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Project 1007 Feasibility Study

Evaluating potential remedies to address the spread of per- and polyfluoroalkyl substances (PFAS) in the Twin Cities East Metropolitan Area

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March 2026

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Appendix A: Attached Figures

Additional figures, beyond in-text figures, are referenced in this Feasibility Study and are provided in Appendix A. In-text figures are numbered by the section in which they are located (ex. the third figure referenced in Section 4 would be Figure 4.3), while figures in Appendix A are numbered sequentially throughout the entire document (ex. Figure 4).

Appendix B: Attached Tables

Additional tables, beyond in-text tables, are referenced in this Feasibility Study and are provided in Appendix B. In-text tables are numbered by the section in which they are located (ex. the third table referenced in Section 4 would be Table 4.3), while tables in Appendix B are numbered sequentially throughout the entire document (ex. Table 4).

Acronyms and Abbreviations

µg/kg	micrograms per kilogram
µg/L	micrograms per liter
3M	3M Company
AECOM	AECOM Environmental Services
AGWC	Anna's Grove Wetland Complex
AOC	area of concern
AOF	adsorbable organic fluorine
ARAR	Applicable or Relevant and Appropriate Requirement
BERA	Baseline Ecological Risk Assessment
CAPEX	capital expenditures
CDWSP	Conceptual Drinking Water Supply Plan
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CSM	Conceptual Site Model
EO	electrochemical oxidation
EPA	U.S. Environmental Protection Agency
EPOC	EPOC Enviro
FS	Feasibility Study
GAC	granular activated carbon
gpd	gallons per day
GRA	General Response Action
HALT	hydrothermal alkaline treatment
HBV	Health-Based Value
HFPO-DA (GenX)	hexafluoropropylene oxide-dimer acid
HI	Hazard Index
HRI	Health Risk Index
HRL	Health Risk Limit
IC	institutional control
ITRC	Interstate Technology and Regulatory Council
IX	ion exchange
kW	kilowatts
kWh	kilowatt hours
L/kg	liters per kilogram

MBWA	Multi-Benefit Well Array
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MDH	Minnesota Department of Health
MDNR	Minnesota Department of Natural Resources
MERLA	Minnesota Environmental Responsibility and Liability Act
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MGD	million gallons per day
MGS	Minnesota Geological Survey
MnDOT	Minnesota Department of Transportation
MPCA	Minnesota Pollution Control Agency
NASA	National Aeronautics and Space Administration
NCP	National Contingency Plan
NF	nanofiltration
NFA	No Further Action
ng/L	nanograms per liter
NMLG	Northeast Metro Lakes Groundwater
ODS	Oakdale Disposal Site
O&M	operations and maintenance
OPEX	operating expenditures
PAB	permeable adsorptive barrier
PDC	Prairie du Chien
PFAS	per- and polyfluoroalkyl substances
PFBA	perfluorobutanoic acid
PFBS	perfluorobutanesulfonic acid
PFHxA	perfluorohexanoic acid
PFHxS	perfluorohexanesulfonic acid
PFNA	perfluorononanoic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonate
POETS	point of entry treatment system
ppb	parts per billion
RAO	Remedial Action Objective
RD	Remedial Design

RFP	Request for Proposals
RI	Remedial Investigation
RO	reverse osmosis
ROD	Record of Decision
RSSCT	rapid small-scale column test
SAFF®	Surface Active Foam Fractionation
SCWO	super critical water oxidation
SDWA	Safe Drinking Water Act
SDSV	MPCA Site-Specific Sediment Screening Value
SLERA	Screening-Level Ecological Risk Assessment
SML	surface microlayer
SRV	Soil Reference Value
SSC	Site-Specific Water Quality Criteria
TOC	total organic carbon
TOF	total organic fluoride
TOP	total oxidizable precursor
TRL	Technology Readiness Level
TSS	total suspended solids
UIC	underground injection control
USD	U.S. Dollars
UV	ultraviolet
VAP	vertical aquifer profile
VBWD	Valley Branch Watershed District
VOC	volatile organic compound
WCL	Washington County Landfill

1 Executive Summary

On behalf of the Minnesota Pollution Control Agency (MPCA), AECOM Technical Services Inc. (AECOM) has completed this Feasibility Study (FS) to evaluate potential remedies to address the spread of per- and polyfluoroalkyl substances (PFAS) in the Twin Cities East Metropolitan area (East Metro) from the Valley Branch Watershed District's (VBWD's) Project 1007 conveyance system (Site). This FS has been completed in accordance with Priority 1 of the 2018 Settlement between the State of Minnesota and 3M Company (3M) (Minnesota v. 3M, 2018) (the Settlement), which is to provide safe and sustainable drinking water resources for current and future generations in the PFAS-impacted communities. This was also addressed by the Conceptual Drinking Water Supply Plan (CDWSP) (MPCA, 2021). Priority 1 additionally directed the MPCA to conduct a source assessment and FS regarding the role of the VBWD's project, known as Project 1007, in the conveyance of PFAS in the environment.

Project 1007 is a flood mitigation project constructed in 1987 by the VBWD to reduce flooding risk to homes in the landlocked sub-watershed of the Tri-Lakes area in Lake Elmo, MN (Lake De Montreville, Lake Olson, and Lake Jane). The Project 1007 conveyance system, which consists of a series of open channels, pipes, dams, storm sewers, and existing surface water bodies, functions to direct water from the Tri-Lakes area to the St. Croix River. Project 1007 is hydrologically connected to two known PFAS disposal sites: Oakdale Disposal Site (ODS) and Washington County Landfill (WCL). During the initial source assessment phase of work, PFAS impacts were found to be conveyed by natural and anthropogenic pathways from the historical source areas, including across groundwater regional divides and watershed boundaries, and vertically through six aquifer systems. As a result, the study area for this FS, referred to as the Site, is defined as the region where PFAS from primary and secondary source areas has migrated via the surface water and groundwater migration pathways associated with, and adjacent to, the Project 1007 conveyance system. The study area therefore results in a region bounded by the Mississippi River to the southwest, the St. Croix River to the east, and regional and sub-regional watershed boundaries for the Ramsey-Washington, South Washington, and Valley Branch Watershed Districts.

The source assessment required by the Settlement included a hydrologic and hydrogeologic investigation of the area surrounding the Project 1007 conveyance system. The investigation focused on understanding the diverse system of surface water bodies and groundwater aquifers that are naturally or otherwise connected with the Project 1007 conveyance system. AECOM developed the comprehensive Conceptual Site Model (CSM) included in this document utilizing the results of that investigation, including data sets of PFAS presence and absence, and interactions of the complex hydraulic system.

This FS has been prepared in general accordance with the U.S. Environmental Protection Agency's (EPA's) *Interim Final Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA, 1988), which describes the general procedure for conducting Remedial Investigations (RIs) and FSs under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). As directed by the Settlement, the focus of the remedies proposed in this FS are on the protection of drinking water aquifers; they do not fully address other exposure routes or ecological impacts as the Settlement directed the investigation to prioritize drinking water impacts. Further work, outside the scope of this FS, may be necessary to fully investigate ecological impacts. The following sections are included in this FS:

- CSM: The results of the source assessment were used to describe the known extent and summarize PFAS migration pathways across the Site.
- Areas of Concern (AOCs): The Site was divided into areas based on the location, media type, and PFAS migration pathways to better develop remedial alternatives specific to each AOC.

- Remedial Action Objectives (RAOs): Specific remedial goals for each AOC were developed to select appropriate remedies and will be used after implementation to measure the success of the implemented remedial actions.
- Remedial Technology and Action Screening: PFAS remediation technologies were evaluated to identify those applicable to each AOC.
- Treatability Studies Summary: Bench-scale and field-based pilot-scale studies were completed as part of this FS to evaluate the effectiveness of emerging technologies with Site-specific water. A pilot study with Surface Active Foam Fractionation (SAFF®) showed effective removal and concentration of PFAS from surface water and groundwater. An electrochemical oxidation (EO) pilot study showed destruction of PFAS from the SAFF concentrate. At the bench-scale, super critical water oxidation (SCWO), photochemical reductive defluorination, ultraviolet (UV) photochemical, plasma, and EO were evaluated to determine the PFAS destruction capabilities of the concentrate produced by the SAFF® system. Additionally, a bench-scale sediment leaching study was conducted to determine the extent to which PFAS would leach from sediment if it was not removed from the Site. Finally, bench-scale rapid small-scale column tests (RSSCTs) were conducted to evaluate the PFAS removal performance of granular activated carbon (GAC) and ion exchange (IX) resin using Site-specific water.
- Development of Remedial Alternatives: Eight remedial alternatives were developed for evaluation. These provide a range of remedial alternatives for consideration with varying cost, implementability, and effectiveness to provide a comparison for consideration.
- Detailed Analysis of Alternatives: Each remedial alternative was evaluated against the criteria as described in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), per Title 40 of the Code of Federal Regulations (CFR) Part 300.
- Comparative Analysis of Alternatives: Each remedial alternative was compared against the other alternatives for each of the NCP criteria.
- Selection of Remedial Alternative and Recommended Next Steps: Primary and secondary recommendations are provided with the rationale for their selection. The recommendations focus on approximate areas where treatment should occur to reduce the continued spread and mass of PFAS within drinking water aquifers. Potential PFAS treatment technologies are identified but additional information is needed to address uncertainties in treatment efficiencies with Site-specific water. Next steps towards implementation of the recommended alternatives are listed and include selecting specific treatment technologies and identifying specific locations for treatment.

As a result of the analysis described in this FS, AECOM recommends the remedial actions below to address Site-wide PFAS concerns and provide safe and sustainable drinking water resources for current and future generations. The primary recommended alternative includes the following components:

- **Source zone control** at WCL and ODS to reduce migration of PFAS downgradient via surface water and groundwater is a prerequisite for successful treatment downgradient of these source areas. For WCL, this includes vertical migration into the bedrock aquifers primarily to the east of WCL and the continued migration of impacts in the Quaternary including those that are discharging into Sunfish Lake and Lake Elmo. For ODS, this includes migration in the Quaternary and bedrock aquifers away from the disposal site and the discharge of PFAS via Raleigh Creek surface water. PFAS at ODS is currently being addressed in the Superfund Program, so specific actions to address impacts within the site boundaries of ODS are not included in this FS. The extent to which 3M will address impacts offsite of ODS will be determined through the Superfund Program.

- **Multi-Benefit Well Array (MBWA)** that would provide groundwater plume control to reduce downgradient migration of PFAS into areas with less or no impacts, reductions of PFAS mass within affected aquifers, and quality drinking water supply to communities. Groundwater extraction as part of the MBWA and subsequent treatment would occur in the communities of West Lakeland, Lake Elmo, and Oakdale. Treated water exceeding the drinking water demand for Lake Elmo and Oakdale communities would be injected into the Jordan Aquifer in West Lakeland, Lake Elmo, Oakdale, and Woodbury for additional plume control. Additional communities, such as the Prairie Island Indian Community could be included in the drinking water supply with modifications to the extraction and injection rates.
- **Surface water treatment** with in-stream permeable adsorptive barriers (PABs) to reduce surface water concentrations resulting from sediment leaching, groundwater discharge, or incidental release of PFAS-containing surface water.
- **Sediment access restrictions** to reduce the potential for public exposure to impacted sediments, including those near residential areas.
- **Long-term monitoring** of groundwater and surface water impacts to determine the effectiveness of remedial measures.

Because there are significant hurdles that must be addressed with the MBWA regarding the use of both the City of Lake Elmo's and City of Oakdale's infrastructure, AECOM offers a secondary recommended alternative that focuses on more localized treatment plants with smaller individual costs compared to the larger, multi-community system. This alternative would also include WCL and ODS source zone treatment as prerequisites for downgradient treatment, surface water PABs, and sediment access restrictions as described in the primary recommendation. This alternative would utilize the MBWA to provide plume control within the central area of the Site, located within the City of Lake Elmo, treat impacts resulting from Raleigh Creek and Eagle Point Lake infiltration, and supply drinking water to the City of Lake Elmo. Groundwater impacts resulting from infiltration of PFAS-impacted surface water at the West Lakeland storage ponds would be addressed with a separate, localized pump and treat system. This recommendation assumes that pumping from the City of Oakdale's municipal supply wells continues to provide some level of plume control in the areas surrounding Oakdale. This recommendation calls for additional source zone treatment to be completed at ODS by 3M, but does not propose specific remedial actions for ODS.

Recommendations for PFAS treatment technologies are dependent on the final use of the treated water and the specific PFAS present. Most likely, a treatment train will be employed, which uses a series or train of technologies to separate, concentrate, and destroy PFAS. While treatability studies were conducted as part of this FS, additional treatability studies are recommended to aid in the selection of specific technologies, especially with regards to the high PFAS-containing groundwater at ODS and WCL. If onsite PFAS destruction is preferred, additional studies would be required to select the destruction technology once the technology to separate and concentrate PFAS is selected.

Prior to final remedy selection and subsequent system design and implementation, additional activities are recommended as summarized in the following list:

- Additional investigation at WCL to better understand the extent of PFAS impacts in soils and groundwater that remain after lining the landfill.
- Additional investigation at ODS to understand the extent and migration pathways of PFAS impacts from this disposal site. Specific requests have been made to 3M to add detail to the ODS CSM and additional investigation activities may be required.
- Additional investigation and data analysis is needed to characterize the extent and magnitude of impacts downgradient from known source areas, and the extent to which they are comingling.

This evaluation will support targeting migration pathways with remedial activities in order to maximize PFAS capture and reduce continued migration.

- Treatability studies to evaluate PFAS removal of the high concentrations of perfluorobutanoic acid (PFBA) from groundwater at WCL, to determine IX media changeout rates for the treatment of groundwater in West Lakeland if the secondary recommendation were to be selected, and to compare PFAS destruction technologies if onsite destruction is desired. Treatability studies may also be required as part of improving remedial efforts at ODS and would be completed under the Superfund process.
- Aquifer injection tests to verify the initial injection modeling work completed to date to determine the aquifer injection capacity and assess the potential for geochemical and structural dissolution.
- Modeling by the Minnesota Department of Natural Resources (MDNR) for groundwater elevation impacts of the selected remedy using the MDNR's Northeast Metro Lakes Groundwater (NMLG) model to determine the impact on White Bear Lake.
- Coordination with municipalities and townships to ensure that the remedial alternative is compatible with their systems and community planning.

These actions will help determine the path forward to achieving reductions in the spread of PFAS contamination throughout the East Metro. Remedial action is necessary to substantially improve source control in the two primary source zones and limit PFAS plume expansion. Remedial action will help to protect the drinking water resources, providing safe and sustainable drinking water supplies for impacted communities for current and future generations.

2 Introduction

On behalf of the Minnesota Pollution Control Agency (MPCA), AECOM Technical Services, Inc. (AECOM) has prepared this Feasibility Study (FS) as required in the 2018 Agreement and Order (Settlement) between the State of Minnesota and 3M Company (3M) (Minnesota v. 3M, 2018) with the Commissioners of the MPCA and the Minnesota Department of Natural Resources (MDNR) named as Co-Trustees of the Settlement funds. The Settlement's first priority is to provide safe and sustainable drinking water resources for current and future generations in per- and polyfluoroalkyl substances (PFAS)-impacted communities, which was addressed by the Conceptual Drinking Water Supply Plan (CDWSP) (MPCA, 2021). A component of this first priority directed the MPCA to conduct a source assessment and FS regarding the role of the Valley Branch Watershed District's (VBWD's) project, known as Project 1007, in the conveyance of PFAS in the environment. This FS, in combination with the source assessment, also known as a Remedial Investigation (RI), has been conducted to fulfill this requirement of the Settlement. The Settlement's second priority, which is not addressed in this FS, is to enhance aquatic resources, wildlife habitat, and outdoor recreational opportunities.

The current geographic extent of the PFAS plumes in the East Metro is over 120 square miles. These PFAS impacts have likely been conveyed by natural and anthropogenic pathways from the historical source areas, across groundwater regional divides and watershed boundaries, and vertically through multiple aquifer systems. Ultimately, the PFAS impacts have traveled from source areas to impact many communities in the East Metro, including those listed below (MPCA, 2025):

- Baytown
- Oakdale
- Maplewood
- Lake Elmo
- West Lakeland
- Prairie Island Indian Community
- Afton
- Lakeland
- Lakeland Shores
- Woodbury
- Cottage Grove
- Newport
- Grey Cloud Island Township
- Denmark Township
- St. Paul Park
- Hastings

A subset of this total area, shown in **Figure 1**, was investigated to determine how Project 1007 contributed to the migration of PFAS from two known former disposal sites located near Project 1007: Oakdale Disposal Site (ODS) and Washington County Landfill (WCL). Project 1007 is a flood mitigation project constructed in 1987 by the VBWD to prevent homes from flooding in the landlocked sub-watershed of the Tri-Lakes area in Lake Elmo, MN, which includes Lake De Montreville, Lake Olson, and

Lake Jane. The Project 1007 conveyance system, which consists of a series of open channels, pipes, dams, storm sewers, and existing surface water bodies, functions to direct water from the Tri-Lakes area to the St. Croix River. For the purposes of this FS, the Site is hydrogeologically defined as the region for which PFAS has migrated from primary and secondary source areas via surface water and groundwater migration pathways associated with, and adjacent to, the Project 1007 conveyance system. Secondary source areas are areas outside of the main disposal site where PFAS has accumulated and would continue to release PFAS even if the primary source areas were addressed. As a result, the study area comprises a region bound by the Mississippi River to the southwest, the St. Croix River to the east, and regional and sub-regional watershed boundaries for the Ramsey-Washington, South Washington, and Valley Branch Watershed Districts.

2.1 Historical Timeline of Events

Historical events beginning over 70 years ago played an integral part in the evaluation and understanding of Project 1007's role in the conveyance of PFAS in the East Metro. **Figure 2.1** provides a summary of key dates for historical events, data, and reports related to the FS.

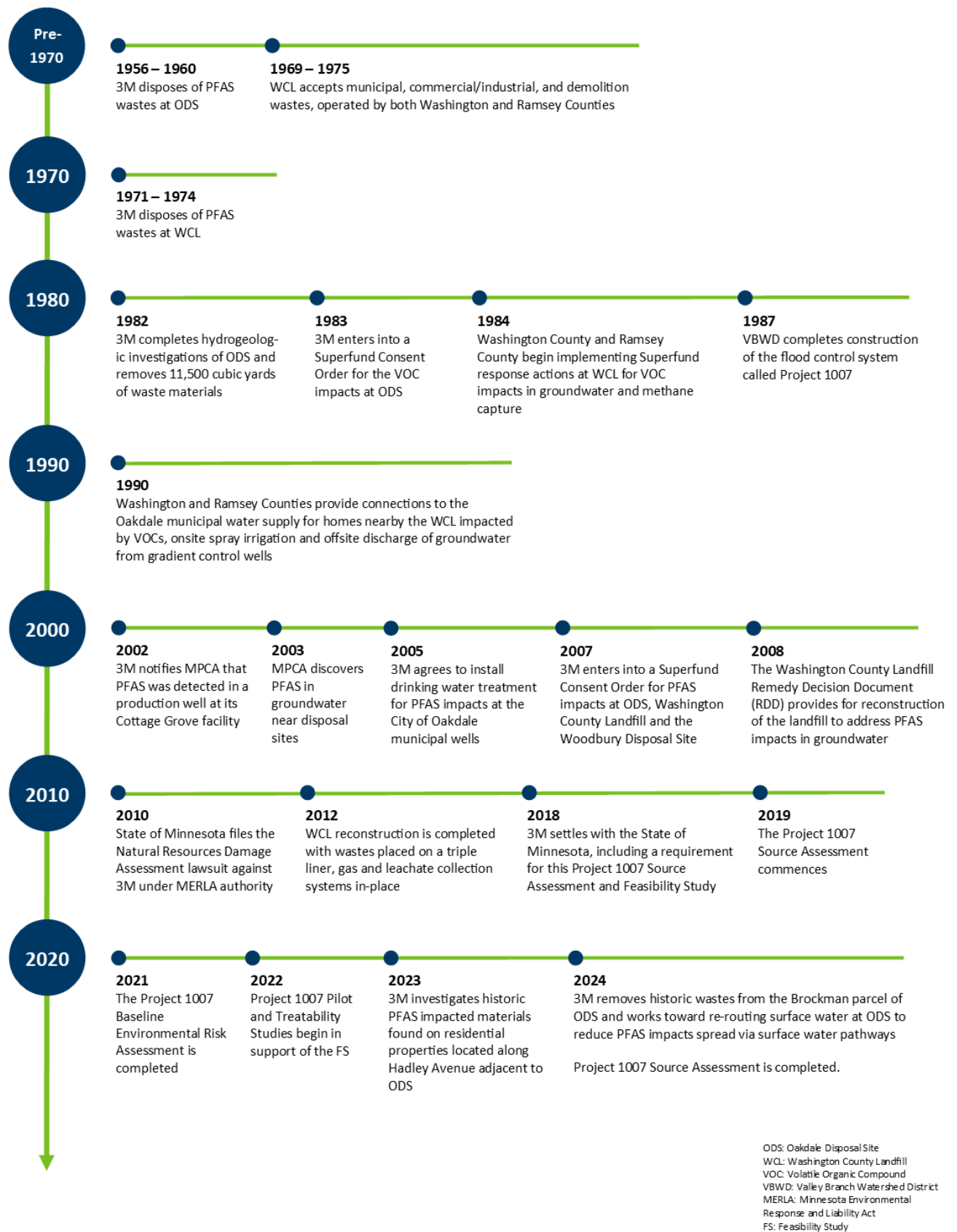


Figure 2.1: Historical timeline of key events related to the spread of PFAS in the East Metro (1950s to present day)

2.2 Purpose of Feasibility Study

The FS and RI have been prepared in general accordance with the U.S. Environmental Protection Agency's (EPA's) *Interim Final Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*, which describes the general procedure for conducting RIs and FSs under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund (EPA, 1988). While the Settlement refers to a source assessment, RI is used in this document to be consistent with nomenclature used by CERCLA. The overall process to address impacted sites identified by CERCLA, shown in **Figure 2.2**, is meant to standardize the way impacted sites are addressed.

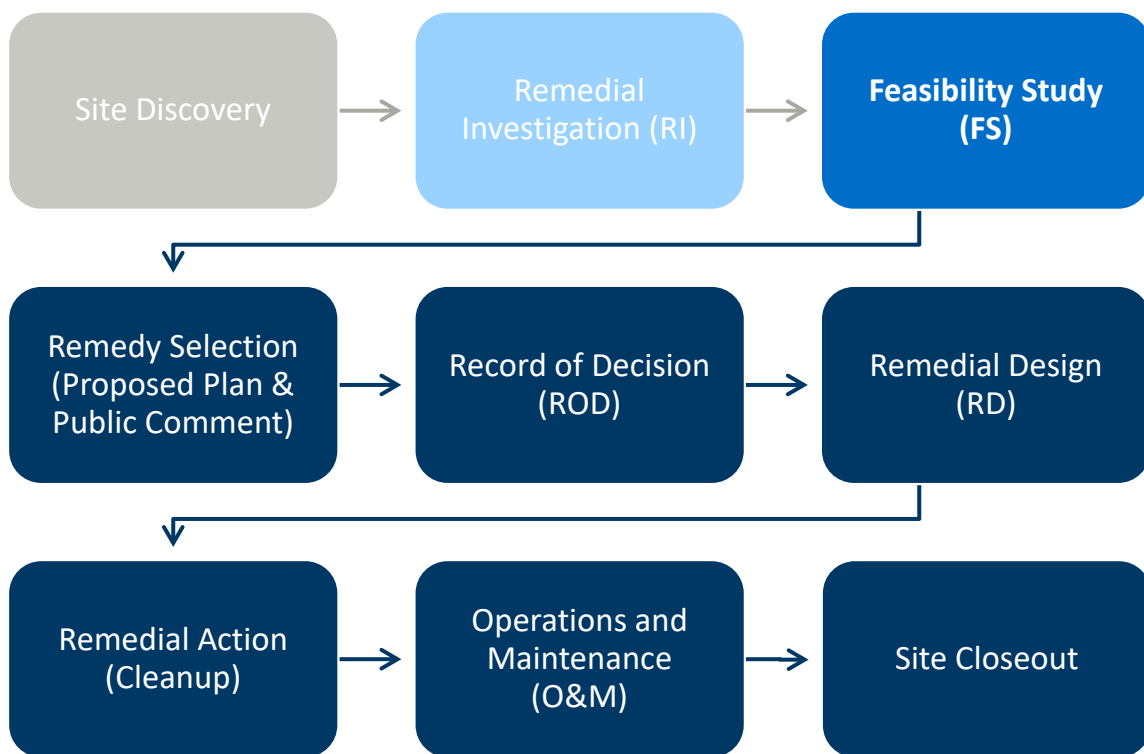


Figure 2.2: CERCLA process to address impacted sites; dark blue squares indicate future work

The Settlement-required RI included an extensive hydrologic and hydrogeologic investigation of the Project 1007 conveyance system, which incorporates the hydraulically diverse system of surface water bodies and groundwater aquifers that are adjacent to and hydraulically connected with Project 1007. The RI was intended to do the following:

- Assess how the Project 1007 conveyance system interacts with the hydraulically complex surface water and groundwater system in the area.
- Assess how the Project 1007 conveyance system contributes to the movement of PFAS from both primary historical source areas, namely ODS and WCL.
- Assess the movement of PFAS through preferential flow paths to areas downstream and/or downgradient of source areas.

The primary objective of this FS under the Settlement is to ensure that appropriate remedial alternatives are developed and evaluated to address unacceptable human health risks that were identified during the RI. This FS is intended to support previous Settlement-related initiatives, including the completion of the CDWSP and the development of long-term Priority 1 goals. Implementing remedial actions that are

developed and evaluated as part of the FS will directly contribute to achieving Settlement requirements and long-term program goals developed in the CDWSP, including:

- Provide safe drinking water to residents and businesses to meet current and future needs under changing conditions, population, and EPA Maximum Contaminant Levels (MCLs), EPA Maximum Contaminant Level Goals (MCLGs), EPA Hazard Index (HI), Minnesota Department of Health (MDH) Health-Based Values (HBVs), Health Risk Limits (HRLs), and MDH Health Risk Indices (HRIs)
- Protect and improve groundwater quality
- Protect and maintain groundwater quantity
- Minimize long-term cost burdens for affected communities

To achieve these goals, this FS provides information for decision makers to aid in selecting an appropriate remedy for the Site and provides a recommendation of a path forward to address the PFAS impacts. It is not intended to be a final decision or a design of a remedial system. This FS identifies potential remediation technologies, screens the remedial technologies for applicability at the Site, uses retained technologies to develop detailed alternatives, and provides a detailed analysis of these alternatives for each of the areas of concern (AOCs) that have been identified at the Site. Remedial Action Objectives (RAOs) were developed in consultation with the MPCA to focus on the reduction of PFAS mass in drinking water aquifers, migration of PFAS in the East Metro, and prevention of exposure to contamination through engineering or institutional controls (ICs). The conceptual remedial approaches were developed to provide initial cost estimates but are expected to be modified as the project progresses.

The criteria used to evaluate the identified remedial approaches are in accordance with the threshold, balancing, and modifying FS criteria in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), Title 40 of the Code of Federal Regulations (CFR) Part 300. Deviations from these criteria are detailed in this report and largely result from the purpose of this FS as directed by the Settlement. This FS focuses on the protection of drinking water aquifers for current and future use. As a result, ecological impacts and human exposure pathways other than drinking water are noted but largely not considered when evaluating remedial alternatives. Additional work, outside the scope of this FS, may be necessary to fully investigate ecological impacts and address other human exposure pathways such as recreation and fish consumption.

3 Site Background

Per- and polyfluoroalkyl substances (PFAS) are man-made chemicals known to persist in the environment for long periods. From the early 1950s through to present day, the 3M Company (3M) facility in Cottage Grove, MN, has produced industrial and commercial products containing PFAS compounds. Both liquid and solid wastes generated from the PFAS production processes were disposed of at two historical disposal locations, Oakdale Disposal Site (ODS) and Washington County Landfill (WCL), located within the Project 1007 Corridor. Both disposal sites have known current and historical connections to surface water and groundwater within the Project 1007 Corridor that are hydraulically and/or hydrogeologically connected, collectively referred to as the Site (**Figure 1**). Surface water and groundwater interactions have been shown to play a key role in the migration of PFAS-impacted water as it moves through the Project 1007 Corridor, infiltrating into the subsurface and then migrating horizontally and vertically through both surficial and deep bedrock aquifers. Additional migration pathways include the re-emergence of PFAS-impacted groundwater into surface water and potential leaching of PFAS from impacted sediments. PFAS impacts are widespread in areas surrounding ODS, WCL, and throughout the Project 1007 Corridor and are present in several media types, multiple watersheds, across groundwater divides, and across drinking water supply aquifers (MPCA, 2023b).

3.1 Construction of Project 1007

The Project 1007 conveyance system and connected surface water bodies are located in the Twin Cities' East Metro and are shown in **Figure 2**. The Project 1007 conveyance system is a major flood relief project constructed in 1987 by the Valley Branch Watershed District (VBWD) to prevent homes from flooding in the landlocked sub-watershed of the Tri-Lakes area in Lake Elmo, MN, which includes Lake De Montreville, Lake Olson, and Lake Jane. The Project 1007 conveyance system, which consists of a series of open channels, pipes, dams, storm sewers, and existing surface water bodies, functions to direct water from the Tri-Lakes area to the St. Croix River. Specifically, the Project 1007 conveyance system carries water discharged from the Tri-Lakes to the convergence with Raleigh Creek at Tablyn Park and then through Raleigh Creek into Eagle Point Lake. Under normal flow conditions, water exiting Eagle Point Lake flows through a 22-inch diversion pipe that runs along the lakebed of Lake Elmo and discharges east of Lake Elmo. Water discharging Eagle Point Lake combines with Lake Elmo outflow water and then continues eastward towards and into Horseshoe Lake. Surface water is discharged from Horseshoe Lake through a series of pipes and channels towards the West Lakeland Ponds. Flow in the West Lakeland Ponds and the connecting channels then drains to the south where it begins being piped to the east along the Minnesota Department of Transportation (MnDOT) Interstate 94 storm sewer system towards the St. Croix River.

The sections that follow discuss the construction of the Project 1007 conveyance system and the resulting changes in surface water flow paths from specific surface water features and source areas.

3.2 Oakdale Disposal Site

ODS accepted a variety of identified and unidentified industrial wastes from the late 1940s until the 1960s. While in operation, the footprint of ODS consisted of three disposal areas, Eberle (approximately 2 acres), Brockman (approximately 5 acres), and Abresch (approximately 55 acres). From 1956 until 1960, the three areas received PFAS-containing wastes, with the Abresch area receiving the majority of the waste. The Abresch Area is further subdivided into four areas of focus, as presented in **Figure 3**: the North Area, the Central Area, the Isthmus Area, and the Southeast Area. The North Area consists of the portion of the Site north of County Highway 14. The Central Area is bordered to the north by County Highway 14, to the east and southwest by wetlands, and to the west by Granada Avenue North. The Isthmus Area is the narrow strip of land, approximately 100 to 300 feet wide and bordered to the east and west by wetlands, that connects the Central Area to the Southeast Area. The Southeast Area is bordered to the northeast by wetlands, to the east by Hadley Avenue North, to the south by wetlands and the railroad, and to the west by wetlands. Raleigh Creek runs approximately from the North Area, southward through the Central Area, then along the eastern edge of the Isthmus Area, before exiting Abresch from the Isthmus Area eastwards towards Hadley Avenue North.

Waste disposal methods included but were not limited to shallow burial of loose waste; trench burial of PFAS waste-containing drums, pails, and barrels; and open burning. In the 1980s, following the detection of volatile organic compound (VOC)-impacted shallow groundwater, portions of the disposal areas were excavated, contaminated bulk solids were transported offsite for incineration, and 39 multi-aquifer wells were sealed (ATSDR, 2008). Excavated contaminated soils were aerated onsite for the removal of VOCs and then land-spread across Abresch. Additionally, approximately 1,000 tons of ash from the incineration of the removed bulk solid waste were land-spread across Abresch. In 1985, a 12-well pump-out system was installed at Abresch to provide vertical gradient control (Barr, 2022).

In 2004, the Minnesota Pollution Control Agency (MPCA) and Minnesota Department of Health (MDH) discovered that PFAS-containing wastes were disposed of at ODS, resulting in a request that 3M sample the discharge water from the groundwater treatment system. The results of that sampling, which confirmed the presence of PFAS in the groundwater at Abresch, led to a broader effort to characterize

the extent of the PFAS contamination in surface water, groundwater, and soil at Abresch. On May 22, 2007, 3M entered into a Settlement Agreement and Consent Order with the MPCA to conduct further Remedial Investigation (RI) and response actions to address PFAS impacts. In 2008, as part of a remedial action response, the pump-out system was expanded to 24 wells, and the extracted water was treated with granular activated carbon (GAC) prior to discharge to the Metropolitan Council Environmental Services sewer system. Additionally, approximately 28,000 cubic yards of soil were excavated and disposed of offsite in 2010 and 2011. The soil selected for removal, which was limited to the North Area, included all soils down to 4 feet below ground surface with perfluorooctane sulfonate (PFOS) concentrations greater than 1 milligram per kilogram (mg/kg) and select soils down to 4 feet above the water table with PFOS concentrations greater than 6 mg/kg (Barr, 2022). **Figure 3** depicts the extent of the soil excavation conducted in the 1980s and the 2000s along with the approximate locations of land-spreading activities.

In 2010, a new groundwater treatment facility was constructed and connected to the expanded pump out well network. Since 2011, annual Site-wide groundwater and surface water sampling activities have been conducted at locations on and surrounding Abresch. In 2020 and 2021, 3M completed additional investigative activities, including the installation of additional groundwater monitoring wells, surface water and sediment sampling, characterization of surface water flow and surface water to groundwater interaction, and geologic and hydrogeologic modeling in the uppermost groundwater aquifers.

Prior to implementation of the remedial activities between the 1980s and 2008, PFAS-containing materials related to historical disposal had been in direct contact with the soil and sediment in excess of 50 years. Further, by the start of PFAS-related remedial activities in 2008, PFAS impacts were documented as having already migrated beyond the Abresch boundaries towards the south and southwest vertically into deep bedrock aquifers used for drinking water. Additionally, although the intent of the groundwater extraction remedial activities was to limit the offsite migration of PFAS impacts, a review of analytical and hydrogeologic data indicates a number of PFAS migration pathways remain. First, Raleigh Creek continues to intermittently flow through Abresch, exiting at Hadley Avenue and flowing eastward towards the Project 1007 conveyance system. Surface water PFAS analytical data from 2006 to the present indicate that this surface water flow path is both a current and historical surface water PFAS migration pathway as well as an additional pathway to groundwater impacts via surface water to groundwater infiltration. The data also reveal that existing shallow groundwater impacts continue to have offsite migration pathways. While the expansion of the pump-out system in 2012 limited vertical migration by maintaining upward gradients between the Platteville Formation and the lower alluvium at portions of Abresch, a downward gradient between the aquifers remains in wells located within the Southeast Area and in wells southwest of Abresch (Barr, 2022). Further, the existing pump-out system provides no hydraulic capture of PFAS-impacted groundwater in deeper bedrock aquifers.

3.3 Washington County Landfill

From 1971 to 1974, WCL accepted PFAS-containing waste from 3M, including wastewater treatment plant sludge, incinerator scrubber sludge and ash, and iron oxide sludge. The landfill was closed in 1975, and a clean soil cap was placed on the landfill. In 1981, VOCs and some heavy metals were detected in groundwater monitoring wells located onsite and in nearby offsite domestic wells, resulting in the installation of an onsite groundwater extraction and remediation system in 1983. The treatment system operated by pumping and then spraying the VOC-contaminated groundwater onto the surface of the landfill to evaporate the VOCs. This sprayed water infiltrating back into the ground created a mounding effect in the water table underneath the landfill, which may have influenced groundwater flow conditions and allowed the migration of PFAS-impacted water in all directions, in particular to the east. In 1987, for the purpose of gradient control, WCL began directly discharging untreated groundwater into Project 1007 via a stormwater sewer connection. As a result, PFAS-impacted waters from WCL were

discharged to the Project 1007 conveyance system until the piped connection was sealed off in 1995 (ATSDR, 2008). **Figure 4** depicts the configuration of WCL and the historical piped connection with Project 1007.

In 2004, the MPCA and MDH discovered that PFAS-containing wastes were disposed of at WCL, triggering the sampling of surface water, groundwater, surface sediment, and soils. In response to the detection of elevated PFAS concentrations in all sampled media, the use of the spray irrigator was terminated, and extracted groundwater was discharged further south into an area of more permeable soil as an interim step. The movement of the discharge location reduced the mounding of the water table, allowing groundwater to return to normal flow conditions (MPCA, 2008). In 2009, the landfill was reconstructed with a triple-liner and a leachate collection system. Contaminated waste was removed prior to the triple-liner installation and then re-placed in the newly lined portion of the landfill, effectively containing the PFAS-containing waste onsite and preventing infiltration of PFAS-impacted waters into the groundwater (URS, 2013).

Although the landfill is now lined and there is no direct connection between PFAS-containing waste in the landfill and groundwater or surface water, PFAS-impacted shallow groundwater and potentially PFAS-impact soil remain in the subsurface below the former landfill footprint and continues to migrate southeast and east towards Sunfish Lake and Lake Elmo, both of which are groundwater-fed surface water bodies. Additionally, the presence of PFAS impacts in deeper aquifers south and southeast of WCL suggests the impacted shallow groundwater had already migrated vertically into the bedrock aquifers prior to landfill reconstruction.

3.4 Surface Water Features

Surface water features affected by Project 1007 are identified and described in this section.

3.4.1 Tri-Lakes

The Project 1007 flood relief project and the Project 1007 conveyance system provide a continuous hydrologic connection from the northwest to southeast through the Site by connecting the Tri-Lakes to Raleigh Creek then conveying water to Eagle Point Lake, under Lake Elmo, then connecting to Horseshoe Lake, the West Lakeland storage ponds, and through storm sewers to the St. Croix River. The portion of the Project 1007 Corridor connecting the Tri-Lakes discharge to Raleigh Creek via the Project 1007 conveyance system, referred to as the Tri-Lakes discharge, is then piped southward until the confluence with Raleigh Creek at Tablyn Park. As previously mentioned, between 1988 and 1995, groundwater extracted by a gradient control well at WCL was directly discharged to the Project 1007 conveyance system. Currently, no surface water connection remains between WCL and the Project 1007 conveyance system.

3.4.2 Sunfish Lake

Sunfish Lake, which is located southeast of WCL, is a groundwater-fed, landlocked lake. Similar to other water bodies within the Project 1007 Corridor, Sunfish Lake is an inferred flow-through lake, with groundwater discharging to the lake on the north side, flowing through the lake as surface water, and infiltrating from the lake back to the subsurface on the south side. Although Sunfish Lake does not have a direct surface connection to the Project 1007 conveyance system, shallow groundwater that discharges to the lake on the north side is downgradient of WCL. Surface water exits Sunfish Lake via surface water infiltration into the subsurface where shallow groundwater then flows to the south before discharging into Lake Elmo. **Figure 5** shows the surface water/groundwater interactions between WCL, Sunfish Lake, and Lake Elmo.

3.4.3 Raleigh Creek

Raleigh Creek is an intermittent stream that runs roughly west to east from ODS to Eagle Point Lake. After flowing through ODS, Raleigh Creek continues eastward through a series of ponded and stream channel-connected wetland areas where interaction with groundwater provides baseflow that typically results in perennial flow except during the winter months and drought conditions. The wetland areas play a key role in surface water interactions with groundwater and near-surface sediments.

Moving west to east, Raleigh Creek first drains to the Menards Wetland Complex, a channelized wetland complex immediately east of ODS and just north of Menards. Continuing east, Raleigh Creek flows under Interstate 694 and then through a second wetland channelized complex south of LA Fitness, referred to as the Fitness Wetland Complex, and then through a third channelized wetland complex south of Pinz, referred to as the Pinz Wetland Complex. These three wetland complexes, which are directly connected to each other and are referred to as the Upper Raleigh Creek Wetland Complexes, are likely groundwater-fed during periods of low flow and sources of surface water infiltration during periods of high flow.

Downstream of the Pinz Wetland Complex, Raleigh Creek continues south-southeast through incised channels before draining into a fourth ponded wetland complex located immediately east of Ideal Avenue in the Anna's Grove neighborhood, referred to as the Anna's Grove Wetland Complex (AGWC). This ponded wetland complex comprises an inlet channel, two ponds, and an outlet channel and is bordered by residential properties to the west, north, and south. Prior to the development of these residential properties in the 1990s, water storage and ponding within AGWC was generally confined to the southwest portion of the wetland complex. In the early 2000s, during the reconstruction of Ideal Avenue, a culvert/flood control structure was installed at the outlet of AGWC above the wetland elevation that resulted in an increase in water storage within AGWC and also reduced downstream flooding. The residential development along this portion of Raleigh Creek, in conjunction with the construction of the flood control structures, appears to have increased water storage in the wetland complex, allowing for the creation of two ponds that regularly hold water. This increase in water storage that occurs in AGWC during wet conditions is likely to facilitate increased infiltration from these ponds.

Downstream of Ideal Avenue, flow in Raleigh Creek from Ideal Avenue to Tablyn Park is generally absent of groundwater baseflow and can be classified as an ephemeral creek that typically only contains flow following spring snow melt and precipitation events. At Tablyn Park, discharge from the Project 1007 conveyance system flows into Raleigh Creek, resulting in generally continuous flow except during winter months and drought periods. Downstream of Tablyn Park, Raleigh Creek continues to the southeast towards the Lake Elmo Park Reserve before draining to the northwestern inlet to Eagle Point Lake.

Figure 6 depicts the Tri-Lakes discharge, Raleigh Creek, and the key current and historical hydrologic features of each water body. **Figure 7** shows the four wetland complexes.

3.4.4 Eagle Point Lake

The primary surface water input to Eagle Point Lake is Raleigh Creek downstream of Tablyn Park, where the creek includes the combined flow of the Tri-Lakes discharge and Raleigh Creek and contains perennial flow except under extreme drought conditions. Other inputs to Eagle Point Lake include Farney Creek and Goose Lake. Farney Creek, which flows west to east and drains to the northwest inlet of Eagle Point Lake downstream of a constructed dam, is dependent on precipitation and, as a result, is regularly dry. During periods of high surface water elevations, Goose Lake is pumped into Eagle Point Lake at the southeastern corner of the lake to mitigate flooding from Goose Lake onto 10th Street North, which crosses through the northern portion of Goose Lake. Neither of these water bodies have a connection to Eagle Point Lake during normal or dry conditions.

Eagle Point Lake has been inferred to be a flow-through lake, with groundwater discharging to the lake on the north and west sides (i.e., up-gradient of the lake), flowing through the lake as surface water, and

infiltrating from the lake back to the subsurface on the south and east sides (i.e., down-gradient of the lake). The exact nature of groundwater discharge to Eagle Point Lake, including the volume of the groundwater discharge and the contributing aquifers, is not fully understood. The edges, inlet, and outlet of Eagle Point Lake can all be characterized as predominantly shallow wetlands.

Surface water from Eagle Point Lake exits through a series of channels and small ponds eastward to the Eagle Point Lake Dam, located on the eastern side of the lake, where a 22-inch pipe diverts outflow from the lake along the bottom of Lake Elmo before discharging into a channel immediately east of Lake Elmo Avenue N and south of 20th Street N. This drainage pathway was constructed as part of Project 1007 to improve water quality and reduce flooding of Lake Elmo. When water levels in Eagle Point Lake exceed an elevation of 896.5 feet, water will flow through a secondary outlet structure that discharges directly into Lake Elmo. Prior to the construction of the Project 1007 conveyance system, Eagle Point Lake drained directly to Lake Elmo. **Figure 8** shows the hydrologic flow paths and relevant Project 1007 infrastructure associated with Eagle Point Lake.

3.4.5 Lake Elmo

The only direct surface water input to Lake Elmo occurs during high flow conditions when water from Eagle Point Lake flows through a secondary outlet structure at the Eagle Point Lake Dam. Like Eagle Point Lake, Lake Elmo is considered to be a flow-through lake where groundwater discharges to the lake, and surface water infiltration from the lake to the subsurface, both occur. Aside from general overland flow, all other inputs to Lake Elmo are the result of groundwater discharge. The first source of groundwater discharge originates from Sunfish Lake, which is located upstream of Lake Elmo and is likely connected to Lake Elmo through shallow subsurface groundwater infiltration from Sunfish Lake and subsequent shallow groundwater discharge to Lake Elmo. The second source of groundwater discharge to Lake Elmo is a buried bedrock valley, where there is a potentially significant hydraulic connection between the lake and deeper aquifers. Although the exact nature of the groundwater discharge to Lake Elmo is not fully understood, a recorded nearly constant outflow from Lake Elmo during extreme drought conditions in 1987 and 1988 is an indicator that groundwater discharge to the lake is occurring. Conversely, the combination of high conductivity of the surficial sediments, an absent bedrock aquitard, and the fractured bedrock zone underlying and adjacent to the bedrock valley likely allow for direct surface water infiltration from the lake into deeper bedrock aquifers.

Surface water exiting Lake Elmo drains via an outflow pipe, which discharges into a channel immediately east of Lake Elmo Avenue N alongside the 22-inch pipe discharge from Eagle Point Lake. The combined discharges then flow east-southeast through a series of channels, pipes, and small ponds before draining to Horseshoe Lake.

3.4.6 Horseshoe Lake

Prior to the construction of Project 1007, Horseshoe Lake received much less surface water, and based on historical imagery, the lobes appeared regularly as disconnected water bodies during dry conditions. Since the completion of Project 1007, the lake holds water year-round, and outflow from the lake is continuous. The sole surface water input to Horseshoe Lake is the combined outflow of Eagle Point Lake and Lake Elmo. Surface water is discharged from Horseshoe Lake through a control structure installed to redirect flow exiting the lake at the northeastern lobe and then through a series of pipes and channels towards the West Lakeland Ponds and connecting channels. Additionally, a shallow bedrock valley branch is mapped as underlying Horseshoe Lake. As with Lake Elmo, this buried bedrock valley could facilitate a direct connection between Horseshoe Lake and deeper aquifers via surface water infiltration. The occurrence and nature of surface infiltration from the lake is not fully understood.

3.4.7 West Lakeland Ponds

The West Lakeland Ponds refers to three ponds located in West Lakeland Township, herein referred to as North Pond, Middle Pond, and South Pond. Historical aerial imagery and VBWD records from before the completion of Project 1007 indicate these ponds were regularly dry with the exception of North Pond, which was historically a gravel pit. As part of the construction of Project 1007 in 1987, water from Eagle Point Lake, Lake Elmo, and Horseshoe Lake was directed via a series of pipes and channels to the West Lakeland Ponds, resulting in nearly continuous flow to and between the ponds except during winter months and periods of extreme drought. Additionally, the outlet from North Pond was deepened and widened, and channels were constructed between the ponds as part of the larger effort to control the inflow of runoff from Project 1007 and mitigate flooding risks in the area. According to a 1985 seepage study, the total seepage rate of the three ponds was measured as between 3.5 and 5 cubic feet per second (VBWD, 2015). Additionally, sinkholes have been reported by residents along the channel between the North and Middle Ponds. The majority of sediment from surface runoff and erosion occurs in North Pond, reducing the infiltration capacity of that pond while preserving the infiltration capacity of the Middle and South Ponds. The high seepage rate of the ponds and the occurrence of sinkholes in their corresponding channels points to significant and rapid surface water infiltration to the subsurface.

Currently, surface water flows north to south through the ponds and connecting channels before being piped eastward towards the St. Croix River via a connection of the outlet from South Pond to the MnDOT Interstate 94 sewer system. Prior to Project 1007 construction, surface water in the West Lakeland Pond area flowed southward through a series of wetlands and streams, which drained to Lake Edith and the Valley Branch Creek System. **Figure 9** shows the hydrologic flow paths and relevant Project 1007 infrastructure associated with Horseshoe Lake and the West Lakeland Ponds.

3.5 Hydrogeologic Features

A series of geological maps and cross-sections produced by the Minnesota Geological Survey (MGS) indicate that the geology of the Twin Cities area consists of Precambrian basement rock situated below Cambrian and Ordovician stratigraphy that is subsequently overlain by unconsolidated Quaternary glacial sediments (MGS, 2016). The MGS identifies multiple geologic units as listed in **Table 3.1**, from youngest to oldest in descending order.

Table 3.1: Twin Cities Area Geologic Units

Symbol	System	Lithostratigraphic Unit	
Quat	Quaternary	Undifferentiated Units	
Od	Ordovician	Galena Group	Decorah Shale (aquitard)
Opvl		Platteville & Glenwood Formations	Platteville Limestone (aquifer)
Ogwd			Glenwood Shale (aquitard)
Os		St. Peter Sandstone	Upper St. Peter Sandstone, Tonti Member (aquifer)
			Lower St. Peter Sandstone, Pigs Eye Member (aquitard)
Ops		Prairie du Chien Group	Shakopee Dolostone with Sand (aquifer)
Opo	Oneota Dolostone (generally a vertical aquitard)		
Cj	Cambrian	Jordan Sandstone (aquifer)	
Cs		St. Lawrence Shale (aquitard)	
Ctc		Tunnel City Group (aquifer)	
Cw		Wonewoc Sandstone (aquifer)	
Ce		Eau Claire Shale (aquitard)	
Cm		Mt. Simon Sandstone (aquifer)	

The Site is underlain by unconsolidated Quaternary-aged glacial and alluvial deposits of varying thickness and lithologies. Groundwater flow within the surficial sediments generally follows surface topography in an eastward direction. As previously mentioned, Lake Elmo is situated within a buried bedrock valley, which is mapped as running roughly north to south through the center of the Site with depths up to 400 feet. The bedrock valley is a narrow, deeply incised paleochannel comprising deeply eroded bedrock units filled in with glacial and alluvial sediments. An additional shallow bedrock valley branch is mapped as extending from the deeper bedrock valley at the southeastern edge of Lake Elmo toward Horseshoe Lake and then southward toward the West Lakeland Ponds. Both valleys play a key role in the surface and groundwater migration pathways as they expose deeper bedrock aquifers to surficial sediments and surface water bodies. **Figure 12** shows the mapped extents of first encountered bedrock units within the Project 1007 Corridor, and **Figure 13** shows the approximate extents of the mapped bedrock valleys.

The shallow-most bedrock formation, the Decorah Shale, functions as an aquitard and is intermittently present, predominantly as erosional remnants in the western portion of the Site. The northern portion of ODS is underlain by the Decorah Aquitard, inhibiting vertical groundwater movement from the Quaternary aquifer(s). Once the Decorah Aquitard vertically pinches out, the Quaternary units are hydrogeologically connected to the Platteville Limestone Aquifer. Continuing west to east, the Platteville Aquifer is present throughout the western portion of the Site until the unit thins and pinches out roughly between Interstate 694 and Inwood Ave. East of this pinch out, the formation is only intermittently present as erosional remnants. Based on available groundwater gauging data, groundwater flow within the Platteville Aquifer is dictated by the presence of a regional groundwater divide running north to south roughly along the western edge of ODS. West of this divide, groundwater flows to the south-southwest, while east of the divide, it flows to the east. The Glenwood Shale Aquitard, which always underlies the Platteville Aquifer, acts as a barrier to vertical groundwater movement from shallow aquifers to underlying aquifers. As a result, groundwater east of the groundwater divide flows horizontally until the Platteville-Glenwood Formations pinch out and vertical flow downward to the underlying St. Peter Sandstone Aquifer is uninhibited.

The St. Peter Sandstone is subdivided into two members, the upper Tonti Member and the lower Pigs Eye Member. The Tonti Member behaves as an aquifer. The Pigs Eye Member, which is the lowermost 10 to 40 feet, is finer-grained and less permeable than the Tonti Member, and as result, is thought to behave like an aquitard. However, leakage can occur through the Pigs Eye Member due to the presence of small fractures and secondary porosity. Additionally, the function of the Pigs Eye Member as an aquitard is not consistent due to variation in lithology and proximity to the top of the bedrock surface, where increased fracturing is expected. A groundwater divide within the St. Peter Aquifer runs roughly north to south along Ideal Avenue, resulting in horizontal groundwater flow west of the divide to the south-southwest and groundwater flow east of the divide to the east-southeast. Per available groundwater gauging data from the Minnesota Well Index and monitoring wells, the potentiometric peak in the St. Peter Aquifer occurs immediately below the eastern edge of the Platteville Aquifer. According to the MGS, the pinch out of the Platteville Aquifer and underlying Glenwood Aquitard may result in a cascade of groundwater to flow downward into the St. Peter Aquifer, resulting in the observed potentiometric peak in this location. This secondary input of groundwater to the St. Peter Aquifer elevates the water table enough so that groundwater flow at this location is to the south-southeast, despite the relative dip of the geologic unit being to the west. Continuing westward along the Project 1007 Corridor, the St. Peter Sandstone begins to pinch out in and around Eagle Point Lake, after which the unit is present intermittently and predominantly as erosional remnants. Thicker occurrences of the St. Peter Sandstone are present northeast and south of the Project 1007 Corridor.

Underlying the St. Peter Sandstone is the Prairie du Chien (PDC) Group. This group consists of the Shakopee Dolostone, which is considered an aquifer, and the lower Oneota Dolostone, which is

considered a vertical aquitard. The Oneota Aquitard can be heavily fractured and “leaky.” The extent to which the Oneota Aquitard functions as a barrier to the underlying Jordan Sandstone Aquifer is not well understood. Where the PDC Group is the first encountered bedrock, predominantly east of Eagle Point Lake, increased fracturing and transmissivity is expected in the Shakopee Aquifer. Where the Shakopee Aquifer is absent, the Oneota Aquitard is the first encountered bedrock and is expected to have enhanced fracturing. The absence of the Shakopee Aquifer is most prevalent along the shallow bedrock valley branch extending southeast towards Horseshoe Lake.

Underlying the Oneota Aquitard is the Jordan Sandstone, which is considered an aquifer. The Jordan Aquifer is present across the entire Site except east of the Cottage Grove Fault, which runs approximately northeast to southwest near the eastern edge of the Site. The Jordan Sandstone formation is the first encountered bedrock along the center of the deeper bedrock valley and in limited areas around the Cottage Grove Fault. The lowermost 20 feet of the Jordan Sandstone is described as grading into a very fine-grained sandstone with lenses of siltstone and shale, resulting in lower permeability and possible retardation of vertical flow.

Groundwater flow within the PDC Group and the Jordan Aquifer is defined by a regional groundwater divide running roughly north to south just west of Eagle Point Lake. West of the divide, groundwater flows to the south-southwest, and east of the divide, it flows east-southeast. Per available gauging data, groundwater within the Jordan Aquifer east of Lake Elmo appears to have a predominantly eastern flow direction. Additionally, because of the use of the Jordan Aquifer as a source of municipal drinking water, groundwater flow direction within the aquifer is heavily influenced by pumping conditions.

The hydrogeologic features of the St. Peter Tonti and Pigs Eye Members, the PDC Group, and the Jordan Aquifer can vary significantly throughout the Site due to the presence and competency of overlying aquifers and aquitards, depth from first encountered bedrock, proximity to buried bedrock valleys, and position relative to the regional bedrock groundwater divide. The PDC Group and the Jordan Aquifer are present throughout the Site until the Cottage Grove Fault, where deeper formations are uplifted and both overlying units are absent. **Figures 14 to 17** show the potentiometric surfaces and the approximate locations of groundwater divides for the Platteville Aquifer, St. Peter Aquifer, Shakopee Aquifer, and the Jordan Aquifer.

Underlying the Jordan Aquifer is the St. Lawrence Shale, which is considered a vertical aquitard. Although vertical leakage can occur through the formation via small fractures and secondary porosity, the St. Lawrence Aquitard generally has a much lower vertical hydraulic conductivity as compared with the Oneota and St. Peter Pigs Eye Member aquitards and, as a result, likely inhibits most vertical groundwater movement from the overlying aquifers. Underlying the St. Lawrence Aquitard is the Tunnel City Group, which comprises the Mazomanie Formation (aquifer) and the Lone Rock Formation (aquitard). The Tunnel City Group is stratigraphically followed by the Wonewoc Sandstone Aquifer, the Eau Claire Shale Aquitard, and finally the Mt. Simon Sandstone Aquifer. Limited gauging data are available for aquifers stratigraphically below the Jordan Aquifer. However, the stratigraphic dips of the bedrock units suggest the presence of a north-to-south running groundwater divide roughly between Eagle Point Lake and Lake Elmo. Horizontal groundwater west of the divide is expected to flow south-southwest, and east of the divide, it is expected to flow east-southeast.

As with the Jordan Aquifer, none of these formations are first encountered bedrock until east of the Cottage Grove Fault where uplift has occurred. Groundwater flow across the fault is not fully understood. Due to further erosion of the bedrock units eastward of the fault, groundwater within the Quaternary Aquifer(s) may interact with the Wonewoc Aquifer and the Eau Claire Aquitard until the erosional edge of the units, at which point groundwater can flow unimpeded from the Quaternary Aquifer(s) into the Mt. Simon Aquifer. Any further downward migration of groundwater is confined by the basal metasedimentary units underlying the Mt. Simon Aquifer.

4 Project 1007 Investigation and Risk Assessment Activities

As required by Priority 1 of the 2018 Agreement and Order (Settlement) between the State of Minnesota and 3M Company (3M) (Minnesota v. 3M, 2018) a source assessment of the Valley Branch Watershed District's (VBWD's) Project 1007 conveyance system (**Figure 2**) was completed. This investigation is documented in the Project 1007 Remedial Investigation (RI) Report, **Appendix C** of the Feasibility Study (FS). From August 2019 to October 2024, AECOM completed hydrologic and hydrogeologic investigations and data collection to support the source assessment of the Project 1007 conveyance system and connected water bodies and groundwater aquifers. The RI analyzed per- and polyfluoroalkyl substances (PFAS) concentrations in sediment, soil, surface water, groundwater, and foam to determine how concentrations varied across the Site within these media and how concentrations changed with seasonal and hydrologic conditions. The following summarizes the investigation activities:

- ◆ Surface water bodies under investigation per the Settlement were located within an approximately 120-square-mile area across the cities of Oakdale, Woodbury, Lake Elmo, and West Lakeland Township. Thirty-four surface water sampling events were completed from August 2019 through October 2024, and 165 unique locations were sampled and analyzed for PFAS as shown on **Figures 18 to 22**. Surface water analytical results are shown in **Figures 42 to 53**.
- ◆ Six SML surface microlayer (SML) and 27 foam samples were collected from surface water body locations between August 2019 and March 2022, as shown on **Figure 25**. Foam and SML analytical results are shown in **Figures 54 to 60**.
- ◆ Sediment sampling and investigations were completed throughout the Project 1007 Corridor and at targeted water bodies located within the expanded Site between August 2019 and March 2023. During this time, 507 sediment samples were collected from 105 unique surface sediment locations and submitted for analysis of PFAS. Sediment sample locations are shown on **Figures 26 to 33**. Sediment analytical results are shown in **Figures 61 to 78**.
- ◆ Groundwater investigations included installation of 105 wells: 54 multi-aquifer wells installed as nests, 11 single-aquifer wells, 20 paired piezometers, 4 pumping wells, and 16 observation wells. These wells were installed into the following aquifers: Quaternary, Platteville, St. Peter, Shakopee, Jordan, Tunnel City, and Wonewoc. Vertical aquifer profile (VAP) and soil samples were collected during well installation and analyzed for PFAS. Groundwater sampling events at newly installed or preexisting wells were generally completed quarterly at the Site from October 2020 through October 2024. More than 1,200 groundwater samples were collected and submitted for laboratory analysis of PFAS. Groundwater sample locations are shown on **Figures 34 to 39**. Groundwater analytical results are shown in **Figures 79 to 120**.

PFAS impacts were found to be widespread throughout the Site, specifically within surface water, sediment, and groundwater. The migration within and between these media are contributing to the migration of PFAS from Oakdale Disposal Site (ODS) and Washington County Landfill (WCL) into drinking water aquifers, as discussed further in the Conceptual Site Model in **Section 5**. Based on the results and analysis presented in this report, the following conclusions were drawn about the migration of PFAS through the Site:

- ◆ There are several key areas of surface water infiltration to groundwater across the Project 1007 corridor: Pre-Confluence Raleigh Creek, Eagle Point Lake, Sunfish Lake, Lake Elmo, Horseshoe Lake, and the West Lakeland Ponds, shown in **Figure 2**. These areas of infiltration have resulted in a larger

groundwater plume than that resulting solely from mass flux within groundwater at ODS and WCL disposal sites.

- ◆ The Project 1007 conveyance system facilitates the migration of PFAS-containing surface water to locations of infiltration, and subsequent migration of PFAS impacts from the Quaternary aquifer into bedrock aquifers, including the Jordan Aquifer, which is used for municipal supply by multiple communities. PFAS-containing surface water is discharged to the St. Croix River via the Project 1007 conveyance system.
- ◆ Different distributions of specific PFAS analytes (referred to as PFAS signatures) within the Site are likely the result of unique waste profiles from the two disposal sites (ODS and WCL). The mixing of these signatures was found in surface water within the Project 1007 Corridor, indicating that impacts from both disposal sites are conveyed by the Project 1007 conveyance system.
- ◆ PFAS impacts likely cycle between surface water and sediment. PFAS impacts in sediment are attributed to sorption from impacted surface water and are likely released to surface water and groundwater under certain conditions.
- ◆ PFAS impacts in shallow groundwater migrate into deeper bedrock aquifers, at times via increased hydraulic connectivity associated with first encountered bedrock units and the buried bedrock valley.
- ◆ Although a potential human health hazard, high PFAS impacts in foam likely do not impact the fate and transport of PFAS across the Site.

In July 2020, AECOM completed a Screening-Level Ecological Risk Assessment (SLERA) using PFAS data from surface water, sediment, and foam samples previously collected from the Project 1007 Corridor. Based on the results of the SLERA, potential risks to ecological receptors were identified, which led to the recommendation for additional sampling to evaluate potential ecological receptors, chemicals, media, and pathways that warrant risk management consideration for the protection of the aquatic community and wildlife.

In September 2020, AECOM conducted tissue sampling of targeted species (i.e., amphibians, crayfish, snails, bottom fish, forage fish, and predator fish) paired with co-located abiotic sampling of surface water, sediment, porewater, and foam media. The results of this sampling effort were evaluated and presented in the 2021 Baseline Ecological Risk Assessment (BERA) (AECOM, 2021), which identified the potential for adverse health risk from exposure to PFAS for select mammals and birds, including the spotted sandpiper, the great blue heron, the little brown bat, the mink, and the muskrat.

In September 2021, AECOM paired vegetative sampling of targeted plant tissue (i.e., cattails, floating vegetation, grasses, and other shoreline vegetation) from the Raleigh Creek wetlands and Eagle Point Lake with co-located surface water and sediment sampling as part of a supplemental ecological risk assessment. The primary purpose of this supplemental ecological sampling was to refine the previous risk calculations by incorporating vegetation that might be consumed by the BERA-identified ecological receptors at risk, specifically the muskrat. In 2022, AECOM prepared an addendum to the previously completed BERA, which provided an updated risk estimate for the muskrat and updated food web models for other herbivorous birds and mammals in the Project 1007 Corridor.

5 Conceptual Site Model

The conceptual site model (CSM) discussion included in this Feasibility Study (FS) provides a summary of the processes that contribute to per- and polyfluoroalkyl substances (PFAS) movement from source areas, through surface water and groundwater migration pathways, and eventually to the environmental receptors of concern: East Metropolitan Area drinking water aquifers. This CSM is a generalized description of how the migration pathways control or influence PFAS movement within the Project 1007 corridor based on the Remedial Investigation (RI) described in **Section 4** and summarized in **Section 5.1** below. The Remedial Investigation Report provides detailed results of the investigation. Understanding how PFAS travels from one location to the next within surface water, sediments, and groundwater is key to achieving the primary objective of the FS under the Settlement, which is to ensure that appropriate remedial alternatives are developed and evaluated to address unacceptable human health risks that were identified during the Project 1007 source assessment.

5.1 Summary of Site-Wide Impacts

A comprehensive source assessment was completed for the Site to determine the magnitude and extent of PFAS impacts. This investigation is detailed in the Remedial Investigation Report (AECOM, 2024). This section provides a summary of source areas identified in the Source Assessment.

5.1.1 Surface Water

Figure 42 through 53 summarize the extent of PFAS contamination within East Metro surface water bodies. These figures illustrate the range of concentrations observed for the six PFAS compounds with current Minnesota Department of Health (MDH) Site-Specific Surface Water Criteria—perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA), perfluorobutanoic acid (PFBA), perfluorobutanesulfonic acid (PFBS), perfluorohexanoic acid (PFHxA), and perfluorohexanesulfonic acid (PFHxS)—and the locations where these compounds exceed the criteria as described below:

- Concentrations of PFOS exceed the Site-Specific Surface Water Criteria through the entire Project 1007 corridor, including within the discharge from the Tri-Lakes upgradient from the confluence at Tablyn Park. Concentrations of PFOS also exceed the criteria in disconnected lakes within the project area.
- Concentrations of PFOA exceed the criteria throughout the Project 1007 corridor, except upgradient of the confluence of Project 1007 within Raleigh Creek.
- Concentrations of PFHxS exceed the criteria within Raleigh Creek and Eagle Point Lake.
- Concentrations of PFHxA only exceed the criteria within Raleigh Creek.
- Concentrations of PFBA only exceed the criteria in Sunfish Lake.
- Concentrations of PFBS exceeding the criteria have not been encountered in surface water.

The PFAS source areas are dominated by PFAS with high proportions of PFOS, PFOA, and PFBA; as such, the discussion of surface water migration pathways focuses primarily on these compounds.

The highest concentrations of PFOS and PFOA in surface water were observed in Raleigh Creek immediately downstream of Oakdale Disposal Site (ODS), in the Upper Raleigh Creek Wetland Complexes and Anna's Grove Wetland Complex (AGWC), and at various locations around Eagle Point Lake. PFBA concentrations were highest in Sunfish Lake. The highest PFBS concentrations were observed in Raleigh Creek immediately downstream of ODS and in the Upper Raleigh Creek Wetland Complexes. PFHxS concentration trends mirror those of PFOS and PFOA, peaking in Raleigh Creek downstream of

ODS, the Upper Raleigh Creek Wetland Complexes, and AGWC. The highest PFHxA concentrations were similarly observed in upper Raleigh Creek, immediately downstream of ODS.

5.1.2 Groundwater

Figures 129 through 158 summarize the extent of PFAS contamination in each aquifer within the Site in exceedance of the MDH Drinking Water Standard, or when lower for a specific PFAS, the U.S. Environmental Protection Agency (EPA) Maximum Contaminant Level (MCL). These figures illustrate in greater detail the range of concentrations of detected and regulated PFAS compounds in the Quaternary, St. Peter, Shakopee, and Jordan Aquifers. MCLs exist for hexafluoropropylene oxide-dimer acid (HFPO-DA) but no exceedances have been observed at the time of writing this report. **Figures 115 through 120** illustrate exceedances of the Hazard Indices issued by both MDH and EPA. **Figures 129 through 158** show plume maps of PFAS impacts across the Site.

Because the source areas are dominated by PFAS with high proportions of PFOS, PFOA, and PFBA, the discussion of groundwater migration pathways focuses primarily on these compounds. The highest PFOS concentrations within the Shakopee Aquifer were observed beneath and to the south of ODS, immediately east of the AGWC, at Washington County Landfill (WCL), immediately south of Eagle Point Lake, and immediately east of the West Lakeland storage ponds. These trends are similar in the Jordan Aquifer, where the highest concentrations of PFOS were observed at and to the south of ODS, at AGWC and the Upper Raleigh Creek Wetland Complexes, immediately southeast of Eagle Point Lake, southwest of Eagle Point Lake, and immediately east of the West Lakeland storage ponds. The highest PFOA concentrations in the Shakopee Aquifer were observed at ODS, at and to the south and southeast of WCL, and south of Eagle Point Lake. Within the Jordan Aquifer, the highest PFOA concentrations were observed west of Hadley Avenue near Tartan High School. The highest PFBA concentrations were observed at and to the south and southeast of WCL in both the Shakopee and Jordan Aquifers. PFHxS, PFHxA, PFBS, and perfluorononanoic acid (PFNA) in exceedance of the criteria were also observed, but these trends generally followed those of PFOS or PFOA.

The regional drinking water supply aquifers are the Shakopee and the Jordan Aquifers as described in **Section 2**. Impacts have been observed in several other aquifers that are not used for drinking water supply, but that facilitate PFAS transport to the Shakopee and Jordan Aquifers and to various surface water bodies and sediments. The sections below discuss these transport mechanisms in detail.

5.1.3 Sediment

Figures 61 through 78 summarize the extent of PFAS contamination within sediment across the Site. The Minnesota Pollution Control Agency (MPCA) established Site-Specific Sediment Screening Values (SDSVs) for both 5-day/week and 2-day/week exposure scenarios associated with recreational activities in sediments within the Project 1007 Corridor: PFOS (18 and 45 ug/kg), PFOA (0.40 and 0.99 ug/kg), PFBA (120,000 and 250,000 ug/kg), PFBS (1,500 and 3,700 ug/kg), PFHxS (170 and 430 ug/kg), PFHxA (2,600 and 6,600 ug/kg), and HFPO-DA (GenX) (160 and 390 ug/kg). Areas with the highest PFOS, PFOA, PFHxS, PFHxA, and PFBS impacts were observed in Raleigh Creek just downstream of ODS, at AGWC and the Upper Raleigh Creek Wetland Complexes, and around Eagle Point Lake. The highest PFBA impacts have been observed in Raleigh Creek just downstream of ODS, at AGWC and the Upper Raleigh Creek Wetland Complexes, and at points around Sunfish Lake and Lake Elmo.

5.2 Tools Used to Develop the CSM

The tools described in this section were used as lines of evidence to determine PFAS migration pathways in the development of this CSM.

5.2.1 PFAS Plume and Concentration Maps

Groundwater plume maps and surface water and sediment concentration maps were developed based on the data collected for the RI. The development of the plume maps is detailed in the Remedial Investigation Report (**Appendix B**). The maps themselves are included in **Appendix A**. These maps were used to identify potential PFAS sources to drinking water aquifers, including those resulting from surface water infiltration.

5.2.2 Groundwater Model and Particle Tracking

A groundwater flow model was developed based on water level data and geologic information across the Site. Particle tracking in the groundwater flow model was used to infer the flow direction of PFAS-containing groundwater from primary and secondary source locations. Details of the model are provided in the Model Report (AECOM, 2024).

5.2.3 PFAS Distribution

As discussed in **Section 7**, the relative fractions of PFOS, PFOA, and PFBA out of the summation of all PFAS detected differs between the wastes disposed of at WCL and ODS, resulting in different PFAS signatures for impacts migrating from each disposal area. The different PFAS signatures can be used to support the association of impacts in a particular location with one or both primary sources. Surface water PFAS distribution can be compared to nearby impacts in groundwater to characterize groundwater impacts as the result of long-distance subsurface migration or surface water infiltration.

5.2.4 Branched/Linear Analysis

Although PFAS are typically depicted as having a single chemical structure with a head group and a single carbon-fluorine tail, long-chain PFAS can have multiple chemical structures. These chemical structures, called isomers, can have a branched carbon-fluorine tail and retain the same chemical formula as single long-chain PFAS. The concentration of branched to linear isomers of specific PFAS analytes can be measured analytically to determine the fate and transport of PFAS in the environment. Branched PFAS migrate at a faster rate within groundwater than linear PFAS; therefore, longer-traveled groundwater plumes have a higher fraction of branched PFAS compared to shorter-traveled groundwater plumes (Sadia et al., 2023). Branched/linear analysis supported the identification of sites where impacted surface water infiltrates to groundwater. At a relatively greater distance from the source areas, the enrichment of linear PFAS (which travels readily in surface water) in groundwater suggests nearby infiltration. Where the impacts are exclusively associated with plume migration in groundwater, linear PFAS would be expected at lower proportions.

5.3 Summary of Migration Pathways

Similar PFAS migration pathways are found throughout the Site. Later sections in this CSM detail variations of these pathways that result from the Site's large size and the widespread distribution of PFAS in different media types.

PFAS are transported downstream with surface water as they flow through the Project 1007 Conveyance System. PFAS behaviors in surface water are influenced by their hydrophilic and hydrophobic properties. The head group of PFAS molecules is hydrophilic and the carbon-fluorine tail is hydrophobic, causing PFAS to readily foam at the water/air interface in response to the turbulent flow conditions found in creeks and lake surfaces. The foam generated under these conditions has elevated PFAS concentrations and can migrate or collect on the surface before collapsing back into surface water or sediment. If turbulent conditions are not present, PFAS can accumulate at the air-water interface, resulting in higher concentrations that can then be transported by wind and wave action. Turbulent conditions are predicted to disrupt the air-water interface, causing any PFAS that has accumulated at the surface

microlayer to become remixed into the underlying water (ITRC, 2025a). Bulk water PFAS concentrations may decrease from dilution throughout the Project 1007 Conveyance System as unimpacted surface water flows into the Conveyance System. Alternatively, surface water concentrations may increase or decrease as a result of groundwater discharge depending on the groundwater PFAS concentrations.

Adsorption and desorption of PFAS to sediment can also result in changes to surface water PFAS concentrations. PFAS in surface water adsorb to sediment as the surface water flows over the sediment and as it infiltrates through the sediment into the groundwater. Adsorption continues until an equilibrium is reached between the water and sediment. The resulting sediment PFAS concentrations are dependent on the sediment characteristics, flow regime, and water PFAS concentrations. For example, depositional environments with high organic content will tend to have higher PFAS concentrations than coarse grain erosional environments. If PFAS concentrations within the water increase, more PFAS will adsorb to the sediment to reestablish an equilibrium. Different specific PFAS will also preferentially adsorb to sediment. Long chain PFAS, including PFOS and PFOA, adsorb more than short chain PFAS, including PFBA and PFBS (ITRC, 2025b).

Alternatively, PFAS desorb or leach from sediment if the surface water PFAS concentrations decrease in order to reestablish equilibrium concentrations. This can result in PFAS migration from sediment to surface water as it flows over the impacted sediment, or from sediment to groundwater as surface water infiltrates through the impacted sediment. The length of time required to achieve a new equilibrium and observe a reduction in sediment concentrations is uncertain but could occur over several years causing the sediment to be a PFAS source to downstream surface water and groundwater (Higgins and Luthy, 2006; Li. et al, 2019). Not all PFAS are expected to desorb from the sediment if surface water PFAS is completely removed, as some PFAS are predicted to be irreversibly bound. This resulting sediment concentration is unknown. A laboratory treatability study is planned, as described in **Section 10**, to better understand the extent of leaching and estimate the time over which leaching can be expected.

PFAS adsorbed to sediment can be mobilized under flow conditions that promote erosion, such as high flow after large rain falls and snowmelt. The PFAS-containing sediment can be washed downstream as suspended particles within the water column until a depositional environment is reached, where the sediment particles settle to the bottom of the surface water body and potentially become a PFAS source to that surface water body (Borthakur et al., 2021; Balgooyen and Remucal, 2021).

Migration of PFAS from surface water to groundwater occurs when surface water infiltrates to groundwater under the conditions where the groundwater elevation is below that of the surface water body. Constructed infiltration ponds may enhance PFAS migration from surface water to groundwater, further increasing the spread of PFAS within the groundwater. Soil at depth is not found to contribute significantly to groundwater impacts as surface water infiltrates, nor is it found to act as a sink to migrating impacts. Impacted soils in and around WCL are an exception and investigation in these areas is ongoing. Several perched water bodies in the project area are understood to have negligible connectivity to groundwater. Groundwater will discharge to surface water if the groundwater elevation is above that of the surface water body. This provides a pathway for PFAS in groundwater to migrate to surface water. An example of this is Valley Branch Creek in Afton where the creek is groundwater fed.

The subsurface geology of the Site consists of Precambrian basement rock situated below Cambrian and Ordovician stratigraphy that is subsequently overlain by unconsolidated Quaternary glacial sediments. Bedrock is gently tilted to the west and progressively more eroded to the east such that first encountered bedrock becomes stratigraphically older from west to east. The Quaternary Aquifer is heterogeneous and anisotropic, and any discussion of Quaternary groundwater flow direction is broadly generalized. Within Cambrian and Ordovician stratigraphy, fracturing and karstification are essential to the hydrogeologic understanding of the Site. An exclusively matrix-based approach to groundwater flow assumes flow within a unit's primary porosity and does not account for the high connectivity within and

between aquifers and aquitards that is provided by secondary porosity. Additionally, the first 50 feet of encountered bedrock are considered to be a highly fractured zone, providing increased vertical connection from the Quaternary Aquifer to deeper bedrock. Municipal, domestic, and irrigation pumping wells alter groundwater flow throughout the Site. As pumping well locations and pumping rates have changed over time, their influence on groundwater flow has continuously shifted. Fault features and a bedrock valley are additional structural features that are discussed in more detail in sections that follow. The geology and hydrogeology are discussed in greater detail in **Section 3.5** of this FS.

The investigation of regional air deposition of PFAS is ongoing and is not addressed further in this CSM.

5.4 Conceptual Site Model

While this CSM describes the PFAS migration pathways and extent of impacts throughout the Site, the focus is on pathways that contribute to the PFAS impacts observed within the drinking water aquifers of the East Metro. As such, the Site is divided into areas based on locations that contribute PFAS to the groundwater, specifically to the Shakopee and Jordan Aquifers. This includes the source areas of ODS and WCL, and areas of surface water infiltration that result in plumes further from the source areas. The source areas are dominated by PFAS with high proportions of PFOS, PFOA, and PFBA; as such, discussion of migration pathways focuses primarily on these compounds.

5.4.1 Washington County Landfill

WCL is one of two primary PFAS source areas in the Project 1007 Corridor. The historical disposal of 3M PFAS-containing industrial waste resulted in PFAS contamination entering the Quaternary sediments and the uppermost groundwater table below the landfill. As described in **Section 3.3**, WCL has been triple-lined and is no longer a PFAS source to groundwater; however, PFAS migrated into the soil and groundwater prior to installation of the lining and continues to migrate downgradient. A groundwater control and treatment system operated from 1984 to 2009. No groundwater treatment is currently ongoing. However, investigation, characterization, and remediation evaluations are ongoing at WCL under the direction of the MPCA. From 1988 through 1995, groundwater pumped from the former WCL remediation system was directly discharged into the Project 1007 conveyance system through a pipe that extended west of the landfill (ATSDR, 2008). Groundwater is no longer discharged and landfill leachate is managed through an onsite recirculation system and offsite disposal. The waste disposed of at WCL is characterized as having high fractions of PFBA and, to a lesser extent, PFOA out of the total PFAS based on groundwater sampling at and immediately downgradient of WCL. PFOS is present but at a smaller fraction. PFBA concentrations downgradient of WCL in the Quaternary Aquifer exceed 200,000 nanograms per liter (ng/L). PFOA and PFOS concentrations exceed 10,000 ng/L and 300 ng/L, respectively.

The Tri-Lakes (Lakes Jane, Olson, and De Montreville) and headwaters of the Project 1007 conveyance system are located north of WCL as shown in **Figure 5.1**. Water from the Tri-Lakes area is piped south into a channel north of County Road 14 in Lake Elmo. Channelized flow continues southward and flows through Beutel Pond before it joins Raleigh Creek at Tablyn Park. Flow continues south toward Eagle Point Lake and is consistently observed within Post-Confluence Raleigh Creek at Tablyn Park, except during periods of extreme drought.

In this area, the Quaternary Aquifer groundwater flow is predominantly to the east and southeast toward Sunfish Lake and Lake Elmo. The St. Peter Aquifer, which underlies the Quaternary Aquifer, is laterally discontinuous and where present, is highly weathered, allowing for hydraulic connectivity between the Quaternary Aquifer and the Shakopee Aquifer. Groundwater within the Shakopee Aquifer flows primarily to the south and southeast. As elsewhere in the Site, the Oneota Aquitard is “leaky” and allows for a hydraulic connection between the Shakopee and Jordan Aquifers. The groundwater within

the Jordan Aquifer also flows to the south and southeast. In all bedrock aquifers, the hydraulic gradient is relatively flat and therefore sensitive to changes in groundwater recharge or extraction. Further east of WCL, flow in both the Shakopee and Jordan Aquifers is more easterly.

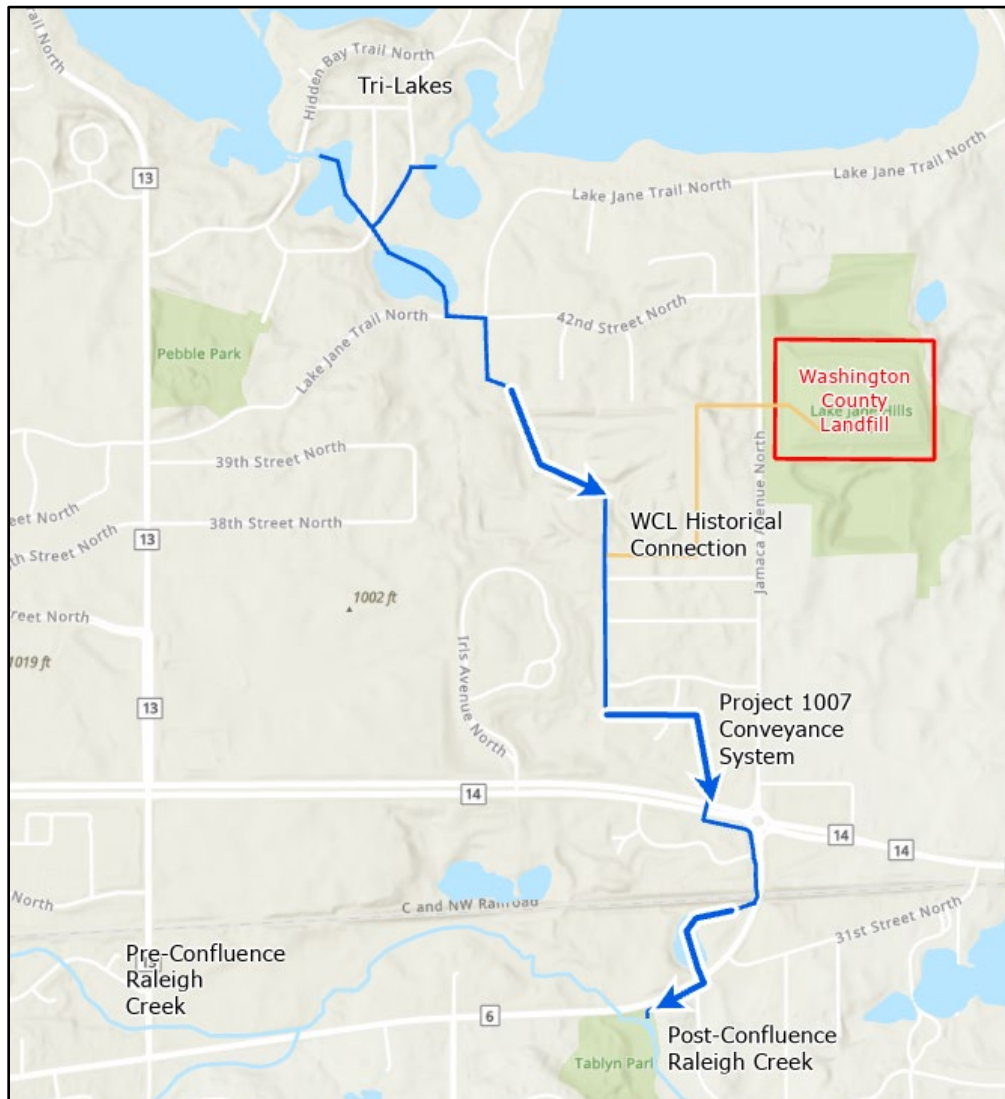


Figure 5.1: Spatial relationship between WCL and the Project 1007 conveyance system

5.4.1.1 WCL – Migration Pathways

Historical PFAS-containing waste disposed of at WCL and subsequent PFAS migration away from the landfill contribute to widespread impacts observed across the Site. The specific migration pathways are depicted in **Figure 5.2** and detailed as follows.

- **[A]** Prior to lining and cover-placement of the landfill wastes, PFAS migrated from WCL wastes into the Quaternary Aquifer, which flows to the south and southeast. PFAS mass in the vadose zone likely acts as a source to ongoing PFAS migration in groundwater from the Site. Vertical migration from the Quaternary Aquifer into the bedrock aquifers also occurs where PFAS continues to migrate with groundwater to the south and southeast.
- **[B]** PFAS-containing shallow groundwater discharges into the northern edges of Sunfish Lake and Lake Elmo. Surface water from Sunfish Lake infiltrates back into groundwater at the southern end of the lake.

- [C] Between 1988 and 1995, untreated groundwater from a landfill remediation gradient control well was directly discharged into a storm sewer connecting the landfill to the newly constructed Project 1007 conveyance system.

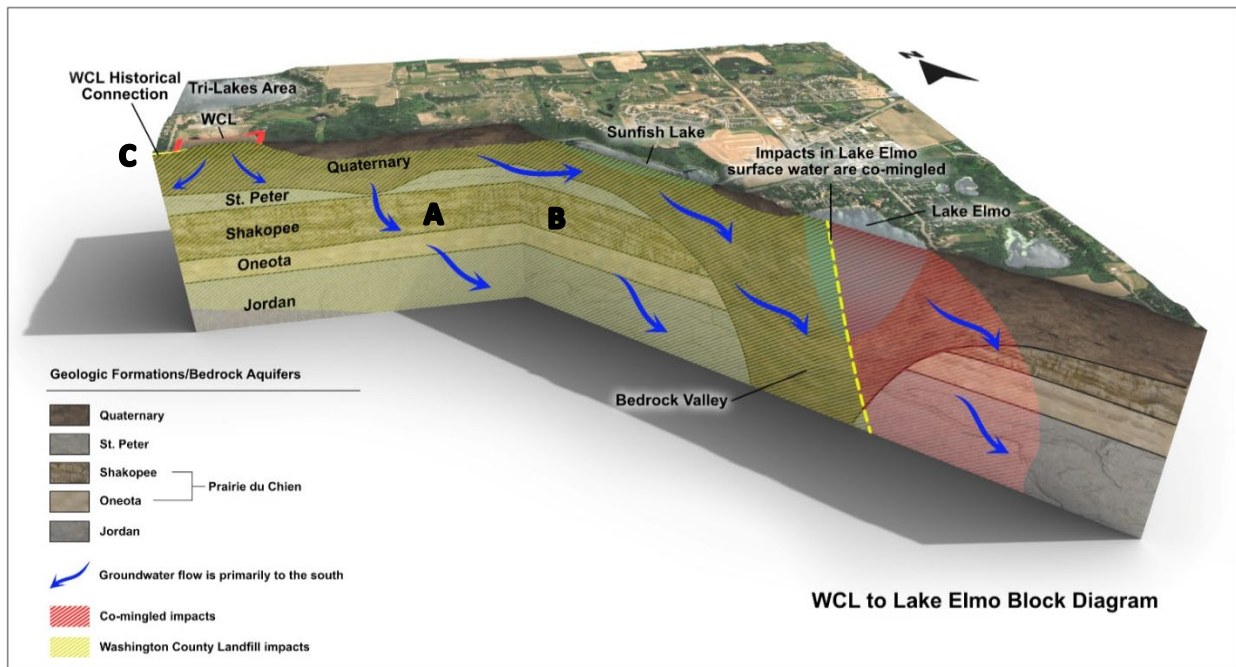


Figure 5.2: WCL block diagram

5.4.1.2 [A] WCL – PFAS Migration in Groundwater

As previously discussed, the historical disposal of PFAS-containing wastes at WCL resulted in PFAS-impacted groundwater in the underlying Quaternary Aquifer. Additionally, the groundwater treatment system that was operated from 1983 until 2009 included spraying groundwater on the landfill to allow volatile organic compounds (VOCs) to volatilize. This may have increased the leaching and subsequent migration of PFAS by artificially increasing the groundwater elevation at WCL. PFAS impacts migrate to the east and southeast within the shallow aquifers as well as vertically into the deeper bedrock aquifers where groundwater flow is generally to the south. The shallow Quaternary Aquifer flow has likely shifted since PFAS-containing waste was originally deposited because of the groundwater treatment system and the installation of two infiltration ponds as part of the reconstruction of the landfill in 2009. Below the landfill, the first encountered bedrock aquifers are the St. Peter and Shakopee Aquifers. The St. Peter Aquifer is discontinuous in this area, and where present, is thin and highly fractured, which allows for the vertical migration of PFAS impacts from the Quaternary Aquifer into the Shakopee Aquifer. PFAS impacts in the Shakopee Aquifer immediately downgradient of WCL have a PFBA-dominant composition. The distinct PFBA-dominant chemical signature associated with WCL is also informative in understanding and documenting groundwater flow in areas to the south and downgradient of WCL. PFAS-impacted groundwater in the Shakopee Aquifer generally migrates from WCL to the south and southeast, as shown in the WCL PFOA plume map (Figure 5.3), as well as vertically into the Jordan Aquifer. The Jordan Aquifer has a stronger southerly component to its groundwater flow beneath WCL, in contrast to Jordan Aquifer impacts resulting from vertical migration from the Quaternary Aquifer east of WCL, which have a more easterly trajectory. Impacts from WCL are undergoing additional delineation to refine the extent and magnitude of the impacts in all directions within all impacted aquifers. The southeasterly component of groundwater flow within the Shakopee and Jordan Aquifers may have been influenced by pumping at the Lake Elmo #1 Municipal Well. This well was completed into the Mt. Simon Aquifer at 805 feet below ground surface and was open to St. Lawrence, which may have allowed for PFAS

communication via mixing at various intervals as shown by down-hole geophysical evaluations conducted by the Minnesota Geological Survey (MGS). Lake Elmo Well #1 was sealed in 2022, but while operational, it likely pulled the plume toward Lake Elmo to the east. Private drinking water supply wells in Lake Elmo immediately south and east of WCL are impacted by this migration.

