via groundwater. PFAS from Spectacle Pond is reaching all three wells via induced infiltration. The Littleton PFAS study provides sampling in groundwater between the landfill and the PWS wells (LLF-MW-7), in the groundwater between the National Grid properties and the PWS wells (3 Sandas Point Road), and in Spectacle Pond. LLF-MW-7, 3 Sandas Point Road, and Spectacle Pond are sources, and each well is its own combination point for calculating source relative contributions.

Table 5-6 through Table 5-8 provide the source concentrations, the combination point concentrations, the scaling factor, and the difference between the observed concentration and the calculated concentration for

each well. Each table identifies the dominant PFAS with a colored box. The radar chart for each source and for the combination point are shown above the table and are also color coded.

The calculations shown in Table 5-6 through Table 5-8 results in relative contributions of PFAS from the landfill, the National Grid properties, and Spectacle Pond. Table 5-9 through Table 5-11 presents the relative contribution percentages.

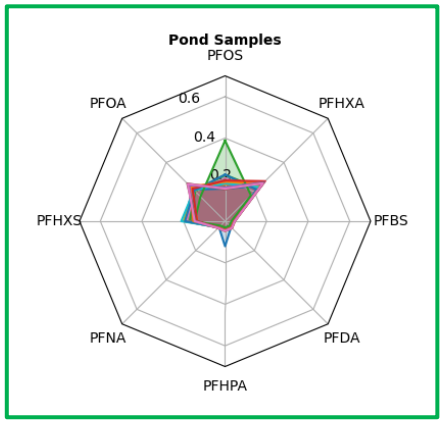
In the case of well SP-01A, the individual PFAS error values are all less than 10 ng/L. The magnitude of the error values for five of the eight PFAS are lower than the range of measured concentrations. Figure 5-4 shows the observed and estimated radar plots for SP-01A. Visual inspection shows that the shapes of both observed and estimated are similar.

SP-01B may be screened at different depths than SP-01A (for which well screen information is not available). For this reason, we evaluated the two wells separately. In the case of well SP-01B, the individual PFAS error values are all less than 8 ng/L. The magnitude of the error values for six of the eight PFAS are lower than the range of measured concentrations. Figure 5-5 shows the observed and estimated radar plots for SP-01B. Visual inspection shows that the shapes of both observed and estimated are similar.

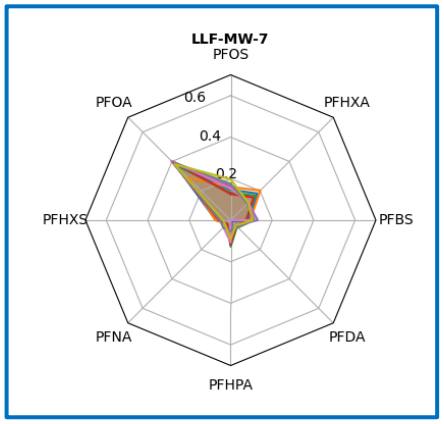
In the case of well SP-02A, the individual PFAS error values are all equal to or less than 7 ng/L. The magnitude of the error values for all eight PFAS are lower than the range of measured concentrations. Figure 5-6 shows the observed and estimated radar plots for SP-02A. Visual inspection shows that the shapes of both observed and estimated are strikingly similar, particularly in comparison to SP-01A/B.

The Project Team concludes that the estimated concentrations in Bennetts Brook, in Spectacle Pond, and each well are approximate but “reasonable.” The word reasonable does not have a technical definition. We use the word to mean that the estimated concentration patterns do not deviate from the observed concentration patterns in any fundamental way and that the predicted errors are small compared to the observed ranges in concentration. The Project Team’s conclusion that this approach is reasonable is based on the results presented here and on our professional judgement. The Project Team evaluated multiple approaches to calculating the contribution of each source to the PFAS at the Spectacle Pond wells. The results of each calculation approach yielded different estimates, but all estimates were in the same range. The method used here delivered as good an estimate as any other approach we tested given the available information.

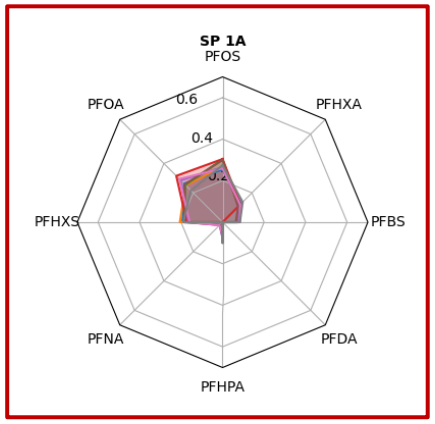
Table 5-6: Relative Contribution Calculation for PFAS in SP-01A



