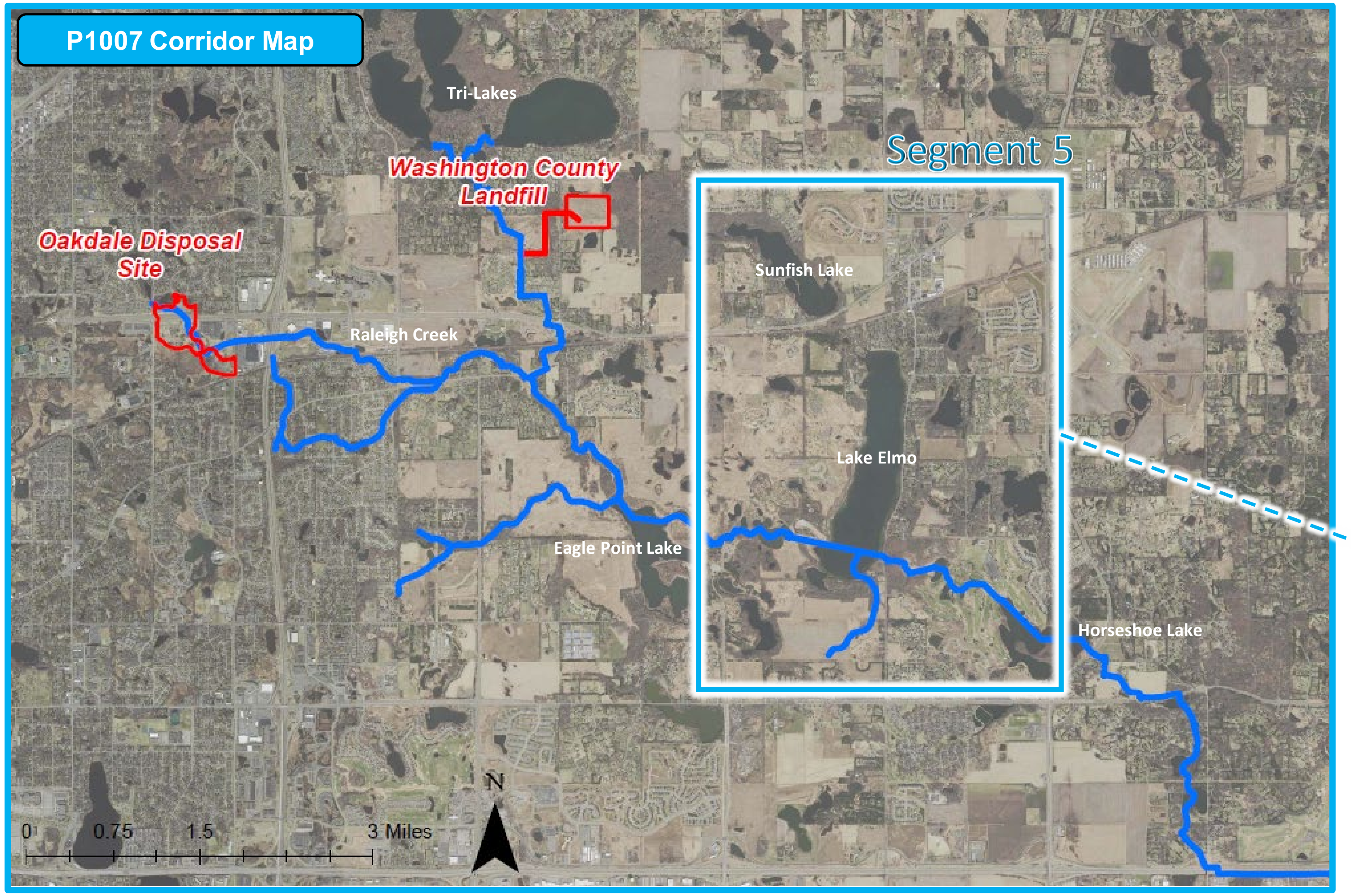
Project 1007 Focused Investigation Progress Report - Segment 5