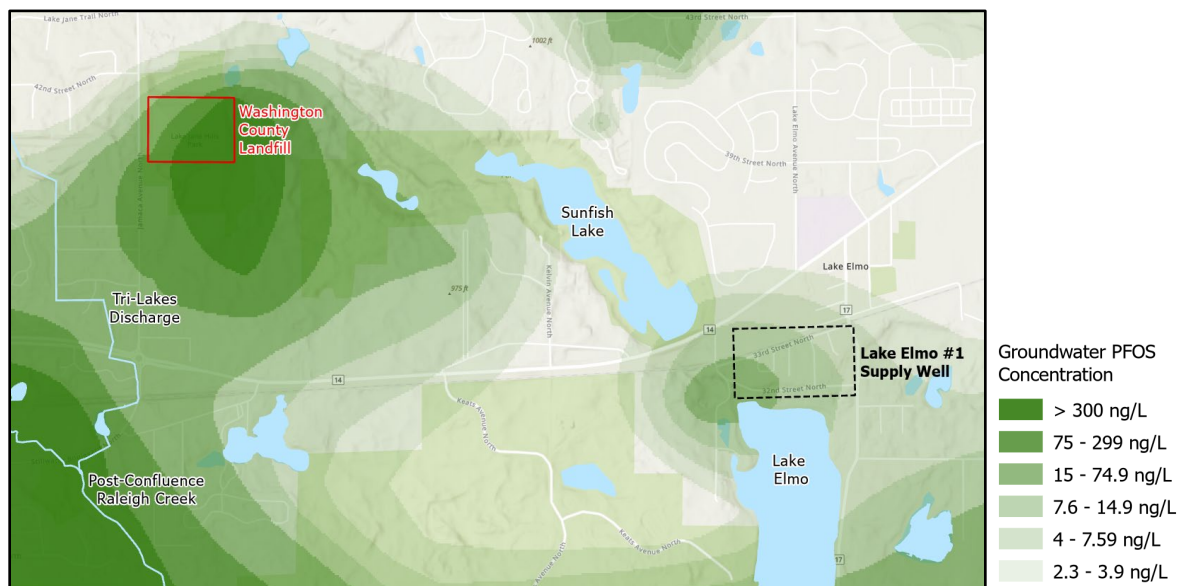


Figure 5.3: WCL PFAS impacts in all groundwater aquifers

5.4.1.3 [B] WCL – PFAS Migration from Shallow Groundwater to Surface Water

PFAS-impacted groundwater below WCL is likely contributing to the presence of PFAS in surface water to the east of the landfill in Sunfish Lake and Lake Elmo. Shallow groundwater flows generally east and southeast from WCL and discharges into the northwestern edge of Sunfish Lake, which is a land-locked and groundwater-fed lake. PFAS impacts in Sunfish Lake have a distinct PFBA-dominant chemical signature associated with impacts at WCL, supporting a groundwater to surface water migration pathway. PFAS concentrations in Sunfish Lake were observed as high as 18 ng/L for PFOS, 189 ng/L for PFOA, and 7,910 ng/L for PFBA. Surface water in Sunfish Lake infiltrates to groundwater at the southern edge of the lake and flows to the south as shallow groundwater, where it then discharges into Lake Elmo. PFBA concentrations in surface water from Tablyn Park to the western edge of Lake Elmo are low (89 ng/L to 334 ng/L) before increasing significantly at Lake Elmo, supporting the WCL groundwater to surface water migration pathway. PFAS concentrations across Lake Elmo are generally consistent; observed PFOS concentrations are as high as 320 ng/L, with concentrations as high as 92 ng/L for PFOA and 1,170 ng/L for PFBA.

5.4.1.4 [C] WCL – PFAS Migration from Untreated Groundwater Discharge to Surface Water

Between 1988 and 1995, untreated groundwater from a landfill remediation gradient control well was discharged directly into a storm sewer connecting the landfill to the newly constructed Project 1007 conveyance system. Following discharge of the WCL gradient control well groundwater to the Project 1007 conveyance system, the combined Tri-Lakes discharge water and WCL groundwater flowed south within Project 1007 to the confluence with Raleigh Creek at Tablyn Park before flowing into Eagle Point Lake. Records from the remediation gradient control system operation indicate approximately 50 to 80 million gallons of WCL PFAS-impacted groundwater were discharged annually to the Project 1007 conveyance system during the time the WCL storm sewer connection was active. Direct discharge from the landfill ended in 1995 and the PFAS concentrations within this historically discharged groundwater are unknown. Surface water in the Project 1007 conveyance system prior to the confluence consists primarily of discharge from the Tri-Lakes, with lesser amounts attributed to stormwater runoff.

Observed PFAS concentrations are consistent with background levels in unimpacted areas. PFOS concentrations in surface water from the Tri-Lakes to the confluence with Raleigh Creek range from 1.6–4.2 ng/L, PFOA from 7.1–10.7 ng/L, and PFBA from 55–180 ng/L. Sediments in the Project 1007 conveyance system south of WCL do not have elevated PFAS concentrations, indicating that they are not a long-term PFAS source.

5.4.2 Oakdale Disposal Site

ODS is one of two primary PFAS source areas in the Project 1007 Corridor. Remedial alternatives for ODS were not developed as part of this FS as the investigation and cleanup actions at ODS are administered under separate Consent Orders between 3M and the MPCA and are managed through the Superfund Program; however, information about the historical disposal of PFAS at ODS and the movement of PFAS away from ODS through groundwater and surface water are important to understanding PFAS migration through the Project 1007 Corridor. Reducing migration from this source area is an important component of the remediation efforts throughout the Site.

Details concerning ODS can be found in **Section 3.2** and information regarding the CSM of ODS can be found in the Conceptual Site Model Update reports completed by Barr Engineering (Barr, 2022; Barr, 2023). 3M is completing additional work to further develop the CSM for ODS. In summary, a variety of industrial wastes as loose waste, drums, pails, and barrels were disposed of at ODS from the late 1940s until the 1960s, including PFAS-containing industrial wastes from 3M. Waste burial took place across the Site, including in or adjacent to low-lying areas that were in direct hydraulic connection with surface waters and groundwater. The PFAS waste disposed of at ODS has a PFOS-dominant profile. PFOA and PFBA concentrations also exceed the applicable criteria.

ODS comprises wetlands and ponds that both contribute to Raleigh Creek and infiltrate to groundwater. Raleigh Creek discharges to the east of ODS and the groundwater plume has migrated away from ODS, primarily to the south (see **Figure 5.4**). Although site remediation activities have occurred since the 1980s, these remedial activities were primarily focused on VOCs until recently. PFAS-containing surface water, soils, and groundwater remain active migration pathways for the movement of PFAS offsite and away from ODS.

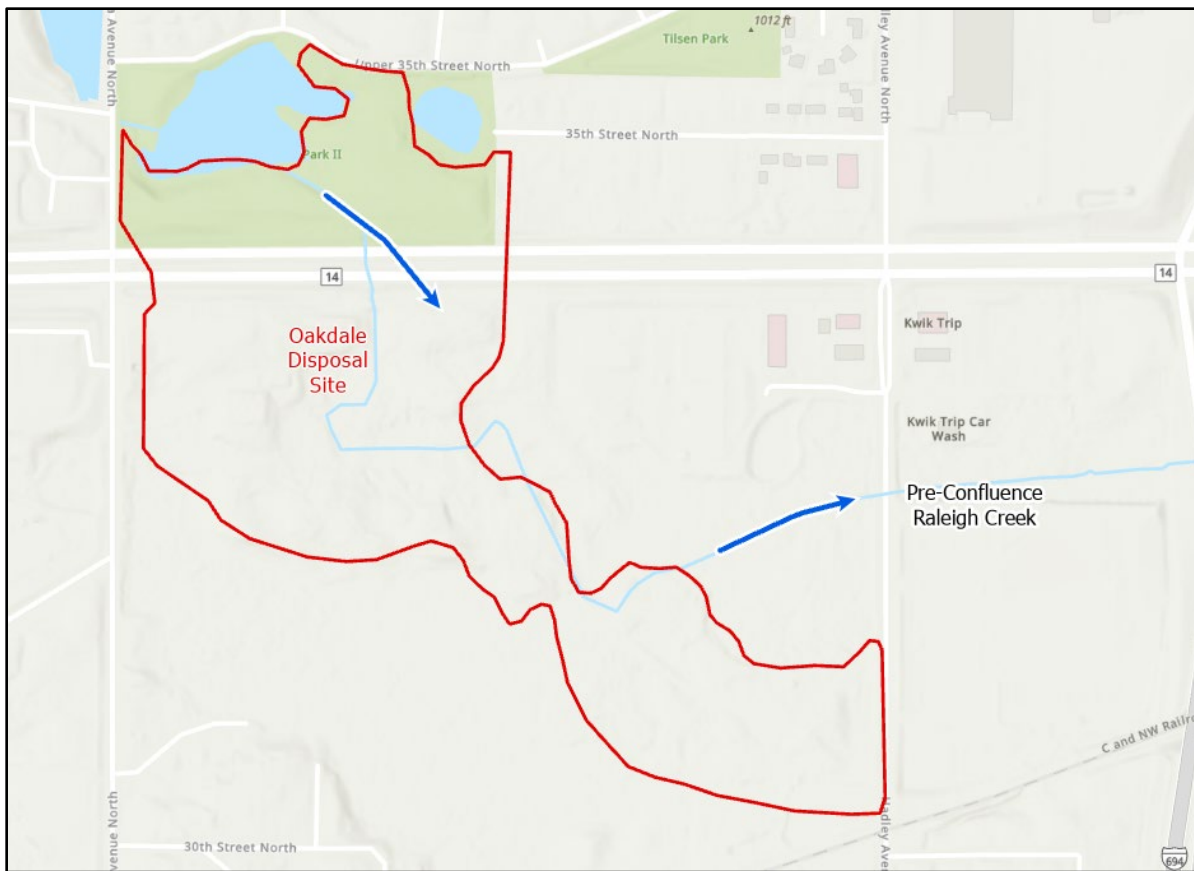


Figure 5.4: ODS (Abresch parcel); Raleigh Creek flow path through ODS

The unconsolidated Quaternary Aquifer, which is controlled by onsite pumping, underlies ODS (Barr, 2022). The Decorah Shale Aquitard is present under a portion of the primary ODS Abresch parcel (Abresch parcel is shown in **Figure 5.4**), providing a localized barrier to vertical groundwater migration in those areas, but this barrier acts as a limited cap, whereby the impacts flow to the edges within the Site and infiltrate vertically at the edges of the Decorah Shale. The Platteville Aquifer is located beneath the Decorah Shale or is in direct contact with the Quaternary Aquifer in areas where the Decorah Shale is not present, providing a direct conduit to the migration of groundwater from the Quaternary Aquifer to a bedrock aquifer. A groundwater divide is present in the Platteville Aquifer near the eastern extent of ODS with groundwater flow in this formation beneath ODS generally flowing to the west-southwest. The Glenwood Shale Aquitard underlies the Platteville Aquifer followed by the St. Peter Aquifer, which flows to the south/southwest, carrying PFAS-impacted groundwater to the south (directly to the Oakdale Municipal Wells) and southwest.

5.4.2.1 ODS – Migration Pathways

PFAS-containing waste disposed of at ODS and the subsequent migration of PFAS source mass away from the disposal site contributes to the widespread impacts observed across the Site. The specific migration pathways are depicted in **Figure 5.5** and detailed as follows:

- **[D]** Migration of PFAS from impacted surface sediments and soils to shallow groundwater due to surface water infiltration.
- **[E]** PFAS-impacted shallow groundwater migrates vertically to the bedrock aquifers where groundwater flows primarily to the south and southwest of ODS.
- **[F]** Periodic flow of PFAS-containing surface water in Raleigh Creek, which flows offsite to the east.

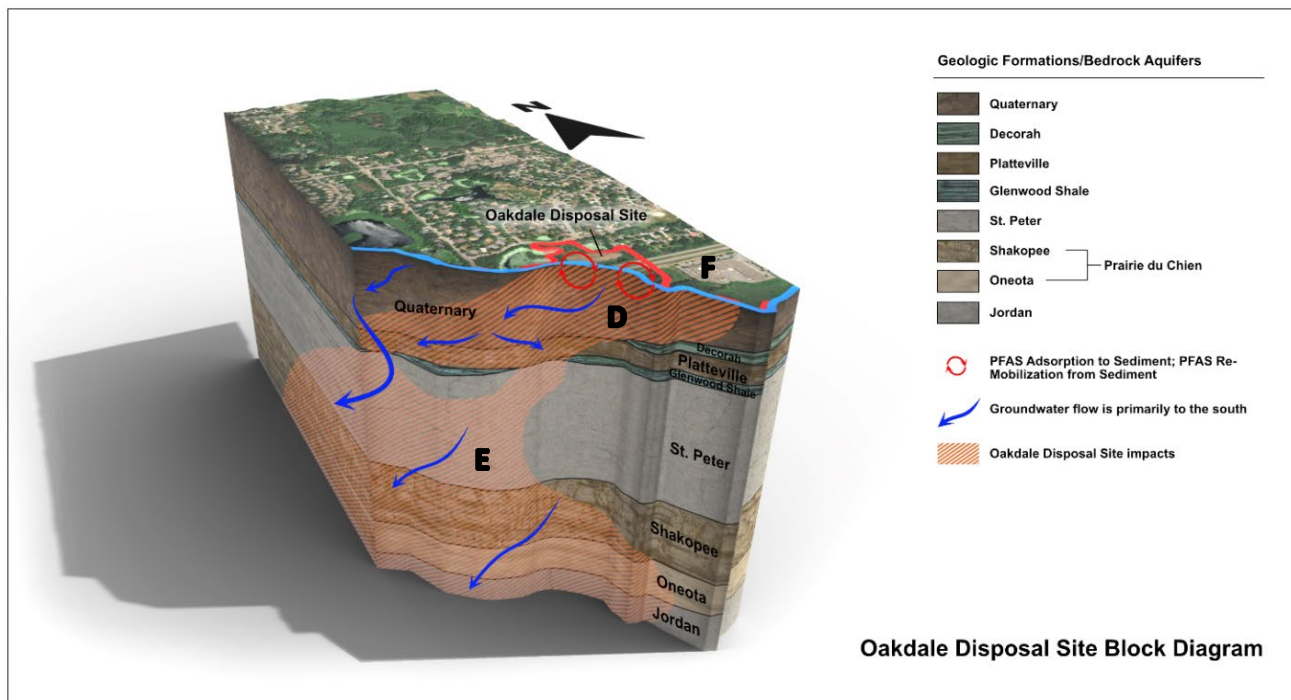


Figure 5.5: ODS block diagram

5.4.2.2 [D] ODS – PFAS Migration in Shallow Groundwater

PFAS within the shallow sediment and soil migrates to groundwater in the Quaternary Aquifer. In the northern portion of the Site, the shallow groundwater is partially controlled by a pump and treat system to minimize offsite migration; however, detections in offsite wells to the southwest indicate migration is occurring. As the Decorah Shale is not uniformly present beneath ODS, vertical migration into the Platteville Aquifer is also observed in monitoring wells onsite and immediately downgradient of ODS.

5.4.2.3 [E] ODS – PFAS Migration in Groundwater

Once within the Platteville Aquifer, PFAS impacts migrate to the south-southwest and vertically to the St. Peter and Shakopee Aquifers where groundwater flow is primarily to the south. The Platteville Aquifer has a lower vertical hydraulic conductivity and higher horizontal hydraulic conductivity (primarily via fracture flow), resulting in additional horizontal migration of PFAS impacts. The leaky properties of the Oneota Aquitard and groundwater pumping at the City of Oakdale municipal supply wells facilitate vertical migration of PFAS-impacted groundwater into the Jordan Aquifer. Concentrations of PFAS in Shakopee and Jordan wells south of ODS exceed 2,400 ng/L for PFOS, 440 ng/L for PFOA, and 1,500 ng/L for PFBA. Pumping at the Tamarack Well Field in Woodbury, which is located to the south of Oakdale, likely influences the flow of PFAS-impacted groundwater to the south (**Figure 5.6**). Delineation of the PFAS plume in this area is limited in the Shakopee and Jordan Aquifers due to the limited number of wells south of ODS. Particle tracking confirms the groundwater flow from ODS is southward.

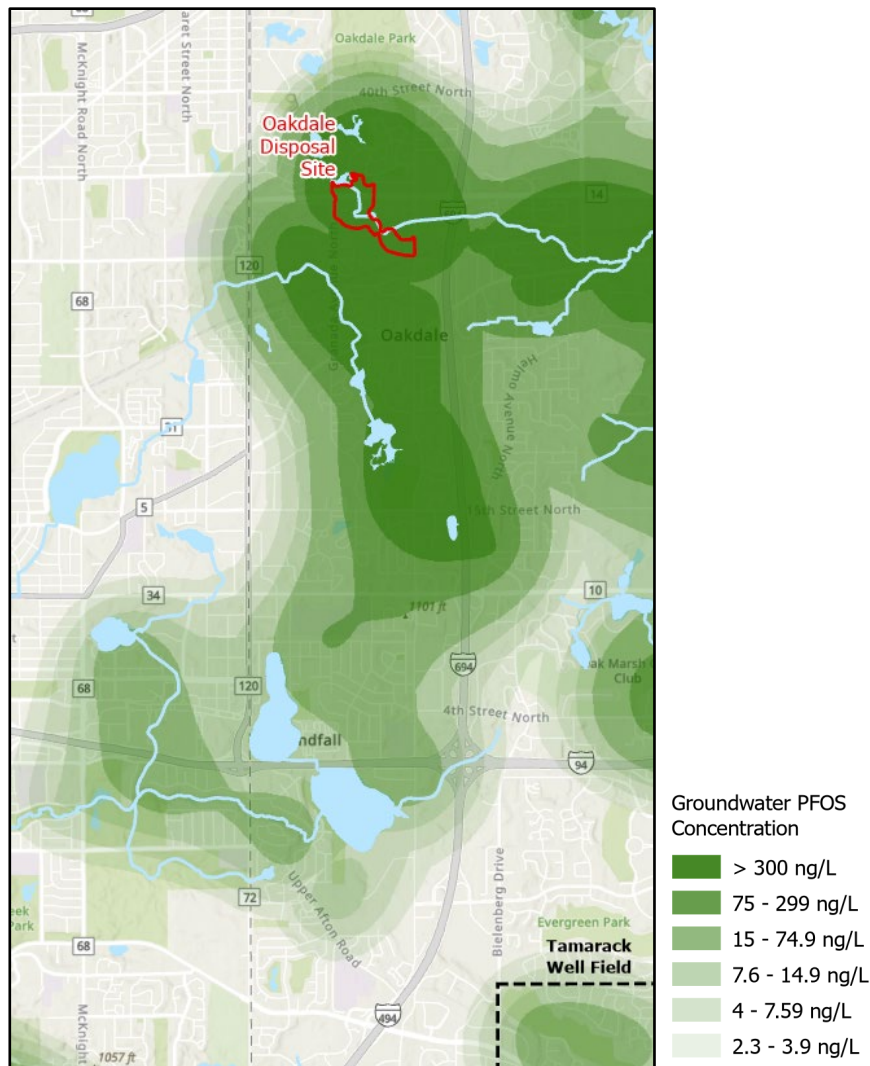


Figure 5.6: ODS PFAS impacts in all groundwater aquifers

5.4.2.4 [F] ODS – PFAS Migration in Surface Water

Raleigh Creek is a small intermittent stream that originates from a stormwater pond upstream of ODS and is located immediately north of Upper 35th Street N and west of Granada Ave. N in Oakdale. Surface water flows east for a short distance before flowing south under County Rd. 14 and into ODS. Raleigh Creek flows through approximately 2,000 feet of ODS surface water and lowlands. PFAS concentrations are observed to increase within the creek as impacts from the wetlands, ponds, and shallow groundwater that discharges within ODS contribute to the flow of the creek. The flow rate is variable and dependent on precipitation events, but flow is consistently observed from ODS except during periods of drought. The maximum observed discharge is 7.8 ft³/sec. As Raleigh Creek flows from ODS, PFOS is the dominant PFAS compound detected in its water at concentrations as high as 8,810 ng/L. PFOA and PFBA are present at concentrations as high as 2,500 ng/L and 1,140 ng/L, respectively.

5.4.3 Raleigh Creek

Raleigh Creek discharges from the of ODS east of Hadley Avenue, which forms the eastern boundary of ODS, through a wetland area, after which it flows through a culvert structure under I-694 and into a second wetland located between I-694 and Hemingway Avenue as shown in **Figure 5.7**. Raleigh Creek continues east-southeast through a culvert under Hemingway Avenue and 32nd Street North through a third wetland south of 32nd Street. These three wetlands comprise the Upper Raleigh Creek Wetland

Complex. These wetlands are likely groundwater-fed during periods of low flow and act as sources of surface water and infiltration of PFAS source mass during periods of high flow. The intermittent flow in the creek upstream and contributions from groundwater base flow typically result in perennial surface water flow within and between the wetlands, except during drought conditions.

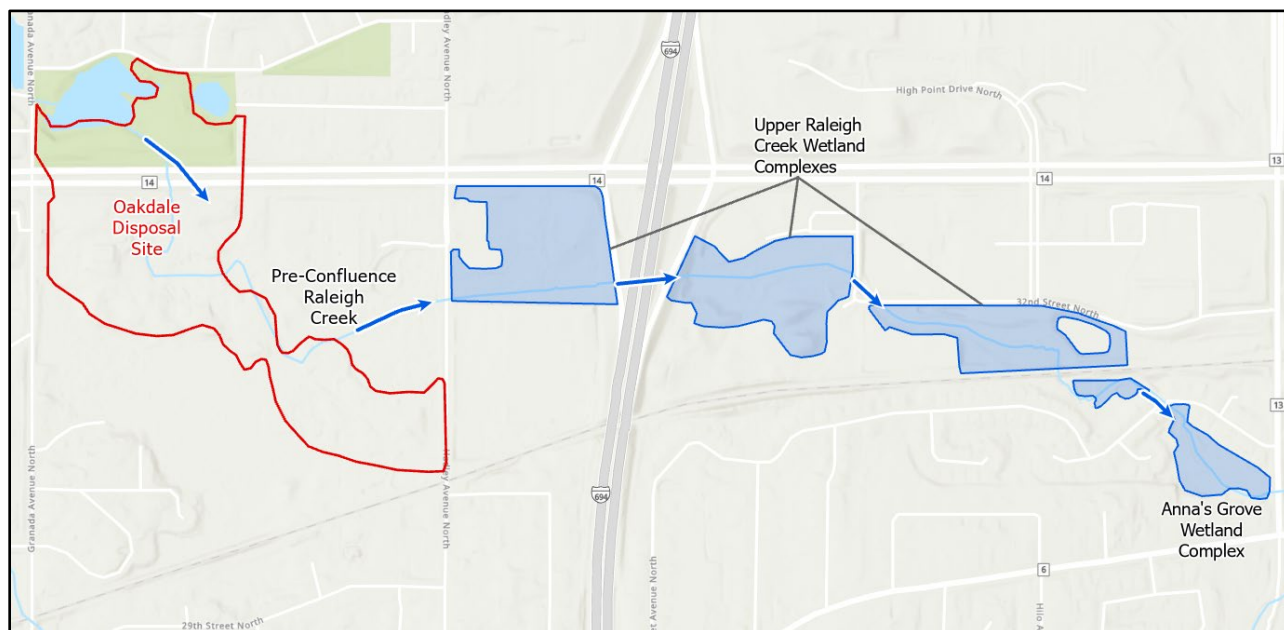


Figure 5.7: Raleigh Creek flow through Wetland Complexes east of ODS

Raleigh Creek continues to flow south-southeast through a series of culverts and incised channels prior to flowing into a fourth ponded wetland area located immediately west of Ideal Avenue, AGWC. This ponded wetland complex comprises an inlet channel under 31st Street North, two periodically flooded ponds, and an outlet structure that flows under Ideal Avenue. AGWC is bordered by residential properties to the west, north, and south. Surface water flow in Raleigh Creek downstream of Ideal Avenue toward Tablyn Park is ephemeral—the creek bed is typically dry except during periods of rainfall and seasonally during snow melt. For most of the year, the elevation of Raleigh Creek is above the water table, so it is characterized as a losing stream. Additional inputs of water to Raleigh Creek between ODS and Tablyn Park are primarily urban/surface runoff transported through open ditches and storm sewers to the creek channel.

The Tri-Lakes discharge provides nearly year-round surface water flow to post-confluence Raleigh Creek via the Project 1007 conveyance system. This results in continuous flow downstream of this point except during the winter months and periods of drought. The combined flow of Raleigh Creek and the Tri-Lakes discharge at Tablyn Park continues south into Lake Elmo Park Reserve, discharging into the northwest corner of Eagle Point Lake.

The geology beneath Raleigh Creek between ODS and Eagle Point Lake is complex with the first encountered bedrock varying throughout the area. The Decorah Aquitard thins and pinches out near the eastern edge of ODS, leaving the Platteville Aquitard as the first encountered bedrock, in which groundwater flow is primarily to the east. Where present, the Glenwood Shale underlying the Platteville Aquifer is a competent aquitard, limiting vertical migration until both units pinch out near AGWC. Where the Glenwood Shale is not present, groundwater within the Platteville Aquifer flows downward into the St. Peter Aquifer, increasing the groundwater elevation and creating a groundwater divide within the St. Peter Aquifer, which causes groundwater to flow both southeast and southwest from AGWC. Vertical groundwater migration can continue into the Shakopee Aquifer and through the “leaky” Oneota Aquitard to the Jordan Aquifer. The groundwater divides for the Shakopee and Jordan Aquifers are located further east than that of the St. Peter Aquifer. The St. Peter Aquifer thins near Eagle

Point Lake and becomes more fractured, further promoting vertical migration into the Shakopee Aquifer. Groundwater within the Shakopee and Jordan Aquifers generally flows to either the southeast, south, or southwest depending on the location.

5.4.3.1 Raleigh Creek – Migration Pathways

The migration pathways that contribute to and influence the spread of PFAS from Raleigh Creek between ODS and Eagle Point Lake are depicted in **Figure 5.8** and include:

- **[G]** PFAS-containing surface water flows to the east from the outfall at ODS to Tablyn Park where the combined flow from Project 1007 flows into Eagle Point Lake.
- **[H]** PFAS-containing surface water infiltrates and moves downward from Raleigh Creek into shallow groundwater aquifers, then migrates south into deeper drinking water aquifers within 0.3 miles.
- **[I]** PFAS-containing surface water contributes to the deposition or settling out of PFAS contamination into creek channel bottoms and wetland sediments resulting in elevated PFAS sediment concentrations. These appear to act as secondary sources where PFAS can accumulate and be intermittently released back into surface water over time.
- **[J]** PFAS-containing groundwater migrates within bedrock units. The groundwater flow direction in this area is variable and dependent on both the unit and the location relative to groundwater divides. In general, the groundwater flows to the south, shifting to the east closer to Eagle Point Lake.

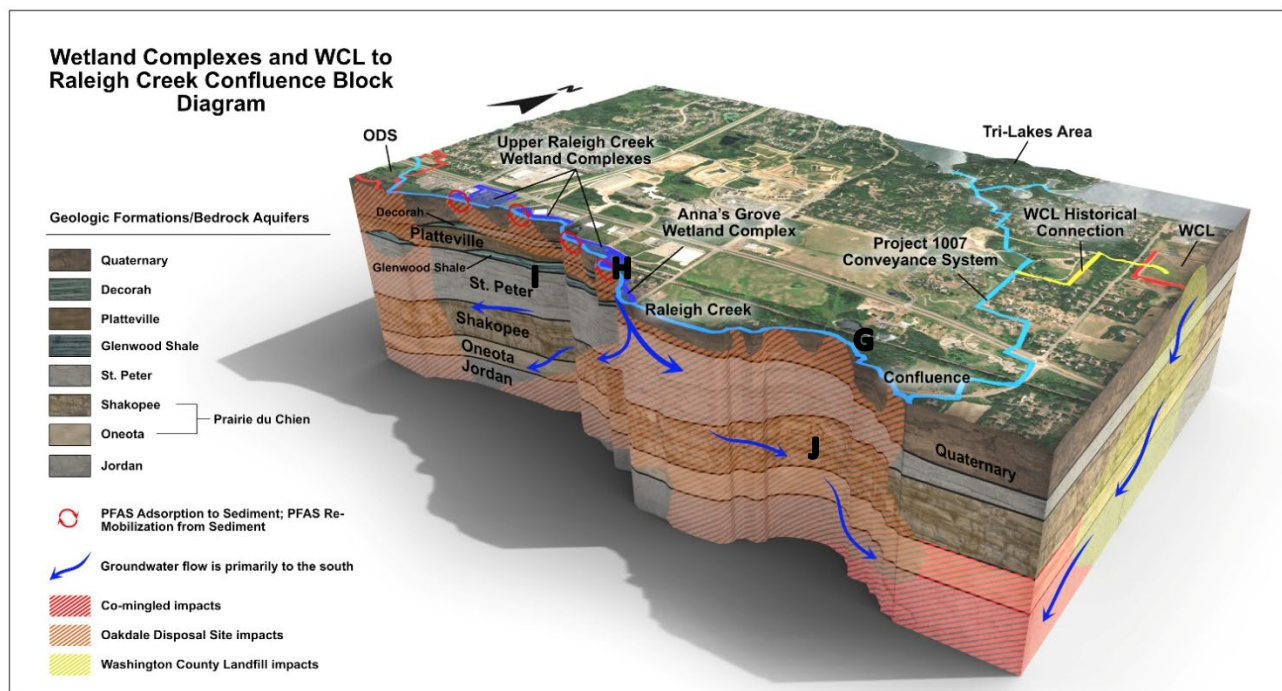


Figure 5.8: Raleigh Creek block diagram

5.4.3.2 [G] Raleigh Creek – PFAS Migration in Surface Water

Raleigh Creek flows from ODS through AGWC and out through a control structure when the water level is sufficiently high, providing a PFAS migration pathway to Eagle Point Lake. In Raleigh Creek, PFOS is the dominant PFAS and is present at concentrations as high as 8,810 ng/L at the outlet from ODS and generally decreases with distance from ODS to Tablyn Park; this section of Raleigh Creek has the highest PFOS concentrations observed in surface water in the Project 1007 area. Pre-confluence PFOS

concentrations at Tablyn Park have been as high as 3,880 ng/L during the monitoring period. Surface water sampling in conjunction with gauging stations indicate that PFAS concentrations in Raleigh Creek are influenced by the volume of flow in the creek, which is driven by seasonality and precipitation events. Generally, there are higher relative PFAS concentrations in Raleigh Creek during high stream flow and wet climate conditions and lower concentrations during low stream flow and dry conditions.

As flow within Raleigh Creek is not continuous downstream of AGWC, the PFAS input to the combined flow with the Tri-Lakes discharge via the Project 1007 conveyance system and subsequent input to Eagle Point Lake is variable. PFOS concentrations downgradient of the confluence at Tablyn Park have been as high as 4.5 ng/L when Raleigh Creek is not flowing past AGWC to 1,230 ng/L when Raleigh Creek is flowing continuously to Tablyn Park.

3M has plans to reroute Raleigh Creek around the Abresch Parcel to the wetland area near I-694. While this would reduce the PFAS load to Raleigh Creek, PFAS would still be expected to be transported downstream via Raleigh Creek after periods of high rainfall and snow melt. Additionally, PFAS resulting from sediment leaching (discussed below) would also continue to be transported downgradient.

5.4.3.3 [H] Raleigh Creek – PFAS Cycling Between Surface Water and Sediment

The movement of PFAS in Raleigh Creek is also influenced by the presence of PFAS in creek bottom and wetland sediments. PFAS contaminated sediments are found throughout Raleigh Creek. The highest PFAS sediment concentrations in the Project 1007 Corridor are observed in the wetlands closest to ODS in the Upper Raleigh Creek Wetland Complex (2,570 ug/kg PFOS, 123 ug/kg PFOA, 39.2 ug/kg PFBA). Deposition of PFAS from the water column occurs in the slower-moving surface waters typical of wetlands, allowing PFAS to adhere by adsorption to sediment particles. PFAS-contaminated sediments in Raleigh Creek and in downstream surface water bodies are identified as potential secondary sources of PFAS. Given the environmental persistence and continued presence of PFAS, these secondary sources, or PFAS sinks, can cycle PFAS between the surface water above and the groundwater below. Although the amount of PFAS in surface water and groundwater released and re-mobilized from sediment has not been measured as part of this investigation, slow releases of PFAS from sediment in Raleigh Creek continue to contribute to PFAS mass flux downstream.

5.4.3.4 [I] Raleigh Creek – PFAS Migration from Surface Water to Groundwater

Groundwater contamination originating from Raleigh Creek surface water infiltration begins as a separate and distinct plume with flow to the southeast from the groundwater contamination plumes at and directly below ODS, which flow to the south and southwest (**Figure 5.9**).

Groundwater PFAS impacts resulting from Raleigh Creek surface water infiltration are first observed in the Quaternary Aquifer to the east and downgradient of the Upper Raleigh Creek Wetland Complex. The horizontal extent of the PFAS plume within the Quaternary Aquifer is not delineated. As in Raleigh Creek, PFOS is the dominant PFAS in Quaternary Aquifer groundwater, indicating that the infiltration of surface water is contributing to the impacts observed in the Quaternary Aquifer.

In the Upper Raleigh Creek Wetlands, surface water may both infiltrate to shallow groundwater and discharge to the wetland surface water further downgradient. As there is consistent year-round flow through the wetlands, even when Raleigh Creek does not flow at a rate high enough to discharge from ODS upstream, groundwater discharge into the Upper Raleigh Creek Wetlands can be inferred. However, the extent and mechanisms of infiltration and discharge are not fully understood in this area.

Concentrations of PFAS in surface water at AGWC are similar to concentrations in Quaternary groundwater, indicating that infiltration occurs. In 2001, re-construction of Ideal Avenue included modifications to one of two Raleigh Creek culverts running underneath Ideal Avenue. The modifications reduced the volume of surface water that discharges to Raleigh Creek during high-flow events, ultimately increasing the volume of water held in AGWC. The increased infiltration of PFAS-impacted

surface water at AGWC further contributes to the PFAS mass in groundwater that migrates downgradient.

Between ODS and Tablyn Park, Raleigh Creek facilitates the movement of PFAS-impacted surface water away from the source area and, through infiltration, contributes to a groundwater plume that migrates to the east and southeast.

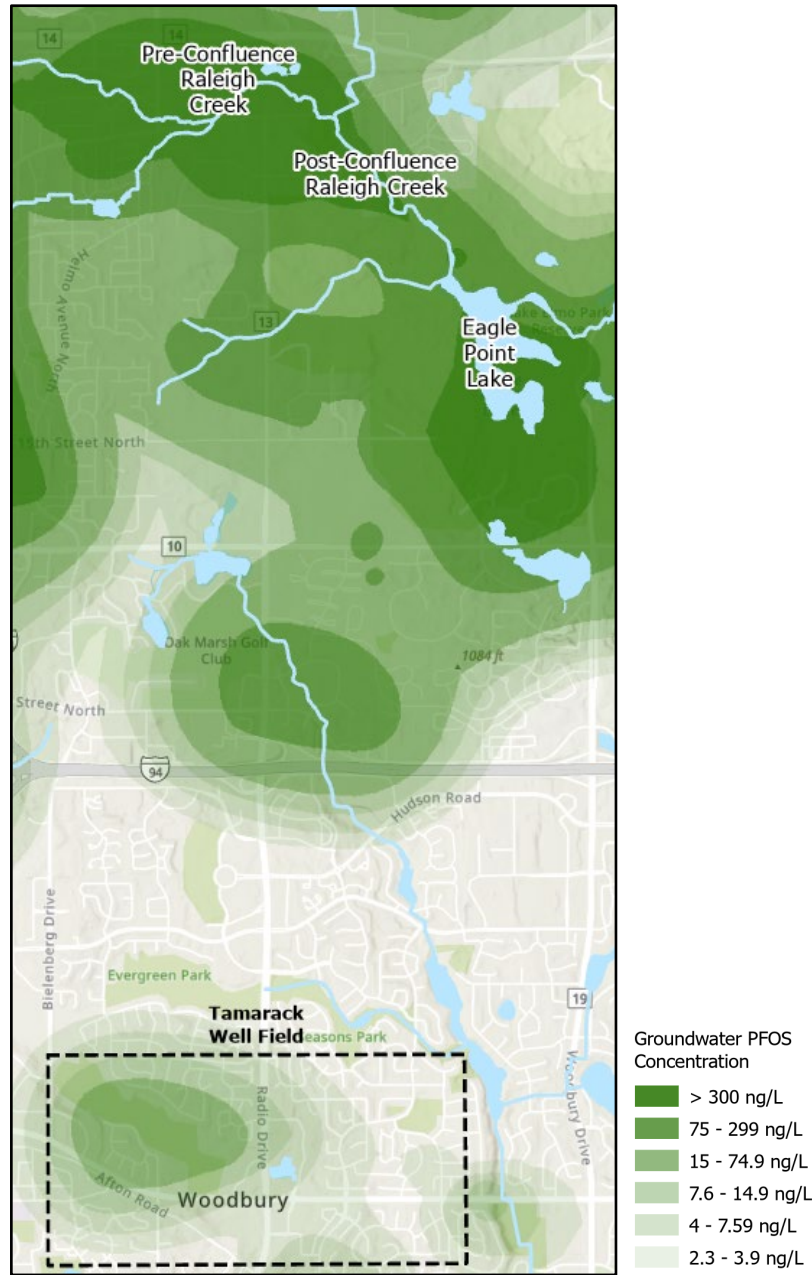


Figure 5.9: Raleigh Creek PFAS impacts in all groundwater aquifers

5.4.3.5 [J] Raleigh Creek – PFAS Migration in Bedrock Aquifers

The Quaternary Aquifer is hydrologically connected to the Platteville Aquifer west of AGWC and to the St. Peter Aquifer east of AGWC, facilitating the migration of PFAS into the bedrock aquifers. Groundwater in the Platteville Aquifer generally flows to the east with limited vertical migration, in part because of the Glenwood Shale Aquitard. Where both bedrock units thin and pinch out near AGWC, PFAS-impacted groundwater flows into the unsaturated St. Peter Aquifer, creating a groundwater

divide. This groundwater divide allows PFAS impacts carried through the Platteville Aquifer and those infiltrating from AGWC to form a dispersed plume that migrates southwest, south, and southeast from AGWC. Vertical migration through the St. Peter Aquifer and into the Shakopee Aquifers carries impacts to the south on either side of the groundwater divide. Impacts to the east of the groundwater divide co-mingle with the impacts resulting from infiltration from Eagle Point Lake, described in detail below.

Vertical migration continues through the Oneota Aquitard into the Jordan Aquifer. The highest contaminant concentration observed in Jordan and Shakopee wells south of Raleigh Creek reach 3,900 ng/L for PFOS, 760 ng/L for PFOA, and 2,200 ng/L of PFBA. Pumping at Oakdale Municipal Wells likely contributed to the vertical migration of PFAS into deeper bedrock aquifers immediately south of AGWC. The southern extent of the plume originating from WCL comingles with impacts observed in the bedrock aquifers. This comingling is discussed in Section 5.4.4.

5.4.4 Comingling of WCL and Raleigh Creek Groundwater Plumes

The mixing of groundwater impacts originating from different source areas in the aquifers near Tablyn Park is characterized by a shift in the distribution of PFAS compounds with depth.

5.4.4.1 Comingling of WCL and Raleigh Creek Groundwater Plumes – Migration Pathways

The migration pathways that contribute to and influence comingling of PFAS impacts are depicted in Figure 5.10 and include:

- [A] PFAS-containing groundwater migrates from WCL to the south and southeast. See Section 5.4.1 for details.
- [J] PFAS-containing groundwater migrates from Raleigh Creek to the south and east. See Section 5.4.3 for details.
- [K] Groundwater impacts from ODS and WCL comingling.

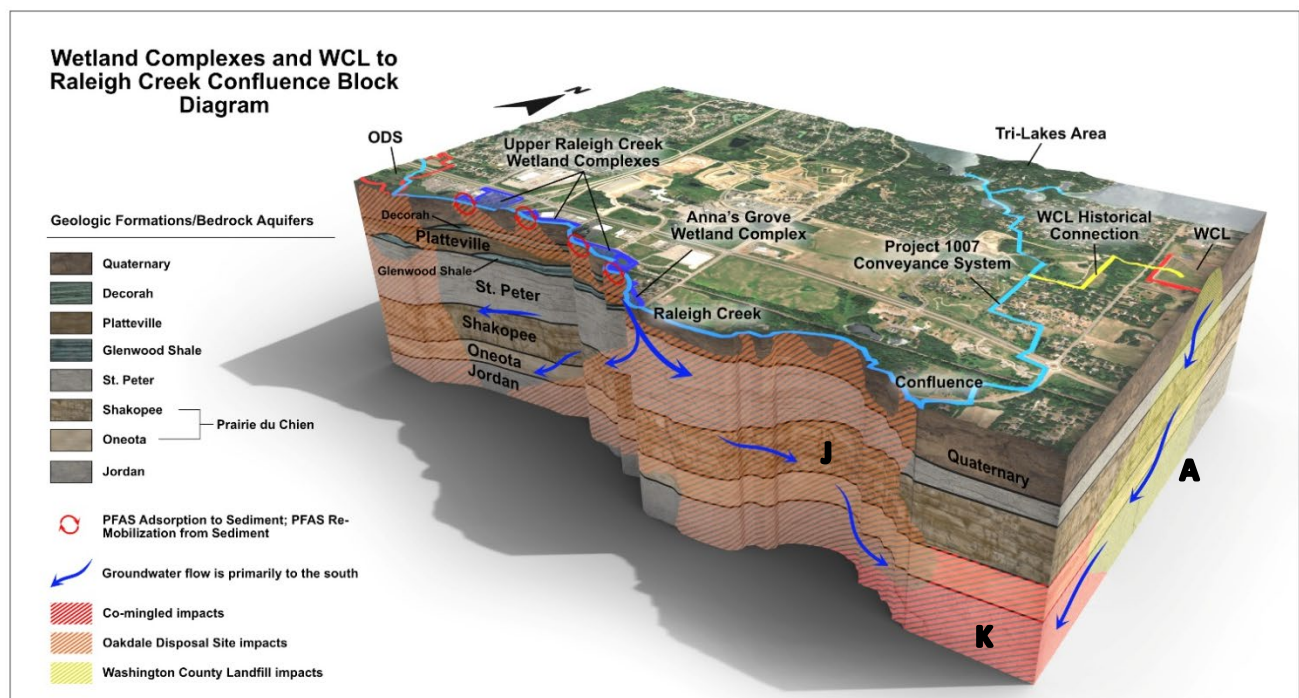


Figure 5.10: Comingling of ODS and WCL impacts block diagram

5.4.4.2 [K] Groundwater Impacts from ODS and WCL Comingling

The PFAS chemical signature of groundwater transitions from being PFOS dominated in the Quaternary and St. Peter Aquifers to having a higher proportion of PFBA and PFOA in the Shakopee Aquifer to having a PFBA-dominated signature in the Jordan Aquifer. This PFBA-dominant chemical signature, with higher concentrations of PFOA than PFOS in the Jordan Aquifer suggests impacted groundwater infiltrating from Raleigh Creek, which is PFOS dominant, has not yet migrated vertically to the Jordan Aquifer immediately below Tablyn Park. PFOS concentrations in Jordan Aquifer wells 0.7 mile downgradient of Tablyn Park, as high as 62.4 ng/L, indicate mixing has occurred within this distance. The precise location and depth where this mixing occurs is not known; however, the data collected in the Tablyn Park area advances the understanding of the groundwater migration pathway at this unique location in the Project 1007 Corridor. As the plume resulting from Raleigh Creek infiltration is observed to have higher concentrations of PFOS and PFOA within the Shakopee Aquifer at Tablyn Park and within the Jordan Aquifer further downgradient, it is difficult to determine the relative contributions of WCL and determine the distance from WCL that these impacts have migrated.

5.4.5 Eagle Point Lake

Eagle Point Lake is fed by both surface water and groundwater. The primary surface water input to Eagle Point Lake is the combined flow from Raleigh Creek and the Tri-Lakes discharge downstream of the confluence, which enters Eagle Point Lake at the northwestern inlet. Water also flows into Eagle Point Lake from Farney Creek along the northwestern side. Eagle Point Lake is in direct hydraulic connection with the shallow Quaternary Aquifer, receiving inflows from groundwater along the upgradient shore (north and west sides) and discharging surface water to groundwater via infiltration along the downgradient shore (south and east sides). Surface water exits Eagle Point Lake through a series of channels and small ponds eastward along the Project 1007 conveyance system. The primary surface water outlet from Eagle Point Lake is the 22-inch Project 1007 Eagle Point Lake discharge pipe, which runs along the bottom of Lake Elmo and discharges into a channel immediately east of Lake Elmo that flows toward Horseshoe Lake. A secondary outlet structure at the Eagle Point Lake Dam allows for the discharge of Eagle Point Lake water directly into Lake Elmo during high-water events. These inputs and outputs to Eagle Point Lake are shown in **Figure 5.11**.

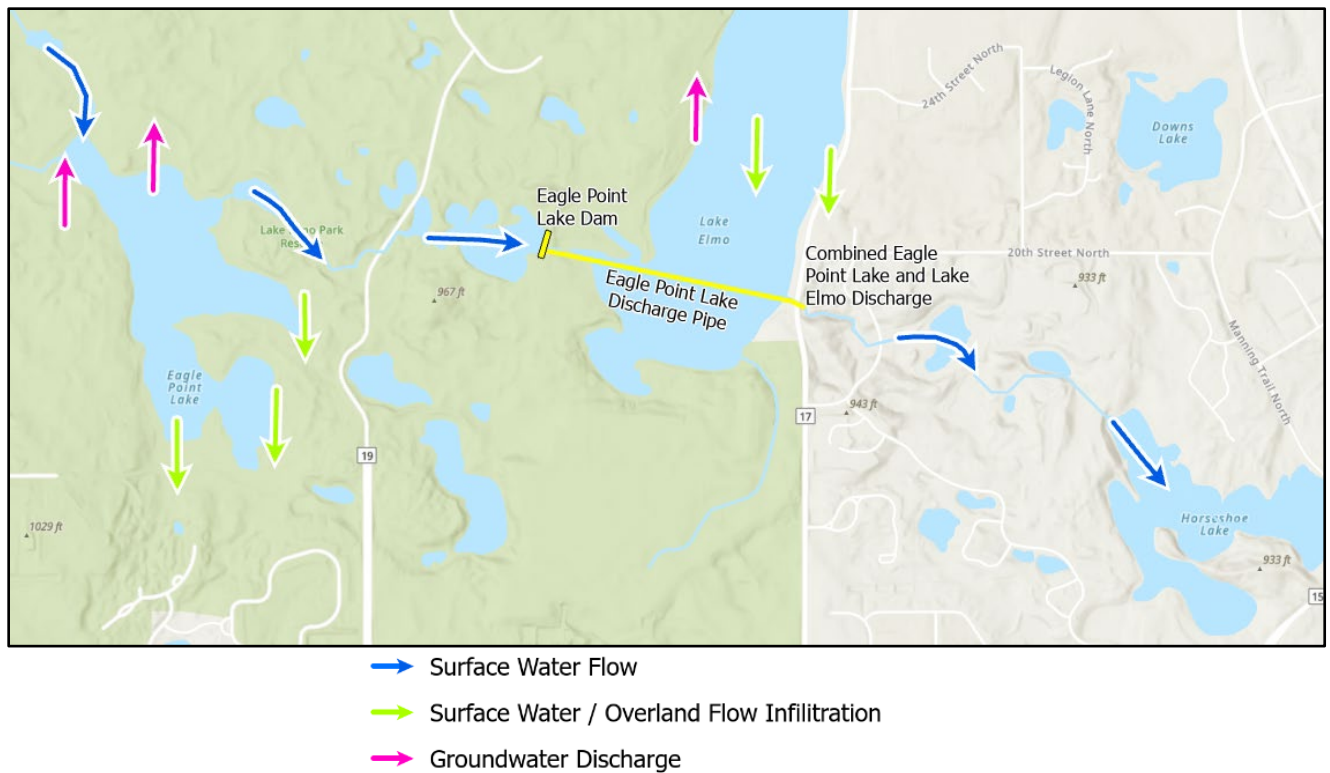


Figure 5.11: Eagle Point Lake to Horseshoe Lake hydrology

The St. Peter Aquifer is the first encountered bedrock immediately to the west and south of Eagle Point Lake, though it is discontinuous in the area and is not present east of Eagle Point Lake. In locations where the St. Peter Aquifer is not present, the Shakopee Aquifer is the first encountered bedrock. As the Shakopee Aquifer nears the bedrock valley to the east, it thins and becomes increasingly fractured, resulting in increased hydraulic connectivity between the Quaternary Aquifer and the underlying Jordan Aquifer. Groundwater flow in the Shakopee and the Jordan is generally to the south and southeast.

5.4.5.1 Eagle Point Lake – Migration Pathways

The migration pathways that contribute to and influence the spread of PFAS in the Eagle Point Lake geographic area are depicted in **Figure 5.12** and include:

- **[L]** PFAS present in Raleigh Creek surface water entering Eagle Point Lake.
- **[M]** The cycling of PFAS between sediment and surface water.
- **[N]** PFAS present in shallow groundwater discharging into Eagle Point Lake from the north and northwest.
- **[O]** Surface water flow out of Eagle Point Lake and downstream (east) toward Lake Elmo and Horseshoe Lake.
- **[P]** Eagle Point Lake surface water infiltration to groundwater.
- **[Q]** Groundwater flow from upgradient to downgradient that includes the continued downgradient migration of PFAS plumes to the south and southeast.

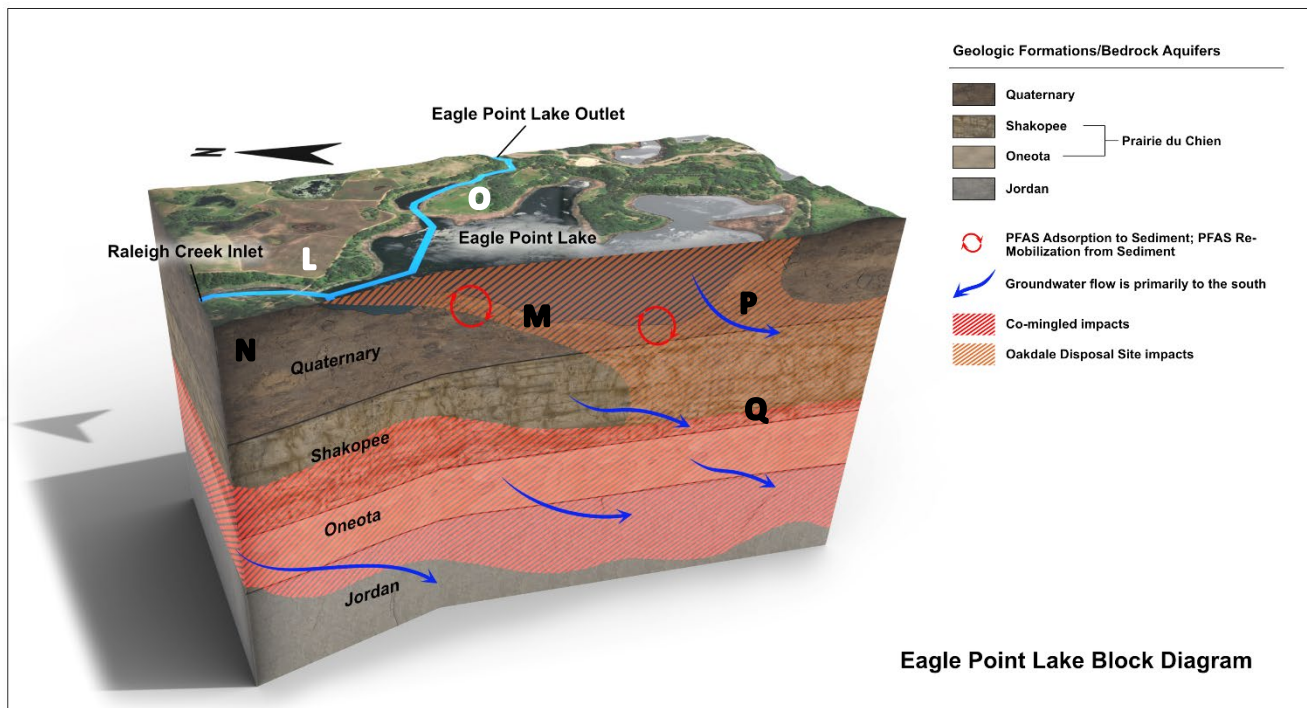


Figure 5.12: Eagle Point Lake block diagram; Quaternary groundwater flow is primarily to the east

5.4.5.2 [L] Eagle Point Lake – PFAS Migration in Surface Water

Raleigh Creek surface water is the primary migration pathway for PFAS to enter Eagle Point Lake. As discussed, the mass of PFAS entering Eagle Point Lake from Raleigh Creek fluctuates seasonally and with precipitation. It is also dependent on whether Raleigh Creek is flowing into the Project 1007 conveyance system at Tablyn Park. When this occurs, PFOS concentrations entering Eagle Point Lake from Raleigh Creek have been as high as 1,230 ng/L. Higher volumes of water flowing in Raleigh Creek correlate with a greater mass of PFAS entering Eagle Point Lake. When Raleigh Creek is not flowing at Tablyn Park, the PFOS concentrations entering Eagle Point Lake ranges from 2 ng/L to 6 ng/L and are a result of background PFAS concentrations that are observed in the Tri-Lakes discharge as discussed in 5.4.1.4 [C]. The influent PFAS concentrations were likely consistently higher when the groundwater pumping system at WCL discharged to Project 1007, as described in Section 5.4.1.

Even with the variable PFAS inflow to Eagle Point Lake, PFAS concentrations within the lake remain consistent, with PFOS concentrations varying from 112 ng/L to 1,340 ng/L in the discharge from Eagle Point Lake over the 5-year study period. PFAS concentrations across Eagle Point Lake are generally consistent, with the exception of elevated PFOS concentrations along the eastern edge of the lake, which have been as high as 5,340 ng/L. This elevated concentration along the downwind shoreline is likely the result of PFAS-containing foam generation and collection along the eastern edge, where it then collapses and reintroduces concentrated PFAS to bulk surface water. Foam is frequently observed along the eastern shoreline.

5.4.5.3 [M] Eagle Point Lake – PFAS Cycling Between Surface Water and Sediment

Raleigh Creek carries PFAS downstream to Eagle Point Lake, where a combination of sediment deposition due to slower flow conditions and adsorption of PFAS to lake sediment particles contributes to sediment PFAS loads. Eagle Point Lake sediments may be acting as a secondary PFAS source at the surface water-sediment interface and where PFAS infiltrates to groundwater. This movement of PFAS between surface water, sediment, and groundwater is influenced by the physical and chemical characteristics of the PFAS mixture, the sediment, and the water. The degree and rate at which PFAS is

adsorbed to and desorbed from sediment has not been evaluated as part of the initial Project 1007 investigation but should be completed before remedial alternatives are selected for Eagle Point Lake.

5.4.5.4 [N] Eagle Point Lake – PFAS Migration from Groundwater to Surface Water

Shallow groundwater discharge to surface water is an additional PFAS migration pathway into Eagle Point Lake. PFAS concentrations within the Quaternary Aquifer immediately upgradient (north and west) of Eagle Point Lake are lower in comparison to areas downgradient (south and east) of Eagle Point Lake (see **Figure 5.13**). The lower concentrations of PFAS in shallow groundwater discharging into Eagle Point Lake limit the contributions of this migration pathway to the total PFAS mass in the lake. The shallow groundwater PFAS impacts are likely a result of upgradient PFAS infiltration from Raleigh Creek to the Quaternary.

5.4.5.5 [O] Eagle Point Lake – PFAS Migration in Surface Water

Surface water flows downstream from Eagle Point Lake through a series of channels and small ponds eastward to the Eagle Point Lake Dam and then exits through the 22-inch Eagle Point Lake discharge pipe installed along the bottom of Lake Elmo. This pipe provides a direct connection of PFAS-containing surface water from Eagle Point Lake to the channel immediately east of Lake Elmo. From there, PFAS-containing surface water flows into Horseshoe Lake. Surface water can also exit Eagle Point Lake through a secondary outlet structure that discharges into Lake Elmo when water levels in Eagle Point Lake exceed an elevation of 896.5 feet. Prior to the Project 1007 conveyance system construction, all outflow from Eagle Point Lake was discharged directly to Lake Elmo.

5.4.5.6 [P] Eagle Point Lake – PFAS Migration from Surface Water to Groundwater

Eagle Point Lake surface water infiltration results in migration of PFAS mass from surface water to groundwater aquifers. Around Eagle Point Lake, higher PFAS impacts in the Quaternary and St. Peter Aquifers are observed predominantly on the downgradient (south and east) side of the lake (see **Figure 5.13**). The PFAS impacts in the Quaternary have a similar PFAS distribution to what is observed in Eagle Point Lake, supporting this migration pathway. The shallow impacts likely continue to migrate to the east and southeast with groundwater flow. As the St. Peter Aquifer is disconnected and highly fractured when present, this allows PFAS to migrate into the Shakopee Aquifer, as observed south of Eagle Point Lake. Vertical migration of PFAS into the Jordan Aquifer is facilitated by a heavily-fractured Oneota Aquitard in this area.

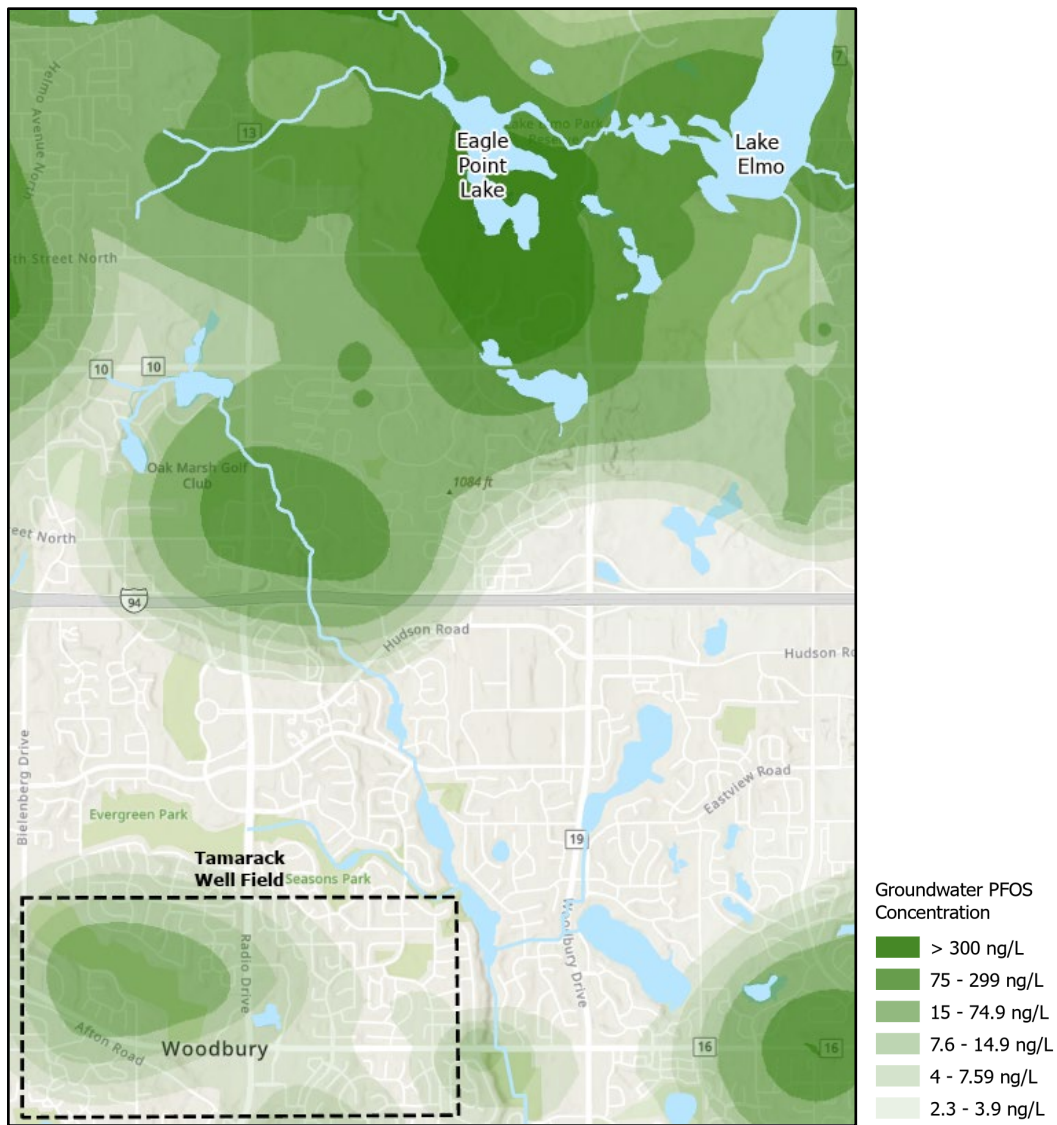


Figure 5.13: Eagle Point Lake PFAS impacts in all groundwater aquifers. The groundwater plume is not modeled as connected because of insufficient wells in this area. The detections within the Tamarack Well Field are likely a result of southerly PFAS migration.

5.4.5.7 [Q] Eagle Point Lake – PFAS Migration in Bedrock Aquifers

Groundwater flow in the Shakopee and Jordan Aquifers east of County Road 13 in this area is generally to the south/southeast. The Shakopee and Jordan Aquifers upgradient from Eagle Point Lake are impacted by the infiltration of Raleigh Creek surface water to groundwater, as discussed in **Section 5.4.3.4 [I]**. This plume migrates southeast from Raleigh Creek. As distance from the point of infiltration increases, the relative proportion of PFBA increases via the mechanisms discussed in **Section 5.2.3**. Impacts from WCL comingle with Raleigh Creek impacts upgradient of Eagle Point Lake as described in **Section 5.4.4**, also contributing to a higher proportion of PFBA. PFAS concentrations in the Shakopee Aquifer immediately upgradient of Eagle Point Lake exceed 140 ng/L for PFOS, 135 ng/L for PFOA, and 745 ng/L for PFBA. A relatively higher ratio in branched/linear analysis of PFOS in Shakopee and Jordan groundwater immediately upgradient of Eagle Point Lake supports characterization of this plume as longer travelled and without additional points of impacted surface water infiltration to groundwater.

Additionally, PFAS impacts directly from WCL may have migrated south within the bedrock aquifers. While particle tracking does not show PFAS migration to the south under current pumping conditions,

historical pumping was variable and groundwater flow direction in this area has been found to be sensitive to these conditions. Groundwater in the Jordan Aquifer 1 mile north of Eagle Point Lake was found to have PFOA and PFBA concentrations of 239 ng/L and 5,240 ng/L, respectively, indicating that impacts from WCL have migrated south toward Eagle Point Lake.

Impacted surface water in Eagle Point Lake infiltrates to groundwater and migrates vertically into the Shakopee and Jordan Aquifers, joining the existing plume that is discussed above (**Figure 5.14**). The relative proportion of PFBA in the groundwater downgradient of Eagle Point Lake decreases because of the infiltration of high-PFOS/PFOA surface water from the lake to the Shakopee and Jordan Aquifers. Comparatively higher PFBA concentrations may be attributed to increased comingling with WCL impacts on the east side of Eagle Point Lake. PFAS concentrations in the Shakopee Aquifer immediately downgradient of Eagle Point Lake exceed 1,130 ng/L for PFOS, 960 ng/L for PFOA, and 2,200 ng/L for PFBA. A relatively lower ratio in branched/linear analysis of PFOS in groundwater downgradient of Eagle Point Lake further supports the surface water to groundwater connection.

Although the groundwater analytical data available from the small number of Jordan Aquifer wells south of Eagle Point Lake is limited, groundwater modeling and simulated particle tracking supports the migration of PFAS-impacted groundwater south and southeast toward the Tamarack Well Field in Woodbury.

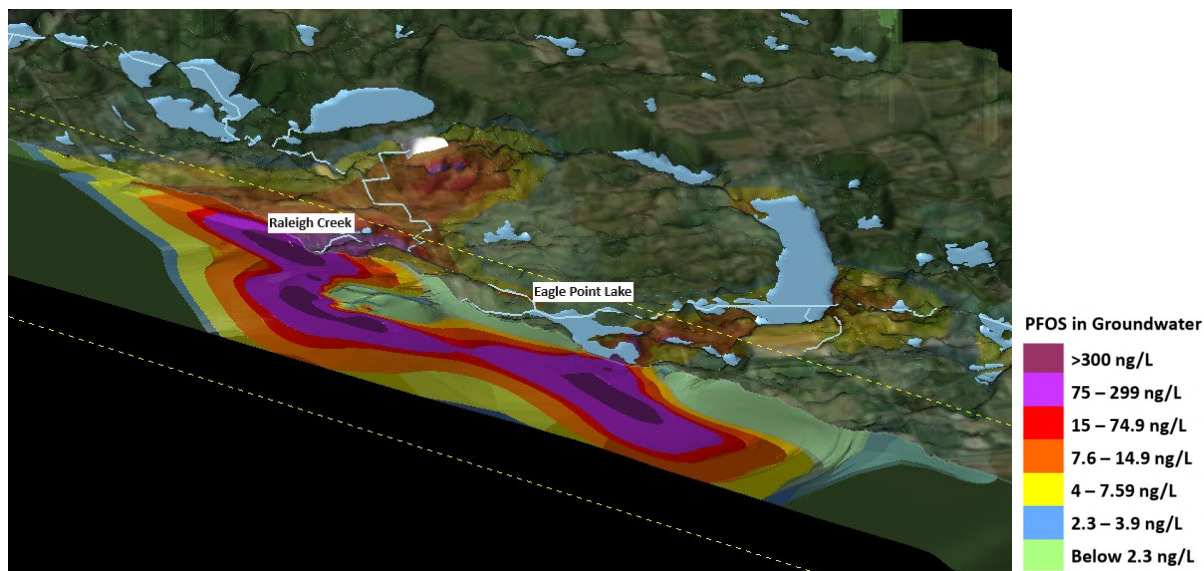


Figure 5.14: PFAS plume as modeled in Leapfrog, a 3D geologic modeling program. The hydraulic connection between deep impacts below Raleigh Creek and those below Eagle Point Lake are shown.

5.4.6 Lake Elmo

During the last glaciation, the bedrock valley beneath Lake Elmo was eroded as deep as the Jordan Aquifer, cutting through the overlying Shakopee Aquifer and Oneota Aquitard. After the glacial retreat, the bedrock valley was partially buried by Quaternary sediments, which now provide hydraulic connection as deep as 300 feet below ground surface to the deeper bedrock aquifers as preferential pathways of more permeable and transmissive materials. The bedrock valley is generally oriented north-south and has a shallower branch mapped to the east toward Horseshoe Lake as shown **Figure 5.15**. This shallower branch does not extend into the Jordan Aquifer.

Lake Elmo is primarily groundwater fed and receives water inputs from groundwater inflows in the northwest and west, with lesser amounts of water from precipitation and surface runoff into the lake. Shallow groundwater inflows from the northwest and includes groundwater flowing from Sunfish Lake. Groundwater also flows into Lake Elmo from the west due to the buried bedrock valley that creates a direct hydraulic connection to the Quaternary, Shakopee, and Jordan Aquifers. The only direct surface

water connection into Lake Elmo is the periodic discharge directly from Eagle Point Lake through the overflow structure at the Eagle Point Lake Dam, which provides a direct surface water connection from ODS to Lake Elmo during periods of high lake elevations and is discussed in more detail below.

Surface water exits Lake Elmo through infiltration into groundwater and discharges along the east side of the lake into the Quaternary Aquifer and the deeper Shakopee and Jordan Aquifers, a pathway facilitated by the presence of the bedrock valley. Surface water also exits Lake Elmo through an elevation control outflow pipe that discharges into the Project 1007 conveyance system at the same location as the Eagle Point Lake discharge pipe.

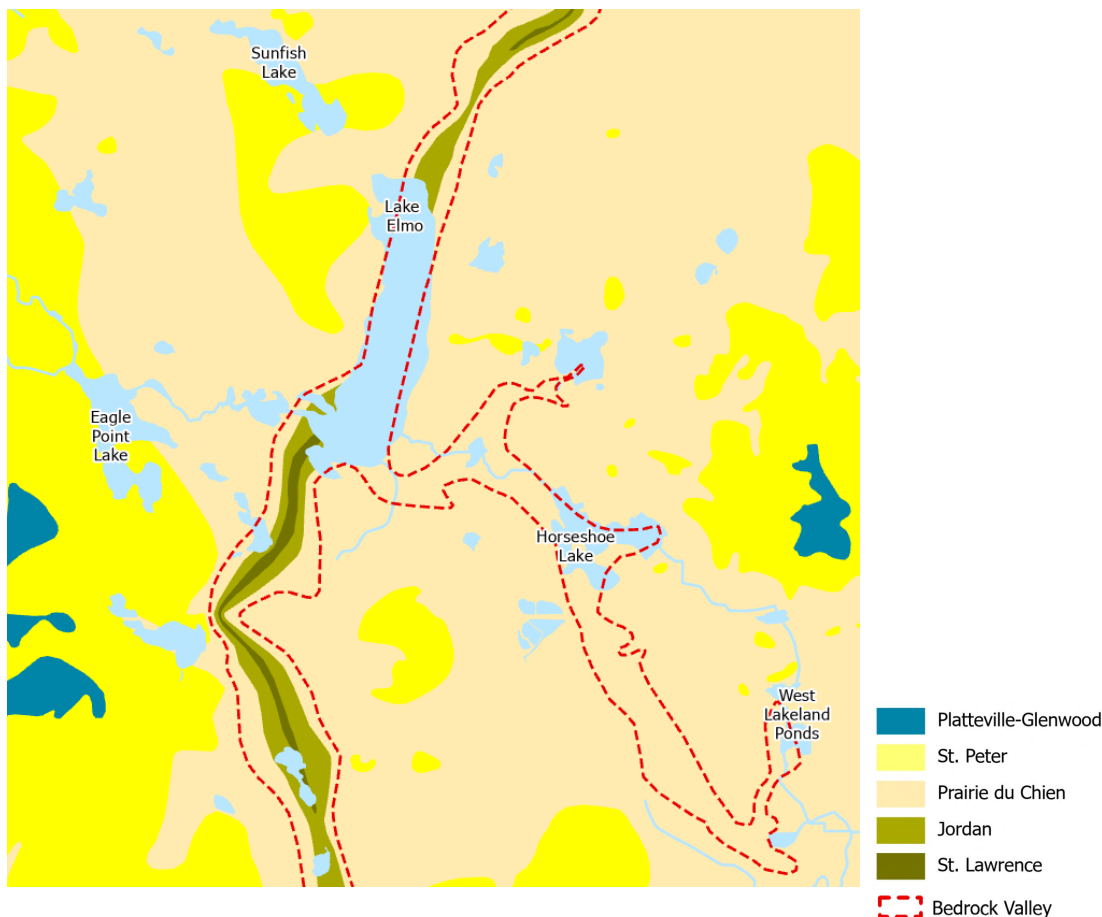


Figure 5.15: Extent of bedrock valley in project area and first encountered bedrock

5.4.6.1 Lake Elmo – Migration Pathways

The migration pathways that contribute to and influence the spread of PFAS in the Lake Elmo geographic area are depicted in **Figure 5.16** and include:

- **[R]** PFAS migrates into Lake Elmo through shallow groundwater discharge from the north and northwest, including water that has flowed through Sunfish Lake, as discussed in **Section 5.4.1**.
- **[S]** PFAS-containing groundwater discharges from bedrock aquifers into Lake Elmo via the bedrock valley hydraulic connection.
- **[T]** PFAS present in Raleigh Creek/Eagle Point Lake surface water enter Lake Elmo through the overflow structure at Eagle Point Lake Dam during periods of higher rainfall and snowmelt.

- [U] Surface water infiltration to aquifers downgradient of Lake Elmo allows for the migration of PFAS to the east of Lake Elmo in the unconsolidated Quaternary Aquifer and deeper bedrock aquifers.
- [V] Surface water containing PFAS discharges through an elevation control structure along the southeast shore of Lake Elmo where it combines with flow from the Eagle Point Lake discharge pipe and flows toward Horseshoe Lake.

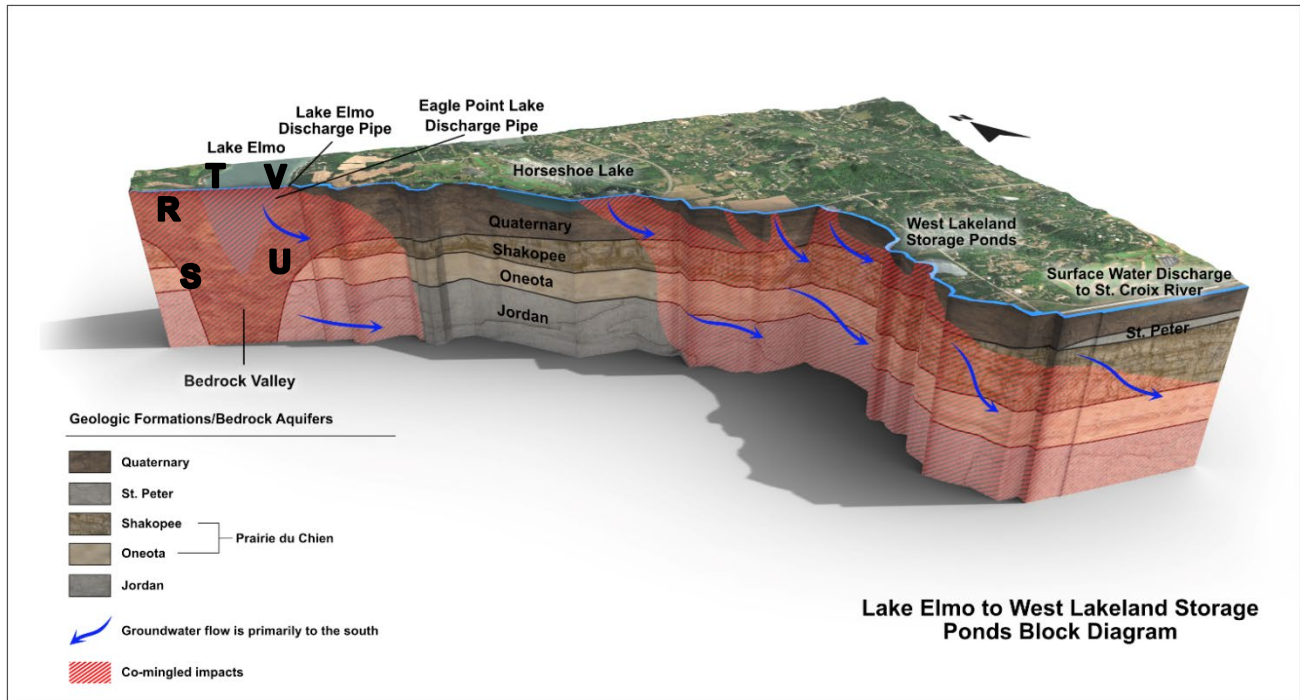


Figure 5.16: Lake Elmo block diagram

5.4.6.2 [R] Lake Elmo – PFAS Migration from Shallow Groundwater to Surface Water

Shallow groundwater carries PFAS southeast from WCL to the north-northeast end of Lake Elmo where it discharges to surface water. The PFAS distribution in Lake Elmo is PFBA dominant, further supporting the migration pathway of PFAS from WCL to Lake Elmo. PFBA concentrations observed in Lake Elmo are elevated compared to other locations within the Project 1007 Corridor, including within Raleigh Creek. Sunfish Lake is the only surface water location with higher observed PFBA concentrations, which are attributable to the same shallow groundwater migration pathway.

5.4.6.3 [S] Lake Elmo – PFAS Migration from Bedrock Aquifers to Surface Water

PFAS-containing groundwater discharges into Lake Elmo from the west and northwest, likely from the Shakopee Aquifer and Oneota Aquitard, and possibly from the Jordan Aquifer. Migration of PFAS impacts into these aquifers was likely facilitated by an increased vertical hydraulic gradient caused by pumping at Lake Elmo Municipal Well #1, which is located directly north of Lake Elmo. The bedrock valley provides a hydraulic connection between the bedrock aquifers and the surface water body, which is up to 140 feet deep.

The PFAS plume west of Lake Elmo is associated with several previously described migration pathways, infiltration and surface water discharge from Raleigh Creek, infiltration to and migration within bedrock beneath WCL, and PFAS migration to bedrock from Eagle Point Lake (Figure 5.17). These pathways include impacts from both ODS and WCL. The relative contribution of each source to Lake Elmo impacts is currently unknown. The PFAS distribution in bedrock aquifers (Shakopee and Jordan) immediately

west of Lake Elmo is relatively higher in PFOS than wells that are solely associated with WCL impacts; PFAS concentrations exceed 270 ng/L of PFOS, 130 ng/L of PFOA, and 1,070 ng/L of PFBA. The branched/linear ratio of PFOS isomers observed in bedrock aquifer wells is also characteristic of a groundwater plume that has traveled far from ODS impacts as opposed to WCL impacts. The limited number of monitoring wells between Eagle Point Lake, Lake Elmo, and WCL limits the understanding of comingling in this area and the migration of PFAS-contaminated groundwater that discharges to Lake Elmo.

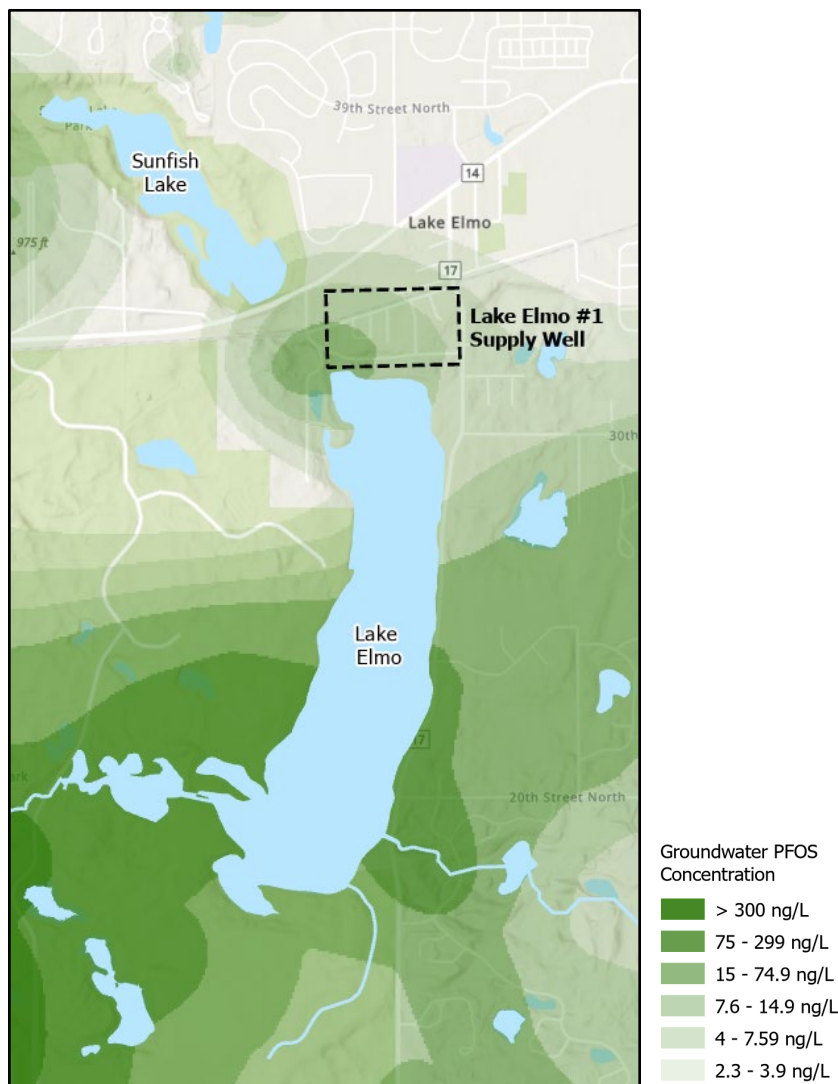


Figure 5.17: Lake Elmo PFAS impacts in all groundwater aquifers. Darker green indicates higher PFAS concentrations. The approximate location of the Lake Elmo #1 Supply Well (now sealed) is shown.

5.4.6.4 [T] Lake Elmo – PFAS Migration in Surface Water

As part of Project 1007, the Eagle Point Lake Dam and its associated discharge pipe were designed to convey approximately 90% of anticipated surface water outflow from Eagle Point Lake under Lake Elmo. Precipitation and snowmelt can increase the water level in Eagle Point Lake beyond 896.5 feet above sea level, at which point it flows through the overflow structure at the dam and directly into Lake Elmo. PFAS loading to Lake Elmo by this pathway has been variable since disposal activities at ODS and WCL began due to the manipulation of surface water drainage systems. The earthen Eagle Point Lake Dam was constructed from 1980 to 1986; Project 1007 was completed in 1987. As discussed, the WCL Historical Connection was connected to Project 1007 from 1988 to 1995. On 11 occasions between 1987

and 2023, high seasonal precipitation events of variable duration have discharged Eagle Point Lake surface water through the overflow structure.

Historically high precipitation in the past 10 years has resulted in the wettest 5 years on record from 2015 to 2019, with 2019 being the wettest year on record for the central Valley Branch Watershed District (VBWD) (VBWD, 2023). Wetter climate conditions associated with climate change are likely to increase the frequency and duration of Eagle Point Lake overflow into Lake Elmo (USACE, 2023) The absence of consistent PFAS sampling from Lake Elmo prior to 2015 limits the assessment of Eagle Point Lake overflow impacts in recent years. In the 4 years since the Project 1007 investigation began, PFAS concentrations in Lake Elmo surface water have remained largely stable. PFAS concentrations in Lake Elmo prior to the construction of Project 1007 are unknown.

5.4.6.5 [U] Lake Elmo – PFAS Migration from Surface Water to Groundwater

PFAS-containing surface water infiltrates from Lake Elmo through the Quaternary Aquifer and into the Shakopee Aquifer, Oneota Aquitard, and the Jordan Aquifer, flowing to the east. Surface water PFAS concentrations are as high as 320 ng/L for PFOS, 90 ng/L for PFOA, and 1,170 ng/L for PFBA. Elevated PFAS impacts in residential Shakopee wells immediately east of Lake Elmo support this migration pathway. The extent of vertical migration from the Shakopee Aquifer through the Oneota Aquitard and into the Jordan Aquifer is unknown due to a lack of PFAS sampling locations. Data from residential wells farther east of the lake indicate impacts taper off with distance. Lake Elmo infiltration to groundwater is not fully understood, but it is not anticipated to be a large contributor to groundwater PFAS plume migration east of the lake.

5.4.6.6 [V] Lake Elmo – PFAS Migration in Surface Water Downstream into Project 1007 Conveyance System

Surface water exits Lake Elmo through the Lake Elmo outlet pipe and the elevation control structure near the southeast corner of the lake. It discharges into the Project 1007 conveyance system immediately east of Lake Elmo Avenue North. The Lake Elmo outlet pipe discharges at the same location as the Eagle Point Lake discharge pipe. The Lake Elmo outlet pipe provides a direct connection of PFAS-containing surface water from Lake Elmo to the channel immediately east of Lake Elmo. From there, PFAS-containing surface water flows toward Horseshoe Lake.

5.4.7 Horseshoe Lake/West Lakeland Storage Ponds

The combined discharge of Lake Elmo and Eagle Point Lake flows through a channel into a series of pipes and ponds before discharging to the western end of Horseshoe Lake. Surface water discharges from Horseshoe Lake through an elevation control structure at the far eastern edge of the lake into a culvert under Manning Avenue. It then flows through the open channels and pipes of the Project 1007 conveyance system before discharging to the North Pond. Once in the North Pond, surface water flows south through Project 1007-widened and deepened channels to the Middle Pond and South Pond, then into the Minnesota Department of Transportation (MnDOT) I-94 drainage system. These ponds are collectively referred to as the West Lakeland storage ponds. Water is continuously piped in the MnDOT I-94 drainage system to its discharge point at the St. Croix River north of I-94, except for a pond located behind the interstate rest stop. This is shown in **Figure 5.18**.

In addition to the movement of surface water through the Project 1007 conveyance system, surface water infiltrates to groundwater in Horseshoe Lake, the West Lakeland storage ponds, and the channels that connect the ponds. Relatively high infiltration rates have been measured around the storage ponds, facilitating the conveyance system design function of providing groundwater recharge, water storage, and dissipating runoff from upstream watersheds (VBWD, 2015). Groundwater flow within the Quaternary Aquifer in this area is largely to the east.