Source 1



Source 2

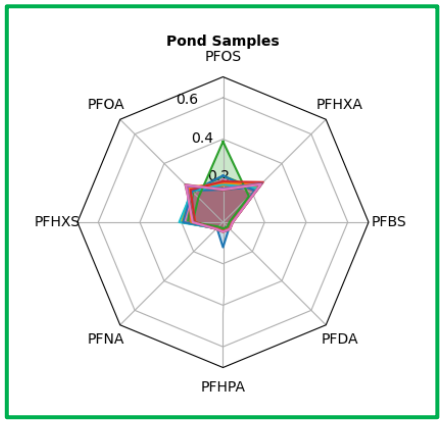


Combination Point

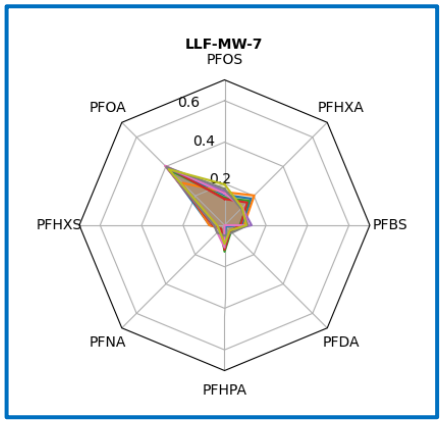
PFAS (ng/L)	Source 1: Spectacle Pond (Average)	Source 2: Landfill (LLF-MW-7)	Observation SP-01A		Source 1 based on PFHxS	Source 2 based on PFOA	Total	Error +: over -: under
	3/2/2020	Avg. 9,11/2020	2/13/2020	Range	1.642x	0.851x		
PFBS	0.9	2.6	2.0	2.7	1.5	2.2	3.7	+1.6
PFDA	0.9	0.6	0.3	1.5	1.5	0.5	2.0	+1.7
PFHpA	2.8	3.3	2.3	3.9	4.6	2.8	7.3	+5.1
PFHxA	5.2	5.5	3.4	4.2	8.5	4.7	13.2	+9.8
PFHxS	3.6	2.1	5.9	8.1	5.9	1.8	7.7	+1.8
PFNA	0.9	0.7	0.6	0.4	1.5	0.6	2.1	+1.5
PFOA	4.8	9.7	8.3	12	7.9	8.3	16	+7.9
PFOS	4.4	4.4	9.6	13	7.2	3.7	11	+1.4
PFAS6+2	**24**	**29**	**32**				**63**	

* SP-01A range calculated based on all samples for well 2018-2020.

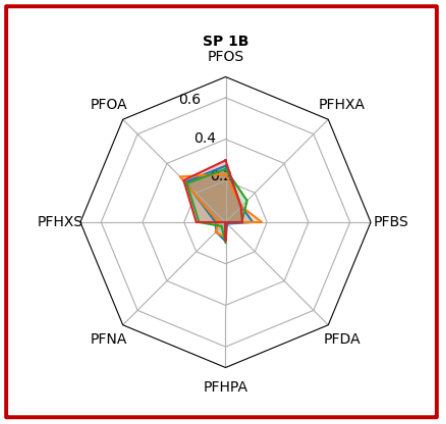
Table 5-7: Relative Contribution Calculation for PFAS in SP-01B



Source 1



Source 2

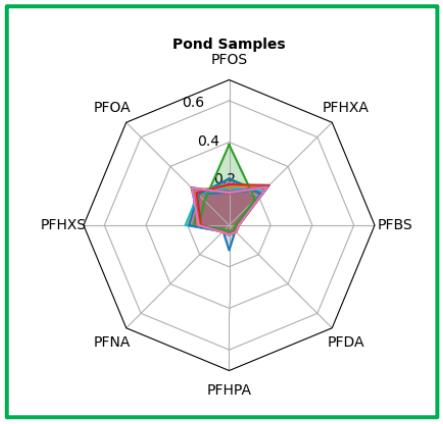


Combination Point

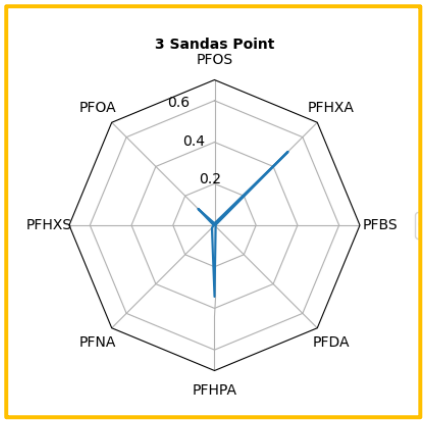
PFAS (ng/L)	Source 1: Spectacle Pond (Average)	Source 2: Landfill (LLF-MW-7)	Observation SP-01B		Source 1 based on PFHxS	Source 2 based on PFOA	Total	Error +: over -: under
	3/2/2020	Avg. 9,11/2020	2/13/2020	Range	0.817x	1.711x		
PFBS	0.9	2.6	8.0	5.9	0.7	4.4	5.2	-2.8
PFDA	0.9	0.6	0.7	0.4	0.7	1.1	1.8	+1.1
PFHpA	2.7	3.3	5.6	3.2	2.3	5.6	7.8	+2.3
PFHxA	5.2	5.5	6.6	3.8	4.2	9.4	14	+7.1
PFHxS	3.6	2.1	2.9	2.3	2.9	3.6	6.5	+3.6
PFNA	0.9	0.7	4.0	3.6	0.7	1.1	1.9	-2.1
PFOA	4.8	9.7	17	9.7	3.9	17	21	+3.9
PFOS	4.4	4.4	17	9.8	3.6	7.5	11	-5.4
PFAS6+2	**24**	**28**	**61**				**69**	

* SP-01B range calculated based on all samples for well 2020-2024.