October 2021

Minnesota Pollution Control Agency

Segment 5: Lake Elmo and Bedrock Valley



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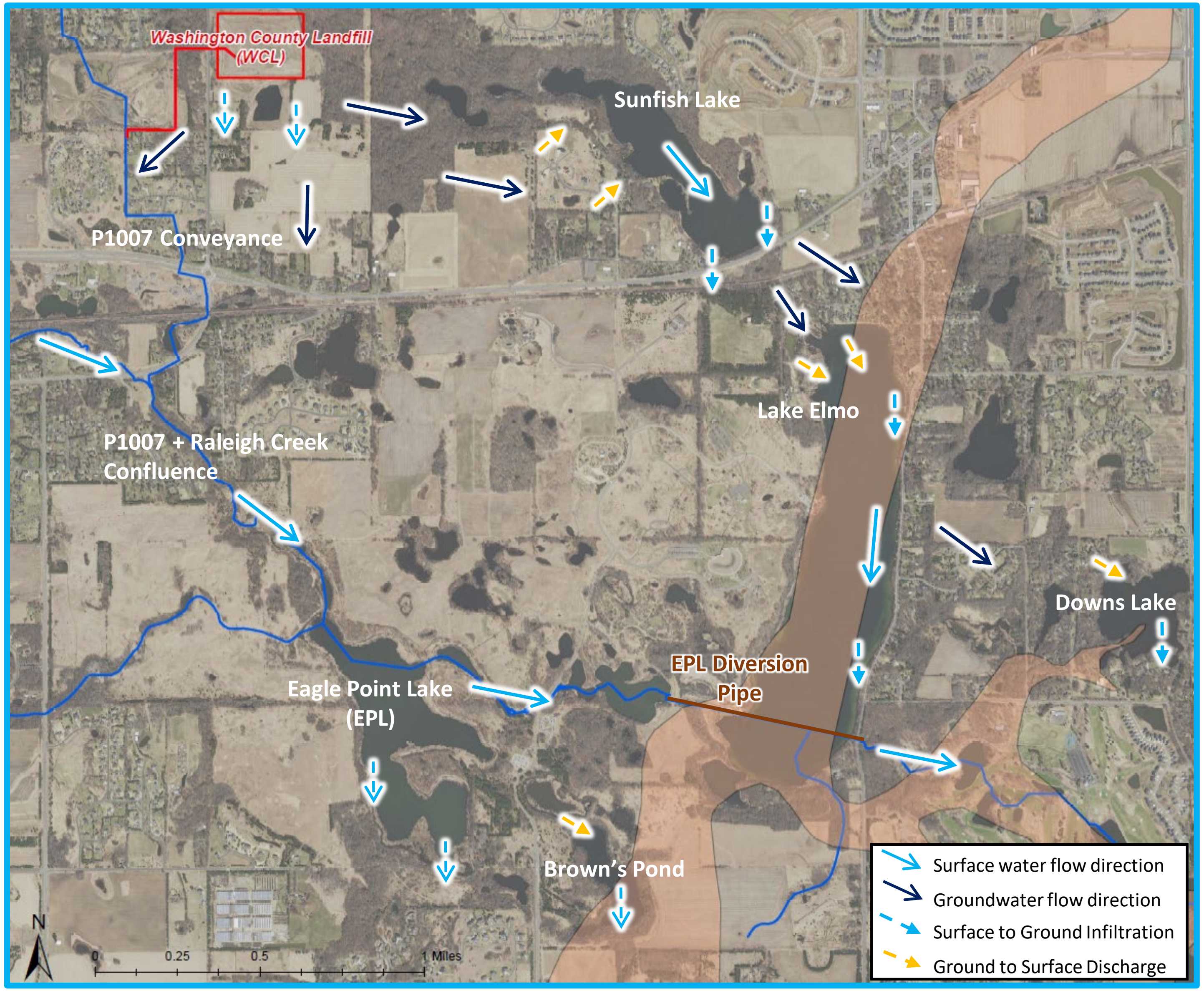
Introduction: Segment 5 Surface and Groundwater Systems



Surface Water Flow Systems

The dominant surface water feature in Segment 5 is Lake Elmo. Lake Elmo is approximately 284 acres in surface area and has a maximum depth of 137 feet. It is primarily groundwater fed although it also receives surface water from the secondary outlet structure of the Eagle Point Dam. Surface water from Eagle Point Lake moves through a 22-inch pipe running along the bottom of Lake Elmo. In effort to reduce water levels and improve water quality in Lake Elmo, the Eagle Point Lake discharge pipe was constructed as part of the P1007 flood mitigation infrastructure project completed in 1987. When water levels exceed an elevation of 896.5 feet, water will flow through a secondary outlet structure that discharges directly into Lake Elmo.

Sunfish Lake is located upgradient of Lake Elmo and is likely connected to Lake Elmo through shallow subsurface groundwater infiltration and discharge.

Groundwater Flow Regimes: Bedrock Valley

Lake Elmo is situated within a buried bedrock valley, a unique geologic feature whereby ancient streams and rivers eroded bedrock layers creating deep valleys later filled in with glacial and alluvial sediments. The combination of high conductivity of the surficial sediments, an absent bedrock aquitard, and the fractured bedrock zone underlying and adjacent to the valley allow for a direct pathway for PFAS-impacted surface and shallow groundwater to enter deeper bedrock aquifers.