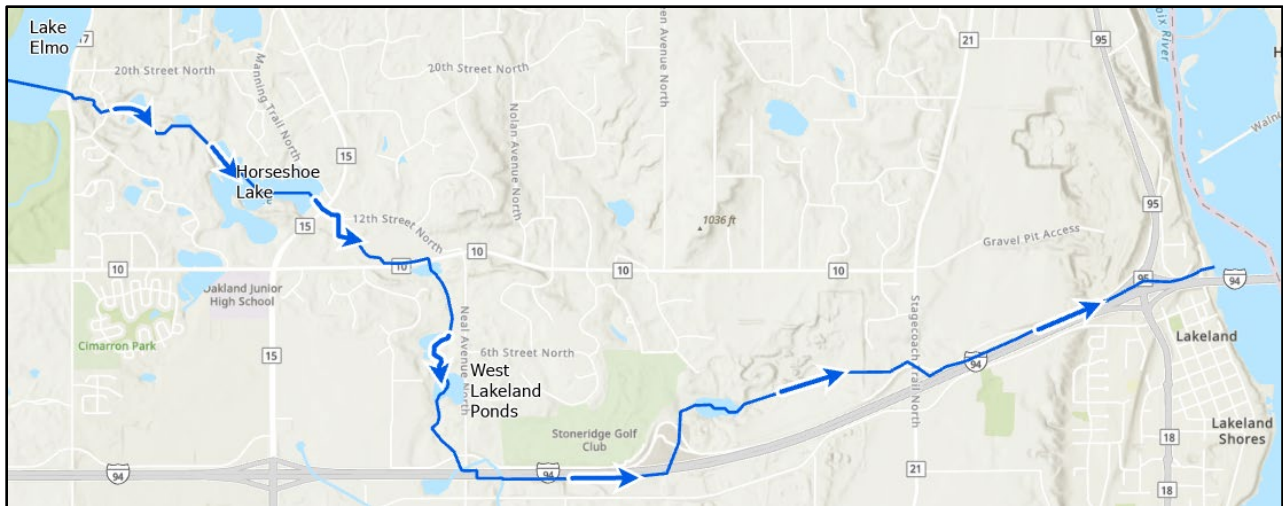


Figure 5.18: Project 1007 conveyance system. The conveyance system east of Lake Elmo to its connection with the MnDOT I-94 drainage system. The system and its discharge point at the St. Croix River is shown.

Prior to the construction of Project 1007, discharge from Lake Elmo followed a natural flow path into Horseshoe Lake followed by a wetland area within West Lakeland to the east and southeast of Horseshoe Lake. These wetlands were likely the headwaters of the north branch of Valley Creek, which flows south through Edith Lake and to the St. Croix River. Valley Creek surface water has shown low detections of PFAS impacts to date in this study period. The southern branch of Valley Creek is a high-value trout stream and receives groundwater discharge from the Jordan Aquifer. High-quality surface water in Valley Creek is directly related to the Jordan Aquifer discharge, which has negligible PFAS impacts in this area.

The Shakopee formation is the first encountered bedrock around Horseshoe Lake and the West Lakeland storage ponds. Generally, the Shakopee Aquifer is encountered first, though it is weathered away in some areas such that the Oneota Aquitard is the first encountered bedrock. A branch of the bedrock valley discussed in the previous section is mapped to extend under Horseshoe Lake and is correlated with increased weathering and fractures within the Prairie du Chien, creating increased vertical connectivity to the Jordan Aquifer. Groundwater flow in bedrock aquifers is generally to the east in this area.

5.4.7.1 Horseshoe Lake/West Lakeland Storage Ponds – Migration Pathways

The migration pathways contributing to and influencing the spread of PFAS through Horseshoe Lake and the West Lakeland storage ponds and within groundwater are depicted in **Figure 5.19** and include:

- **[W]** PFAS-containing surface water discharges from Eagle Point Lake via the Eagle Point Lake discharge pipe and from Lake Elmo via the Lake Elmo outlet pipe.
- **[X]** Infiltration of PFAS-impacted surface water to groundwater from Horseshoe Lake, the West Lakeland storage ponds, and connecting channels to the Quaternary Aquifer and subsequent vertical migration to bedrock aquifers.
- **[Y]** Migration of PFAS within bedrock aquifers to the east.
- **[Z]** Discharge of PFAS-impacted surface water to the St. Croix River.

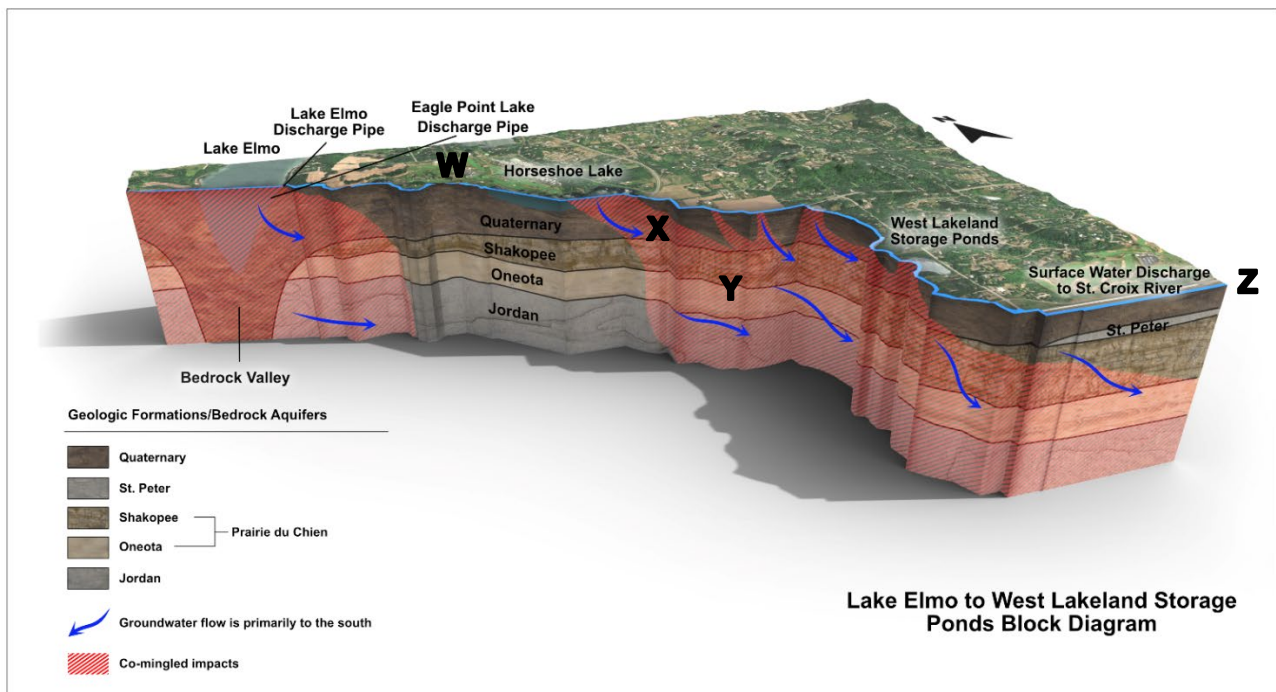


Figure 5.19: Horseshoe Lake and West Lakeland storage ponds block diagram. Red plume indicates co-mingled impacts from WCL and ODS.

5.4.7.2 [W] Horseshoe Lake/West Lakeland Storage Ponds – PFAS Migration in Surface Water

The Lake Elmo outlet pipe discharges at the same location as the Eagle Point Lake discharge pipe upgradient of Horseshoe Lake. The two surface water discharges have distinct PFAS chemical signatures – Eagle Point Lake discharge water has relatively high PFAS concentrations and is dominated by PFOS (characteristic of ODS) and Lake Elmo discharge water has comparatively low PFAS concentrations and is dominated by PFBA (characteristic of WCL). Consequently, the resulting PFAS concentrations and relative distributions in the mixed effluent of these surface water bodies that are observed downstream in the Project 1007 conveyance system surface water are different from upgradient locations within the corridor. PFOA concentrations are similar within the effluent of Lake Elmo and Eagle Point Lake. Influent water to Horseshoe Lake during the study period had PFAS concentrations as high as 210 ng/L for PFOS, 78 ng/L for PFOA, and 490 ng/L for PFBA.

Since PFAS disposal at ODS began in the late 1950s, a surface water migration pathway has connected ODS to Horseshoe Lake and the West Lakeland area through Raleigh Creek, Eagle Point Lake, and Lake Elmo. The volume of surface water and associated mass of PFAS conveyed beyond Lake Elmo increased after construction of the Project 1007 conveyance system and the Eagle Point Lake discharge pipe in 1987. Prior to construction, it is likely that PFAS-containing surface water from Eagle Point Lake would have been diluted over the course of its natural path through Lake Elmo toward Horseshoe Lake. The Eagle Point Lake discharge pipe provided a direct pathway for surface water in Eagle Point Lake to enter the conveyance system east of Lake Elmo to Horseshoe Lake and may have resulted in relatively higher PFAS concentrations in Horseshoe Lake and the West Lakeland Ponds. The extent to which this has occurred is uncertain. Over the study period, the maximum surface water PFAS concentrations from Horseshoe Lake to the West Lakeland storage ponds range from 735 ng/L for PFOS, 190 ng/L for PFOA, and 980 ng/L for PFBA.

5.4.7.3 [X] Horseshoe Lake/West Lakeland Storage Ponds – PFAS Migration from Surface Water to Groundwater

Infiltration of PFAS-impacted surface water to groundwater is the primary migration pathway contributing to the plume beneath Horseshoe Lake and the West Lakeland Ponds. The ponds and channels in this area were sited and designed to increase surface water infiltration to ground as part of larger flood mitigation efforts in West Lakeland. The Shakopee Aquifer and Oneota Aquitard are highly fractured in this area, facilitating rapid migration from the Quaternary Aquifer to the Jordan Aquifer. A high density of residential wells pumping from the Jordan Aquifer in the area likely contribute to vertical migration as well. High PFAS concentrations in the Shakopee and Jordan Aquifers downgradient of surface water features exhibit branched/linear ratios that are characteristic of recent surface infiltration, as opposed to a longer traveled groundwater plume, as described in **Section 5.4.2**. PFAS concentrations in Shakopee and Jordan wells between Horseshoe Lake and the West Lakeland storage ponds exceed 250 ng/L for PFOS, 140 ng/L for PFOA, and 640 ng/L for PFBA.

PFAS impacts in groundwater upgradient of Horseshoe Lake and the West Lakeland storage ponds are low, further indicating that observed groundwater impacts are due to infiltration at these locations rather than plume migration associated with Lake Elmo impacts.

5.4.7.4 [Y] Horseshoe Lake/West Lakeland Storage Ponds – PFAS Migration in Bedrock Aquifers

Once PFAS impacts migrate into the Shakopee and Jordan Aquifers, they continue to migrate eastward affecting private drinking water supply wells in West Lakeland until the Cottage Grove Fault, which is the eastern extent of these aquifers, as shown in **Figure 5.20**. There is evidence of PFAS east of the fault, but whether the impacts are directly related to Project 1007 is unclear. Data in this area are limited and additional investigation is needed to understand the hydrogeologic mechanisms by which PFAS may be migrating to bedrock east of the fault.

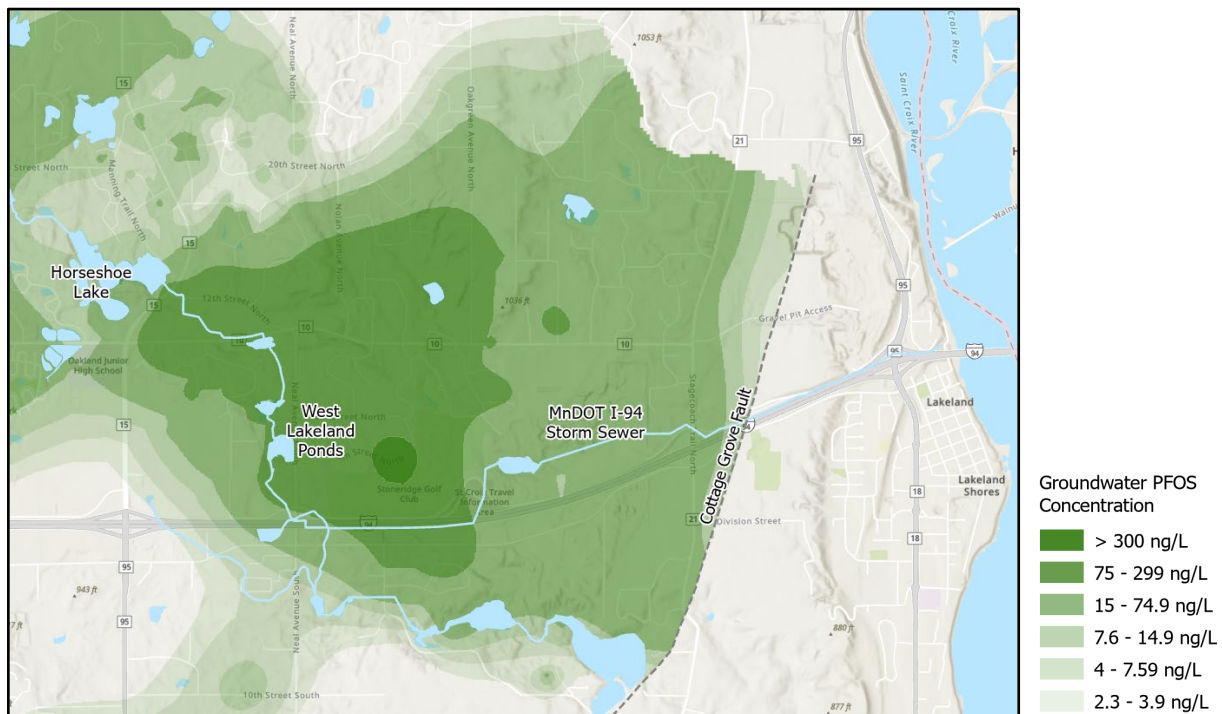


Figure 5.20: Horseshoe Lake and West Lakeland storage ponds PFAS impacts in groundwater. Darker green indicates higher PFAS concentrations. Observed impacts east of the Cottage Grove fault (grey line) are not shown because the hydraulic connectivity is not well understood.

5.4.7.5 [Z] Horseshoe Lake/West Lakeland Storage Ponds – PFAS Migration in Surface Water to St. Croix River

PFAS impacts enter the St. Croix River at the outfall of Project 1007, located north of the I-94 bridge. PFOS, PFOA, and PFBA concentrations at the outfall were observed to be low relative to surface water upstream in Project 1007 when sampled in 2019, ranging from below detection to 37.7 ng/L, below detection to 17.7 ng/L, and below detection to 102 ng/L, respectively. Detections of PFAS downstream of the outfall are inconsistent due to dilution of the Project 1007 effluent.

6 Evaluation of Surface Water, Sediment, and Groundwater Restoration Potential

Enhancing the quality, quantity, and sustainability of drinking water in the East Metro is the highest priority (Priority 1) of the Settlement. To accomplish this priority, the Conceptual Drinking Water Supply Plan (CDWSP) identifies long-term goals that include recommendations for projects that will provide safe, sustainable drinking water and minimize long-term cost burdens for the 14 communities affected by per- and polyfluoroalkyl substances (PFAS) (MPCA, 2021). These projects have been implemented or are planned for implementation as part of expedited or major capital projects and focus on providing safe drinking water by installing new wells, constructing or upgrading water treatment plants, connecting residents to public water supplies, and supplying point of entry treatments systems (POETSs) to select private well owners.

These expedited and major capital projects were not intended to clean up PFAS-contaminated groundwater within the aquifers prior to extraction for drinking water supply or to prevent further PFAS plume migration. These projects also do not address the underlying causes of the PFAS contamination in the East Metro, which include existing PFAS contamination at the former PFAS disposal areas (specifically Oakdale Disposal Site [ODS] and Washington County Landfill [WCL]) and large PFAS masses that have accumulated in sediment, surface water, and groundwater as a result of decades of PFAS migration from the disposal sites. PFAS continues to leave ODS via surface water at Raleigh Creek and groundwater based on well sampling results immediately downgradient of ODS. The majority of the WCL waste has been moved to a lined landfill, although higher concentrations of PFAS remain in the groundwater near the landfill that will continue to migrate downgradient. These disposal sites have resulted in widespread surface water and groundwater impacts. The groundwater impacts are the primary focus of this FS and are detailed in the Project 1007 Remedial Investigation (RI) Report (**Appendix C**) and summarized in **Section 5** of this FS.

To achieve the Priority 1 objective of enhancing the quality, quantity, and sustainability of drinking water in the East Metro, PFAS migration must be limited and PFAS concentrations within drinking water aquifers must be reduced. The extent to which this is technically practicable with regards to the reduction of PFAS concentrations within the current plume footprint is uncertain. Achieving drinking water standards within the aquifers, as opposed to at the tap, is not feasible within a reasonable timeframe as remedial alternatives must overcome existing conditions that will impact both long-term and short-term effectiveness, including:

- Releases from former disposal areas ODS and WCL continue to discharge PFAS to groundwater and/or surface water.
- The widespread, regional distribution of PFAS contamination in multiple drinking water aquifers.
- The widespread distribution and accumulation of PFAS contamination in sediments in wetlands and surface water bodies throughout the Project 1007 Corridor potentially acting as secondary sources contributing to PFAS migration.
- Recalcitrance of PFAS in environmental media.
- Restrictions to groundwater pumping that may impact White Bear Lake as required by the court order.

However, these challenges should not prevent implementation of remedial measures to reduce PFAS concentrations within the drinking water aquifers. When restoration of groundwater to beneficial uses is not practicable within a timeframe that is reasonable given the circumstances of the Site (EPA, 1988), preventing further migration of the plume and spread of PFAS through surface water and groundwater

should be the focus of the remedial alternatives. Reducing current concentrations is a component of preventing continued migration and has the additional benefit of reducing treatment requirements and costs to communities who currently treat their municipal supply wells for PFAS. This and preventing additional communities from requiring treatment for PFAS in the future is a realistic goal when limiting or removing downgradient migration.

The remedial alternatives analyzed in this FS address two considerations. The first consideration is to evaluate what technologies are commercially available to treat PFAS in the different impacted media contributing to the drinking water aquifers. The second consideration is to determine where and to what extent treatment should occur as preventing further migration of PFAS contamination could be accomplished with varying degrees of effectiveness through both regional and location-specific remediation approaches. An example of a regional approach is the implementation of a large pump and treat system. This, described later in this FS as the Multi-Benefit Well Array (MBWA) system, would achieve all four Priority 1 long-term goals. It would provide safe drinking water to residents, protect/improve groundwater quality by way of preventing further plume migration, and include a purpose-built municipal drinking water supply system, providing sufficient drinking water to meet current and future demand while minimizing long-term cost burdens for affected communities (**Section 2.2**). Alternatively, location-specific remediation approaches could be implemented to control specific areas of the plume posing the biggest risk to downgradient communities. Smaller-scale remedial alternatives offer advantages to the region-wide alternatives as a result of lower costs and more flexible implementability considerations; however, the effectiveness of smaller scale remedial approaches do not control the further spread of PFAS to the same extent as a regional approach. Other remedial approaches can also address surface water and sediment impacts with opportunities to reduce the continued downgradient migration of PFAS impacts. Remedial alternatives for these media range from inexpensive alternatives (rerouting of Raleigh Creek) to expensive alternatives that would treat large volumes of water from impacted surface water bodies in the East Metro. Technologies capable of addressing the PFAS impacts would then be paired with these varied approaches. The final remedial approach must balance the effectiveness and state of the technologies capable of removing PFAS from the environment along with the cost and ability to implement the treatment system(s).

Removal of PFAS mass from the East Metro should be the priority for whatever remedial alternatives are considered/implemented. No single solution is currently available that will address the vast distribution of PFAS in the surface water, sediment, groundwater, and drinking water simultaneously; however, there are several options that can be coordinated to make a difference in the water quality and sustainability of the Project 1007 Corridor.

7 Areas of Concern

Based on the findings in the Project 1007 source assessment, areas of concern (AOCs) were identified that appropriately partition the Site into geographic, hydrogeologic, and media-specific areas where remedial alternatives will be evaluated. These AOCs are based on PFAS distribution and concentration gradients, and per- and polyfluoroalkyl substances (PFAS) migration pathways across the Site. Comingling of PFAS contamination in surface waters and groundwater is extensive in dynamic hydrogeologic environments such as the Project 1007 Corridor. Multiple primary and secondary PFAS source areas and a complex system of transport mechanisms and migration pathways are present. As a result, the boundaries of each AOC were drawn with flexibility that will allow for a comprehensive evaluation of media-specific remedial alternatives to address the many challenges associated with reducing risks to human health receptors and enhancing the quality, quantity, and sustainability of drinking water in the Twin Cities East Metro.

The AOCs presented below were developed for surface water, groundwater, and sediment as shown in **Figures 159 through 161**, respectively. The extent or boundaries of each AOC may change as plume migration occurs.

7.1 Washington County Landfill Surface Water and Shallow Groundwater – AOC 1

The Washington County Landfill (WCL) Surface Water and Shallow Groundwater AOC (AOC 1) includes the observed groundwater impacts within the Quaternary Aquifer underlying and to the south, east, and southeast of WCL as well as surface water impacts within Sunfish Lake (**Figure 159**). The boundaries of AOC 1 are generally defined by the extent of the PFAS impacts within the Quaternary Aquifer and the migration pathway of shallow groundwater flow from WCL towards the east, discharging to Sunfish Lake. As a result, AOC 1 includes migration pathways and receptors pertaining to both groundwater and surface water.

PFAS Inputs and Outputs

From 1971 to 1974, WCL accepted PFAS-containing waste. As the landfill was not lined, PFAS likely leached from the waste to the underlying soils and groundwater until the landfill was reconstructed with a triple liner in 2009. Although there is currently no direct connection between PFAS-containing waste in the landfill and the groundwater, PFAS-impacts remain in groundwater in the Quaternary Aquifer underlying the former landfill footprint and thus continue to contribute to downgradient PFAS plumes and connected surface water bodies. The groundwater impacts are characterized by a higher proportion of perfluorobutanoic acid (PFBA) and lower proportion of perfluorooctane sulfonate (PFOS) in comparison to PFAS impacts associated with Oakdale Disposal Site (ODS), which are typically PFOS-dominant. PFAS-impacted shallow groundwater from within AOC 1 will migrate vertically into deeper bedrock aquifers, acting as the PFAS input to the WCL Bedrock Aquifer AOC (AOC 2).

Additionally, PFAS-impacted shallow groundwater generally flows east and southeast, discharging into the northwestern edge of Sunfish Lake, which is land-locked and groundwater-fed. PFAS impacts in Sunfish Lake have a distinct PFBA-dominant signature, similar to those of WCL, supporting this migration pathway. Surface water in Sunfish Lake infiltrates at the southern edge of the lake to groundwater, which then flows south, discharging into Lake Elmo and creating a PFAS migration pathway to the Lake Elmo Surface Water AOC (AOC 8). Similar to Sunfish Lake, PFAS impacts in Lake Elmo are characterized by relatively elevated PFBA impacts and a PFBA-dominant PFAS signature, supporting the migration pathway between Sunfish Lake and Lake Elmo. These surface water to groundwater migration pathways from WCL are depicted in **Figure 5**.

Applicable Criteria

Within AOC 2, concentrations of PFOS, perfluorooctanoic acid (PFOA), PFBA, perfluorohexanesulfonic acid (PFHxS), and perfluorohexanoic acid (PFHxA) exceed the Minnesota Department of Health (MDH) Health-Based Values (HBVs) / Health Risk Limits (HRLs) in the Quaternary Aquifer, with the highest concentrations occurring immediately underlying and to the south of WCL. In Sunfish Lake, PFOS and PFOA regularly exceed the Minnesota Pollution Control Agency (MPCA) Site-Specific Water Quality Criteria (SSCs). Additionally, while not in exceedance of the respective SSC, concentrations of PFBA in Sunfish Lake are the highest in surface water across the Project 1007 Corridor with the maximum detected concentration of PFBA (5.6 parts per billion [ppb]) just below the PFBA SSC of 5.7 ppb.

Potential Receptors

Receptors of PFAS impacts within AOC 1 are recreational users of Sunfish Lake, which include both homeowners around the lake and the public via access from Sunfish Lake Park Reserve. Consumption of fish from Sunfish Lake is also a possibility. Based on a Screening Level Ecological Risk Assessment (SLERA)

(AECOM, 2021), ecological receptors are not predicted to be impacted; however, tissue sampling has not been completed to confirm there is no ecological risk or the need for a fish consumption advisory.

7.2 Washington County Landfill Bedrock Aquifer – AOC 2

The WCL Bedrock Aquifer AOC (AOC2) includes observed impacts within the Shakopee Aquifer and Jordan Aquifer at and downgradient of WCL, extending to the south and southeast of WCL (**Figure 160**). The boundaries of AOC 2 are generally defined by the limits of PFAS contaminant migrating away from the WCL source area within the Shakopee and Jordan Aquifers and extend downgradient to the estimated location where comingling occurs with the plume associated with Raleigh Creek + Eagle Point Lake Groundwater AOC (AOC 7). This comingling begins approximately at and south of Tablyn Park, where the infiltration of PFAS-impacted surface water from Raleigh Creek and the continued southern migration of PFAS-impacted groundwater from WCL in the Shakopee and Jordan Aquifers both occur.

PFAS Inputs and Outputs

As previously described for in the WCL Surface Water and Shallow Groundwater AOC (AOC 1), historical disposal of PFAS-containing wastes at WCL have resulted in PFAS contamination in soils and shallow groundwater underlying WCL. These impacts then migrate south and southeast within the Quaternary Aquifer, as described for AOC 1, as well as vertically into the deeper bedrock Shakopee and Jordan Aquifers of AOC 2. Impacted groundwater in the Shakopee Aquifer generally migrates from WCL south and southeast as well as vertically into the Jordan Aquifer. The predominant PFAS compounds in the Shakopee and Jordan Aquifers are PFBA and PFOA, giving AOC 2 a PFBA-dominant signature that is distinct from other groundwater AOCs.

The primary downgradient AOC that may receive PFAS-impacted groundwater from AOC 2 is the plume associated with AOC 7 to the south of WCL. There is no defined discharge point of AOC 2 groundwater to the downgradient AOC 7 plume. However, the transition from AOC 2 to AOC 7 near Tablyn Park is characterized by changes in the PFAS composition and concentrations within the groundwater plume that align with the distinction between the separate and unique primary source areas of the two AOCs.

Applicable Criteria

PFBA, PFOS, PFOA, PFHxS, and PFHxA all exceed the drinking water standards in the St. Peter and Shakopee Aquifers immediately downgradient (south) of WCL. Exceedances of PFOA and PFBA are observed in the first Jordan Aquifer monitoring well downgradient of WCL, which is just north of Tablyn Park at the southern edge of AOC 2. Once in the Jordan Aquifer, impacted groundwater continues to migrate south and southeast towards AOC 7.

Potential Receptors

Receptors of PFAS impacts within AOC 2 include private wells completed in the St. Peter and Shakopee Aquifers as well as potential future public or private supply wells screened within the Jordan Aquifer. Additionally, as a result of the recent shut off of Lake Elmo Well No. 1 at the northern end of Lake Elmo, PFAS impacts within the Shakopee Aquifer may now migrate farther east towards currently unimpacted areas, in the direction of a cluster of private wells pumping from the Shakopee Aquifer.

7.3 Oakdale Disposal Site Surface Water – AOC 3

The ODS Surface Water AOC (AOC 3) encompasses surface water impacts within the extent of one of the three historically operated disposal sites, the Abresch location (Abresch). For the purposes of this report, Abresch is further subdivided into four areas of focus, as presented in **Figure 3**: the North Area, the Central Area, the Isthmus Area, and the Southeast Area. Abresch is bordered to the north by a series of ponded wetlands. Raleigh Creek, the headwaters of which are immediately upstream, enters at the northwest corner of the North Area. The North Area consists of the portion of Abresch north of County

Highway 14. Raleigh Creek then flows through a culvert under County Road 14 into the southern portion of Abresch, where it continues southward through the Central Area, along the eastern edge of the Isthmus Area, and then exits from the Isthmus Area eastwards towards Hadley Avenue North. The Central Area is bordered to the north by County Highway 14, to the east and southwest by wetlands, and to the west by Granada Avenue North. The Isthmus Area is the narrow strip of land, approximately 100 to 300 feet wide and bordered to the east and west by wetlands, that connects the Central Area to the Southeast Area. The Southeast Area is bordered to the northeast by wetlands, to the east by Hadley Avenue North, to the south by wetlands and the railroad, and to the west by wetlands.

PFAS Inputs and Outputs

Private contractors disposed of liquid and solid industrial wastes at ODS from the late 1940s until the 1960s, with documented PFAS-containing waste disposed of between 1956 and 1960, leading to the contamination of sediment, soils, and surface water throughout the Site. In the 1980s, some of the onsite contaminated soils were excavated, treated for the removal of volatile organic compounds (VOCs), and land-spread onsite following VOC aeration. Since soil treatment activities were focused on VOC remediation, PFAS concentrations would have likely remained in the soils and groundwater. PFAS-impacted soils were excavated in the late 2000s; however, removed soils were limited to the North Area and only included the removal of the highest PFOS-impacted soils. As a result, lesser-impacted soils in the North Area and any impacted soils from the ponds north of the Site and from portions of the Site south of County Highway 14 remain. Though the current onsite pump-out system is designed to prevent offsite migration of impacted shallow groundwater and to prevent vertical migration into deeper aquifers by reversing the vertical gradient between the Quaternary and Platteville Aquifers, this system does not address potential sediment leaching and the mobilization of PFAS throughout Abresch, including surface water discharge downstream of Abresch and Hadley Avenue.

Prior to entering the North Area of ODS under Granada Avenue, PFAS concentrations in Raleigh Creek are PFBA-dominant and are generally consistent with typical background urban surface water for the area. As Raleigh Creek enters the Abresch from the northwest, PFAS impacts in surface water increase rapidly in the North Area and continue to increase as Raleigh Creek flows through the Central Area, where historical land-spreading activities predominantly occurred (**Figure 3**). Raleigh Creek, which intermittently flows through Abresch, is primarily losing water to groundwater as a result of pumping activities related to the onsite pump-out system. However, given the varying water transport mechanisms and the widespread nature of PFAS impacts in all media, PFAS likely cycles between sediment, surface water, and groundwater across ODS. Continuing downstream along Raleigh Creek towards the Southeast Area, PFAS concentrations decrease slightly until the outlet at Hadley Avenue.

Though the magnitude of PFAS concentrations vary in the surface waters within AOC 3, all impacted areas have a common PFOS-dominant PFAS signature. Where Raleigh Creek exits at Hadley Avenue, the distribution of PFAS compounds maintain this signature.

Via the discharge of Raleigh Creek at Hadley Avenue, AOC 3 directly contributes to the Raleigh Creek Surface Water AOC (AOC 5). Additionally, AOC 3 is connected to the ODS Groundwater AOC (AOC 4) via infiltration. While remedies for this AOC are not proposed as part of this FS, surface water at ODS does impact other AOCs both downstream and downgradient in surface and groundwater. Future remedial decisions on downgradient AOCs will most likely depend on decisions made to address the surface water impacts at ODS.

Applicable Criteria

Within AOC 3, concentrations of PFOS, PFOA, perfluorobutanesulfonic acid (PFBS), PFHxS, and PFHxA all exceed their respective SSCs. Surface water concentrations of PFOS, PFOA, PFBA, PFBS, PFHxS, and PFHxA in AOC 3 are the highest observed corridor wide. At the Hadley Avenue outlet, only concentrations of PFOS, PFOA, and PFHxS exceed SSCs.

Finally, concentrations of PFOS and PFOA exceed the Swimming Screening Values (MPCA, 2023a). However, recreational use of Raleigh Creek within AOC 3 is unlikely as the ODS is fenced and has controlled entry.

Potential Receptors

The receptors of PFAS within AOC 3 are primarily ecological receptors as the site is fenced and access to the public is restricted. Ecological receptors include aquatic plants, invertebrates, fish, amphibians and reptiles, aquatic-dependent birds and mammals, as detailed in the 2021 Baseline Ecological Risk Assessment (BERA) (AECOM, 2021).

7.4 Oakdale Disposal Site Groundwater – AOC 4

The ODS Groundwater AOC (AOC 4) encompasses the observed impacts within the aquifers underlying and downgradient of ODS (**Figure 160**). The impacted aquifers include the shallow Quaternary, Platteville, and St. Peter Aquifers and the deeper Shakopee and Jordan Aquifers, both of which are sources of drinking water. As the containment of the shallow groundwater impacts immediately underlying ODS is currently being addressed by the onsite groundwater pump-out and treatment system, the focus of AOC 4 is on the migration pathways contributing to and future migration pathways from the already impacted drinking water aquifers. As a result, the geographic extent of AOC 4 is limited to those PFAS impacts that have migrated offsite into the bedrock aquifers.

PFAS Inputs and Outputs

As previously described, private contractors disposed of liquid and solid industrial wastes at ODS from the late 1940s until the 1960s, with documented PFAS-containing waste disposed of between 1956 and 1960, leading to the contamination of sediment, soils, and surface water throughout the Site. Contaminant transport mechanisms such as leaching and erosion from precipitation and surface water flow over and through PFAS-impacted soil and sediment at ODS have resulted in infiltration to shallow groundwater, which has then migrated both horizontally within the aquifers and vertically into deeper aquifers. Within the Quaternary Aquifer, the relative distribution of PFAS compounds varies, but the signature tends to be generally PFOS-dominant. Once offsite and in deeper aquifers, the distribution of PFAS compounds does consistently have a high PFOS fraction, which distinguishes these impacts from those at WCL.

Impacts to the Quaternary Aquifer appear to be confined predominantly to the boundary of ODS, likely a result of the groundwater pump-out system. While the Decorah Aquitard acts as a barrier to downward groundwater migration to the underlying Platteville Aquifer, this aquitard is only present in the northern portion of ODS. The intent of the expansion of the pump-out system in 2012, in addition to limiting the offsite migration of impacts within the Quaternary Aquifer, was to prevent vertical migration into deeper aquifers by reversing the vertical gradient between the Quaternary and Platteville Aquifers where the Decorah Aquitard is absent. While well gauging data show this reverse of gradient across some of ODS, a downward gradient between the aquifers remains in some onsite wells and wells southwest of ODS (Barr, 2022).

PFAS impacts not captured by the pump-out system either before or after its expansion generally migrate south and southwest away from ODS through a variety of underlying aquifers including the St. Peter, Prairie du Chien (Shakopee), and Jordan Aquifers. **Figures 15 through 17** depict the relative groundwater flow directions in each bedrock aquifer.

Applicable Criteria

Concentrations of PFOS, PFOA, and PFHxS exceed their respective SSC in both the Shakopee and Jordan Aquifers and are among the highest reported for each aquifer corridor wide.

Potential Receptors

Receptors of PFAS impacts within AOC 4 include municipal drinking water wells in the City of Oakdale. Changes in pumping conditions could lead to the migration of these impacts farther south towards future municipal wells or into other groundwater AOCs.

7.5 Raleigh Creek Surface Water – AOC 5

The Raleigh Creek Surface Water AOC (AOC 5) includes the portion of Raleigh Creek beginning at the eastern edge of ODS at Hadley Avenue and continues roughly west to east until Tablyn Park (**Figure 159**). The ODS to Ideal Avenue portion of Raleigh Creek flows through a series of ponded and channel-connected wetland complexes. Between Ideal Avenue and Tablyn Park, flow is channelized and intermittent, largely only receiving flow following precipitation events. At Tablyn Park, flow from Raleigh Creek is combined with Tri-Lakes discharge via the Project 1007 conveyance system. Given the relatively lower concentrations of PFAS compounds observed in this portion of Raleigh Creek, due to the additional input of the Tri-Lakes discharge, the extent of AOC 5 is limited to Raleigh Creek from Hadley Avenue to the confluence with the Project 1007 conveyance system at Tablyn Park.

PFAS Inputs and Outputs

PFAS entering AOC 5 originates as surface water discharge from the ODS Surface Water AOC (AOC 3). The magnitude of PFAS-impacted surface water in Raleigh Creek is influenced by seasonality and precipitation and primarily corresponds to periods when the flow from ODS is connected to the downstream stretch of Raleigh Creek. Generally, higher relative PFAS concentrations occur during high stream flow and wet conditions and lower concentrations occur during low stream flow and dry conditions. Additionally, because of the elevation of the culvert structure at Ideal Avenue, PFAS-impacted surface water only reaches Tablyn Park when water levels are above normal flow conditions. Although PFAS-impacted surface water is transported west to east along Raleigh Creek from ODS to Tablyn Park, the fate and transport of PFAS within AOC 5 is also influenced by deposition of PFAS in shallow sediments in wetland areas and infiltration into groundwater in both wetland areas and losing stream portions of Raleigh Creek. The Upper Raleigh Creek Wetland Complexes located close to ODS (**Figure 7**) are likely groundwater-fed during periods of low flow as well as sources of surface water infiltration during periods of high flow. The increased water storage at the wetland complex immediately upstream of Ideal Avenue likely promotes additional PFAS-impacted surface water infiltration into groundwater as is observed in the increase in PFAS concentrations in the shallow groundwater aquifers immediately downgradient of this location. Where flow is intermittent between Ideal Avenue and Tablyn Park, Raleigh Creek is presumed to be a losing stream. These PFAS migration pathways are depicted in **Figure 6**. All of these infiltration migration pathways contribute to the Raleigh Creek + Eagle Point Lake Groundwater AOC (AOC 7). The extent that impacted sediments may be acting as a source or sink of PFAS is not well understood. When flow from ODS to Tablyn Park along Raleigh Creek is connected, PFAS-impacted surface water that does not infiltrate to groundwater contributes to the Eagle Point Lake Surface Water AOC (AOC 6). Similar to the conditions that influence the magnitude of PFAS entering Raleigh Creek from ODS, the amount of PFAS mass within the surface water exiting Raleigh Creek and discharging to Eagle Point Lake is influenced by flow conditions; higher flow within Raleigh Creek results in greater mass of PFAS discharge into Eagle Point Lake.

Applicable Criteria

Concentrations of PFOS, PFOA, PFHxS, and PFHxA all exceed their respective SSC throughout AOC 5. Although recreational use of Raleigh Creek is limited by access and suitability of recreational features, the concentration of PFOS also exceeds the Swimming Screening Value. The highest concentrations of PFAS occur in the portion of Raleigh Creek that flows between ODS and Ideal Avenue and exceedances of the SSCs occur during both wet and dry conditions.

Potential Receptors

Since Raleigh Creek flows through numerous residential areas, the receptors of PFAS within AOC 5 are predominantly recreational users engaging in activities such as wading and playing within Raleigh Creek. Ecological receptors including fish, crayfish, and frogs are also at risk based on the elevated PFOS concentrations found in select tissue samples collected within Raleigh Creek, which also puts higher-level organisms at risk according to food web modeling (AECOM, 2021). High PFOS-containing foam is also commonly observed along Raleigh Creek, including within residential areas. While this does not increase the risk to drinking water receptors, the foam is an exposure risk to humans and animals who may come in contact with it as PFOS concentrations in the foam have been observed as high as 13,800 µg/L.

7.6 Eagle Point Lake Surface Water – AOC 6

The Eagle Point Lake Surface Water AOC (AOC 6) consists of Eagle Point Lake, which is located within Lake Elmo Park Reserve (**Figure 159**). The primary surface water input to Eagle Point Lake is Raleigh Creek downstream of the confluence with the Tri-Lakes discharge via the Project 1007 conveyance system. Other inputs to Eagle Point Lake include Farney Creek and Goose Lake, though these inputs are infrequent and minimal. Surface water from Eagle Point Lake exits through a series of channels and small ponds eastward to Eagle Point Lake Dam. Under normal flow conditions, all outflow from Eagle Point Lake is diverted through a 22-inch pipe, which runs along the bottom of Lake Elmo and then discharges into a channel east of Lake Elmo. During high flow conditions, outflow from Eagle Point Lake also exits through a secondary outlet structure that discharges directly into Lake Elmo.

PFAS Inputs and Outputs

PFAS entering the AOC 6 primarily originates as surface water discharge from the Raleigh Creek Surface Water AOC (AOC 5). The magnitude of PFAS-impacted surface water entering Eagle Point Lake is dependent on the connection of surface water outflow from ODS to Raleigh Creek and whether this portion of Raleigh Creek has enough flow to contribute to the combined discharge with the Tri-Lakes discharge into Eagle Point Lake. As discussed for AOC 5, this connection is influenced by seasonality and precipitation. Higher relative PFAS concentrations occur in Raleigh Creek both upstream and downstream of the confluence during high stream flow and wet conditions. Because PFAS concentrations in the main body of Eagle Point Lake remain relatively stable, additional inputs to the lake are possible. These possible PFAS inputs include groundwater discharge to the lake on its north and west sides and mobilization of PFAS from lake sediment. These PFAS migration pathways are shown in **Figure 8**.

Although PFAS-impacted surface water primarily exits Eagle Point Lake through the 22-inch diversion pipe that discharges east of Lake Elmo, PFAS migration pathways from the lake may also include infiltration into groundwater along the eastern and southern portions of Eagle Point Lake and deposition in shallow lake sediments along shorelines. The surface water flow migration pathways contribute to both the Horseshoe Lake + West Lakeland Surface Water AOC (AOC 9) during normal flow conditions and the Lake Elmo Surface Water AOC (AOC 8) during high flow conditions. The infiltration migration pathway from Eagle Point Lake likely contributes to the plume associated with the Raleigh Creek + Eagle Point Lake Groundwater AOC (AOC 7) as supported by the observed increase in concentrations of PFAS compounds within the Shakopee and Jordan Aquifers downgradient of the lake.

Applicable Criteria

In Eagle Point Lake, the concentrations of PFOA and PFOS exceed their respective SSC. Additionally, the concentration of PFOS exceeds the Swimming Screening Value throughout the lake. Although Eagle Point Lake is not used for swimming, recreational users who canoe and kayak on this lake may also wade into the water. Further, the canoe landing is located along the shore of the eastern lobe of the lake with

the highest reported PFAS concentrations and where PFAS-impacted foam has been observed to accumulate.

Potential Receptors

As Eagle Point Lake is located within a park reserve, potential receptors of PFAS impacts within AOC 6 are primarily recreational users who boat on this lake. Ecological receptors are at risk based on the elevated PFOS concentrations found in select tissue samples collected within Eagle Point Lake (AECOM, 2021). Additionally, MDH has posted a fish consumption advisory for the lake.

7.7 Raleigh Creek + Eagle Point Lake Groundwater – AOC 7

The Raleigh Creek + Eagle Point Lake Groundwater AOC (AOC 7) encompasses impacts in the shallow and bedrock aquifers resulting from infiltration of impacted surface water from Raleigh Creek and Eagle Point Lake. The extent of the AOC includes groundwater impacts downgradient of Raleigh Creek and Eagle Point Lake, approximately bordered to the north by Raleigh Creek, to the east by Lake Elmo, to the south by Interstate 94, and to the west by Interstate 694 (**Figure 160**). Additionally, the plume associated with the WCL Bedrock Aquifer AOC (AOC 2) comingles with the plume associated with AOC 7 at Tablyn Park where infiltration from Raleigh Creek and the continued southern migration of PFAS-impacted groundwater in the Shakopee and Jordan Aquifer from WCL both occur.

PFAS Inputs and Outputs

The most elevated PFAS concentrations in the Quaternary and St. Peter Aquifers are observed immediately downgradient of the wetland complexes along Raleigh Creek, where PFAS migration via impacted surface water infiltration occurs as depicted in **Figure 6**. This significant migration pathway is particularly evident downgradient of the wetland complex adjacent to Ideal Avenue, referred to as the Ideal Avenue Wetland Complex (part of Anna’s Grove Wetland Complex [AGWC]). As previously described, the construction of the control structure at AGWC increased the volume and duration of water detention in the wetland and as a result, infiltration to the subsurface. This migration pathway of infiltrating PFAS-impacted surface water is demonstrated by the similarity of concentrations and distributions of PFAS compounds between surface water and monitoring wells in the Quaternary and St. Peter Aquifers. The Platteville Aquifer and underlying Glenwood Aquitard pinch out immediately upgradient of AGWC, allowing for a direct connection and migration pathway between the Quaternary Aquifer and the underlying St. Peter Aquifer. Further, the upper portion of the St. Peter Aquifer is unsaturated, allowing for a steep vertical gradient from the Quaternary Aquifer and into the St. Peter and other underlying aquifers.

Continuing eastward along Raleigh Creek, PFAS impacts are present in the Quaternary, St. Peter, and Shakopee Aquifers at the confluence of Raleigh Creek and the Project 1007 conveyance system at Tablyn Park, likely due to impacted surface water infiltration from Raleigh Creek into the underlying aquifers. Additionally, concentrations of PFBA exceed the SSC in the three aquifers in the northeastern portion of the AOC immediately upgradient of the confluence at Tablyn Park, pointing to contribution from the plume associated with AOC 2. While the extent of the WCL groundwater plume (AOC 2) is not fully understood once comingling with AOC 7 occurs, an equal distribution of PFOA and PFOS observed in a Shakopee Aquifer well south and downgradient of Tablyn Park further supports the continued comingled classification of these two plumes.

Moving southward along Raleigh Creek towards Eagle Point Lake, impacts within the Quaternary and St. Peter Aquifers are significantly lower in concentration. Around Eagle Point Lake, PFAS impacts in the Quaternary and St. Peter Aquifers are observed predominantly east of the lake and match characteristics of PFAS impacts in surface water in that area, where surface water infiltration may occur as depicted in **Figure 8**.

Elevated concentrations of PFAS compounds within the Shakopee and Jordan Aquifers are observed immediately south of Eagle Point Lake, where concentrations of PFOS and PFOA are the highest reported in the Shakopee Aquifer and among the highest reported for the Jordan Aquifer within this AOC. However, the PFAS impacts in these aquifers can be characterized as PFBA-dominant with nearly equal concentrations of PFOS and PFOA, while impacts in Eagle Point Lake are generally PFOS-dominant. The PFAS impacts in these deep bedrock aquifers point to the continued southern migration of the previously described comingled plume.

Applicable Criteria

Throughout this AOC, concentrations of both PFOS and PFOA exceed the HBVs in all aquifers. Concentrations of PFBA exceeding the HRL have been reported in the Quaternary, St. Peter, and Shakopee Aquifers around the northeastern portion of the AOC immediately upgradient of Tablyn Park, likely the result of the migrating plume associated with AOC 2. Finally, concentrations of PFHxS exceeding the HBV were observed in the Quaternary and St. Peter Aquifers immediately downgradient of AGWC, and concentrations of PFHxS and PFHxA exceeding the HBVs were reported from a vertical aquifer profile (VAP) sample collected from the Shakopee Aquifer immediately downgradient of AGWC.

Potential Receptors

Receptors of PFAS impacts within AOC 7 are municipal and private drinking water wells within the cities of Oakdale and Lake Elmo. Additionally, groundwater particle tracking (AECOM MODFLOW Groundwater Model) supports a current and continued southern migration pathway of this plume towards the Woodbury municipal wells, which currently has concentrations of PFOA and PFOS that exceed their respective SSCs.

7.8 Lake Elmo Surface Water – AOC 8

This AOC consists of Lake Elmo, which is considered to be a flow-through lake in which both groundwater discharge to the lake and surface water infiltration from the lake to the subsurface occur (**Figure 159**). Aside from localized overland flow to the lake during precipitation events or spring snow melt, surface water does not flow into Lake Elmo except for occasional surface water discharges from the Eagle Point Lake Dam under abnormally high water levels in Eagle Point Lake. Lake Elmo discharges via surface water at a culvert near the southeastern corner of the lake. Lake Elmo is located partially within the Lake Elmo Park Reserve with public access, including a boat launch. Private homes surround the remaining lakeshore. The lake is used for recreation.

PFAS Inputs and Outputs

As discussed for the WCL Surface Water and Shallow Groundwater AOC (AOC 1), historical leaching of PFAS from WCL entered the Quaternary Aquifer and has migrated to the east and southeast, including into Lake Elmo via groundwater discharge (**Figure 5**). PFAS input to Lake Elmo may also occur as a result of PFAS-impacted groundwater from the Raleigh Creek + Eagle Point Lake Groundwater AOC (AOC 7) migrating through the bedrock valley that Lake Elmo is situated in and discharging to surface water. PFAS also periodically discharges to Lake Elmo during periods of abnormally high water elevations in Eagle Point Lake via the secondary overflow structure at the Eagle Point Lake Dam.

PFAS-containing surface water exits Lake Elmo via an outflow pipe, which discharges into a channel immediately east of Lake Elmo Avenue alongside the discharge pipe from Eagle Point Lake. The combined discharges then flow into the Horseshoe Lake + West Lakeland Surface Water AOC (AOC 9). Impacted surface water from Lake Elmo likely infiltrates to groundwater and into the deeper Shakopee and Jordan Aquifers, a pathway facilitated by the presence of the bedrock valley. However, this pathway has not been well studied and based on residential well monitoring data that show PFAS impacts tapering off with distance from the lake, Lake Elmo surface water infiltrating into groundwater is not predicted to have a large contribution to the groundwater immediately east of Lake Elmo.

Applicable Criteria

Within Lake Elmo, concentrations of both PFOS and PFOA exceed their respective SSCs. While the PFBA concentration does not exceed the respective SSC criteria, it is elevated as compared to upstream surface water locations within the Project 1007 Corridor. The concentration of PFOS exceeds the Swimming Screening Value immediately downgradient of the secondary outlet from the Eagle Point Lake Dam when water flows through this outlet during periods of higher water levels. The concentration of PFOS has not been observed to exceed criteria elsewhere in the lake.

Potential Receptors

The MDH has posted a fish consumption advisory for Lake Elmo as high PFAS concentrations have been observed in fish tissue samples collected from the lake (AECOM, 2021). The lake is also used for aquatic recreation and does have public access, including a boat launch at Lake Elmo Park Reserve. PFAS is not largely a concern for recreational users of the lake because concentrations only exceed the Swimming Screening Value immediately downgradient of the Eagle Point Lake Dam during abnormally high water levels in Eagle Point Lake. The area where this water flows is a wetland area not frequented by recreational users. PFAS-containing foam has been observed to accumulate along the shores of Lake Elmo, including at the public boat and canoe launches in the Lake Elmo Park Reserve.

7.9 Horseshoe Lake + West Lakeland Surface Water – AOC 9

The Horseshoe Lake + West Lakeland Surface Water AOC (AOC 9) encompasses the Project 1007 conveyance system flow path from Horseshoe Lake, eastward through the downstream channelized wetlands, and then southward through the three West Lakeland Ponds (North, Middle, and South) and connecting channels before reaching the discharge pipe at the southern end of South Pond (**Figure 159**).

PFAS Inputs and Outputs

PFAS enters AOC 9 from the combined discharges of Eagle Point Lake and Lake Elmo at the channel immediately east of Lake Elmo Avenue just south of 20th Avenue, which then flows towards Horseshoe Lake. The two surface water inputs have differing concentrations of specific PFAS constituents with PFBA-dominant impacts from Lake Elmo and PFOS-dominated impacts from Eagle Point Lake. The resulting PFAS concentrations and relative distributions of PFAS compounds in AOC 9 are different from surface water PFAS concentrations observed upgradient within the Project 1007 Corridor.

PFAS-impacted surface water exits AOC 9 at the piped outlet of South Pond, which connects to the Interstate 94 storm sewer system before discharging into the St. Croix River. PFAS-impacted surface water also leaves AOC 9 via infiltration from the surface water bodies then entering the West Lakeland Groundwater AOC (AOC 10). The ponds and channels within AOC 9 were specifically designed to promote infiltration to manage stormwater as part of Project 1007. The PFAS migration pathways are shown in **Figure 9**.

Applicable Criteria

Concentrations of PFOS and PFOA both exceed their respective SSC throughout AOC 9. PFOS concentrations also occasionally exceed the Swimming Screening Value. Although there is no public access for swimming, AOC 9 is located within residential areas and homeowners have access to the surface water.

Potential Receptors

As Horseshoe Lake and the West Lakeland Ponds are located within residential areas, potential receptors of PFAS within AOC 9 are recreational users who may enter or consume fish from these surface water bodies. Although there are no beaches or public access points to these water bodies, homes do border Horseshoe Lake, the ponds, and connecting channels, and there is evidence of boating

and wading in these areas. Ecological receptors including fish, crayfish, and frogs are at risk based on the elevated PFOS concentrations found in select tissue samples collected within Horseshoe Lake, the ponds, and connecting channels, which also puts higher-level organisms at risk according to food web modeling (AECOM, 2021).

Finally, PFAS-containing foam has been observed to accumulate immediately downstream of the Horseshoe Lake discharge on the east side of Manning Avenue. Although this area is not residential, there is still a potential for the public to come into contact with this foam, which has been reported with the highest concentrations of PFOS corridor wide.

7.10 West Lakeland Groundwater – AOC 10

The West Lakeland Groundwater AOC (AOC 10) encompasses impacts in the shallow and bedrock aquifers in the West Lakeland area that are predominantly resulting from the infiltration of PFAS-impacted surface water from Horseshoe Lake, the West Lakeland Ponds, and the connecting channels (**Figure 160**). Though the extent of the impacts within each aquifer are not fully delineated, the plume associated with AOC 10 is mapped as extending from the western edge of Horseshoe Lake southeastward across West Lakeland Township towards the St. Croix River.

PFAS Inputs and Outputs

The source of PFAS within AOC 10 is predominantly from the infiltration of PFAS-impacted surface water within the Horseshoe Lake + West Lakeland Surface Water AOC (AOC 9). Impacts in the Quaternary and Shakopee Aquifers have been observed immediately downgradient of Horseshoe Lake, indicating contributions of PFAS-impacted surface water infiltration from Horseshoe Lake. High PFAS concentrations within the Shakopee Aquifer continue downgradient of the West Lakeland Ponds, again indicating that surface water infiltration from these water bodies is a key migration pathway of PFAS impacts. In this area, the Shakopee Aquifer is generally the first encountered bedrock and is thinner, fractured, and in some areas absent, leading to a weathered and potentially fractured Oneota Aquitard. Weathering of these geologic units facilitates the migration of PFAS vertically into the Jordan Aquifer. PFAS concentrations within the Jordan Aquifer are relatively low near Horseshoe Lake and do not become elevated until flow nears the channelized wetlands connecting Horseshoe Lake to the West Lakeland Ponds, indicating that vertical migration into the Jordan Aquifer does not occur immediately at Horseshoe Lake.

The eastern extent of the impacts within both the Shakopee and Jordan Aquifers is largely defined by the Cottage Grove Fault, which marks the eastern-geologic extent of the aquifers. The southern extent of PFAS impacts in AOC 10 appears to be Interstate 94. However, the private wells with identified PFAS contamination that were used to define the southern extent of the PFAS plume near Lake Edith may be a result of a historical surface water infiltration pathway that existed prior to the construction of Project 1007 when surface water in West Lakeland discharged south of the current Interstate 94 into a series of wetlands and channels towards Lake Edith.

Vertical migration of PFAS from the Jordan Aquifer into deeper aquifers is unknown due to the limited analytical data from below the Jordan Aquifer. Additional pumping from the Jordan Aquifer or from deeper aquifers, especially to the northeast of the current plume extent, could further promote migration of the plume into lesser impacted areas, including into the Tunnel City Aquifer. The PFAS impacts within AOC 10 do not migrate into any other downgradient surface water or groundwater AOCs.

Applicable Criteria

Concentrations of both PFOS and PFOA exceed the MDH HBVs within the Quaternary, Shakopee, and Jordan Aquifers.

Potential Receptors

Receptors of PFAS within AOC 10 are private drinking water wells within the Shakopee and Jordan Aquifers. As a result of the PFAS impacts observed in this AOC, concentrations of PFAS in numerous domestic supply wells exceed drinking water standards and are currently only potable via in-home granular activated carbon (GAC) filtration. Continued eastward migration of this plume within drinking water aquifers with groundwater flow combined with pumping further east is expected to lead to the detection of impacts in additional wells.

7.11 Upper Raleigh Creek Wetland Complexes Sediment – AOC 11

The Upper Raleigh Creek Wetland Complexes Sediment AOC (AOC 11) consists of the PFAS-impacted sediments within three wetland complexes that Raleigh Creek flows through after exiting ODS at Hadley Avenue (**Figure 161**). The first of the three wetland complexes is located between Hadley Avenue and Interstate 694. Raleigh Creek flows under Interstate 694 and discharges to the second wetland complex east of Interstate 694 and west of Hemingway Avenue. Raleigh Creek then flows under the intersection of Hemingway Avenue and 32nd Street into the third wetland (**Figure 7**). These individual wetland complexes are incorporated into a single AOC because of their proximity to each other and ODS, similarity in PFAS migration patterns, and similar risk to potential receptors.

Although these three wetland complexes are grouped together into one AOC, there are observed variations in PFAS concentrations within each of the wetland complexes that are influenced by their proximity to source area, the creek flow morphology and depositional environment, and total organic carbon content (TOC) of the wetland sediment.

PFAS Inputs and Outputs

The source of PFAS impacts in AOC 11 is predominantly from the Raleigh Creek Surface Water AOC (AOC 5) whereby impacted surface water in Raleigh Creek flows into the wetland resulting in deposition of PFAS-containing particulates and adsorption of PFAS into wetland sediment. PFAS-impacted shallow groundwater discharging to Raleigh Creek during periods of low flow and subsequent adsorption is another potential source of PFAS impacts to the surface sediments.

AOC 11 may contribute PFAS mass to the Raleigh Creek Surface Water AOC (AOC 5) and the Raleigh Creek + Eagle Point Lake Groundwater AOC (AOC 7) via sediment leaching of PFAS into surface and groundwater. The extent to which sediment-bound PFAS may be mobilized as a potential source of PFAS to either groundwater or surface has not been measured; however, even after surface water impacts are reduced, this secondary source reservoir of PFAS in the sediment will remain as a source of PFAS to both downstream surface water and groundwater.

Applicable Criteria

The concentrations of PFOS exceed both the 5-days/week and 2-days/week MPCA Site-Specific Sediment Screening Values (SDSVs) across all three wetland complexes at depths up to 36 inches; although in general, concentrations are the highest in samples collected from the first 12-inch depth interval. The concentration of PFOA is also elevated but does not exceed any criteria.

Potential Receptors

Although PFOS concentrations exceed the 5-days/week and 2-days/week SDSVs and the wetlands are accessible to the public, resulting in the potential for the public to come into contact with high PFOS-containing sediment, these wetland complexes are located within commercial areas that are not frequented by the public. Ecological receptors of PFAS within AOC 11 include fish, crayfish, and frogs, all of which were found to have elevated PFOS concentrations (AECOM, 2021). Based on tissue samples collected and food web modeling completed, larger animals were also found to be at potential risk for PFOS exposure.

7.12 Anna's Grove Wetland Complex Sediment – AOC 12

The AGWC Sediment AOC (AOC 12) consists of the sediment within a large, ponded wetland complex that Raleigh Creek flows through (**Figure 161**). It is located immediately west of Ideal Avenue and downgradient of the Upper Raleigh Creek Wetland Complexes Sediment AOC (AOC 11) and is bordered by residential properties on the west, north, and south. The outlet structures of this wetland complex under Ideal Avenue are designed to reduce downstream flooding by constricting the flow of Raleigh Creek out of the wetland. This results in increased water storage duration and subsequently increases the rate of PFAS deposition and the infiltration of PFAS-impacted surface water through sediments and into groundwater. As a result, high PFAS concentrations are observed within the sediments across AGWC.

PFAS Inputs and Outputs

The source of PFAS impacts in AOC 12 is predominantly from the Raleigh Creek Surface Water AOC (AOC 5) whereby impacted surface water in Raleigh Creek flows into the wetland, resulting in the deposition of PFAS and adsorption to wetland sediments. AOC 12 may contribute PFAS mass to the Raleigh Creek Surface Water AOC (AOC 5) and the Raleigh Creek + Eagle Point Lake Groundwater AOC (AOC 7). As with the other sediment AOCs, this PFAS mass could potentially be a long-term secondary source that continues to leach into groundwater or surface water after the surface water impacts are reduced.

Applicable Criteria

Concentrations of PFOS exceed the 2-days/week and 5-days/week SDSVs in sediment samples collected up to 36 inches below ground surface and exceed the 5-days/week SDSV in sediment samples collected up to 48 inches below ground surface. Similar to the AOC 11, concentrations are generally the highest in samples collected from the first 12-inch depth interval.

Potential Receptors

The primary potential receptor pathway of PFOS within AOC 12 is human exposure to the sediment during recreational activities. Several homes and a bike trail border AGWC, and there is evidence of children playing in multiple locations where high concentrations of PFOS-containing sediment are present. Additionally, ecological receptors including fish, crayfish, and frogs were found to be at risk based on elevated PFOS concentrations in tissue samples collected from AGWC, which also puts higher-level organisms at risk according to food web modeling (AECOM, 2021).

7.13 Eagle Point Lake Sediment – AOC 13

The Eagle Point Lake Sediment AOC (AOC 13) consists of the sediment within Eagle Point Lake (**Figure 161**). Although elevated PFAS concentrations are present throughout the lake, the higher concentrations are generally closer to shore, within the eastern and southeastern lobes of the lake, and in the wetland area at the lake inlet. These areas tend to be shallower waters with more aquatic vegetation, like that of a wetland environment.

PFAS Inputs and Outputs

The PFAS accumulation within Eagle Point Lake sediments is a result of deposition of particulates containing PFOS and adsorption of PFOS to sediment from the Eagle Point Lake Surface Water AOC (AOC 6). The PFAS impacts within AOC 13 may be contributing to AOC 6 by mobilizing back into surface water as well as mobilizing into surface water infiltrating to groundwater where it would contribute to the Raleigh Creek + Eagle Point Lake Groundwater AOC (AOC 7). As with the other sediment AOCs, this PFAS mass could potentially be a long-term secondary source that continues to leach into groundwater or surface water after the surface water impacts are reduced.

Applicable Criteria

Concentrations of PFOS exceed the 2-days/week and 5-days/week SDSVs in sediment samples throughout the lake. Exceedances for PFOS were only observed in the first 6-inch depth interval, though limited depth interval sampling was conducted for this AOC. Concentrations of PFOA are also elevated but do not exceed any criteria.

Potential Receptors

Receptors of PFAS in AOC 13 are predominantly ecological. Elevated PFOS concentrations were found in fish, crayfish, frogs, and snails collected from Eagle Point Lake, which also puts higher-level organisms at risk according to food web modeling (AECOM, 2021). Eagle Point Lake is completely within Lake Elmo Park Reserve, making it easily accessible to the public, though the wetland nature of the lake may reduce the likelihood of the public entering the lake. Recreation tends to be limited to canoeing and kayaking, which could require wading into the water in an area with high PFOS-containing sediment.

8 Remediation Action Objectives

Remedial Action Objectives (RAOs) establish the degree to which a site requires control or remedial action to meet the objectives of protecting human health and the environment. These objectives are used to guide the identification and evaluation of remedial alternatives. In accordance with U.S. Environmental Protection Agency (EPA) guidelines, RAOs traditionally reflect goals that specify media of concern, potential exposure routes, and receptors. The overall focus of the RAOs for this Feasibility Study (FS) is the protection of drinking water aquifers to prevent human exposure to per- and polyfluoroalkyl substances (PFAS) through drinking water. The receptors identified include private and municipal drinking water wells along with the drinking water aquifers themselves. Typically, ecological receptors and human receptor pathways other than drinking water, such as recreation, dermal contact with PFAS-containing foam, and fish consumption, are also included in RAOs; however, the direction provided by the Settlement excludes these receptor pathways from this FS. Future work may include RAOs specific to these receptor pathways.

RAOs traditionally focus on achieving regulatory standards. At this Site, the RAOs were developed to protect current and future use of these aquifers for potable water with the ultimate goal of returning impacted drinking water aquifers back to their beneficial use to the maximum extent possible. Given the scope of the impacts, the RAOs for this FS focus on the reduction of PFAS mass within the aquifers and limiting the migration, or mass flux, of PFAS to downgradient areas, especially those that are currently unimpacted, including deeper unimpacted aquifers across the East Metro. RAOs were developed based on the PFAS migration pathway into each area of concern (AOC), specific receptors within and immediately downgradient of each AOC, and on downgradient PFAS migration pathways from one AOC into another AOC.

To measure the effectiveness of an implemented remedial action, the RAOs must be quantitative. However, measuring mass flux across a Site as large as Project 1007 with multiple primary and secondary source areas and migration pathways of PFAS is difficult. Further, the Remedial Investigation (RI) identified data gaps, emphasizing that the PFAS migration pathways are not fully understood for all areas of the Site. For this reason, concentrations downgradient of the implemented remedies, specifically those at the fringe of the plumes, will be evaluated and compared to those observed prior to implementation if available. An effective remedy will result in a stable or decreasing PFAS concentration trend. Wells sampled in areas with low or no PFAS impacts will be monitored to ensure additional PFAS impacts are not detected. Similarly, stable or decreasing PFAS concentration trends in monitoring wells closer to areas with high PFAS concentrations, indicating areas with a higher PFAS mass in the groundwater, will be used to quantify PFAS mass reduction. While not directly included in the RAOs, the amount of PFAS mass removed from the groundwater should be quantified annually to ensure the system

is continuing to remove PFAS mass. Observation of a decreasing trend in PFAS mass in an AOC would trigger a review of the system to determine what changes should be made.

While the relevant criteria are not components of the RAOs, they do identify the ultimate goals of the remedial efforts. If these criteria are achieved in an AOC, remediation could cease. The standards that are protective of human health and drinking water receptors are the Site-Specific Water Quality Criteria (SSC) for reducing surface water impacts or exceedances, the Minnesota Department of Health (MDH) drinking water Health-Based Values (HBVs) and Health Risk Limits (HRLs) for groundwater concentrations, and the Site-Specific Sediment Screening Values (SDSVs) and Soil Reference Values (SRVs) for sediment. EPA also has Maximum Contaminant Levels (MCLs) for PFAS in drinking water. Additional criteria may be developed in the future that must be considered for the protection of human health and be included in setting cleanup standards. The lower of these standards for a specific PFAS analyte will be used. A 5-year review cycle is recommended to determine whether changes should be made to the remedial action and whether remediation should continue. A 5-year review cycle also allows for the incorporation of new findings related to PFAS and the migration pathways within the Site.

The following sections identify the RAOs for each AOC along with a summary of the goal for each RAO as it relates to the protection of drinking water aquifers, how the RAO will be evaluated, and descriptions of exposure pathways, if any, that are not specifically addressed by the RAOs within each AOC.

8.1 Washington County Landfill Surface Water and Shallow Groundwater – AOC 1

1A. Reduce mass flux of PFAS horizontally into Sunfish Lake and Lake Elmo and downgradient within the Quaternary Aquifer. Evaluate the reduction through statistical analysis of samples collected from a Quaternary well network located at the downgradient (eastern to southern) edge of Washington County Landfill (WCL) as part of a long-term monitoring plan.

1B. Reduce mass flux of PFAS vertically into the drinking water aquifers (Shakopee and Jordan). Evaluate the reduction through statistical analysis of samples collected from a Shakopee and Jordan well network located within the boundary and immediately downgradient of the WCL as part of a long-term monitoring plan.

1C. Show decreasing PFAS concentration trends in Sunfish Lake in long-term monitoring based on statistical analysis of water samples collected from Sunfish Lake.

The groundwater PFAS in AOC 1 that exceed their respective HBVs or HRLs are perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA), perfluorobutanoic acid (PFBA), all of which also exceed the Hazard Index (HI). Impacted shallow groundwater within AOC 1 migrates vertically to deeper aquifers. Groundwater also flows to the east and southeast discharging into the northwestern edge of Sunfish Lake, where PFOS and PFOA exceed the SSCs. Smaller ponds between WCL and Sunfish Lake within the boundary of Sunfish Lake Park Reserve exceed the SSCs for PFOS, PFOA, PFBA, perfluorobutanesulfonic acid (PFBS), perfluorohexanesulfonic acid (PFHxS), and perfluorohexanoic acid (PFHxA). The goal of these RAOs is to reduce the mass flux of PFAS away from the WCL source area towards downgradient receptors including groundwater-fed surface water bodies (i.e., Sunfish Lake and Lake Elmo) and the Shakopee and Jordan Aquifers via vertical migration.

The success of a remedial approach in achieving these RAOs will be evaluated by sampling a sentinel monitoring well network within and beyond the extent of the current plume within the Quaternary Aquifer. Surface water concentrations in Sunfish Lake will also be monitored to determine how reductions in Quaternary Aquifer impacts have reduced PFAS concentrations in Sunfish Lake. Although outside of this AOC, Lake Elmo can also be used to evaluate the reduction in mass flux; however, decreases in concentrations within Lake Elmo are expected to take longer to occur and will also be dependent on other PFAS migration pathways.

These RAOs do not address the potential for incidental contact of the public with PFAS-containing foam that has been observed to accumulate along the shore of Sunfish Lake, which is accessible by private residences.

8.2 Washington County Landfill Bedrock Aquifers – AOC 2

2A. Reduce PFAS concentrations in the current plume extent within the drinking water aquifers (Shakopee and Jordan). Evaluate the reduction through statistical analysis of samples collected from a Shakopee and Jordan monitoring well network located south and east of WCL as part of a long-term monitoring plan.

2B. Slow the downgradient migration of PFAS into unimpacted drinking water aquifers as monitored by the following:

- *Long-term monitoring of a Shakopee and Jordan well network downgradient of the current plume extent*
- *Long-term monitoring at select private wells that are currently unimpacted or impacted with low concentrations of PFAS*

The groundwater PFAS impacts in AOC 2 include impacts to two drinking water aquifers, the Shakopee and Jordan Aquifers. PFAS impacts from AOC 2 may also migrate into the Raleigh Creek + Eagle Point Lake Groundwater AOC (AOC 7). Immediately downgradient and south of WCL, PFBA, PFOS, and PFOA exceed the MDH HBV or HRL drinking water standards in the Shakopee Aquifer. Only PFOA and PFBA exceed the MDH HBV or HRL standards in the Jordan Aquifer in this area.

Reducing the PFAS concentrations within the current plume extent will reduce operating costs for communities currently using these aquifers for drinking water. In monitoring the success of this RAO, care will be taken to understand the impacts of upgradient treatment within AOC 1. Depending on this treatment, decreases or even stabilization of PFAS concentrations may require extended time depending on how and where the impacts from WCL occurs. Efforts to reduce PFAS concentrations and remove PFAS mass from the drinking water aquifers will aid in achieving RAO 2B, which is to reduce the continued migration of the PFAS plume beyond the current plume extent (horizontally within the Shakopee and Jordan Aquifers and vertically into deeper aquifers). The migration of PFAS impacts in the Shakopee and Jordan Aquifers includes movement towards, and comingling with, the existing plume associated with the AOC 7 and continued movement to the east-southeast towards private drinking water wells. As the exact extent of the plume is unknown, monitoring PFAS concentration trends for wells at the fringe of the plume can be used to monitor plume migration.

With the recent cessation of use and the sealing of Lake Elmo Municipal Well #1, located southeast of WCL, migration of existing PFAS impacts in the Shakopee and Jordan Aquifers may shift from east-southeast to predominantly east towards and beyond Sunfish Lake. Multiple homes with unimpacted private wells are located in this area. PFAS impacts have already begun to migrate into the Jordan Aquifer immediately downgradient of WCL and the prevention of vertical migration of PFAS impacts is necessary to protect the Tunnel City Aquifer for future use as a drinking water source.

The success of a remedial approach in achieving these RAOs will be evaluated by sampling a sentinel monitoring well network south and east of WCL for PFAS within and beyond the extent of the current plume, both horizontally and vertically. To extend the monitoring well network, select private wells could also be sampled.

8.3 Oakdale Disposal Site Surface Water – AOC 3

3A. Reduce the discharge of PFAS-impacted surface water from the former Oakdale Disposal Site (ODS) to the Raleigh Creek Surface Water AOC (AOC 5).

PFOS, PFOA, PFBS, PFHxS, and PFHxA exceed their respective SSCs in Raleigh Creek at ODS. PFAS-impacted surface water intermittently flows within Raleigh Creek through ODS and exits via the culvert under Hadley Avenue. Raleigh Creek concentrations of PFOS, PFOA, PFHxS, and PFHxA have also been consistently observed downstream of ODS throughout the monitoring period since 2006, indicating that PFAS are being discharged from ODS via surface water.

The goal of RAO 3A is to reduce PFAS-impacted surface water from being discharged from ODS where it migrates downstream through Project 1007 and infiltrates to the drinking water aquifers. Remedial alternatives for RAO 3A will not be developed as 3M and the Minnesota Pollution Control Agency (MPCA) are addressing source area response actions under the 2007 Settlement Agreement and Consent Order including, but not limited to, the potential re-routing of Raleigh Creek around ODS. Completion of this work may reduce surface water PFAS contributions to groundwater and drinking water aquifers and limit downstream and offsite migration of surface water.

The success of a remedial approach in achieving this RAO will be evaluated by sampling Raleigh Creek immediately downstream of the discharge from ODS and any nearby surface water bodies that could receive surface water from ODS under varying flow conditions. Sampling would be conducted during a range of flow conditions including after heavy rainfall to ensure PFAS impacts are not being discharged.

This RAO does not directly address surface water concentrations within Raleigh Creek and in downstream wetlands, thus the risk to ecological receptors is also not addressed. This RAO does not address PFOS and PFOA concentrations that exceed the Swimming Screening Values. Additional RAOs may be developed for ODS through the Superfund program.

8.4 Oakdale Disposal Site Groundwater – AOC 4

4A. Reduce PFAS concentrations over time in the current plume within the drinking water aquifers (Shakopee and Jordan). Evaluate the reduction through statistical analysis of samples collected from a Shakopee and Jordan monitoring well network located south of ODS as part of a long-term monitoring plan that also includes a downgradient sentinel well network.

4B. Reduce further PFAS mass loading to the drinking water aquifers (Shakopee and Jordan) by reducing the vertical migration of PFAS from the Quaternary Aquifer within the footprint of ODS. Evaluate the reduction through statistical analysis of samples collected within a Quaternary and Shakopee monitoring well network downgradient of ODS as part of a long-term monitoring plan.

4C. Slow the downgradient migration of PFAS into unimpacted drinking water aquifers as demonstrated through the following:

- Long-term monitoring of a Shakopee and Jordan well network downgradient of the current plume extent*
- Long-term monitoring at select private or municipal supply wells that are currently unimpacted or impacted with low concentrations of PFAS*

The groundwater PFAS impacts in AOC 4 include two primary drinking water aquifers, the Shakopee and Jordan Aquifers, with PFOS, PFOA, and PFHxS exceeding the HBVs. The goals of RAOs 4A and 4B are to reduce the concentrations of PFAS impacts within the Shakopee and Jordan Aquifers and to reduce the continued migration of the shallow groundwater impacts to these drinking water aquifers. As groundwater within ODS is outside the scope of this FS, remedial alternatives will not be developed to address these Quaternary Aquifer impacts. The success of RAOs 4A and 4C are dependent on achieving 4B and the effectiveness of the groundwater extraction treatment system already in place at ODS and will not be further addressed in this FS. The goal of RAO 4C is to prevent the continued migration of the PFAS plume beyond the current extent, both horizontally within the Shakopee and Jordan Aquifers and vertically to deeper aquifers.

PFAS concentrations in the Jordan Aquifer are highest in the ODS supply wells 5 and 9 located south of ODS, suggesting that these wells may contribute to the PFAS migration pathway from ODS to the Jordan Aquifer. A change in pumping conditions could alter this migration pathway. The extent of vertical migration in AOC 4 from the Shakopee and Jordan Aquifers into the Tunnel City Aquifer is unknown because wells have not been installed within this aquifer downgradient of ODS. The prevention of vertical migration of PFAS impacts is necessary to protect the Tunnel City Aquifer for future use as a drinking water source.

The success of a remedial approach in achieving these RAOs will be evaluated by sampling a monitoring well network south of ODS for PFAS within and beyond the extent of the current plume, both horizontally and vertically. PFAS concentrations in wells installed at the fringe of the plume, such as in areas where PFAS concentrations are less than 10 nanograms per liter (ng/L), can be used to monitor migration of the plume as the extent of the plume is not well understood.

The extent to which 3M is required to address PFAS impacts offsite from ODS will be determined through the Superfund program. Additional RAOs may be developed through the Superfund program to address these impacts. Additional RAOs may also be developed to address other receptor pathways and source material that may be present on the Site.

8.5 Raleigh Creek Surface Water – AOC 5

5A. Decrease PFAS concentrations in Raleigh Creek between Hadley Avenue and its confluence with Project 1007 at Tablyn Park. Evaluate the reduction through statistical analysis of samples collected from Raleigh Creek surface water as part of a long-term monitoring plan.

5B. Decrease the mass flux of PFAS into Eagle Point Lake. Evaluate the reduction through statistical analysis of samples collected from the influent of the lake.

PFOS, PFOA, PFHxS, and PFHxA exceed the SSCs within AOC 5. Surface water within AOC 5 infiltrates to groundwater along Raleigh Creek, providing a pathway for PFAS migration from surface water to the Shakopee and Jordan drinking water aquifers. This migration pathway is most evident within a series of wetland complexes along Raleigh Creek between Hadley Avenue and Ideal Avenue that promote infiltration during high flow conditions. The goal of RAO 5A is to reduce the concentrations of PFAS in surface water in order to reduce PFAS migration to the drinking water aquifers via infiltration. Infiltration of surface water into groundwater between Hadley Avenue and Tablyn Park contributes to PFAS migration to the Shakopee and Jordan Aquifers within the Raleigh Creek + Eagle Point Lake Groundwater AOC (AOC 7). The goal of RAO 5B is to reduce the discharge of PFAS-impacted surface water to downstream surface water bodies where PFAS also migrates into the drinking water aquifers via infiltration.

The success of a remedial approach in achieving these RAOs will be evaluated by routine sampling of Raleigh Creek for PFAS prior to where it connects with the Project 1007 conveyance system at Tablyn Park. PFAS mass flux from sediment to surface water may be impacting surface water concentrations and will be considered when analyzing the PFAS concentrations.

RAO 5A does not address the potential for incidental human contact with PFAS-containing foam that has been observed to accumulate within AOC 5, including in residential areas. The RAOs also do not address PFOS and PFOA concentrations that exceed the Swimming Screening Values. Although Raleigh Creek is not large enough for swimming, there is the potential for wading or playing within the creek, especially as it flows through residential areas. Because the Swimming Screening Values are higher than the respective SSCs, PFOS and PFOA concentrations will be below both criteria if RAOs 5A and 5B are achieved. The adverse exposure risk from PFAS to ecological receptors that were identified in the Baseline Ecological Risk Assessment (BERA) within AOC 5 is also not directly addressed by these RAOs (AECOM, 2021). While the reduction of PFAS concentrations will aid in the protection of ecological

receptors and recreational users, the RAOs and future sampling will not specifically evaluate these exposure pathways.

8.6 Eagle Point Lake Surface Water – AOC 6

6A. Reduce surface water PFAS concentrations in Eagle Point Lake over time. Evaluate the reduction through statistical analysis of routine sampling as part of a long-term monitoring plan to prevent the migration of PFAS to groundwater via infiltration.

6B. Reduce the PFAS mass discharged to the Lake Elmo Surface Water AOC (AOC 8) and Horseshoe Lake + West Lakeland Surface Water AOC (AOC 9) to aid in the reduction of PFAS concentrations within these downgradient surface water bodies. Evaluate through statistical analysis of routine samples collected from the influent to these downgradient AOCs and samples collected within these downgradient waterbodies as part of a long-term monitoring plan.

PFOS, PFOA, and PFHxS exceed the SSCs within Eagle Point Lake. PFAS-impacted surface water from Eagle Point Lake infiltrates to groundwater at the southern and eastern sides of the lake, facilitating the movement of PFAS-impacted surface water from Eagle Point Lake to the Shakopee and Jordan drinking water aquifers. Additionally, PFAS-impacted surface water flows from Eagle Point Lake into Horseshoe Lake and the West Lakeland storage ponds. The goal of RAO 6A is to reduce PFAS concentrations in Eagle Point Lake to reduce the mass flux of PFAS to the drinking water aquifers via infiltration. This will also aid in achieving RAO 6B to reduce the discharge of PFAS-impacted surface water from Eagle Point Lake to AOC 8 and subsequently AOC 9.

The success of a remedial approach in achieving these RAOs will be evaluated by routine sampling of Eagle Point Lake surface water. The potential effect of mass flux of PFAS from sediment to surface water should be considered when evaluating the data.

These RAOs do not address the potential for incidental human contact with the PFAS-containing foam that has been observed to accumulate along the eastern shore of Eagle Point Lake. This includes near the Lake Elmo Park Reserve canoe landing where the public accesses the lake. PFOS concentrations in Eagle Point Lake also exceed the Swimming Screening Value. Because the Swimming Screening Values are higher than the respective SSCs, PFOS and PFOA concentrations will be below both criteria if RAOs 6A and 6B are achieved. RAOs 6A and 6B do not address the high PFOS concentrations observed in fish tissue, which have resulted in the MPCA posting a fish consumption advisory for Eagle Point Lake. A reduction of PFAS concentrations in Eagle Point Lake surface water will likely aid in reducing PFAS concentrations in fish tissue, after multiple progenies. The adverse exposure risk from PFAS to ecological receptors that were identified in the BERA within AOC 6 is not directly addressed by these RAOs (AECOM 2021). While the reduction of PFAS concentrations will aid in the protection of ecological receptors and recreational users, the RAOs and future sampling will not specifically evaluate these exposure pathways.

8.7 Raleigh Creek + Eagle Point Lake Groundwater – AOC 7

7A. Reduce PFAS concentrations over time in the current plume within the drinking water aquifers (Shakopee and Jordan). Evaluate the reduction through statistical analysis of samples collected from a Shakopee and Jordan monitoring well network located within the current plume extent south of Eagle Point Lake and Raleigh Creek.

7B. Reduce downgradient PFAS migration into unimpacted drinking water aquifers as monitored by the following:

- *Long-term monitoring of the Shakopee and Jordan well network downgradient of the current plume extent*

- *Long-term monitoring at select private or municipal supply wells that are currently unimpacted or impacted with low concentrations of PFAS*

Groundwater PFAS exceedances in AOC 7 are present in the two primary drinking water aquifers, the Shakopee and Jordan Aquifers. PFOS and PFOA exceed their respective HBVs in both aquifers throughout AOC 7 with varying concentrations depending on proximity to areas where infiltration of impacted surface water occurs, such as along Raleigh Creek and Eagle Point Lake. PFBA exceeds the HRL in the Shakopee Aquifer in the northeastern portion of the AOC, near Tablyn Park. PFHxS and PFHxA exceeded their respective HBVs within the Shakopee Aquifer in one sample collected immediately downgradient of Anna's Grove Wetland Complex (AGWC). PFOS and PFOA exceed the HRL in the Jordan Aquifer near AGWC.

The goal of RAO 7A is to reduce the concentrations of PFAS within the Shakopee and Jordan Aquifers. This also requires, in part, achieving RAOs 5A and 6A to reduce the mass flux of PFAS into the drinking water aquifers. This reduction in the PFAS mass flux should also aid in achieving RAO 7B, which is to reduce the spread of PFAS-impacted groundwater to both unimpacted areas within the Shakopee and Jordan Aquifers and deeper aquifers. Based on the current understanding of the groundwater flow regime, the PFAS plume is expected to continue to migrate to the south towards several of the City of Woodbury's municipal wells in which PFOS and PFOA are in exceedance of HRLs. Changes in pumping conditions could further promote this migration pathway or create new migration pathways into unimpacted areas. The extent of vertical migration in AOC 7 from the Shakopee and Jordan Aquifers into the deeper aquifers is not fully understood but is modeled to be minimal. The prevention of vertical migration of PFAS impacts is necessary to protect the Tunnel City Aquifer for future use as a drinking water source.

The success of a remedial approach in achieving these RAOs will be evaluated by sampling of a monitoring well network within and south of the extent of the current PFAS plume.

8.8 Lake Elmo Surface Water – AOC 8

8A. Reduce surface water PFAS concentrations in Lake Elmo over time. Evaluate the reduction through statistical analysis of samples collected as part of a long-term monitoring plan.

8B. Reduce the discharge of PFAS-impacted surface water to the Horseshoe Lake + West Lakeland Surface Water AOC (AOC 9). Evaluate the reduction through statistical analysis of routine samples collected from the Lake Elmo discharge as part of a long-term monitoring plan.

PFOS and PFOA exceed the SSCs within Lake Elmo. Because the lake is situated within the buried bedrock valley, PFAS-impacted surface water from Lake Elmo has a direct hydraulic connection to the Shakopee and Jordan Aquifers. The goal of RAO 8A is to reduce PFAS concentrations in Lake Elmo, which will also reduce PFAS-impacted surface water infiltrating from the lake to deeper aquifers via the bedrock valley. The goal of RAO 8B is to reduce the discharge of PFAS-impacted surface water to downstream surface water bodies within AOC 9. PFAS impacts in these surface water bodies are also known to infiltrate to drinking water aquifers.

The success of a remedial approach in achieving these RAOs will be evaluated by sampling for PFAS concentrations in Lake Elmo surface water. Evaluation of concentration trends over time will account for the size and long hydraulic retention time of Lake Elmo compared to other lakes within the Project 1007 conveyance. Additionally, multiple PFAS migration pathways contribute to the impacts observed in Lake Elmo. Analysis of the trends of specific PFAS can be used to evaluate the impact of implemented remedial actions on these different pathways and to determine which PFAS are being effectively controlled and which are still contributing to the PFAS load within Lake Elmo.

These RAOs do not address the potential for incidental human contact with PFAS-containing foam observed to accumulate at multiple locations along the shores of Lake Elmo, including near the boat and canoe launches in the Lake Elmo Park Reserve. PFOS concentrations exceed the Swimming Screening Value immediately downgradient of the secondary outlet from the Eagle Point Lake Dam where surface water discharges to Lake Elmo during high Eagle Point Lake water elevations. Because the Swimming Screening Values are higher than the respective SSCs, PFOS and PFOA concentrations will be below both criteria if RAOs 8A and 8B are achieved. The adverse exposure risk from PFAS to ecological receptors that were identified in the BERA within AOC 8 is not directly addressed by these RAOs (AECOM, 2021). While the reduction of PFAS concentrations will aid in the protection of ecological receptors and recreational users, the RAOs and future sampling will not specifically evaluate these exposure pathways.

8.9 Horseshoe Lake + West Lakeland Surface Water – AOC 9

9A. Reduce PFAS concentrations within Horseshoe Lake and the downstream West Lakeland Ponds and connecting channels. Evaluate the reduction through statistical analysis of samples collected from surface water within this AOC as part of a long-term monitoring plan.

PFOS and PFOA exceed the SSCs within AOC 9. Surface water within AOC 9 from Horseshoe Lake, the West Lakeland Ponds, and the channels connecting these ponds infiltrates to the Shakopee and Jordan drinking water aquifers. This infiltration results in a PFAS migration pathway from AOC 9 to the West Lakeland Groundwater AOC (AOC 10). The first goal of RAO 9A is to reduce PFAS in surface water throughout AOC 9. This reduction will aid in achieving the second goal of RAO 9A, which is to reduce the continued migration of PFAS into the Shakopee and Jordan Aquifers via infiltration. The focus of RAO 9A is on reducing surface water concentrations as opposed to preventing the infiltration of groundwater because these ponds and channels were specifically designed as stormwater infiltration ponds and are essential to stormwater management within the Project 1007 Corridor.

The success of a remedial approach in achieving this RAO will be evaluated by sampling surface water in Horseshoe Lake, the West Lakeland Ponds, and the channels connecting the storage ponds.