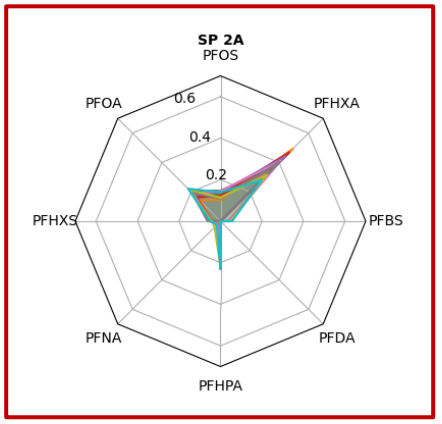
Table 5-8: Relative Contribution Calculation for PFAS in SP-02A



Source 1



Source 2



Combination Point

PFAS (ng/L)	Source 1: Spectacle Pond (Average)	Source 2: National Grid (3 Sandas Pt)	Observation SP-02A		Source 1 based on PFHxS	Source 2 based on PFHxA	Total	Error +: over -: under
	3/2/2020	2/3/2020	2/13/2020	Range	0.769x	0.159x		
PFBS	0.9	1.0	2.1	3.6	0.7	0.2	0.9	-1.2
PFDA	0.9	2.0	0.3	0.7	0.7	0.3	1.0	+0.7
PFHpA	2.7	84	8.5	9.5	2.2	13	16	+7.0
PFHxA	5.2	123	20	28	4.0	20	24	+4.0
PFHxS	3.6	1.0	2.8	1.8	2.8	0.2	2.9	+0.2
PFNA	0.9	4.4	1.0	0.7	0.7	0.7	1.4	+0.4
PFOA	4.8	28	11	5.9	3.7	4.4	8.1	-2.5
PFOS	4.4	2.2	7.7	3.5	3.4	0.4	3.7	-3.9
PFAS6+2	**24**	**246**	**51**				**57**	

* SP-02A range calculated based on all samples for well 2018-2024.

Table 5-9: Relative Contribution Percentages SP-01A

	Spectacle Pond	Landfill
PFBS	40%	60%
PFDA	74%	26%
PFHpA	62%	38%
PFHxA	65%	35%
PFHxS	77%	23%
PFNA	72%	28%
PFOA	49%	51%
PFOS	66%	34%

Table 5-10: Relative Contribution Percentages SP-01B

	Spectacle Pond	Landfill
PFBS	14%	86%
PFDA	41%	59%
PFHpA	29%	71%
PFHxA	31%	69%
PFHxS	45%	55%
PFNA	39%	61%
PFOA	19%	81%
PFOS	32%	68%

Table 5-11: Relative Contribution Percentages SP-02A

	Spectacle Pond	National Grid
PFBS	81%	19%
PFDA	69%	31%
PFHpA	14%	86%
PFHxA	17%	83%
PFHxS	95%	5%
PFNA	50%	50%
PFOA	46%	54%
PFOS	91%	9%

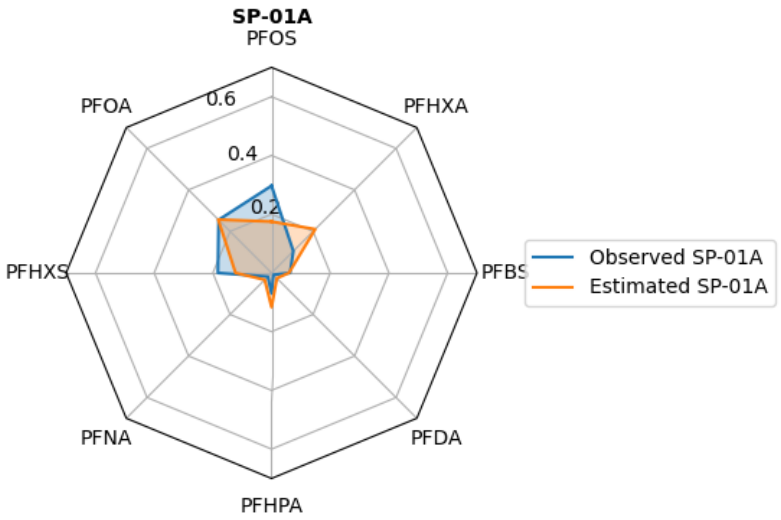


Figure 5-4: Radar Plot for Comparison of Observed PFAS and Estimated PFAS at SP-01A