The extent that PFAS is transported through the surficial sediments within the valley and discharging into other lakes is unknown.

Washington County Landfill

Since the construction of the Eagle Point Lake discharge pipe in 1987, impacted surface water from the Oakdale Disposal Site has been diverted from Lake Elmo when the surface elevation of Eagle Point Lake is 896.5 feet above mean sea level and below. The extent to which the Washington County Landfill (WCL) contributes to PFAS impacts in Lake Elmo is poorly understood but is likely connected via surface water infiltration and groundwater discharge between Sunfish Lake and Lake Elmo and further facilitated by the presence of the bedrock valley.

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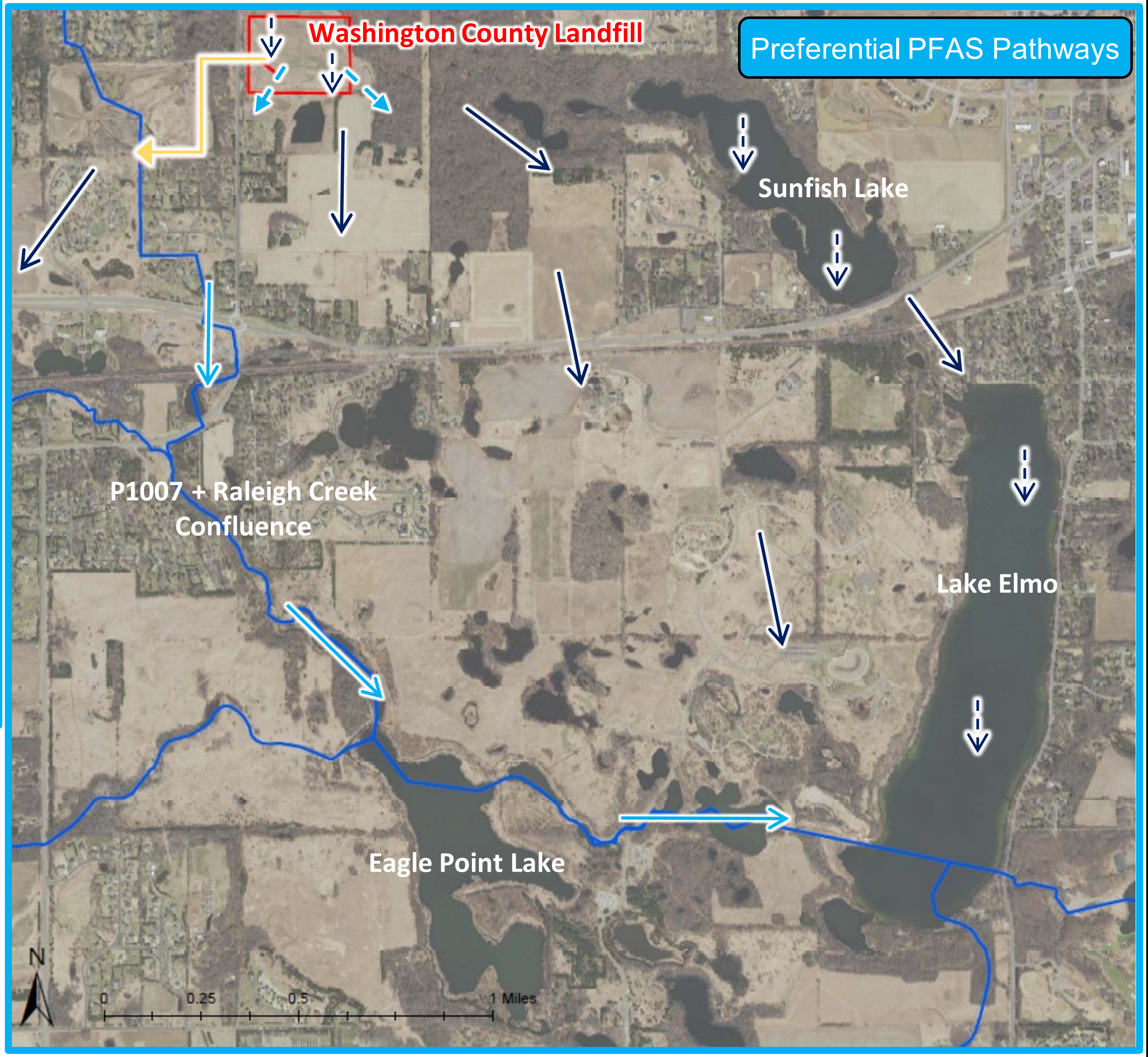
Project 1007: Historic and Current Surface Water Flow from WCL