An RAO was not developed to address the potential for incidental human contact with the PFAS-containing foam observed to accumulate in the channel downstream of Horseshoe Lake. This area is accessible to the public but is not frequented for recreational purposes. PFOS concentrations in surface water from the West Lakeland South Pond exceed the Swimming Screening Value. Although this pond does not have public access, homes do border this pond. Because the Swimming Screening Values are higher than the respective SSCs, PFOS and PFOA concentrations will be below both criteria if RAO 9A is achieved. The adverse exposure risk from PFAS to ecological receptors that were identified in the BERA within AOC 9 is not directly addressed by RAO 9A (AECOM, 2021). While the reduction of PFAS concentrations will aid in the protection of ecological receptors and recreational users, the RAO and future sampling will not specifically evaluate these exposure pathways.

8.10 West Lakeland Groundwater – AOC 10

10A. Reduce PFAS concentrations over time in the current plume in the drinking water aquifers (Shakopee and Jordan). Evaluate the reduction through statistical analysis of samples collected from a Shakopee and Jordan monitoring well network located within the current plume extent.

10B. Slow the downgradient migration of PFAS into unimpacted drinking water aquifers as monitored by the following:

- *Long-term monitoring of a Shakopee and Jordan well network downgradient of the current plume extent*

- *Long-term monitoring at select private or municipal supply wells in currently unimpacted or impacted but low concentrations of PFAS*

Groundwater PFAS exceedances in AOC 10 (for PFOS and PFOA) are present in the two primary drinking water aquifers, the Shakopee and Jordan Aquifers. The goal of RAO 10A is to reduce PFAS groundwater concentrations in the Shakopee and Jordan Aquifers. The goal of RAO 10B is to prevent migration of the PFAS plume beyond the current extent, both horizontally within the Shakopee and Jordan Aquifers towards unimpacted areas and vertically into deeper aquifers. The extent of vertical migration in AOC 10 from the Shakopee and Jordan Aquifers into the deeper aquifers, including the Tunnel City Aquifer, is not fully understood as a result of a lack of wells in the Tunnel City Aquifer. Under current pumping conditions, vertical migration from the Jordan Aquifer to the Tunnel City Aquifer is limited by the St. Lawrence Aquitard. The prevention of vertical migration of PFAS impacts is necessary to protect the Tunnel City Aquifer for future use as a drinking water source.

The success of a remedial approach in achieving these RAOs will be evaluated by sampling of a sentinel monitoring well network for PFAS within and beyond the extent of the current plume, both horizontally and vertically. Private and municipal wells could also be used to monitor the plume migration.

8.11 Upper Raleigh Creek Wetland Complexes Sediment – AOC 11

11A. Prevent human exposure of PFAS-containing sediments at concentrations above the relevant sediment criteria for the protection of human health.

11B. Reduce downgradient migration of PFAS currently adsorbed to sediment into surface water and groundwater. Evaluate the reduction through statistical analysis of samples collected within the surface water downgradient of this AOC as part of a long-term monitoring plan.

PFOS and PFOA exceed the 2-days/week SDSV in the wetland complexes along Raleigh Creek between Hadley Avenue and Ideal Avenue. Within AOC 11, surface water flows through each wetland complex before either discharging to downstream water bodies (Raleigh Creek and Eagle Point Lake) or infiltrating through PFAS-impacted sediment into shallow groundwater. Through these pathways, PFAS source mass may leach from sediments to either surface water or groundwater. Although the wetland complexes within this AOC are not located within a residential area, they are accessible to the public with portions owned by the City of Oakdale. The goal of RAO 11A is to prevent incidental ingestion of and dermal contact with PFAS-containing sediment at concentrations above the 2-days/week SDSV. The goal of RAO 11B is to prevent the increase of PFAS concentrations in downstream surface water bodies and groundwater due to the leaching of PFAS from sediment.

The success of a remedial approach in achieving these RAOs will be dependent on the selected remedial alternative and will only include sampling of sediment if the remedial approach includes sediment mass removal in the AOC. Sampling of downstream surface water bodies and downgradient groundwater may be necessary to determine whether leaching of PFAS-impacted sediments is continuing to occur; however, this evaluation of downstream surface water and downgradient groundwater must also take into consideration the inputs from other PFAS migration pathways.

While the reduction of PFAS concentrations will aid in the protection of ecological receptors, the RAOs and future sampling will not specifically evaluate these exposure pathways within this AOC.

8.12 Anna’s Grove Wetland Complex Sediment – AOC 12

12A. Prevent exposure of PFAS-containing sediments at concentrations above the relevant sediment criteria for the protection of human health.

12B. Reduce the downgradient migration of PFAS currently adsorbed to the sediment into surface water and groundwater. Evaluate the reduction through statistical analysis of samples collected within surface water downgradient of this AOC as part of a long-term monitoring plan.

PFOS and PFOA exceed the 2-days/week SDSV throughout AGWC. Within AOC 12, surface water flows through the impacted wetland complex before either discharging to downstream water bodies (Raleigh Creek and Eagle Point Lake) or infiltrating through PFAS-impacted sediment into shallow groundwater. Through these pathways, PFAS source mass can be leached from sediment to either surface water or groundwater. AOC 12 is located within a residential area and is bordered by a bike trail, providing easy public access to this wetland area. The goal of RAO 12A is to prevent incidental ingestion of and dermal contact with PFAS-containing sediment at concentrations above the 5-days/week SDSV. The goals of RAO 12B are to prevent the increase of PFAS concentrations in downstream surface water bodies and groundwater that result from PFAS leaching from wetland sediments.

The success of a remedial approach in achieving these RAOs will be dependent on the selected remedial alternative and will only include sampling of sediment if the remedial approach includes sediment mass removal in the AOC. Sampling of downstream surface water bodies and downgradient groundwater may be necessary to determine whether leaching of PFAS-impacted sediments is continuing to occur; however, this evaluation of downstream surface water and downgradient groundwater must also take into consideration the inputs from other PFAS migration pathways.

While the reduction of PFAS concentrations will aid in the protection of ecological receptors, the RAOs and future sampling will not specifically evaluate these exposure pathways within this AOC.

8.13 Eagle Point Lake Sediment – AOC 13

13A. Prevent exposure of PFAS-containing sediments at concentrations above the relevant sediment criteria for the protection of human health.

13B. Reduce downgradient migration of PFAS currently adsorbed to the sediment into surface water and groundwater. Evaluate the reduction through statistical analysis of samples collected within surface water downgradient of this AOC as part of a long-term monitoring plan.

PFOS and PFOA exceed of the 2-days/week SDSV at Eagle Point Lake, including along the shoreline adjacent to the canoe launch within Lake Elmo Park Reserve. Within this AOC, surface water flows over the PFAS-impacted sediments before either discharging to downstream water bodies or infiltrating into shallow groundwater. Through these pathways, PFAS source mass can be leached from sediments to either surface water or groundwater. The goal of RAO 13A is to prevent incidental ingestion of and dermal contact with PFAS-containing sediments at concentrations above the 2-days/week SDSV. The goals of RAO 13B are to prevent the increase of PFAS concentrations in groundwater and downstream surface water bodies due to the leaching of PFAS from sediment.

The method to determine the success of a remedial approach in achieving these RAOs will be dependent on the selected remedial alternative and will only include sampling of sediment if the remedial approach includes sediment mass removal in the AOC. Sampling of downstream surface water bodies and downgradient groundwater may be necessary to determine whether leaching of PFAS-impacted sediments is continuing to occur; however, this evaluation of downstream surface water and downgradient groundwater must also take into consideration the inputs from other PFAS migration pathways.

While the reduction of PFAS concentrations will aid in the protection of ecological receptors, the RAOs and future sampling will not specifically evaluate these exposure pathways within this AOC.

9 Remedial Technology and Action Screening

Technologies and remedial actions capable of per- and polyfluoroalkyl substances (PFAS) treatment are rapidly evolving and their commercial availability is expanding. The purpose of this section is to screen PFAS treatment technologies and other remedial actions based on the information available at the time of preparing this report for their application to treat groundwater, surface water, and sediment within the areas of concern (AOCs) to meet the Remedial Action Objectives (RAOs) and minimize the risk of PFAS exposure for the protection of human health. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) criteria of effectiveness, implementability, and relative cost were used as screening metrics. A fourth screening criterion, technology readiness, was also incorporated to screen technologies that are in the process of being commercially developed and account for the rapid pace at which technology development is occurring. The technologies and remedial actions were screened separately for each media type (groundwater, surface water, and sediment). In analyzing the remedial alternatives for this Site, AECOM evaluated both the actual PFAS treatment technologies that are commercially available as well as the locations where treatment can be implemented to prevent further migration of PFAS within a specific matrix. This section focuses on the technologies that could be applicable to each AOC. **Section 11** discusses where treatment would be most effective and impactful. The technologies that passed the screening discussed in this section are incorporated in the alternatives developed for **Section 11**.

9.1 General Response Actions

The technologies included in the screening can be generally separated into the following General Response Actions (GRAs) that will result in a reduction of PFAS. The GRAs evaluated for the Site include the following:

- No further action (NFA)
- Access restrictions
- Long-term monitoring
- Surface water hydrology modifications
- In-situ treatment
- Ex-situ treatment

These GRAs are applied differently for each of the media addressed in this Feasibility Study (FS). The sections below describe the GRAs for each media type are described and list technologies that were evaluated within each of those GRAs. **Appendix D** includes a detailed description of each technology and an evaluation of its screening.

9.1.1 Groundwater General Response Actions

This section explores each of the GRAs relative to their application for groundwater.

9.1.1.1 No Further Action

NFA typically indicates that no additional actions or responses will be implemented within a specific AOC, including no further sampling. Typically, current or interim remedial actions are also be terminated; however, as the Shakopee and Jordan Aquifers are currently and will likely continue to be used for drinking water in the future, NFA will not ensure the protection of human health. In this FS, the NFA response, when applied to groundwater, indicates that no further action to reduce PFAS concentrations within the drinking water aquifers would occur. However, treatment would continue for

all private and public supply wells. This ensures the public is not exposed to PFAS through drinking water. The PFAS treatment that would occur is detailed in the Minnesota Pollution Control Agency's (MPCA) Conceptual Drinking Water Supply Plan (CDWSP) (MPCA, 2021).

9.1.1.2 Access Restrictions

Access restrictions include both institutional controls (ICs) and engineering controls (ECs). ICs are administrative controls or legal restrictions placed on the groundwater use to protect the public against inadvertent exposure to PFAS and/or to protect the integrity of a functioning or completed remedy. Applicable ICs may include groundwater use restriction or management areas, property deed notices, and declaration of environmental restrictions. ECs are put in place to physically prevent the public from being exposed to PFAS through their drinking water and include monitoring and treatment.

9.1.1.3 Long-Term Monitoring

Long-term monitoring is similar to NFA but incorporates sampling to monitor PFAS concentrations. One component of long-term monitoring is the evaluation of the impacts of upgradient treatment on downgradient AOCs. Reducing the PFAS migration from one AOC has the potential to reduce PFAS concentrations within another AOC.

9.1.1.4 In-Situ Treatment

In-situ treatment is the treatment of groundwater in the subsurface without extraction. The benefit of in-situ treatment is that it does not require an extensive well and piping network to remove and treat groundwater; however, treatment over a large area is more difficult, especially at the depth of the Site's drinking water aquifers. The available in-situ treatment option is permeable adsorptive barriers (PABs), which require injection of adsorptive material into an aquifer. The barriers would adsorb PFAS to prevent continued migration, though the adsorptive media in the barriers has a finite capacity to adsorb PFAS and may require replacement after exhaustion of the initial media occurs.

9.1.1.5 Ex-Situ Treatment

Ex-situ treatment requires the pumping of groundwater from impacted aquifers for treatment above the ground surface. This would require a well network in the treatment area and associated piping to connect the wells to a water treatment plant. The scale application of extraction system can vary from a localized area to an entire region. A larger regional groundwater extraction system, referred to as a Multi-Benefit Well Array (MBWA), was evaluated to treat the groundwater and provide clean drinking water to affected communities. More information on the MBWA is provided in **Appendix K**. This multi-faceted approach targets several goals: a reduction of groundwater PFAS concentrations, slowing of the continued downgradient plume migration, and distribution of clean drinking water to affected communities.

Multiple treatment technologies are being considered for their ability to separate and/or destroy PFAS in groundwater. The ex-situ technologies listed here would be combined to form a treatment train to remove PFAS from the bulk groundwater and achieve target concentrations. The majority of the technologies evaluated for groundwater treatment in this FS fall into this GRA and are categorized as follows:

- Target-achieving separation
 - Single-use/virgin granular activated carbon (GAC)
 - Reactivated GAC
 - Regenerated GAC
 - Single-use ion exchange (IX)

- Regenerable IX
- Novel adsorbents
- Nanofiltration/reverse osmosis (NF/RO)
- Non-target-achieving separation
 - Coagulation and flocculation
 - Electrocoagulation and flocculation
 - Foam fractionation
 - Ozofractionation
- Disposal and destruction
 - Landfill
 - High-temperature incineration and thermal oxidation
 - Supercritical water oxidation (SCWO)
 - Hydrothermal alkaline treatment (HALT)
 - Electrochemical oxidation (EO)
 - Plasma
 - Photolysis and photochemical destruction

Separation technologies transfer PFAS from a high-volume waste stream into a lower-volume highly concentrated stream. For the purpose of this FS, separation technologies were divided into target achieving and non-target achieving categories. Non-target achieving technologies are those that may not meet all established treatment targets but still result in significant PFAS reductions. The treatment targets established for screening groundwater treatment technologies and the regulatory standards they are based upon are discussed in **Section 9.2.1**. Treated effluent fated for drinking water distribution or aquifer re-injection would be subject to the lowest established drinking water standards. Treated effluent discharged to surface water would be subject to the Site-Specific Surface Water Criteria. The FS project-specific remedial targets are set to below these standards to provide further protection and to accommodate future decreases in standards. The technologies compatible with ex-situ groundwater treatment were scored for effectiveness based on their ability to meet target concentrations with a treatment train approach; see **Table 1 (Appendix B)** for a summary of scoring.

The approach to implementing a treatment train is discussed in **Section 9.2.1**.

9.1.2 Surface Water General Response Actions

This section explores each of the GRAs relative to their application for surface water.

9.1.2.1 No Further Action

NFA indicates that no additional actions or responses will be implemented at a specific AOC. Any interim remedial actions, including sampling, will cease.

9.1.2.2 Access Restrictions

Access restrictions include both ICs and ECs. ICs are administrative controls or legal restrictions used to protect the public against inadvertent exposure to hazardous constituents. ICs may include fish consumption advisories and signage. ECs are not currently in place, but could include fencing and the removal of access points.

9.1.2.3 Long-Term Monitoring

Long-term monitoring is a variation of NFA but incorporates sampling to monitor PFAS concentrations over time. A component of this GRA is monitoring to determine whether upgradient treatment affects PFAS groundwater concentrations in downgradient AOCs. For example, long-term monitoring could be used to monitor changes in PFAS concentration in downstream AOCs (e.g. Raleigh Creek and Eagle Point Lake) as a result of remedial action at the Oakdale Disposal Site (ODS).

9.1.2.4 Surface Water Hydraulic Modifications

The surface water flow path and hydraulic controls along the Project 1007 conveyance system could be altered to stop or limit PFAS migration pathways both within the conveyance system and between surface water and groundwater. The following surface water hydraulic modifications were considered for this FS:

- Reroute stream channel
- Pipe stream channel
- Reduce flow out of Eagle Point Lake using existing control structure

The modifications could have impacts on the stormwater conveyance system. Modeling would be required to ensure that changes to the surface water system would not increase flood risks along the conveyance system. These modifications would not result in removal of PFAS mass from the entire system, but they could reduce the migration of PFAS from one AOC to another and could reduce downgradient migration.

9.1.2.5 In-Situ Treatment

In-situ treatment of surface water removes PFAS from water without removing the water from the surface water feature. The only technology being screened for in-situ treatment of surface water is a PAB. This technology would filter PFAS out of the water as it passes through the permeable barrier.

9.1.2.6 Ex-Situ Treatment

Ex-situ treatment removes surface water from the surface water feature for treatment. Adequate surface water pumping rates would be needed to ensure downstream PFAS concentration reductions occur. The majority of the technologies evaluated for surface water treatment in this FS fall into this GRA and are the same as those listed for ex-situ groundwater treatment in **Section 9.1.1.5**.

9.1.3 Sediment General Response Actions

This section explores each of the GRAs relative to their application for sediment.

9.1.3.1 No Further Action

NFA indicates that no additional actions or responses will be implemented at a specific sediment AOC. Any interim remedial actions, including sampling, will be terminated. There would be no further reduction of PFAS concentrations in the sediment within the AOC and no additional protection against incidental exposure to the public of PFAS-containing sediment.

9.1.3.2 Access Restrictions

Access restrictions include both ICs and ECs. ICs are administrative controls or legal restrictions used to protect the public against inadvertent exposure to hazardous constituents and may include signage and notification to residents of areas containing sediments with PFAS concentrations in exceedance of the Site-specific Sediment Screening Values (SDSVs). ECs such as fencing prevent the public from encountering hazards, in this case PFAS-impacted sediment.

9.1.3.3 Long-Term Monitoring

Long-term monitoring is a variation on NFA but incorporates sampling to monitor the PFAS concentrations. A component of this GRA is monitoring to determine whether upgradient treatment has an effect on downgradient AOCs. Reducing PFAS concentrations upgradient and subsequently the amount of PFAS that enters a specific AOC could result in a reduction in PFAS concentrations. In the case of the sediment AOCs, a reduction in the overlying surface water concentrations may result in a reduction in sediment concentrations.

9.1.3.4 In-Situ Treatment

In-situ treatment of sediment stabilizes or removes PFAS without extracting sediment from the Site. The following in-situ treatment technologies were evaluated for this FS:

- PAB
- Soil mixing/stabilization
- Thermal treatment
- Soil washing
- Phytoremediation

9.1.3.5 Ex-Situ Treatment

Ex-situ treatment removes sediment from an AOC for further treatment or disposal. The following ex-situ treatment technologies were evaluated for this FS:

- Extraction
 - Excavation
 - Dredging
- Stabilization
 - Ex-situ stabilization
- Separation
 - Soil washing
 - Thermal desorption
- Disposal and destruction
 - Landfill
 - Incineration
 - HALT

Extraction is a category unique to sediment treatment. Compared to groundwater and surface water treatment, the localized nature of impacted sediment may make bulk extraction suitable as a standalone technology to treat sediment AOCs. Bulk extraction of an aquifer, lake, or stream is not a technologically feasible alternative, thus is it not considered for groundwater or surface water.

The treatment targets established for screening sediment treatment technologies and the regulatory standards they are based upon are discussed in **Section 9.2.1**. The ex-situ technologies listed here could be combined to form a treatment train to achieve PFAS separation, destruction, or stabilization in the bulk sediment.

9.2 Technology Screening Criteria and Methodology

Technology screening qualitatively assesses each technology's ability to achieve the RAOs and minimize exposure pathways for the protection of human health using the CERCLA criteria of effectiveness, implementability, and cost as defined in the National Contingency Plan (NCP) (Title 40 of the Code of Federal Regulations [CFR] 300.430 (e) (7)). As PFAS technologies are rapidly evolving, a fourth criterion of technology readiness was included in this FS to evaluate the viability of new technologies for full-scale use. Technologies that are not viable based on these considerations were eliminated from further consideration.

9.2.1 Effectiveness

Effectiveness refers to the ability of a technology or remedial action to perform either independently or as a component of a broader alternative to achieve RAOs under the conditions and limitations present at a site. The NCP (40 CFR 300) defines effectiveness as the “degree to which an alternative reduces toxicity, mobility, or volume through treatment; minimizes residual risk; affords long-term protection; complies with Applicable or Relevant and Appropriate Requirements (ARARs); minimizes short-term effects; and how quickly it achieves protection.” Section 4.2.5 of the CERCLA Remedial Investigation (RI)/FS Guidance (USEPA/540/G-89/004) states that the evaluation of remedial technologies with respect to effectiveness should focus on: “(1) the potential effectiveness of process options in handling the estimated areas or volumes of media and meeting the remediation goals identified in the RAOs; (2) the potential impacts to human health and the environment during the construction and implementation phase; and (3) how proven and reliable the process is with respect to the contaminants and conditions at the site” (EPA, 1988).

PFAS treatment may involve a treatment train approach in which multiple technologies are used to capture, concentrate, and destroy PFAS. Therefore, the evaluation of effectiveness is based on the role that each technology would have within the treatment train when applicable. Technologies may also have different effectiveness scoring criteria depending on the broad GRA (e.g., in-situ treatment, ex-situ treatment, access restrictions) each technology falls within. For example, groundwater extracted in a pump-and-treat system (ex-situ treatment) that will be used as municipal supply water or re-injected into an aquifer would have different treatment criteria than an in-situ water treatment technology that is intended to reduce environmental PFAS concentrations as opposed to providing drinking water. These effectiveness scoring criteria, as applied to each GRA, are described in greater detail in **Appendix D**.

9.2.1.1 Regulatory-Established PFAS Standards

Federal regulatory standards for PFAS in drinking water have been developed for perfluorooctanesulfonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorohexanesulfonic acid (PFHxS), perfluorohexanoic acid (PFHxA), perfluorobutanesulfonic acid (PFBS), perfluorobutanoic acid (PFBA), perfluorononanoic acid (PFNA), and hexafluoropropylene oxide-dimer acid (HFPO-DA) and its ammonium salts (also referred to as “Gen X” chemicals). Federal standards include Maximum Contaminant Levels (MCLs) and unenforcable Maximum Contaminant Levels Goals (MCLGs) for PFOA, PFOS, PFHxS, PFNA, and HFPO-DA. PFAS mixtures containing two or more of PFHxS, PFNA, GenX, and PFBS are regulated using the Hazard Index (HI). **Table 9.1** presents the U.S. Environmental Protection Agency (EPA) MCLs and MCLGs for regulated PFAS (EPA, 2024a; EPA, 2024b).

Table 9.1: Summary of EPA PFAS National Primary Drinking Water Regulations

Compound	Final MCLG	Final MCL
PFOA	Zero	4.0 ng/L
PFOS	Zero	4.0 ng/L
PFHxS	10 ng/L	10 ng/L
PFNA	10 ng/L	10 ng/L
HFPO-DA (GenX)	10 ng/L	10 ng/L
Mixtures containing two or more of PFHxS, PFNA, HFPO-DA, and PFBS	1 (unitless) Hazard Index	1 (unitless) Hazard Index

The HI MCL is a dimensionless value calculated based on the concentrations of PFHxS, PFNA, HFPO-DA, and PFBS and relative to PFAS-specific health-based water concentrations shown in the equation below as the denominators. The calculation can result in an HI value greater than 1 even if no individual compound is above the final MCL. For example, a water source that had a concentration of 5 nanograms per liter (ng/L) for each of HFPO-DA, PFNA, and PFHxS and 1,000 ng/L of PFBS would be below each individual compound’s MCL but would have a HI of 2. With a HI of 2, the water would require further treatment prior to use as drinking water, even though none of the individual PFAS species are above the applicable MCL.

$$HI = \frac{[HFPO - DA] \text{ ng/L}}{10 \text{ ng/L}} + \frac{[PFBS] \text{ ng/L}}{2000 \text{ ng/L}} + \frac{[PFNA] \text{ ng/L}}{10 \text{ ng/L}} + \frac{[PFHxS] \text{ ng/L}}{10 \text{ ng/L}}$$

Minnesota-specific standards must also be considered, for both drinking water applications and for injection into groundwater. The Minnesota Department of Health (MDH) has set several categories of criteria for different PFAS species, including some species not currently regulated by EPA MCLs, namely perfluorobutanoic acid (PFBA) and perfluorohexanoic acid (PFHxA) (MDH, 2024). For groundwater, these include Health Risk Limits (HRLs) and Health-Based Values (HBVs) for different exposure durations. Both HRLs and Groundwater HBVs are used to evaluate potential health risks to humans from exposures to a chemical and the most conservative exposure durations should be regarded as treatment goals. Although HRLs have been formalized in Minnesota rules, HBVs have not yet been promulgated.

MDH has also developed a Health Risk Index (HRI) that calculates an additivity value for multiple PFAS. Additivity is considered for every health endpoint for which MDH has developed an HRL or HBV. For PFAS, potential health endpoints are the liver system, immune system, developmental, thyroid (specifically the endocrine mediated effect on the thyroid), and cancer. Additivity is further evaluated based on exposure duration, with durations specified as Acute, Short-term, Subchronic, Chronic, and Cancer. In the case of PFAS species regulated by MDH, no species have Acute standards, and all Short-term, Subchronic, and Chronic values are the same for individual compounds. The Cancer exposure values are used for calculating the cancer HRI for compounds with a cancer health endpoint (PFOA and PFOS).

Additivity is specifically calculated for each endpoint as follows and the highest value is used. EPA additivity (i.e., HI) is also applicable but would not be higher than the MDH additivity unless the water sample contains HFPO-DA or PFNA. All values are in ng/L. Also, because the EPA MCL for PFHxS is lower (10 ng/L) than the MDH HRL (47 ng/L), the EPA MCL is used for calculations with PFHxS.

$$Developmental \ HRI = \frac{[PFOA] \text{ ng/L}}{0.24 \text{ ng/L}} + \frac{[PFOS] \text{ ng/L}}{2.3 \text{ ng/L}} + \frac{[PFHxA] \text{ ng/L}}{200 \text{ ng/L}}$$

$$\text{Liver System HRI} = \frac{[\text{PFOA}] \text{ ng/L}}{0.24 \text{ ng/L}} + \frac{[\text{PFOS}] \text{ ng/L}}{2.3 \text{ ng/L}} + \frac{[\text{PFHxS}] \text{ ng/L}}{10 \text{ ng/L}} + \frac{[\text{PFBA}] \text{ ng/L}}{7,000 \text{ ng/L}}$$

$$\text{Immune System HRI} = \frac{[\text{PFOA}] \text{ ng/L}}{0.24 \text{ ng/L}} + \frac{[\text{PFOS}] \text{ ng/L}}{2.3 \text{ ng/L}}$$

$$\text{Thyroid HRI} = \frac{[\text{PFHxA}] \text{ ng/L}}{200 \text{ ng/L}} + \frac{[\text{PFHxS}] \text{ ng/L}}{10 \text{ ng/L}} + \frac{[\text{PFBA}] \text{ ng/L}}{7,000 \text{ ng/L}} + \frac{[\text{PFBS}] \text{ ng/L}}{100 \text{ ng/L}}$$

$$\text{Cancer HRI} = \frac{[\text{PFOA}] \text{ ng/L}}{0.0079 \text{ ng/L}} + \frac{[\text{PFOS}] \text{ ng/L}}{7.6 \text{ ng/L}}$$

Like with the HI, exceedance of a calculated HRI may occur without exceedance of any individual species. For example, for the Thyroid HRI, a PFHxA concentration of 100 ng/L, a PFHxS concentration of 5 ng/L, a PFBA concentration of 3,500 ng/L, and a PFBS concentration of 50 ng/L would be below the regulatory limit of each individual compound, but the HRI would be 2. In this scenario, as the compounds used for HRIs are different than the HI, and due to the significantly lower MDH HRL for PFBS, the HI would only be 0.525. HRIs do not regulate PFNA or HFPO-DA but are much stricter than the EPA MCL for PFBS and also regulate PFBA and PFHxA which the EPA MCLs do not regulate. Thus, water with higher PFBA, PFBS, and PFHxA concentrations are more likely to exceed an HRI than to exceed the HI. **Table 9.2** summarizes MDH HRLs and HBVs and MPCA Site-Specific Water Quality Criteria (SSC) (MPCA, 2023c). SSC would apply to the treatment of Site surface water as well as to any water discharged to surface water (e.g., pumped groundwater that is treated and then discharged to surface water). *Italicized* values indicate a concentration below the method detection limit at the time of writing this report. Detection limits for PFAS as of August 2024 are on the order of 1–2 ng/L.

Table 9.2: Summary of MDH PFAS Standards and MPCA SSCs for Groundwater and Surface Water

Applicable MDH Criteria	MDH 2024 Groundwater HRLs	MDH 2024 Groundwater HBVs	MDH 2024 Cancer HBVs	MPCA SSC
Analyte	ng/L	ng/L	ng/L	ng/L
PFBA	7,000	-	-	5,700
PFOA	35	<i>0.24</i>	<i>0.0079</i>	25
PFBS	100	-	-	140
PFHxA	200	-	-	220
PFHxS	47	-	-	20
PFOS	300	2.3	7.6	0.05
HFPO-DA	10	-	-	-

Site-specific sediment cleanup values have not been established for the Site, though Site-Specific Sediment Screening Values (SDSVs) have been established. The MPCA established SDSVs in March 2024 using the EPA’s Superfund methodology for soil and modified it to reflect the sediment exposure pathways for those recreating in areas on the banks of waterbodies where sediments may be present that are only sometimes water covered. These SDSVs were established for two tiers of exposure to PFAS-impacted sediment: 5-days/week and 2-days/week. The 5-days/week SDSV applies to AOC 12 (Anna’s Grove Wetland Complex – Sediment), and the 2-days/week SDSV applies to AOC 11 (Upper

Raleigh Creek Wetland Complexes – Sediment) and AOC 13 (Eagle Point Lake – Sediment) as established by the RAOs according to expected residential and/or recreational receptors in each area. In the absence of Site-specific cleanup values, SDSVs are considered to be applicable standards until Site-specific cleanup values are established. **Table 9.3** summarizes the MPCA PFAS SDSVs for sediment.

Table 9.3: Summary of MPCA SDSVs

Compound	MPCA SDSV – 5 Days/Week (µg/kg)	MPCA SDSV – 2 Days/Week (µg/kg)
PFOA	0.40	0.99
PFOS	18	45
PFHxS	170	430
PFBS	1,500	3,700
PFHxA	2,600	6,600
PFBA	120,000	250,000
HFPO-DA	160	390

9.2.1.2 In-Situ Treatment Technology Scoring for Effectiveness

Treatment technologies are screened against other technologies within the same GRA. Effectiveness scoring for water treatment technologies within the in-situ treatment technology GRA is based on their ability to reduce or prevent PFAS mass transport downstream and downgradient via PFAS sequestration in place. In addition to effectiveness in reducing PFAS mass transport downstream and downgradient, each sediment in-situ technology was scored on its ability to reduce concentrations in sediment and to prevent public exposure to sediments relative to the relevant SDSVs. The limited capacity of sediment in-situ technologies to achieve SDSVs, at their current state of development, excludes them from being scored in that capacity.

9.2.1.3 Ex-Situ Treatment Technology Scoring for Effectiveness

The effluent generated by ex-situ remediation systems is subject to the federal and state regulatory limits discussed earlier in this section. Generally, treatment targets are set to the lowest applicable standard. Exceptions to this include PFOA and PFOS, whose treatment targets are set to non-detect instead of their respective HBVs, as the HBVs are below current detection limits. As discussed, it is possible for the HI or HRIs to exceed a value of 1 without an individual compound exceeding its individual regulatory standard. Thus, it is critical that the HI and HRIs are calculated whenever PFAS samples are collected to ensure compliance with all applicable regulations and not just the regulatory standards for individual compounds.

An additional consideration for treatment technologies is the ability to meet future standards. Currently, the lowest regulatory limits are for long-chain PFAS species. For example, the lowest PFOA standard is 0.0079 ng/L, compared to PFHxA, which has a limit of 200 ng/L, and PFBA, which has a limit of 7,000 ng/L. Regulatory limits for safe levels of PFAS compounds in drinking water have consistently decreased; therefore, it is reasonable to assume future limits for short-chain species may be even lower. Thus, a secondary consideration when evaluating effectiveness is the ability of a treatment technology to meet lower limits, should regulatory limits be decreased in the future.

Consequently, effectiveness scoring within the ex-situ GRA is based on project-specific treatment targets set to current standards to provide further protection. Secondary consideration is given to the ability of a treatment technology to accommodate for future decreases in regulatory limits. **Table 9.4** consolidates the lowest regulatory standards for drinking water between EPA and MDH at the time of

writing this report. These regulatory standards establish the framework for the FS water treatment target concentrations, which are also displayed in **Table 9.4**.

Table 9.4: Ex-Situ Water Treatment: Drinking Water Treatment Targets for Drinking Water Distribution or Aquifer Injection

Compound	Lowest Standard	Lowest Standard Value	Treatment Target
PFOA	MDH Cancer HBV	< 0.0079 ng/L	Non-Detect
PFOS	MDH Groundwater HBV	< 2.3 ng/L	Non-Detect
PFHxS	EPA MCL	< 10 ng/L	< 10 ng/L
HFPO-DA	EPA MCL	< 10 ng/L	< 10 ng/L
PFNA	EPA MCL	< 10 ng/L	< 10 ng/L
PFBS	MDH HRL	< 100 ng/L	< 100 ng/L
PFHxA	MDH HRL	< 200 ng/L	< 200 ng/L
PFBA	MDH HRL	< 7,000 ng/L	< 7,000 ng/L
HI	EPA MCL	< 1	< 1
HRI	MDH	< 1	< 1

Table 9.5 summarizes the relevant standards and treatment targets for surface water bodies as established by the MPCA. Treatment targets for ex-situ remedial measures equal these standards, with the exception of PFOS because the SSC for PFOS is below current detection limits. The treatment target for PFOS is thus set to non-detect.

Table 9.5: Ex-Situ Water Treatment: Surface Water Treatment Targets

Compound	Site-Specific Water Quality Criteria (SSC)	Treatment Target
PFOA	< 25 ng/L	< 25 ng/L
PFOS	< 0.05 ng/L	Non-Detect
PFHxS	< 20 ng/L	< 20 ng/L
PFBS	< 140 ng/L	< 140 ng/L
PFHxA	< 220 ng/L	< 220 ng/L
PFBA	< 5,700 ng/L	< 5,700 ng/L

Ex-situ water treatment technologies were divided into two categories: separation and disposal/destruction. Ex-situ separation technologies, which can yield effluent concentrations below the treatment targets outlined in **Table 9.4** and **Table 9.5**, are considered “target-achieving” for the purposes of this technology screening. The treatment train approach, which pairs multiple technologies together, allows for distinction between technologies that offer preliminary bulk PFAS treatment (“non-target achieving”) and those that render the polished effluent suitable for discharge or distribution. The preliminary treatment technologies discussed in this screening include those that target PFAS removal and not those that target water chemistry adjustments that are typically necessary prior to PFAS treatment, such as metals removal. While target-achieving separation technologies can be applied as the sole treatment technology, a treatment train approach, which places a non-target-achieving separation technology before the terminal target-achieving separation stage, is expected to reduce costs, energy consumption, and waste production. The target-achieving separation stage options tend to

be more expensive and require more energy; thus, reducing their operating time improves efficiency. Effectiveness is therefore scored considering the ability of non-target-achieving technologies to achieve initial high PFAS mass removal and the ability of target-achieving technologies to meet FS treatment targets.

“Target-achieving” and “non-target achieving” distinctions have not been applied to sediment treatment due to the limited availability and stage of development of sediment treatment technologies at the time of writing this report. Ex-situ sediment treatment targets are equal to the 2024 MPCA SDSVs relevant to each sediment AOC.

Effectiveness for destruction/disposal technologies for all media is scored against the ability of ex-situ destruction technologies to achieve high PFAS mass removal and against the ability of disposal technologies to eliminate exposure pathways. PFAS waste streams are typically concentrated to increase PFAS concentrations and reduce volume prior to introduction to a destruction step. Destruction technologies use a variety of approaches to destroy PFAS and are not expected to reach effluent standards given the potentially high influent concentrations. While some technologies may be capable of achieving effluent standards, recycling of destruction effluent into a concentration or separation process may be more energy efficient than treating to effluent standards. Disposal technologies transport PFAS waste to an inaccessible location that aims to minimize human health exposure pathways. Those options that risk future transport of PFAS waste back into the environment or other communities are scored as having poor effectiveness.

9.2.2 Implementability

Implementability refers to the relative degree of difficulty anticipated in implementing a particular remedial technology or remedial action under technical, regulatory, and schedule (administrative) constraints posed by a site. As suggested by the CERCLA RI/FS Guidance, technologies can be eliminated from further consideration if a technology or remedial action cannot be effectively implemented at a site. As discussed in Section 4.2.5 of the CERCLA RI/FS Guidance, “technical implementability is used as an initial screening of technology types to eliminate those that are clearly ineffective or unworkable at a site.” Within the Project 1007 conveyance, technical implementability may be affected by flow conditions, geologic properties, and required treatment capacity. Regulatory implementability will be limited by regulations that apply to the Site. In the context of Project 1007, this could involve, but is not limited to, PFAS concentrations and other water quality parameters of treated water prior to distribution or discharge, restrictions governing the transportation and disposal of PFAS-containing waste, and pumping rates. The distribution of remediated water for drinking water supply or its injection into aquifers may necessitate additional permitting. Administrative implementability, which includes “the ability to obtain necessary permits for offsite actions, the availability of treatment, storage, and disposal services (including capacity), and the availability of necessary equipment and skilled workers to implement the technology,” is also considered in the initial screening.

9.2.3 Relative Cost

For the initial screening of technologies and remedial actions, the cost criterion is relative, meaning quantitative cost estimates are not prepared. Rather, it compares remedial technology and action costs using narrative terms. Section 4.2.5 of CERCLA RI/FS Guidance states that “cost plays a limited role in the screening” of remedial technologies. Relative capital and anticipated operations and maintenance (O&M) costs are used rather than detailed cost estimates. At this stage in the process, the cost analysis is made based on engineering judgment, and each technology is evaluated as to whether costs are “high, moderate, or low.”

9.2.4 Technology Readiness

As PFAS technologies are rapidly being developed, many treatment technologies are currently in development. For this FS, only commercially available technologies are included for consideration. However, even those technologies that are commercially available are at different stages of development. Some technologies have been implemented at full scale for multiple PFAS treatment projects, while others have only been demonstrated by field or pilot tests. A nine-level Technology Readiness Levels (TRL) system is often employed to assess a particular technology's maturity level, where TRL of 1 is the lowest ranking, and TRL of 9 is the highest ranking. This system was initially developed by the National Aeronautics and Space Administration (NASA) to assess space programs but has been modified and adopted by several organizations over time. Because PFAS remedial technologies are rapidly being developed, tested, and piloted to determine their ability to address PFAS impacts, this system has been used to evaluate these technologies' degree of commercialization at the time of writing this FS. The TRL system prescribed for this technology screening follows the U.S. Department of Energy's definitions (DOE, 2009). Only technologies with a TRL of 6 or above were considered in this FS. In general, technologies with a TRL of 6 were given a poor readiness score, those with a 7 or 8 were given a moderate readiness score, and those with a 9 were given a good readiness score.

9.2.5 Assessment Grading

The individual technologies and their associated process options were assessed based on the criteria described above using a relative grading scale of "good," "moderate," or "poor" for the effectiveness, implementability, and technology readiness screening criteria and "high," "moderate," and "low" for the relative cost. Once the assessment against each of the four criteria was completed, a "retained" or "not retained" determination was made.

The results of the technology screening are summarized in **Table 1** (groundwater), **Table 2** (surface water), and **Table 3** (sediment), found in **Appendix B**.

9.3 Summary of Retained Technologies

This section summarizes the treatment technologies or remedial actions that were retained during the technology screening and how they would be applied at the Site for development into alternatives, which are addressed in **Section 11**. For more details on the technologies evaluated, see **Appendix D**.

9.3.1 Groundwater Treatment

The extent of groundwater treatment could vary from smaller, localized treatment systems to a region-wide approach, depending on the selected remedy. The placement of extraction wells for a groundwater treatment system within a specific AOC as well as the treatment technology selected for a specific AOC will greatly impact the effectiveness in achieving the RAOs of preventing downgradient migration and reducing PFAS concentrations within the drinking water aquifers. If extraction wells are not placed in appropriate areas, plume capture may be inefficient or ineffective. The geographic locations where treatment should occur within the Site to provide optimal plume control is discussed in detail in **Section 11**. Potential remedial technologies and approaches were evaluated to determine the potential scalability in capacity and whether they would be applicable for both the localized and regionwide treatment. In general, a larger treatment system would have higher costs and may be harder to implement, but the treatment effectiveness of a larger system would be higher and thus effectiveness at achieving the RAOs would increase. For more details on each screened technology, see **Appendix D**.

The scoring basis for effectiveness of groundwater treatment differed between each of the GRAs. The effluent of ex-situ treatment, would be required to meet the lowest applicable drinking water standards between the MDH HBVs/HRLs and the EPA MCLs, either as a standalone technology or as part of a

treatment train, as the effluent would be used for municipal water supply or injected back into the drinking water aquifers downgradient of extraction. A potential treatment train to achieve the lowest applicable standards could include a pretreatment step to remove the majority of the PFAS followed by a polishing filtration step to achieve the drinking water standards. The concentrated PFAS, either in an aqueous solution or bound on a solid media, would then be disposed of or destroyed. The evaluated technologies were scored based on their ability to be effective within this treatment train approach. While in-situ technologies do not need to achieve the same effluent standards, as the groundwater would not be removed, their ability to achieve the RAOs was still considered within the scoring.

The technologies retained for further evaluation are described below for each GRA, along with their use within a treatment train where applicable. These retained technologies, their potential use, and applicable AOCs are summarized in **Table 1 of Appendix B**. Unless otherwise stated below, the technologies were evaluated for all AOCs.

9.3.1.1 No Further Action

As municipal and private well treatment for the affected communities in the project area must continue, actions in this NFA GRA would include but are not limited to the expansion of the Oakdale drinking water treatment plant, construction of a water treatment plant in Lake Elmo, connecting additional homes to municipal supply, and installing and maintaining point of entry treatment systems (POETSs) on private wells. Additional homes and municipalities may require treatment as the PFAS plumes continue to migrate. These costs and implementability were considered in the screening. Although this remedial action would not achieve the RAOs, NFA was evaluated for all AOCs per the NCP requirement to provide a comparison for other remedial actions and technologies.

9.3.1.2 Access Restrictions

Access restrictions include groundwater use restrictions or management areas, property deed notices, and environmental restrictions. Although this remedial action will not achieve the RAOs, access restrictions are easy to implement and would aid in the protection of human health. For these reasons, access restrictions were evaluated for all AOCs for incorporation into Site-wide remedial alternatives.

9.3.1.3 Long-Term Monitoring

Long-term monitoring is similar to NFA; however, monitoring would be conducted to evaluate how the PFAS plume changes over time. This remedial approach also includes monitoring for the reduction of PFAS within an AOC as a result of treatment in an upgradient AOC. The effectiveness of long-term monitoring and its reliance on upgradient treatment for groundwater is likely to be poor in achieving the RAOs as the large mass of PFAS within the groundwater would continue to migrate downgradient; however, understanding PFAS movement throughout the Site is an important component of a remedial response, thus long-term monitoring is retained to be incorporated into Site-wide remedial alternatives.

9.3.1.4 In-Situ Treatment

PABs are injectable slurries composed of PFAS-adsorptive material. PABs are injected perpendicular to the direction of groundwater flow. The distance between injection points is dependent on the geology and the resulting radius of influence of each injection. PABs can be effective at reducing PFAS concentrations at downgradient locations, but they are not implementable in the bedrock aquifers or across the wide plumes observed at the Site. PABs were not retained for evaluation.

9.3.1.5 Ex-Situ Treatment

This section discusses ex-situ treatment technologies and their applicability to groundwater treatment.

Single-use GAC

Single-use, or virgin, GAC is a highly porous hydrophobic media that adsorbs organic chemicals, including PFAS, to active sites in the media. GAC is highly effective at removing long-chain PFAS until the majority of active sites are filled by PFAS or other organic chemicals in the water, at which time contaminant breakthrough occurs and the GAC must be replaced. Short-chain PFAS are also removed by GAC, though lower efficiencies and faster breakthrough times are observed, with decreasing performance as the number of carbons decrease. For example, PFBA, which has three carbons, would be expected to breakthrough before six-carbon PFHxA, which would be expected to breakthrough before PFOA, which has eight carbons. Single-use GAC may be disposed of at a landfill, destroyed by incineration, or returned to the manufacturer where it is processed into reactivated GAC (described below). Other destruction technologies are in development to destroy GAC and PFAS adsorbed onto its surface. Single-use GAC can be implemented for drinking water end-use as either a standalone technology to remove PFAS from groundwater or as a polishing step after a separate technology is used to remove the bulk of the PFAS. Single-use GAC as a standalone technology would require frequent GAC changeouts, resulting in higher O&M costs. Potential future regulations could increase the costs associated with landfilling and incineration of PFAS-containing waste, which may impact the future implementability; though, these concerns are mitigated if the GAC is returned to the manufacturer for reactivation. Natural organic matter, iron, and manganese can shorten the life of GAC media, potentially requiring a pretreatment step. Single-use GAC was retained for further consideration for all groundwater AOCs because it is highly effective at meeting the FS treatment targets; however, to improve the long-term sustainability and reduce O&M costs, reactivated or regenerable GAC, described below, should be considered in the future.

Reactivated GAC

Reactivated GAC uses the same removal mechanisms as single-use GAC. After breakthrough occurs, instead of disposing of or destroying the spent GAC, it is treated with steam at high temperatures without oxygen to strip PFAS and other contaminants from the active sites on the GAC, restoring the capacity of the GAC to adsorb more PFAS. The off-gas is then treated to destroy PFAS and other contaminants. The reactivated GAC has similar adsorptive properties as single-use GAC and can achieve the FS treatment targets, particularly for long-chain PFAS. Short-chain PFAS are also removed by reactivated GAC, though lower efficiencies and faster breakthrough times occur, with decreasing performance as the number of carbons decreases. There are no reactivation facilities in the state of Minnesota, which could mean potentially higher transportation costs to bring the GAC to a reactivation facility. Reactivated GAC can come from bulk GAC, including both spent virgin GAC and GAC that has already undergone reactivation, that has been mixed at a reactivation facility and is derived from multiple users. When GAC changeouts occur, the Site would receive a mix of reactivated GAC. Alternatively, if a site's GAC usage is large enough, virgin GAC can be purchased by a facility and can be reactivated without the mixing in of other users' GAC. That option requires a large (typically > 80,000 lbs at a time) mass of GAC to be reactivated at the same time. Once the GAC is reactivated, it would be returned to the Site for use. Bulk reactivated GAC cannot be used for drinking water treatment, but it is possible that Site-specific GAC reactivated in a food-grade facility could be used for drinking water treatment. Natural organic matter, iron, and manganese can shorten GAC media life, potentially requiring a pretreatment step. As reactivated GAC is effective at meeting the FS treatment targets, it was retained for further consideration for all groundwater AOCs.

Regenerated GAC

Regenerated GAC uses the same removal mechanisms as single-use GAC except that instead of reactivating, disposing of, or destroying the spent GAC, it is treated onsite with a solvent or steam under lower temperature conditions than for reactivation to remove the PFAS. The PFAS is concentrated into a liquid waste stream for disposal or destruction. Regenerated GAC is typically not as efficient as single-

use or reactivated GAC and may require regenerations at a higher frequency than media changeouts; however, it could still achieve the FS treatment targets. Regeneration increases the complexity of a treatment train and regenerated GAC does have a finite lifespan. Eventually, the regenerated GAC will have to be replaced with new GAC. Regeneration would reduce the frequency of offsite transport of GAC, reducing the volume of media that would have to be reactivated, disposed of, or destroyed. GAC regeneration is an area of active research and the effectiveness of regenerable GAC may increase as new methods are developed. As with single-use GAC, regenerated GAC could be used as a standalone filtration step within a treatment train or as a polishing step after initial concentration. Both would result in a liquid PFAS concentrate that would be disposed of or destroyed. Regenerated GAC cannot be used for drinking water treatment at this time. Natural organic matter, iron, and manganese can shorten GAC media life, and regeneration would not be effective at removing these non-PFAS contaminants, requiring a pretreatment step to extend the usable life of the GAC. As regenerated GAC is effective at meeting the FS treatment targets for long-chain species and would offer a way to reduce media consumption, it was retained for further consideration at all groundwater AOCs.

Single-use IX

Single-use IX uses positively charged polystyrene beads with a neutral hydrophobic backbone to remove negatively charged, or anionic, PFAS through both electrostatic interactions with the negatively charged PFAS head groups and hydrophobic interactions with the fluorinated alkyl chain. IX is effective at achieving the FS treatment targets but has limited mass-loading capabilities and requires filter media changeout to prevent contaminant breakthrough. Currently, the spent media is either disposed of in a landfill or destroyed by incineration. IX resin is typically more expensive than GAC but has a larger capacity, resulting in a longer time between media changeouts and smaller vessels/footprint. In a treatment train, single-use IX could be used as either a standalone treatment technology to remove PFAS from groundwater or as a polishing step after a separate technology is used to remove the bulk of the PFAS. Similar to GAC, IX resins generally exhibit greater performance with long-chain PFAS compared to short-chain PFAS; however, short-chain PFAS removal of IX is typically far superior to short-chain PFAS removal by GAC. Single-use IX resin could be used for drinking water treatment. Pretreatment would be required to remove natural organic matter, iron, and manganese to prevent fouling of the IX resin. Single-use IX used as a standalone technology as opposed to in a treatment train would result in more frequent media changeouts, resulting in higher O&M costs. Potential future regulations could increase costs associated with the landfilling and incineration of PFAS-containing waste, which may impact the future implementability. Single-use IX was retained for further consideration because it is highly effective at meeting the FS treatment targets; however, to improve the long-term sustainability and reduce O&M costs, regenerable IX, described below, should be routinely evaluated as an alternative if single-use IX is implemented at the Site.

Regenerable IX

Regenerable IX uses the same removal mechanisms as single-use IX, but it is treated onsite with a regenerant solution, typically a mixture of a salt or base and an organic solvent, to remove the PFAS rather than being disposed of or destroyed. Regenerable IX is most applicable to source zones with high total PFAS (> 10,000 ng/L) due to the high capital costs required. Distillation can be used to reclaim the solvent and concentrate the PFAS into a high-salinity waste stream (“still bottoms”) for disposal or destruction. The regenerated IX resin is typically not as efficient as single-use IX resin and necessary regenerations may become more frequent over time. Eventually, the interval at which regenerations are performed will become too short and/or the cost to perform more frequent regenerations will become prohibitively expensive and the resin will have to be replaced with fresh resin. Regenerated IX resin could not be used for drinking water treatment at this time. Regeneration will increase the complexity of a treatment train, but it would reduce the volume of IX resin sent to a landfill or incineration, reducing media disposal costs and the uncertainty around potential regulatory limitations on the disposal of spent IX resin. Careful evaluation would be needed as the concentrated still bottoms may have their

own disposal challenges given the high concentrations of total dissolved solids (e.g., sodium chloride, other salts) present. As with single-use IX, the regenerated media could be used as a standalone filtration step within a treatment train or as a polishing step after initial concentration. Both would result in an aqueous PFAS concentrate that would be disposed of or destroyed. Regenerable IX was retained for further consideration because it is effective at meeting the MDH HBVs/HRLs and would reduce media consumption. Additionally, resin vendors are investigating regional regeneration facilities, which would allow resin to be regenerated offsite by the vendor. Although no plans to construct such a facility have been announced, this possibility should be kept in mind as a potential future option that would allow for the re-use of resin without the installation of onsite regeneration equipment.

NF and RO Membranes

NF and RO membranes use high pressures to force water through semi-permeable membranes, separating clean water (permeate) from PFAS and other dissolved ions (concentrate). The primary difference between NF and RO is the membrane pore size that can result in different removal efficiencies, particularly of short-chain or ultra-short chain PFAS. Site-specific testing would be recommended to determine which membranes are the most effective. NF and RO are capable of achieving the MDH HBVs/HRLs and are suitable for drinking water use. The membrane concentrate can be between 5% and 30% of the influent volume, with NF membranes generating a smaller volume of concentrate and RO membranes generating a larger volume of concentrate. Membrane concentrate contains PFAS and other contaminants/dissolved ions present in the water and likely cannot be discharged without additional treatment to remove PFAS from the concentrate, which could be performed using many of the treatment technologies discussed in this section (e.g., GAC, IX, foam fractionation). NF and RO membranes were both retained for evaluation for groundwater treatment because they are capable of achieving the MDH HBVs/HRLs and have potential as a preconcentration step for other treatment technologies.

Foam Fractionation

Foam fractionation uses air injection to create an air-water interface to which PFAS, and specifically long-chain PFAS, preferentially migrate. As the air bubbles rise, the air removes PFAS from the bulk liquid and causes a high-concentration PFAS foam to form at the top of the water column. This foam is removed and further concentrated, resulting in a small volume of highly concentrated PFAS waste, often referred to as “concentrate.” A foam fractionation pilot demonstration using a Surface Active Foam Fractionation (SAFF®) system was completed with groundwater as part of this FS. High removal efficiencies were observed and the MDH HRLs were achieved but the MDH HBVs were not. A more detailed summary of the SAFF® pilot test conducted as part of this FS can be found in **Section 10**; the full SAFF® report is provided in **Appendix E**. SAFF®, and foam fractionation more broadly, is not currently approved for drinking water treatment, though it could potentially be used with another technology that is approved. Foam fractionation is capable of removing 99% of PFOS and PFOA to reduce the amount of media used in filtration and was retained for evaluation as a potential pretreatment technology.

Landfill Disposal

Landfill disposal is an alternative for disposal of PFAS-impacted media or PFAS concentrate. A limited number of landfills will accept PFAS-impacted waste, none of which are located in Minnesota, so the waste would need to be transported long distances. As the PFAS are not destroyed, there remains a risk that the PFAS will leach from the landfill. Solidification can greatly reduce this risk, but increase disposal costs. Landfill disposal was retained as an option to dispose of PFAS concentrate and spent media from processing groundwater because it could provide an interim option as other PFAS destruction technologies undergo additional testing and development for full-scale deployment. There is also no concern that byproducts may be formed or that the PFAS may be aerosolized, as with the PFAS destruction technologies.

Incineration

Incineration of waste at temperatures above 1,100°C is capable of destroying PFAS. Waste would be transported to a facility by a vendor and incinerated offsite. There are no PFAS incineration facilities in the state of Minnesota, potentially increasing the cost of this technology. Incineration was retained as a technology for destruction as it can be effective at destroying PFAS and could be used with any of the wastes generated by the separation technologies required to achieve the MDH HBVs/HRLs.

Supercritical Water Oxidation

SCWO is an onsite treatment that heats water under pressure until it is above the supercritical point. Supercritical fluid water has properties of both the liquid and vapor phases, which promotes the oxidation of organic chemicals including PFAS. The destruction efficiency is over 99% and it has been tested with aqueous PFAS concentrates in addition to spent GAC. An issue with Site-specific concentrate is that it may not contain a high enough carbon content, requiring the addition of a co-fuel to sustain the reaction. See **Appendix G** for more information on bench testing completed as part of this FS. Because SCWO is highly effective, it was retained for further consideration.

Hydrothermal Alkaline Treatment

HALT is similar to SCWO but the required temperature and pressure are lower because the reaction is carried out under alkaline conditions. HALT has been shown to be highly effective with over 99% destruction of total PFAS observed. HALT could also potentially be used for GAC regeneration, though this is currently only applicable at the bench-scale. Testing would be required to determine the efficiency of HALT with Site-specific concentrate or media and any Site-specific operation and maintenance concerns that may impact implementability. HALT was retained for further consideration because it may be effective at PFAS destruction.

Electrochemical Oxidation

EO applies an electrical current across an anode-cathode pair within a conductive solution to defluorinate PFAS. Direct oxidation of PFAS occurs on the surface of the anode and indirect oxidation of PFAS is mediated by hydroxyl radicals and other reactive species generated in the aqueous phase. In an onsite pilot study that was conducted as part of this FS, EO was found to reduce the total PFAS by 98% in PFAS concentrate derived from foam fractionation treatment of groundwater. See **Appendix G** for more information on bench testing. EO could be used to destroy aqueous waste streams such as those generated by GAC regeneration, IX regeneration, RO/NF, or foam fractionation but could not be applied to solid media. Because EO has been shown to be effective with Site-specific PFAS concentrate, it was retained for further consideration as an onsite destruction technology for concentrated waste streams.

Plasma

Plasma is an ionized gas that forms highly reactive species capable of PFAS destruction. Although bench scale studies were only completed with Site-specific surface water concentrate for this FS, the studies did show that plasma was effective at destroying PFAS. See **Appendix G** for more information on bench testing. Plasma destruction could be completed with an aqueous PFAS concentrate, but an onsite pilot study would have to be conducted to determine whether there are any Site-specific O&M concerns that may impact its implementability. Plasma is retained for further consideration as a technology capable of destroying concentrated PFAS.

Photolysis and Photochemical Destruction

Photolysis and photochemical destruction are the breakdown of chemicals using energy from light. A photocatalyst, or a compound that becomes reactive in the presence of light, is required to break the carbon-fluorine bonds of PFAS. Although bench scale studies were only completed with Site-specific surface water concentrate for this FS, the studies did show that photolysis and photochemical destruction were effective at destroying PFAS. See **Appendix G** for more information on bench testing.

This technology is in development and additional pilot studies are required to determine the extent to which photolysis and photochemical destruction would be applicable at the Site to destroy aqueous PFAS concentrates. As photolysis and photochemical destruction could be effective at destroying PFAS, it was retained for further consideration.

9.3.2 Surface Water Treatment

The treatment of surface water is imperative to the protection of drinking water aquifers as surface water infiltrates to groundwater, providing a pathway for PFAS migration. As with groundwater treatment, the location of treatment and the resulting effectiveness at achieving the RAOs is evaluated in **Section 11**. Potential remedial technologies and approaches were evaluated to determine their scalability and whether they would be applicable for the volume of surface water within each AOC. For more details on each screened technology, see **Appendix D**.

As with groundwater, the scoring basis for effectiveness of potential surface water remedial technologies or actions differed between each of the GRAs. As ex-situ technologies remove water from the surface water body, the effluent of ex-situ treatment, either as a standalone technology or as part of a treatment train, will likely be required to meet the SSC prior to discharge back to the receiving surface water body. A treatment train approach could be used to achieve the SSC. As with groundwater treatment, this could include a pretreatment process to remove the majority of the PFAS followed by a polishing filtration step to achieve drinking water standards. Non-PFAS pretreatment to remove natural organic matter may be required. The concentrated PFAS, either in an aqueous solution or bound on a solid media, would then be disposed of or destroyed. The technologies evaluated in this FS were scored based on their ability to be effective within this treatment train approach. In-situ technologies do not need to achieve the same effluent standards as the surface water would not be removed; however, their ability to achieve the RAOs was still considered for the scoring.

The technologies retained for further evaluation are described below for each GRA, along with their use within a treatment train where applicable. These retained surface water treatment technologies, their potential use, and applicable AOCs are summarized in **Table 2 (Appendix B)**.

9.3.2.1 No Further Action

NFA indicates that no additional action, including monitoring, will be conducted at the Site resulting in no costs for this remedial alternative. NFA would result in the continued downgradient migration of PFAS including into the drinking water aquifers. Although this remedial action would not achieve the RAOs, NFA was retained for all AOCs per the NCP requirement to provide a comparison for other remedial actions and technologies.

9.3.2.2 Access Restrictions

Access restrictions prevent human exposure to impacted surface water through institutional and engineering controls such as fish consumption advisories and signage, fencing, and removal of access points. Although access restrictions do not address the surface water impacts and would not achieve the RAOs, they are easy to implement and would prevent additional human exposure to PFAS impacts. For these reasons, access restrictions were retained for all AOCs for incorporation into Site-wide remedial alternatives.

9.3.2.3 Long-Term Monitoring

Long-term monitoring is similar to NFA; however, monitoring would be conducted to evaluate the extent to which PFAS concentrations change overtime within the Project 1007 conveyance route. This remedial approach also includes monitoring for the reduction of PFAS within an AOC as a result of treatment in an upgradient AOC. Long-term monitoring itself does not reduce PFAS concentration within an AOC, however, long-term monitoring can help inform if additional remedial action is needed within

an AOC. For example, a reduction in PFAS concentrations at the outlet of ODS due to remedial action at ODS may result in reduction of PFAS concentrations in downstream AOCs (e.g., Raleigh Creek). The effectiveness of long-term monitoring and its reliance on upgradient treatment for surface water is likely to be poor in achieving the RAOs; however, understanding PFAS movement throughout the Site is an important component of a remedial response, thus long-term monitoring is retained to be incorporated into Site-wide remedial alternatives.

9.3.2.4 Surface Water Hydrology Modifications

Flow reduction at the control structures located throughout the Project 1007 conveyance route was evaluated as an alternative to reduce the spread of PFAS-impacted surface water downgradient. The control structures located at the Eagle Point Lake Dam are the target of this remedial approach as reducing the flow of water would result in a decrease of the total mass of PFAS transferred into Horseshoe Lake and the West Lakeland storage ponds. As this is an easily implementable action that could reduce the downgradient migration of PFAS, it was retained to be incorporated in Site-wide remedial alternatives.

9.3.2.5 In-Situ Treatment

PABs are installed within the stream channel to adsorb PFAS as the surface water flows through the barrier. The effectiveness is dependent, in part, on the contact time of the surface water with the barrier. A PAB would likely reduce the flow of water, and a bypass would be installed to prevent upstream flooding, reducing the effectiveness of the PAB during high-flow events. While the effluent of a PAB would be unlikely to achieve the SSC, it is easily implementable and can reduce PFAS concentrations. Reducing the concentrations of PFAS in the surface water would reduce the downgradient migration, making it a reasonable candidate as an interim measure. Consequently, PABs were retained for treatment in the Raleigh Creek Surface Water AOC and West Lakeland Surface Water AOC. The other surface water AOCs do not have defined channels in which to install the PAB.

9.3.2.6 Ex-Situ Treatment

Single-use GAC is expected to require more extensive pretreatment for surface water treatment than for groundwater treatment because of the high levels of natural organic material likely in Site surface water. Single-use GAC was retained for all surface water AOCs for further consideration because it is highly effective at meeting the FS treatment targets; however, to improve the long-term sustainability and reduce O&M costs, reactivated or regenerable GAC, described below, should be routinely evaluated as alternatives if single-use GAC is implemented at the Site.

Reactivated GAC considerations, discussed in **Section 9.3.1** for groundwater applications, apply here. Surface water may have increased organic material loading, which may require additional pretreatment. Physical implementation of this ex-situ treatment may have lower capital costs for surface water because wells are not required for extraction. Because reactivated GAC is effective at meeting the SSCs, it was retained for further consideration at all surface water AOCs.

Regenerated GAC considerations, discussed in **Section 9.3.1** for groundwater applications, also apply here. Because regenerated GAC is effective at meeting the MDH HBVs/HRLs for long-chain PFAS species and would offer a way to reduce media consumption, it was retained for further consideration at all surface water AOCs.

Foam fractionation uses air injection to cause the PFAS to foam at the air-water interface. This foam is removed and further concentrated, resulting in a small volume of highly concentrated PFAS waste, or concentrate. Foam fractionation, specifically a SAFF® system, was piloted with surface water as part of this FS, with high removal efficiencies observed. Over 99% of PFOS and PFOA were removed from surface water, although the SSC was not achieved for PFOS. Foam fractionation was retained as a

potential pretreatment technology as it is capable of reducing the amount of media used in filtration in other parts of a treatment train.

Single-use IX considerations for groundwater treatment, discussed in **Section 9.3.1**, broadly apply here. Higher concentrations of natural organic matter in surface water increase the risk of fouling the IX resins compared to groundwater treatment. Other non-PFAS contaminants in surface water, as well as the variation of these contaminants, also present a fouling risk for IX resin and increase operation difficulty. Additional pretreatment would likely be required for use of IX with surface water as compared to groundwater. Although operational challenges and increased pretreatment needs are expected, single-use IX resin was retained for further evaluation due to its ability to meet treatment targets.

Regenerable IX considerations for groundwater treatment, discussed in **Section 9.3.1**, broadly apply here. Similar to single-use IX, the higher concentrations of natural organic matter and other non-PFAS contaminants could increase the pretreatment requirements and increase the risk of fouling the IX media. Regeneration of the IX media is unlikely to remove all of the natural organic matter or biological films that can form in the presence of natural organic matter, increasing the criticality of proper pretreatment. Despite these challenges, regenerable IX was retained for further evaluation due to its ability to meet treatment targets and to reduce adsorptive media use.

The disposal and destruction technologies retained for groundwater treatment were also retained for surface water treatment. **Section 9.3.1** provides the descriptions and rationales for using these technologies.

9.3.3 Sediment Treatment

The treatment of sediment is important for the protection of drinking water aquifers due to its continuous interaction with surface water from which sediments sorb PFAS and to which it leaches. As with groundwater and surface water treatment, the location of sediment treatment and the resulting effectiveness at achieving the RAOs is evaluated in **Section 11**. Potential remedial technologies and approaches were evaluated to determine current treatment capacities and whether a technology could be used to treat the volume of sediment within each AOC. For more details on each screened technology, see **Appendix D**.

The scoring basis for effectiveness of potential sediment remedial technologies or actions differed between each of the GRAs. SDSVs would need to be met for soil that undergoes in-situ treatment and remains in place, or for soil that is removed for ex-situ treatment and replaced after treatment. Many of the soil treatments would have an effluent waste stream, which would have to undergo further treatment. In general, the treatment of these effluent streams was not considered as part of this assessment, as it would be similar to other waste streams and could be managed by technologies discussed in the groundwater and surface water sections. Ex-situ treatment in which clean fill is used and the impacted soil is not returned to the Site would not be required to meet the SDSVs. However, the impacted soil would need to meet any applicable limits for its final disposal location.

The technologies retained for further evaluation are described below for each GRA, along with their use within a treatment train where applicable. These retained sediment treatment technologies, their potential use, and applicable AOCs are summarized in **Table 3 (Appendix B)**.

9.3.3.1 No Further Action

NFA indicates that no additional action, including monitoring, will be conducted at the Site, resulting in no costs for this remedial alternative. NFA would result in the continued downgradient migration of PFAS including into the drinking water aquifers. Although this remedial action would not achieve the RAOs, NFA was retained for all AOCs per the NCP requirement to provide a comparison for other remedial actions and technologies.

9.3.3.2 Access Restrictions

Access restrictions prevent human exposure to impacted sediment through institutional and engineering controls such as fish consumption advisories and signage, fencing, and removal of access points. Although access restrictions do not address the concerns of PFAS migrating to groundwater from sediment and would not achieve the RAOs, they are easy to implement and would prevent additional human exposure to PFAS-impacted sediment. For these reasons, access restrictions were retained for all AOCs for incorporation into Site-wide remedial alternatives.

9.3.3.3 Long-Term Monitoring

Long-term monitoring is similar to NFA; however, monitoring would be conducted to evaluate the extent to which PFAS concentrations change overtime within the Project 1007 conveyance route. This remedial approach also includes monitoring for the reduction of PFAS within an AOC as a result of treatment in an upgradient AOC. Long-term monitoring itself does not reduce PFAS concentration within an AOC, however, long-term monitoring can help inform if additional remedial action is needed within an AOC. For example, a reduction in PFAS concentrations at the outlet of ODS due to remedial action at ODS may result in reduction of PFAS concentrations in Raleigh Creek, which may result in a reduction of PFAS concentrations in sediment over time. The effectiveness of long-term monitoring and its reliance on upgradient treatment for sediment is likely to be poor in achieving the RAOs; however, understanding PFAS movement throughout the Site is an important component of a remedial response, thus long-term monitoring is retained to be incorporated into Site-wide remedial alternatives.

9.3.3.4 In-Situ Treatment

PAB, soil mixing/stabilization, thermal treatment, soil washing, and phytoremediation were all evaluated. However, none of these in-situ treatment technologies have been retained for the treatment of sediment because of poor implementability, poor effectiveness, limited field demonstration, and uncertainty regarding long-term impacts. As research progresses and additional bench and pilot testing is performed, these treatments may become more practical and should be routinely evaluated.

9.3.3.5 Ex-Situ Treatment

Many of the ex-situ treatment technologies for PFAS treatment rely on desorption of PFAS from the sediment into an aqueous waste stream, requiring subsequent treatment of this aqueous waste stream. Aqueous waste stream technologies are not separately evaluated here as the ex-situ treatment for surface water or groundwater treatment options could be similarly applied to this aqueous waste. Additionally, while some ex-situ sediment treatments could reduce the amount of PFAS in sediment, until PFAS mass flux from ODS is stopped, no ex-situ treatment of sediment is recommended.

Extraction

Excavation is an extraction technique that transfers sediment from within a delineated area to an external staging, treatment, or disposal area using large machinery and physical removal. It could be implemented during seasonally dry periods at the upper Raleigh Creek and Anna's Grove Wetland Complexes. Further sampling would be needed to determine the extent of excavation required to meet RAOs. Soil contaminated with PFAS is difficult to identify in the field, unless impacted with other contaminants that are visually apparent; confirmation soil sampling is needed to determine the effectiveness of excavation, potentially making it an iterative process. Excavation was retained in this FS as it could be an effective way to remove contaminated soil. However, it would require long periods of dry weather to be most effective and improved source zone at ODS must first be completed prior to the start of any excavation to prevent re-contamination of soil.

Dredging

Dredging is an extraction technique that removes submerged sediment from below surface water bodies. It eliminates the need for dewatering of surface water bodies, but it can remobilize contaminants and increase suspended solids in downstream waters. Dredging would remove soil for further treatment, landfill disposal, incineration, or destruction. Whether dredging activities would be approved by regulatory agencies or other stakeholders in an area such as Eagle Point Lake and its surrounding wetlands is unknown. Additionally, dredging would pose a risk of disruption to the Site and downstream waters, as large amounts of sediment could be remobilized in the process. Consequently, dredging was not retained for evaluation.

Stabilization

Ex-situ stabilization is similar to in-situ stabilization, but involves excavating soil prior to treatment. Ex-situ stabilization was not retained for evaluation because of poor implementability, poor effectiveness, limited field demonstration in wetland areas, and uncertainty regarding long-term impacts. As research progresses and additional bench and pilot testing is performed, this treatment may become more practical and should be routinely evaluated.

Separation

Soil washing is a PFAS separation technology that couples fractionation based on size or density with a wash solution to desorb PFAS from a solid matrix and transfer it to an aqueous waste stream. Soil would first be excavated or dredged and then transferred to a soil washing facility. Soil washing is less applicable to high clay and high organics soils and better suitable for sandy soils. Soil washing was not retained as an option as few facilities exist and it is limited in implementability. As research progress and testing/scale up occurs, soil washing may become more practical and should be routinely evaluated.

Thermal desorption is a PFAS separation technology that separates PFAS from solid media by heating it to near or above the boiling point of PFAS, transferring PFAS from sediment to the vapor phase. The process generates a volatilized PFAS gas stream that requires further treatment, typically via thermal oxidation or carbon adsorption, and renders a cleaned soil that can be re-used. Thermal desorption is energy intensive and expensive and thus was not retained for evaluation.

Incineration

Incineration at temperatures above 1100°C is capable of destroying PFAS. Excavated sediment or a PFAS concentrate resulting from treatment (e.g., liquid waste resulting from soil washing) would be transported offsite to a facility by a vendor and incinerated. There are no PFAS incineration facilities in the state of Minnesota, which could mean potentially higher disposal costs. Large amounts of soil will not be combusted and will remain as ash. Further, incinerator operators typically avoid incinerating large volumes of soil, potentially increasing implementability challenges and costs for this treatment technology. Thus, incineration was not retained as an option for impacted soil.

Landfilling

Landfill disposal is an alternative for disposing of PFAS-impacted soil. A limited number of landfills accept PFAS-impacted waste, none of which are located in Minnesota, so the waste would need to be transported long distances. As the PFAS in the soil are not destroyed, there remains a risk that the PFAS will leach from the landfill. Stabilization may be required to limit the migration of PFAS in the landfill leachate, and there is uncertainty regarding future regulations for landfill disposal of PFAS-containing materials. Landfilling was retained as an option to dispose of soil because it is the only technically feasible and cost-effective method for disposal, and it could provide an interim option as other soil-specific technologies are further tested and developed for full-scale deployment.

Hydrothermal Alkaline Treatment

HALT uses high water temperatures and pressures along with a strong base to destroy PFAS under alkaline conditions. Although HALT was retained for concentrated waste streams from groundwater and surface water treatment, and HALT may be able to destroy PFAS bound on GAC, it is scalable to treat removed soil. For that reason, HALT was not retained for evaluation in this FS for sediment.

10 Pilot Tests and Treatability Studies

Treatability studies, which can be laboratory screening, bench-scale testing, or pilot-scale testing, are typically performed as part of a Feasibility Study (FS) to evaluate remedial technologies. These studies help to verify applicability of a remedial technology to site-specific conditions; optimize full-scale design and operating conditions; and improve cost estimates (EPA, 1989). Multiple treatability studies were conducted as part of this FS for potential per- and polyfluoroalkyl substances (PFAS) remedial alternatives.

A Surface Active Foam Fractionation (SAFF®) unit procured through a Request for Proposals (RFP) by the Minnesota Pollution Control Agency (MPCA) under the Settlement was operated as a pilot-system to address interim remedial action needs in surface water and groundwater in the Project 1007 area. The SAFF® pilot study aimed to remove PFAS contaminants resulting from two primary source areas: Oakdale Disposal Site (ODS) and Washington County Landfill (WCL). The pilot test was completed in the Spring of 2025 and has informed the feasibility of applying SAFF® technology to PFAS-impacted groundwater and surface water over several years of operations, through various seasonal conditions, and under varied system controls.

Several hundred gallons of concentrated PFAS waste, or secondary SAFF® concentrate, were generated during the pilot study. An RFP was issued by the MPCA to PFAS destruction technology vendors to evaluate the destruction capabilities of their technology on Site-specific PFAS SAFF® concentrate. For the bench-scale evaluation, concentrate derived from the treatment of surface water was used, though concentrate derived from groundwater treatment was also generated by the project. Four technologies (electrochemical oxidation [EO], super critical water oxidation [SCWO], plasma, and photochemical) were evaluated by seven vendors, with technology sizes ranging from bench-scale to commercially available services. An EO field demonstration was also performed using a DE-FLUORO™ pilot-scale system. Additional field demonstrations are recommended to further evaluate potential destruction technologies.

Two additional bench-scale studies were completed using Site-specific water to further evaluate the feasibility of applying other PFAS treatment technologies for full-scale treatment. The first study evaluated groundwater treatment using rapid small-scale column tests (RSSCTs) to estimate granular activated carbon (GAC) and ion exchange (IX) media usage using all applicable state and federal regulatory criteria. The groundwater bench-scale study also evaluated pretreatment requirements. The second study, a sediment leaching study, evaluated the potential for desorption of PFAS into Raleigh Creek, should PFAS loading to Raleigh Creek decrease.

This section summarizes the results from all completed treatability studies. Detailed reports are included in **Appendix E** through **Appendix I**. **Section 14** proposes additional pilot studies to close Site data gaps and clarify design specifications prior to implementation of a remedial action.

10.1 Surface Active Foam Fractionation Pilot

To test the feasibility of foam fractionation technology for treatment of PFAS-impacted surface water and groundwater within the Project 1007 Site, the MPCA procured a SAFF®20 foam fractionation system manufactured by EPOC Enviro (EPOC). The SAFF®20 is the smaller of two 40-foot shipping container-based systems manufactured by EPOC that utilize their SAFF® technology. The SAFF®20 utilizes two primary fractionation vessels and one secondary fractionation vessel for PFAS removal. EPOC also manufactures a SAFF®40, which can treat approximately twice the flow of the SAFF®20 and utilizes four primary fractionation vessels and two secondary fractionation vessels for PFAS removal. The SAFF®40 can also incorporate tertiary fractionation to further decrease the volume of PFAS concentrate

generated. EPOC was the only vendor to respond to the RFP for the foam fractionation pilot. The SAFF®20 pilot unit is referred to as the SAFF® for conciseness in this report.

The SAFF® was deployed at Tablyn Park in Lake Elmo, MN, in November 2022 and testing concluded in the Spring of 2025. **Figure 162** shows the general site location for the SAFF® pilot study. During this pilot study, SAFF® was separately evaluated using groundwater from both the Shakopee and Jordan Aquifers and surface water from Raleigh Creek. The pilot study tested the ability of SAFF® technology to remove PFAS from impacted water and to produce a PFAS concentrate that could be disposed of or destroyed. The Tablyn Park SAFF® Report (**Appendix E**) discusses SAFF® technology and the pilot study findings in greater detail. Overall, the goals of the pilot study were to:

- Operate the PFAS removal system using influent waters with varying PFAS concentrations and water chemistries;
- Determine the feasibility of operating the SAFF® unit with different surface water flow conditions and from different groundwater aquifers;
- Evaluate the system's performance to determine optimal operational parameters; and
- Use the results to evaluate potential effectiveness of the technology for full-scale implementation.

The primary PFAS of interest for this study were perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) due to their high concentrations and exceedances of relevant state and federal regulatory criteria across the Site in both surface water and groundwater. Equipment tuning was completed by adjusting the volume of air injected, treatment time, top-up rate, and run style to minimize the PFOS and PFOA concentrations in the effluent.

Approximately 10 million gallons of water were treated during the study period. Groundwater was pumped from wells installed at Tablyn Park and surface water was pumped from Raleigh Creek. All treated water was discharged to Raleigh Creek downstream of the surface water intake location. Approximately 800 gallons of PFAS concentrate, also referred to as secondary fractionate, was generated by the SAFF® unit and was periodically transported from Tablyn Park to the MPCA-managed WCL between January 2022 and May 2025 for staging to await further treatment. WCL was used only for staging waste; no waste was disposed of at WCL. The secondary fractionate was used for bench-scale destruction studies and the DE-FLUORO™ pilot study that were performed as part of this FS. The remaining secondary fractionate not used for bench- and pilot-scale studies was transported offsite by Clean Harbors for incineration.

10.1.1 Results

Operational parameters were varied to determine the impact of treatment time, energy input, and run styles (stepwise, continuous top-up, dosing with secondary concentrate, and oscillation, defined below) on PFAS removal efficiency. The study evaluated SAFF®'s ability to remove PFAS from the bulk effluent stream and minimize the volume of concentrated PFAS waste using both a short-list of PFAS analytes for rapid turnaround time as well as U.S. Environmental Protection Agency (EPA) Method 1633 list of PFAS analytes for more thorough results. Adsorbable organic fluorine (AOF) and total oxidizable precursor (TOP) assay were measured at several points throughout treatment with negligible changes to concentrations observed. The discussion below highlights the removal efficiency, energy consumption, and throughput achieved with optimized settings applied to the Shakopee Aquifer, Jordan Aquifer, and Raleigh Creek influent waters. **Appendix E** includes a more comprehensive discussion of the pilot study and associated analyses.

10.1.1.1 Groundwater

Groundwater from both the Jordan and Shakopee Aquifers was tested as part of this pilot study. Both groundwater sources tested produced less stable foam than that reported for the manufacturer's other deployments. This was likely the result of low levels of organic material and/or co-foaming compounds in the influent groundwater that typically aid in foam formation. As a result, PFAS removal was achieved through bubble fractionation, where PFAS adhered to the air-water interface in bubbles and subsequently spilled over the top cone in the system, as opposed to foam fractionation, where PFAS and organics/co-foaming compounds form foam that spills over the top cone.

Four different run styles, defined below, were tested to evaluate the impact on removal efficiency:

- Stepwise: Venturi pump frequency, which equates to the amount of air injected, was increased with each fractionation step, increasing the amount of air injected as the run progressed.
- Continuous top-up: Treated water was continuously pumped into the bottom of the vessel to promote spillover of the higher PFAS-containing water at the top of the vessel.
- Dosing with secondary concentrate: Secondary SAFF[®] concentrate was added to runs to increase the initial concentration of PFAS in a vessel to promote foam formation.
- Oscillation: Venturi pump speed was oscillated between higher and lower frequencies, with both the high- and low-frequency set points increasing throughout the duration of the run.

Within each of these run styles, the length of run and venturi pump energy input were also varied.

The most effective run style was oscillation. Generally, for each run style, longer treatment times and higher energy input corresponded to higher PFAS removal efficiencies.

Table 10.1 compares effluent concentrations achieved during the groundwater pilot study in nanograms per liter (ng/L) with current regulatory standards and the project remedial targets defined by this FS as discussed in **Section 9**. Influent and effluent concentrations of PFOA, PFOS, perfluorohexanesulfonic acid (PFHxS), hexafluoropropylene oxide-dimer acid (HFPO-DA), perfluorononanoic acid (PFNA), perfluorobutanesulfonic acid (PFBS), perfluorohexanoic acid (PFHxA), and perfluorobutanoic acid (PFBA) were monitored to evaluate PFAS removal performance. The associated Hazard Indices (HIs) were also evaluated. At optimized parameters, SAFF[®] treatment yielded groundwater from both aquifer sources below the EPA Maximum Contaminant Levels (MCLs) but did not consistently achieve the Minnesota Department of Health (MDH) Health Risk Limits (HRLs) or Health Based Values (HBVs) for PFOA and PFOS, indicating downstream polishing would be required. Some variability in performance was observed.

Table 10.1: SAFF®-Treated Groundwater Effluent Results in ng/L from Optimized Settings Relative to Regulatory Standards

Compound	PFOA	PFOS	PFHxS	HFPO-DA	PFNA	PFBS	PFHxA	PFBA	HI ⁽¹⁾
Lowest Regulatory Standard	< 0.0079 ⁽²⁾	< 2.3 ⁽³⁾	< 10 ⁽⁴⁾	< 10 ⁽⁴⁾	< 10 ⁽⁴⁾	< 100 ⁽⁵⁾	< 200 ⁽⁵⁾	< 7000 ⁽⁵⁾	< 1 ⁽⁴⁾
Shakopee Aquifer									
Influent	281	939	34.1	<1.50	2.12	15.4	44.3	372	<3.78
Optimized Effluent	<1.77	2.67	1.62	<1.50	<1.77	13.5	36.1	361	<0.496
Optimized Removal Efficiency (%)	99.4	99.7	95.2	NC ⁽⁶⁾	16.5	12.3	18.5	3.0	>86.9
Jordan Aquifer									
Influent	64.5	28.5	2.43	<1.50	<1.77	<1.77	7.7	444	< 0.571
Optimized Effluent	2.3	<1.72	<1.72	<1.50	<1.72	<1.72	6.73	431	< 0.495
Optimized Removal Efficiency (%)	97.2	94.0	29.2	NC	NC	NC	12.6	2.93	>13.3

¹ HI and corresponding removal efficiencies were calculated using instrument limits of detection if the reported value was not above instrument detection limits.

² MDH Cancer HBV

³ MDH Groundwater HBV

⁴ EPA MCL

⁵ MDH HRL

⁶ NC = Not Calculated as influent was below detection limits

Varying treatment times were considered to understand the relationship between daily treatment capacity of the system and effluent concentrations, as longer treatment times reduce the daily throughput for a SAFF® unit. **Figure 10.1** illustrates the relationship between throughput and removal efficiency for the Shakopee Aquifer. The lowest effluent concentrations were observed at 50 minutes of treatment, which correlates to approximately 25,000 gallons per day (gpd) with a SAFF®20 system. Similar operating conditions with a SAFF®40 would increase daily treatment volume to approximately 50,000 gpd. Reducing the treatment time to 30 minutes increased daily capacity to approximately 35,000 gpd, though it also resulted in a slight increase in effluent concentrations. These results demonstrate that treatment time, equipment capacity, and effluent concentrations must be balanced in a long-term installation to achieve the optimal outcome. For example, if polishing with adsorptive media is required to meet PFOA and PFOS discharge limits, overall projects costs could potentially be decreased by increasing daily throughput and reducing the number of SAFF® units required. This would include marginal increases in adsorptive media usage due to higher flowrates. Adsorptive media usage was evaluated in bench-scale RSSCTs as part of this FS; details on the results are provided in **Section 10.4** and **Appendix F**.

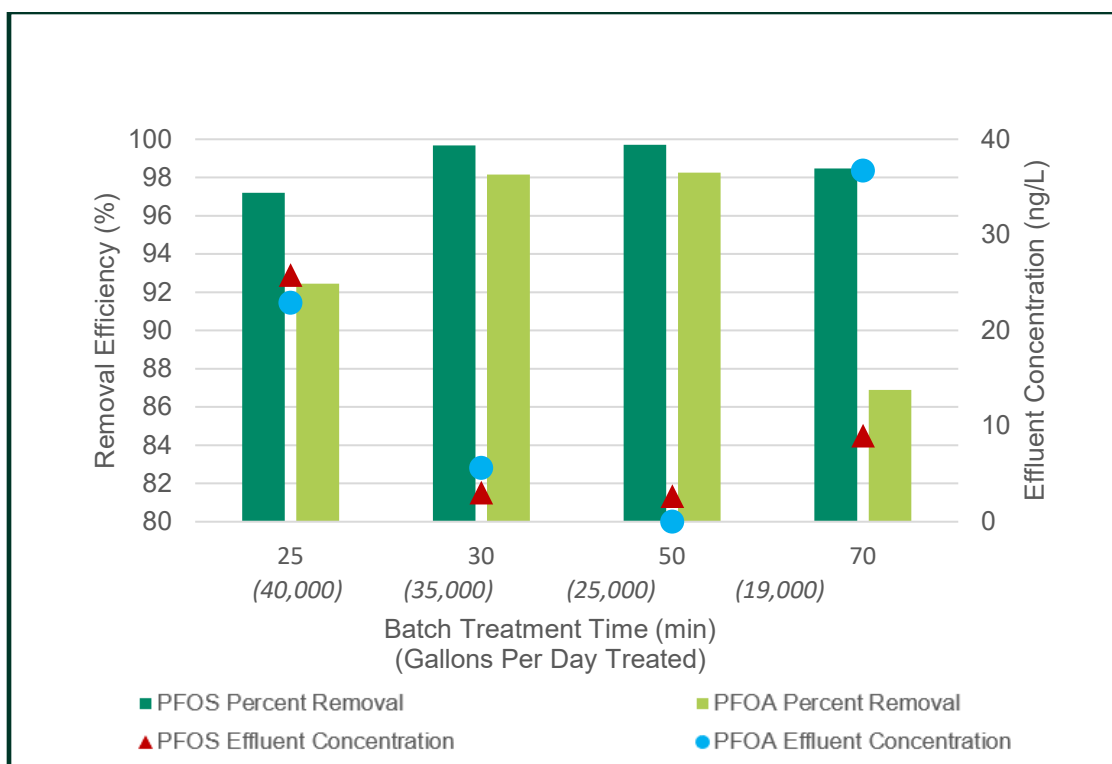


Figure 10.1: Varying treatment duration, throughput, and removal efficiency for Shakopee Aquifer groundwater treated by SAFF®

Concentration factors, which are calculated by dividing the concentration of a specific PFAS compound after a stage of treatment by the initial influent concentration of that compound, were calculated for PFOA and PFOS during long-term operations in both the Shakopee and Jordan Aquifers. **Table 10.2** gives concentration factors through the process using concentrations in Tank 3 (primary fractionation concentrate) and in Tank 4 (secondary fractionation concentrate). Concentrations of PFAS are given in micrograms per liter ($\mu\text{g/L}$). Concentration factors provided a relative measure for volume reduction of the influent water contaminated with PFAS to the final volume of PFAS waste that requires further treatment.