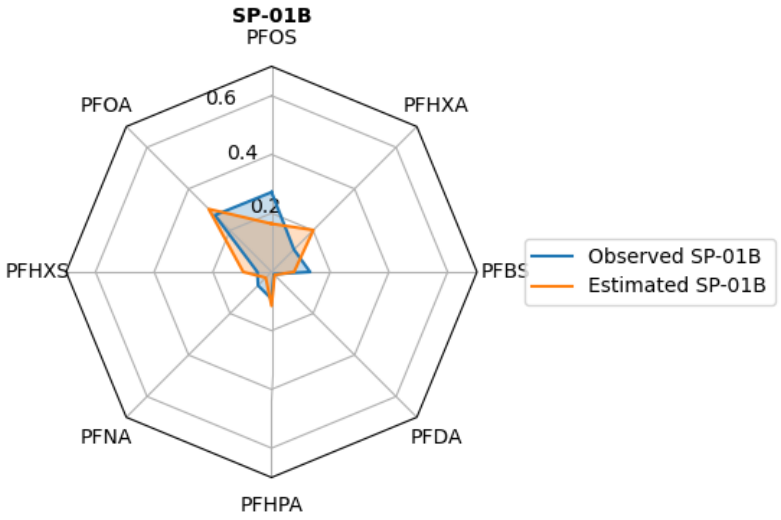


Figure 5-5: Radar Plot for Comparison of Observed PFAS and Estimated PFAS at SP-01B

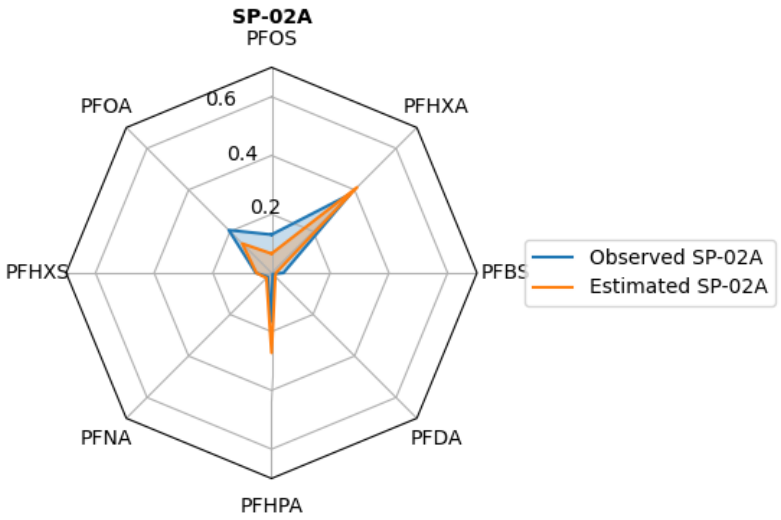


Figure 5-6: Radar Plot for Comparison of Observed PFAS and Estimated PFAS at SP-02A

5.2 Estimated PFAS Concentrations at Active Wells

The Project Team concluded that PFAS concentrations at the Spectacle Pond wellfield are stable, and that the average concentrations are representative of conditions prior to the start of PFAS sampling at the wellfield. The Project Team also developed PFAS-specific contribution percentages at each location in the CSM where multiple sources of PFAS combine. The Project Team used this information and the known site history (i.e., the Littleton Landfill operated for decades before it was closed in 1988, AFFF was used annually from 2007 to 2018 at the National Grid properties, and AFFF was used at Routhier's in 1994) to estimate concentrations at the Spectacle Pond wellfield from 2000 to 2022.

The annual estimated concentration is the average concentration minus the portion of that concentration that is attributed to a source that is not yet present. For example, the average concentration of PFOA at well SP-02A is 9.6 ng/L for current conditions. The relative contribution calculations indicate that 54% of the PFOA is coming from the National Grid properties via groundwater, and 46% of the PFOA is coming from Spectacle Pond. Of that 46%, 10% is coming from the National Grid properties, 57% is coming from the Quarry Stream (i.e., indirectly from the Littleton Landfill), and 33% is coming from Bennetts Brook. Of that 33%, 76% is coming from the landfill, and 24% is coming from Routhier's. Contributions from the National Grid properties do not begin until 2008 (i.e., the year after the start of AFFF use).

The estimated PFOA concentration at well SP-02A in 2000 is 3.9 ng/L. The concentration increases to the approximate present-day level of 9.6 ng/L in 2008. From 2008 to 2022 the concentration remains constant. Figure 5-7 through Figure 5-10 presents the estimated concentration of PFOA, PFOS, PFHxS, and PFNA at the Ayer PWS wells. Estimated concentrations for individual PFAS are included as Attachment 1 of this report.