Washington County Landfill History

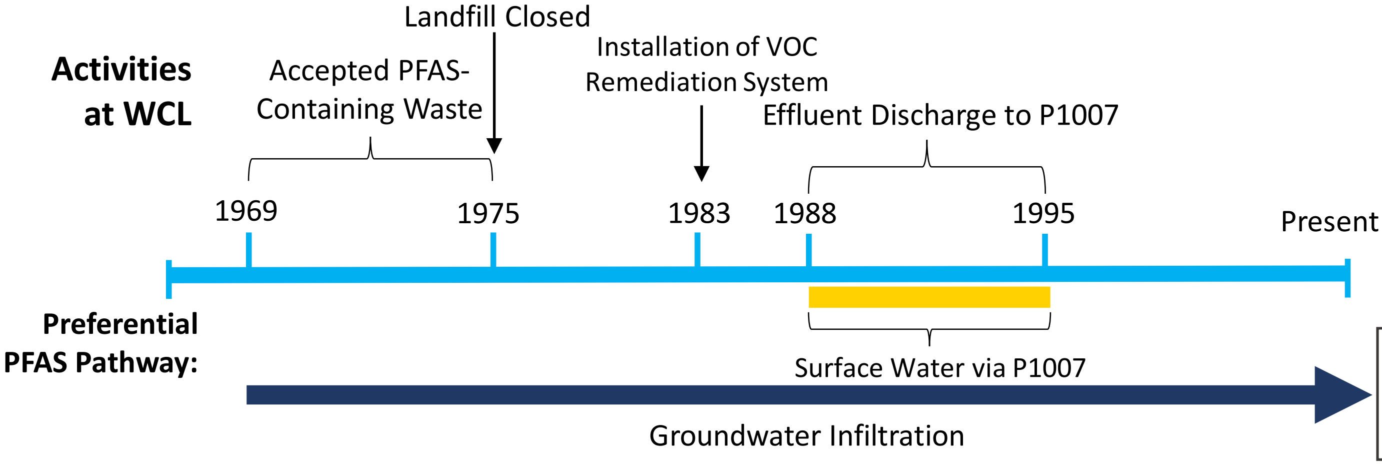
From 1969 to 1975, the Washington County Landfill (WCL) accepted PFAS-containing waste including wastewater treatment plant sludge, incinerator scrubber sludge and ash, and iron oxide sludge. As part of a larger flood mitigation infrastructure project completed in 1987 (P1007), a series of pipes and channels were constructed between the Tri-Lakes and Tablyn Park to direct surface water out of the land-locked Tri-Lakes area and away from the regularly-flooded residential area southward towards Raleigh Creek.

In 1988, the WCL began directly discharging untreated gradient control well effluent into P1007 via a stormwater sewer connection. As a result, PFAS-impacted waters from WCL were discharged to the P1007 system until the piped connection was sealed off in 1995.

Prior to and after this connection, PFAS-impacted waters from WCL likely migrated via surface runoff to the east-southeast for a limited distance and vertically into the subsurface via infiltration. Groundwater flow direction around WCL is not well understood and varies by depth. However, PFAS-impacted groundwater likely flows from WCL to the south, southwest, and southeast and into Sunfish Lake and Lake Elmo via infiltration and discharge between the surface water bodies and the shallow subsurface.



Surface Water Flow Direction (1988-1995)
Surface Water Flow Direction (Present)
Inferred Runoff Direction
Surface Water Infiltration
Groundwater Flow Direction



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Comparison of Two Source Areas: Oakdale Disposal Site vs. WCL

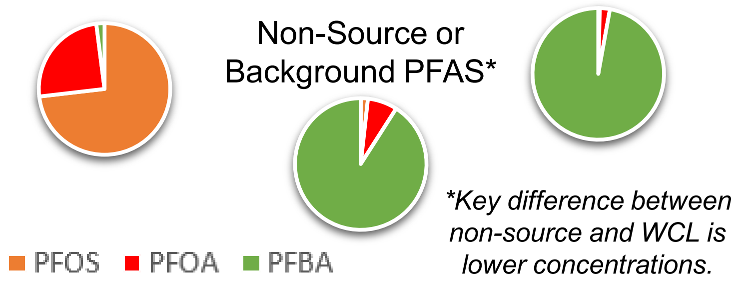
Disposal Site-Specific PFAS-Containing Waste

The Oakdale Disposal Site (ODS) accepted liquid and solid industrial waste, while the Washington County Landfill (WCL) accepted a variety of industrial and wastewater treatment plant waste. The PFAS contamination associated with these two historic waste streams is made up of different PFAS compounds, resulting in a PFAS "signature" that may be unique to each source area.