Table 10.2: Shakopee and Jordan Aquifer Concentration Factors

Species	Influent	Tank 3	Tank 3 Concentration Factor	Tank 4	Tank 4 Concentration Factor
Shakopee Aquifer					
PFOS	1.2 $\mu\text{g/L}$	32 $\mu\text{g/L}$	26x	21,000 $\mu\text{g/L}$	17,500x
PFOA	0.4 $\mu\text{g/L}$	10 $\mu\text{g/L}$	24x	9,600 $\mu\text{g/L}$	24,000x
Jordan Aquifer					
PFOS	0.001 $\mu\text{g/L}$	0.09 $\mu\text{g/L}$	95x	1,730 $\mu\text{g/L}$	1,800,000x
PFOA	0.023 $\mu\text{g/L}$	0.76 $\mu\text{g/L}$	32x	668 $\mu\text{g/L}$	29,000x

To achieve 99% removal of both PFOS and PFOA from groundwater influent, approximately 5 kilowatt hours (kWh) were consumed per 1,000 gallons of influent groundwater. Operating at these optimized settings with the SAFF®20 pilot unit allowed for a throughput of approximately 25,000 to 35,000 gpd. Energy savings would likely be achieved with a full-scale system.

10.1.1.2 Surface Water

Unlike groundwater tested for this pilot, Raleigh Creek surface water foamed readily, likely due to higher concentrations of total organic carbon (TOC). Stepwise and oscillation were the only run styles tested with surface water; PFAS results indicated oscillation was the most effective run style. Similar to operations adjustments made during groundwater tuning, venturi pump frequency, treatment time, and top-up settings were systematically adjusted to minimize effluent concentrations. **Table 10.3** provides the optimized effluent concentrations achieved during the surface water pilot study. Target PFAS and treatment targets were set according to the MPCA Site-Specific Water Quality Criteria (SSC); for Raleigh Creek, this includes PFOS, PFOA, PFHxS, PFHxA, PFBS, and PFBA. At optimized settings, treated SAFF® effluent was below the MPCA SSC for all compounds except for PFOS.

Table 10.3: SAFF®-Treated Raleigh Creek Surface Water Effluent from Optimized Settings Relative to Regulatory Standards

Compound	PFOA	PFOS	PFHxS	PFBS	PFHxA	PFBA
MPCA Site-Specific Water Quality Criteria (ng/L)	< 25	< 0.05	< 20	< 140	< 220	< 5700
Raleigh Creek Influent (ng/L)	515	1570	41.1	18.4	51.5	303
Raleigh Creek Effluent Achieved by Optimized Settings (ng/L)	2.12	1.8	1.69	8.08	22	175
Optimized Raleigh Creek Removal Efficiency (%)	99.6	99.9	95.9	56.1	57.3	42.2

The removal efficiencies at different treatment times were also evaluated for surface water to assess the potential applicability for a full-scale system, shown in **Figure 10.2**. Like treatment of the Shakopee Aquifer, the lowest effluent concentrations were observed following a 50-minute treatment time. Effluent concentrations increased slightly following a 30-minute treatment time, with larger increases observed with even shorter treatment times.

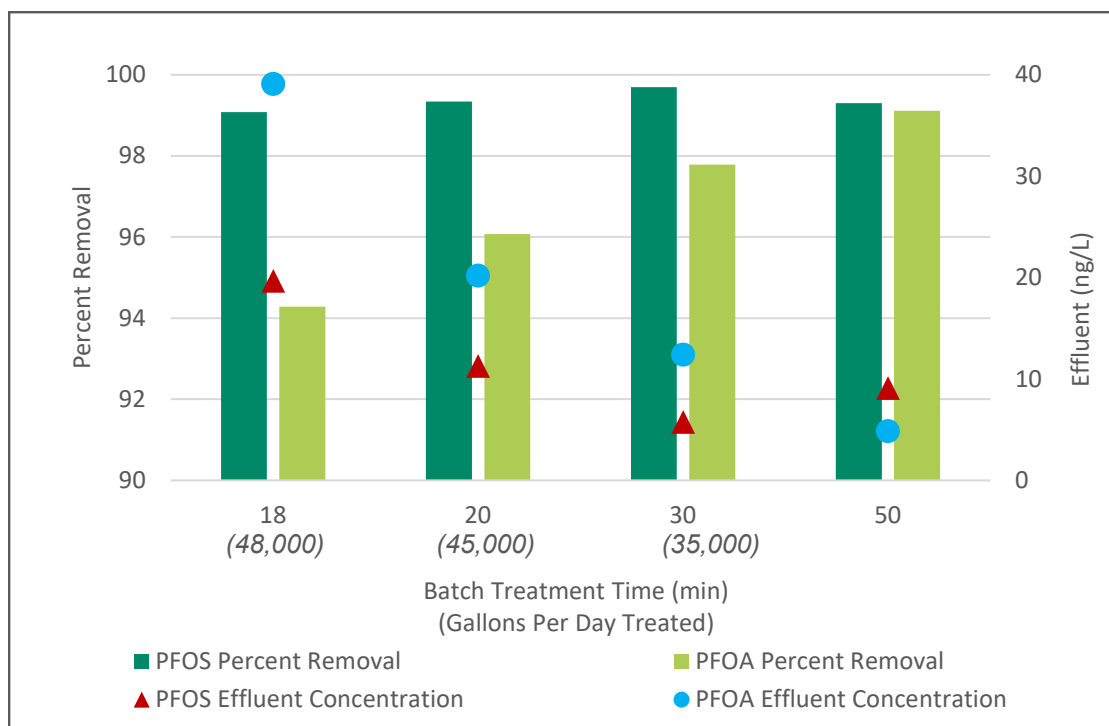


Figure 10.2: SAFF® energy consumption, throughput, and removal efficiency for surface water treated by SAFF®

To achieve 99% removal of both PFOS and PFOA, approximately 3.5 kilowatts (kW) were consumed per 1,000 gallons. Operating at these optimized settings with the SAFF®20 pilot unit allowed for throughput of approximately 35,000 to 45,000 gpd. Similar to Shakopee and Jordan Aquifer operations, concentration factors were calculated for Raleigh Creek operations, shown in **Table 10.4**. TOC concentration factors were also calculated, as TOC levels were higher in Raleigh Creek than the groundwater aquifers. TOC increased throughout the process, indicating SAFF® can remove TOC as well as PFAS. PFOS and PFOA concentration factors were lower than in the groundwater aquifers due to the increased foaming observed in Raleigh Creek. While the increased TOC levels and increased foaming decreased required treatment time and allowed for higher removal at lower venturi pump speeds, this also resulted in lower concentration factors. At 45,000 gpd though, a concentration factor of 7,000x would result in only 6.5 gallons of secondary PFAS concentrate per day, which still offers a significant volume reduction.

Table 10.4: Raleigh Creek Concentration Factors

Species	Influent	Tank 3	Tank 3 Concentration Factor	Tank 4	Tank 4 Concentration Factor
PFOS	2.2 µg/L	65 µg/L	30x	16,700 µg/L	8,000x
PFOA	0.8 µg/L	23 µg/L	30x	5,500 µg/L	7,000x
TOC	8.1 mg/L	11.7	1.4x	160	20x

10.1.2 Conclusion

Foam fractionation, and specifically SAFF® treatment as a standalone technology, is unlikely to be a comprehensive treatment solution for effluent fated for drinking water distribution or aquifer reinjection. Foam fractionation–treated effluent PFOS concentrations from the Shakopee Aquifer and PFOA concentrations from the Jordan Aquifer exceeded the remedial target of non-detect. If SAFF®-treated groundwater or surface water is discharged to surface water, it is expected to meet surface water target concentrations for all compounds except PFOS.

SAFF® is not an approved treatment for PFAS in drinking water in the state of Minnesota at the time of writing this report. However, this pilot study demonstrated bulk removal of PFOA and PFOS with effluent concentrations approaching the regulatory standards, demonstrating foam fractionation could play an important role within a treatment train approach. Polishing by an adsorptive media such as GAC or IX is expected to be required to meet Site effluent standards. Use of a polishing media could allow for reduced treatment times, if the subsequent increase in effluent concentrations and increased use of adsorptive media was nominal compared to the increased throughput per SAFF® unit. SAFF® was ineffective at removal of short-chain PFAS, particularly PFBA, which is present at high concentrations near WCL.

These results indicate that if foam fractionation is to be incorporated into a full-scale remedial alternative, the following should occur:

- Further demonstration of scalability;
- Piloting of novel modifications to SAFF® technology that could improve PFBA removal, throughput, and overall efficiency;
- Evaluation of other foam fractionation vendors and their technology, as additional companies offer commercially available equipment compared to when the initial RFP was issued; and
- Piloting additional PFAS separation technologies before or after SAFF® to assess their removal capability within other treatment trains.

The current treatment capacity of foam fractionation systems may not be sufficient to meet the expected treatment requirements for groundwater and surface water. For example, a SAFF®40 has an advertised maximum capacity of approximately 250,000 gpd, but operation at the settings used in this pilot would result in a throughput of approximately 70,000 to 90,000 gpd per unit. To achieve the expected treatment capacity required for surface water and groundwater, a prohibitory number of SAFF®40s would be required. However, with new vendors and offerings becoming available, non-container based units may be available that could better reach treatment capacities required for groundwater remediation. Operations and maintenance (O&M) challenges posed by limited space in the container-based system (further discussed in **Appendix E**) could also be improved with a skid-based system.

AECOM recommends additional pilot- and bench-scale studies to evaluate the use of foam fractionation within other treatment trains. SAFF® may also be effective in the treatment of nanofiltration (NF) or reverse osmosis (RO) concentrate water to reduce the volume of this waste stream. Treatability study recommendations are discussed in greater detail in **Section 14**.

In summary, the results discussed above are expected to broaden the understanding of SAFF® technology's full capabilities and to identify the treatment trains best suited to the Site and the project's remedial objectives.

10.2 DE-FLUORO™ Pilot Study

A field study to evaluate EO for PFAS destruction was conducted with a DE-FLUORO™ unit using the PFAS concentrate from the SAFF® system. EO utilizes a current applied across an anode-cathode pair. PFAS destruction occurs at the anode through direct oxidation as electrons are transferred from PFAS to the anode and through advanced oxidation processes mediated by hydroxyl radicals, which are generated within the reactor (Liang, 2018). Organic compounds, including PFAS, lose electrons during the EO process. In the case of PFAS, electron loss leads to the sequential defluorination of PFAS and the complete mineralization of PFAS into carbon dioxide and fluoride ions. EO has been successfully demonstrated at the lab-scale and in several field demonstrations; however, testing with Site-specific PFAS concentrate under the conditions found at the Site was important to verify the destruction capacity. Additionally, results from a pilot study could be used to improve the engineering design of a full-scale DE-FLUORO™ system. The DE-FLUORO™ pilot system was housed within a trailer and operated at WCL in Lake Elmo, MN. WCL was selected as the location for this pilot study because SAFF® concentrate was already being stored in a shed at WCL and it allowed the footprint of the work being conducted at Tablyn Park, where the SAFF® pilot study was conducted, to remain smaller.

The primary objectives of this study were to:

- Evaluate ability of DE-FLUORO™ and EO to reduce total PFAS mass in SAFF® concentrate
- Determine the applicability of a full-scale system within a treatment train

Two experiments with PFAS concentrate from the SAFF® treatment of groundwater from the Shakopee Aquifer were conducted between February 28, 2023 and May 10, 2023.¹ Experiments were run with a starting volume of 157 to 200 liters; other operational parameters were kept consistent through each experiment and are detailed in **Appendix F**.

¹ Two experiments were also conducted with SAFF concentrate from the treatment of surface water; however, the project team determined that the system was not functioning properly, and the resulting data was not representative of the DE-FLUORO™ destruction capabilities. Additionally, the continued treatment of surface water was not proposed and the destruction of PFAS concentrated from groundwater would be the focus of future field demonstrations. For this reason, the data from the surface water SAFF concentrate field demonstration are not included in this FS. These observed performance issues have been resolved with the DE-FLUORO™ unit and will continue to be evaluated in future DE-FLUORO™ field demonstrations at other sites.

10.2.1 Results

PFAS and AOF concentrations were monitored to determine optimal reaction times. While each experiment was conducted for a total of 125 hours, rapid decreases in AOF concentration were observed within the first 24 hours with 86% and 84% reduction from the initial concentration for experiments 1 and 2, respectively. After approximately 100 hours of treatment time, AOF was reduced by 95.9% in experiment 1 and 93.9% in experiment 2. Slightly higher concentrations were observed at 125 hours. **Table 10.5** summarizes the reductions and effluent concentrations for the two experiments.

The fate of PFAS was evaluated at the end of each experiment to confirm that the observed decreases were a result of destruction and not transfer of PFAS to components of the system. The mass of AOF on system components, including the air emissions system, was compared to the starting AOF mass. Based on this analysis, PFAS mass was found to have been aerosolized, captured by the air emission system, and adhered to the recirculation filter. The remaining balance of AOF lost, likely due to destruction, was 81.0% and 70.2% for experiments 1 and 2, respectively. Although a closed fluorine mass balance could not be completed, fluoride ion concentrations did increase. As long-chain PFAS species are degraded, they are converted to shorter-chain species before complete destruction converts the fluorine in PFAS molecules to fluoride (e.g., PFOS → PFH_xS → PFBS → fluoride). Fluoride formation provides evidence of complete destruction, or mineralization, of PFAS.

Byproduct formation of shorter-chain PFAS, hydrofluoric acid, hydrogen, and perchlorate were also observed. Hydrogen was managed through the air emissions system. Similarly, hydrofluoric acid was managed through pH control and an alkaline scrubber within the air emissions system. Perchlorate formation was observed, though less than 2% of the chloride in the concentrate was converted to perchlorate. The resulting effluent perchlorate concentrations were 5.2 milligrams per liter (mg/L) and 7.1 mg/L in experiments 1 and 2, respectively. Shorter treatment times may result in lower effluent perchlorate concentrations, but perchlorate would still likely require management within the PFAS treatment train. PFBA and PFBS concentrations increased, indicating that sequential defluorination was occurring, but their effluent concentrations remained below the MDH HBVs.

Table 10.5: Concentrations of Selected PFAS Compounds from DE-FLUORO™ Analytical Results

Experiment No.	Sample	Analyte concentration (ng/L)								
		Total PFAS	PFOS	PFOA	PFHxS	PFHxA	PFBS	PFBA	AOF	TOP
Experiment 1 (SAFF® Groundwater Concentrate)	Baseline (T0) ⁽¹⁾	595,929	474,000	100,000	6,420	365	53	568	580,000	56,117
	Final (T125)	21,580	10,200	8,050	768	356	57	869	24,000	19,458
	% reduction	- 96.4	- 97.8	- 92.0	- 88.0	- 2.0	+ 7.6	+ 53.0	- 95.9	65.3
	Minimum concentration	7,434 (T102)	1,760 (T66)	2,760 (T102)	427 (T102)	296 (T102)	53 (T0)	568 (T0)	10,000 (T102)	19,458 (T125)
Experiment 2 (SAFF® Groundwater Concentrate)	Baseline (T0)	562,164	436,000	110,000	6,390	333	61	552	490,000	562,370
	Final (T125)	26,680	1,280	18,100	3,330	449	63	1,090	30,000	27,003
	% reduction	- 95.3	- 99.7	- 83.5	- 47.9	+ 35.0	+ 2.8	+ 97.5	- 93.9	95.2
	Minimum concentration	26,680 (T125)	1,280 (T125)	18,100 (T125)	3,330 (T125)	333 (T0)	55 (T8)	552 (T0)	30,000 (T125)	27,003 (T125)

¹ (TX) denotes reaction time in hours.

10.2.2 Conclusion

The DE-FLUORO™ EO system demonstrated an effective reduction in total PFAS mass in the SAFF® groundwater concentrate. System improvements that occurred between experiments 1 and 2 allowed for continuous operation with minimal requirements of the operator. If this technology scales effectively, large PFAS mass reductions can be expected for a concentrated influent. Although the effluent concentrations would not achieve regulatory standards, DE-FLUORO™ could be effectively incorporated into a treatment train where PFAS become highly concentrated prior to destruction by DE-FLUORO™. The effluent could be recirculated back to the influent of the SAFF® or other concentration technology for further concentration, allowing for optimization of energy consumption within the entire treatment train. EO may also be effective at treating PFAS concentrate from other separation technologies. That option could be evaluated in the future with Site-specific concentrate. For example, still bottoms generated by IX have demonstrated success in other non-DE-FLUORO™ EO applications. If the DE-FLUORO™ EO technology is considered for full-scale implementation, further pilot testing at larger volumes should be conducted to evaluate scalability. The use of different PFAS concentrates should also be evaluated if SAFF® treatment of raw groundwater or surface water is not expected to be the separation/concentration step prior to DE-FLUORO™ EO destruction.

10.3 Destruction Technology Bench-Scale Studies

SAFF® concentrate generated by the SAFF® pilot study was used to conduct bench-scale studies with additional destruction technologies. This testing helped to determine which additional technologies should be recommended for evaluation at the pilot scale. Through the RFP for PFAS Destructive Technology Test on MPCA (SAFF®) Concentrate for Project 1007, 374Water° (SCWO), Axine (EO), General Atomics through Bay West (SCWO), Claros Technologies (ultraviolet [UV] oxidation), Ensipred Solutions (photoactivated reductive defluorination), Onvector (plasma), and Revive Environmental (SCWO) were selected to complete bench-scale PFAS destructive treatment studies.

Each vendor was provided with 1 to 5 gallons of SAFF®-generated Raleigh Creek (surface water) PFAS concentrate from the same waste drum. Sample collection and testing took place between July 2023 and April 2024. Each vendor was asked to test their resulting effluent for AOF, TOP, and PFAS by method EPA Method 1633 to assess the destruction efficiency; however, only some of the vendors provided sufficient supporting analytical data to verify PFAS destruction and mineralization (e.g., decrease in total organic fluorine, increase in fluoride ion concentration). Thus, destruction cannot be fully verified for all technologies. The sections that follow summarize the results of the bench-scale studies. **Appendix G** presents a detailed review of the respective technologies with a specific focus on PFAS concentration reduction, production of byproducts, energy consumption, and maintenance and cost considerations. Data gaps and the additional data required to support technology selection for a pilot study are also addressed.

10.3.1 Super Critical Water Oxidation

SCWO utilizes high temperatures and pressures that are above the supercritical point of water to destroy PFAS and other organic chemicals. 374Water° and Revive Environmental utilized bench-scale reactors to evaluate the destruction efficiency. General Atomics used a full-scale unit and, therefore, diluted the concentrate to achieve sufficient volume. This difference should be accounted for when evaluating the data as there can be differences in both destruction and energy efficiencies between lab-scale and full-scale units. The following destruction efficiencies were observed:

- 374Water° observed a 98.79% reduction in AOF.
- General Atomics observed > 99.8% reduction in AOF (effluent was below the detection limit).

- Revive Environmental observed a 93% reduction in total organic fluoride (TOF).

The seven vendors reported either AOF or TOF, though not all vendors specified the reason for their selection. In general, AOF offers lower reporting limits than TOF, due in part to elevated detection limits for fluoride ion by ion-selective electrode.

The SCWO reaction typically requires a co-fuel to sustain the reaction, as the energy content of the PFAS concentrate is low. 374Water^o used isopropyl alcohol as co-fuel, while General Atomics used diesel fuel. It is unclear whether Revive used a co-fuel.

The byproducts of SCWO are halogens, which can form corrosive acids including hydrofluoric acid. The formation of these acids is mitigated through pH adjustments. An ash consisting of dissolved and inorganic solids is also produced during the reaction, which can lead to salt deposition within the unit. Air emissions are generally minimal, and General Atomics was the only vendor to measure PFAS in the air emissions to ensure PFAS was not being aerosolized.

Energy consumption rates were reported by 374Water^o as 1.12 kWh per gallon treated and by General Atomics as 8.52 kWh per gallon treated. Revive did not provide an energy consumption estimate. The energy consumption is expected to vary for a full-scale system.

10.3.2 Electrochemical Oxidation

EO destroys PFAS through oxidation as a current is applied across an anode-cathode pair. Axine was the only EO vendor to conduct bench-scale tests. The bench-scale study was performed using a 10-liter glass cell, which is a scaled down version of the commercial-scale reactor containing 30 cells. A TOF reduction of >99% was observed over the treatment time. Sodium hydroxide was required for pH maintenance to prevent precipitation of dissolved minerals and manage the formation of hydrofluoric acid. Hydrogen and perchlorate can be produced during EO, but their production was not discussed in Axine's report.

Higher TOF reduction can occur with more energy consumption. The desired effluent concentrations and the optimal energy consumption required to achieve them will need to be considered for a full-scale system. Axine reported an energy consumption of 11.25 kWh per gallon for this bench-scale study.

10.3.3 Photoactivated Reductive Defluorination

The Enspired Solutions photoactivated reductive defluorination system (PFASigator) operates at ambient temperature and pressure and utilizes a proprietary chemical reaction to achieve sequential defluorination. This reaction is activated with UV light. The bench-scale study found a 91.7% reduction in AOF. The consumables required for this technology are a surfactant and a proprietary chemical that promotes chemical reduction. Byproducts of the reaction are shorter-chain PFAS; for example, slight increases in PFBA were observed throughout the experiment. However, the concentration of PFBA decreased at higher UV dosages. The surfactant is also still present at the end of the reaction and requires destruction or removal prior to discharge of treated water.

Higher rates of destruction can be achieved with higher doses of UV light, which requires additional energy. This energy need should be considered in a full-scale treatment train approach. Energy consumption could potentially be reduced by increasing the treatment dose but decreasing the treatment time and reconcentrating and recirculating the effluent to improve overall destruction efficiency.

10.3.4 UV Oxidation

UV oxidation utilizes radical species formed through UV irradiation to oxidize and destroy PFAS. Claros demonstrated an 85.0% reduction in AOF. As the surface water concentrate had high concentrations of organic matter, the UV transmittance was reduced and the concentrate required dilution. This issue may not be a concern if groundwater concentrate is being treated as the natural organic matter in

groundwater concentrate is less than for surface water. Claros did not describe the consumables required for the reaction. The byproducts of this reaction are shorter-chain PFAS, including PFBA; however, PFBA was found to decrease between 6 and 24 hours of treatment, which suggests the concentrate could be treated for PFBA by extending the treatment time.

The energy requirement for the UV oxidation study was 0.58 kWh per gallon. Like photoactivated reductive defluorination, this energy requirement could be reduced through shorter treatment times. A 63.33% reduction in AOF was observed in the first 6 hours of treatment.

10.3.5 Plasma

Onvector utilized highly chemically reactive species including hydroxyl radicals that are produced in a plasma reactor to destroy PFAS by breaking the molecules into byproducts. To improve PFAS destruction, RO can be implemented as a polishing step to concentrate the PFAS after each treatment interval to improve destruction efficiency. A reduction of 69.15% in AOF was observed in the effluent following plasma treatment. The AOF was further reduced to non-detect following RO treatment. The consumables required for this technology are argon gas for plasma production and RO membranes, though Onvector did not provide the expected RO membrane life. The concentration of PFBA was higher after plasma treatment; however, RO polishing of the plasma effluent and recirculation of the RO concentrate provided controlled discharge of PFBA. The energy requirement for the plasma study was 13.0 kWh per gallon.

10.3.6 Conclusions

In summary, all vendors and technologies had promising destruction efficiencies and could be candidates for pilot demonstration. Of these bench-scale studies, Axine and General Atomics demonstrated the largest reductions in AOF; however, other technologies had lower effluent concentrations of specific PFAS as detailed further in **Appendix G**. Claros and 374Water[®] had the lowest energy consumption; however, the reported energy consumptions may not be representative of the energy requirements of a full-scale unit. Energy requirements will be reevaluated after the MPCA has selected the remedial alternative and will likely be dependent on the required capacity of the destruction technology.

Although some comparisons can be made between these technologies, the bench-scale data do not provide sufficient information to select a destruction technology. Scaling from bench- to full-scale systems can greatly alter the overall destruction efficiency and energy consumption. Additionally, overall cost, O&M, and the selected separation and concentration technologies must also be considered when selecting a destruction technology. This FS recommends additional pilot testing to better assess the capabilities and limitations of the destruction technologies prior to final technology selection. These pilot studies should be conducted after the separation and concentration technologies and Site treatment locations are selected as specific water chemistry and PFAS composition vary across the Site. The ability to treat groundwater PFAS concentrate should also be further evaluated as metals precipitation may pose issues. In the case of some of the technologies, including UV oxidation, a concentrated PFAS stream may also result in improved destruction as the turbidity and natural organic matter concentrations will be lower. **Appendix G** provides a detailed review of data gaps and next steps.

10.4 Groundwater Treatability Study

The groundwater treatability study evaluated the pretreatment of groundwater and GAC and IX adsorbent media. GAC and IX PFAS removal performance was evaluated for four water sources, specifically an untreated Jordan Aquifer sample, an untreated Shakopee Aquifer sample, a SAFF[®]-treated Shakopee Aquifer sample, and an untreated shallow groundwater sample near WCL. Sample

locations are shown in **Figure 163**. Because adsorbent media can be impacted (e.g., useful life can be shortened) by poor influent water quality, pretreatment technologies were evaluated using water from the Jordan Aquifer. The specific objectives of the bench-scale treatability study included the following:

1. Determine whether influent iron and manganese concentrations in the Jordan Aquifer groundwater are acceptable for the PFAS adsorption process.
2. If not acceptable, determine the best pretreatment process through bench-scale treatability testing to control the concentrations and/or levels in the Jordan Aquifer groundwater for the adsorption process.
3. Evaluate two adsorbent media for regulated PFAS compounds in each impacted test water via RSSCTs for the following media:
 - a. Calgon's Filtrasorb® 400 (F400), a bituminous coal-based GAC; and
 - b. Purolite's PFA 694E (PFA), a single-use, divinylbenzene-crosslinked polystyrene IX resin
4. Evaluate the relative performance among the adsorbent media while tested under controlled laboratory flow-through conditions; specifically:
 - a. Evaluate the time to breakthrough of PFAS compounds in the media tested; and
 - b. Evaluate the volume of water treated per mass of sorbent (specific throughput rate)
5. Determine the optimum media for PFAS removal from each test water.

10.4.1 Pretreatment Evaluation

The pretreatment evaluation for Jordan Aquifer groundwater focused on metals and specifically iron removal, which is known to cause fouling of GAC and specifically IX resins, as well as total suspended solids (TSS). Manganese removal was also evaluated, though influent concentrations of manganese were already below recommended maximum concentrations. Low iron concentrations were observed in the Jordan Aquifer water sample at the lab, indicating iron in the sample had oxidized and precipitated during sample transportation and storage. As this is not representative of what would be expected in a drinking water treatment plant, iron was spiked back into the sample as ferrous chloride tetrahydrate to provide a more realistic initial concentration of dissolved iron for the pretreatment evaluation.

Sodium hypochlorite, sodium hypochlorite with a catalytic media (GreensandPlus™ and Pyrolusite as OxiPlus75™), hydrogen peroxide, and potassium permanganate were tested using jar testing to evaluate ability to reduce the total iron concentration. Sodium hypochlorite with an anionic polymer (ChemTreat Inc., P816E) was added during the same oxidation tests for TSS removal.

Table 10.6 summarizes aquifer pretreatment performance; full results can be found in **Appendix H**. Using catalytic media in conjunction with an oxidant is a common process for iron removal. When combined with sodium hypochlorite, both Pyrolusite and GreensandPlus™ were graded excellent at reducing total iron and TSS, meaning they successfully met the water quality criteria. Effluent iron concentrations were below the laboratory detection limit of 0.05 mg/L. Sodium hypochlorite alone and sodium hypochlorite with an anionic polymer had limited performance; either the iron or TSS were close or less than the target effluent concentration of 1.0 mg/L under some conditions. Finally, hydrogen peroxide and potassium permanganate oxidation performed poorly as the hydrogen peroxide oxidation only met the criteria under one specific condition, and for potassium permanganate oxidation, neither TSS nor total iron were removed to the SSC levels. Sodium hypochlorite with Pyrolusite or sodium hypochlorite with GreensandPlus™, which had the best performance of all evaluated options and had iron results consistently below the instrument detection limit, are recommended for use in full-scale treatment.

Table 10.6: Bench-Scale Jordan Aquifer Pretreatment Performance Summary

Treatment Process	Test Water Performance Level
Sodium Hypochlorite	Limited
Sodium Hypochlorite + Pyrolusite	Excellent
Sodium Hypochlorite + GreensandPlus™	Excellent
Sodium Hypochlorite + anionic polymer	Limited
Hydrogen Peroxide	Poor
Potassium Permanganate	Poor

10.4.2 Rapid Small-Scale Column Tests

GAC and IX PFAS removal performance was evaluated using RSSCTs for four water sources, specifically an untreated Jordan Aquifer sample, an untreated Shakopee Aquifer sample, a SAFF®-treated Shakopee Aquifer sample from the pilot study performed as part of this FS, and an untreated shallow groundwater sample collected near the location where WCL Tests were run using Calgon Carbon’s Filtrasorb® 400 (F400), a commonly used GAC, and Purolite’s PFA 694E IX resin. Ten treated effluent samples were collected during the RCCTs for each test and media type. Breakthrough was determined by the number of bed volumes and specific throughput (calculated as liters of water treated per kilogram of sorbent material [L/kg]) that were treated before a regulatory criteria was surpassed. As multiple regulatory criteria must be considered, specific throughputs were calculated for multiple regulatory criteria, specifically, EPA MCLs, MDH HRLs/HBVs/Health Risk Indices (HRIs), and MPCA Site-Specific Surface Water Quality Criteria. See **Section 9** and **Appendix H** for greater details on relevant regulatory criteria.

Table 10.7 summarizes breakthrough results for the Jordan Aquifer, Shakopee Aquifer, and SAFF®-treated Shakopee Aquifer samples. Results in **Table 10.7** demonstrate that IX consistently outperformed GAC for the drinking water aquifers. For all three water sources, IX resin had a higher specific throughput in L/kg than GAC. In both the Jordan Aquifer and the SAFF®-treated Shakopee Aquifer samples, breakthrough of IX resin was not observed. Thus, the specific breakthroughs presented in **Table 10.7** are minimum values. Results also demonstrate that foam fractionation pre-treatment of groundwater can reduce adsorptive media use. Foam fractionation provides bulk removal of PFAS, reducing the PFAS loading to adsorptive media. The Shakopee Aquifer results demonstrate this removal is much more significant with IX resin than with GAC. Based on the results of these tests, IX resin is recommended over GAC for use in drinking water treatment. Additionally, foam fractionation should be evaluated for potential use to decrease adsorptive media use.

Table 10.7: Jordan Aquifer, Shakopee Aquifer, and SAFF®-Treated Shakopee Aquifer RSSCT Results Summary

PFAS	Criteria	Jordan Aquifer		Shakopee Aquifer		SAFF®-Treated Shakopee Aquifer	
		GAC	IX	GAC	IX	GAC	IX
Units	ng/L	L/kg	L/kg	L/kg	L/kg	L/kg	L/kg
PFOA	0.2	4,364	>153,068	25,798	81,342	25,928	>152,337
PFOS	2.3	5,000	>153,068	22,000	>153,569	>184,093	>152,337
PFHxS	10	18,000	>153,068	71,000	>153,569	>184,093	>152,337
PFBA	7,000	>179,847	>153,068	>183,882	>153,569	>184,093	>152,337
PFHxA	200	>179,847	>153,068	>183,882	>153,569	>184,093	>152,337
PFBS	100	>179,847	>153,068	>183,882	>153,569	>184,093	>152,337
EPA HI	1.0	25,000	>153,068	57,000	>153,569	>184,093	>152,337
Thyroid HRI	1.0	27,631	>153,569	48,358	>153,569	63,700	>152,337
Minimum Specific Throughput		4,364	>153,068	22,000	81,342	25,928	>152,337

Table 10.8 summarizes the WCL shallow groundwater results. Given the uncertainty regarding the eventual discharge location of the treated water from WCL, specific regulatory criteria that would apply to the WCL treated water are unknown. For the purposes of the RSSCTs, discharge to surface water was assumed and MPCA SSC were used for the evaluation. WCL shallow groundwater has significantly higher PFAS concentrations (specifically PFOA and PFBA) compared to the drinking water aquifers. Consequently, rapid breakthrough of both GAC and IX were observed. Minimum specific throughputs were calculated for both GAC and IX; however, actual specific throughputs would be much lower than what is calculated. Concentrations of PFBA were well in exceedance of the MPCA SSC after the first effluent sample was collected, indicating breakthrough had previously occurred. Results indicate that neither GAC nor IX would be suitable for treatment of WCL shallow groundwater; additional treatment technologies, specifically ones that can target the removal of PFBA, will be required to economically treat WCL shallow groundwater.

Table 10.8: Washington County Landfill Shallow Groundwater RSSCT Results Summary

PFAS	Criteria	WCL Shallow Groundwater - GAC	WCL Shallow Groundwater - IX
Units	ng/L	L/kg	L/kg
PFOA	25	< 4,391	21,000
PFOS	0.05	< 4,391	> 152,072
PFHxS	20	< 4,391	> 152,072
PFBA	5,700	< 4,391	< 6,723
PFHxA	220	< 4,391	17,000
PFBS	140	9,000	> 152,072
EPA HI	1.0	< 4,391	< 6,723
Thyroid HRI	1.0	< 4,391	< 6,723
Minimum Specific Throughput		< 4,391	< 6,723

10.4.3 Conclusions

The groundwater treatability studies provided valuable information that will inform the design of a full-scale treatment system. Sodium hypochlorite + Pyrolusite and sodium hypochlorite + GreensandPlus™ performed well at removing iron and manganese from the tested water. Further testing is not recommended as results indicate satisfactory performance of sodium hypochlorite + Pyrolusite or sodium hypochlorite + GreensandPlus™.

RSSCT results indicated superior performance of IX compared to GAC with water from both the Shakopee Aquifer and Jordan Aquifer. IX is recommended over GAC for drinking water treatment. RSSCTs at WCL indicated a media only treatment system would be prohibitively expensive. Additional work is needed to determine the optimal treatment train for WCL source zone control; **Section 14** discusses recommended pilot and treatability studies in greater detail.

10.5 Leachability Study

Three sediment areas of concern (AOCs) were identified as part of the Project 1007 FS. Sediment AOCs have been impacted by PFAS due to contamination in Raleigh Creek and Project 1007. This study evaluated the potential for leaching of PFAS from impacted sediments to identify whether PFAS-impacted sediments could serve as a long-term source for PFAS contamination once Raleigh Creek's PFAS concentrations are decreased by remedial action from 3M. The specific test objectives were to:

1. Determine the partitioning coefficient of PFAS between the clean water phase and the impacted sediment phase for each sediment sample.
2. Evaluate the long-term leachability of total and individual PFAS compounds in five different impacted sediments under flow-through conditions.

Five samples were collected from the following locations, shown in **Figure 164**:

- AOC 11: Upper Raleigh Creek Wetland Complex – One sample was collected from a channelized portion of the wetland (sample URCWC-C).
- AOC 12: Anna's Grove Wetland Complex (AGWC) – One sample was collected from the southern pond, which is typically flooded except for under drought conditions (sample AGWC-POND), and one sample was collected from the intermittently flooded wetland area (sample AGWC-WETLAND).
- AOC 13: Eagle Point Lake – One sample was collected from the middle of the eastern lobe of the lake (sample EPL1-SUBMERGED), and one sample was collected from near the eastern shore where higher PFAS concentrations have been observed (sample EPL2-SHORELINE).

Appendix G provides partitioning values calculated for sediments. The results from flow-through conditions are summarized in **Figure 10.3**, which shows that the cumulative total PFAS mass released during testing was higher for all sediments relative to a control sample (used to evaluate background contamination in test apparatus), with sample AGWC-WETLAND having the highest total PFAS mass released. Although higher aqueous concentrations of PFAS were observed at the beginning than at the end of the tests, significant loss of PFAS mass was still observed at the end of the testing. This result indicates a potential for significant PFAS loading back to surface water once PFAS loading to Raleigh Creek is decreased. Consequently, in-stream permeable absorptive barriers (PABs) are recommended for further study as they could be implemented relatively quickly and provide removal of PFAS in surface water. **Appendix M** offers more details on initial PAB cost estimates and design.

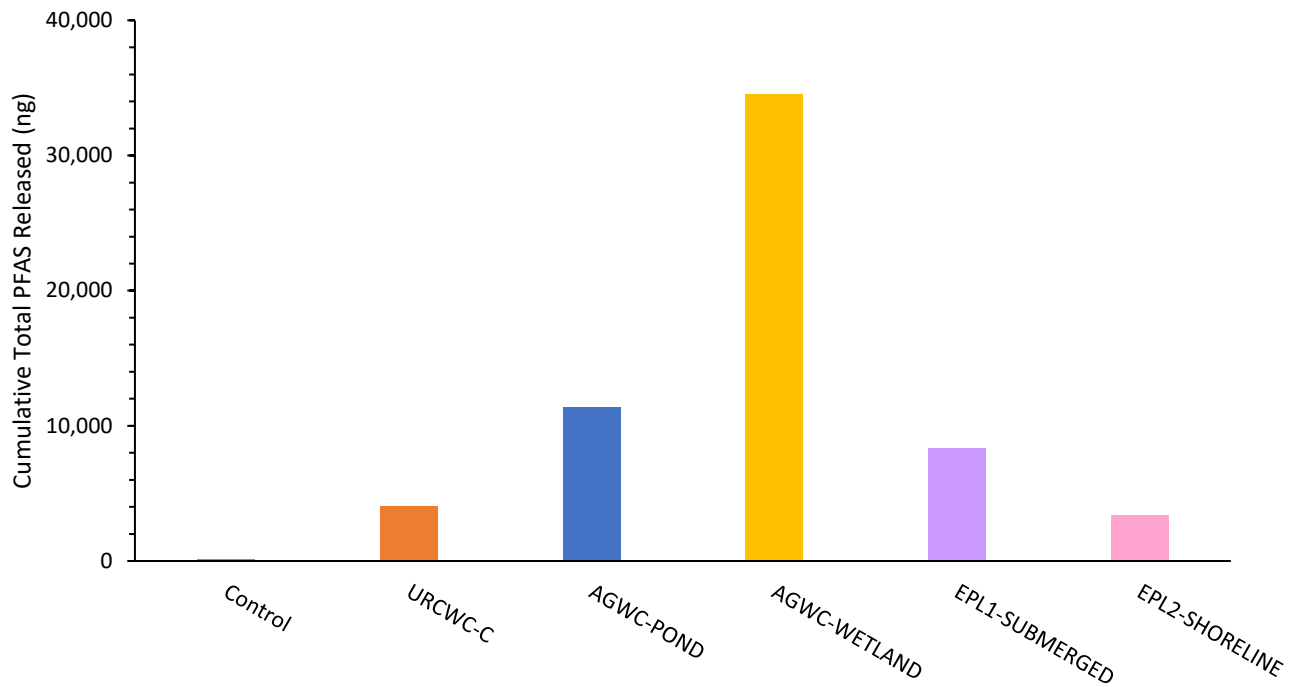


Figure 10.3: Cumulative total PFAS released during bench-scale leachability tests

11 Development of Remedial Alternatives

This section provides a summary of the expectations defined in the National Contingency Plan (NCP) for developing remedial alternatives and the general Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidelines for evaluating each alternative.

11.1 Basis for Development of Remedial Alternatives

The NCP (Title 40 of the Code of Federal Regulations [CFR] 300.430(e)(2)) identifies the primary objective of a Feasibility Study (FS) as development of remedial alternatives that protect human health and the environment by addressing the risks posed through the currently known exposure pathways. The Project 1007 remedial alternatives have been developed in general accordance with the NCP (40 CFR 300.430(e)(2)) with a focus on the Priority 1 objective of the 2018 Settlement to enhance the quality, quantity, and sustainability of drinking water in the East Metro. Therefore, the basis for the remedial alternatives prioritizes the drinking water exposure pathway. However, other contaminant exposure pathways are presented and discussed. The unique Project 1007 Site characteristics and complexities were used to determine the number and types of alternatives included in this FS.

Additional criteria are outlined for the development of source control in the NCP (40 CFR 300.430(e)(3)) as follows:

- A range of alternatives in which treatment that reduces the toxicity, mobility, or volume of the hazardous substances, pollutants, or contaminants is a principal element. As appropriate, this range shall include an alternative that removes or destroys hazardous substances, pollutants, or contaminants to the maximum extent feasible, eliminating or minimizing, to the degree possible, the need for long-term management.
- Alternatives, as appropriate, that, at a minimum, treat the principal threats posed by the Site but vary in the degree of treatment employed and the quantities and characteristics of the treatment residuals and untreated waste that must be managed.
- One or more alternatives that involve little or no treatment but provide protection of human health and the environment primarily by preventing or controlling exposure to hazardous substances, pollutants, or contaminants through engineering controls, for example, containment and, as necessary, institutional controls (ICs) to protect human health and the environment and to ensure continued effectiveness of the response action.

In addition, the NCP [40 CFR 300.430(a)(1)(iii)(F)] sets expectations that:

- Groundwater be returned to beneficial uses wherever practicable, within a timeframe that is reasonable given the circumstances of the Site. When restoration of groundwater to beneficial uses is not practicable, the U.S. Environmental Protection Agency (EPA) expects to prevent further migration of the plume, prevent exposure to the contaminated groundwater, and evaluate further risk reduction.

These expectations formulate the basis for developing and screening the remedial alternatives presented in the following sections to reduce per- and polyfluoroalkyl substances (PFAS) impacts and continued PFAS migration, specifically within drinking water aquifers.

11.2 Basis for Evaluation of Remedial Alternatives

Requirements specified under CERCLA Section 121 were used as a general guideline for evaluating each alternative. The requirements include protection of human health and the environment, a preference for permanent solutions that incorporate treatment as a principal element (to the maximum extent

practicable), and cost effectiveness. For this FS, the focus is predominantly on the protection of human health through the protection of drinking water aquifers. The protection of ecological receptors and human health through non-drinking water exposure routes was not considered when developing or recommending alternatives; however, the proposed treatment may offer tangential benefits. Additional efforts may be required in the future to address these other exposure routes and receptors to meet state and federal standards. The requirements typically also include compliance with Applicable or Relevant and Appropriate Requirements (ARARs). However, as discussed further below, the ability to achieve Remedial Action Objectives (RAOs) serves as the ARAR compliance. To assess whether alternatives meet the requirements, EPA has identified nine criteria in the NCP that must be evaluated in detail. These criteria are categorized into three groups presented below:

Threshold Criteria (each alternative must meet the threshold requirements to be eligible for selection)

- a. Overall protection of human health and the environment
- b. Ability to achieve RAOs

Primary Balancing Criteria

- a. Long-term effectiveness and permanence
- b. Reduction of toxicity, mobility, or volume
- c. Short-term effectiveness
- d. Implementability
- e. Cost

Modifying Criteria

- a. State acceptance
- b. Community acceptance

At this time, this FS has not been submitted for public comment. Community acceptance is expected to be evaluated once the FS is posted for public comment. State acceptance is expected to be evaluated at the same time. As a result, neither state acceptance nor community acceptance are discussed further in this FS. General descriptions of the remaining seven evaluation criteria are provided in the sections that follow.

11.2.1 Overall Protection of Human Health and the Environment

This criterion focuses on whether the alternative achieves and maintains adequate protection of human health and the environment within the Source Area, in accordance with the RAOs. Evaluation of this criterion should describe how risks are eliminated, reduced, or mitigated through treatment, engineering, or ICs. As stated above, the focus of this FS is on the protection of human health by exposure through drinking water. Other receptor pathways may require additional remedial actions outside of what is identified in this FS to be protective.

11.2.2 Ability to Achieve RAOs

This criterion evaluates an alternative's ability to achieve the RAOs developed for each area of concern (AOC). The Remedial Investigation (RI) and FS are being completed in accordance with the 2018 Settlement (Minnesota v. 3M, 2018). Because the first priority of this settlement is to address drinking water supplies impacted by PFAS and ensuring the East Metro has access to safe drinking water, the RAOs were developed primarily to address impacts to drinking water sources. Large areas of impacted groundwater are located geographically outside of the previously identified Site boundaries of the two

primary source areas that are managed under the state Superfund program. Oakdale Disposal Site (ODS) and Washington County Landfill (WCL) have separate existing Records of Decision (RODs), which address the ARARs process. The ARARs identified for the two Superfund sites may need to be re-evaluated to include the Project 1007 FS AOCs.

Due to these factors, an AOC-specific approach is presented to evaluate remedial alternatives that achieve the RAOs. This is predicated on control of the sources at ODS and WCL that continue to contribute contamination to the overall region. Because WCL is managed through the Minnesota Pollution Control Agency (MPCA) Closed Landfill Program, remedies are proposed for this source area. Remedies to address impacts at ODS are outside the scope of this FS since ODS is managed by 3M.

In short, the ARARs process is currently addressed in the Superfund (CERCLA/Minnesota Environmental Response and Liability Act) process for each of the on-going source area National Priorities List / Permanent List of Priorities sites (ODS and WCL). The respective ARARs were established within the ROD and Remedy Decision Document for each of these source areas and have not been altered since the inception of the 2018 Settlement. Therefore, the evaluation criterion for remedial alternatives to achieve RAOs for the Project 1007 AOCs are those technologies that may effectively reduce the concentrations, migration, and treatment needs for drinking water resources and supplant the ARAR process in this study.

As discussed in **Section 6**, achieving drinking water standards within the Site aquifers is not feasible within a reasonable timeframe given the existing conditions of the Site, especially the diffuse nature of the PFAS plume across the Site, the current state of technologies, and the cost. However, a reduction of PFAS migration to protect downgradient drinking water sources is achievable and is the focus of the remedial alternatives. Reducing or offsetting drinking water treatment needs is part of an overall pathway interruption objective. Currently available technologies were evaluated for their ability to achieve the RAOs. As technologies for PFAS treatment advance, additional evaluation may be warranted. Further evaluation may also be needed to address other human-health exposure pathways and ecological receptors.

11.2.3 Long-term Effectiveness and Permanence

The long-term effectiveness and permanence criterion evaluates the effectiveness of an alternative in achieving an overall reduction in risk to human health after the RAOs have been met. It considers the degree to which the alternative provides sufficient long-term controls and reliably maintains protection from unacceptable levels of exposure of human and environmental receptors. While the alternatives were not developed to provide protection for ecological receptors, the ability of the alternative to provide these benefits is discussed to provide information regarding what risks may remain after the implementation. The principal factors addressed by this criterion include the magnitude of residual risk and the adequacy and reliability of controls. The alternatives may take different lengths of time to achieve this long-term effectiveness.

The evaluation of adequacy and reliability of controls assesses the effectiveness of any treatment, containment, or institutional measure that is part of the alternative. Factors considered include performance characteristics, maintenance requirements, and expected durability. Information and data from treatability studies, past performance, and similar technology applications are incorporated into the evaluation as appropriate. ICs are considered where they potentially improve the effectiveness of engineered measures. ICs that are recorded in property records are commonly used by the MPCA as part of a risk management decision to control future risk at a site due to residual contamination.

11.2.4 Reduction of Toxicity, Mobility, or Volume through Treatment

This criterion reflects the preference for response action alternatives containing a principal component that substantially reduces toxicity, mobility, or volume of hazardous substances within the Source Area.

The evaluation considers the extent that the response action process technologies can effectively and irreversibly fix, transform, immobilize, and/or reduce the volume of waste materials and contaminated media.

11.2.5 Short-Term Effectiveness

This criterion addresses the effects of the alternative during the construction and implementation phase until the RAOs are achieved. The evaluation considers the effects on human health and the environment posed by operations conducted during the response action. Both the potential impacts and associated mitigative measures are examined for their ability to protect the community, remedial action workers, and environmental receptors over the duration of the activities. The analysis also includes an assessment of measures such as engineering and ICs that are expected to minimize potential risks to the public and workers.

Additionally, EPA's *Principles for Greener Cleanups* outlines the Agency's policy for evaluating and minimizing the environmental footprint of activities undertaken when cleaning up a contaminated site (EPA, 2009). These principles encourage the voluntary and comprehensive evaluation of cleanup actions to ensure the protection of human health and the environment and to reduce the environmental footprint of cleanup activities to the maximum extent possible. In considering these principles, EPA urges cleanup programs to perform the remediation, and subsequent environmental footprint reduction, in a manner that is consistent with applicable statutes and regulations and without compromising cleanup objectives, community interests, the reasonableness of cleanup timeframes, or the protectiveness of the cleanup actions.

The five core elements of sustainable remediation, as per the EPA's *Principles for Greener Cleanups*, are presented below and were evaluated in the short-term effectiveness criterion for each remedial alternative:

- Reducing total energy use and increasing the percentage of energy from renewable resources
- Reducing air pollutants and greenhouse gas emissions
- Reducing water use and negative impacts on water resources
- Improving material management and waste reduction efforts
- Protecting ecosystem services during site cleanup

11.2.6 Implementability

This criterion examines the technical and administrative factors affecting implementation of an alternative and considers the availability of services and materials required during implementation. Technical assessment factors include the feasibility of construction and operation, necessary future actions, and monitoring systems failure detection accuracy. Administrative factors examined include permitting and coordination requirements among the lead agency and other regulatory agencies. Services and materials considerations include treatment, storage, and disposal capacities; equipment and operator availability; and prospective technology applicability or development requirements.

11.2.7 Cost

The cost criterion reviews capital costs (direct and indirect) and operations and maintenance (O&M) costs. A present worth analysis is used to produce a common basis for costs that occur over different time periods. Cost information for each alternative includes a cost estimate table that provides details for each of the major cost elements and annual O&M costs. A summary of assumptions used to estimate the capital cost for each major component of the alternative is also included. When compared with each other, many of the alternatives have duplicate cost components that are accounted for individually.

In an FS, the design for a remedial action is conceptual, not detailed, and the cost estimate is “order-of-magnitude.” Typical unit rates derived from work at the Site and other sites were also used to estimate costs. As a result of the assumptions made in developing the costs, the expected level of accuracy of the estimated costs in the FS range from minus 30 percent to plus 50 percent. Furthermore, costs projected in the future have increased uncertainty.

For each alternative, the cost estimates are split into capital (construction) and O&M. Each of these groups also includes contingency and project management costs. The contingency cost is used to cover unknowns, unforeseeable circumstances, or unanticipated conditions that are not possible to evaluate from the data available at the time the estimate is prepared. There may be unforeseen inflation rates and increases in costs of material that cannot be anticipated.

11.3 Screening of AOC-Specific Remedial Approaches

As a result of the size of the Site and the number of AOCs, an additional screening was conducted to provide rationale for the selection of remedial actions for each AOC in the development of Site-wide alternatives. The purpose of this section is to document the remedial actions that were considered for each AOC and provide the rationale for why they were either included or excluded from the Site-wide alternatives evaluated using the NCP criteria in **Sections 12** and **13**. Specific technologies were not screened but instead the general response actions were considered. For example, pump and treat was evaluated in this screening but not whether granular activated carbon (GAC) or ion exchange (IX) resin should be implemented. The results of this screening were used to develop the Site-wide alternatives, which are described in **Section 11.4**. Specific treatment trains that are applicable for each alternative are summarized in **Section 11.5** and detailed in **Appendix I**. Recommendations that do not directly address drinking water but are inexpensive remedies to address other human-health exposure routes are also included in the alternatives even though these may not be directly in response to RAOs.

Although recommendations for remedial actions are provided, the Site is complex and uncertainty remains regarding how upgradient treatment may affect downgradient PFAS concentrations and dominant migration pathways within a specific AOC. Thus, remedial actions will need to be flexible and continue to be evaluated after initial implementation to optimize remedial efforts. For example, the planned reroute of Raleigh Creek by 3M is expected to result in a reduction in surface water PFAS concentrations within Raleigh Creek and Eagle Point Lake. If this does not occur, or the re-route is shown to be ineffective in substantially reducing downstream concentrations, additional remedial actions that were screened out in this section may need to be reconsidered. A monitoring plan will be implemented with the selected alternative to ensure the remedial action is effective and evaluate whether changes need to be made. Five-year reviews and evaluation of the monitoring data are required by CERCLA to evaluate the effectiveness of the selected alternative. This approach will be taken at this Site to ensure data from the monitoring network is being evaluated regularly and changes to the selected remedial alternative are being made as needed based on the data.

Additionally, remedial action within some AOCs should not occur until upstream treatment is underway or substantially completed. For example, sediment remediation should not be conducted until surface water treatment has begun and concentrations within the surface water have been reduced. Similarly, some remedial actions were screened out within a specific AOC based on the expected response of the AOC to upgradient treatment. If the response is not as expected, then these remedial actions should be reconsidered.

For groundwater treatment, multiple conceptual extraction systems are proposed in this FS. Systems could be implemented separately or as a combination of some of the following options:

- Localized pump and treat system: Water would be extracted through a series of pumping wells for treatment and groundwater control. The treated water would either be discharged to a receiving

surface water body or, in most cases, injected to the same aquifer it was extracted from to provide additional control of the plume.

- **Localized Multi-Benefit Well Array (MBWA):** Water would be extracted from pumping wells for plume control. The extracted water would be treated and some of it would be distributed to the community in place of the current drinking water supply wells. The remaining water, with the would be injected back into the aquifer for additional control of the plume. The injection rate would be dependent on the demand for drinking water and would be expected to vary through the year. This would be completed at a small scale where individual communities would be served by the extracted water. Only water extracted from the bedrock aquifers would be considered for drinking water supply.
- **Regional MBWA:** This is a similar approach to the localized MBWA but on a larger scale. A regional extraction well network would be installed with treatment in both Lake Elmo and Oakdale, which would provide drinking water supply to both communities. Extraction would also occur in West Lakeland to enhance groundwater plume control. The excess water not needed to meet community drinking water demand would be injected back into the aquifer to provide additional plume control. Compared to the localized MBWA, the regional MBWA would provide better plume control through higher rates of groundwater extraction, treatment, and injection.

11.3.1 AOC 1: Washington County Landfill – Surface Water and Shallow Groundwater

Remedial approaches at AOC 1 would target the groundwater within the Quaternary Aquifer and the receiving surface water bodies, specifically Sunfish Lake. The following remedial approaches were considered for AOC 1:

- Long-term monitoring of groundwater in the Quaternary and Sunfish Lake
- Access restrictions to surface water
- Permeable adsorptive barrier (PAB)
- Localized groundwater pump and treat system
- Surface water pump and treatment system of Sunfish Lake

Of these approaches, only a localized pump and treat system and access restrictions were retained for further consideration in the Site-wide alternatives. High PFAS concentrations are observed immediately downgradient of WCL, likely from PFAS in the unsaturated soils or sorbed onto soil particles. This is likely a long-term PFAS source to aquifers immediately downgradient of WCL. A groundwater pump and treat system in the AOC 1 source area would remove PFAS from groundwater in an area with higher concentrations than elsewhere on the Site, resulting in less required treatment capacity for the same mass of PFAS removal from groundwater compared to locations further downgradient. A pump and treat system would also aid in the reduction of mass flux of PFAS within the drinking water aquifers from WCL towards municipal supply wells and private wells. Access restrictions to the surface water in this AOC could be implemented with the pump and treat system to provide additional protection against incidental public exposure.

Other remedial approaches were not retained for further consideration for the following reasons:

- Long-term monitoring was not retained for further consideration because decreases in the PFAS concentrations would be a result of downgradient migration of impacts. Treating groundwater with high PFAS concentrations within this AOC will be more efficient and cost-effective than treating groundwater further downgradient, which would not achieve the RAO of decreasing downgradient PFAS migration.

- An injected PAB was not retained because a barrier only traps PFAS and does not remove it from the environment. The long-term stability of the barrier is uncertain, which could potentially result in leaching of PFAS back into the groundwater. Additionally, the spatial extent of the PFAS impacts and high concentrations may inhibit the implementation of a PAB. A PAB would not achieve the RAO of permanently removing PFAS mass from the environment.
- Surface water treatment of Sunfish Lake was not retained because the impacts observed within Sunfish Lake are a result of groundwater impacts and it will be more effective to treat the larger groundwater plume as opposed to only the groundwater that passes through Sunfish Lake. Additionally, treating the upgradient groundwater plume will likely result in decreases in PFAS concentrations within Sunfish Lake. Surface water treatment of Sunfish Lake would be less effective than other approaches at achieving the RAOs of removing PFAS mass from the environment and reducing downgradient migration.

Additional investigation is required to ensure that the remedial actions taken in AOC1, specifically at WCL, are sufficient to achieve the RAOs. Specifically, the extent of PFAS impacts within the historical extent of WCL and in the area where water was sprayed as part of the volatile organic compound (VOC) treatment system. Although the landfill was lined, soil impacts below the original footprint of the waste are still in place and in contact with the groundwater. Remaining impacted soil will likely continue to leach PFAS to the groundwater. Additionally, pump tests would aid in determining the pumping rates required to limit downgradient PFAS migration. Pending this investigation, additional remedial measures may be proposed such as source mass removal in the form of excavation or deep trenching or in-situ PAB or other sequestration media.

11.3.2 AOC 2: Washington County Landfill – Bedrock Aquifers

Remedial approaches within AOC 2 would target the Shakopee and Jordan Aquifers downgradient of WCL. The following remedial approaches were considered for AOC 2:

- Long-term monitoring
- Localized pump and treat system disconnected from the drinking water system
- Localized MBWA
- Regional MBWA

All the approaches identified for this AOC were retained for Site-wide development of remedial alternatives. Long-term monitoring was retained because upgradient treatment within AOC 1 could result in reductions in PFAS concentrations migrating to AOC 2. Long-term monitoring provides a low-cost and easily implementable alternative compared to the others considered within the AOC; however, the extent reductions in PFAS concentrations may be limited as existing PFAS mass in AOC 2 would not be removed. The localized pump and treat system, localized MBWA, and regional MBWA would all prevent continued downgradient migration and reduce PFAS concentrations within AOC 2. Extraction wells as part of an MBWA would provide drinking water to communities.

11.3.3 AOC 3: Oakdale Disposal Site – Surface Water

AOC 3 is included because implementation of remedial measures to prevent the continued migration of PFAS via surface water from ODS is crucial for achieving the RAOs at the Site; however, the development of remedial alternatives for this AOC is outside the scope of this FS. The 3M Consent Order (MPCA, 2007) states that 3M must prevent the release of PFAS from ODS, including release via surface water discharge. Therefore, remedial action in this AOC is the responsibility of 3M. It is anticipated that remediation at AOC 3 would be addressed by 3M through the 2007 Consent Order rather than this FS.

The analysis of alternatives for downgradient AOCs 4–13 assume PFAS is no longer migrating from ODS via surface water. 3M is in the process of re-routing Raleigh Creek around ODS, which is expected to greatly reduce PFAS concentrations within Raleigh Creek. However, sediment impacts directly downgradient of the ODS Abresch parcel are anticipated to contribute to downgradient impacts until the sediment is addressed. Intermittent discharges of PFAS from ODS during snowmelt or large rain events may also occur. Additional efforts, beyond the reroute, may be required to address these surface water impacts.

11.3.4 AOC 4: Oakdale Disposal Site – Downgradient Bedrock Aquifers

Remedial approaches within AOC 4 would target the Shakopee and Jordan Aquifers downgradient of ODS. This AOC does include ODS and the groundwater impacts in the Quaternary and bedrock aquifers located within the extent of the disposal site; however, remedial alternatives for groundwater at the source zone of ODS were not developed as part of this FS because that work is expected to be addressed through the 2007 Consent Order. The analysis of remedial alternatives for this AOC assumes that remediation at the source zone to reduce contaminant mass flux to the bedrock aquifers at ODS will occur. Thus, the approaches for AOC 4 address the impacts that have already migrated downgradient. These approaches may be adjusted depending on the extent to which 3M is required to address offsite impacts from ODS under the 2007 Consent Order. The following remedial approaches were considered for AOC 4:

- Long-term monitoring
- Localized pump and treat system disconnected from the drinking water system
- Localized MBWA
- Regional MBWA

Of these approaches, long-term monitoring and the regional MBWA approach were retained for further consideration. The Oakdale municipal supply wells downgradient of ODS currently capture a significant portion of the impacts migrating from ODS, limiting the continued migration to the south. The impacts not captured are modeled to either migrate into the Raleigh Creek + Eagle Point Lake Groundwater AOC (AOC 7), where they could be addressed by the associated remedial approach for that AOC, or they migrate to the southwest, under St. Paul, MN towards the Mississippi River. The plume in this area is also not well defined and, while modeling efforts support this migration direction, the extent to which impacts have migrated in this direction is not well understood. A localized MBWA array was not retained because modeling indicates pumping in AOC 7 is required, limiting the benefits of using a MBWA in this AOC. A localized pump and treat system that is disconnected from the drinking water system would be difficult to coordinate with existing and planned municipal supply wells and more information regarding the plume migrating to the southwest is required before the effectiveness of this approach can be assessed. If pumping within Oakdale were to change or if Oakdale were to transition to surface water in response to the White Bear Lake court order, the use of a pump and treat system would be reconsidered. Alternatively, 3M may be required to address the migration of these impacts through the 2007 Consent Order. Development of alternatives for that migration is outside the scope of this FS.

Long-term monitoring was retained for further consideration because remediation and source zone control at ODS with the capture currently provided by the Oakdale municipal supply wells could potentially achieve the RAOs over an extended monitoring period. The RAOs could also be achieved through the implementation of the regional MBWA approach. The extraction wells would be placed to improve PFAS capture with improved efficiency over the current municipal supply wells capture of ODS impacts. The extracted water would be distributed using the existing drinking water distribution systems with any remaining water injected back into the aquifer to further limit the migration of PFAS.

11.3.5 AOC 5: Raleigh Creek Surface Water

Remedial approaches in AOC 5 would target the surface water along Raleigh Creek and would include treatment of PFAS impacts leaching from sediment. The following remedial approaches were considered for AOC 5:

- Long-term monitoring
- In-situ PAB
- Ex-situ treatment of surface water

Long-term monitoring and in-situ PAB were retained for further consideration. Ex-situ treatment was not retained for further consideration for the Raleigh Creek Surface Water AOC because 3M's plans to reroute Raleigh Creek to bypass ODS may significantly reduce the mass flux of PFAS migrating from ODS via surface water, except during large storm events and snowmelt. As ex-situ treatment of surface water in Raleigh Creek (e.g., GAC treatment of the entire creek flow) would be costly, active treatment should be considered after the effect of the reroute is evaluated through long-term monitoring. This AOC may need evaluation beyond this drinking water-focused FS to address potential impacts to other receptors such as biota and recreational users of the creek.

Passive treatment in the form of an in-stream PAB offers a lower-cost remedial alternative to remove PFAS within this AOC. The PAB was retained for further consideration in Site-wide alternatives as a lower-cost option. The PAB is expected to remove PFAS that may continue to migrate downstream because of sediment leaching and overflow from ODS during snow melt and rain events. PABs are easily removed when treatment is no longer required. Additional evaluation of the effectiveness of a PAB is recommended using a bench-scale study. A PAB would likely be installed downgradient of Anna's Grove Wetland Complex (AGWC) to adsorb PFAS that leaches from the wetland sediment.

Other remedial approaches such as sediment capping to reduce the release of PFAS from sediment were screened out in **Section 9** and are not considered here.

11.3.6 AOC 6: Eagle Point Lake Surface Water

Remedial approaches in AOC 6 would target surface water and sediment leaching within Eagle Point Lake. The following remedial approaches were considered for AOC 6:

- Long-term monitoring
- In-situ PAB
- Ex-situ treatment of surface water

In the Eagle Point Lake Surface Water AOC, only long-term monitoring was retained for further consideration. The work being completed under the 2018 Settlement agreement upgradient of Eagle Point Lake, including rerouting Raleigh Creek around ODS and potential passive treatment of Raleigh Creek are expected to have a net positive impact on the PFAS concentrations within Eagle Point Lake although the magnitude of PFAS reduction is uncertain. PFAS discharge from ODS during high precipitation, snow melt, and lake sediment leaching may result in unquantified surface water impacts. If the result of long-term monitoring shows additional treatment is required to achieve the RAOs, ex-situ treatment would be reevaluated.

A PAB was not retained for this AOC because this lake does not have a defined stream channel. The water discharged from Eagle Point Lake is being proposed to be treated with a PAB in AOC 9: Horseshoe Lake + West Lakeland Surface Water, as described below.

11.3.7 AOC 7: Raleigh Creek + Eagle Point Lake Groundwater

Remedial approaches within AOC 7 would target the PFAS impacts within the Shakopee and Jordan Aquifers resulting from the infiltration of PFAS in Raleigh Creek and Eagle Point Lake. The following remedial approaches were considered for AOC 7:

- Long-term monitoring
- Localized pump and treat system disconnected from the drinking water system
- Localized MBWA
- Regional MBWA

Within the Eagle Point Lake + Raleigh Creek Groundwater AOC, all proposed approaches were retained for further consideration in Site-wide remedial alternatives. While long-term monitoring may not address impacts already present within the drinking water aquifers, removing the discharge of PFAS from ODS via Raleigh Creek will likely decrease PFAS concentrations within Raleigh Creek and Eagle Point Lake, and subsequently the amount of PFAS entering this AOC. A localized pump and treat system could be implemented to further control the downgradient migration of PFAS and capture PFAS within the current plume. This treatment would be planned in conjunction with the capture that is expected by the Lake Elmo municipal supply wells that are planned as described in the Conceptual Drinking Water Supply Plan (CDWSP) (MPCA, 2021). Additionally, two approaches could be taken to provide safe drinking water to the communities. The regional MBWA approach would include treatment of multiple AOCs and provide safe drinking water to multiple communities while the localized MBWA approach would only provide safe drinking water to the city of Lake Elmo.

11.3.8 AOC 8: Lake Elmo Surface Water

Remedial approaches in AOC 8 would target the Lake Elmo surface water. The following remedial approaches were considered for AOC 8:

- Long-term monitoring
- In-situ PAB
- Reduction of flow through Eagle Point Lake Dam Secondary Outlet
- Ex-situ treatment of Lake Elmo surface water

Long-term monitoring was retained for the development of Site-wide alternatives. Upgradient treatment in the source area AOCs (1, 2, 3, and 4) are expected to decrease the mass of PFAS entering Lake Elmo and subsequently decrease the PFAS concentrations within the surface water. Long-term monitoring would be utilized to establish whether this expected reduction is occurring. A reduction of flow through the Eagle Point Lake Dam secondary outlet was not retained because of the potential for upgradient flooding and the potential to increase the infiltration of surface water to groundwater in upgradient surface water AOCs.

Treatment of surface water in Lake Elmo was not retained for consideration in Site-wide alternative development because the treatment capacity required to demonstrate decreasing PFAS trends would be technically and financially infeasible. Lake Elmo also has lower surface water PFAS concentrations compared to elsewhere in the Project 1007 corridor, so treatment would remove less PFAS from the environment for each gallon of water treated compared to other AOCs. Surface water treatment elsewhere would have a larger positive effect on protecting the drinking water aquifers. A PAB was not retained because this lake does not have a defined stream channel in which to install a PAB. Treatment of the discharge from Lake Elmo is described in AOC 9: Horseshoe Lake + West Lakeland Surface Water AOC below to be protective of the surface water within AOC 9.

11.3.9 AOC 9: Horseshoe Lake + West Lakeland Surface Water

Remedial approaches in AOC 9 would target the surface water within Horseshoe Lake and the West Lakeland storage ponds. The following remedial approaches were considered for AOC 9:

- Long-term monitoring
- Hydraulic reduction in flow from Eagle Point Lake
- In-situ PAB of the discharge from Eagle Point Lake
- In-situ PAB of the combined discharge from Eagle Point Lake and Lake Elmo
- Ex-situ treatment of the discharge from Eagle Point Lake
- Ex-situ treatment of the combined discharge from Eagle Point Lake and Lake Elmo

Numerous approaches were retained to decrease the mass flux of PFAS entering this AOC. These include long-term monitoring to determine the impact of upstream treatment including source zone treatment at ODS with the reroute of Raleigh Creek and source zone treatment at WCL within AOC 1. Passive treatment of the combined flow from Eagle Point Lake and Lake Elmo with a PAB was retained for further consideration in the development of Site-wide alternatives. Passive treatment provides a low-cost alternative to reduce PFAS concentrations in the water flowing into this AOC and subsequently decrease the migration of PFAS into the drinking water aquifers within West Lakeland. While PFAS concentrations are higher in the Eagle Point Lake discharge, treatment of only this flow would not address the perfluorooctanoic acid (PFOA) mass that is being discharged from Lake Elmo. The effectiveness of the PAB will be evaluated in a planned bench-scale study, as described in **Section 10**, to better understand the adsorptive capacity and confirm the effectiveness with Site-specific surface water.

Reduction in hydraulic flow through the pipe under Lake Elmo could reduce the mass of PFAS entering West Lakeland. However, if flow were reduced in this pipe, PFAS would not be removed from the Project 1007 corridor but would instead follow a different natural subsurface migration pathway, likely increasing the mass flux of PFAS into AOC 7. Decreasing the flow through the dam could also impact upstream flooding. For these reasons, a reduction in hydraulic flow from Eagle Point Lake was not retained for the development of Site-wide alternatives.

Active treatment of the influent to this AOC, both combined flow from Lake Elmo and Eagle Point Lake and from Eagle Point Lake alone, was not retained for consideration in the development of Site-wide alternatives because the treatment capacity that would be required to demonstrate decreasing PFAS trends would be technically and financially infeasible. Further, the treatment of upgradient AOCs, where the PFAS concentrations are higher, would result in more PFAS being removed from the Site and greater PFAS removal efficiency, i.e., more PFAS being removed for every gallon of water treated.

11.3.10 AOC 10: West Lakeland Groundwater

Remedial approaches within AOC 10 would target the PFAS impacts within the Shakopee and Jordan Aquifers resulting from the infiltration of PFAS in Raleigh Creek and Eagle Point Lake. The following remedial approaches were considered for AOC 10:

- Long-term monitoring
- Localized pump and treat system disconnected from the drinking water system
- Localized MBWA
- Regional MBWA

All the proposed remedial approaches were retained for consideration for Site-wide alternatives except for the localized MBWA. The residents of West Lakeland were polled as part of the development of the CDWSP (MPCA, 2021) and the majority preferred not to implement a municipal drinking water supply system and instead to remain on private supply wells with point of entry treatment systems (POETs). Should this community input or opinion change, the localized MBWA could be reconsidered as part of the larger regional MBWA options.

A localized pump and treatment system was retained to capture PFAS impacts within this AOC and decrease downgradient migration towards other communities. The treated water would be injected back into the groundwater. The regional MBWA would extract water from West Lakeland, but it would be incorporated into the supply for Lake Elmo and Oakdale. Long-term monitoring would be evaluated as upstream treatments improve groundwater conditions.

11.3.11 AOCs 11, 12, and 13: Sediment

The remedial approaches for the sediment AOCs are screened together as the approaches are similar across the individual AOCs. PFAS treatment technologies and general remedial approaches were screened in **Section 9**. The following remedial approaches were retained and considered for the treatment of sediment (AOCs 11, 12, and 13):

- Long-term monitoring
- Access restrictions
- Extraction via sediment excavation or dredging followed by ex-situ treatment

Of these approaches, only access control and long-term monitoring were retained for the development of Site-wide alternatives. More details concerning excavation and the rationale for screening it out are in **Appendix L**. The sediment AOCs are all currently receiving contributions from ODS via discharge to Raleigh Creek. Until Raleigh Creek is rerouted and surface water is no longer contributing PFAS to the sediment AOCs, sediment remediation should not be implemented. Additionally, the extent to which PFAS will leach from the sediment and continue to act as a PFAS source to downgradient surface water and groundwater is uncertain. The need for sediment remediation should be reevaluated after the sediment leachability study described in **Section 10** is complete. Depending on those results, additional monitoring after the Raleigh Creek reroute is completed will likely be proposed to confirm whether the sediment is a long-term PFAS source to surface water and groundwater. Because sediment remediation is costly and difficult to conduct and requires significant disruption of wetland habitats, confirmation that sediment remediation is required for the protection of drinking water aquifers is proposed. Surface water and sediment sampling is recommended to determine the extent that PFAS is leaching from the sediment and predict whether sediment may continue to leach PFAS. This recommendation does not apply to the protection of ecological receptors.

The protection of human health from PFAS exposure could be largely achieved with access restrictions (e.g., signage and fencing). If additional investigations are conducted and results show PFAS impacts within homeowner's yards, additional remedial action may be required to be protective.

11.4 Alternatives Selected for Detailed Analysis

Site-wide alternatives were developed based on the remedial approaches retained in **Section 11.3**. These alternatives represent a range of costs, and address the RAOs to a varying degree. The alternatives are summarized in **Table 4** (see **Appendix B**) and evaluated in **Section 12** and **Section 13**.

11.4.1 Alternative 1

Alternative 1 is the no further action (NFA) alternative for each AOC. This alternative provides a basis for comparison to alternatives that address the PFAS impacts at the Site, as is required within the FS process. NFA typically indicates that no remedial actions or interventions would be implemented within a specific AOC, including no further monitoring, and any interim remedial actions already in place would also cease.

Actions to control migration of PFAS may be required at the source areas by programmatic requirements or legal agreements related to specific source areas, such as the 2007 Consent Order between 3M and MPCA. For example, the Consent Order states that 3M must prevent or minimize the release of PFAS from ODS, including release via surface water discharge (and through groundwater migration) (MPCA, 2007). However, for the purpose of this FS, Alternative 1 assumes no additional treatment beyond what is already in place and required for treating drinking water to be protective of human health is completed.

Figure 11.1 depicts areas where groundwater would not be treated within the Site and impacts would continue to migrate downgradient. Because these aquifers are currently used and will continue to be used for drinking water, the NFA response for groundwater in this FS must include treatment of water extracted for drinking water to be protective of human health. This treatment of private and public supply wells would continue to ensure the public is not exposed to PFAS through drinking water. The CDWSP details a plan to provide safe drinking water to currently impacted residents of the East Metro (MPCA, 2021) that does not consider remediation efforts to limit plume migration to be protective of drinking water aquifers downgradient of the current plume extent. While residents would continue to have access to safe drinking water under this alternative, it would not provide for safe and sustainable drinking water resources for future generations. Also, it would not reduce long-term drinking water treatment needs now or in the future, nor reduce exposures from impacted secondary source areas, and drinking water treatment needs would likely even expand as the un-controlled PFAS plume continued to spread.

For surface water and sediment AOCs, this alternative would not include any remedial action or interventions beyond what is already in place. If surface water and sediment impacts are not addressed, surface water would continue to spread PFAS downstream, and biota living in and around impacted surface water as well as people spending time in contact with surface waters would continue to be exposed to PFAS contaminants through this exposure route.

The cost of a NFA alternative is typically zero; however, significant costs are required to provide safe drinking water to communities located within the Site now and into the future. The costs to provide safe drinking water are expected to increase as the unmitigated PFAS plume continues to migrate downgradient and impact additional communities. Therefore, the typical zero cost does not apply in this circumstance. Cost estimates to provide safe drinking water to communities in the East Metro were developed as part of the CDWSP (MPCA, 2021) were used to develop community-specific cost estimates for drinking water treatment if no other remedial actions were to be implemented for the communities impacted by PFAS impacts associated with Project 1007.

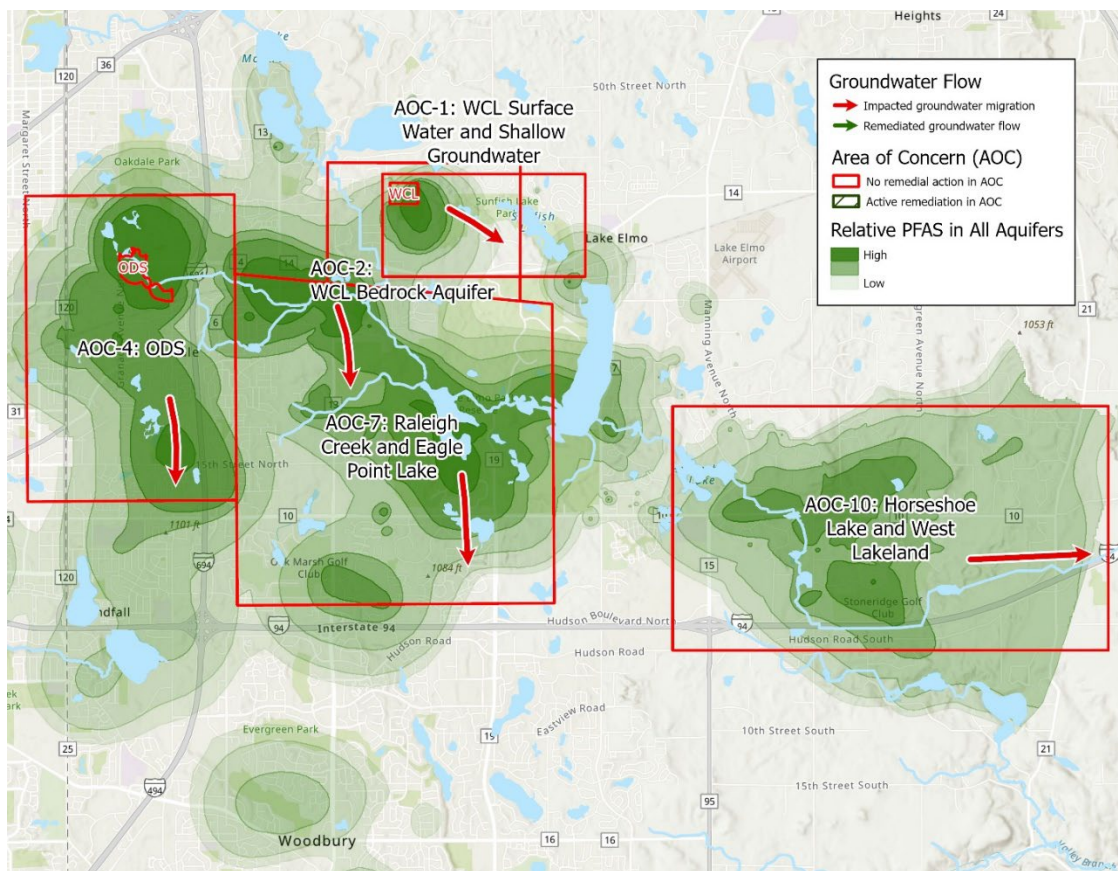


Figure 11.1: Groundwater AOCs not addressed by Alternative 1: Alternative 1 would provide no treatment of groundwater, surface water, or sediment. No PFAS migration pathways to drinking water aquifers would be addressed.

11.4.2 Alternative 2

Alternative 2 provides source zone control at WCL and anticipates 3M will implement additional source zone control at ODS to limit the continued migration of PFAS from this source area via surface water and groundwater. Alternative 2 also includes access restrictions and long-term monitoring for the three sediment AOCs, four surface water AOCs, and five groundwater AOCs.

This FS does not propose specific remedial actions at the ODS source area to address surface water or groundwater. ODS is regulated by the Superfund program and through that program 3M is responsible for implementing remedies necessary to address contamination from ODS. While surface water at ODS (AOC 3) and groundwater at immediately downgradient of ODS (included in AOC 4) were identified as AOCs because of their importance to downgradient surface water AOCs and drinking water aquifers, this FS assumes that remedial actions at the ODS source area would be addressed by 3M through the Superfund program. Generally, the ODS impacts 3M is assumed to address are:

- The discharge of PFAS from ODS into Raleigh Creek surface water
- Ongoing sources of PFAS contamination to groundwater and migration of PFAS impacts in groundwater from ODS

The extent to which 3M is responsible for the control and clean up of PFAS impacts and the specific remedial alternatives that would be used are expected to be evaluated through the Superfund process, and so are not discussed in detail in this FS. The costs associated with remedial actions that are anticipated to be completed by 3M are also not included. As WCL is managed through MPCA’s Closed-Landfill Program, specific remedial actions are included in this FS to address the impacts at this source area.

All the proposed alternatives except Alternative 1 include access restrictions and long-term monitoring. Different levels of access restrictions to prevent people from coming into contact with contaminated surface water and sediment were considered. Long-term monitoring involves the installation of a monitoring well network and surface water and sediment monitoring stations. The monitoring network would be similar for Alternatives 2 through 8, as monitoring should be conducted to assess the migration of the plume throughout the Site based on upgradient changes, even in AOCs without active remediation. Monitoring at AOC 3 and in areas of AOC 4 determined to require monitoring through the Superfund Program is expected to be undertaken by 3M through the Superfund program to assess the effectiveness of the remedial measures undertaken at the ODS source zone. The extent to which 3M is responsible for monitoring outside of AOC 3 and outside ODS in AOC 4 will be determined through the Superfund program.

Table 4 (Appendix B) summarizes the remedial actions proposed within each AOC for Alternative 2. **Figure 11.2** shows which groundwater AOCs would have active remediation and **Figure 11.3** shows the sediment AOCs with access restrictions and long-term monitoring. As previously mentioned, treatment of drinking water for affected communities would still be required and is included in the cost analysis for this alternative. The technologies considered for each pump and treat system are described in **Section 11.5**, with additional details available in **Appendix J**.

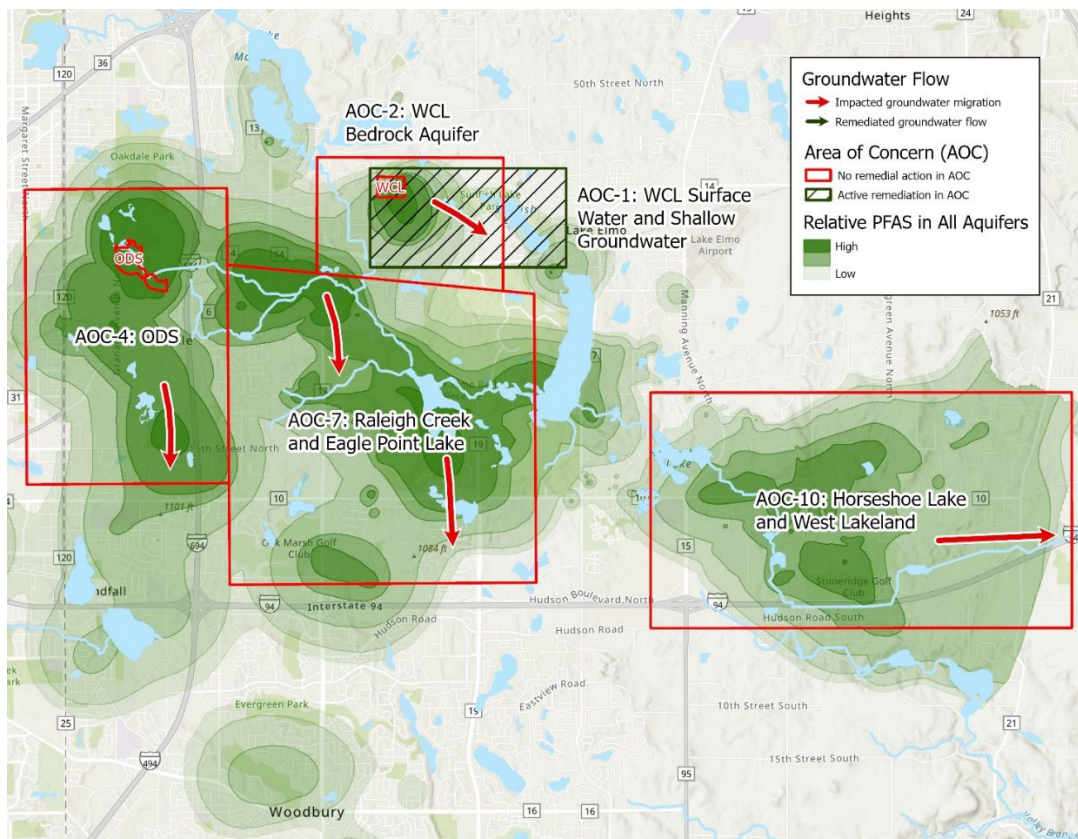


Figure 11.2: Groundwater AOCs addressed by Alternative 2: Implementation of source zone treatment at WCL would reduce mass flux from AOC 1; however, the PFAS mass within the deeper aquifers in AOC 2 would continue downgradient migration. Migration pathways within other groundwater AOCs would also not be directly addressed.

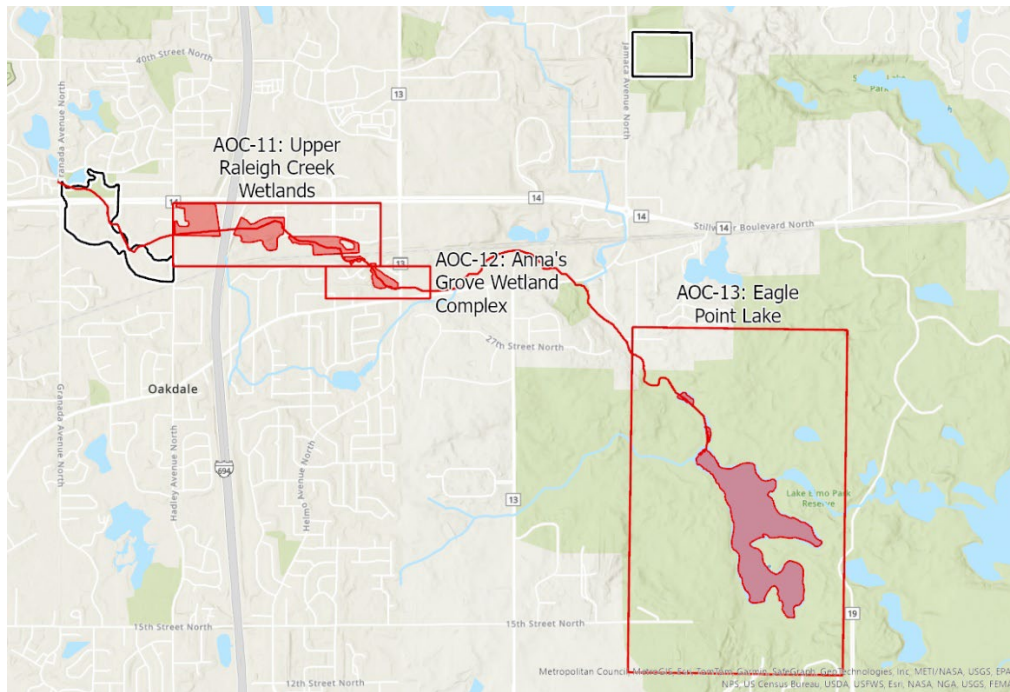


Figure 11.3: Sediment AOCs addressed by Alternatives 2–8: Long-term monitoring and access restrictions will be employed in all sediment AOCs in Alternatives 2 through 8.

11.4.3 Alternative 3

Alternative 3 provides source zone control for WCL and assumes source area control would also occur for ODS groundwater and surface water as described in Alternative 2. Additionally, surface water treatment in the form of in-situ PABs downstream of the AGWC and downstream of the Eagle Point Lake and Lake Elmo discharge pipes would decrease downgradient migration of PFAS through surface water flow and subsequent infiltration to groundwater, reducing the mass flux of PFAS to the drinking water aquifers. Access restrictions are also proposed for the three sediment AOCs and five groundwater AOCs.

Table 4 (Appendix B) summarizes the remedial actions proposed within each AOC for Alternative 3. **Figure 11.4** shows which groundwater AOCs would have active remediation and **Figure 11.5** shows the proposed locations of surface water PABs. Long-term monitoring would be conducted on AOCs without active remediation to determine the effectiveness of upgradient treatment, including at ODS, at achieving the RAOs of downgradient AOCs. As mentioned in Alternative 2, monitoring at AOC 3 would be included in the remedial action proposed by 3M. As previously mentioned, treatment of drinking water for affected communities would still be required and is included in the cost analysis for this alternative. The treatment technologies being considered for each pump and treat system are described in **Section 11.5**.