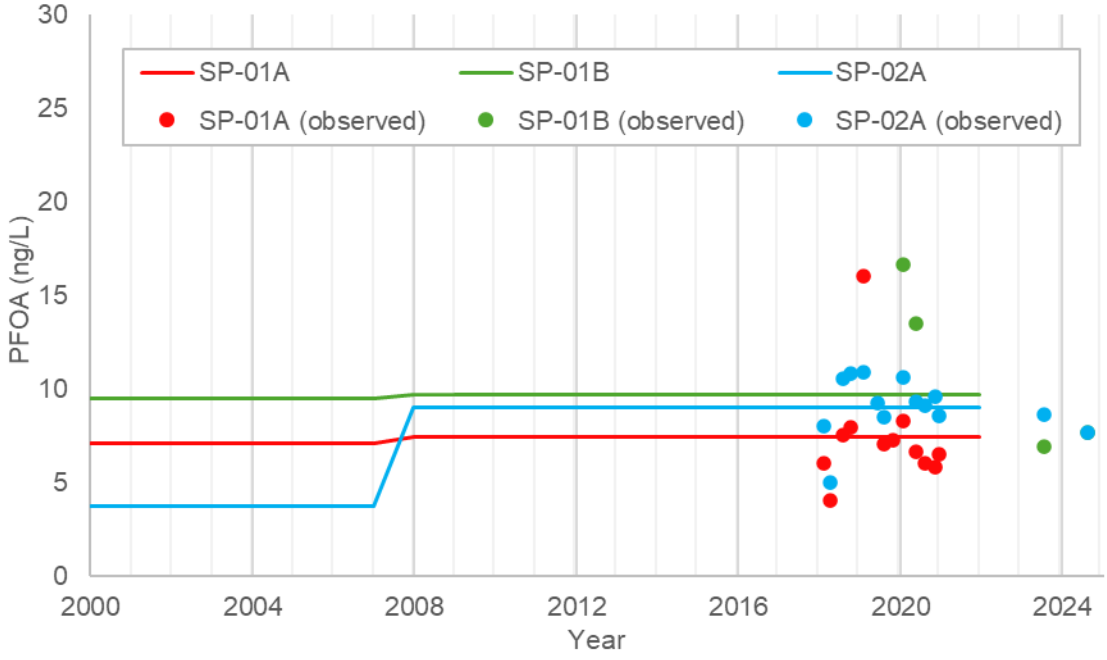


Figure 5-7: Estimated PFOA Concentration at Ayer PWS Wells, 2000-2022

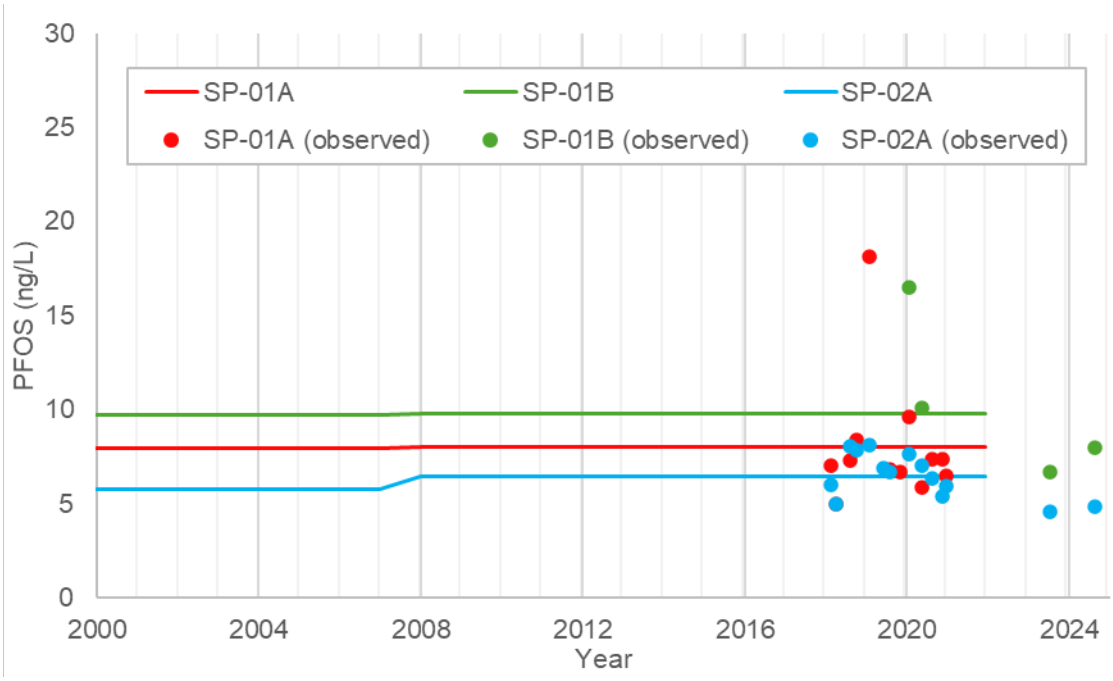


Figure 5-8: Estimated PFOS Concentration at Ayer PWS Wells, 2000-2022

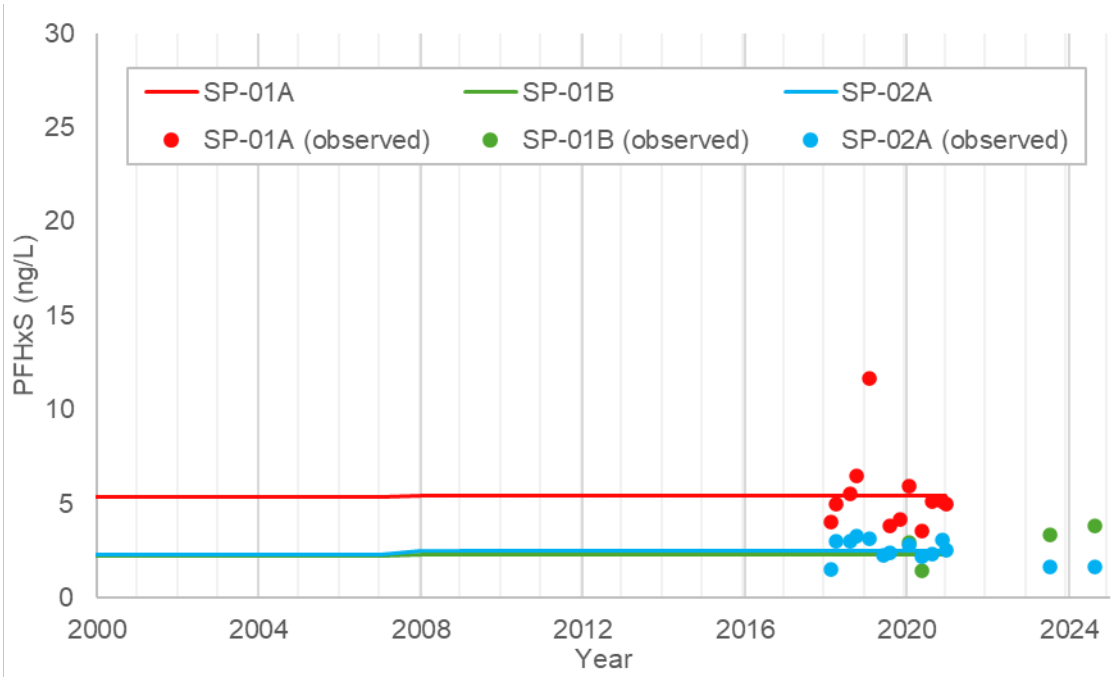


Figure 5-9: Estimated PFHxS Concentration at Ayer PWS Wells, 2000-2022

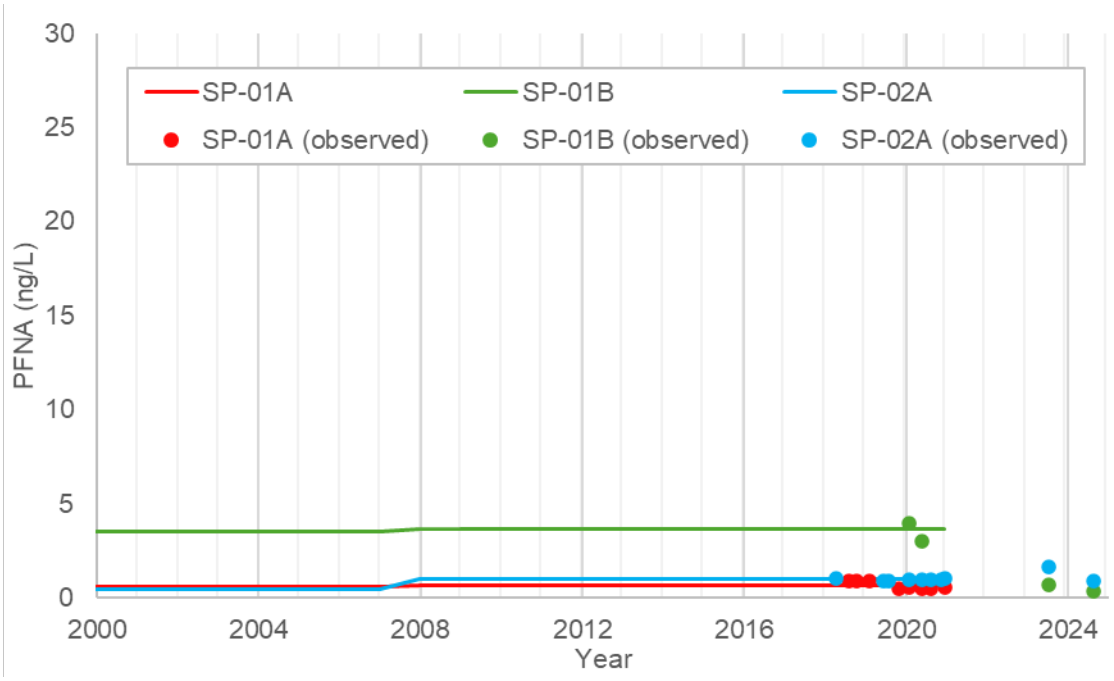


Figure 5-10: Estimated PFNA Concentration at Ayer PWS Wells, 2000-2022

5.3 Estimated PFAS Concentrations at Decommissioned Wells

The estimated PFAS concentrations in Attachment 1 are estimates of the PFAS entering the Ayer drinking water supply system from the Spectacle Pond wellfield at three wells for which there is PFAS sampling (i.e., SP-01A, SP-01B, and SP-02A). SP-01A came online in 2010, and SP-02A came online in 2018. These two wells replaced the original wells SP-01 and SP-02. The Project Team is not aware of any PFAS sampling completed for the decommissioned wells. Estimates of PFAS concentrations at SP-01 and SP-02 must be derived from the estimates for the newer wells.

As shown in Figure 2-4, SP-02A is screened at a deeper interval than SP-02. This may mean that water from SP-02 may have consisted of more pond water and less aquifer water than water from SP-02A, but there is no way to quantitatively evaluate a difference based on the available information. For the purposes of estimating historical PFAS concentrations, the Project Team recommends that SP-02 be considered equivalent for SP-02A.

Determination of an appropriate proxy well for SP-01 is more complicated. The relative contribution percentages shown in Table 5-6 and Table 5-7 suggest that SP-01A is drawing more water from the pond than SP-01B. The most likely reason for this would be if SP-01A is screened at a shallower depth than SP-01B, but the actual screen depths for SP-01A were not provided to the Project Team. SP-01 had two screen depths with the deeper screen likely in the same strata as the screen for SP-01B and the shallower screen approximately 12 ft above the deeper screen. For lack of more definitive information, the Project Team recommends that SP-01 be considered equivalent to the average of SP-01A and SP-01B.

5.4 Limitations

The PFAS concentration estimates in this report are based on the available information, but there are important pieces of information that are not available (e.g., the date of construction of the Littleton Landfill). A list of the critical missing information is provided in Section 4.5. This missing information leads us to estimate PFAS concentrations at the Ayer PWS based on assumption of stable concentrations at the wells. We use this assumption for the estimation of concentrations from 2000 to 2022, and we believe it to be a valid assumption based on the available measured PFAS concentrations.

At some point in the past, there was no PFAS at the Ayer PWS. Over time PFAS has been transported to the wells. Concentrations at the wells have increased over time. That process has been ongoing for as much as 70 years. The available PFAS sampling at the wells indicate stable concentrations, but the six years of sampling is short relative to the potential transport time. The short period (relative to the time since the release of PFAS) and the limited groundwater quality sampling away from the well prevent us from developing an estimate of concentrations that includes a trend over time.

We do not know if the observed concentrations represent the leading edge of an arriving plume, the trailing edge of a plume that has already passed the wells, or a continuous source that has reached a static condition. Without the ability to identify a clear positive or negative trend in the available sample results, we cannot evaluate the likelihood of our estimate being an over prediction or an under prediction.

These limitations based on the consideration of groundwater are compounded by additional limitations based on surface water. Surface water transport occurs on the time scale of days. PFAS may have arrived in Spectacle Pond within hours or days of the fires at Routhier's. Surface water sampling in 2020 tells us

nothing about what concentrations may have been immediately after the fires. It is possible that PFAS reached Spectacle Pond and is now bound in the sediments of Spectacle Pond. The Project Team is not aware of any sediment sampling in Spectacle Pond. Given that between 20% and 83% of the water pumped by the Ayer PWS is infiltrated through the bottom of Spectacle Pond, the potential for sediments to be a PFAS source is significant.

An additional limitation to this work includes the inability to evaluate precursor transformation due to limited information about the identity and concentrations of other PFAS compounds being released from the sources in Ayer prior to environmental transport. In addition, it is important to note that the relative abundances of the perfluorinated PFAS (e.g., PFOA, PFOS, and PFHxA) used in the radar plots can change within a plume during groundwater transport due to their formation from transformation of precursor compounds.

Nevertheless, despite limited data on PFAS releases from suspected sources, the approach we used to estimate PFAS concentrations in the Ayer public wells are reasonable and incorporate all information available at the time of our study.

5.5 Summary

The Project Team collected information about the Ayer PWS wells, the relevant sources of PFAS, and the local hydrology and hydrogeology to develop a CSM. The CSM identifies potential transport pathways for PFAS to arrive at the Ayer PWS wells from the PFAS source sites. The Project Team then estimated likely PFAS concentrations at the wells for the years 2000 through 2022. The methodology used in estimating the PFAS is based on the assumption of stable concentrations at the wells and leverages as much of the available information as possible to incorporate changes to the PFAS concentrations at the wells. Ultimately, two of the three sources of PFAS (i.e., the Littleton Landfill and Routhier's) pre-date the period for PFAS estimation. This leads to very limited changes in PFAS concentrations at the wells.

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Attachment 1: Estimated PFAS Concentrations at Spectacle Pond Wellfield

Spectacle Pond SP-01A Estimate of PFAS Concentrations

Annual PFAS Concentration (ng/L)

Year	*PFBS*	*PFDA*	*PFHpA*	*PFHxA*	*PFHxS*	*PFNA*	*PFOA*	*PFOS*
2000	2.8	0.6	1.6	2.6	5.3	0.6	7.1	7.9
2001	2.8	0.6	1.6	2.6	5.3	0.6	7.1	7.9
2002	2.8	0.6	1.6	2.6	5.3	0.6	7.1	7.9
2003	2.8	0.6	1.6	2.6	5.3	0.6	7.1	7.9
2004	2.8	0.6	1.6	2.6	5.3	0.6	7.1	7.9
2005	2.8	0.6	1.6	2.6	5.3	0.6	7.1	7.9
2006	2.8	0.6	1.6	2.6	5.3	0.6	7.1	7.9
2007	2.8	0.6	1.6	2.6	5.3	0.6	7.1	7.9
2008	2.9	0.7	2.2	3.7	5.4	0.7	7.4	8.0
2009	2.9	0.7	2.2	3.7	5.4	0.7	7.4	8.0
2010	2.9	0.7	2.2	3.7	5.4	0.7	7.4	8.0
2011	2.9	0.7	2.2	3.7	5.4	0.7	7.4	8.0
2012	2.9	0.7	2.2	3.7	5.4	0.7	7.4	8.0
2013	2.9	0.7	2.2	3.7	5.4	0.7	7.4	8.0
2014	2.9	0.7	2.2	3.7	5.4	0.7	7.4	8.0
2015	2.9	0.7	2.2	3.7	5.4	0.7	7.4	8.0
2016	2.9	0.7	2.2	3.7	5.4	0.7	7.4	8.0
2017	2.9	0.7	2.2	3.7	5.4	0.7	7.4	8.0
2018	2.9	0.7	2.2	3.7	5.4	0.7	7.4	8.0
2019	2.9	0.7	2.2	3.7	5.4	0.7	7.4	8.0
2020	2.9	0.7	2.2	3.7	5.4	0.7	7.4	8.0
2021	2.9	0.7	2.2	3.7	5.4	0.7	7.4	8.0
2022	2.9	0.7	2.2	3.7	5.4	0.7	7.4	8.0