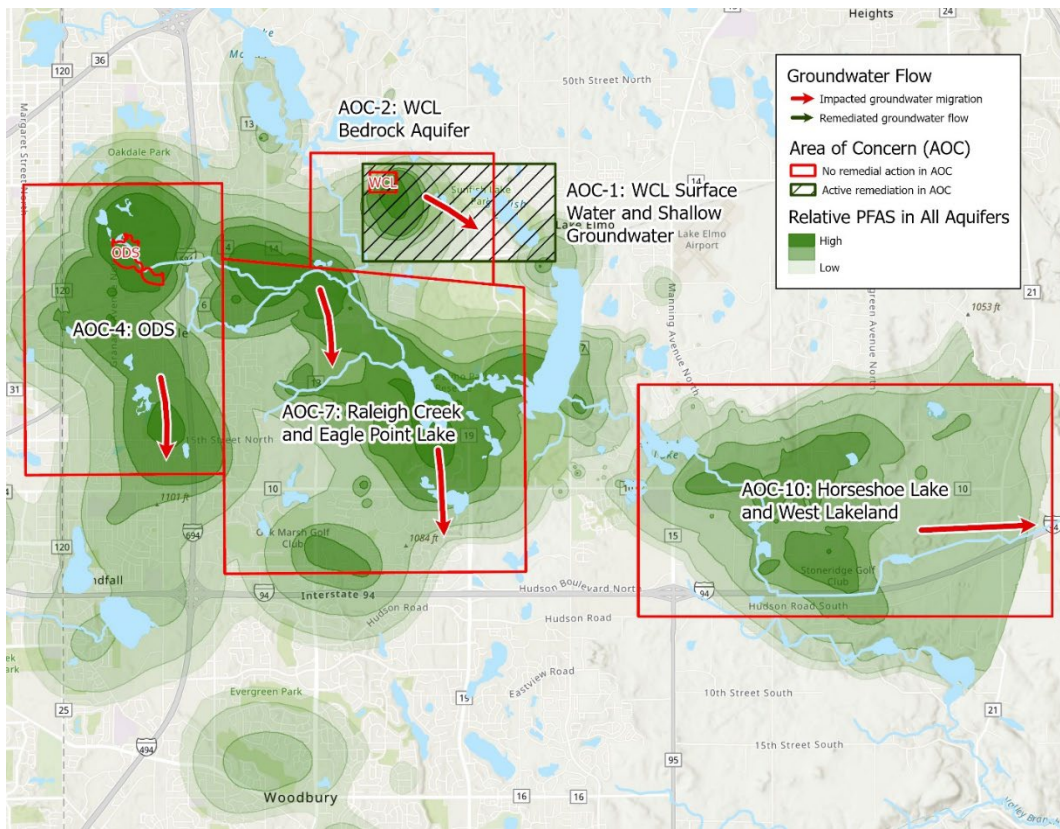


Figure 11.4: Groundwater AOCs addressed by Alternative 3: Implementation of source zone treatment at WCL would reduce mass flux from AOC 1; however, the PFAS mass within the deeper aquifers in AOC 2 would continue downgradient migration. Migration pathways within other groundwater AOCs would not be directly addressed in this alternative. PABs in the surface water would reduce infiltration of PFAS into the groundwater but would not change the migration pathways of PFAS within the other groundwater AOCs.

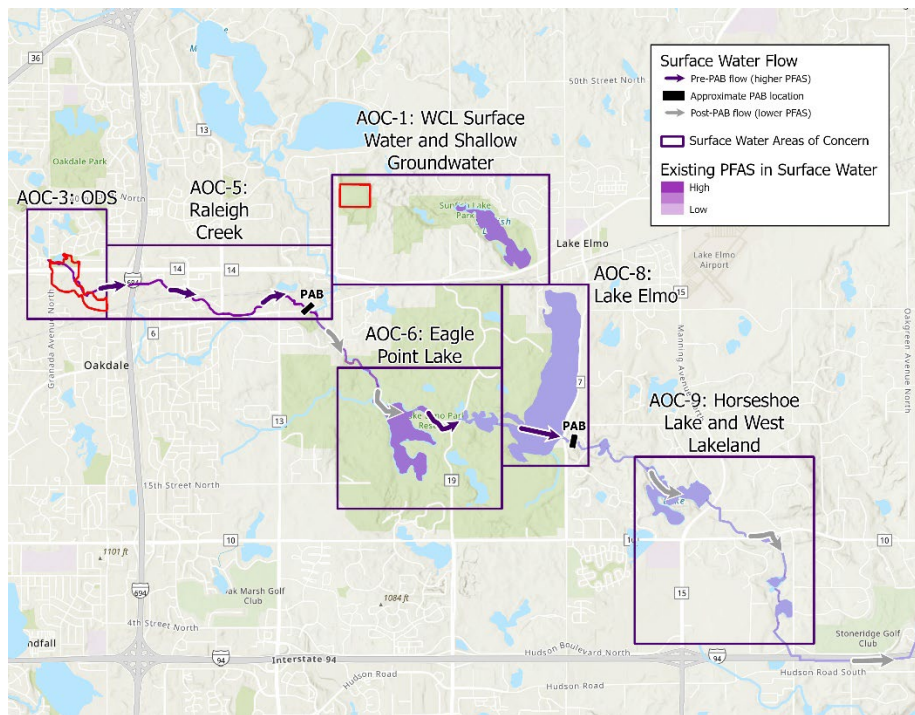


Figure 11.5: Surface water AOCs addressed by Alternatives 3–8: Surface water treatment would be implemented with a PAB within AOC 5 (downstream of AGWC) and another upgradient of AOC9 (downstream of the Eagle Point Lake and Lake Elmo discharge pipes).

11.4.4 Alternative 4

Alternative 4 includes the same pump and treat system in AOC 1 and additional source zone control at ODS by 3M as was included in Alternative 3. Alternative 4 provides additional treatment within the drinking water aquifers to further limit PFAS migration within those aquifers through a pump and treat system within groundwater AOCs 1, 2, 7, and 10. The surface water treatment and access descriptions described in Alternative 3 is also included in this alternative. The water extracted and treated would be injected back into the Jordan Aquifer to increase the capture of PFAS and reduce continued downgradient migration within the Jordan Aquifer.

Table 4 (Appendix B) summarizes the remedial actions proposed within each AOC for Alternative 4. **Figure 11.6** shows which groundwater AOCs would have active remediation. Long-term monitoring would be conducted on AOCs without active remediation to determine the effectiveness of upgradient treatment, including at ODS, at achieving the RAOs of downgradient AOCs. This monitoring will aid in adjustments to the upgradient treatment as necessary to meet RAOs. As previously mentioned, treatment of drinking water for affected communities would still be required and is included in the cost analysis for this alternative. The technologies being considered for each pump and treat system are described in **Section 11.5**. The conceptual well and piping network proposed for AOCs 1, 2, 7, and 10 is shown in **Figures J.2 to J.5** in **Appendix J**; details on the conceptual pump and treat system are available in **Appendix J**.

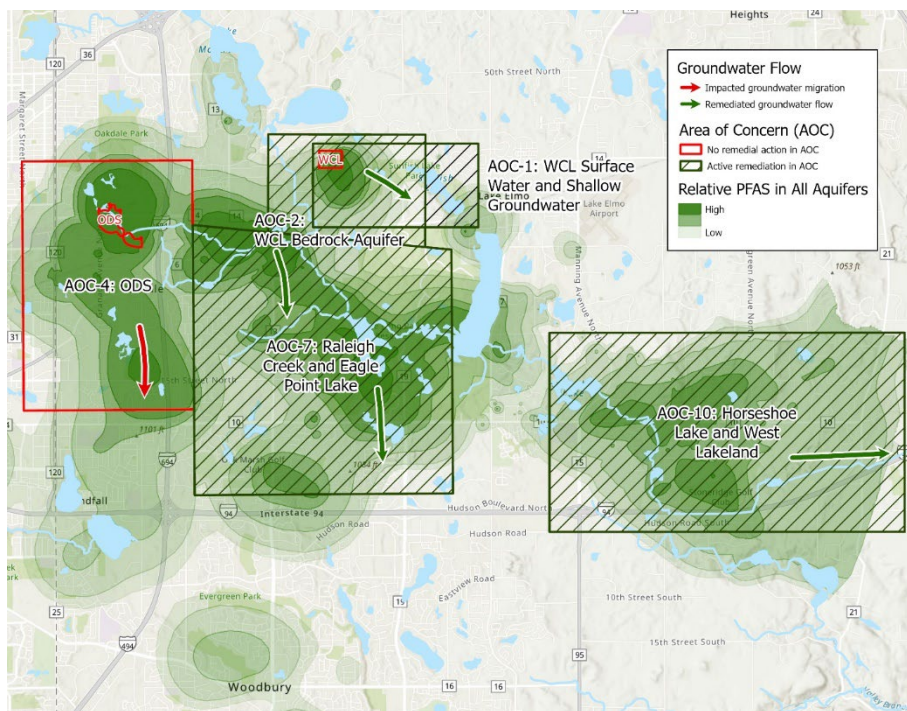


Figure 11.6: Groundwater AOCs addressed by Alternative 4: Active remediation would be implemented at all groundwater AOCs except AOC 4 in addition to PABs to reduce PFAS migration via surface water.

11.4.5 Alternative 5

Alternative 5 is the first of the conceptual MBWA alternatives. Groundwater would be extracted from the Jordan Aquifer in AOCs 2 and 7 and treated like the pump and treat systems described in Alternatives 2 through 4. However, instead of injecting all treated water back into the Jordan Aquifer to improve capture, water would be treated for distribution for municipal supply. The remaining treated water would be injected into the Jordan Aquifer to improve the PFAS capture. Alternative 5 would specifically provide drinking water to the City of Lake Elmo through the treatment of groundwater in AOC 2 and AOC 7. Alternative 5 also includes all remedial actions discussed in Alternative 3 (**Figure 11.4** and **Figure 11.5**).

Table 4 (Appendix B) summarizes the remedial actions proposed within each AOC for Alternative 5. **Figure 11.7** shows which groundwater AOCs would have active remediation. As drinking water would be provided to Lake Elmo, the costs provided in the CDWSP for the supply of safe drinking water to this city would be reevaluated and cost estimates updated to reflect the installation of the MBWA. Long-term monitoring would be conducted on AOCs without active remediation to determine the effectiveness of upgradient treatment, including at ODS, at achieving the RAOs of downgradient AOCs. The technologies being considered for the MBWA and pump and treat systems are described in **Section 11.5**.

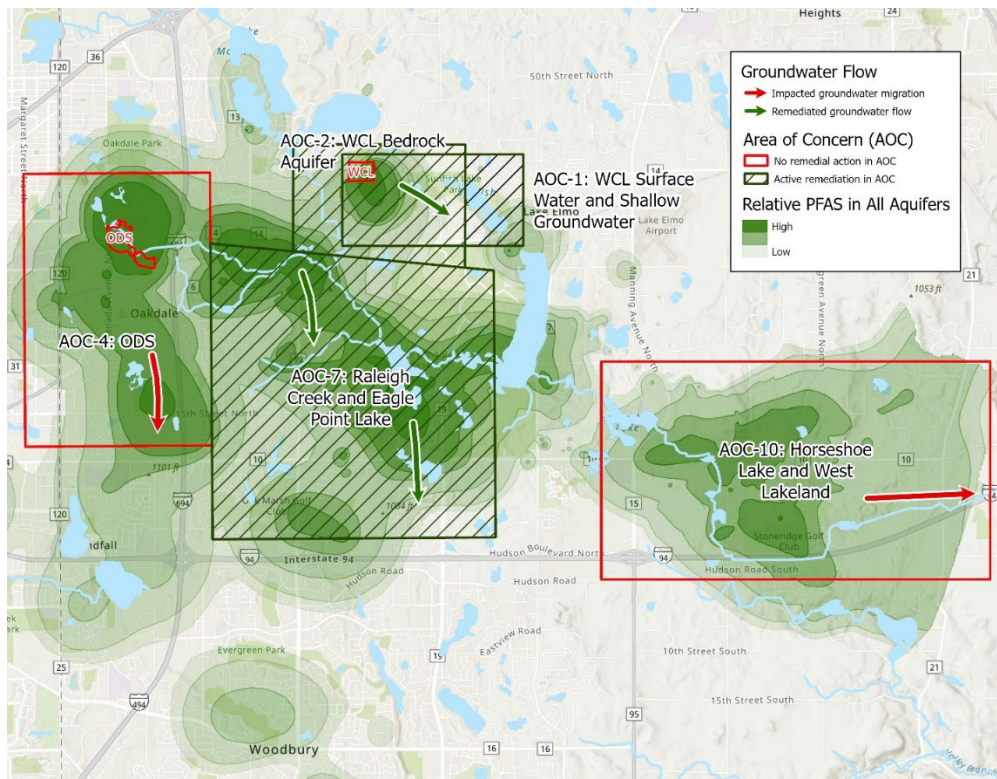


Figure 11.7: Groundwater AOCs addressed by Alternative 5: AOCs 2 and 7 would be treated by a MBWA in addition to source zone treatment at WCL and the PABs to reduce PFAS migration via surface water.

11.4.6 Alternative 6

Alternative 6 includes the same conceptual MBWA discussed in Alternative 5 in which groundwater would be extracted and treated for drinking water distribution, with excess treated water injected back into the Jordan Aquifer for improved plume capture. Alternative 6 also includes a localized pump and treatment system in AOC 10 in which water would be extracted, treated, and injected to improve plume control in this AOC. Alternative 6 also includes all remedial actions described in Alternative 3.

Table 4 (Appendix B) summarizes the remedial actions proposed within each AOC for Alternative 6. **Figure 11.8** shows which groundwater AOCs would have active remediation. As drinking water would be provided to Lake Elmo, the costs outlined in the CDWSP for the supply of safe drinking water to this city would be reevaluated to reflect the installation of the MBWA. Long-term monitoring would be conducted on AOCs without active remediation to determine the effectiveness of upgradient treatment, including at ODS, at achieving the RAOs of downgradient AOCs. The technologies being considered for the MBWA and pump and treat systems are described in **Section 11.5**.

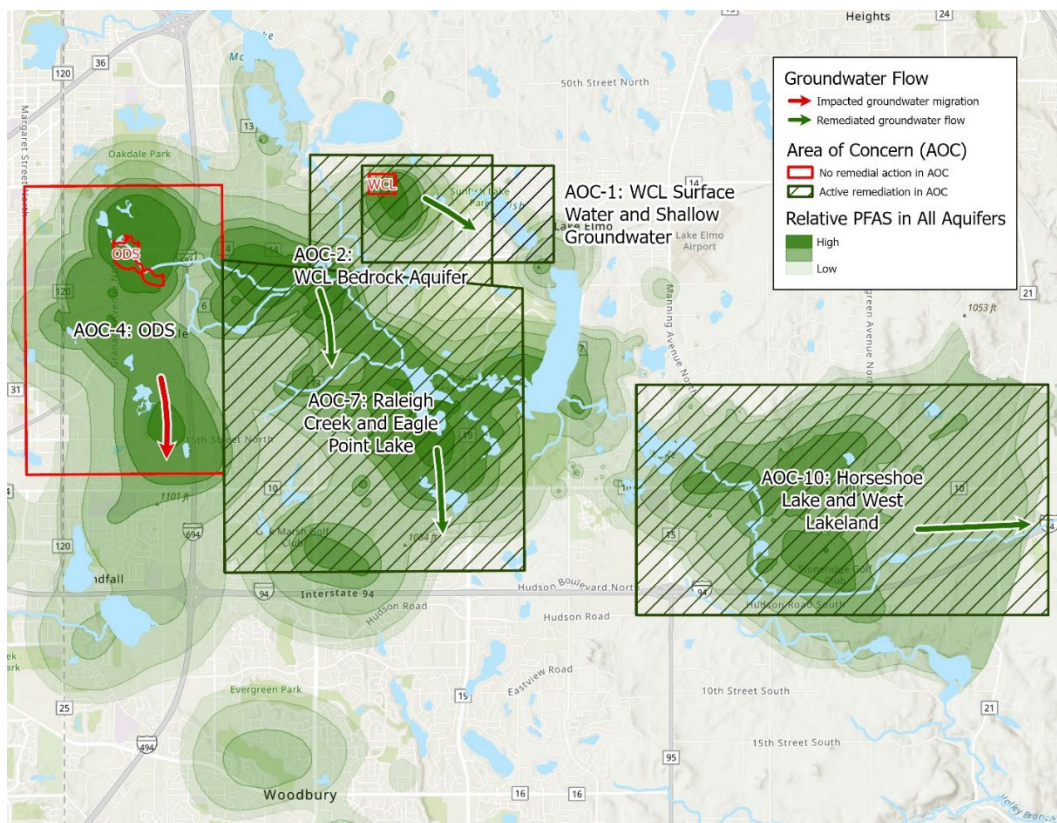


Figure 11.8: Groundwater AOCs addressed by Alternative 6: AOCs 2 and 7 would be treated by a MBWA in addition to source zone treatment at WCL and the PABs to reduce PFAS migration via surface water. AOC 10 would have a separate pump and treat system.

11.4.7 Alternative 7

Alternative 7 is another conceptual MBWA alternative. The conceptual MBWA in Alternative 7 would extract water from AOCs 2, 4, and 7 and provide drinking water to the cities of Lake Elmo and Oakdale. Inclusion of Oakdale in the conceptual MBWA would improve groundwater plume capture compared to existing pumping conditions in Oakdale. Like Alternative 6, a pump and treat system separate from the MBWA would be included in AOC 10. Alternative 7 also includes all remedial actions described in Alternative 3 (**Figure 11.3** and **Figure 11.4**).

Table 4 (Appendix B) summarizes the remedial actions proposed within each AOC for Alternative 7. **Figure 11.9** shows which groundwater AOCs would have active remediation. As drinking water would be provided to the cities of Lake Elmo and Oakdale, the safe drinking water supply costs outlined in the CDWSP would be reevaluated to reflect the installation of the MBWA. Long-term monitoring would be conducted at AOCs without active remediation to determine the effectiveness of upgradient treatment, including at ODS, at achieving the RAOs of downgradient AOCs. The technologies being considered for the MBWA and pump and treat systems are described in **Section 11.5**.

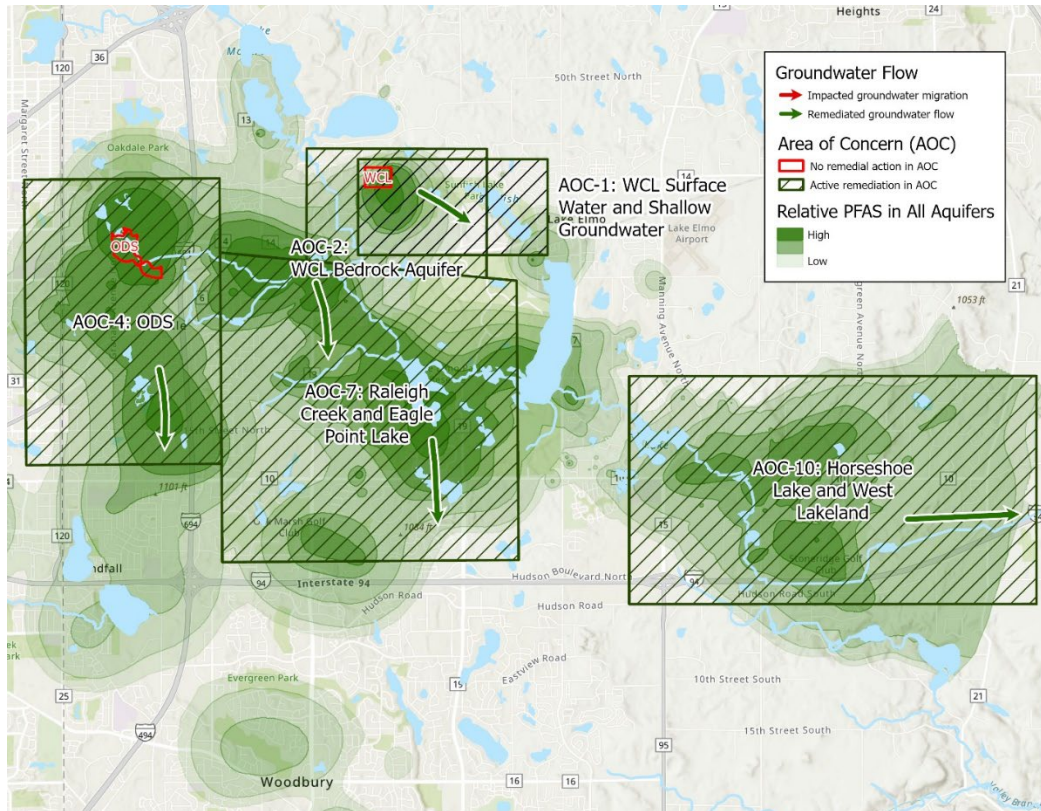


Figure 11.9: Groundwater AOCs addressed by Alternative 7: AOCs 2, 4, and 7 would be treated by a MBWA with drinking water supply to the cities of Lake Elmo and Oakdale. AOC 10 would have a separate pump and treat system.

11.4.8 Alternative 8

Alternative 8 includes the most robust conceptual MBWA. Groundwater would be extracted from AOCs 2, 4, 7, and 10 included in this alternative. As AOC 10 would be included in the MBWA, no separate pump and treat system would be included in AOC 10. Treated water would provide drinking water supply to the cities of Lake Elmo and Oakdale. The remaining water would be injected into the Jordan Aquifer to increase capture of PFAS impacts and reduce continued downgradient migration. This alternative would treat all groundwater AOCs and reduce PFAS migration within all the groundwater AOCs to unimpacted drinking water aquifers. Alternative 8 also includes all remedial actions described in Alternative 3.

Table 4 (Appendix B) summarizes the remedial actions proposed within each AOC for Alternative 8. **Figure 11.10** shows which groundwater AOCs would have active remediation. As drinking water would be provided to the cities of Lake Elmo and Oakdale, the costs outlined in the CDWSP for the supply of safe drinking water to these cities would be reevaluated to reflect the installation of the MBWA. Long-term monitoring would be conducted on AOCs without active remediation to determine the effectiveness of upgradient treatment, including at ODS, at achieving the RAOs of downgradient AOCs. The technologies being considered for the MBWA and pump and treat systems are described in **Section 11.5**.

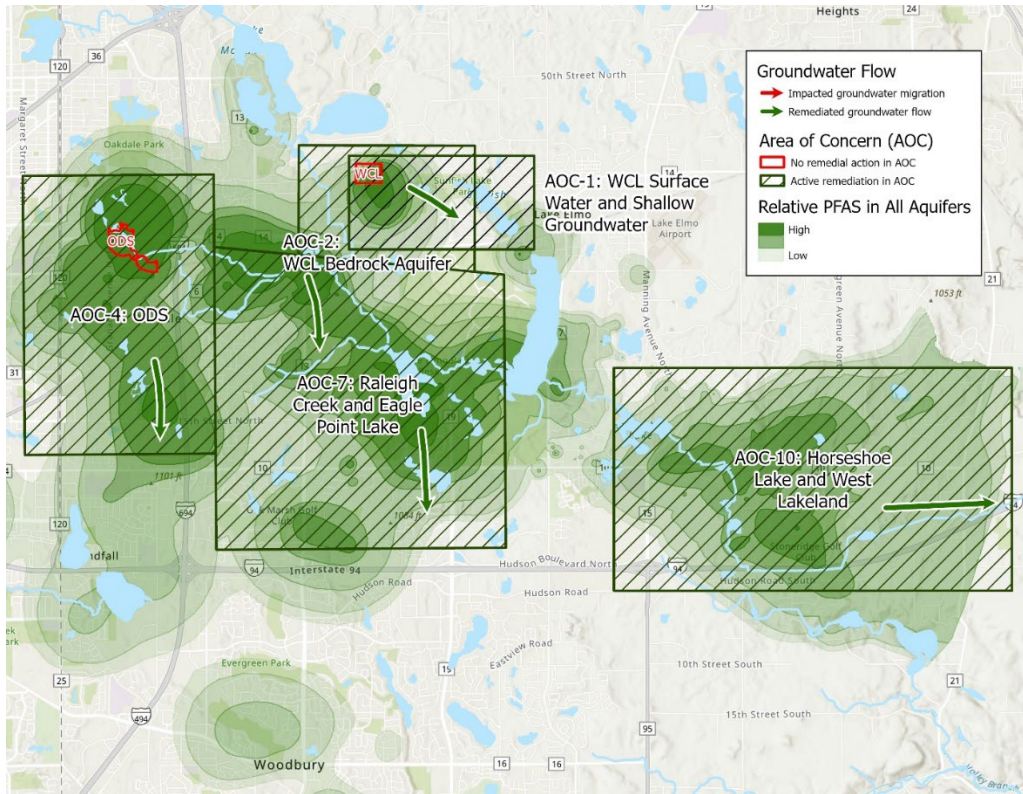


Figure 11.10: Groundwater AOCs addressed by Alternative 8: AOCs 2, 4, 7, and 10 would be treated by a MBWA with drinking water supply to the cities of Lake Elmo and Oakdale.

11.5 Proposed Treatment Technologies

Treatment trains were developed based on the retained technologies in **Section 9** for evaluation as part of this FS to address the specific PFAS impacts in the AOCs with proposed treatment for each alternative. These treatment trains were divided into those suitable for drinking water treatment and those that are only suitable for non-drinking water supply pump and treat. The technologies were also separated out as not all PFAS treatment technologies are approved for use in drinking water systems. **Table 11.1** lists the treatment trains, the AOCs, and alternatives for which they are applicable. The treatment trains applicable for non-drinking water pump and treat are further evaluated in **Appendix I** and the treatment trains applicable for drinking water are further evaluated in **Appendix J**.

Table 11.1: Summary of Proposed Treatment Trains

Treatment Train	Description	Applicable Alternatives (Applicable AOCs)
Non-Drinking Water Treatment Trains		
Reactivated Granular Activated Carbon (GAC)	Reactivated GAC would be used to remove all target PFAS from extracted water. PFAS destruction would occur when GAC is reactivated offsite.	Alt 4 (AOCs 2, 7, & 10) Alt 6 (AOC 10) Alt 7 (AOC 10)
Single-Use Ion Exchange (IX)	Single-use IX resin would be used to remove short- and long-chain PFAS from extracted water. The IX resin would then be disposed of or destroyed.	Alt 2 (AOC 1) Alt 3 (AOC 1) Alt 4 (AOCs 1, 2, 7, & 10) Alt 5 (AOC 1) Alt 6 (AOCs 1 & 10) Alt 7 (AOCs 1 & 10) Alt 8 (AOC 1)
Reactivated GAC + Single-Use IX	Reactivated GAC would be used to remove long-chain PFAS such as perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) from extracted water. This would be followed by single-use IX to target short-chain PFAS such as perfluorobutanoic acid (PFBA). PFAS removed by GAC would be destroyed during GAC offsite reactivation while a separate destruction or disposal alternative would be implemented for the IX resin.	Alt 2 (AOC 1) Alt 3 (AOC 1) Alt 4 (AOCs 1, 2, 7, & 10) Alt 5 (AOC 1) Alt 6 (AOCs 1 & 10) Alt 7 (AOCs 1 & 10) Alt 8 (AOC 1)
Nanofiltration/ Reverse Osmosis (NF/RO) + Reactivated GAC + Single-Use IX	NF/RO would be used to separate PFAS from the bulk phase of extracted water. The PFAS concentrated in water not passed through the membranes (reject water) would be treated with reactivated GAC to remove long-chain PFAS such as PFOS and PFOA. The GAC removal would be followed by treatment with single-use IX resin to target short chain PFAS such as PFBA. PFAS removed by the GAC would subsequently be destroyed during offsite GAC reactivation while a separate destruction or disposal alternative would be implemented for the IX resin.	Alt 2 (AOCs 1) Alt 3 (AOCs 1) Alt 4 (AOCs 1, 2, 7, & 10) Alt 5 (AOC 1) Alt 6 (AOCs 1 & 10) Alt 7 (AOCs 1 & 10) Alt 8 (AOC 1)
Regenerable IX	Regenerable IX resin would be used to remove long- and short-chain PFAS from extracted water. Regeneration would be performed using a solvent regenerant, and subsequent distillation of the PFAS-containing spent regenerant would occur onsite to recover the solvent for reuse and to concentrate the aqueous PFAS-containing portion for disposal. The PFAS concentrate would be disposed of or destroyed.	Alt 2 (AOC 1) Alt 3 (AOC 1) Alt 4 (AOC 1) Alt 5 (AOC 1) Alt 6 (AOC 1) Alt 7 (AOC 1) Alt 8 (AOC 1)
Foam Fractionation + GAC or IX Polishing	Foam fractionation would be used to remove predominantly long-chain PFAS from the pumped water. The foam fractionation PFAS concentrate would be disposed of or destroyed. Polishing media (reactivated GAC or single-use IX resin) would then be used to further remove residual long-chain PFAS to achieve the required concentrations for re-injection. Polishing would also remove short-chain PFAS to required standards. The PFAS removed by GAC would be destroyed during offsite reactivation. IX resin would be managed with a separate destruction or disposal step.	Alt 2 (AOC 1) Alt 3 (AOC 1) Alt 4 (AOCs 1, 2, 7, & 10) Alt 5 (AOC 1) Alt 6 (AOCs 1 & 10) Alt 7 (AOCs 1 & 10) Alt 8 (AOC 1)
NF/RO + Foam Fractionation + IX Polishing	NF/RO would be used to separate PFAS from the bulk of the extracted water. The PFAS concentrated in the reject water would be treated with foam fractionation to remove the bulk of long-chain PFAS from the membrane reject and provide further concentration. The foam fractionation concentrate would be disposed of or destroyed. Foam fractionation effluent would be further treated by single-use IX resin to meet treatment targets. IX resin would be disposed or destroyed.	Alt 2 (AOCs 1) Alt 3 (AOC 1) Alt 4 (AOCs 1, 2, 7, & 10) Alt 5 (AOC 1) Alt 6 (AOCs 1 & 10) Alt 7 (AOCs 1 & 10) Alt 8 (AOC 1)

Treatment Train	Description	Applicable Alternatives (Applicable AOCs)
Drinking Water Treatment Trains		
GAC Only	GAC would be used to remove PFAS with a lead/lag vessel configuration. The lead GAC would be replaced as needed and the lag would become the new lead vessel. Spent GAC would be incinerated or landfilled.	Alt 5 (AOCs 2 & 7) Alt 6 (AOCs 2 & 7) Alt 7 (AOCs 2, 4, & 7) Alt 8 (AOCs 2, 4, 7, and 10)
GAC and RO Parallel Trains	RO would be used for treatment of wells with higher PFBA concentrations to reduce media usage.	Alt 5 (AOCs 2 and 7) Alt 6 (AOCs 2 and 7) Alt 7 (AOCs 2, 4, and 7) Alt 8 (AOCs 2, 4, 7, & 10)
GAC with RO Polish	GAC treatment would be followed by RO polishing to reduce PFBA effluent concentrations without requiring as many GAC vessel changes.	Alt 5 (AOCs 2 & 7) Alt 6 (AOCs 2 & 7) Alt 7 (AOCs 2, 4, & 7) Alt 8 (AOCs 2, 4, 7, & 10)
GAC with IX Polish	Lead/lag GAC would be followed by a single IX polish vessel to reduce GAC media usage while achieving lower effluent concentrations.	Alt 5 (AOCs 2 & 7) Alt 6 (AOCs 2 & 7) Alt 7 (AOCs 2, 4, & 7) Alt 8 (AOCs 2, 4, 7, & 10)
GAC Pre-Treatment with IX Lead/Lag Treatment	A single GAC vessel would be followed by lead/lag IX treatment. The GAC vessel would be used as sacrificial pre-treatment to extend the IX media life by removing non-PFAS contaminants that can shorten IX media life.	Alt 5 (AOCs 2 & 7) Alt 6 (AOCs 2 & 7) Alt 7 (AOCs 2, 4, & 7) Alt 8 (AOCs 2, 4, 7, & 10)

11.6 Summary

The eight alternatives presented in **Section 11.4** reflect a range of costs and levels of implementability to achieve the RAOs and other NCP criteria. The alternatives can be summarized as follows:

- Alternative 1: NFA would be taken throughout the Site, including monitoring. PFAS treatment of drinking water would continue. Treatment at ODS would continue as it is currently being conducted.
- Alternative 2: Treatment of the shallow groundwater at WCL would provide source zone treatment. Additional treatment at ODS by 3M would reduce offsite migration of PFAS in surface water and groundwater. Sediment access restrictions would be implemented for the sediment AOCs.
- Alternative 3: Treatment of the shallow groundwater at WCL would provide source zone treatment. Additional treatment at ODS by 3M would reduce offsite migration of PFAS in surface water and groundwater. In-situ PAB would be used in surface water to reduce the mass of PFAS migrating from surface water into the drinking water aquifers. Sediment access restrictions would be implemented for the sediment AOCs.
- Alternative 4: In addition to the treatment included in Alternative 3, pump and treat systems for AOCs 2, 7, and 10 would be used to reduce PFAS concentrations in groundwater and PFAS migration. The extracted water would be reinjected into the Jordan Aquifer.
- Alternative 5: In addition to the treatment included in Alternative 3, a localized MBWA for AOCs 2 and 7 would be used to reduce groundwater concentrations and migration and provide drinking water to the City of Lake Elmo. Excess water would be injected into the Jordan Aquifer.

- Alternative 6: In addition to the treatment included in Alternatives 3 and 5, a localized pump and treat system would be installed in AOC 10 to reduce migration of PFAS eastwards into areas that are currently unimpacted. The treated water would be injected into the Jordan Aquifer.
- Alternative 7: In addition to the treatment included in Alternative 3, Alternative 5 would be expanded to include extraction within and supply to the City of Oakdale. Excess water would be injected into the Jordan Aquifer. Like Alternative 6, a pump and treat system would be installed in AOC 10 and treated water would be injected into the Jordan Aquifer.
- Alternative 8: In addition to the treatment included in Alternative 3, the full regional MBWA would be installed with extraction for treatment in AOCs 2, 4, 7, and 10 and drinking water supplies to the cities of Oakdale and Lake Elmo. Excess water would be injected into the Jordan Aquifer.

These alternatives are evaluated according to the NCP criteria in **Sections 12** and **13**.

12 Detailed Analysis of Alternatives

This section provides evaluation of the remedial action alternatives described in **Section 11.4**, with respect to the National Contingency Plan (NCP) criteria defined in **Section 11.1**. The following sections document the analysis of each considered NCP criteria for each alternative and provide the qualitative scoring for each alternative by NCP criterion.

Each of the alternatives would provide safe drinking water to the residents of Lake Elmo, Oakdale, and West Lakeland either through the actions described as part of a proposed alternative or through the actions detailed in the Conceptual Drinking Water Supply Plan (CDWSP). The CDWSP also addresses communities outside of the Project 1007 (Site) area with drinking water impacted by Washington County Landfill (WCL) and Oakdale Disposal Site (ODS). Decisions made within the Project 1007 area could impact downgradient communities as some alternatives do not provide plume control to limit per- and polyfluoroalkyl substances (PFAS) migration through the drinking water aquifers. Selection of a remedial alternative that does not provide plume control would likely result in continued migration of the PFAS plume through the drinking water aquifers. As a result, currently unaffected communities would likely be affected in the future as PFAS impacts continue to migrate through the subsurface. And treatment for PFAS in additional communities would likely be required in the future.

The alternatives presented in this Feasibility Study (FS) focus primarily on where treatment would occur as opposed to individual treatment trains (e.g., source zone treatment only or source zone + diffuse plume control). Currently, PFAS treatment of drinking water generally relies on single-use granular activated carbon (GAC) both at municipal facilities and in point of entry treatment systems (POETSS) for private wells. Less widely used drinking water treatment technologies that are considered for use in remedial alternatives include ion exchange (IX) resin and nanofiltration (NF) or reverse osmosis (RO) membranes; these technologies are discussed in **Appendix K** as part of the Multi-Benefit Well Array (MBWA). IX and NF/RO membranes are also considered for pump and treat systems that would not supply drinking water, as are foam fractionation and regenerable IX resin. These technologies are discussed in **Appendix J** as they relate to pump and treat systems.

Remedial technologies that address human-health impacts from sediment and surface water matrices are considered in detail in associated appendices. **Appendix G** discusses destruction technologies that were tested using Site-specific PFAS concentrate and the applicability of these technologies to Site-specific waste streams. Potential sediment remedial actions are discussed in **Appendix L**, and permeable adsorptive barriers (PABs) that may address particular surface waters are discussed in **Appendix M**. As a result, specific treatment trains are not discussed in detail in the following alternatives.

Though not detailed in this FS, a major consideration for community acceptance of remedial alternatives will be maintenance of safe groundwater elevations. To protect private wells, surface water bodies, and municipal supply wells, groundwater levels must be maintained at sustainable levels as defined by the Minnesota Department of Natural Resources (MDNR). Extraction and injection rates must not negatively impact the groundwater elevations throughout the Site. Groundwater withdrawal within 5 miles of White Bear Lake is also complicated by court rulings that limit new groundwater appropriations permits in that area.

As stated previously, this FS does not provide specific remedial alternatives to address groundwater or surface water impacts within the property boundaries at ODS. Remedial action at ODS is outside of the scope of this FS, as it is owned by the 3M Company (3M) and is managed through the Superfund Program. 3M is under legal obligation from the 2007 Consent Order to prevent the release of PFAS from ODS, including release via surface water discharge and groundwater migration (MPCA, 2007). As PFAS-impacted surface water and likely groundwater continue to migrate from this source area, additional source area control would make a Site wide approach to the reduction of PFAS mass and migration in the drinking water aquifers more effective. Removal of PFAS at the source is more efficient as there is

more contaminant removal per unit of water or soil/sediment treated. PFAS removed at the source is also then not migrating offsite for less efficient downgradient treatment. Decrease in the migration of PFAS (mass flux) from the ODS source area, via groundwater and surface water, is a crucial component in reducing the mass of PFAS within drinking water aquifers as all areas of concern (AOCs) except AOC 1 (WCL – surface water and shallow groundwater) receive PFAS mass from ODS. Remedial actions have historically been taken to reduce the impacts of volatile organic compounds (VOCs) and PFAS in shallow soils and the uppermost groundwater units at ODS; however, these reductions were not successful in achieving control of PFAS spread via surface water and groundwater pathways. Additionally, areas beyond the boundary of ODS may also require treatment by 3M but this will be determined through the Superfund program.

In Alternative 1, treatment would continue with the groundwater pump out system as currently implemented. For Alternatives 2–8, this FS assumes additional treatment at ODS would occur to address source area impacts. This includes the reroute of Raleigh Creek around ODS. The planned reroute of Raleigh Creek around ODS would reduce the volume of water entering and, therefore, leaving ODS. This reroute is expected to reduce the PFAS mass that migrates from ODS to Raleigh Creek and was incorporated into the analysis of the impact of these efforts in Alternatives 2–8. However, PFAS-containing surface water is still expected to be discharged from ODS during periods of heavy rainfall and snow melt. Additional remedial action may be required to address this discharge of PFAS-impacted surface water. As a result of these continued PFAS migration pathways, the re-route is not expected to meet the Site-Specific Water Quality Criteria (SSC) discussed in **Section 9** and additional remedial actions may be required. A pump and treat system is currently operating at ODS to control groundwater flow and limit the migration of PFAS-impacted groundwater offsite. The effectiveness of this system was not evaluated as part of this FS. If future monitoring shows this system is not adequate in limiting offsite migration, then additional remedial efforts should be implemented at ODS. 3M is expected to conduct monitoring efforts at ODS, including the continued migration of impacts offsite, for both groundwater and surface water to determine the effectiveness of the remedial actions. If offsite migration is confirmed, this FS assumes that additional groundwater control and/or other actions such as source mass in soil would be conducted to reduce the downgradient migration of PFAS impacts. As the focus of this FS is on drinking water aquifers, additional actions may also be required by 3M to address additional impacts, including those offsite, to comply with state and federal regulations. As WCL is managed through MPCA's Closed-Landfill Program, specific remedial actions are included in this FS to address the impacts at this source area.

Oakdale municipal supply wells, which extract groundwater downgradient of ODS, aid in plume control in the drinking water aquifers near ODS. Municipal well extraction aids in reducing mass flux downgradient of the Oakdale municipal wells. With additional supply wells planned under the CDWSP, mass flux will likely be further reduced through AOC 4 (Downgradient ODS Groundwater) as total pumping rates would increase. Additionally, once the Raleigh Creek reroute is completed, surface water PFAS concentrations within AOC 5 (Raleigh Creek – Surface Water) and other downgradient surface water AOCs are expected to decrease over time, with the possible exception of Lake Elmo, whose impacts are likely a combination of groundwater migration from WCL and groundwater migration of impacts that have infiltrated from surface water impacted by PFAS from ODS.

All the proposed alternatives except Alternative 1 include long-term monitoring, which involves the installation of a monitoring well network. The monitoring well network would be similar for Alternatives 2 through 8, as monitoring should be performed even in AOCs without active remediation. Continued monitoring will facilitate assessment of the plume migration throughout the Site based on upgradient changes. Monitoring would also be used to justify changes to the selected remedial alternative and implemented design.

While the focus of this FS is drinking water resources, previous actions have been taken to protect human health through other exposure routes. These include:

- WCL reconstruction (2009–2012)
- Fish consumption advisories on surface water bodies within the Project 1007 conveyance system
- Warnings to residents to avoid touching foam around the Site to prevent dermal exposure and incidental ingestion of PFAS
- Notification of Anna’s Grove Wetland Complex (AGWC) residents to avoid entering the wetlands or handling sediment to avoid PFAS exposure

Other receptor pathways, including ecological receptors, were not considered in determining the optimal alternative recommended in this report. This FS was completed in accordance with Priority 1 of the 2018 Settlement between the State of Minnesota and 3M (Minnesota v. 3M, 2018) (the Settlement), which is to provide safe and sustainable drinking water resources for current and future generations in the PFAS-impacted communities. This may not address all relevant requirements to comply with Minnesota Environmental Responsibility and Liability Act (MERLA). Additional work, outside the scope of this FS, may be necessary to comply with these regulations.

12.1 Alternative 1

Alternative 1 is the no further action (NFA) alternative, which is required to be included per the NCP. Traditionally, NFA means no further remedial actions would be taken, and any ongoing remedial actions, including groundwater monitoring, would be stopped. NFAs for surface water and sediment would mean discontinuing surface water and sediment sampling and no additional surface water or sediment remedial actions would occur within the Site. While on-going groundwater monitoring for Project 1007 outside of ODS would be stopped in this alternative, current treatment of groundwater pumped by municipal supply wells, treatment of private wells and the required sampling for these systems, and the ODS groundwater pump and treat system with the required sampling would continue. Drinking water supplies would rely on the plan detailed in the CDWSP, which lays out a treatment plan for both municipal facilities and private wells (MPCA, 2021). Current treatment at ODS would continue but would not be expanded to address current offsite migration. **Figure 12.1** summarizes the concerns addressed by Alternative 1.

The CDWSP was published prior to the recent changes to several PFAS limits in drinking water, specifically the Environmental Protection Agency’s (EPA’s) Maximum Contaminant Levels (MCLs) and the Minnesota Department of Health’s (MDH’s) Health Based Values (HBVs) and Health Risk Limits (HRLs). The HBVs and HRLs for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) are currently lower than what was considered in the CDWSP. These updated standards will likely result in more private and municipal supply wells requiring treatment and different treatment methods (e.g., IX instead of GAC) may be more economical to achieve the new drinking water standards. Potential future decreases of PFAS drinking water standards may further impact the treatment and associated costs. For example, perfluorobutanoic acid (PFBA) may pose future challenges. The current acceptable drinking water concentrations for PFBA are high compared to PFOA and PFOS. If these standards were to be lowered, not only would additional wells require treatment, but that treatment might be significantly more expensive because PFBA is more mobile through the subsurface than other longer-chain PFAS species, and it is difficult to remove with traditional treatment methods.

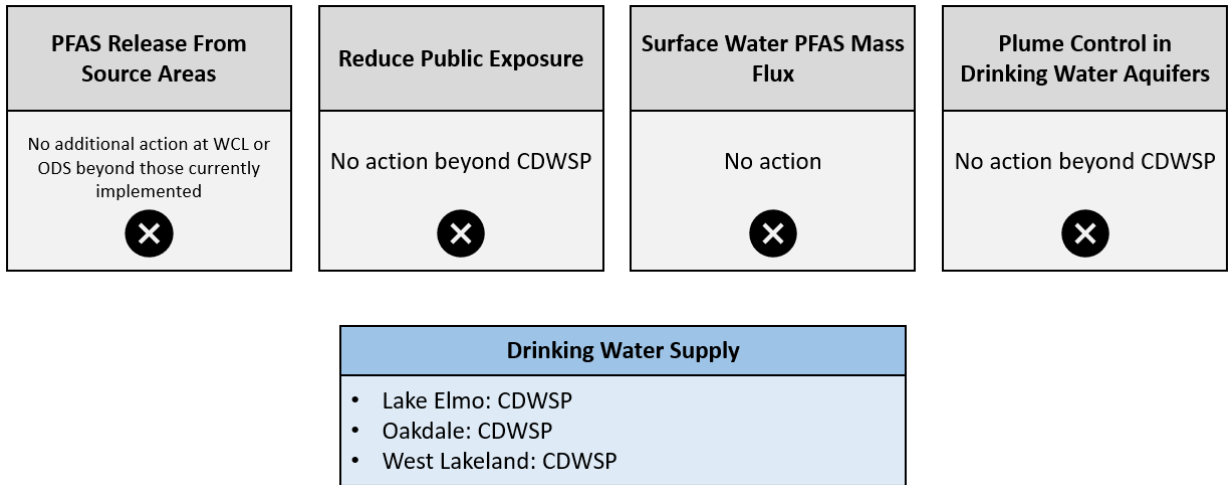


Figure 12.1: Alternative 1 impact

Figure 12.2 illustrates the impact of Alternative 1 using groundwater particle tracking. While the current Oakdale municipal supply wells largely capture the groundwater plume that spreads from ODS, which decreases migration of PFAS towards Woodbury’s municipal supply wells, continued migration from other plume areas would create risk for the drinking water supply of other communities in the East Metro. The PFAS impacts in the southwest direction from the ODS area, including and to the south and west of the 3M headquarters property in Maplewood, toward the Battle Creek area and to the Mississippi River are not currently delineated. This delineation, when complete, will aid in understanding the comprehensive geographic span of impacts originating from the ODS area.

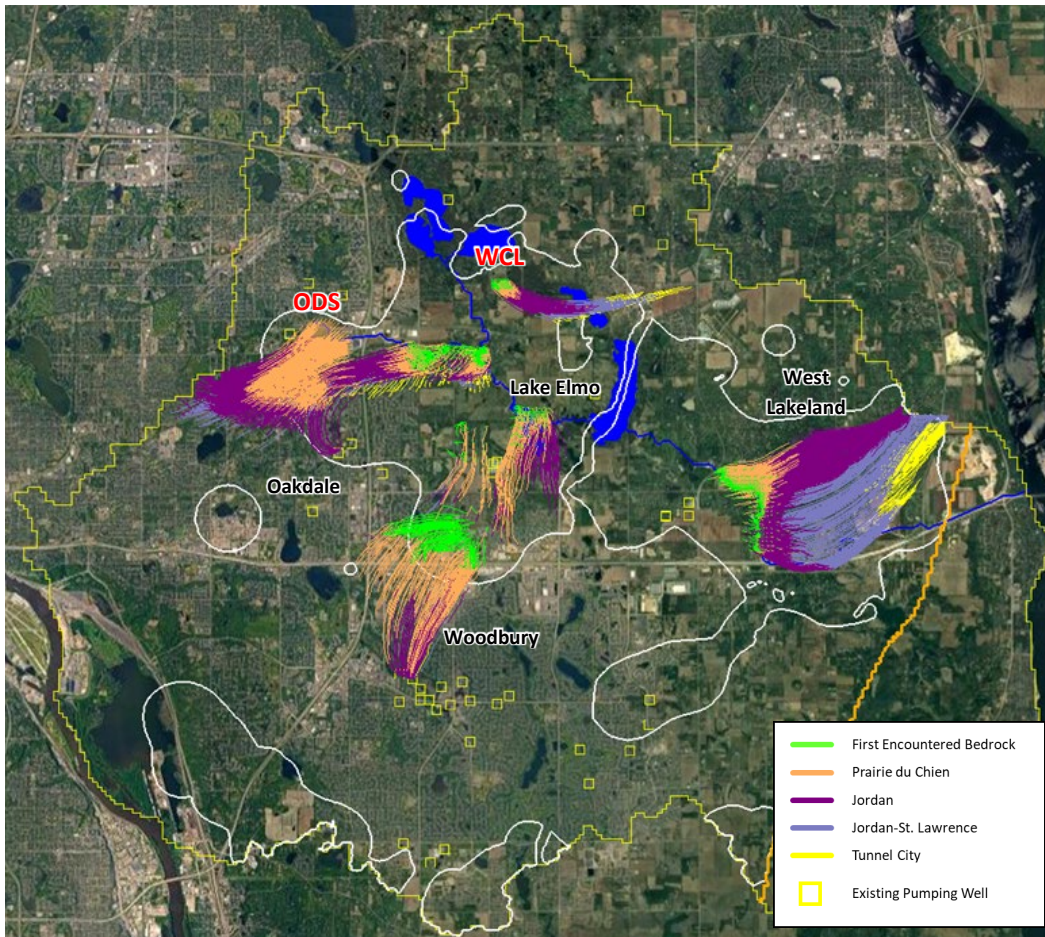


Figure 12.2: Particle tracking results for Alternative 1 with particles released from the first encountered bedrock with a 50-year travel time with municipal drinking water supplying continuing to be drawn from groundwater aquifers at the current rates. Particles are released from source areas and water bodies where PFAS-impacted surface water infiltrates to groundwater.

As a result of the White Bear Lake Court Order, the cities of Oakdale and Lake Elmo are considering switching to surface water for the municipal supply provided by the Saint Paul Regional Water Services. Under these conditions, the current extent of plume capture that is achieved by municipal supply wells would no longer occur.

12.1.1 Overall Protection of Human Health and the Environment

Overall, Alternative 1 has low protection of human health and of the environment. The ability of this alternative to protect human health and mitigate potential risks is scored on a qualitative scale from low to high and is summarized as follows:

- Protection of communities with known PFAS impacts: Moderate. Although risk is mitigated with POETS or treatment of municipal water, the lack of source zone control in this alternative would allow continued mass flux of PFAS into the drinking water aquifers. Continued mass loading of PFAS, particularly PFBA, which is more mobile and harder to treat than PFOA or PFOS, may pose a future risk to communities as drinking water standards evolve.
- Protection of communities downgradient of current plume extent: Low. The groundwater plumes would continue to migrate, spreading impacts to currently unaffected communities. Additionally, PFOA HBVs are below current analytical detection limits. Consequently, residents downgradient of the plume with well results below detection limits may still be consuming PFAS at unsafe levels.

- Protection against incidental exposure: Low. The potential for exposure to contaminated sediment and foam would remain. No remedial actions would be taken to decrease PFAS concentrations in surface water or sediment or to protect human health. Reduction of exposure risk would rely on residents heeding previous notifications to minimize their potential exposure during outdoor recreational activities and making lifestyle changes to minimize other exposure routes.

12.1.2 Ability to Achieve RAOs

Alternative 1 would not achieve the majority of the Remedial Action Objectives (RAOs), as summarized in **Table 5 (Appendix B)**, because protection of the drinking water aquifers would not occur. With no remedial actions implemented, mass flux from the WCL source zone would continue unmitigated and the PFAS impacts from ODS would also continue to migrate from surface water and likely groundwater. While the pump and treat system at ODS would continue, this is likely not sufficient and downgradient migration of PFAS impacts already in the groundwater resulting from this source area and other points of infiltration, including Eagle Point Lake and West Lakeland storage ponds, as detailed in **Figure 12.2**, would continue, resulting in impacts migrating into unimpacted areas. This would likely result in more private homes requiring POETs and additional communities requiring treatment of their municipal supply. This alternative is therefore scored as low for its ability to achieve the RAOs.

12.1.3 Long-Term Effectiveness and Permanence

Alternative 1 is scored overall as low for long-term effectiveness as PFAS is expected to continue to migrate downgradient and the drinking water aquifers would not be protected. **Table 6 (Appendix B)** provides additional rationale for the scoring.

12.1.4 Reduction of Toxicity, Mobility, or Volume through Treatments

Alternative 1 is scored as low for the reduction of toxicity, mobility, and volume as no PFAS would be removed from the Site beyond the existing drinking water treatment. In this FS, reduction in volume is based on mass reduction in the drinking water aquifers and reduction of the expansion of the plume. Treatment methods employed by this alternative are single-use GAC treatment at municipal treatment plants and GAC POETs based on the recommendations in the CDWSP. **Table 7 (Appendix B)** provides additional rationale for the scoring.

12.1.5 Short-Term Effectiveness

Alternative 1 is scored as low to moderate for short-term effectiveness. **Table 8 (Appendix B)** summarizes short-term effectiveness scoring and rationale for Alternative 1. The time until protection is achieved was more heavily weighted than other short-term effectiveness criteria when determining the overall score. Other short-term effectiveness criteria (ability to mitigate risks to community during implementation and ability to mitigate potential impacts on workers) can be managed with standard best practices and pose minimal risks to workers and the public. Additionally, while important to consider, potential environmental impacts of remedial action were weighed less heavily than time until protection is achieved because the main priority of this FS is to provide safe and sustainable drinking water resources for current and future generations in the PFAS-impacted communities. Environmental impacts of remedial action are important to consider, but protection of human health through exposure to PFAS-impacted drinking water must be prioritized. As a result, time until protection is achieved, which considers drinking water risk, is more heavily weighted than other criteria.

12.1.6 Implementability

Alternative 1 is scored as moderate to high for implementability as there are technical and administrative concerns for implementing the plans outlined in the CDWSP. The plan laid out in the

CDWSP would be followed to provide drinking water to residents, but as discussed previously, the reductions in HBVs and HRLs and continued migration of the plume will likely increase the number of public and private well treatment needs, increasing the challenge of implementability in the future. **Table 9** summarizes specific implementability considerations as well as scoring and rationale for Alternative 1.

12.1.7 Cost

Table 10 and **Table 11 (Appendix B)** summarize the costs for Alternative 1. Costs are expected to be moderate to high. Costs include both capital expenditures (CAPEX) (**Table 10**) and operating expenditures (OPEX) (**Table 11**). While a traditional NFA alternative would not have any costs associated with it as no remedial actions would be taken, safe drinking water must still be provided to all residents, regardless of whether or not additional remedial action is taken. Some of the alternatives discussed in this FS would provide safe drinking water to residents as a result of the remedial efforts, while others, including Alternative 1, would not directly provide safe drinking water to residents. To provide a more accurate comparison of overall project costs, the cost for communities to provide safe drinking water to residents is included for alternatives that do not otherwise provide safe drinking water as part of remedial action. These drinking water costs are derived from the CDWSP. As no plume control would be implemented, additional homes and communities are expected to require treatment in the coming years. An initial cost estimate was conducted as part of the CDWSP; however, this evaluation likely underestimates the plume migration as it was completed prior to the completion of the Project 1007 investigation activities and prior to the release of the 2024 MDH HBVs and HRLs and EPA MCLs.

Expected drinking water costs include costs from the CDWSP (MPCA, 2021) to meet the 2040 drinking water demand, POETSs costs, and expected costs for the cities of Lake Elmo and Oakdale based on Settlement grant applications. Costs from the CDWSP were adjusted for inflation. POETSs costs are based on state contract pricing for POETS installation. Costs associated with upgrades to the cities of Oakdale and Lake Elmo drinking water infrastructure were based on information provided by the MPCA and a memo prepared for the City of Lake Elmo (Focus Engineering, 2024). Although the CDWSP did include an estimate of the number of additional POETSs that would be required as plume migration continues, the number of additional POETSs and their associated costs are likely an underestimate. Additional municipal supply wells may require treatment beyond those covered in the CDWSP as well. Given the uncertainty in future drinking water treatment requirements, costs are assumed to be moderate to high. The actual costs would depend on plume migration and the number of communities requiring additional treatment. Thus, while a range of costs are included in this report to account for the uncertainty of future treatment costs, the costs are still likely an underestimate of actual costs associated with future drinking water treatment. Costs associated with the continued operation of the ODS pump and treat system are not included.

12.2 Alternative 2

Alternative 2 includes source zone treatment at WCL and additional treatment ODS including the Raleigh Creek reroute, long-term monitoring, and access restrictions to sediment and surface water AOCs. Like Alternative 1, continued treatment of drinking water would occur as described in the CDWSP to provide safe drinking water to affected communities. Additionally, as with all other alternatives, additional remediation action by 3M at ODS to reduce PFAS migration from ODS is assumed, as dictated by the 2007 Consent Order. **Figure 12.3** summarizes the concerns addressed by Alternative 2.

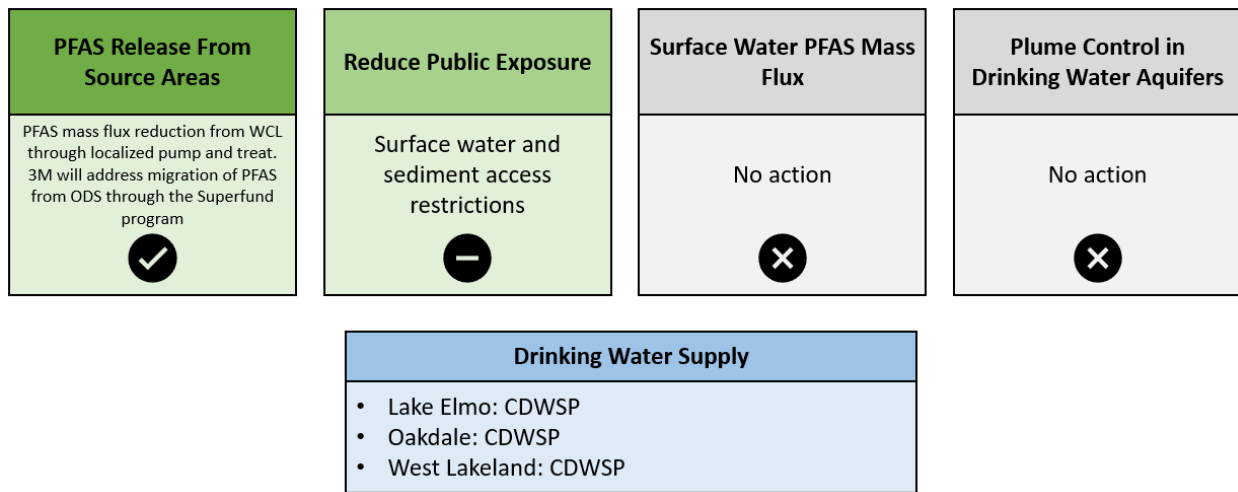


Figure 12.3: Alternative 2 impact

Figure 12.4 illustrates the particle tracking results for Alternative 2. The pump and treat system at WCL would reduce source zone migration into the bedrock aquifers and subsequent downgradient migration. Similarly, additional treatment at ODS would also reduce PFAS migration from this source area. The extent to which 3M will be required to address PFAS impacts that have migrated offsite will also be determined through the Superfund program. If additional hydraulic control is implemented in areas with high PFAS concentration immediately downgradient of ODS, this Alternative will have increased effectiveness. The current Oakdale municipal supply wells largely capture the groundwater plume that spreads within the drinking water aquifers from ODS, reducing migration south towards Woodbury and St. Paul; however, PFAS mass already present in the drinking water aquifers elsewhere within the Site would continue to migrate, risking the water supply of multiple other communities in the East Metro. While a conceptual design of a pump and treat system was prepared for this FS (**Appendix J**), additional geological study around WCL is needed, due to the highly fractured subsurface, to improve modeling prior to implementation of a pump and treat system.

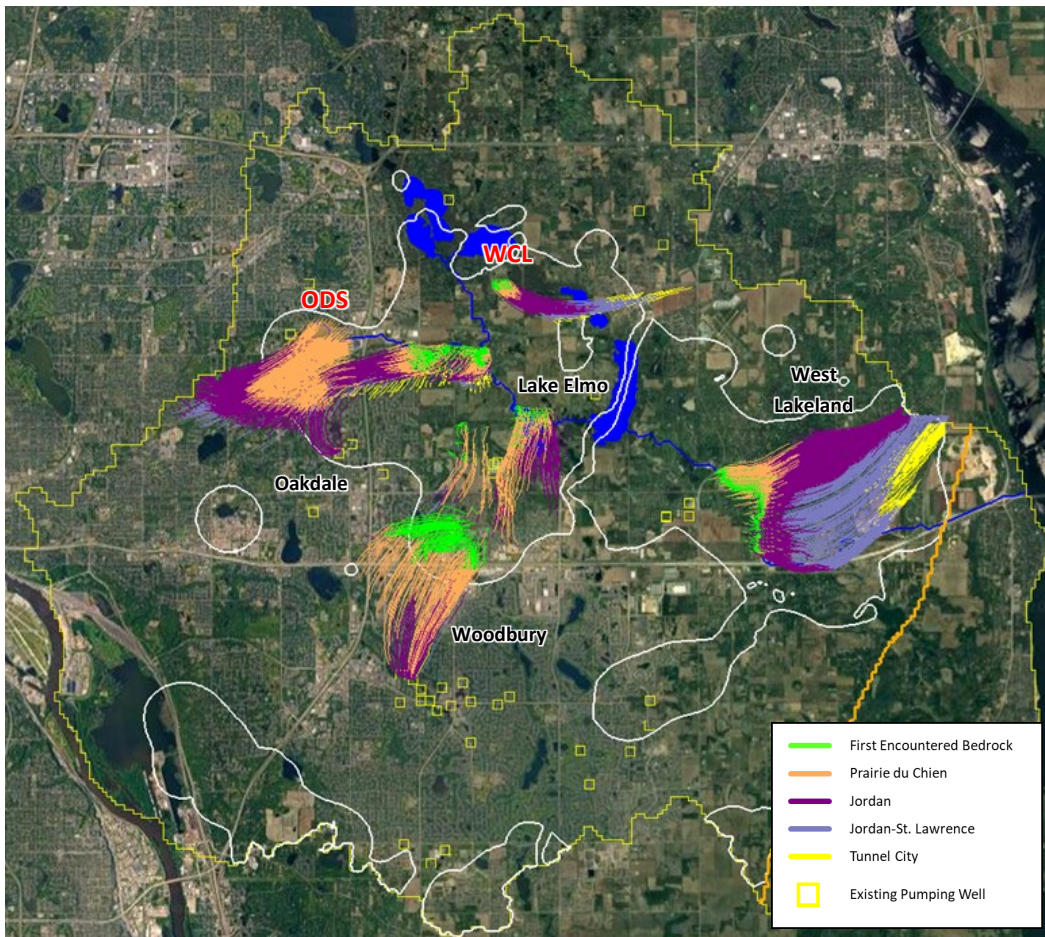


Figure 12.4: Particle tracking for Alternative 2 with particles released from the first encountered bedrock with a 50-year travel time. Particles are released from source areas and water bodies where PFAS-impacted surface water infiltrates to groundwater.

12.2.1 Overall Protection of Human Health and the Environment

Sitewide, Alternative 2 has low-to-moderate protection of human health and of the environment. The ability of this alternative to protect human health and mitigate potential risks is summarized as follows:

- Protection of communities with known PFAS impacts: Moderate to high. Risk would be mitigated with POETSs or treatment of municipal water, and WCL source zone control (in addition to assumed improved ODS source zone control) would decrease mass flux of PFAS into the drinking water aquifers.
- Protection of communities downgradient of current plume extent: Low. The groundwater plume would continue to migrate even with WCL and additional ODS source zone control, spreading impacts to currently unaffected communities. Treatment at the source zones would decrease the mass flux of PFAS to these downgradient communities. Also, the PFOA HBV is below current analytical detection limits. Consequently, residents downgradient of the plume with well results below detection limits may still be consuming PFAS at unsafe levels.
- Protection against incidental exposure: Moderate. The potential for exposure to contaminated sediment and foam would remain. The implementation of access controls and signage around surface water and sediment would decrease exposure risk for humans but would not decrease PFAS concentrations within these AOCs.

12.2.2 Ability to Achieve RAOs

Alternative 2 would achieve a limited number of RAOs, as summarized in **Table 5 (Appendix B)**, but overall would not result in protection of drinking water aquifers. Source zone mass flux from WCL and ODS would decrease, but downgradient migration of the existing PFAS plume, as illustrated in **Figure 12.4**, would continue. This may result in PFAS impacts from the diffuse WCL and ODS plumes and co-mingled diffuse plumes migrating into areas that are currently unimpacted. This alternative is therefore scored as low to moderate for its ability to achieve the RAOs.

12.2.3 Long-Term Effectiveness and Permanence

Alternative 2 is scored as low to moderate for long-term effectiveness. While an important component of long-term effectiveness, PFAS removal targeted only at the source areas would have limited long-term effectiveness as the mass of PFAS already within the bedrock aquifers would continue to migrate downgradient. **Table 6 (Appendix B)** provides additional rationale for the scoring.

12.2.4 Reduction of Toxicity, Mobility, or Volume through Treatments

Alternative 2 is scored as low to moderate for the reduction of toxicity, mobility, and volume. **Table 7 (Appendix B)** provides additional rationale for the scoring.

12.2.5 Short-Term Effectiveness

Alternative 2 is scored as moderate for short-term effectiveness. Specific considerations are listed in **Table 8 (Appendix B)**. The time until protection is achieved was more heavily weighted than other short-term effectiveness criteria when determining the overall score. Other short-term effectiveness criteria (ability to mitigate risks to community during implementation and ability to mitigate potential impacts on workers) can be managed with standard best practices and pose minimal risks to workers and the public. Additionally, while important to consider, potential environmental impacts of remedial action were weighted less heavily than time until protection is achieved because the main priority of this FS is to provide safe and sustainable drinking water resources for current and future generations in the PFAS-impacted communities. Environmental impacts of remedial action are important to consider, but protection of human health through exposure to PFAS-impacted drinking water must be prioritized. As a result, time until protection is achieved, which considers drinking water risk, is more heavily weighted than other criteria.

12.2.6 Implementability

Alternative 2 is scored as moderate to high for implementability. The implementation of access restrictions/signage and continuation of long-term monitoring is straightforward and would not require significant financial investment. The plan laid out in the CDWSP would be followed to provide drinking water to residents, but as discussed previously, the reductions in HBVs and HRLs and continued migration of the plume will likely increase the number of public and private well treatment needs, increasing the challenge of implementability in the future. **Table 9 (Appendix B)** provides additional rationale for the scoring.

12.2.7 Cost

Table 10 and **Table 11 (Appendix B)** summarize the CAPEX and OPEX cost estimates, respectively, for Alternative 2. Costs are expected to be moderate to high. As previously discussed, high uncertainty exists for costs associated with the CDWSP, as they were developed prior to MDH's release of updated HBVs and HRLs. To account for this uncertainty, a range of costs are presented for drinking water treatment.

In the long term, the installation of source zone remediation at WCL would likely help to decrease drinking water treatment costs by decreasing the diffuse PFAS impacts, but source zone treatment would not decrease costs for treatment of communities at the edge of plumes as PFAS in the plumes continue to migrate towards currently unaffected drinking water wells and communities. Given the potential plume migration in the future and the future need for new treatment systems in currently unaffected communities, costs are expected to be moderate to high. This continued migration of PFAS would also likely result in increased sampling and treatment system costs, increasing total costs for the future. However, estimates for these potential increased future costs are not included in this FS given the high uncertainty in potential costs from continued plume migration if plume control is not implemented.

Cost ranges are provided for the WCL treatment, as costs would depend on the remedial technology selected. Costs estimated for this FS are expected to be accurate to -50% to +100%, commensurate with a Class V estimate. More detailed information can be found in **Appendix J**. High and low-cost ranges are summarized in **Table 10** and **Table 11**; the lowest and highest cost treatment trains are included to provide the complete range of probable costs. The treatment train with the highest CAPEX cost is not necessarily the treatment train with the highest OPEX cost, as some treatment options are high CAPEX/low OPEX or low CAPEX/high OPEX. Costs are not included for treatment at ODS.

12.3 Alternative 3

Alternative 3 would focus on source zone treatment of the shallow groundwater at WCL and groundwater and surface water impacts at ODS, access restrictions to sediment AOCs, interim treatment of surface water with PABs, and continued long-term monitoring. Like Alternative 1, continued treatment of drinking water for affected communities would occur as outlined in the CDWSP (MPCA, 2021). Additionally, as with all Alternative 2, additional remediation action by 3M at ODS, which would reduce PFAS migration from ODS as dictated by the Consent Order. The intent would be to discontinue the treatment with PABs after Raleigh Creek surface water concentrations are reduced and sediment leaching no longer results in increased surface water concentrations downgradient of areas with impacted sediment. Additional work may be required to address ecological impacts from contaminated surface water and sediment; however, only human impacts are addressed with this FS. **Figure 12.5** summarizes the concerns addressed by Alternative 3.

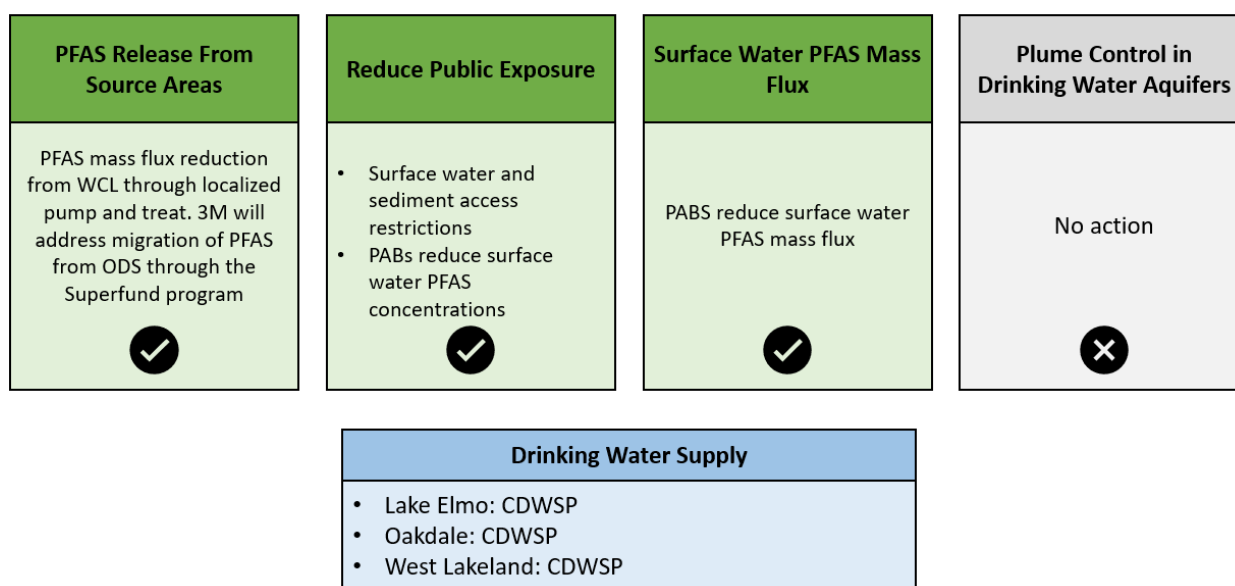


Figure 12.5: Alternative 3 impact

Figure 12.6 illustrates the particle tracking results for Alternative 3. The proposed pump and treat system at WCL and ODS remedial actions would serve to reduce source zone migration and the mass flux of PFAS into the drinking water aquifers. Although a conceptual design of a pump and treat system at WCL was prepared, additional geological study around WCL is needed to improve modeling prior to implementation of a pump and treat system. PABs, while expected to reduce exposure risks to sediment and surface water, would only minimally affect groundwater plumes by potentially reducing PFAS mass that migrates into the drinking water aquifers via infiltration from locations such as along Raleigh Creek, Eagle Point Lake, and the West Lakeland ponds. The PABs may improve conditions at the surface but would have a smaller impact on the drinking water aquifer units.

Within the drinking water aquifers, the current Oakdale municipal supply wells largely capture the groundwater plume that spreads within the drinking water aquifers from ODS, reducing migration south towards Woodbury and St. Paul; however, PFAS mass already present in the drinking water aquifers elsewhere within the Site would continue to migrate, risking the water supply of multiple other communities in the East Metro. The plume is not completely delineated to the southwest of ODS and the extent of migration in this area is not well understood.

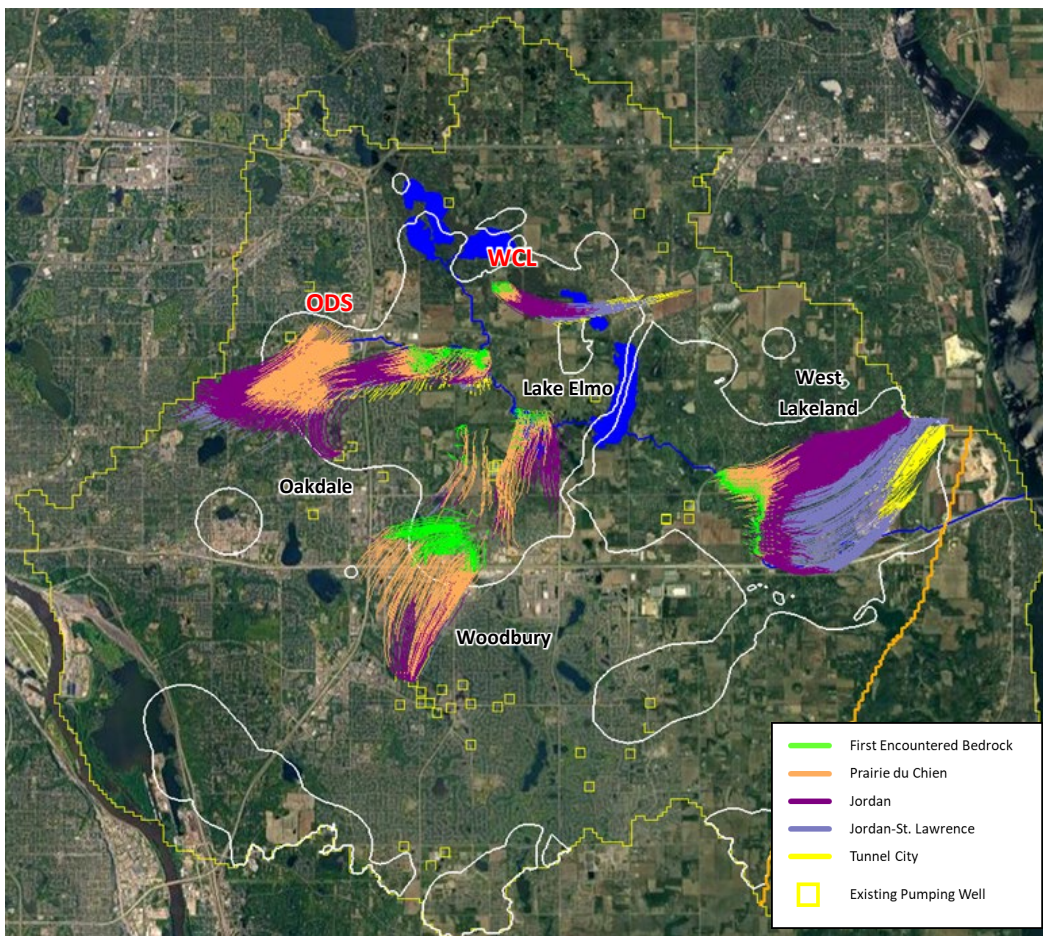


Figure 12.6: Particle tracking for Alternative 3 with particles released from the first encountered bedrock with a 50-year travel time. Particles are released from source areas and water bodies where PFAS-impacted surface water infiltrates to groundwater.

12.3.1 Overall Protection of Human Health and the Environment

Sitewide, Alternative 3 provides low-to-moderate protection of human health and of the environment but is not protective of the drinking water aquifers. The ability of this alternative to protect human health and mitigate potential risks is summarized as follows:

- Protection of communities with known PFAS impacts: Moderate to high. Risk would be mitigated with POETSS or treatment of municipal water, and source zone control and PABs would decrease mass flux of PFAS into the drinking water aquifers.
- Protection of communities downgradient of current plume extent: Low to moderate. Source zone control and PABs would decrease mass flux of PFAS from surface water to drinking water aquifers, but the groundwater plume would continue to migrate, spreading impacts to currently unaffected communities. Additionally, the PFOA HBV is below current analytical detection limits. Consequently, residents downgradient of the plume with well results below detection limits may still be consuming PFAS at unsafe levels.
- Protection against incidental exposure: Moderate. Access restrictions and signage would decrease the potential exposure risk to contaminated sediment and foam, and PABs would decrease PFAS concentrations in surface water AOCs.

12.3.2 Ability to Achieve RAOs

Alternative 3 would achieve some of the RAOs as summarized in **Table 5 (Appendix B)** but overall would not result in protection of the drinking water aquifers. Source zone mass flux would decrease, but downgradient migration of PFAS in the existing plume, depicted in **Figure 12.6**, would continue, resulting in the impacts migrating into areas that are currently unimpacted. This alternative is therefore scored as low to moderate for its ability to achieve the RAOs.

12.3.3 Long-Term Effectiveness and Permanence

Alternative 3 is scored as low to moderate for long-term effectiveness. Alternative 3 would result in permanent removal of PFAS from groundwater at and immediately downgradient of WCL and from surface water, which would reduce the mass flux of PFAS into the drinking water aquifers. The current pump and treat system at ODS does remove PFAS from the environment and additional remedial measures at ODS may also result in the permanent removal of a larger PFAS mass, depending on what is implemented. The Raleigh Creek reroute does not remove PFAS mass from the environment. However, significant PFAS mass is already present within the drinking water aquifers and would continue to migrate downgradient into currently unimpacted areas. These efforts, therefore, would have limited long-term effectiveness as PFAS is expected to continue to migrate downgradient and the drinking water aquifers would not be protected. **Table 6 (Appendix B)** provides additional rationale for the scoring.

12.3.4 Reduction of Toxicity, Mobility, or Volume through Treatments

Alternative 3 is scored as low to moderate for the reduction of toxicity, mobility, and volume. As described with Alternative 2, source zone treatment would reduce mass flux of PFAS into and then through the drinking water aquifers. The PABs would further reduce the mass flux into the drinking water aquifers; however, the PFAS mass outside of the source areas and from select surface water bodies would not be addressed. **Table 7 (Appendix B)** provides additional rationale for the scoring.

12.3.5 Short-Term Effectiveness

Short-term effectiveness for Alternative 3 is scored as moderate with the specific rationale provided in **Table 8 (Appendix B)**. The time until protection is achieved was more heavily weighted than other short-term effectiveness criteria when determining the overall score. Other short-term effectiveness criteria (ability to mitigate risks to community during implementation and ability to mitigate potential impacts on workers) can be managed with standard best practices and pose minimal risks to workers and the public. Additionally, while important to consider, potential environmental impacts of remedial action were weighted less heavily than time until protection is achieved because the main priority of this FS is to provide safe and sustainable drinking water resources for current and future generations in the PFAS-

impacted communities. Environmental impacts of remedial action are important to consider, but protection of human health through exposure to PFAS-impacted drinking water must be prioritized. As a result, time until protection is achieved, which considers drinking water risk, is more heavily weighted than other criteria.

12.3.6 Implementability

Alternative 3 is scored as moderate to high for implementability. Implementation of access restrictions and signage, and continuation of long-term monitoring is straightforward and would not require significant financial investment. Although using PABs for in-situ surface water treatment is an emerging use of the technology, challenges related to the technical feasibility could be overcome. The plan laid out in the CDWSP would be followed to provide drinking water to residents, but as discussed previously, the reductions in HBVs and HRLs and continued migration of the plume will likely increase public and private well treatment needs, increasing the challenge of implementability in the future. **Table 9 (Appendix B)** provides additional rationale for the scoring.

12.3.7 Cost

Table 10 and **Table 11 (Appendix B)** summarize the CAPEX and OPEX costs, respectively, for Alternative 3. Costs are expected to be moderate to high. Costs estimated for this FS are expected to be accurate to -50% to +100%, commensurate with a Class V estimate. Additional details on AOC 1 pump and treat costs can be found in **Appendix J** and additional details on PAB costs can be found in **Appendix M**. As previously discussed, high uncertainty exists for costs associated with the CDWSP, as they were developed prior to MDH's release of updated HBVs and HRLs. To account for this uncertainty, a range of costs is presented for drinking water treatment.

In the long term, the installation of source zone remediation at WCL and ODS and the use of PABs would help to decrease drinking water treatment costs by decreasing the mass of PFAS in aquifers that must be treated. However, source zone treatment would not decrease costs for treatment of communities at the edge of the plume as PFAS in the plume would continue to migrate towards currently unaffected communities. This continued migration of PFAS would also likely result in increased sampling and treatment system costs, increasing total costs for the future. However, estimates for these potential increased future costs are not included in this FS given the high uncertainty in potential costs from continued plume migration if plume control is not implemented. The cost of remedial actions at ODS are not included in this FS.

12.4 Alternative 4

Alternative 4 would include all remedial actions taken in Alternative 3, including access restrictions, long-term monitoring, AOC 1 (WCL – Surface Water and Shallow Groundwater) pump and treat system, additional treatment at ODS, PABs at AOCs 5 and 9 as well as installation of pump and treat system(s) for the plumes in the bedrock aquifers in AOC 2 (WCL – Bedrock Aquifers), AOC 7 (Raleigh Creek + Eagle Point Lake – Groundwater), and AOC 10 (West Lakeland – Groundwater). Water pumped from extraction wells in AOCs 2, 7, and 10 would be treated to treatment targets as defined in **Section 9** of this FS and then re-injected to improve capture efficiency of extraction wells and reduce plume migration. **Figure 12.7** summarizes the concerns addressed by Alternative 4.

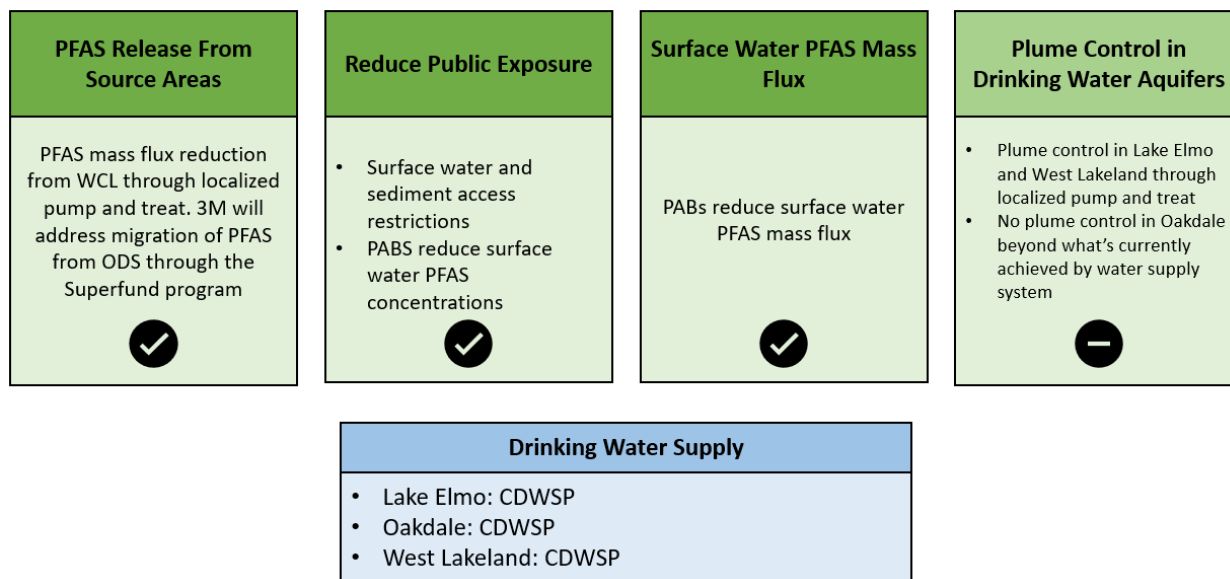


Figure 12.7: Alternative 4 impact

Figure 12.8 illustrates the particle tracking results for Alternative 4. The current Oakdale municipal supply wells largely capture the groundwater plume that spreads from ODS, reducing impacts to Woodbury’s water supply. A pump and treat system at WCL would reduce source zone migration. Installation of a pump and treat system for AOCs 2, 7, and 10 would also significantly reduce migration of the existing PFAS plumes, limiting the spread to other communities.

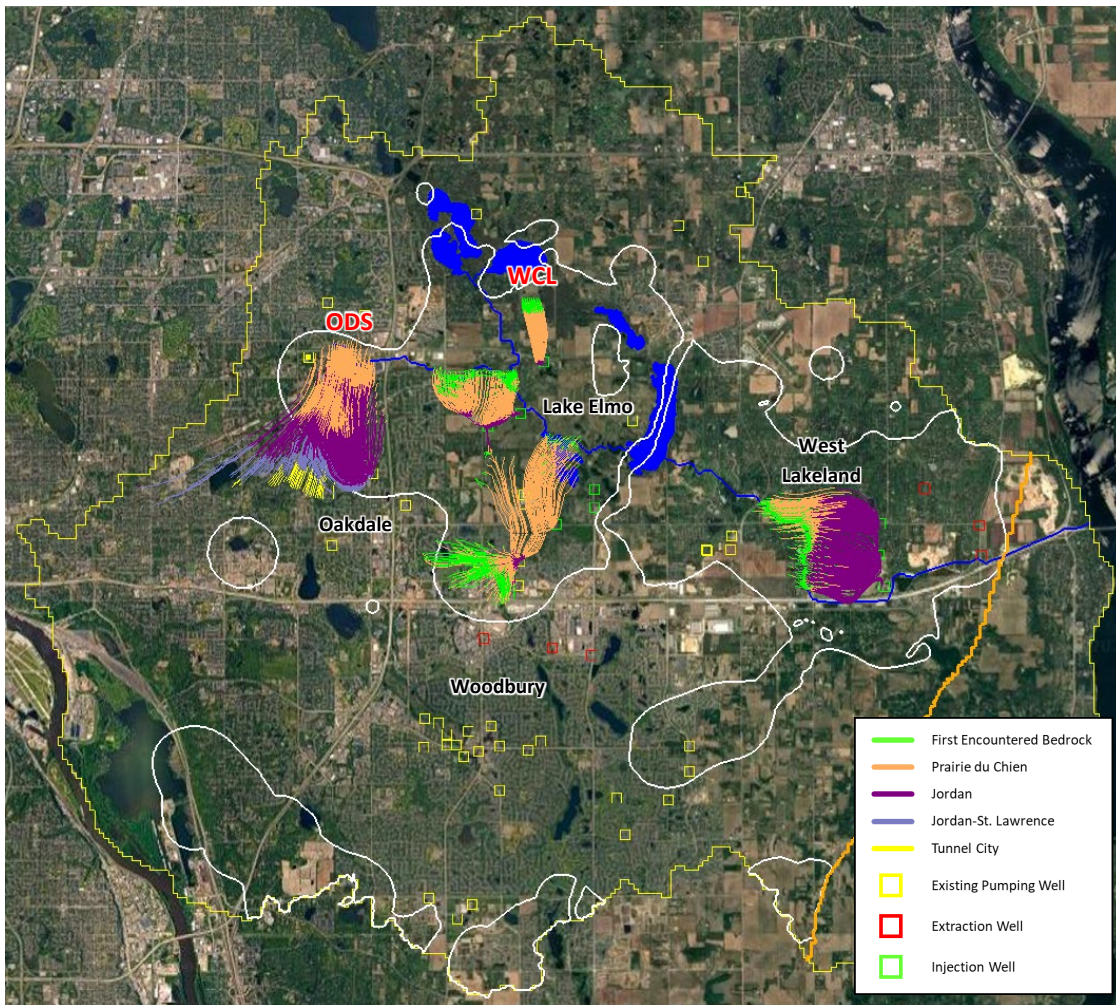


Figure 12.8: Particle tracking for Alternative 4 with particles released from the first encountered bedrock with a 50-year travel time. Particles are released from source areas and water bodies where PFAS-impacted surface water infiltrates to groundwater.

12.4.1 Overall Protection of Human Health and the Environment

Alternative 4 provides moderate-to-high protection of human health and of the environment as drinking water receptors within and downgradient of the current plume extent are protected. The ability of this alternative to protect human health and the potential risks are summarized as follows:

- Protection of communities with known PFAS impacts: Moderate to high. Risk would be mitigated with POETSS or treatment of municipal water, and source zone control would decrease mass flux of PFAS into the drinking water aquifers.
- Protection of communities downgradient of current plume extent: Moderate to high. Source zone control and PABs would decrease mass flux from shallow impacts into drinking water aquifers, and groundwater pump and treat systems would reduce the migration of the PFAS mass that is already within the drinking water aquifers to the east of the Site in the direction of the St. Croix River and towards areas that are currently unimpacted by PFAS.
- Protection against incidental exposure: Moderate to high. Access restrictions and signage would decrease the potential exposure risk to contaminated sediment and foam, and PABs would decrease PFAS concentrations in downstream surface water AOCs.

Although groundwater pump and treat systems would reduce the spread of the PFAS mass in drinking water aquifers to the east of the Site, the migration of PFAS would likely continue south to southwest of ODS into areas that are currently unimpacted. There are no municipal supply wells immediately in the area southwest of ODS. This PFAS migration could be altered with changes in pumping conditions elsewhere within the East Metro, such as changes to the Oakdale and Woodbury municipal supply pumping rates and locations. The extent of treatment at ODS by 3M, especially that outside of the ODS site property would impact this migration. Additionally, as detailed in **Section 5**, the drinking water aquifers would not likely be restored and able to be used for drinking water without treatment; however, total PFAS mass in the drinking water aquifers would be reduced over time through the pump and treat systems and drinking water treatment. With the reduction of PFAS mass from the source areas, surface water, and within the current plume extent, migration of PFAS downgradient into unimpacted areas south and southwest of ODS may eventually be controlled by municipal supply wells within the current plume extent and use of the proposed pump and treat system could potentially be discontinued. Five-year reviews would be utilized to assess data and determine how the pump and treat system could be optimized.

12.4.2 Ability to Achieve RAOs

The ability of Alternative 4 to address RAOs within each AOC is summarized in **Table 5 (Appendix B)**. Overall Alternative 4 is scored as moderate to high for its ability to achieve the RAOs.

12.4.3 Long-Term Effectiveness and Permanence

Alternative 4 is scored as moderate to high for long-term effectiveness. Alternative 4 would result in permanent removal of PFAS from groundwater downgradient of WCL and from surface water, which would reduce the mass flux of PFAS into the drinking water aquifers. The pump and treat systems would address the PFAS mass currently within the bedrock aquifers and reduce PFAS mass flux and the continued spread of the plume in most areas of the Site except for areas to the south and southwest of ODS. Depending on the treatment at ODS, additional PFAS may be removed from the environment; however, the Raleigh Creek reroute alone will not result in the removal of PFAS, just limit the migration through the surface water pathway. Based on the extent and volume of PFAS impacts within the Site, the expected treatment time is unknown. **Table 6 (Appendix B)** provides additional rationale for the scoring.

12.4.4 Reduction of Toxicity, Mobility, or Volume through Treatments

Alternative 4 is scored as moderate to high for the reduction of toxicity, mobility, and volume. As described with Alternative 3, treatment of source zones and surface water impacts would reduce mass flux of PFAS into and through the primary drinking water aquifers (Shakopee and Jordan Aquifers). With Alternative 4, the PFAS mass currently within the drinking water aquifers would be reduced through pumping and subsequent treatment. The evaluation of this alternative focuses on where groundwater extraction should occur to improve plume control, while the efficiency of the groundwater treatment trains once the groundwater extraction has occurred is addressed in **Appendix J. Table 7 (Appendix B)** provides additional rationale for the scoring.

12.4.5 Short-Term Effectiveness

Alternative 4 is scored as moderate to high for short-term effectiveness with the specific rationale provided in **Table 8 (Appendix B)**. The time until protection is achieved was more heavily weighted than other short-term effectiveness criteria when determining the overall score. Other short-term effectiveness criteria (ability to mitigate risks to community during implementation and ability to mitigate potential impacts on workers) can be managed with standard best practices and pose minimal risks to workers and the public. Additionally, while important to consider, potential environmental

impacts of remedial action were weighted less heavily than time until protection is achieved because the main priority of this FS is to provide safe and sustainable drinking water resources for current and future generations in the PFAS-impacted communities. Environmental impacts of remedial action are important to consider, but protection of human health through exposure to PFAS-impacted drinking water must be prioritized. As a result, time until protection is achieved, which considers drinking water risk, is more heavily weighted than other criteria.

12.4.6 Implementability

Alternative 4 is scored as moderate for implementability. The pump and treat systems for AOCs 2, 7, and 10 would re-inject treated water into the Jordan Aquifer. This injection of treated water would aid in plume capture and would result in a lower overall extraction rate being required. Injection would cause localized groundwater mounding to occur, which would reverse the groundwater gradient in an area, reducing the continued spread of the PFAS plume. Permitting for the groundwater treatment system would require coordination with multiple state and federal regulatory agencies including MDH who administers Minnesota Well Code for all wells installed within the state. Appropriation permitting is conducted by MDNR. Groundwater injection permitting would be conducted by the U.S. Environmental Protection Agency (EPA) Region V office for underground injection control (UIC) permitting and Safe Drinking Water Act (SDWA) compliance.

Additionally, injection studies are needed to ensure the modeled injection capacity is accurate and injection pumping rates will not result in fracturing. Geochemical studies are needed to ensure the injection of water will not result in the release of minerals that may impact downstream drinking water supply. The injection studies should be completed considering the water quality following a specific treatment train.

Implementation of access restrictions and signage, and continuation of long-term monitoring is straightforward and would not require significant financial investment. Although the use of PABs for in-situ surface water treatment is an emerging use of this technology, the challenges related to the technical feasibility could be overcome. The plan laid out in the CDWSP would be followed to provide drinking water to residents. As discussed previously, the reductions in HBVs and HRLs and continued migration of the plume would likely increase the number of public and private well treatment needs, but these needs would be mitigated with plume control from pump and treat plants. **Table 9 (Appendix B)** provides additional rationale for the scoring.

12.4.7 Cost

Table 10 and **Table 11 (Appendix B)** summarize the CAPEX and OPEX costs, respectively, for Alternative 4. Costs are expected to be high. Costs estimated for this FS are expected to be accurate to -50% to +100%, commensurate with a Class V estimate. Additional details on AOCs 1, 2, 7, and 10 pump and treat costs can be found in **Appendix J**, and additional details on PAB costs can be found in **Appendix M**. Total project cost would vary in part depending on the treatment train(s) and treatment plant geography selected for the pump and treat systems. This report assumes two separate treatment plants would be constructed for: one treatment plant for AOCs 2 and 7, and another for AOC 10. **Appendix J** also provides cost comparisons for single treatment plant that would treat all groundwater extracted from AOCs 2, 7, and 10 at a centralized location. The lowest and highest cost treatment trains are included in **Table 10** and **Table 11** to provide the complete range of probable costs. Costs from the CDWSP for Lake Elmo, Oakdale, and West Lakeland are included in this alternative. A range of costs is presented for drinking water treatment in these cities to account for uncertainty.

The installation of pump and treatment systems in AOCs 2, 7, and 10 would help to improve plume control and decrease costs to downgradient communities by reducing the spread of the PFAS plume. However, the construction of pump and treat systems separate from drinking water treatment plants

would result in duplicative treatment of PFAS. Treated water from the pump and treat systems would be injected back into contaminated aquifers. After mixing with contaminated water, the treated water would be re-extracted by communities for drinking water treatment. Treatment costs for additional remedial activities at ODS are not included.

12.5 Alternative 5

Alternative 5 is the first remedial alternative to include the MBWA, which would use extraction and injection wells to reduce the mass flux of PFAS in specific areas of the Site; pumped water would also be used to provide safe drinking water with the excess water injected back into the aquifers. In this alternative, drinking water from the MBWA would be provided to residents of Lake Elmo. **Figure 12.9** summarizes the concerns addressed by Alternative 5.

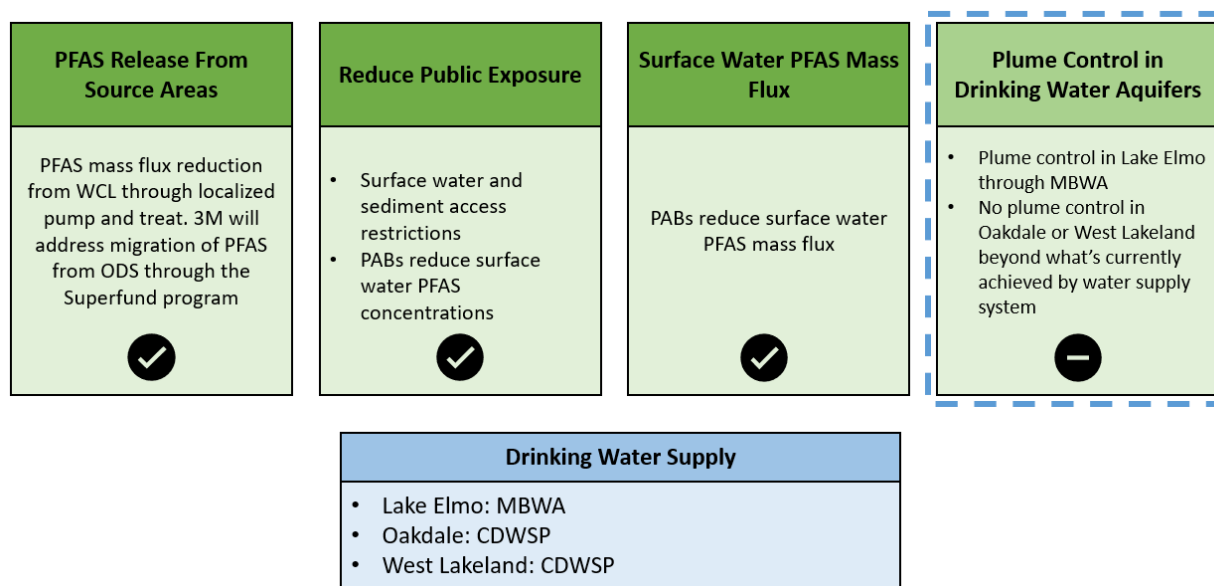


Figure 12.9: Alternative 5 impact

Alternative 5 would also include access restrictions, long-term monitoring, PABs, and a source zone pump and treat system at WCL. Additional remediation action by 3M at ODS would reduce PFAS migration from ODS as dictated by the Consent Order, is assumed.

Figure 12.10 illustrates particle tracking results for Alternative 5. The current Oakdale municipal supply wells largely capture the groundwater plume that spreads from ODS, particularly to the south, reducing the impacts to Woodbury's water supply, and a pump and treat system at WCL would reduce source zone migration. Installation of the MBWA for Lake Elmo would help to reduce migration of the plume east, but some plume migration, particularly from West Lakeland (AOC 10) and to the southwest of ODS, would continue. Because the impacts to the southwest of ODS are a result of direct offsite migration from ODS, additional remedial efforts by 3M would likely be required to comply with MERLA.

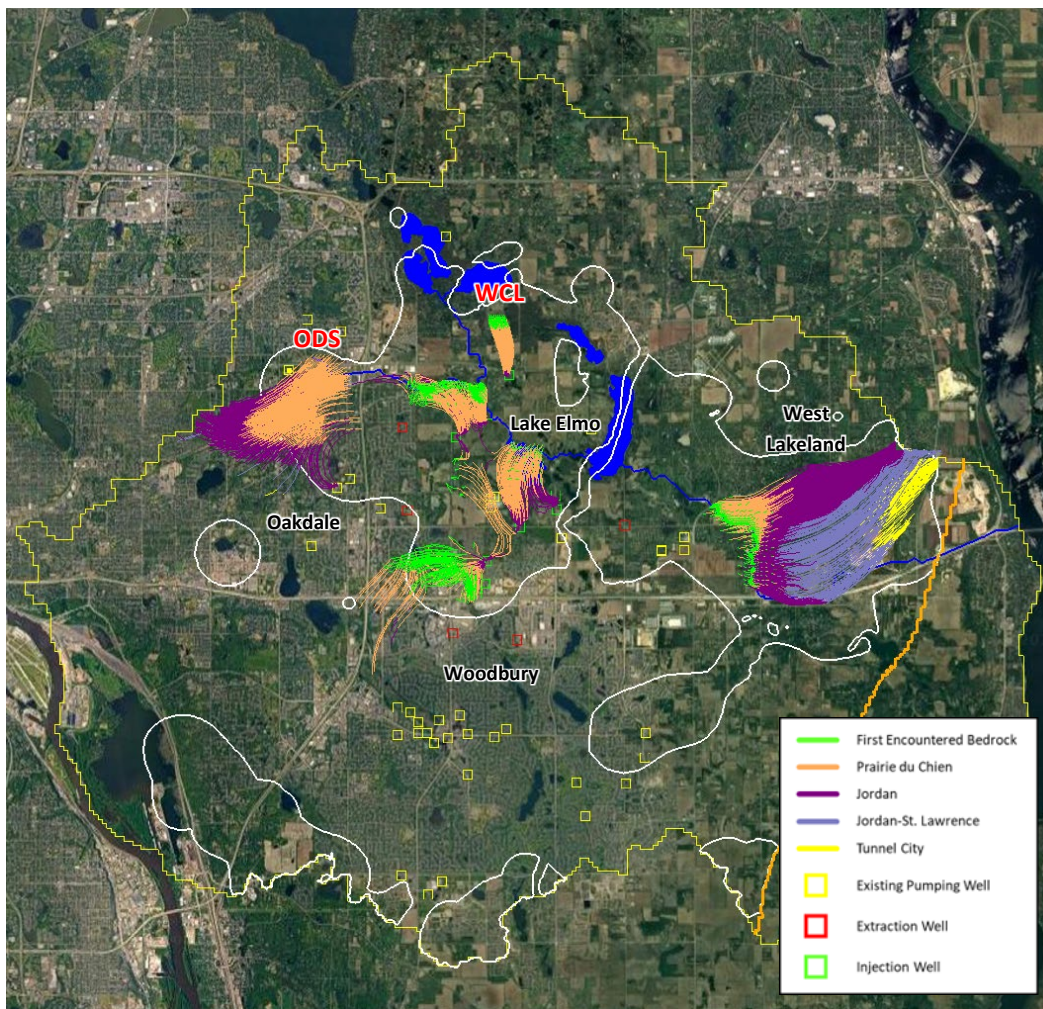


Figure 12.10: Particle tracking for Alternative 5 with particles released from the first encountered bedrock with a 50-year travel time. Particles are released from source areas and water bodies where PFAS-impacted surface water infiltrates to groundwater.

12.5.1 Overall Protection of Human Health and the Environment

Alternative 5 provides moderate-to-high protection of human health and of the environment. The protection and potential risks are summarized as follows:

- Protection of communities with known PFAS impacts: Moderate to high. Risk would be mitigated with extraction and injection associated with the MBWA for Lake Elmo residents and POETs or treatment of municipal water as outlined in the CDWSP for other affected communities. Source zone control would decrease mass flux of PFAS into the drinking water aquifers.
- Protection of communities downgradient of current plume extent: Low to moderate. Treatment at the source zones and installation of PABs will decrease mass flux from shallow impacts into drinking water aquifers and the MBWA south of Raleigh Creek and Eagle Point Lake will reduce plume migration in this area; however, the plume would continue to migrate downgradient in other areas of the Site, notably in West Lakeland. This migration would spread the impacts into currently unaffected communities. As HBVs are below current detection limits, sampling results may not detect unsafe levels.
- Protection against incidental exposure: Moderate to high. Access restrictions and signage would decrease potential exposure risk to contaminated sediment and foam, and PABs would decrease concentrations in downstream surface water and sediment AOCs.

Total PFAS mass in the drinking water aquifers would be reduced over time within a limited area of the total plume.

12.5.2 Ability to Achieve RAOs

The ability of Alternative 5 to address RAOs is summarized in **Table 5 (Appendix B)**. This alternative is generally scored as moderate for the ability to achieve RAOs, except for the RAOs concerning AOC 10.

12.5.3 Long-Term Effectiveness and Permanence

Alternative 5 is scored as moderate for long-term effectiveness and permanence. Downgradient migration of PFAS would be reduced from AOCs 2 and 7 with use of the MBWA for municipal supply in the City of Lake Elmo. Since the extraction well network in the MBWA would provide both remediation of the aquifer and safe drinking water to the city of Lake Elmo, plume capture from these extraction wells would continue indefinitely. This alternative would have long-term operational flexibility as pumping rates and the numbers of extraction and injection wells could be varied, allowing future operations to adapt to plume migration (i.e., pumping rates could be increased or decreased based on reviews of sampling data, within the confines of the White Bear Lake court ruling). There is also flexibility to meet increased water demand of communities should they continue to grow or if additional communities like the Prairie Island Indian Community, located near Interstate-94 west of West Lakeland, needed a source of safe drinking water.

Source zone control at WCL with a pump and treat system is expected to significantly reduce the additional mass flux into the drinking water aquifers. While this will have a delayed impact, reduction in the total additional mass of PFAS entering the drinking water aquifers will reduce the future treatment needs of communities. Depending on the treatment at ODS, additional PFAS may be removed from the environment; however, the Raleigh Creek reroute alone will not result in the removal of PFAS, just limit the migration through the surface water pathway. Based on the extent and volume of PFAS impacts within the entire Site, the expected treatment time is unknown.

Plume control for AOC 10 is not included in this alternative. Continued spread of the plume from West Lakeland could result in additional communities that are currently unaffected requiring PFAS removal from their drinking water in the future, as extraction wells for the Lake Elmo MBWA are not expected to provide plume capture in AOC 10. **Table 6 (Appendix B)** provides additional rationale for the scoring.

12.5.4 Reduction of Toxicity, Mobility, or Volume through Treatments

Alternative 5 is scored as moderate for the reduction of toxicity, mobility, and volume. Treatment of the source zones would greatly reduce the PFAS mass within the Site. This, in addition to treatment of surface water, would decrease the migration of PFAS into and through the drinking water aquifers. PFAS mass in the drinking water aquifers would be reduced south of Raleigh Creek and Eagle Point Lake through the MBWA. The evaluation of this alternative focuses on where groundwater extraction should occur to improve plume control, while the efficiency of the groundwater treatment trains once the groundwater extraction has occurred is addressed in **Appendix K. Table 7 (Appendix B)** provides additional rationale for the scoring.

12.5.5 Short-Term Effectiveness

Alternative 5 is scored as moderate to high for short-term effectiveness with the specific rationale provided in **Table 8 (Appendix B)**. The short-term effectiveness for specific treatment trains is discussed in **Appendix J, Appendix K, and Appendix M**. The time until protection is achieved was more heavily weighted than other short-term effectiveness criteria when determining the overall score. Other short-term effectiveness criteria (ability to mitigate risks to community during implementation and ability to mitigate potential impacts on workers) can be managed with standard best practices and pose minimal

risks to workers and the public. Additionally, while important to consider, potential environmental impacts of remedial action were weighted less heavily than time until protection is achieved because the main priority of this FS is to provide safe and sustainable drinking water resources for current and future generations in the PFAS-impacted communities. Environmental impacts of remedial action are important to consider, but protection of human health through exposure to PFAS-impacted drinking water must be prioritized. As a result, time until protection is achieved, which considers drinking water risk, is more heavily weighted than other criteria.

12.5.6 Implementability

Alternative 5 is scored as moderate to high for implementability. The MBWA system for AOCs 2 and 7 that would provide drinking water to Lake Elmo would also re-inject treated water into the Jordan Aquifer. Like Alternative 4, groundwater treatment would require coordination with MDNR, MDH, and EPA Region V UIC. **Table 9 (Appendix B)** provides additional rationale for the scoring.

12.5.7 Cost

Table 10 and **Table 11 (Appendix B)** summarize the CAPEX and OPEX cost estimates, respectively, for Alternative 5. Costs are expected to be moderate to high. Costs estimated for this FS are expected to be accurate to -50% to +100%, commensurate with a Class V estimate, except for MBWA costs, which are expected to be accurate to -30% to +50%. Additional details on AOC 1 pump and treat costs can be found in **Appendix J** and additional details on PAB costs can be found in **Appendix M**. Total project cost would vary depending in part on the treatment train selected for the AOC 1 pump and treat system. The lowest and highest cost treatment trains are included in **Table 10** and **Table 11** to provide the complete range of probable costs. Similarly, for the MBWA, low- and high-cost treatment options are included for comparison. Full details of costs associated with the MBWA can be found in **Appendix K**. Costs from the CDWSP for Oakdale and West Lakeland are included in this alternative. As drinking water for Lake Elmo would be supplied by the MBWA, costs derived from the CDWSP for Lake Elmo are not included in this alternative. A range of costs is presented for drinking water treatment in Oakdale and West Lakeland to account for uncertainty. These costs do not include treatment at ODS.

12.6 Alternative 6

Alternative 6 also incorporates the MBWA described in Alternative 5 to address groundwater impacts and provide safe drinking water. In this alternative, drinking water would be provided to residents of Lake Elmo and additional plume control would occur in West Lakeland through a localized pump and treat system that is separate from the MBWA. Treated water would be injected into the Jordan Aquifer to help maintain safe groundwater elevations and provide additional plume control. **Figure 12.11** summarizes the concerns addressed by Alternative 6.

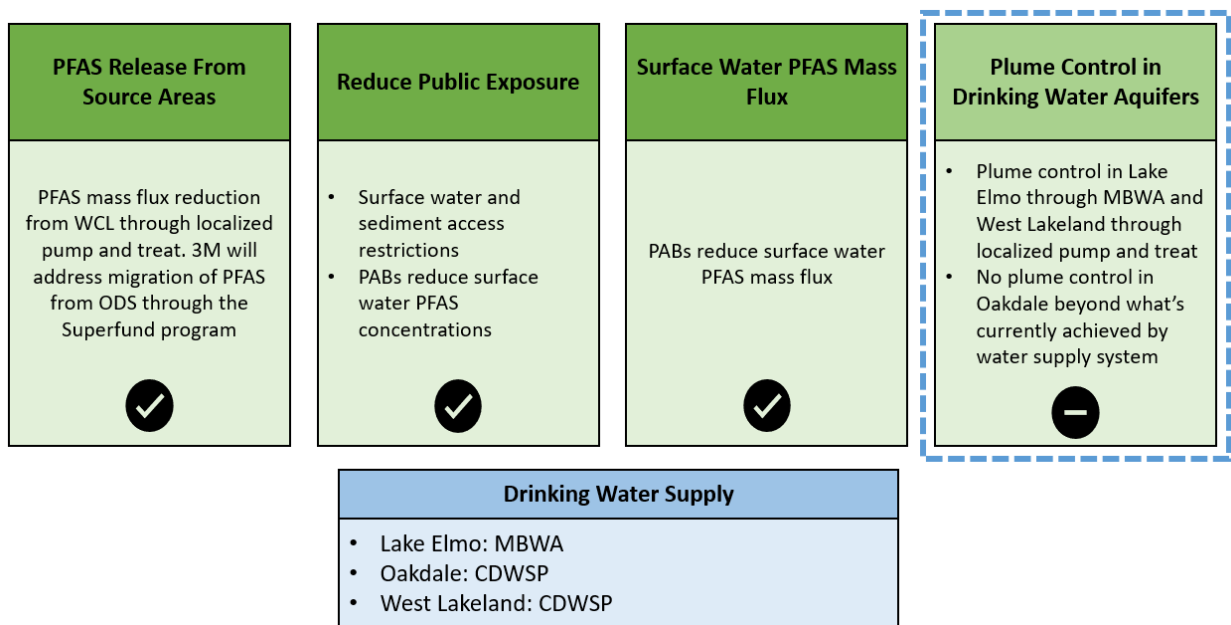


Figure 12.11: Alternative 6 impact

Alternative 6 would also include access restrictions, long-term monitoring, PABs, source zone pump and treat system at WCL, and additional treatment at ODS by 3M. Additional remediation action by 3M at ODS would reduce PFAS migration from ODS as dictated by the Consent Order is assumed. Because this alternative does not address migration of impacts to the south and southwest of ODS beyond what is captured by the Oakdale municipal supply wells, additional remedial efforts by 3M may be required in that area to comply with MERLA.

Figure 12.12 illustrates the particle tracking results for Alternative 6. Like other alternatives, the current Oakdale municipal supply wells largely capture the groundwater plume that spreads from ODS, protecting Woodbury's water supply, and a pump and treat system at WCL would reduce source zone migration. Installation of the MBWA for Lake Elmo would help to reduce migration of the plume to the east, and inclusion of a pump and treat system in West Lakeland would help to protect communities that are currently unaffected.

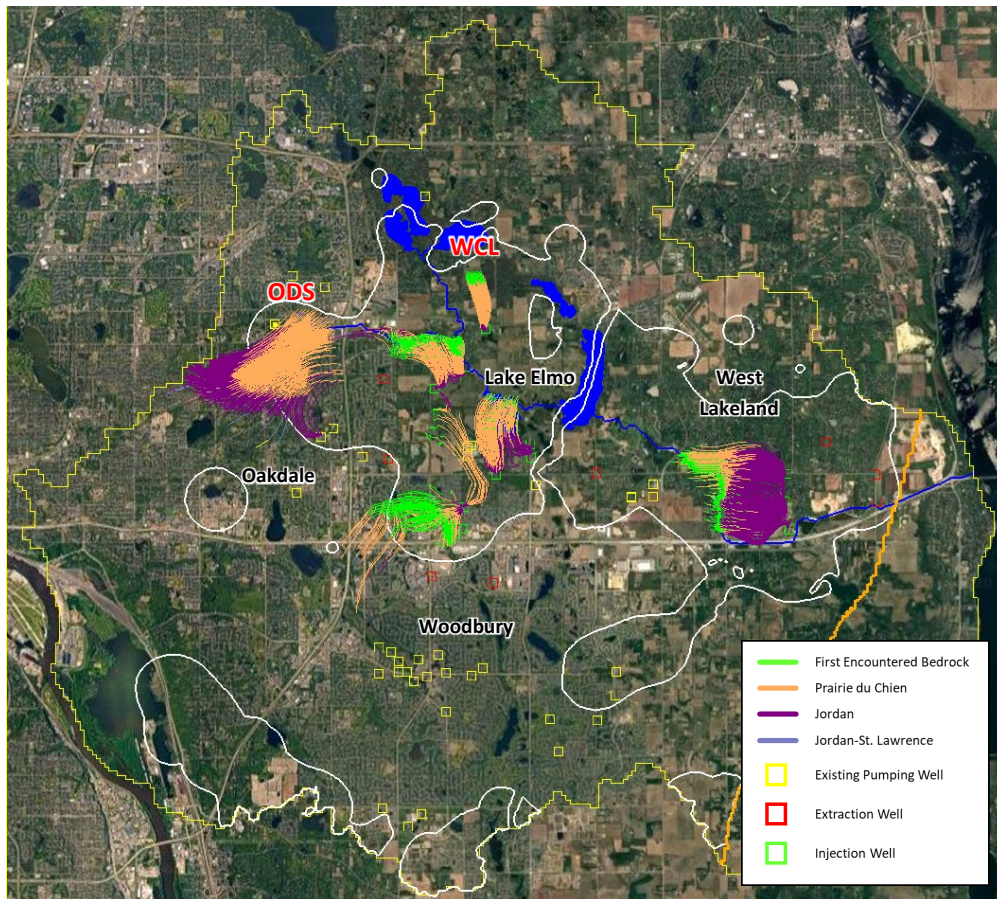


Figure 12.12: Particle tracking for Alternative 6 with particles released from the first encountered bedrock with a 50-year travel time. Particles are released from source areas and water bodies where PFAS-impacted surface water infiltrates to groundwater.

12.6.1 Overall Protection of Human Health and the Environment

Alternative 6 provides moderate to high protection of human health and of the environment. The protection and potential risks are summarized as follows:

- Protection of communities with known PFAS impacts: Moderate to high. Risk would be mitigated with the MBWA for Lake Elmo residents and POETs or treatment of municipal water as outlined in the CDWSP for other affected communities. Source zone control would decrease mass flux of PFAS into the drinking water aquifers.
- Protection of communities downgradient of current plume extent: Moderate to high. PABs would decrease mass flux of PFAS from surface water into drinking water aquifers, and the combination of MBWA and pump and treat system in West Lakeland would provide groundwater plume control, reducing PFAS migration to the east of the Site towards the St. Croix River and towards areas that are currently unimpacted with PFAS. The plume would not be controlled to the south and southwest of ODS beyond the limited capture by the Oakdale municipal supply wells; however, there are no municipal supply wells immediately downgradient of this area.
- Protection against incidental exposure: Moderate to high. Access restrictions and signage would decrease potential exposure risk to contaminated sediment, surface water, and foam, and PABs would decrease concentrations in downstream surface water and sediment AOCs.

Migration of PFAS may still occur in other areas of the Site into areas that are currently unimpacted, such as to the south and southwest of ODS. This migration could be altered with changes in pumping

conditions elsewhere within the East Metro. As discussed for Alternative 4 in **Section 12.4.1**, total PFAS mass in the drinking water aquifers would be reduced over time, and long-term monitoring and five-year reviews would be utilized to assess effectiveness and optimization.

12.6.2 Ability to Achieve RAOs

The ability of Alternative 6 to address RAOs is summarized in **Table 5 (Appendix B)**. This alternative is scored as moderate to high for its ability to achieve the RAOs.

12.6.3 Long-Term Effectiveness and Permanence

Alternative 6 is scored as moderate to high long-term effectiveness and permanence as the downgradient migration of PFAS, specifically into unimpacted drinking water aquifers, is reduced. Since the extraction well network in the MBWA provides both remediation of the aquifer and safe drinking water to the city of Lake Elmo, plume capture from these extraction wells would continue indefinitely. At the same time, safe groundwater elevations would be maintained via injection of excess treated water. As the plume concentrations are reduced over time, a reduction in the volume required to treat and inject is expected in response to the MBWA extraction and plume control.

There may be flexibility in the pumping rates and the numbers of extraction and injection wells, allowing future operations to adapt to plume migration (i.e., pumping rates could be increased or decreased based on reviews of data from the monitoring well network). There may also be flexibility to meet increased water demand of communities should they continue to grow, as less water could be reinjected and could instead be used for drinking water.

Source zone control at WCL with a pump and treat system is expected to significantly reduce the additional mass flux into the drinking water aquifers, reducing the future treatment needs of communities. Depending on the treatment at ODS, additional PFAS may be removed from the environment; however, the Raleigh Creek reroute alone will not result in the removal of PFAS, just limit the migration through the surface water pathway. Based on the extent and volume of PFAS impacts within the entire Site, the expected treatment time is unknown. **Table 6 (Appendix B)** provides additional rationale for the scoring.

12.6.4 Reduction of Toxicity, Mobility, or Volume through Treatments

Alternative 6 is scored as moderate to high for the reduction of toxicity, mobility, and volume. Treatment of the source zones would greatly reduce the PFAS mass within the Site. This, in addition to treatment of surface water, would decrease the migration of PFAS into and through the drinking water aquifers. PFAS mass in the drinking water aquifers would be reduced south of Raleigh Creek and Eagle Point Lake through the MBWA. A localized pump and treat system would be installed in West Lakeland to reduce migration in the drinking water aquifers east of West Lakeland. The evaluation of this alternative focuses on where groundwater extraction should occur to improve plume control, while the efficiency of the groundwater treatment trains once the groundwater extraction has occurred is addressed in **Appendix K** and efficiency of the treatment trains for the West Lakeland pump and treat system addressed in **Appendix J**. **Table 7 (Appendix B)** provides additional rationale for the scoring.

12.6.5 Short-Term Effectiveness

Alternative 6 is scored as moderate to high for short-term effectiveness with the specific rationale provided in **Table 8 (Appendix B)**. The short-term effectiveness for specific treatment trains is discussed in **Appendix J**, **Appendix K**, and **Appendix M**. The time until protection is achieved was more heavily weighted than other short-term effectiveness criteria when determining the overall score. Other short-term effectiveness criteria (ability to mitigate risks to community during implementation and ability to mitigate potential impacts on workers) can be managed with standard best practices and pose minimal

risks to workers and the public. Additionally, while important to consider, potential environmental impacts of remedial action were weighed less heavily than time until protection is achieved because the main priority of this FS is to provide safe and sustainable drinking water resources for current and future generations in the PFAS-impacted communities. Environmental impacts of remedial action are important to consider, but protection of human health through exposure to PFAS-impacted drinking water must be prioritized. As a result, time until protection is achieved, which considers drinking water risk, is more heavily weighted than other criteria.

12.6.6 Implementability

Alternative 6 is scored as moderate to high for implementability. The MBWA system for AOCs 2 and 7 that would provide drinking water to Lake Elmo and the West Lakeland pump and treat system in AOC 10 would also re-inject treated water into the Jordan Aquifer. Like previous alternatives, groundwater treatment would require coordination with MDNR, MDH, and EPA Region V UIC. **Table 9 (Appendix B)** provides additional rationale for the scoring.

12.6.7 Cost

Table 10 and **Table 11 (Appendix B)** summarize the CAPEX and OPEX cost estimates, respectively, for Alternative 6. Costs are expected to be high. Costs estimated for this FS are expected to be accurate to -50% to +100%, commensurate with a Class V estimate, except for MBWA costs, which are expected to be accurate to -30% to +50%. Additional details on AOC 1 and AOC 10 pump and treat costs can be found in **Appendix J**, and additional details on PAB costs can be found in **Appendix M**. Total project cost would vary depending in part on the treatment train selected for the AOC 1 and AOC 10 pump and treat systems. The lowest and highest cost treatment trains are included in **Table 10** and **Table 11** to provide the complete range of probable costs. Similarly, for the MBWA, low- and high-cost treatment options are included for comparison. Full details of costs associated with the MBWA can be found in **Appendix K**. Costs to implement the CDWSP for Oakdale and West Lakeland are included in this alternative. As drinking water for Lake Elmo would be supplied by the MBWA, costs derived from the CDWSP for Lake Elmo are not included in this alternative. A range of costs is presented for drinking water treatment in **Appendix K**. Improved plume control through this alternative is expected to reduce costs to downgradient communities that are not captured in this analysis. These costs do not include treatment at ODS.

12.7 Alternative 7

Alternative 7 is an additional MBWA-based remedial alternative. In this alternative, drinking water would be provided to residents of Lake Elmo and Oakdale with groundwater extraction in both communities and injection of the remaining water into the Jordan Aquifer. A localized pump and treat system would be implemented in West Lakeland with the treated water injected into the Jordan Aquifer. **Figure 12.13** summarizes the concerns addressed by Alternative 7.

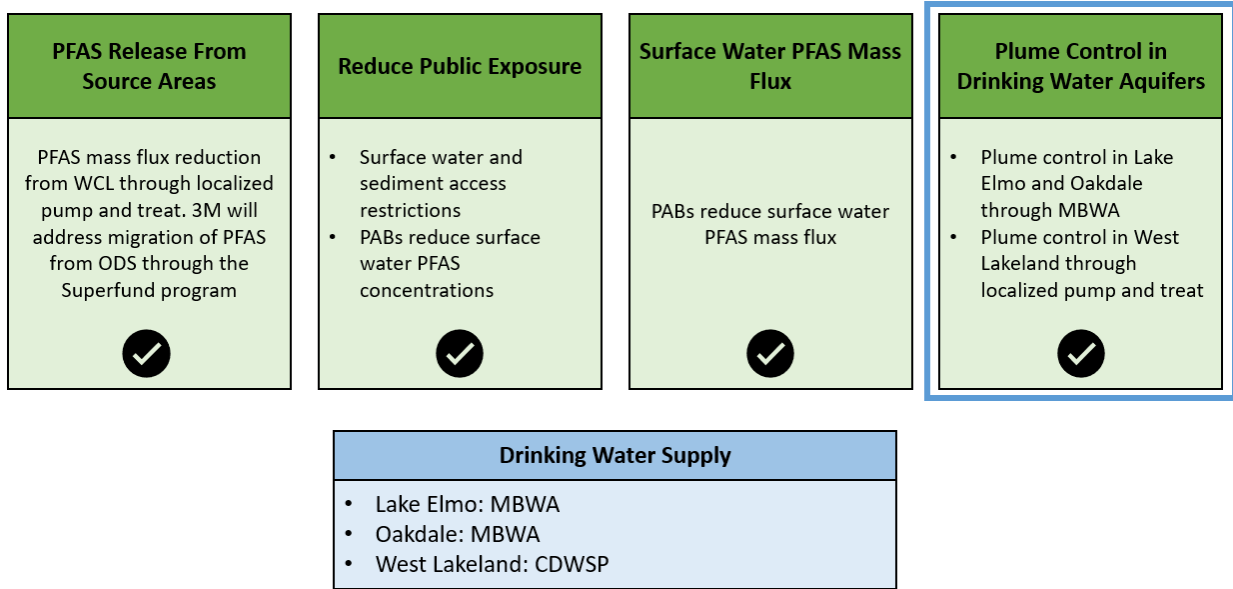


Figure 12.13: Alternative 7 impact

This alternative could be amended to include the Prairie Island Indian Community as the proposed development could be connected to the MBWA or the water extracted in West Lakeland could be treated to drinking water standards to provide to these residents. Alternatively, should West Lakeland decide to switch to municipal supply in the future, the extraction well network and potentially the treatment plant could be similarly repurposed. Future treatment of drinking water for this community is discussed in the CDWSP.

Alternative 7 would also include access restrictions, long-term monitoring, PABs, and a source zone pump and treat system at WCL. Additional remediation action by 3M at ODS to reduce PFAS migration from ODS as dictated by the Consent Order is assumed.

Figure 12.14 illustrates the particle tracking results for Alternative 7. The MBWA would improve control of the plume in Oakdale, reducing migration to the west, and a pump and treat system at WCL would reduce source zone migration. Installation of the MBWA for Lake Elmo would help to reduce migration of the plume east, and a pump and treat system in West Lakeland would help to protect communities that are currently unaffected.

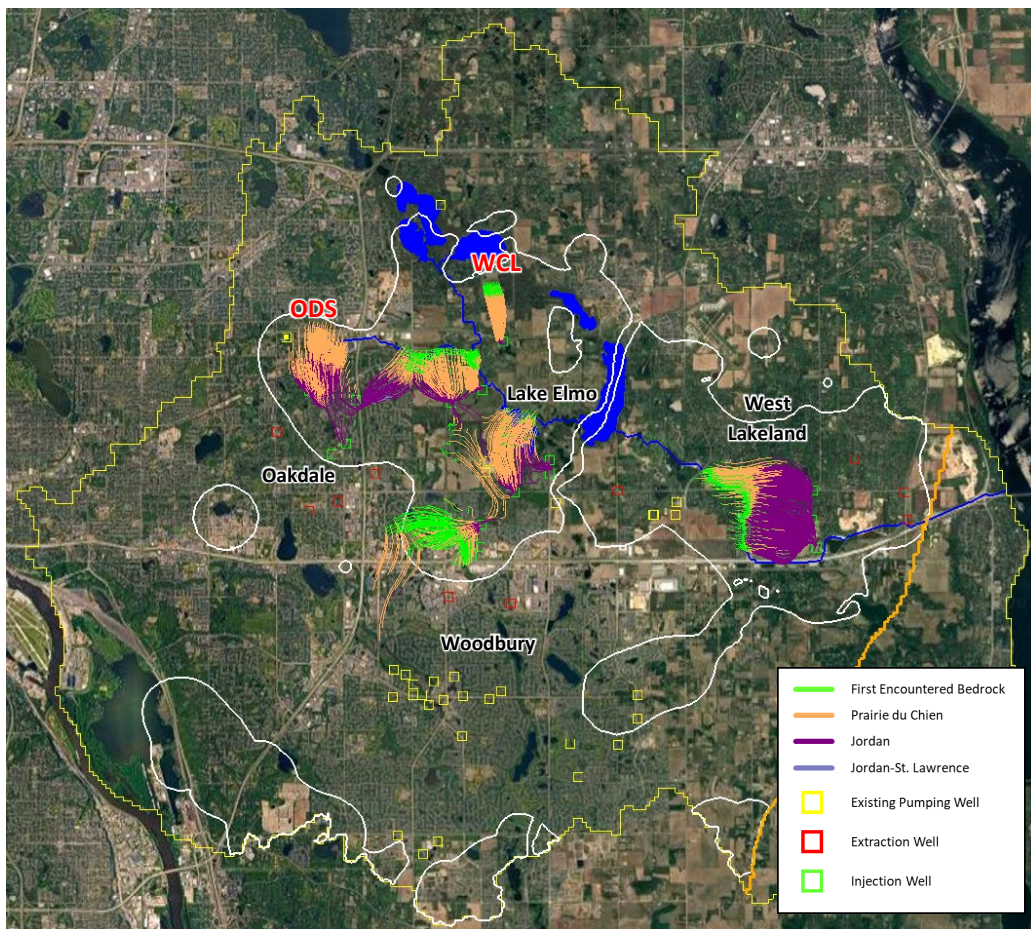


Figure 12.14: Particle tracking for Alternative 7 with particles released from the first encountered bedrock with a 50-year travel time. Particles are released from source areas and water bodies where PFAS-impacted surface water infiltrates to groundwater.

12.7.1 Overall Protection of Human Health and the Environment

Alternative 7 is highly protective of human health and of the environment. The protection and potential risks are summarized as follows:

- Protection of communities with known PFAS impacts: High. Risk would be mitigated with an MBWA for Lake Elmo and Oakdale residents and POETSs or treatment of municipal water. Source zone control would decrease mass flux of PFAS into the drinking water aquifers.
- Protection of communities downgradient of current plume extent: High. PABs would decrease mass flux from surface water into drinking water aquifers, and the combination of the MBWA and the pump and treat system in West Lakeland would provide groundwater plume control, reducing PFAS migration to the west, south, and east of the Site towards areas that are currently unimpacted with PFAS.
- Protection against incidental exposure: Moderate to high. Access restrictions and signage would decrease potential exposure risk to contaminated sediment, surface water, and foam, and PABs would decrease concentrations in surface water and sediment AOCs.

Five-year reviews would be utilized to assess data and determine how the pump and treat system could be optimized.

12.7.2 Ability to Achieve RAOs

The ability of Alternative 7 to address RAOs is summarized in **Table 5 (Appendix B)**. This alternative is scored moderate to high for its ability to achieve the RAOs.

12.7.3 Long-Term Effectiveness and Permanence

Alternative 7 is scored as high for long-term effectiveness and permanence as the downgradient migration of PFAS, specifically into unimpacted drinking water aquifers, is reduced. Since the extraction well network in the MBWA provides both remediation of the drinking water aquifers and safe drinking water to the cities of Lake Elmo and Oakdale, plume capture from these extraction wells would continue indefinitely. This alternative also has long-term operational flexibility as pumping rates and the numbers of extraction and injection wells could be varied, allowing future operations to adapt to plume migration (i.e., pumping rates could be increased or decreased based on reviews of sampling data from the monitoring well network). There is also flexibility to meet increased water demand of communities should they continue to grow, as less water could be reinjected and could instead be used for drinking water. Long-term operations of the West Lakeland pump and treat system also have the flexibility to adjust pumping rates and the well network to adjust to changes in the plume.

Source zone control at WCL with a pump and treat system is expected to significantly reduce the additional mass flux into the drinking water aquifers, reducing the future treatment needs of communities. Depending on the treatment at ODS, additional PFAS may be removed from the environment; however, the Raleigh Creek reroute alone will not result in the removal of PFAS, just limit the migration through the surface water pathway. Based on the extent and volume of PFAS impacts within the entire Site, the expected treatment time is unknown. **Table 6 (Appendix B)** provides additional rationale for the scoring.

12.7.4 Reduction of Toxicity, Mobility, or Volume through Treatments

Alternative 7 is scored as high for reduction of toxicity, mobility, and volume. Treatment of the source zones would significantly reduce the PFAS mass within the Site. This, in addition to treatment of surface water, would decrease the migration of PFAS into and through the drinking water aquifers. PFAS mass in the drinking water aquifers would be reduced south of Raleigh Creek and Eagle Point Lake and ODS with PFAS removal and hydraulic control through the MBWA. A localized pump and treat system in West Lakeland would reduce migration in the drinking water aquifers east of West Lakeland. The evaluation of this alternative focuses on where groundwater extraction should occur to improve plume control, while the efficiency of the groundwater treatment trains once the groundwater extraction has occurred is addressed in **Appendix K** and efficiency of the treatment trains for the West Lakeland pump and treat addressed in **Appendix J**. **Table 7 (Appendix B)** provides additional rationale for the scoring.

12.7.5 Short-Term Effectiveness

Alternative 7 is scored as high for short-term effectiveness with the specific rationale provided in **Table 8 (Appendix B)**. The short-term effectiveness for specific treatment trains is discussed in **Appendix J**, **Appendix K**, and **Appendix M**. The time until protection is achieved was more heavily weighted than other short-term effectiveness criteria when determining the overall score. Other short-term effectiveness criteria (ability to mitigate risks to community during implementation and ability to mitigate potential impacts on workers) can be managed with standard best practices and pose minimal risks to workers and the public. Additionally, while important to consider, potential environmental impacts of remedial action were weighted less heavily than time until protection is achieved because the main priority of this FS is to provide safe and sustainable drinking water resources for current and future generations in the PFAS-impacted communities. Environmental impacts of remedial action are important to consider, but protection of human health through exposure to PFAS-impacted drinking

water must be prioritized. As a result, time until protection is achieved, which considers drinking water risk, is more heavily weighted than other criteria.

12.7.6 Implementability

Alternative 7 is scored as moderate for implementability. The MBWA system for AOCs 2 and 7 that would provide drinking water to Lake Elmo and Oakdale and the West Lakeland pump and treat system in AOC 10 would also re-inject treated water into the Jordan Aquifer. Like Alternative 4, groundwater treatment would require coordination with MDNR, MDH, and EPA Region V UIC. **Table 9 (Appendix B)** provides additional rationale for the scoring.

12.7.7 Cost

Table 10 and **Table 11 (Appendix B)** summarize the CAPEX and OPEX costs, respectively, for Alternative 7. Costs are expected to be high. Costs estimated for this FS are expected to be accurate to -50% to +100%, commensurate with a Class V estimate, except for MBWA costs, which are expected to be accurate to -30% to +50%. Additional details on AOC 1 and AOC 10 pump and treat costs can be found in **Appendix J** and additional details on PAB costs can be found in **Appendix M**. Total project cost will vary depending in part on the treatment train selected for the AOC 1 and AOC 10 pump and treat systems. The lowest and highest cost treatment trains are included in **Table 10** and **Table 11** to provide the complete range of probable costs. Similarly, for the MBWA, low- and high-cost treatment options are included for comparison. Full details of costs associated with the MBWA can be found in **Appendix K**. Costs from the CDWSP are included in this alternative for West Lakeland only, as drinking water for Lake Elmo and Oakdale would be supplied by the MBWA. A range of costs is presented for drinking water treatment in West Lakeland to account for uncertainty. Improved plume control through this alternative is expected to reduce costs to downgradient communities that are not captured in this analysis. These costs do not include treatment at ODS.

12.8 Alternative 8

Alternative 8 is the final MBWA-based remedial alternative. In this alternative, drinking water would be provided to residents of Lake Elmo and Oakdale with groundwater extraction in Oakdale, Lake Elmo, and West Lakeland. As the residents of West Lakeland have previously expressed a preference to remain on private wells treated with POETSS, water extracted in West Lakeland would be piped to the treatment plant in Lake Elmo for distribution or injection. Injection wells would be located in West Lakeland, Oakdale, Lake Elmo, and Woodbury. **Figure 12.15** summarizes the concerns addressed by Alternative 8.

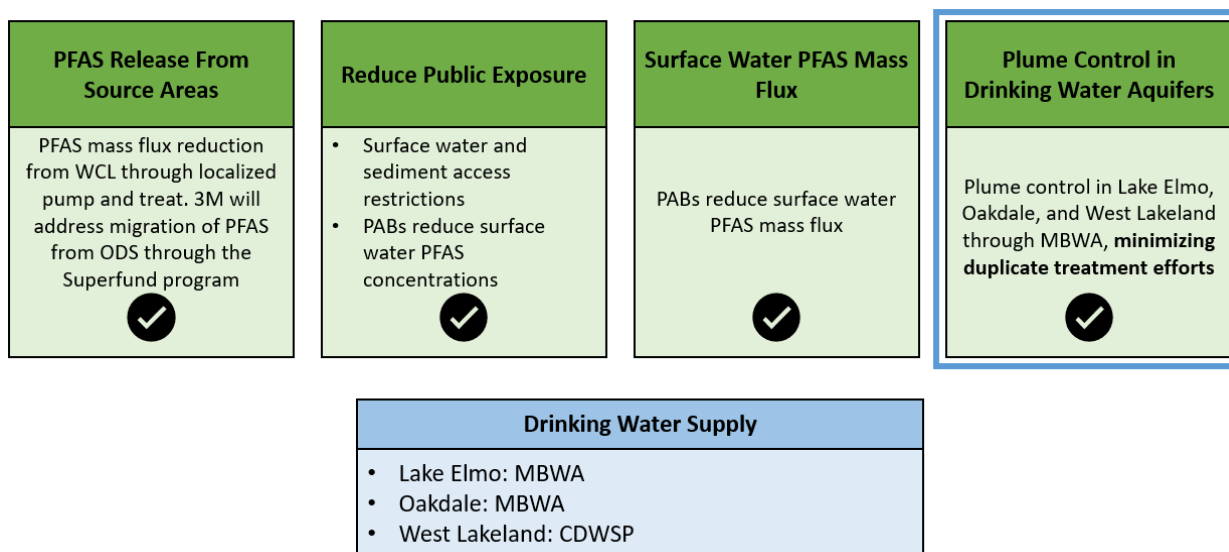


Figure 12.15: Alternative 8 impact

This alternative could be amended to include the Prairie Island Indian Community as the proposed development is located along the piping network that would connect West Lakeland to Lake Elmo. Treated water could either be pumped to the Prairie Island Indian Community or the community could install its own treatment plant and utilize water extracted in West Lakeland. This would prevent unintended plume migration, which may occur if a supply well were installed within the community.

This alternative also provides the most long-term flexibility, should other communities including West Lakeland decide to transition to municipal supply in the future. Additional extraction wells could be installed to increase supply and simultaneously provide greater control over plume migration. These alterations are not included in the evaluation of this alternative but would be discussed with the communities and MPCA if this alternative were to be selected.

Alternative 8 would also include access restrictions, long-term monitoring, surface water PABs, and a source zone pump and treat system at WCL. Additional remediation action by 3M at ODS to reduce PFAS migration from ODS as dictated by the Consent Order is assumed.

Figure 12.16 illustrates particle tracking results for Alternative 8. As shown, the MBWA configuration would improve control of the plume underneath Oakdale (AOC 4), Lake Elmo (AOC 2 and 7), and West Lakeland (AOC 10), reducing migration to the west, south, and east. The pump and treat system at WCL would reduce source zone migration.

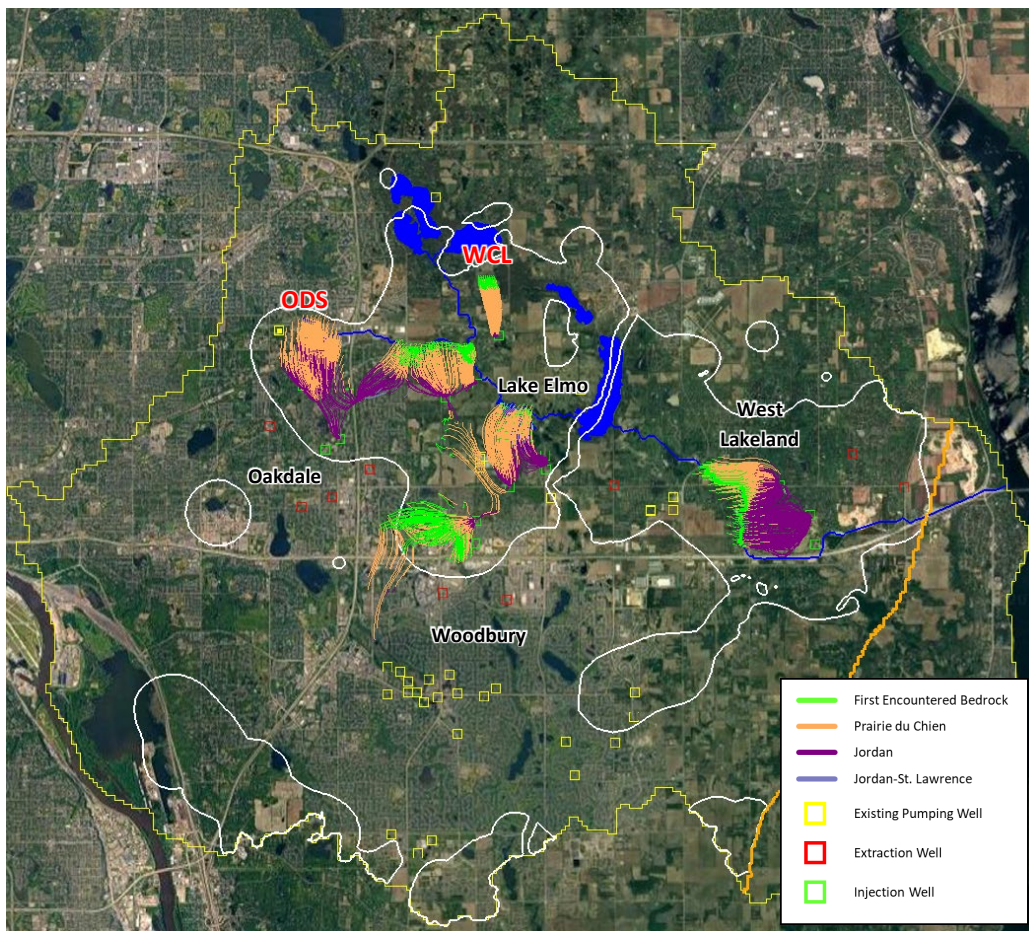


Figure 12.16: Particle tracking for Alternative 8 with particles released from the first encountered bedrock with a 50-year travel time. Particles are released from source areas and water bodies where PFAS-impacted surface water infiltrates to groundwater.

12.8.1 Overall Protection of Human Health and the Environments

Alternative 8 is highly protective of human health and of the environment. The protection and potential risks are summarized as follows:

- Protection of communities with known PFAS impacts: High as risk is mitigated with the public supply of treated water from the MBWA for Lake Elmo and Oakdale, and POETSs on impacted private wells of homes not connected to public supply including residents in West Lakeland. Additionally, source zone treatment would reduce the mass flux of PFAS into the drinking water aquifers, further reducing the risk.
- Protection of communities downgradient of current plume extent: High as source zone treatment and PABs will decrease mass flux from surface water and shallow soils into drinking water aquifers, and the MBWA would provide groundwater plume control, reducing PFAS migration to areas that are currently unimpacted with PFAS, specifically to the west, south and east of the Site.
- Protection against incidental exposure: Moderate to high as access restrictions, signage, and PABs would decrease potential exposure risk to contaminated sediment, surface water, and foam and decrease concentrations in surface water and sediment AOCs.

12.8.2 Ability to Achieve RAOs

The ability of Alternative 8 to address RAOs is summarized in **Table 5 (Appendix B)**. This alternative is scored moderate to high for its ability to achieve the RAOs.

12.8.3 Long-Term Effectiveness and Permanence

Alternative 8 is scored as high for long-term effectiveness and permanence as the downgradient migration of PFAS, specifically into unimpacted drinking water aquifers, is reduced. Since the extraction well network in the MBWA provides both remediation of the aquifer and safe drinking water to the cities of Lake Elmo and Oakdale, plume capture will continue indefinitely. This alternative also has long-term operational flexibility as pumping rates and the numbers of extraction and injection wells can be varied, allowing future operations to adapt to plume migration (i.e., pumping rates could be increased or decreased based on reviews of quarterly sampling data). There is also flexibility to meet increased water demand of communities should they continue to grow, as less water could be reinjected and could instead be used for drinking water.

Source zone control at WCL with a pump and treat system is expected to significantly reduce the additional mass flux into the drinking water aquifers, reducing the future treatment needs of communities. Depending on the treatment at ODS, additional PFAS may be removed from the environment; however, the Raleigh Creek reroute alone will not result in the removal of PFAS, just limit the migration through the surface water pathway. Based on the extent and volume of PFAS impacts within the entire Site, the expected treatment time is unknown. **Table 6 (Appendix B)** provides additional rationale for the scoring.

12.8.4 Reduction of Toxicity, Mobility, or Volume through Treatments

Alternative 8 is scored as high for the reduction of toxicity, mobility, and volume. Treatment of the source zones would greatly reduce the PFAS mass within the Site. This, in addition to treatment of surface water, would decrease the migration of PFAS into and through the drinking water aquifers. PFAS mass in the drinking water aquifers across the Site would be reduced through the MBWA. The evaluation of this alternative focuses on where groundwater extraction should occur to improve plume control, while the efficiency of the groundwater treatment trains once the groundwater extraction has occurred is addressed in **Appendix K** and efficiency of the treatment trains for the West Lakeland pump and treat addressed in **Appendix J**. **Table 7 (Appendix B)** provides additional rationale for the scoring.

12.8.5 Short-Term Effectiveness

Alternative 7 is scored as high for short-term effectiveness with the specific rationale provided in **Table 8 (Appendix B)**. Safe drinking water would be provided for affected communities, and plume control would prevent impacts from spreading to other communities. The short-term effectiveness for specific treatment trains is discussed in **Appendix J**, **Appendix K**, and **Appendix M**. The time until protection is achieved was more heavily weighted than other short-term effectiveness criteria when determining the overall score. Other short-term effectiveness criteria (ability to mitigate risks to community during implementation and ability to mitigate potential impacts on workers) can be managed with standard best practices and pose minimal risks to workers and the public. Additionally, while important to consider, potential environmental impacts of remedial action were weighted less heavily than time until protection is achieved because the main priority of this FS is to provide safe and sustainable drinking water resources for current and future generations in the PFAS-impacted communities. Environmental impacts of remedial action are important to consider, but protection of human health through exposure to PFAS-impacted drinking water must be prioritized. As a result, time until protection is achieved, which considers drinking water risk, is more heavily weighted than other criteria.

12.8.6 Implementability

Alternative 8 is scored as moderate for implementability. The MBWA system that would provide drinking water to Lake Elmo and Oakdale and treat water from West Lakeland (addressing impacts in AOCs 2, 4, 7, and 10) would also re-inject treated water into the Jordan Aquifer. Like previous

alternatives, groundwater treatment would require coordination with MDNR, MDH, and EPA Region V UIC. **Table 9 (Appendix B)** provides additional rationale for the scoring.

12.8.7 Cost

Table 10 and **Table 11 (Appendix B)** summarize the CAPEX and OPEX costs for Alternative 8. Costs are expected to be high. Costs estimated for this FS are expected to be accurate to -50% to +100%, commensurate with a Class V estimate, except for MBWA costs, which are expected to be accurate to -30% to +50%. Additional details on AOC 1 pump and treat costs can be found in **Appendix J**, and additional details on PAB costs can be found in **Appendix M**. Total project cost will vary depending in part on the treatment train selected for the AOC 1 pump and treat system. The lowest and highest cost treatment trains are included in **Table 10** and **Table 11** to provide the complete range of probable costs. Similarly, for the MBWA, low- and high-cost treatment options are included for comparison. Full details of costs associated with the MBWA can be found in **Appendix K**. Costs from the CDWSP are included in this alternative for West Lakeland only, as drinking water for Lake Elmo and Oakdale would be supplied by the MBWA. A range of costs is presented for drinking water treatment in West Lakeland to account for uncertainty. Improved plume control through this alternative is expected to reduce costs to downgradient communities that are not captured in this analysis. These costs do not include treatment at ODS.

12.9 Conclusion

Alternatives discussed in this section would provide safe drinking water for residents of Lake Elmo, Oakdale, and West Lakeland, either through treatment planned in the CDWSP or with the MBWA. Long-term protection of drinking water aquifers would vary significantly by alternative, as would degree of protection of downgradient communities. Alternatives are compared against each other in **Section 13** with the recommendation provided in **Section 14**.

13 Comparative Analysis of Alternatives

The comparative analysis of alternatives in this section compares each of the alternatives (presented in **Section 12**) against one another with respect to each of the nine National Contingency Plan (NCP) criteria. Evaluation of the criteria helps to identify the significant differences and key issues across the alternatives. The purpose of the analysis is to identify the advantages and disadvantages of each alternative relative to one another so key tradeoffs and decision-makers can be identified (EPA, 1988). The comparative analysis results are summarized in **Table 13.1**.

Table 13.1: Alternative Rankings by NCP Criteria

NCP Criteria	1. Overall Protection of Human Health and the Environment	2. Ability to Achieve RAOs	3. Long-Term Effectiveness and Permanence	4. Reduction of Toxicity, Mobility, or Volume through Treatment	5. Short-Term Effectiveness	6. Implementability	7. Cost
Method of Ranking	Most protective to least protective	Most likely to least likely to achieve	Most effective and permanent to least effective and permanent	Highest reduction to least reduction	Most effective to least effective during implementation	Easiest to most difficult	Costs are not ranked due to significant uncertainty in costs.
Alternative Rankings	Alternative 7 and Alternative 8 Alternative 4 and Alternative 6 Alternative 5 Alternative 3 Alternative 2 Alternative 1	Alternative 7 and Alternative 8 Alternative 4 and Alternative 6 Alternative 5 Alternative 3 Alternative 2 Alternative 1	Alternative 7 and Alternative 8 Alternative 6 Alternative 4 Alternative 5 Alternative 3 Alternative 2 Alternative 1	Alternative 7 and Alternative 8 Alternative 4 and Alternative 6 Alternative 5 Alternative 3 Alternative 2 Alternative 1	Alternative 8 Alternative 7 Alternative 6 Alternative 4 Alternative 5 Alternative 3 Alternative 2 Alternative 1	Alternative 1 Alternative 2 Alternative 3 Alternative 5 Alternative 6 Alternative 7 Alternative 8 and Alternative 4	25-year cost estimates are provided in Section 13.7 .

13.1 Overall Protection of Human Health and the Environment

The overall protection of human health and the environment criterion considered current and future protection of communities with known per- and polyfluoroalkyl substances (PFAS) impacts, protection of communities downgradient of current plume extent, and protection against incidental exposure. As the focus of this Feasibility Study (FS) is the provision of safe drinking water to communities and the protection of the drinking water aquifers, these are the focus areas of the criterion. The impacts to other human exposure pathways and environmental risks are documented within this FS in the event they impact future decisions; however, these impacts did not affect the recommendations in this FS.

The alternatives presented are protective of drinking water receptors currently affected by PFAS either through municipal supply treatment or through point of entry treatment systems (POETSS) at private wells. However, long-term protection of drinking water receptors is not equal between the alternatives as they each provide varying degrees of groundwater extraction and PFAS plume control within the drinking water aquifers. The differences among the alternatives would directly relate to the potential of drinking water receptors that are currently unimpacted from becoming impacted in the future for a specific alternative. Providing adequate protection of downgradient wells is a particular concern as the Minnesota Department of Health’s (MDH’s) Health-Based Values (HBVs) for perfluorooctanoic acid (PFOA) is below the current-day laboratory detection limits. Exposure to PFAS concentrations above safe drinking water levels is possible before laboratory testing advancements are made. The ability of an alternative to control the plume and protect downgradient aquifers from impacts largely dictated the ranking of the alternatives.

Alternative 1 is the only alternative where additional remedial action would not be taken at Oakdale Disposal Site (ODS) to decrease the mass flux of PFAS from area of concern (AOC) 3 (ODS – Surface Water) and into groundwater downgradient of this disposal site (AOC 4). Although remedial action at ODS is outside the scope of this FS, as discussed in **Section 12**, it would reduce the PFAS mass loading to downgradient AOCs, including AOC 4 (Downgradient ODS Groundwater) and AOC 5 (Raleigh Creek Surface Water). Reduction of PFAS mass flux from ODS in both groundwater and surface water is crucial in effectively reducing concentrations within and migration through the drinking water aquifers downgradient. One planned remedial action by 3M is the rerouting of Raleigh Creek, which should reduce much of the PFAS migration throughout the Site via surface water. This action is important for reduction of PFAS concentrations in Site surface water, particularly AOC 5 (Raleigh Creek – Surface Water) and AOC 6 (Eagle Point Lake – Surface Water). Additional remedial actions such as increasing groundwater extraction or removal of impacted soils and sediments will likely be required to reduce the migration of PFAS away from ODS.

Human health would also be protected through the implementation of access restrictions to the sediment AOCs in Alternatives 2 through 8. Specifically, access restrictions would reduce the risk of incidental ingestion associated with contact by the public, particularly homeowners in the area, with impacted sediment in AOC 11 (Upper Raleigh Creek Wetland Complexes – Sediment), AOC 12 (Anna’s Grove Wetland Complex – Sediment) and AOC 13 (Eagle Point Lake – Sediment). The reroute of Raleigh Creek along with the installation of in-stream permeable adsorptive barriers (PABs) in AOC 5 (Raleigh Creek – Surface Water) and AOC 9 (Horseshoe Lake/West Lakeland – Surface Water) proposed in Alternatives 3 through 8 may reduce the risk of human exposure to impacted surface water and foam containing high PFAS concentrations. Protection of environmental receptors would occur with reductions in PFAS concentrations in surface water. The implementation of a Washington County Landfill (WCL) source zone treatment at AOC 1 (WCL – Surface Water and Shallow Groundwater) in Alternatives 2 through 8 would aid in the reduction of PFAS migrating into surface water bodies downstream of WCL including Sunfish Lake and Lake Elmo. Additional investigation is required to project the amount of time for restoration to occur, as the contaminant mass flux from the landfill, which is ultimately discharging into surface water bodies, is not currently well understood. Groundwater treatment downgradient of WCL in AOC 2 (WCL – Bedrock Aquifers) and AOC 7 (Raleigh Creek + Eagle Point Lake – Groundwater) in Alternatives 4 through 8 would further aid in reducing the migration of PFAS from groundwater to surface water, including into Lake Elmo and possibly Eagle Point Lake.

Given the similarities of many of the alternatives, plume control and protection of drinking water aquifers is used as the primary differentiator. As 7 of the 8 alternatives include source zone treatment at WCL and 6 of the 8 alternatives include PABs, these remedial approaches are not discussed below unless they are used to differentiate two alternatives. Alternative 1, or no further action (NFA), is the only alternative without source zone control at WCL.

Alternatives 7 and 8 are the most protective of human health. Both alternatives would utilize the Multi-Benefit Well Array (MBWA) to provide drinking water to residents in the cities of Oakdale and Lake Elmo. These alternatives provide the most complete plume control of all the alternatives considered in this FS, while also providing the most protection for downgradient communities. The difference between the alternatives is the method of treatment and the ultimate use of the extracted and treated water from AOC 10 (West Lakeland – Groundwater). In Alternative 7 the water will be treated by a localized pump and treat system in West Lakeland with injection of the entire volume of treated water back into the aquifer. Water extracted in West Lakeland in Alternative 8 will be incorporated into the MBWA for distribution to the cities of Oakdale and Lake Elmo and injection in these cities and West Lakeland. This difference is not expected to make one alternative more protective than the other, as the additional injection capacity is not needed for effective plume control.

Alternatives 4 and 6 are the next most protective of human health, followed by Alternative 5. Alternative 6 includes an MBWA in Lake Elmo to treat groundwater from AOC 2 (WCL – Bedrock

Aquifers) and AOC 7 (Raleigh Creek + Eagle Point Lake – Groundwater) and a pump and treat system in West Lakeland to treat water from AOC 10 (West Lakeland – Groundwater). Alternative 4 would utilize localized pump and treat systems for AOCs 2, 7, and 10 to achieve similar levels of expected plume control along with a separate municipal supply system by the City of Lake Elmo. Alternatives 4 and 6 are ranked lower than Alternatives 7 and 8 due to variation in the treatment of groundwater south of ODS. Alternatives 4 and 6 would rely on the existing municipal supply wells in Oakdale to provide plume containment from AOC 4 (Downgradient ODS Groundwater). As discussed previously, the existing wells do not provide complete plume capture, allowing continued migration of the plume south-southeast towards the Mississippi River. However, Alternatives 7 and 8 would add extraction wells as part of the MBWA in this area, improving plume control in AOC 4. Alternative 5 would only provide plume control within the drinking water aquifers impacted by WCL (AOC 2) and infiltration from Raleigh Creek and Eagle Point Lake (AOC 7), which primarily consists of the plume located within the City of Lake Elmo. Plume control within the drinking water aquifers would not occur in West Lakeland, allowing for the continued eastern migration in this area of the Site. Alternative 5 would also rely on the City of Oakdale municipal supply wells, which provide incomplete plume capture. As Alternative 5 would not provide plume control in AOCs 4 or 10, it is ranked lower than Alternatives 4, 6, 7, and 8 because of the continued migration of PFAS-contaminated groundwater that would occur.

Alternatives 1, 2, and 3 would not include groundwater plume control within the drinking water aquifers and are thus the least protective of human health and the environment. Of these alternatives, Alternative 3 would be more protective than Alternatives 1 or 2 because of the incorporation of in-stream PABs to decrease mass flux of PFAS in surface water AOCs, specifically AOC 5 (Raleigh Creek – Surface Water) and AOC 9 (Horseshoe Lake/West Lakeland – Surface Water). Alternative 2 is more protective than Alternative 1 because of the inclusion of source zone treatment at WCL and access restrictions around contaminated surface water and sediment. Alternative 1, which is the NFA alternative, and current day scenario, would be the least protective of all alternatives considered. Under Alternative 1, no source zone control would be implemented at WCL, allowing continued mass flux of highly concentrated PFAS away from the landfill. Additionally, no groundwater plume control would be implemented, allowing continued plume migration through the drinking water aquifers towards communities that are currently unimpacted. Source zone treatment at ODS would still be expected in Alternative 1 in addition to all others as ODS is managed under the Superfund program.

13.2 Ability to Achieve the Remedial Action Objectives

The ability of each alternative to achieve specific Remedial Action Objectives (RAOs) by AOC is discussed in **Section 12**. Alternatives are ranked for this criterion based on the aggregate scoring of their ability to meet the RAOs across all the AOCs.

Alternatives 8 and 7 are the most likely to achieve RAOs across the AOCs as these alternatives include extraction and injection networks in all groundwater AOCs. This would provide plume control and reduce PFAS concentrations within the existing plume as well as reduce the migration of PFAS to areas that are currently unimpacted based on testing with current-day analytical methods. The difference between these alternatives is whether West Lakeland is incorporated into the MBWA or is a separate, localized pump and treat system. This is not expected to substantially impact the ability of either alternative to achieve applicable RAOs. Both alternatives also provide protection against incidental exposure to impacted sediments through access restrictions and would incorporate PABs to reduce surface water concentrations of PFAS.

Alternatives 4 and 6 are the next most likely to achieve the RAOs. These alternatives differ in that Alternative 6 would incorporate the MBWA and provide municipal supply to the City of Lake Elmo with injection of the remaining water into the Jordan Aquifer, while Alternative 4 treated water would only be injected into the Jordan Aquifer and not provide municipal supply. These two alternatives would not

be as effective at meeting all RAOs as they do not include additional treatment of the plume south of ODS (AOC 4). However, as this plume is partially captured by the Oakdale supply wells, limited plume migration is expected. Alternatives 4 and 6 provide plume control in West Lakeland to meet the RAOs in AOC 10 as well. These alternatives also provide protection against incidental exposure to impacted sediments through access restrictions and would incorporate PABs to reduce surface water concentrations of PFAS.

Alternative 5 does not include pump and treat in West Lakeland (AOC 10) to limit PFAS migration within the drinking water aquifers and is, therefore, unlikely to achieve the RAOs as the plume would continue to migrate to the east towards communities along the St. Croix River. Reduced plume control from AOC 2 (WCL – Bedrock Aquifers) and AOC 7 (Raleigh Creek + Eagle Point Lake – Groundwater) would be achieved through a MBWA municipal supply for the City of Lake Elmo. The ability to achieve the RAOs from AOCs 2 and 7 is the same as in the previously described alternatives. As with previously described alternatives, access restrictions would be imposed to the sediment AOCs and PABs would be implemented to target surface water RAOs.

Alternatives 2 and 3 are unlikely to achieve RAOs as these alternatives focus only on source zone mass control. Alternative 3 does address surface water impacts with PABs specifically within AOC 5 (Raleigh Creek – Surface Water) and AOC 9 (Horseshoe Lake/West Lakeland – Surface Water), which may reduce the infiltration of PFAS from surface water into the drinking water aquifers. Both alternatives would reduce the mass flux of PFAS from AOC 1 (WCL – Surface Water and Shallow Groundwater), which is an important component of the Site-wide remedial approach, but would not address the PFAS mass already within the drinking water aquifers that would continue to migrate downgradient to unimpacted areas. The only PFAS removal from the drinking water aquifers would occur through extraction for municipal supply. These alternatives both provide protection against exposure to PFAS-impacted sediment through access restrictions. With the inclusion of PABs in addition to the proposed Raleigh Creek reroute around ODS by 3M, Alternative 3 would further reduce surface water concentrations in AOC 5 (Raleigh Creek – Surface Water) and AOC 9 (Horseshoe Lake/West Lakeland – Surface Water), aiding in the achievement of surface water RAOs within and downstream of these AOCs. Achieving surface water RAOs is unlikely without surface water treatment, as outlined in Alternative 2, because sediment leaching and discharge of PFAS-impacted groundwater into surface water, specifically into Lake Elmo, would likely result in continued surface water impacts. However, neither alternative would achieve RAOs for any groundwater AOCs, specifically AOC 2 (WCL – Bedrock Aquifers), AOC 7 (Raleigh Creek + Eagle Point Lake – Groundwater), and AOC 10 (West Lakeland – Groundwater).

Alternative 1 would not achieve the RAOs as PFAS mass would continue to migrate away from WCL, ODS, and within the drinking water aquifers towards areas without known PFAS impacts. PFAS removal would only occur through the extraction and treatment of groundwater for municipal supply. While this does provide some level of capture in Oakdale and potentially in Lake Elmo after the installation of the recently proposed municipal supply wells, migration would largely continue into unimpacted areas (Focus Engineering, 2024). The lack of source zone treatment in AOC 1 (WCL – Surface Water and Shallow Groundwater) at WCL would also result in continued migration of PFAS impacts into the drinking water aquifers. Finally, this alternative would not provide protection against incidental exposure of the public to impacted sediment, nor does it incorporate any surface water actions besides the proposed reroute of Raleigh Creek around ODS.

13.3 Long-Term Effectiveness

Based on the widespread impacts across the Site, uncertainty with the amount of PFAS mass remaining at the two source areas, and the low PFAS drinking water standards, the required treatment time is uncertain but is expected to take several decades. Remediation of the drinking water aquifers will occur as PFAS-contaminated groundwater is extracted and treated, either for use as drinking water or for

injection back to groundwater. Source zone treatment in AOC 1 (WCL – Surface Water and Shallow Groundwater) would decrease mass flux of PFAS into the bedrock aquifers, decreasing required treatment time downgradient of this source area. Similarly, additional source zone treatment at ODS, while outside the scope of this FS, is also needed to improve the effectiveness of treatment in AOC 4 (Downgradient ODS – Groundwater). Decreased mass of PFAS in surface water would also decrease mass loading to groundwater, specifically to AOC 7 (Raleigh Creek + Eagle Point Lake – Groundwater) and AOC 10 (West Lakeland – Groundwater). This decrease in mass loading to groundwater would further decrease the required treatment time, although to a lesser extent than source zone treatment at both WCL and ODS where PFAS mass is most concentrated. The focus of this FS is the ability to provide safe drinking water to all communities in the East Metro and to protect drinking water aquifers; therefore, for the long-term effectiveness criterion, alternatives are ranked primarily by their ability to meet this focus.

Alternatives 8 and 7 are expected to have the highest long-term effectiveness. In addition to source zone control at AOC 1 (WCL – Surface Water and Shallow Groundwater), both alternatives provide groundwater plume control across the entire Site, including AOC 2 (WCL – Bedrock Aquifers), AOC 4 (Downgradient ODS Groundwater), AOC 7 (Raleigh Creek + Eagle Point Lake - Groundwater), and AOC 10 (West Lakeland – Groundwater). Implementation of remedial actions in these AOCs would provide long-term drinking water supply protection as well as protection of downgradient receptors. Alternatives 4 and 6 incorporate similar levels of groundwater extraction as Alternatives 7 and 8 but are slightly less effective in the long-term. This is due to the migration that would continue to occur from the groundwater plume south of ODS in AOC 4 (Downgradient ODS Groundwater). This plume would become more diffuse as it migrates south-southwest towards the Mississippi River. There are minimal downgradient receptors and no municipal or private drinking water wells in this area, limiting the potential exposure to the public. Alternative 6 is ranked slightly higher than 4 because of the long-term sustainability component. Separating drinking water treatment from remedial pumping duplicates efforts and requires additional infrastructure, reducing the overall sustainability. Should sufficient groundwater plume control be observed along with decreases in PFAS concentrations in extracted water, these alternatives could be modified in the future to reduce the volume of water extracted and injected to optimize operations costs.

Alternative 5 provides reduced long-term effectiveness compared to the previously discussed alternatives. The City of Lake Elmo would be provided safe drinking water through the MWBA, which would also provide plume control in AOC 2 (WCL – Bedrock Aquifers) and AOC 7 (Raleigh Creek + Eagle Point Lake – Groundwater). However, the lack of plume control in AOC 10 (West Lakeland – Groundwater) would allow the plume to continue migrating east from West Lakeland into downgradient communities and the St. Croix River. Communities downgradient of the plume would have to treat their water in the future. Additionally, incomplete plume control around ODS would allow the groundwater plume to continue migrating south-southeast. As the plume would likely be diluted when it reaches these downgradient communities, granular activated carbon (GAC) used per mass of PFAS removed would be higher as more dilute concentrations would likely decrease GAC performance.

Alternatives 2 and 3 provide significantly less long-term effectiveness, with Alternative 3 being slightly more effective than Alternative 2 because of the incorporation of in-stream PABs in AOC 5 (Raleigh Creek – Surface Water) and AOC 9 (Horseshoe Lake/West Lakeland – Surface Water). While source zone control in AOC 1 (WCL – Surface Water and Shallow Groundwater) would reduce additional PFAS mass flux into the drinking water aquifers, it would not impact the mass already in the drinking water aquifers. These alternatives do not include plume control besides the extraction that occurs by the cities of Oakdale and Lake Elmo for municipal supply, thus PFAS would continue to migrate through AOC 2 (WCL – Bedrock Aquifers), AOC 4 (Downgradient ODS Groundwater), AOC 7 (Raleigh Creek + Eagle Point Lake – Groundwater), and AOC 10 (West Lakeland – Groundwater). PFAS would continue to migrate,

predominantly towards municipal supply wells in communities immediately downgradient of the plume as the municipal supply wells impact groundwater flow directions within the East Metro.

Alternative 1 provides the lowest long-term effectiveness because the source mass at AOC 1 (WCL – Surface Water and Shallow Groundwater) would continue to migrate into the drinking water aquifers. Existing PFAS mass in the drinking water aquifers is also expected to continue to migrate, further impacting downgradient drinking water supplies as described for Alternatives 2 and 3.

13.4 Reduction of Toxicity, Mobility, and Volume through Treatments

The rankings of the alternatives under the reduction of toxicity, mobility, and volume through treatments criterion were largely determined by the ability of each alternative to reduce the downgradient migration of PFAS and the reduction of the mass of PFAS within the drinking water aquifers. Specific considerations, discussed in detail for each alternative in **Section 12**, are:

- Treatment processes employed by alternative
- Amount of PFAS that would be treated
- Degree of expected reduction in toxicity, mobility, or volume
- Degree to which treatment is irreversible
- Type and quantity of residuals that would remain following treatment
- Degree to which treatment reduces Site risks

These specific considerations for each alternative were aggregated into a single score within **Section 12** and used to rank the alternatives below. This analysis focuses on where treatment would occur and not the proposed treatment processes. Analysis of the proposed treatment options are included in **Appendix J** for the pump and treat technologies and **Appendix K** for the drinking water treatment technologies. In all the proposed technologies, the captured PFAS would be permanently removed from the Site and likely destroyed through the proposed technologies.

Alternatives 7 and 8 would have the highest reduction in toxicity, mobility, and volume. These two alternatives treat the largest volume of impacted water and reduce the migration of PFAS from the source areas and through the bedrock aquifers. Mass transfer of PFAS from the AOC 1 (WCL – Surface Water and Shallow Groundwater) source zone and ODS into the drinking water aquifers would be reduced. Additionally, plume capture through extraction and injection wells in AOC 2 (WCL – Bedrock Aquifers), AOC 4 (Downgradient ODS Groundwater), AOC 7 (Raleigh Creek + Eagle Point Lake – Groundwater), and AOC 10 (West Lakeland – Groundwater) would reduce plume migration into unimpacted areas of the drinking water aquifers. This is demonstrated by the particle tracking results for Alternative 7 (**Figure 12.14**) and Alternative 8 (**Figure 12.16**).

Alternatives 4 and 6 treat a smaller volume of water across the entire Site and do not reduce impacts downgradient of ODS in AOC 4 (Downgradient ODS Groundwater). The Oakdale municipal supply wells partially contain this plume as modeled by the particle tracking for Alternative 4 (**Figure 12.8**) and Alternative 6 (**Figure 12.12**); however, downgradient migration would continue, increasing the volume of PFAS-impacted groundwater. Alternatives 4 and 6 would remove similar volumes of PFAS-impacted water and provide similar levels of groundwater plume control to Alternatives 7 and 8 in AOC 2 (WCL – Bedrock Aquifers), AOC 7 (Raleigh Creek + Eagle Point Lake – Groundwater), and AOC 10 (West Lakeland – Groundwater) in addition to source zone control in AOC 1 (WCL – Surface Water and Shallow Groundwater) and at ODS.

Alternative 5 is ranked lower than the previously described alternatives because it extracts and treats a smaller volume of PFAS-impacted water and does not include volume reduction of PFAS-impacted water

in West Lakeland (AOC 10). This would allow PFAS impacts already within the drinking water aquifers in AOC 10 to continue to migrate into areas that are currently unimpacted based on current-day analytical methods, as demonstrated in **Figure 12.10**. Continued spread of the PFAS plume throughout drinking water aquifers that are currently unimpacted would result in an increase of the volume of PFAS-impacted groundwater throughout the region.

Alternatives 3, 2, and 1, ranked in that order, offer the least reduction in the volume of PFAS-impacted water and mobility of PFAS across the Site. None of these three alternatives address PFAS mass already in the drinking water aquifers. The only PFAS mass that would be removed from the groundwater plume would be what is captured by municipal supply wells, which this FS has demonstrated is insufficient to reduce plume migration. Alternative 3 provides the largest reduction in PFAS-impacted water as it incorporates both source zone treatment at AOC 1 (WCL – Surface Water and Shallow Groundwater), ODS which contributes to AOC 4 (Downgradient of ODS) and in-stream PABs in AOC 5 (Raleigh Creek – Surface Water) and AOC 9 (Horseshoe Lake/West Lakeland – Surface Water) to reduce migration of PFAS from surface water to groundwater. Alternatives 4 through 8 also include this treatment. Alternative 2 incorporates WCL and ODS source zone treatment in AOC 1 but does not include PABs in AOCs 5 and 9 and would thus have less reduction than Alternative 3. Alternative 1 provides the least volume reduction, in addition to the lack of mass removal in downgradient AOCs, as it does not include source zone mass removal at WCL or additional treatment at ODS, allowing for PFAS in the vadose zone and Quaternary Aquifer to continue to migrate into the drinking water aquifers. This continued migration will result in the continued spread of the source zone mass downgradient, effectively increasing the total volume of PFAS-impacted groundwater. These effects are demonstrated in particle tracking for Alternative 1 (**Figure 12.2**), Alternative 2 (**Figure 12.4**), and Alternative 3 (**Figure 12.6**).

13.5 Short-Term Effectiveness

The short-term effectiveness criterion was evaluated for each alternative based on the following considerations:

- Ability to mitigate risks to the community during implementation of an alternative
- Ability to mitigate potential impacts on workers
- Potential environmental impacts of remedial actions
- Time until protection is achieved

At the Site, exposure to PFAS through drinking water is the highest risk while dermal and inhalation risks are relatively low. With drinking water treatment as the primary focus of this FS, the time until protection is achieved was given the greatest weight among the considerations listed above, followed by potential environmental impacts of remedial actions. Unlike other remediation projects, which could involve potential re-release of a contaminant while remedial action is taken, the main implementation risks are standard construction risks. Any construction project could pose a marginal risk to community members and workers; however, these risks are readily mitigated with industry-standard safe work practices. Thus, risks to workers and the community during implementation and operation of the remedial actions are weighted lower than time until protection is achieved. Finally, some aspects of environmental impact are dependent on the treatment train selected; proposed pump and treat treatment trains are detailed in **Appendix J**, and proposed MBWA treatment trains are detailed in **Appendix K**.

Alternative 8 would have the highest short-term effectiveness as it would pump the most water and provide the most complete groundwater plume capture. Alternative 8 would include the largest total treatment plant capacity of any of the alternatives and thus a higher risk of construction accidents compared to other alternatives due to the larger treatment plant size. The higher risk, which could easily

be mitigated through health and safety plans and proper controls, is offset in scoring by the increased effectiveness of plume capture and the corresponding protection of drinking water aquifers (decreasing time until protection achieved). No risks beyond standard construction risks are expected with this alternative.

Alternatives 7, 6, and 4 are expected to have the next highest short-term effectiveness in that order. Like Alternative 8, risks to the community and workers could be mitigated with standard safety practices for all three alternatives. Alternative 7 would provide more plume control than Alternative 6, thus is expected to achieve protection in slightly less time. Alternative 4, which would extract less water than Alternatives 6 or 7, would duplicate efforts as remediation would be separated from drinking water treatment. This duplication of treatment efforts could decrease the effectiveness of plume control as extraction wells may not be optimally placed and is also likely to have a larger environmental impact by utilizing multiple treatment plants.

Alternatives 5, 3, and 2 are next in terms of short-term effectiveness. In Alternative 5, use of the MBWA to combine some plume control in Lake Elmo with drinking water treatment could decrease the environmental impact of this alternative. However, as this alternative does not include plume control in West Lakeland, this alternative is scored lower than others that do include more substantial plume control. For that same reason, Alternatives 3 and 2 are ranked lower than previous alternatives. Neither alternative includes plume control, though both include source zone treatment at WCL and improved source zone treatment at ODS, which would decrease mass loading to the drinking water aquifers. Alternative 3 is ranked above Alternative 2 as it includes in-stream PABs, which may decrease mass loading to drinking water aquifers from surface water, improving time until protection is achieved.