Spectacle Pond SP-01B Estimate of PFAS Concentrations

Annual PFAS Concentration (ng/L)

Year	*PFBS*	*PFDA*	*PFHpA*	*PFHxA*	*PFHxS*	*PFNA*	*PFOA*	*PFOS*
2000	5.9	0.4	2.8	3.2	2.3	3.5	9.5	9.8
2001	5.9	0.4	2.8	3.2	2.3	3.5	9.5	9.8
2002	5.9	0.4	2.8	3.2	2.3	3.5	9.5	9.8
2003	5.9	0.4	2.8	3.2	2.3	3.5	9.5	9.8
2004	5.9	0.4	2.8	3.2	2.3	3.5	9.5	9.8
2005	5.9	0.4	2.8	3.2	2.3	3.5	9.5	9.8
2006	5.9	0.4	2.8	3.2	2.3	3.5	9.5	9.8
2007	5.9	0.4	2.8	3.2	2.3	3.5	9.5	9.8
2008	5.9	0.4	3.2	3.8	2.3	3.6	9.7	9.8
2009	5.9	0.4	3.2	3.8	2.3	3.6	9.7	9.8
2010	5.9	0.4	3.2	3.8	2.3	3.6	9.7	9.8
2011	5.9	0.4	3.2	3.8	2.3	3.6	9.7	9.8
2012	5.9	0.4	3.2	3.8	2.3	3.6	9.7	9.8
2013	5.9	0.4	3.2	3.8	2.3	3.6	9.7	9.8
2014	5.9	0.4	3.2	3.8	2.3	3.6	9.7	9.8
2015	5.9	0.4	3.2	3.8	2.3	3.6	9.7	9.8
2016	5.9	0.4	3.2	3.8	2.3	3.6	9.7	9.8
2017	5.9	0.4	3.2	3.8	2.3	3.6	9.7	9.8
2018	5.9	0.4	3.2	3.8	2.3	3.6	9.7	9.8
2019	5.9	0.4	3.2	3.8	2.3	3.6	9.7	9.8
2020	5.9	0.4	3.2	3.8	2.3	3.6	9.7	9.8
2021	5.9	0.4	3.2	3.8	2.3	3.6	9.7	9.8
2022	5.9	0.4	3.2	3.8	2.3	3.6	9.7	9.8

Spectacle Pond SP-02A Estimate of PFAS Concentrations

Annual PFAS Concentration (ng/L)

Year	*PFBS*	*PFDA*	*PFHpA*	*PFHxA*	*PFHxS*	*PFNA*	*PFOA*	*PFOS*
2000	1.5	0.4	0.8	2.0	2.3	0.5	3.7	5.8
2001	1.5	0.4	0.8	2.0	2.3	0.5	3.7	5.8
2002	1.5	0.4	0.8	2.0	2.3	0.5	3.7	5.8
2003	1.5	0.4	0.8	2.0	2.3	0.5	3.7	5.8
2004	1.5	0.4	0.8	2.0	2.3	0.5	3.7	5.8
2005	1.5	0.4	0.8	2.0	2.3	0.5	3.7	5.8
2006	1.5	0.4	0.8	2.0	2.3	0.5	3.7	5.8
2007	1.5	0.4	0.8	2.0	2.3	0.5	3.7	5.8
2008	1.9	0.6	10.2	22.5	2.5	1.0	9.0	6.5
2009	1.9	0.6	10.2	22.5	2.5	1.0	9.0	6.5
2010	1.9	0.6	10.2	22.5	2.5	1.0	9.0	6.5
2011	1.9	0.6	10.2	22.5	2.5	1.0	9.0	6.5
2012	1.9	0.6	10.2	22.5	2.5	1.0	9.0	6.5
2013	1.9	0.6	10.2	22.5	2.5	1.0	9.0	6.5
2014	1.9	0.6	10.2	22.5	2.5	1.0	9.0	6.5
2015	1.9	0.6	10.2	22.5	2.5	1.0	9.0	6.5
2016	1.9	0.6	10.2	22.5	2.5	1.0	9.0	6.5
2017	1.9	0.6	10.2	22.5	2.5	1.0	9.0	6.5
2018	1.9	0.6	10.2	22.5	2.5	1.0	9.0	6.5
2019	1.9	0.6	10.2	22.5	2.5	1.0	9.0	6.5
2020	1.9	0.6	10.2	22.5	2.5	1.0	9.0	6.5
2021	1.9	0.6	10.2	22.5	2.5	1.0	9.0	6.5
2022	1.9	0.6	10.2	22.5	2.5	1.0	9.0	6.5

Digital Attachment 1: Previous Study Reports