Alternative 1 poses the least risk to the community or workers during implementation of remedial actions as there would be no remedial actions implemented. Short-term risk to communities is also relatively low, as temporary treatment has already been installed for many communities. However, as this alternative incorporates no remedial actions, the time until protection is achieved and the corresponding risk to communities, when considered for the long-term risk to communities, is high. Not only would the groundwater PFAS plume continue to spread to currently unaffected communities, this alternative also does not include source zone control. This will allow additional mass loading to the drinking water aquifers, which will further degrade the aquifers. Finally, while the environmental impact of Alternative 1 in the short-term may be lower than other alternatives, since no remedial actions would be taken, reliance on single-use GAC and consumption of adsorptive media could increase as the plume spreads. Treatment of a plume as it gets increasingly dilute decreases the efficiency of treatment and increases the amount of GAC required. As such, Alternative 1 has the lowest short-term effectiveness due to the time until drinking water aquifers are protected and potential long-term environmental impact.

13.6 Implementability

The implementability criterion incorporates an analysis of technical feasibility, administrative feasibility, and availability of services and materials. Where appropriate, potential short- and long-term variation in scoring of these considerations is discussed. The core tenant of this FS is that safe drinking water must be provided to all affected communities. Although not all the alternatives include an MBWA, which combines groundwater treatment with municipal supply, the implementation of drinking water treatment is considered in this evaluation. Key components in this evaluation are the number of treatment plants that would be installed, including those for municipal supply as described in the Conceptual Drinking Water Supply Plan (CDWSP), the amount of total water that would be treated for both plume capture and drinking water supply, and whether injection permitting would be required.

Table 13.2 summarizes the number of treatment plants and total volume of water treated for each

alternative. The pumping estimates of the pump and treat and MBWA plants may be altered during the design phase once the final alternative is selected.

Table 13.2: Summary of Total Volume of Groundwater Treated by Alternative

Alternative ⁽¹⁾	Number of Water Treatment Plants	FS Proposed Treatment Volume (MGD)	2040 Average Daily Demand from CDWSP (MGD)	Total Volume Treated (MGD)
Alternative 1	2 (Oakdale and Lake Elmo)	No treatment	Lake Elmo: 2.3 Oakdale: 3.1	5.4
Alternative 2	3 (Oakdale, Lake Elmo, and WCL)	WCL Treatment: 0.8	Lake Elmo: 2.3 Oakdale: 3.1	6.4
Alternative 3	3 (Oakdale, Lake Elmo, and WCL)	WCL Treatment: 0.8	Lake Elmo: 2.3 Oakdale: 3.1	6.4
Alternative 4	4 or 5 (Oakdale, Lake Elmo, WCL, and West Lakeland and Raleigh Creek / Eagle Point Lake pump and treat) ⁽²⁾	WCL Treatment: 0.8 Bedrock Aquifer Pump and Treat: 7.2	Lake Elmo: 2.3 Oakdale: 3.1	13.6
Alternative 5	3 (Oakdale, Lake Elmo MBWA, and WCL)	WCL Treatment: 0.8 MBWA: 7.1	Oakdale: 3.1	11.0
Alternative 6	4 (Oakdale, Lake Elmo MBWA, WCL, and West Lakeland)	WCL Treatment: 0.8 MBWA: 7.1 Bedrock Aquifer Pump and Treat: 2.9	Oakdale: 3.1	13.9
Alternative 7	4 (Oakdale MBWA, Lake Elmo MBWA, WCL, and West Lakeland)	WCL Treatment: 0.8 MBWA: 10.8 Bedrock Aquifer Pump and Treat: 2.9	No separate drinking water treatment	14.5
Alternative 8	3 (Oakdale MBWA, Lake Elmo MBWA, and WCL)	WCL Treatment: 0.8 MBWA: 15.3	No separate drinking water treatment	16.1

¹ All Alternatives assume treatment occurs at ODS; ODS treatment is outside the scope of this FS and is managed through the Minnesota Pollution Control Agency (MPCA) Superfund program.

² Separate treatment plants could be constructed to treat groundwater from Raleigh Creek / Eagle Point Lake and West Lakeland, or a larger, combined plant could be built to treat water from all three areas. For more details, see **Appendix J**.

Legend: CDWSP = Conceptual Drinking Water Supply Plan; MBWA = Multi-Benefit Well Array; MGD = million gallons per day; WCL = Washington County Landfill.

Alternative 1 is currently considered the most implementable in the short-term because it does not have any actions outside what is outlined in the CDWSP (MPCA, 2021). Oakdale and Lake Elmo would install new wells and treatment facilities independently of each other. POETs would continue to be installed on private wells in West Lakeland and elsewhere in the East Metro based on well sampling results. However, the implementability of this alternative faces long-term challenges. As the plume would continue to migrate, additional downgradient communities would require treatment and additional private wells would require POETs, which would increase the complexity of implementation. Operations and maintenance may also be more complex for downgradient communities who already have drinking water treatment, such as Woodbury, because lack of source zone treatment in Alternative 1 would likely result in greater PFAS loading to the system. Additionally, the CDWSP was published prior to MDH publishing updated HBVs for PFOA and perfluorooctane sulfonate (PFOS). The combination of continued plume migration and lowered intervention limits would likely result in increased frequency of GAC change outs and a subsequent increase in the disposal of impacted media. Although this alternative

is the most implementable in the short term, as it requires no additional remedial actions, long-term challenges would likely decrease the implementability of this alternative in the future.

Alternatives 2 and 3 are similar to each other and are expected to be slightly less implementable compared to Alternative 1 because of the addition of the WCL pump and treat system. Alternative 3 would be slightly less implementable than Alternative 2 because of the addition of the in-stream PABs. Although the use of PABs is not expected to greatly decrease the implementability, it will require additional permits and engineering efforts.

Alternative 5 is the most implementable out of the alternatives that include active treatment of the drinking water aquifers beyond the current extraction for municipal drinking water supply. The conceptual MBWA proposed in Alternative 5 would replace the Lake Elmo municipal supply wells and drinking water treatment plant. However, depending on the implementation timeframe, utilization of existing infrastructure would be prioritized during full-scale design and would likely result in changes to the conceptual MBWA presented in this document. The implementability of Alternative 5 is lower than Alternatives 2 and 3 because the required treatment capacity is higher for Alternative 5, and Alternative 5 includes injection wells and additional extraction wells compared to the proposed Lake Elmo municipal supply wells to aid in plume capture. Permitting would be required for the injection of treated water. Although injection permitting is not expected to delay the project, it would require additional effort to obtain state and federal agency approval.

Alternative 6 is less implementable than Alternative 5 because it includes an additional pump and treat system in West Lakeland. The location of a treatment plant in West Lakeland has not been specified and the degree to which the associated piping network would impact the implementability depends on the location of the treatment plant.

Alternative 7 is less implementable than Alternative 6 because it includes larger treatment facilities and would require coordination between the cities of Lake Elmo and Oakdale for injection of treated water. The conceptual MBWA proposed in this alternative would utilize separate treatment plants so both communities can meet their water demand throughout the year. However, injection of excess treated water into the Jordan Aquifer would utilize a combined piping network for the injection. Separating the systems would allow less flexibility in injecting sufficient water to promote PFAS capture and may increase the costs as a longer piping network would likely be required but would not require coordination between the communities.

Alternatives 4 and 8 are expected to be the least implementable and to have a similar level of implementability. While both would require permitting for injection well networks, both alternatives would also have their own, unique challenges. Alternative 4 requires the installation of separate pump and treatment systems in addition to drinking water supply wells and treatment plants. This duplication of effort by having separate treatment plants for remediation and drinking water treatment decreases the implementability of this alternative by requiring redundant efforts to achieve similar levels of groundwater capture. However, separation of the remediation pump and treatment plant from the provision of drinking water may face fewer administrative challenges as less coordination with the affected communities would be required. Alternative 8 has lower implementability relative to the other MBWA alternatives because it requires Oakdale, Lake Elmo, and West Lakeland to coordinate efforts to extract water for supply to Oakdale and Lake Elmo. While the two cities would have separate drinking water plants to provide municipal supply to their communities, the injection well network would be combined, requiring coordination between the communities. If the communities raised objections to having a combined injection well network, the well networks could be separated between the two communities. Separate networks would result in additional piping and would allow for less flexibility in coordinating efforts to meet demand and inject treated water back into the Jordan Aquifer at the specified injection rates.

13.7 Cost

Table 13.3 provides summary cost estimate ranges of capital expenditures (CAPEX) and yearly operating expenditures (OPEX) for each alternative. **Section 12** provides a more detailed breakdown of cost estimates by remedial action for each alternative. Some alternatives include incorporation of an MBWA to use extracted groundwater to provide drinking water to residents in addition to plume control. Regardless of whether the MBWA is implemented, safe drinking water supply to these communities is required. Thus, drinking water supply costs for Lake Elmo, Oakdale, and West Lakeland are included for all alternatives, including the non-MBWA alternatives. Inclusion in these cost analyses provides a more accurate representation of the cost to supply communities with safe drinking water, in addition to remedial efforts.

Drinking water costs are largely based on information provided in the CDWSP, though costs were updated for inflation and increased costs of POETSS as provided by the MPCA. As previously discussed, the CDWSP was written prior to MDH publishing updated HBVs for PFOA and PFOS. As a result of these lowered values, OPEX costs are expected to increase for currently affected communities due to increased GAC changeouts. Additionally, other communities that do not currently require treatment will likely require treatment in the future. There is uncertainty around this as the HBV for PFOA is below current instrument detection limits, meaning communities that are currently believed to be unimpacted may in fact have PFOA levels above the HBVs. As a result, costs derived from the CDWSP are likely underestimating the true cost of treatment that will be required.

Multiple treatment trains were considered for both pump and treat systems and the MBWA drinking water systems. Cost estimates are treatment train dependent; thus, the highest and lowest cost options are included to provide the potential range of total project cost. Additionally, the costs to supply drinking water to Lake Elmo and Oakdale for the non-MBWA alternatives may be updated in the future based on the estimates provided to the MPCA by the affected communities.

Cost estimates are accurate to -50% to +100%, consistent with a Class V estimate. The MBWA costs are accurate to -30% to +50% due to the increased confidence in flow rates and locations of treatment plants. However, all other cost estimates, and thus the overall costs estimates, were prepared to the -50% to +100% estimating accuracy. Media usage rates were determined using rapid small-scale column tests (RSSCTs). Additionally, as costs associated with PFAS treatment including GAC, ion exchange (IX) resin, and destruction and disposal have been increasing rapidly, these cost estimates should be reevaluated prior to final selection of a treatment train. Costs presented in **Table 13.3** attempt to account for these uncertainties.

Table 13.3: Summary Ranges of Capital Expenditure and Operating Expenditure Costs by Alternative in Million USD

Alternative	CAPEX (Million USD)	Yearly OPEX (Million USD)
Alternative 1: No further action	\$148M to \$187M	\$4.2M to \$8.3M
Alternatives 2–8: WCL Source Area Treatment Costs		
Alternatives 2–8: WCL Source Area Treatment ⁽¹⁾	\$17M to \$49M	\$1.5 to \$44.4M
Alternatives 2–8: Non-Source Area Treatment Costs		
Alternative 2: Access restrictions and long-term monitoring of AOCs downgradient of source areas	\$151M to \$190M	\$4.3M to \$8.6M
Alternative 3: Treatment in areas of known infiltration from surface water and long-term monitoring / access restrictions of areas downgradient of treatment.	\$155M to \$193M	\$5.2M to \$9.5M
Alternative 4: Treatment in areas of known surface water infiltration, localized treatment of groundwater AOCs, and long-term monitoring / access restrictions of AOCs downgradient of treatment.	\$242M to \$399M	\$8.9M to \$18.7M
Alternative 5: Extraction and treatment of groundwater in Lake Elmo for MBWA, public supply to Lake Elmo, no additional groundwater treatment in West Lakeland or Oakdale.	\$143M to \$214M	\$8.2M to \$24.6M
Alternative 6: Extraction and treatment of groundwater in Lake Elmo for MBWA, public supply to Lake Elmo, separate groundwater treatment in West Lakeland.	\$181M to \$308M	\$10.0M to \$29.2M
Alternative 7: Extraction and treatment of groundwater in Oakdale and Lake Elmo for MBWA, public supply to Oakdale and Lake Elmo, and separate treatment in West Lakeland.	\$210M to \$366M	\$12.0M to \$41.3M
Alternative 8: Regional MBWA treatment in all groundwater AOCs (Oakdale, Lake Elmo, and West Lakeland) and public supply to Oakdale and Lake Elmo.	\$210M to \$356M	\$10.8M to \$39.8M

¹ Source area treatment at WCL is included in Alternatives 2 through 8. Funding sources may be separate for treatment at WCL as opposed to treatment throughout the Project 1007 Site, thus treatment costs for WCL are presented separately. Costs to treat ODS are not included here because they are outside the scope of this FS. Total treatment costs for treatment located within the Project 1007 Site and the source zone treatment at WCL can be calculated by adding the costs of WCL treatment to the cost listed for Alternatives 2–8.

Cumulative costs ranges for WCL (AOC 1) treatment are shown in **Figure 13.1**, with sorbent-based (e.g., GAC or IX) treatment trains compared to foam fractionation–based treatment trains. Significant cost uncertainty exists due to high levels of perfluorobutanoic acid (PFBA). No differences in treatment are proposed for AOC 1 in Alternatives 2–8; **Figure 13.1** is applicable for WCL treatment for these alternatives. Cumulative cost range comparisons of Alternative 1 to each other alternative for 25 years of operation are shown in **Figure 13.2** (Alternative 2), **Figure 13.3** (Alternative 3), **Figure 13.4** (Alternative 4), **Figure 13.5** (Alternative 5), **Figure 13.6** (Alternative 6), **Figure 13.7** (Alternative 7), and **Figure 13.8** (Alternative 8). These figures show treatment costs for all proposed remedial actions except for actions proposed for AOC 1. Costs are given in million U.S. Dollars (USD). For this analysis, costs are not adjusted for inflation; more detailed cost comparison of several alternatives may be warranted prior to final alternative selection.

Costs for additional treatment at ODS were not developed as part of this FS. Those would be developed by 3M and used in the determination of additional remedial actions through the Superfund program.

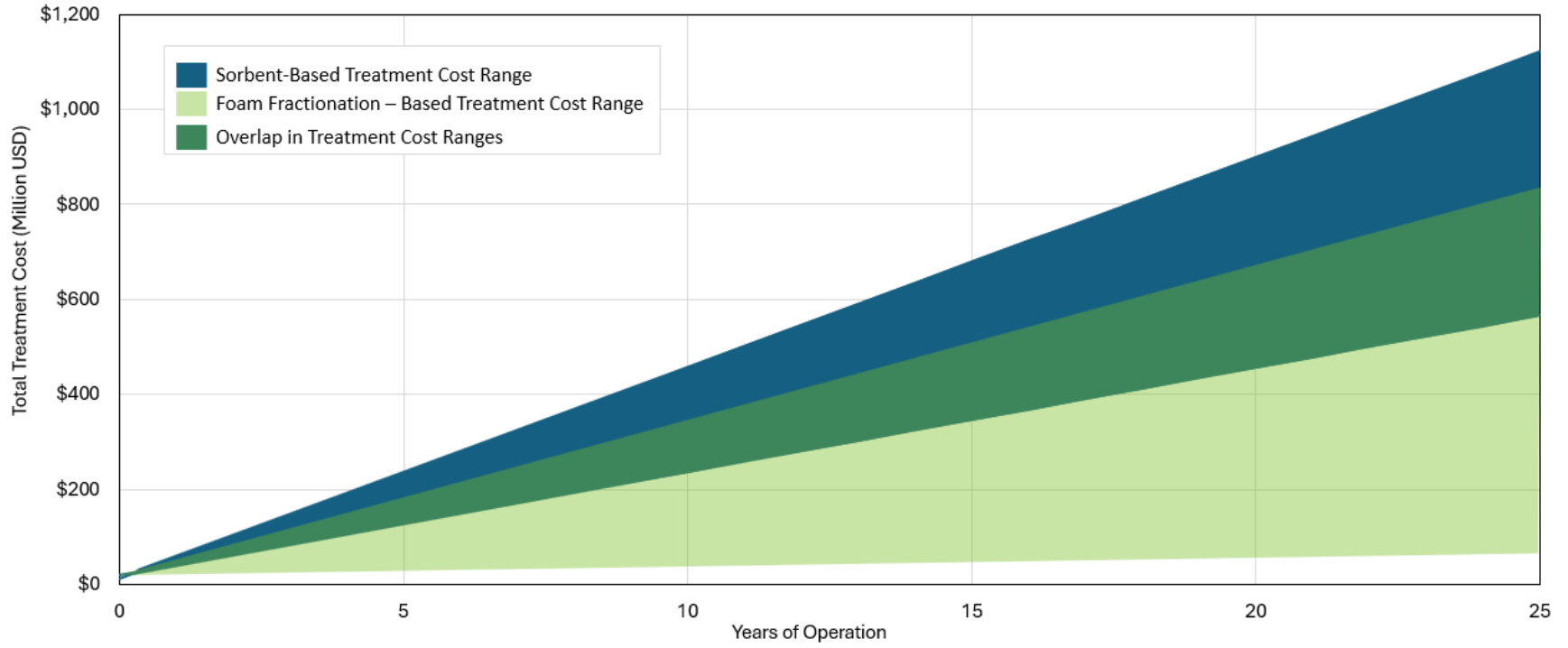


Figure 13.1: Washington County Landfill 25-year operating cost ranges: sorbent-based treatment versus foam fractionation-based treatment

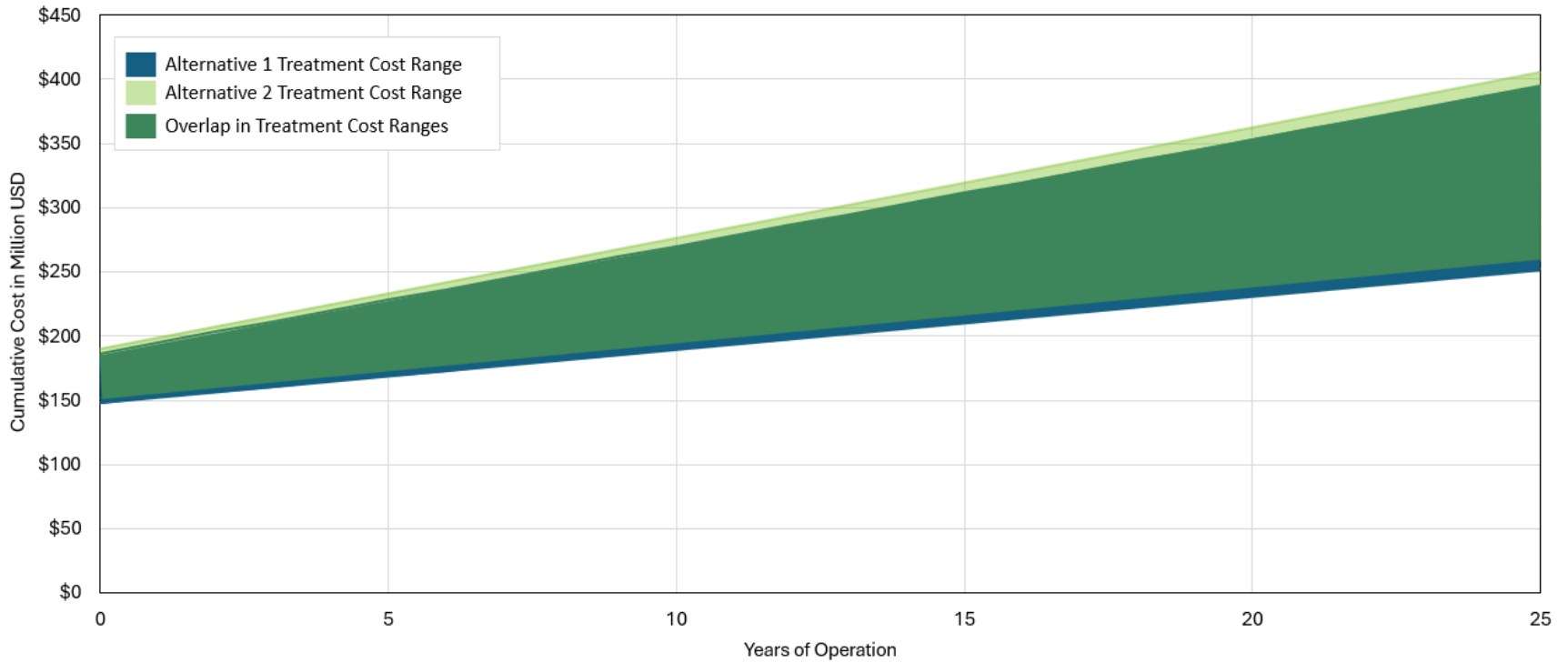


Figure 13.2: 25-year operating cost comparison: Alternative 1 and Alternative 2

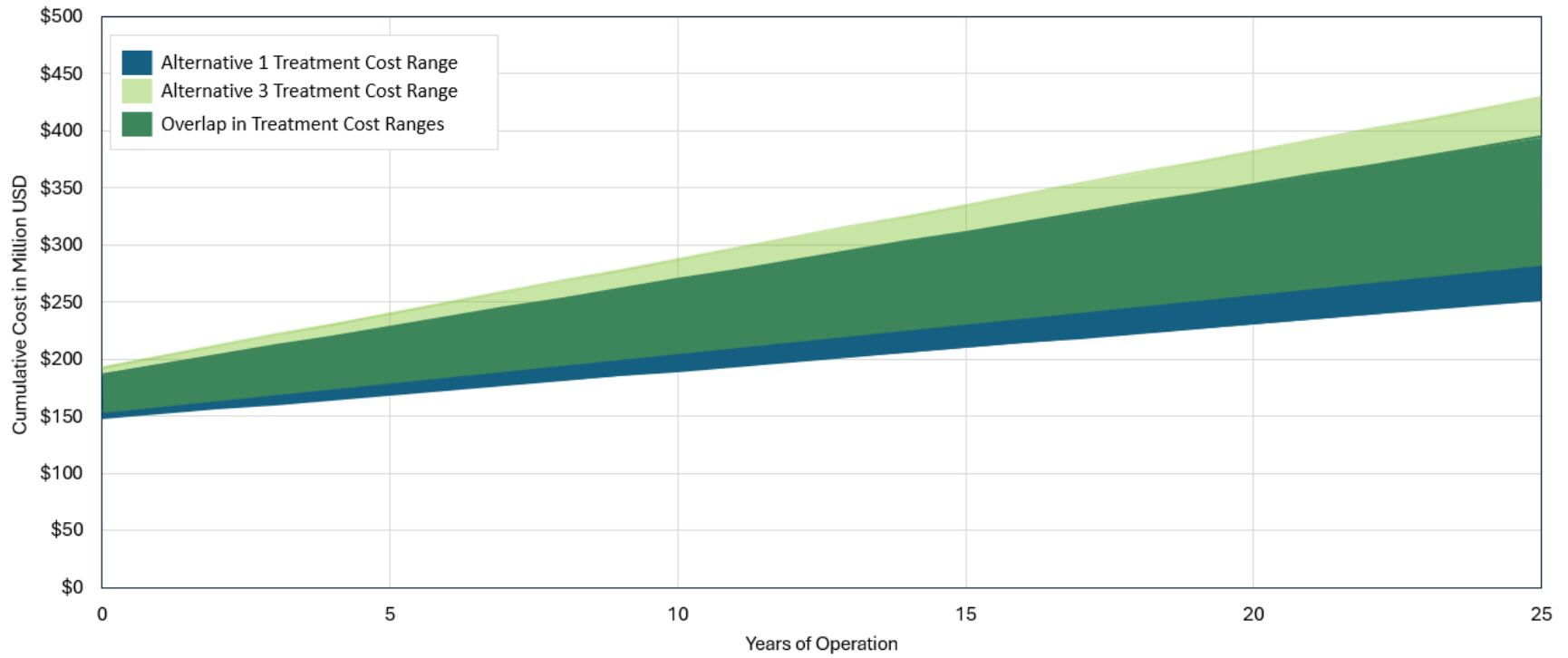


Figure 13.3: 25-year operating cost comparison: Alternative 1 and Alternative 3

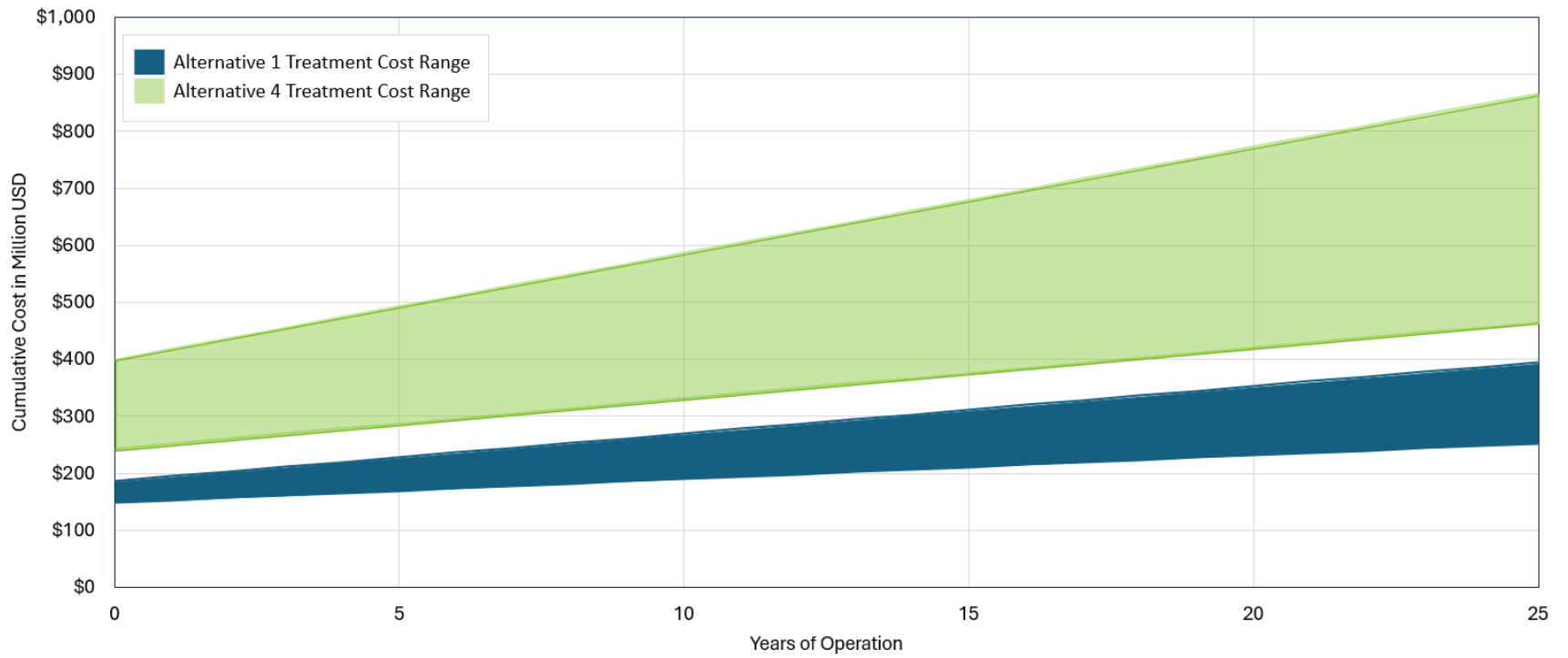


Figure 13.4: 25-year operating cost comparison: Alternative 1 and Alternative 4

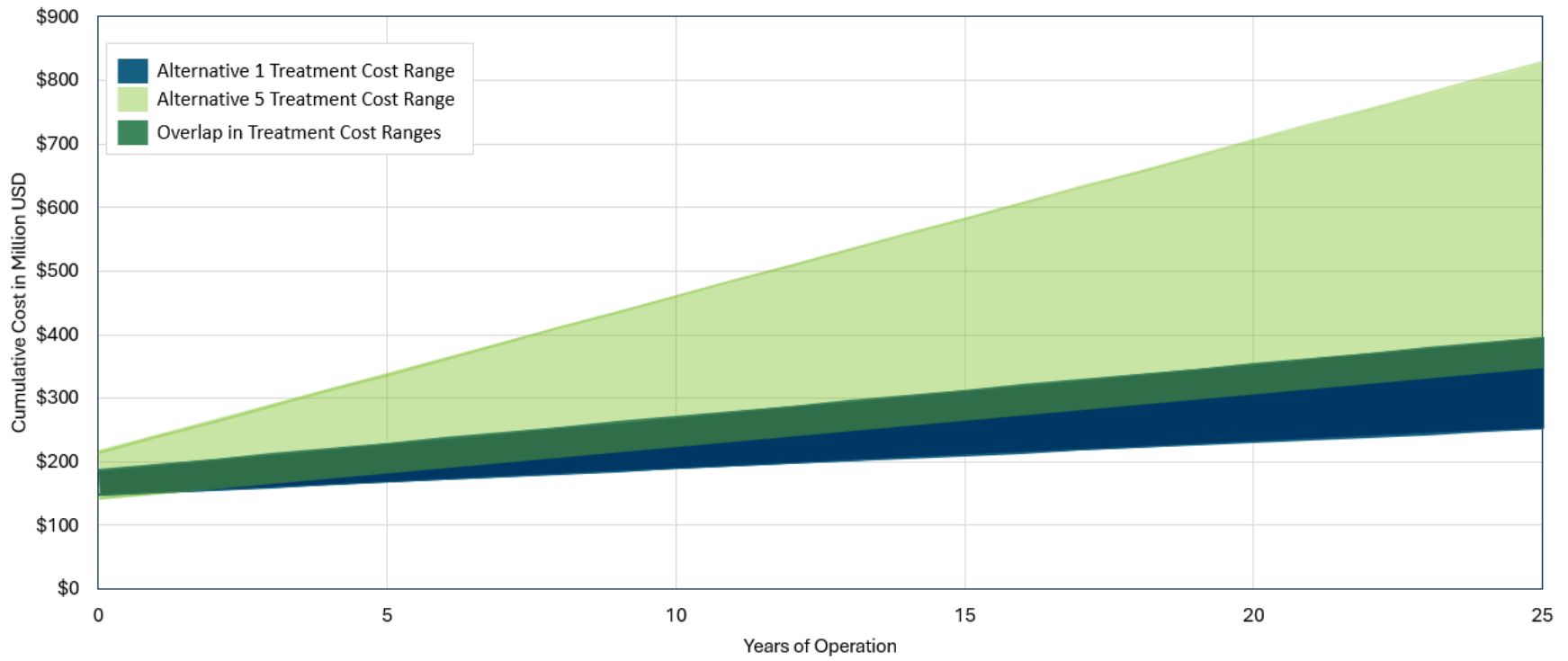


Figure 13.5: 25-year operating cost comparison: Alternative 1 and Alternative 5

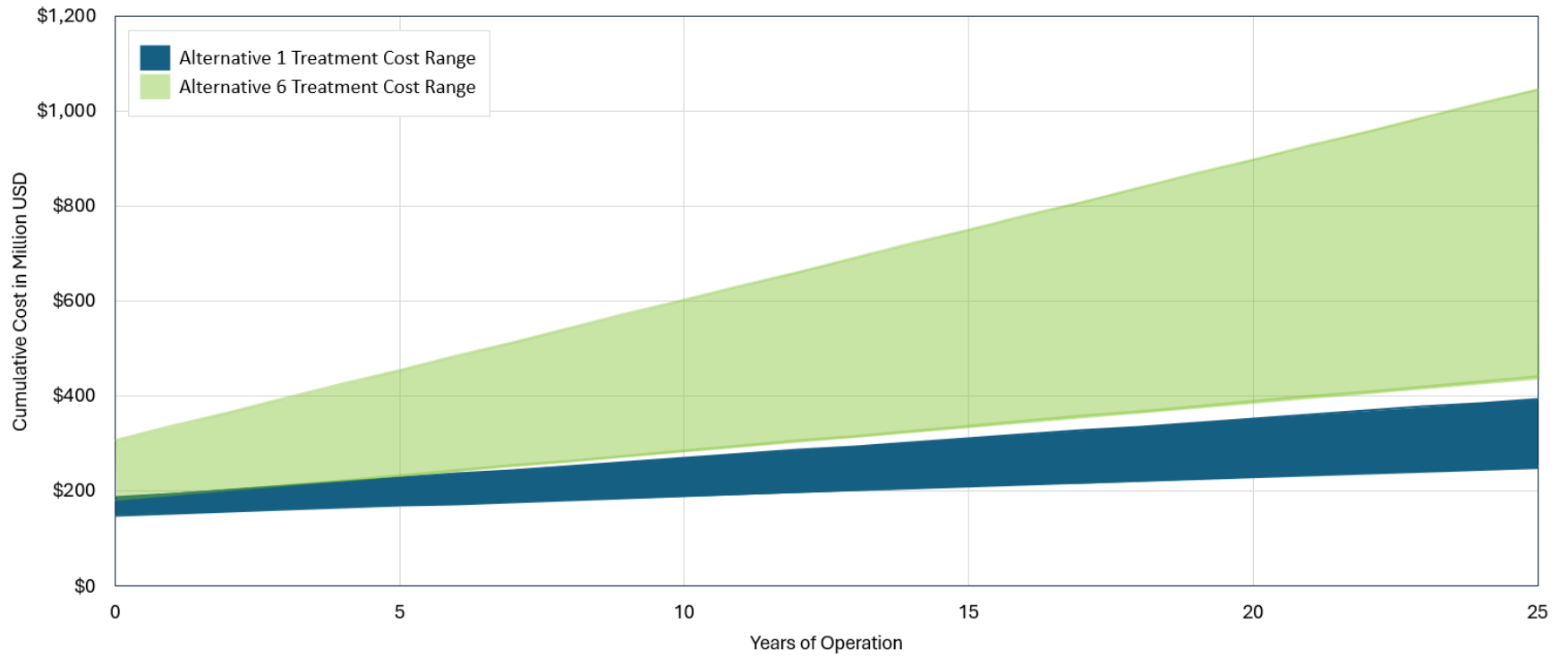


Figure 13.6: 25-year operating cost comparison: Alternative 1 and Alternative 6

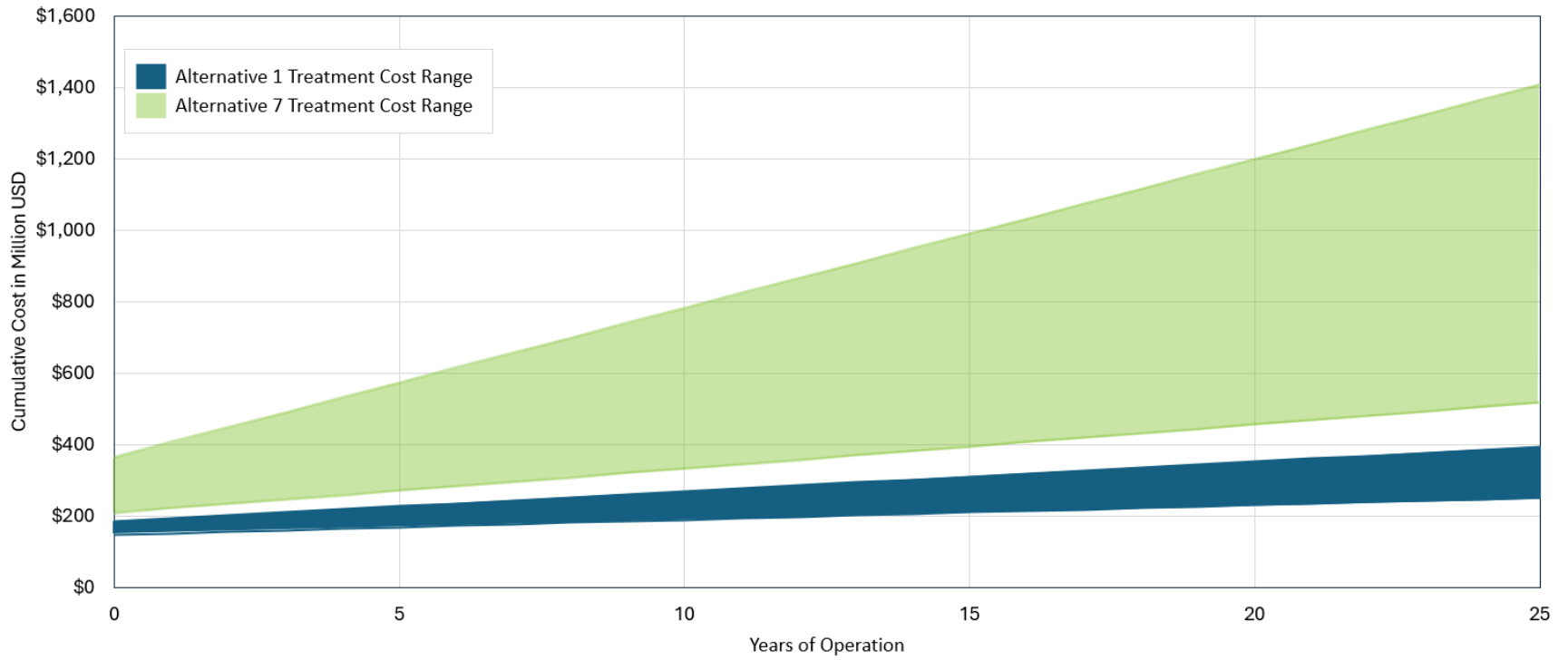


Figure 13.7: 25-year operating cost comparison: Alternative 1 and Alternative 7

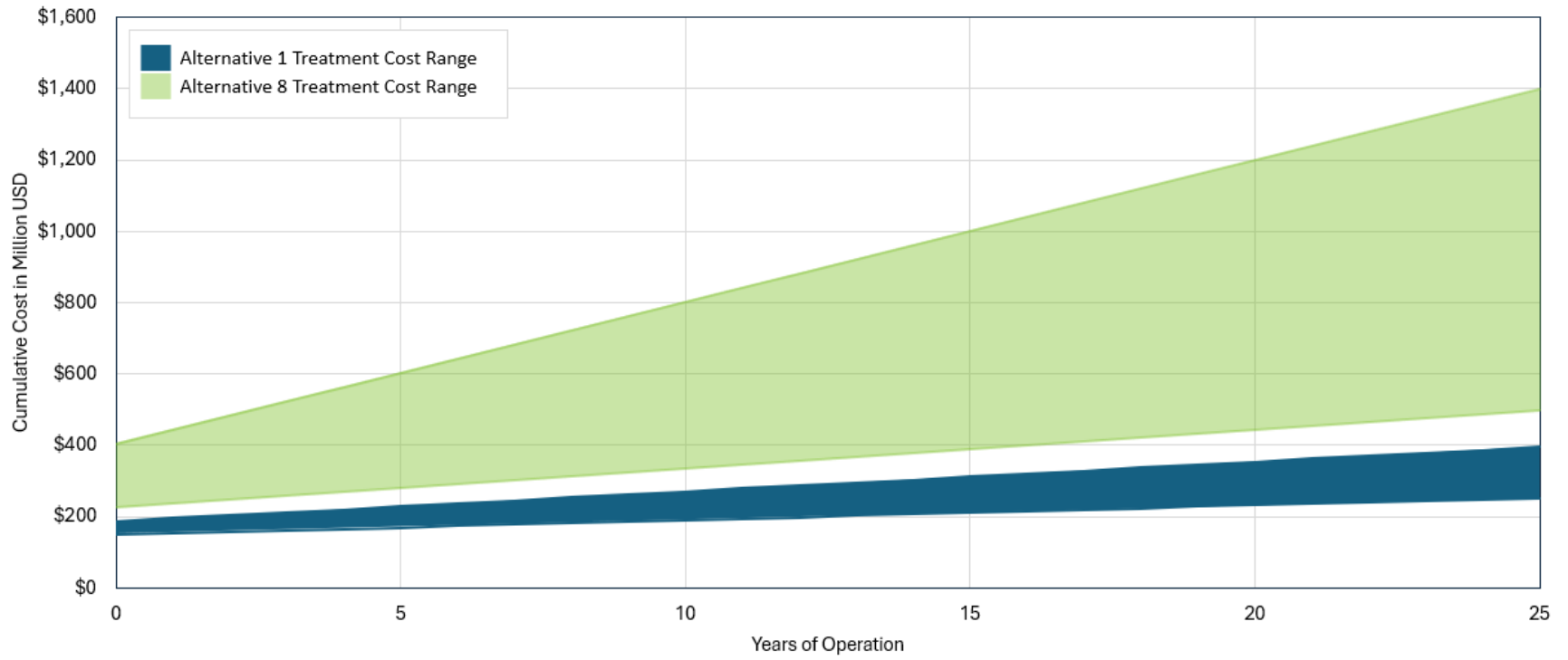


Figure 13.8: 25-year operating cost comparison: Alternative 1 and Alternative 8

13.8 Green and Sustainable Remediation

Consideration of remedial action sustainability is not a specific NCP criterion and was thus not included in **Section 12**. Instead, it was incorporated into both long-term and short-term effectiveness, albeit in a limited fashion. These limited considerations fall short of recent sustainable remediation standards, including the MPCA's *Green and Sustainable Remediation* (MPCA, 2024) and the Interstate Technology and Regulatory Council's (ITRC's) *Sustainable Resilient Remediation* (ITRC, 2021) guidance. To better understand the comprehensive long-term impacts of remediation at the regional scale, additional work is required. This work is discussed further in **Section 14**.

13.9 Protection of Other Receptor Pathways

As this FS focuses on drinking water aquifers and the protection of drinking water for current and future uses, other receptor pathways were not considered in the evaluation. Other receptor pathways include other ways for humans to come in contact with PFAS including through recreation such as swimming or through fish consumption. The alternatives presented also do not address ecological receptors, which are known to be impacted based on the Baseline Ecological Risk Assessment (AECOM, 2021). Additional remedial actions may be required to address these receptor pathways to be protective of human and ecological health.

14 Recommendations and Next Steps

This section recommends a remedial alternative based on the analysis completed in this Feasibility Study (FS) and summarizes the actions that should be taken to proceed towards the design and implementation of the recommended actions.

14.1 Recommended Alternative

Based on the analysis completed in **Sections 12 and 13**, AECOM recommends Alternative 8 to address Site-wide per- and polyfluoroalkyl substances (PFAS) concerns focused on the protection of drinking water aquifers. Alternative 8, depicted in **Figure 14.1** below, includes the following components:

- Source zone control at Oakdale Disposal Site (ODS) to reduce migration of PFAS from the disposal site in the Quaternary and bedrock aquifers and subsequent discharge at Hadley Avenue via Raleigh Creek surface water. This would be completed by 3M under the Superfund Program and this FS does not include any proposed specific remedial actions or changes to the remedial alternatives outlined for ODS in the Minnesota Decision Document (MPCA, 2008). While specific remedial actions are not discussed, this FS assumes 3M will complete additional source zone treatment at ODS to reduce the migration of PFAS impacts via groundwater and surface water.
- Source zone control at Washington County Landfill (WCL) must occur to reduce the migration of PFAS downgradient via surface water and groundwater and for treatment downgradient of these source areas to be effective. At WCL, ongoing sources include vertical migration into the bedrock aquifers, primarily to the east of WCL, and continued migration of impacts in the Quaternary Aquifer, which also discharge into Sunfish Lake and Lake Elmo.
- Groundwater extraction by the Multi-Benefit Well Array (MBWA) for treatment to provide drinking water supply to the cities of Lake Elmo and Oakdale. Extraction would occur in West Lakeland, Lake Elmo, and Oakdale. Treated water in excess of the drinking water demand for Lake Elmo and Oakdale would be injected into the Jordan Aquifer in West Lakeland, Lake Elmo, Oakdale, and Woodbury to achieve plume control of impacts migrating in the following areas:
 - South and southwest from ODS towards St. Paul and Maplewood within the Jordan and Shakopee Aquifers
 - South from ODS, Raleigh Creek, and Eagle Point Lake towards the Tamarack Well Field in Woodbury within the Jordan and Shakopee Aquifers
 - East from the West Lakeland storage ponds within the Jordan and Shakopee Aquifers towards communities and private wells along the St. Croix River
 - East and southeast from WCL within the Jordan and Shakopee Aquifers towards unimpacted aquifers east of WCL and discharging to Lake Elmo
 - From multiple areas of the Site vertically into the Tunnel City Aquifer
- Surface water treatment with in-situ permeable adsorptive barriers (PABs) to reduce surface water concentrations resulting from sediment leaching or incidental release of PFAS-containing surface water from ODS targeting the following migration pathways:
 - Downstream from Raleigh Creek to Eagle Point Lake and infiltration from both water bodies
 - Downstream from Eagle Point Lake and Lake Elmo to Horseshoe Lake and the West Lakeland storage ponds with infiltration from these listed waterbodies
- Sediment access restrictions to reduce the potential for public exposure to impacted sediments, including those near residential areas

- Long-term monitoring of groundwater and surface water impacts

Alternative 8 was selected as the preferred remedy because it provides the most widespread protection of drinking water aquifers while also supplying drinking water to affected communities. Alternative 8 also provides flexibility in meeting future drinking water demands for the cities of Oakdale and Lake Elmo. Further, Alternative 8 could be designed to meet drinking water demands of other communities, such as West Lakeland or the planned Prairie Island Indian Community located near Interstate 94 east of Lake Elmo. This alternative would also reduce the total number of water treatment plants constructed by combining remediation treatment with drinking water treatment, thus minimizing duplicate treatment efforts. PFAS discharge requirements would be the same for both remediation and drinking water treatment; consolidated treatment plants would provide the same standard of water to communities and increase the cost-effectiveness of treatment plant operations. The detailed analysis and comparison of the alternatives are presented in **Sections 12** and **13**, respectively.

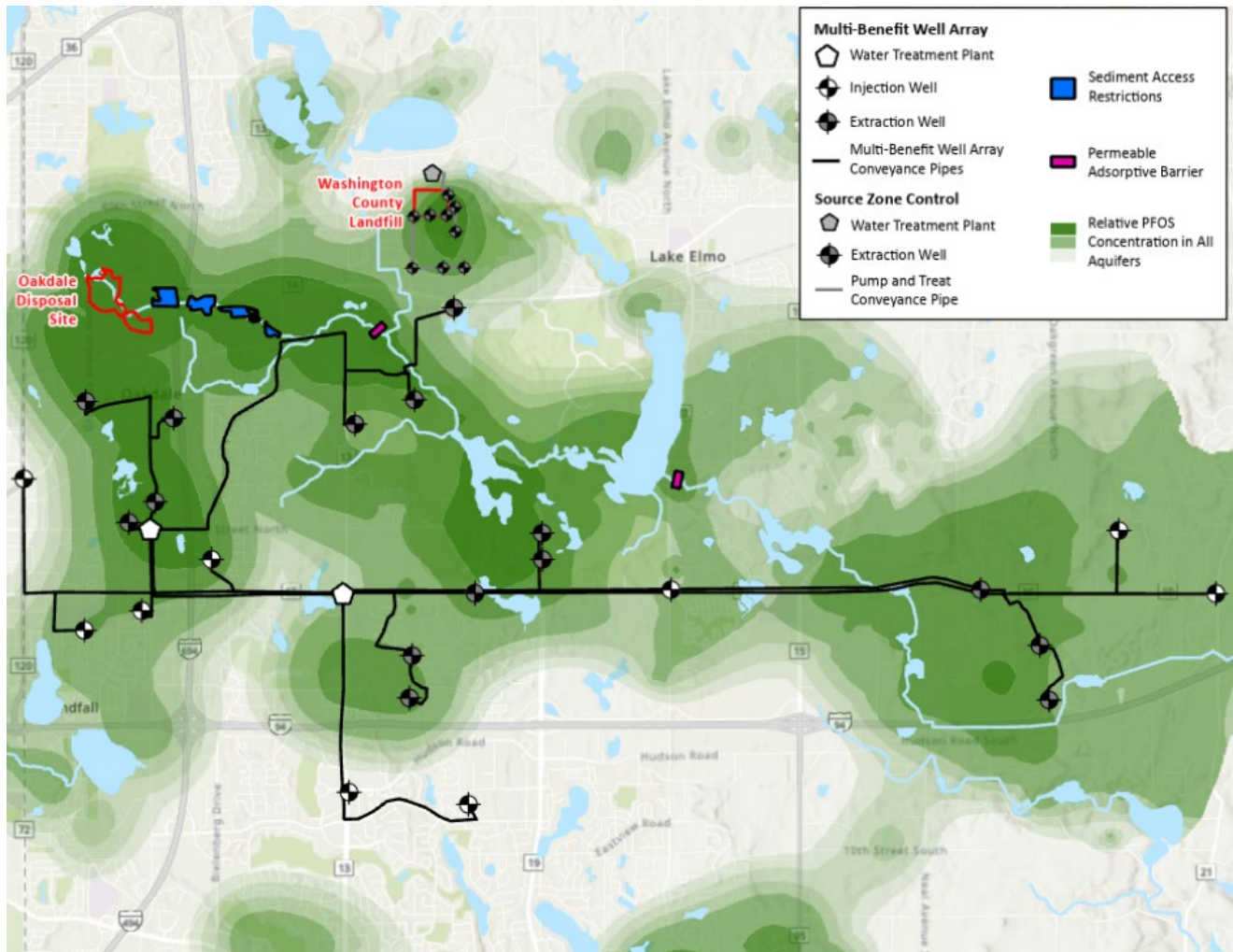


Figure 14.1: Locations of proposed remedial actions in Alternative 8

The primary challenges regarding Alternative 8 are the costs for construction and annual operations and maintenance (O&M). Based on the initial cost estimate, the capital expenditures (CAPEX) costs are expected to range from \$227.0M to \$404.2M. Annual operating expenditures (OPEX) cost estimates are expected to range from \$12.3M to \$84.2M. **Appendices I** and **J** detail these cost estimates, which can be broken down by component as follows:

- WCL pump and treat (including treatment plant and piping)
 - CAPEX: \$16.9M to \$48.6M
 - OPEX: \$1.5M to \$44.4M
- ODS additional investigation and remediation
 - Costs will be associated with ODS to reduce migration of PFAS; however, these costs were not estimated as part of this FS. The work and associated costs completed under the Superfund Program will be the responsibility of 3M.
- MBWA (including treatment plant and all associated wells, piping, and storage)
 - CAPEX: \$198.4M to \$343.8M
 - OPEX: \$8.4M to \$35.8M
- West Lakeland point of entry treatment systems (POETSS)²
 - CAPEX: \$5.5M
 - OPEX: \$1.5M to \$2.9M
- Access Restrictions
 - CAPEX: \$1.5M
 - OPEX: \$24K
- Surface water treatment with PABs
 - CAPEX: \$3.3M
 - OPEX: \$0.83M
- Long-Term Monitoring
 - CAPEX: \$1.6M
 - OPEX: \$0.14M to \$0.29M

The treatment plants for Oakdale and Lake Elmo are separate, and each community would operate with a separate supply. However, there are logistical concerns that will require coordination between the fluctuating water demands of the communities and the extraction and injection requirements of the remediation system to capture PFAS and reduce plume migration. The volume of water extracted and injected will likely vary due to seasonal fluctuations in drinking water demand. Although the extraction systems will be separate for each community, the excess water for injection will likely be combined. This alternative will also require coordination with West Lakeland and Woodbury to install injection wells and the piping network.

The proposed MBWA was developed based on known plume impacts, migration pathways, and community needs at the time of the preparation of this FS. Community input was not incorporated into this FS. Since the development of the well configuration included in this FS, Lake Elmo and Oakdale have both indicated they are evaluating the needs of their communities and determining how to best incorporate current infrastructure in response to increasing drinking water demand, plume migration, and changes in land availability. The information they gather will likely result in changes to the well configuration that is presented in this FS; however, the overall purpose and objectives of the MBWA to decrease plume migration while also providing drinking water will not change. If the Minnesota

² Treatment costs for the West Lakeland POETSS were included as part of Alternative 8 as the costs to provide safe drinking water to West Lakeland, Oakdale, and Lake Elmo were included in the alternatives to provide an accurate cost comparison.

Pollution Control Agency (MPCA) decides to move forward with this recommendation, a focused FS is recommended to evaluate these issues and to update the well configuration and piping array. Potential changes to the well configuration include additional wells east of WCL and a treatment plant in that area. Although costs will change in response to changes in the well configuration, the costs developed for this FS will still provide an estimate of the costs associated with this alternative.

As with the MBWA, the locations of the PABs may be adjusted based on current and planned developments along the Project 1007 conveyance. If this remedy is selected, the locations will be evaluated for suitability for a PAB. Selection of locations and implementation will also require discussions with and approval by the Valley Branch Watershed District (VBWD) and Minnesota Department of Natural Resources (MDNR).

Sediment treatment is not recommended at this time to protect drinking water aquifers. Sediment sampling indicates PFAS is currently adsorbed to the sediments within the wetlands along Raleigh Creek and within Eagle Point Lake, which are secondary PFAS source areas. If sediment impacts were to be remediated, upstream impacts from ODS (an un-remediated source area) could result in continued PFAS loading from impacted surface water to downstream sediment areas of concern (AOCs), leading to the reintroduction of PFAS to the treated sediments. This sediment treatment recommendation may be revised after the completion of ongoing sediment leaching studies and post-monitoring of 3M's Raleigh Creek reroute around ODS. To communicate risks associated with exposure to impacted sediments to nearby residents and Lake Elmo Park Reserved visitors, access restrictions are proposed for all sediment AOCs. Continued communication with Anna's Grove residents is recommended to further discourage residential exposure from the Anna's Grove Wetland Complex (AGWC) Sediment (AOC 12). Appropriate access restrictions such as signage and fencing will be determined for each sediment AOC as appropriate.

This recommendation focuses on the protection of drinking water aquifers and does not account for ecological receptors. As indicated in the Baseline Ecological Risk Assessment (BERA) (AECOM, 2021), surface water and sediment concentrations do pose a risk to ecological receptors and the proposed remedial actions are not focused on reducing this risk. The decision to focus on the protection of drinking water aquifers was made based on the language of the 2018 Settlement.

14.2 Secondary Recommendation

This FS provides a secondary recommendation to accommodate potential community preferences and to provide a lower-cost alternative. Alternative 6 was selected because of its lower cost and because it would provide drinking water only to the City of Lake Elmo, as the city has been receptive to the MBWA concept as a way to alleviate concerns surrounding increasing drinking water supply demands as the city continues to grow. The City of Oakdale is already removing PFAS to a limited extent from the Jordan Aquifer with its municipal supply wells and would continue to do so under the plans outlined in the Conceptual Drinking Water Supply Plan (CDWSP).

Alternative 6 provides the same level of plume control in West Lakeland and Lake Elmo as Alternative 8 but differs in plume control south and southwest of ODS. In Alternative 6, plume control in this area occurs through the existing extraction for municipal supply by the City of Oakdale. Based on modeling efforts, the Oakdale municipal supply wells do not completely capture the PFAS plume in this area, and plume migration would be expected to continue to the south and southwest of ODS. The planned locations of the new Oakdale municipal supply wells would not be sufficient to provide capture in this area. The groundwater in this area is not used for municipal supply. Drinking water is supplied by the Saint Paul Regional Water Services, which sources water from the Mississippi River. Also, the PFAS migration pathways in this area are not well understood or fully delineated. If this alternative were to be selected, AECOM recommends that plume control west and southwest of ODS be incorporated into the ongoing remedial efforts at ODS to limit the continued migration of this plume.

As discussed in **Section 14.1**, the well configuration shown in **Figure 14.2** may change after further discussions with the City of Lake Elmo and West Lakeland Township. The City of Lake Elmo is evaluating their drinking water needs, the results of which would impact combining the MBWA with the current and planned drinking water distribution system. Potential changes could involve the construction of two smaller water treatment plants, one at the proposed location and one further north, to address potential pressure issues within the drinking water distribution system and land availability changes. If the MPCA were to choose Alternative 6, a focused FS to further develop the MBWA well array is recommended.

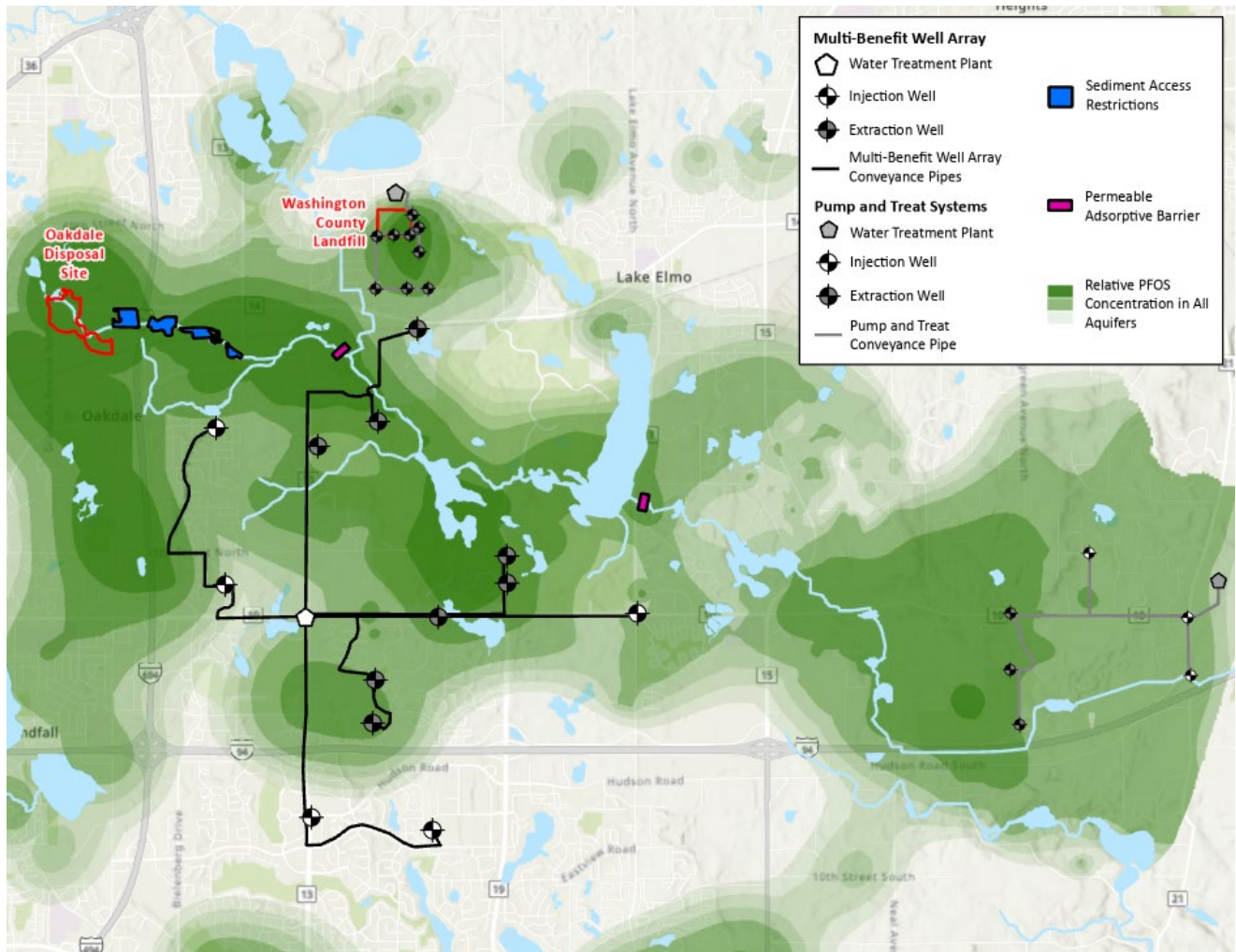


Figure 14.2: Remedial action locations for the secondary recommendation, Alternative 6

14.3 Recommended Treatment Trains

14.3.1 Multi-Benefit Well Array

The MBWA treatment processes would require approval for drinking water treatment by Minnesota Department of Health (MDH). Technologies approved for drinking water treatment are more limited than those available for other applications. AECOM proposes the following treatment trains:

- Granular activated carbon (GAC) lead/lag vessels
- Parallel trains of GAC and reverse osmosis (RO) (RO would address water with higher perfluorobutanoic acid [PFBA] concentrations)

- GAC with nanofiltration (NF)/RO polish
- GAC with ion exchange (IX) resin polish
- GAC pretreatment with IX lead/lag treatment

Additional information on these treatment trains is provided in **Appendix J**. Based on the results of the rapid small-scale column tests (RSSCTs) (**Appendix F**), AECOM recommends GAC pretreatment with IX lead/lag treatment. The RSSCTs showed that GAC lead/lag vessels would require frequent changeouts due to rapid PFAS breakthrough, resulting in increased O&M costs. RO is more expensive but could achieve improved PFBA removal if that is an expectation of the communities. Before selecting this treatment train, community preferences with regard to the water quality of the effluent, especially the PFBA concentrations, must be understood. PFBA is elevated in some areas of the Site; however, when blended with water from other extraction wells, concentrations would be below the MDH Health Based Value (HBV). Whether this standard will be further decreased in the future and whether the communities prefer a treatment system that will decrease the PFBA concentrations below current MDH HBVs is uncertain and should be considered when selecting a treatment train.

14.3.2 Oakdale Disposal Site Additional Source Zone Treatment

Additional source zone treatment is required at ODS to reduce PFAS migration from this source area to downgradient areas. PFAS is migrating away from the disposal site via surface water where it then infiltrates into the drinking water aquifers, as described in the Conceptual Site Model (**Section 5**). Additionally, PFAS is likely migrating away from ODS via groundwater as well, resulting in PFAS continuing to enter the drinking water aquifers. As PFAS surface water and groundwater is at higher concentrations within a smaller volume at ODS compared to downgradient areas, it is more cost effective to treat at the source area compared to the larger diffuse plume downgradient. Source zone treatment is required prior to the implementation of additional pumping downgradient as installation of the MBWA or other large pump and treat systems will result in the continued migration of this large mass of PFAS downgradient where a larger volume of water must be treated to remove the same mass of PFAS.

While treatment at ODS is important for this FS, alternatives were not developed as part of this FS. Remedial activities at ODS are being conducted through the Superfund Program. An FS was developed in 2008 (Weston 2008) and the selected remedies are captured in the Minnesota Decision Document (MPCA, 2008). The effectiveness of the selected remedy is being evaluated by Superfund and additional actions are likely required to be protective of human health and the environment as required by the Settlement Agreement and Consent Order (MPCA, 2007). 3M has proposed a reroute of Raleigh Creek around ODS; however, additional remedial actions to address other sources of PFAS migration from the Site including, but not limited to, release of PFAS via surface water during large precipitation events, release of PFAS from sediments, and migration of PFAS-impacted groundwater away from the disposal site, will likely be needed to ensure protection of human health.

14.3.3 Washington County Landfill Pump and Treat

The groundwater at WCL contains high concentrations of perfluorooctanoic acid (PFOA), PFBA, and perfluorooctane sulfonate (PFOS). PFBA, a short-chain PFAS compound, is more difficult to remove from water as it has a shorter breakthrough time in GAC and IX media compared to long-chain PFAS. A treatment train approach is expected to be needed, as different technologies have varied treatment efficiencies for long- and short-chain PFAS. RSSCTs conducted as part of this FS demonstrated that GAC and IX are not feasible as standalone technologies due to rapid PFAS breakthrough (less than 1 day). Additional treatability studies are needed prior to selection of remedial technologies. AECOM recommends pursuing treatability studies for the following treatment trains at WCL:

- Foam fractionation with IX polishing
- NF/RO membranes with reactivated GAC and single-use IX treatment of membrane concentrate
- Regenerable IX
- NF/RO with foam fractionation treatment of the membrane concentrate followed by IX polishing

Appendix I includes additional information about these treatment trains. If groundwater treatment at WCL is pursued, additional technologies should be evaluated; removal of PFAS, especially short chain PFAS such as PFBA, is an area of active technology development. Additional commercially available technologies may be available in the future. An appropriate destruction technology should also be tested and selected depending on the treatment train to initially separate the PFAS from the bulk water.

The pilot studies recommended in **Section 14.4.2** would determine the effectiveness of these different treatment trains. The treatability studies will also help to better estimate the treatment costs associated with each treatment train.

14.3.4 Permeable Adsorptive Barriers

An in-stream, gravity-fed PAB is proposed to minimize the required footprint and treatment costs to reduce surface water PFAS concentrations. AECOM recommends surface modified clay media as this type of media has a higher hydraulic conductivity than other types of adsorptive media, increasing the volume of surface water that can be treated by the PAB. This method would target mass flux reductions but is not expected to achieve the MPCA Site-Specific Surface Water Criteria, especially during high-flow events.

Additional treatability testing would be required to design the system. The most important design parameter is the hydraulic conductivity of the media. Not all flow is expected to be treated during periods of higher rain fall; a concrete overflow channel would be included to allow a bypass of the PABs during high-flow events to prevent upstream flooding or overtopping of the PAB. The hydraulic conductivity of the adsorptive media will determine the portion of flow through the media as well as the portion of water that is treated by the PAB. The performance of the adsorptive media should also be studied to determine the number of flow cells needed to achieve desired PFAS removal and to estimate the service life of adsorptive media.

14.3.5 Non-Drinking Water Pump and Treat

If Alternative 6 is selected rather than Alternative 8, AECOM recommends a localized non-drinking water pump and treatment system to control plume migration in West Lakeland. Because PFBA concentrations are lower in West Lakeland and treated effluent will not be used for drinking water, other treatment trains were considered. The recommended treatment trains are as follows:

- Reactivated GAC followed by single-use IX
- Foam fractionation followed by single-use IX

Other technologies, such as regenerable IX, are not recommended at this time considering the relatively low concentrations of PFAS compared to the higher concentration (typically >10,000 nanogram per liter [ng/L] total PFAS) required to make regenerable IX cost-effective. Regenerable IX should be reconsidered in the future if the implementation costs decrease or other technological advances increase the implementability of a regenerable IX system, as described in **Appendix I**.

Additional pilot studies and discussions with vendors beyond what was conducted for this FS are needed to evaluate the current state of the technologies at the time of implementation. Foam fractionation at the scale required for the pump and treat system is in the design phase elsewhere but has not been implemented; additional information from vendors is needed to understand the plant footprint and

technology limitations as well as to understand new technologies that have come to market recently. IX resins with improved PFAS sorption capabilities have been developed. Additional work may be needed to evaluate the performance of these new IX resins with Site-specific water. Acceptable disposal, treatment, or destruction options for the PFAS-containing waste generated by these two processes must also be considered. PFAS destruction technologies are more limited for solid media compared to the aqueous concentrate generated by foam fractionation. If Alternative 6 is selected as the remedial alternative, additional work will be needed to consider these issues prior to the selection of a treatment technology.

14.4 Next Steps

14.4.1 ODS Investigations

3M has prepared Conceptual Site Models (CSMs) for ODS (Barr, 2022; Barr, 2023) and has identified additional investigation activities (Barr, 2022) that are in the process of being completed. Once 3M completes these activities and further develops the CSM for ODS, MPCA will determine if additional investigation is required based on identified data gaps. This will be conducted through the Superfund Program. Data gaps that have been identified to date include a better understanding of the extent to which PFAS continues to migrate vertically within the disposal site and horizontally away from the disposal site and the extent to which PFAS soils that were not excavated in 2011 are a continued source of PFAS to surface water and groundwater. MPCA will continue to identify areas of investigations and comment on submitted work plans by 3M to continue the investigation activities at ODS.

14.4.2 Washington County Landfill Investigations

Additional investigation is required to complete a detailed CSM of the WCL source area. The CSM will inform the design and implementation of an effective pump and treat system. The focus of the Remedial Investigation (RI) for the Project 1007 FS was on downgradient migration patterns from the WCL source area, not on the source area itself. While ODS investigations are outside the scope of this FS (as they are being addressed by 3M as outlined above), recommendations for further work at WCL are within the scope. As demonstrated by the migration pathways identified by the RI, control of the source areas is crucial to limiting the continued downgradient migration of PFAS mass. Successful design of the recommended pump and treat system at WCL will be dependent on a thorough understanding of the geology and hydrogeology of the area along with improved knowledge on the distribution of PFAS. As such, AECOM recommends the following activities for WCL, as described further below:

- Drilling of additional wells to confirm migration pathways
- Aquifer pump test in the Quaternary Aquifer and potentially the Shakopee Aquifer
- Injection or infiltration tests if the state wants to pursue this as an option to discharge treated water
- Soil sampling

Additional well drilling is in progress, with wells installed in 2024 and 2025 and additional wells planned for 2026. The planned wells are expected to evaluate migration pathways, specifically to the east and southeast into Lake Elmo via groundwater discharge of the bedrock aquifers. These wells are expected to aid in the delineation of impacts within the bedrock aquifers to the east of WCL and could be repurposed as a monitoring well network to assess the performance of a future pump and treat system.



Figure 14.3: Recommended investigation activities at Washington County Landfill

An aquifer pumping test is required to better understand the vertical and horizontal hydraulic conductivity of the Quaternary Aquifer and shallow bedrock in the vicinity of WCL. This information will be used to determine the required pumping rates for effective plume capture and ensure stability of groundwater at safe elevations. This information is critical to obtain prior to design of a pump and treatment system as the required pumping rates will determine the number of extraction wells and the required size of a future treatment plant.

Injection or infiltration testing is also required prior to the design of a treatment system if the MPCA wants to consider injection as a discharge method for the treated water. Injection of treated water would provide a discharge option for treated water and help maintain safe groundwater elevations. However, additional testing is required to correctly size an infiltration array and to confirm that injection would be a suitable option for discharging treated water. Alternatively, a sanitary sewer or surface water discharge connection could be established.

AECOM also recommends additional soil sampling at WCL. When municipal waste was initially placed in WCL in the 1950s and 1960s, the landfill was not lined. To prevent the continued leaching of PFAS from the landfilled material, the PFAS-containing waste was removed and placed in a newly constructed triple-lined landfill in 2012. However, shallow soils beneath the solid waste were not removed, potentially leaving behind soil that could be highly contaminated with PFAS. As a result, a substantial PFAS mass may still be present within the shallow soils, particularly within the vadose zone. The historical footprint of the landfill extended beyond the footprint of the triple-lined landfill constructed in 2012, so soil that could be contaminated could be sampled without disturbing the landfill liner. This sampling may help determine the extent to which PFAS source mass is still present in shallow soil and could continue to leach into groundwater.

The results from the proposed investigation efforts, in combination with results from previous investigations, would be used to develop a comprehensive CSM of the WCL source area. This data could also be used in other modeling efforts to better understand the mass flux of PFAS from the source area both before and during treatment.

14.4.3 Pilot and Treatability Studies

Several pilot and treatability studies were performed as part of this FS. This work, which is detailed in **Section 10** and associated appendices, provided a valuable initial assessment of PFAS treatment technologies. The SAFF® pilot study demonstrated that foam fractionation could effectively treat low-foaming and even non-foaming groundwater, removing significant amounts of PFOA and PFOS. Bench- and pilot-scale destruction work demonstrated PFAS in foam fractionation concentrate could be destroyed, breaking the cycle of PFAS migration through the environment. Bench-scale RSSCTs demonstrated the superior performance of IX resin compared to GAC for PFAS treatment for drinking water. However, these studies also revealed knowledge gaps, which inform the need for additional pilot and treatability studies before a final remedial alternative can be selected for both source zone control at WCL and plume control in the form of the MBWA and/or pump and treatment systems. AECOM recommends additional PFAS destruction pilot studies if MPCA wants to pursue onsite PFAS destruction. Pilot and treatability studies may be required at ODS to improve the removal of PFAS but those will be proposed by 3M through the Superfund Program.

14.4.3.1 WCL Pilot and Treatability Studies

As previously mentioned, high PFBA concentrations at WCL make it difficult to select a treatment train without additional treatability and pilot studies with Site-specific groundwater. Evaluating technologies with Site-specific water is a crucial component of evaluating the effectiveness of the technology, determining design parameters, and completing a more precise cost estimate. AECOM recommends the following pilot and treatability studies related to the WCL pump and treatment system, with studies prioritized as primary and secondary recommendations:

Primary:

- SAFF®: Although a pilot study was completed at Tablyn Park, the PFAS plume composition is different at WCL. Moving the SAFF® to WCL to determine PFAS removal at the source zone, with specific consideration of PFBA removal, is recommended.
- Since MPCA purchased the SAFF®, additional foam fractionation vendors have brought new technology to market. A bench-scale analysis of one or more vendors is recommended to compare PFBA removal performance to SAFF®.
- RSSCTs: Additional RSSCTs are recommended to evaluate the use of IX media to treat the effluent of the SAFF® system. Polishing of the effluent may be required to achieve the treatment targets. The RSSCTs would test IX resin performance, specifically targeted for the removal of short-chain PFAS.

Secondary:

- NF/RO: Although OPEX and CAPEX tend to be higher for NF or RO membranes, membrane treatment is likely to achieve higher PFBA removal than foam fractionation. AECOM recommends a membrane treatment pilot study be conducted at WCL if other technologies do not prove to be efficient at removing PFAS at the concentrations present in the groundwater. A pilot test would evaluate the efficiency and estimate electrical requirements and the volume of membrane concentrate that would then require further treatment either with adsorptive media (GAC + IX resin) treatment or with a foam fractionation and IX resin treatment train.
- SAFF® with membrane concentrate: If the SAFF® were moved to WCL and a membrane pilot study was conducted, the SAFF® could also be tested on the membrane concentrate. Using the SAFF® to further concentrate PFAS in the membrane concentrate would allow the membrane to be operated with a lower recovery, using less energy but resulting in a larger volume of membrane concentrate. The SAFF® would then be used to further concentrate the PFAS with less energy.
- Regenerable IX should be pursued if foam fractionation, NF/RO with adsorptive media treatment, or NF/RO with foam fractionation and IX polishing are not successful. Regenerable IX may effectively reduce PFBA concentrations more than other technologies but could require more oversight than other technologies.

These treatability studies would use existing infrastructure at WCL to the extent possible, allowing them to be implemented quickly. Completion of these studies could facilitate the selection of a treatment train for the WCL ground water pump and treatment system.

14.4.3.2 Plume Control Treatability Studies

If Alternative 6 is selected, RSSCTs should also be completed with water specifically from West Lakeland as it has a different PFAS mixture than the water at the locations tested as part of this FS. The RSSCTs would determine the optimal media to reduce the frequency of changeouts. This information could then be used to compare the costs associated with NF/RO and foam fractionation and determine the optimal treatment train.

14.4.3.3 Destruction Technology Pilot Studies

AECOM recommends additional pilot studies of destruction technologies if onsite destruction is preferred. However, these should not be completed until a remedial alternative and treatment train for the separation and concentration of PFAS are selected. Water chemistry, PFAS mixture, and the volume of PFAS concentrate to be destroyed are dependent on the remedial alternative and treatment train selected. Based on bench-scale studies, the following destruction technologies are recommended for further study:

- Supercritical water oxidation (SCWO)
- Hydrothermal alkaline treatment (HALT)
- Electrochemical oxidation (EO)
- Photochemical reduction
- Photochemical oxidation
- Plasma

Because an EO pilot study was completed as part of this FS (discussed in **Appendix D**), AECOM recommends that pilot studies be completed with at least two additional technologies. The selection of additional destruction technologies to study will be dependent on the specific water chemistry, the treatment train the destruction technology would be incorporated into, cost, operation requirements, and stakeholder concerns.

14.4.4 Modeling by MDNR for White Bear Lake Court Order

Modeling of the selected system with the associated extraction and injection wells will be completed by MDNR using the Northeast Metro Lakes Groundwater (NMLG) model to ensure that the White Bear Lake water level will not be negatively affected in accordance with the White Bear Lake court order (White Bear Lake Restoration Association and White Bear Lake Homeowners' Association vs. MDNR and Town of White Bear Lake and City of White Bear Lake, 2020). Analysis of initial modeling of Alternative 8 suggests that the recommended alternative may positively impact the lake level because the MBWA extraction wells are located further away from White Bear Lake compared to current municipal supply wells. Additional modeling efforts are ongoing and are expected to be included in this FS as an addendum upon completion.

14.4.5 Community Input

One of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) criteria to evaluate the remedial alternatives is community acceptance. Community input was not evaluated for the preparation of this FS. Further discussions with the affected communities are needed to better understand their concerns and any potential limitations related to the recommended alternative. AECOM proposes that community concerns be addressed in a focused FS that updates the conceptual well array through further analysis of community needs, existing infrastructure, and continued plume migration. The focused FS would also update costs and conceptual designs to incorporate new water treatment infrastructure planned and built by the communities simultaneously to the writing of this FS.

14.4.6 Bedrock Aquifer Injection Studies

Injection capacity modeling and bench-scale geochemical analysis has been completed at the University of Minnesota for the Jordan Aquifer (Shandilya, 2022). The injection modeling results were used to determine maximum injection rates at each proposed injection well location. Additional geochemical analysis is recommended to verify that injecting water into the Jordan Aquifer will not result in leaching

of naturally occurring manganese or arsenic. Testing to date has only been completed in the Shakopee Aquifer and not the Jordan Aquifer where the injection wells would be screened.

14.4.7 Permits

The permitting processes should be initiated upon selection of a remedy to ensure that the permit requirements are being considered in the design of the final systems. Permits may be required from the following:

- MDNR: Groundwater appropriations for the WCL pump and treat and the MBWA extraction wells
- MDH: MN well code and liquids injection regulation per State Statute 1031.681
- U.S. Environmental Protection Agency (EPA) Region V: Underground injection control (UIC) permitting in Minnesota
- VBWD: Permitting for the PAB
- MDNR: Permitting for work within a stream channel for the PAB
- MPCA: Air permits depending on the treatment technologies implemented
- MPCA: NPDES discharge permit if the proposed WCL pump and treat system ultimately discharges treated water to a surface water body
- Metropolitan Council: Discharge permit to discharge backwash from treatment to sewer system

Additional permits may be required depending on the alternative and treatment train selected. Administrative coordination and permitting applications, especially those related to the MBWA, should be pursued in collaboration with municipal representatives. Community engagement may be integrated into this process by presenting the MBWA technical and administrative phased approach to applicable local units of government and interested parties.

14.4.8 Green and Sustainable Remediation

The FS follows the standard process of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)/NCP phases and considers the greener cleanups components according to EPA's *Greener Cleanups* (2009); however, this process does not meet the framework for sustainable remediation, including the MPCA *Green and Sustainable Remediation* and Interstate Technology and Regulatory Council's (ITRC's) *Sustainable Resilient Remediation* guidance (MPCA, 2024; ITRC, 2021). In order to understand the long-term impacts of remediation at the regional scale, the frameworks developed in these guidance documents should be considered in the selection of a treatment train including the PFAS destruction technology. Following the most current guidance from the state and other sources, including ITRC, a comprehensive sustainable remediation evaluation of the selected remedial alternative would incorporate environmental, social, and economic considerations into the remedial process. This evaluation could be accomplished through quantitative measurement of the environmental footprint of the preferred remedial alternatives and treatment trains using existing tools, including a lifecycle assessment of treatment materials generation, transportation, and disposal. Semi-quantitative or qualitative metrics such as environmental justice considerations for environmentally overburdened communities in the areas of PFAS impacts, treatment, and disposal/destruction facilities could also be collected and evaluated.

14.4.9 Develop and Install a Monitoring Network

A broader network of monitoring wells should be installed for improved long-term monitoring. As part of the RI in this FS, monitoring wells were installed with a focus on determining migration pathways. Additional wells should be added to the current monitoring well network to better assess the

effectiveness of remedial actions. These wells would be installed downgradient of the proposed extraction and injection well networks to evaluate changes in PFAS concentrations and determine whether Remedial Action Objectives (RAOs) are being achieved. The use of private and public wells could also be considered for inclusion into the long-term monitoring plan. Commencing monitoring of the well network prior to the installation of remedial actions will allow baseline concentrations to be understood and will help to determine the success of the actions in meeting the RAOs.

14.4.10 Additional Remedial Investigation

The RI presented as part of this FS includes data gathered through October 2024. Investigation and data analysis activities have continued since then to better understand the extent and magnitude of impacts from the known disposal sites in the East Metro. Additional information has also indicated that other PFAS sources may be comingling with impacts from the known disposal sites. AECOM recommends that these efforts continue to better understand PFAS migration pathways. Additional investigation activities could include the following:

- Sampling additional private wells to delineate PFAS plume extents
- Drilling of new wells in areas that currently do not have wells to evaluate the migration of PFAS and potential comingling of plumes
- Additional sample analysis such as non-target analysis and branched/linear isomer analysis
- Statistical analysis to identify areas where other sources may be contributing
- Evaluation of the impacts of atmospheric deposition from previous incineration activities at the 3M Cottage Grove facility and how these impacts may be comingling with other known PFAS sources

This list is not meant to be comprehensive as additional activities may be warranted depending on the ongoing investigation and analysis. The information gathered from any additional RI activities will be used to update the recommended remedial alternative and better address the PFAS impacts in the East Metro during the design of the remediation system and well networks.

14.4.11 Selection of Final Alternative and Design Phase

Figure 14.4 provides a visual representation of some of the next steps needed to select a remedial alternative and treatment train at WCL. This figure focuses on the selection of a treatment train and does not include all required activities.

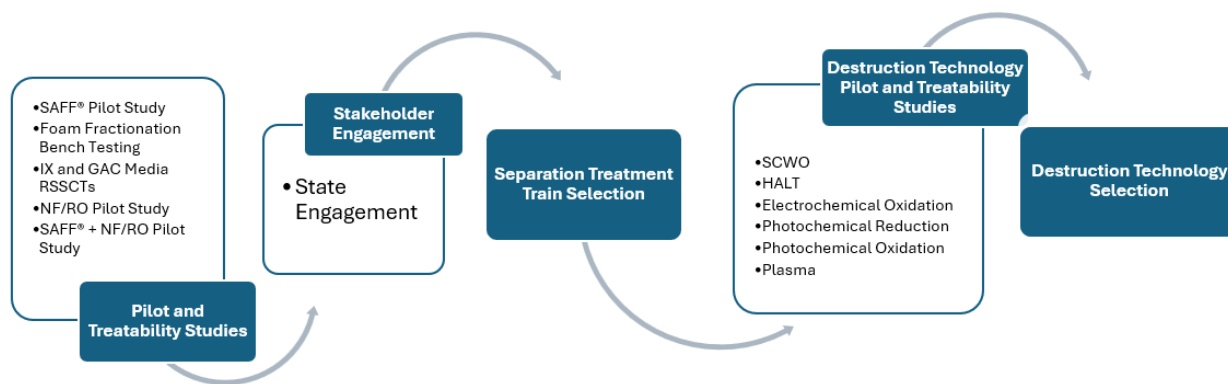


Figure 14.4: Recommended pilot studies for Washington County Landfill

Figure 14.5 provides a summary of some of the next steps for implementation of the MBWA, should Alternative 8 be selected as the remedial alternative. Although this flow chart does not include all required next steps, it does provide the general order of required activities.

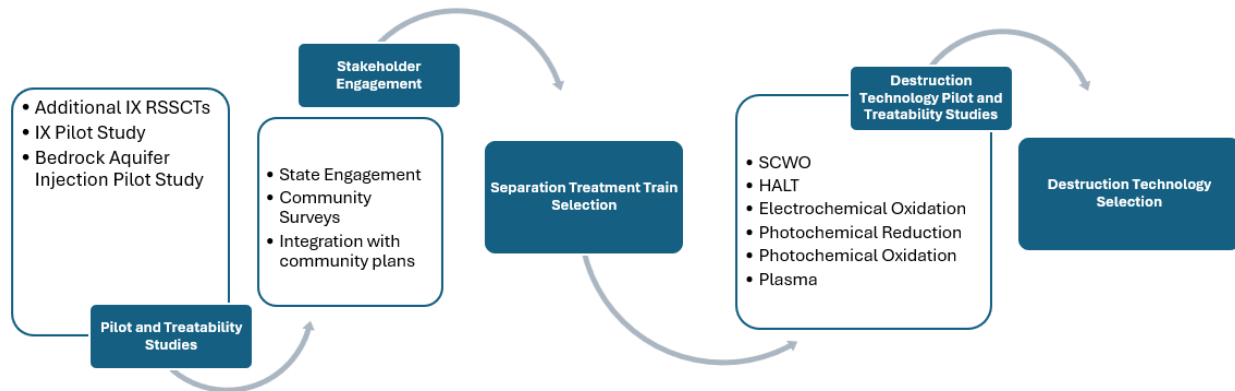


Figure 14.5: Recommended pilot studies for the MBWA

Alternatively, should Alternative 6 be selected as the remedial alternative, Figure 14.6 shows the general order of required activities for implementation.

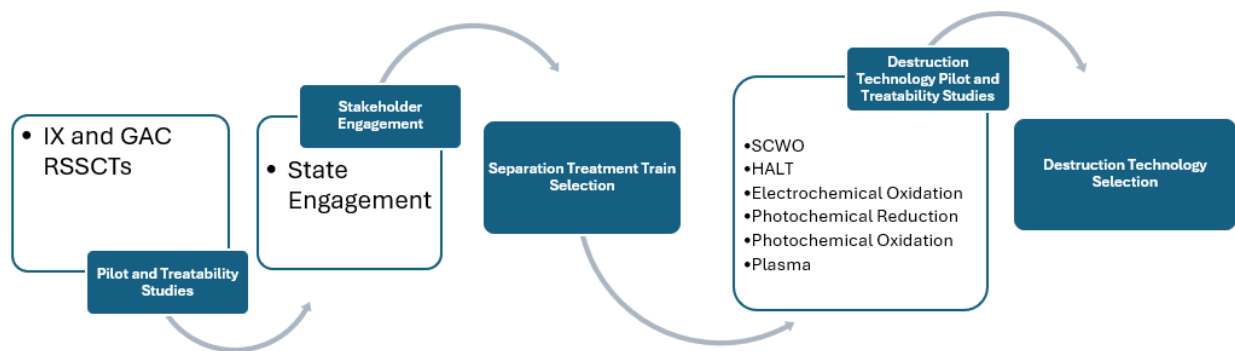


Figure 14.6: Recommended pilot studies if Alternative 6 is selected instead of Alternative 8 for the West Lakeland localized pump and treatment system

Completion of these recommended activities and next steps is required prior to final selection of a remedial alternative and associated treatment trains. Design and implementation of remedial activities cannot begin until a final alternative is selected.

14.5 Potential Timeline

AECOM developed a conceptual timeline to convey the implementation schedule of the recommended remedial actions. Delays in planning would push the timeline back accordingly. Other factors that could delay the implementation of a remedial treatment system include permitting, vendors and delivery of supplies, coordination of subcontractors, and agreement of the communities upon review of the designs. The conceptual timeline is shown in Figure 14.7. The work at ODS is not included in this timeline because that would be completed in coordination with 3M and the specific investigation and remedial activities are not defined in this FS.

	Year 1	Year 2	Year 3	Year 4	Year 5	Years 6-7	Years 8-10	Years 11-15
Sediment	Implement access control							
	Sediment Leaching Study							
		Reassess recommendation						
			Monitor after Raleigh Creek Reroute					
			Reevaluate the need for sediment remediation					
Surface Water	PAB Pilot Studies							
	Initiate Permits							
	Design							
		Implementation						
				Monitor effectiveness and O&M				
						Reevaluate Need		
Washington County Landfill	Additional Investigation							
	Treatability and Pilot Studies							
		Finalize Recommendations						
		Discharge/injection permits						
		Remedial System Design						
		Well and Piping Installation						
			Treatment Plant Installation and Startup					
				Monitor effectiveness				
Multi-Benefit Well Array	Treatability and Pilot Studies							
	Injection Well Permitting Process							
	Injection Well Studies							
	Work with communities							
	Green and Sustainable Remediation							
	Design of well and piping network							
		Finalize Treatment Recommendation						
				Lake Elmo Treatment Plant Design				
				Oakdale Treatment Plant Upgrade Design				
					Lake Elmo Implementation and Startup			
				Oakdale Implementation and Startup				
					Monitor Effectiveness			

Figure 14.7: Conceptual implementation timeline after selection of a remedial alternative. Timeline does not include efforts at ODS as these will be determined under the Superfund Program.

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