The PFAS signature associated with ODS is generally PFOS-dominant, while the PFAS signature from WCL is generally PFBA-dominant. As a result, analysis of the PFBA:PFOS ratio or the relative distribution of key compounds can be used to evaluate a possible PFAS source contribution at different locations.

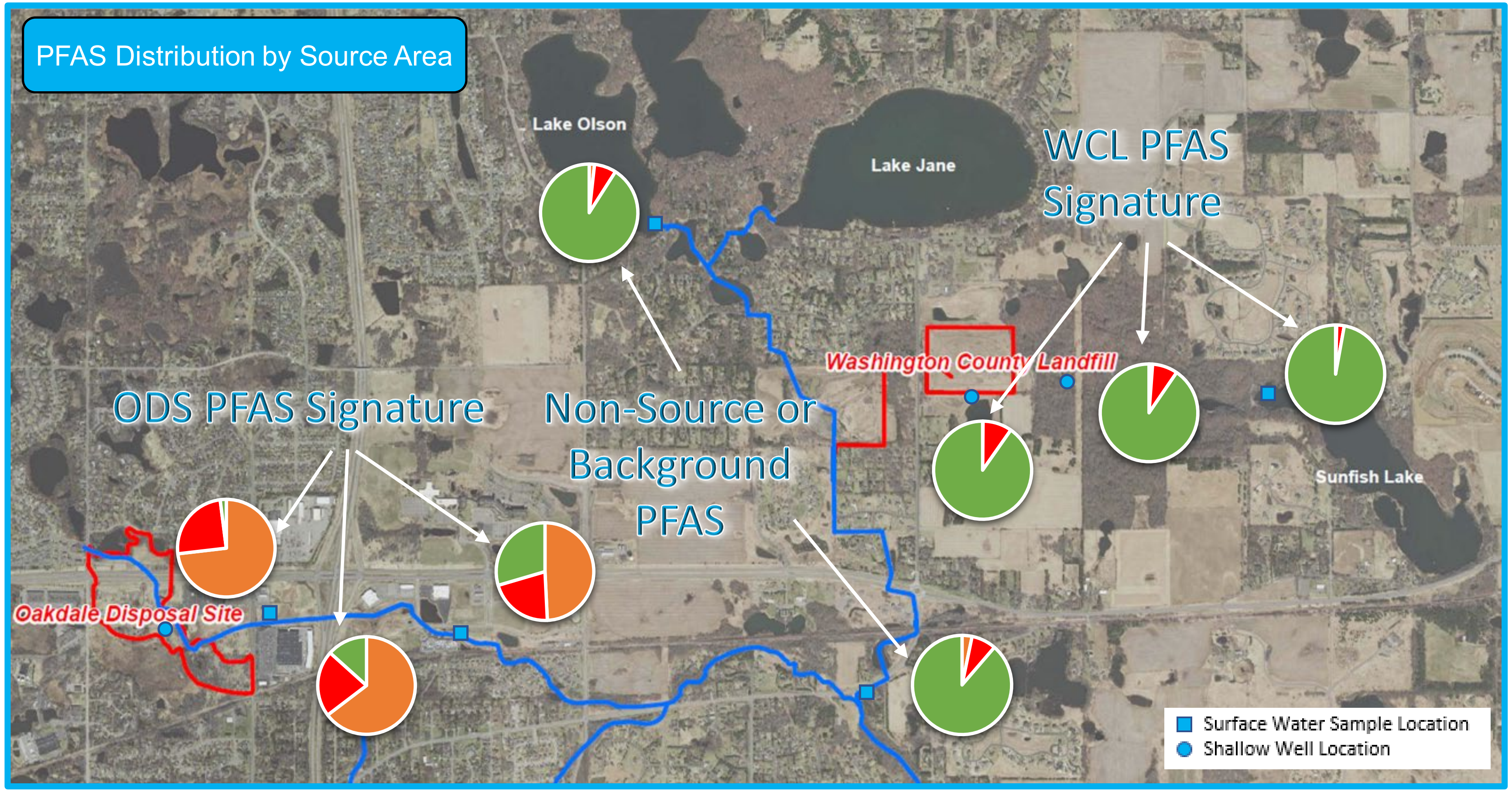
Locations that are not associated with either ODS or WCL impacted waters may have a similar PFAS signature; however, the concentrations of all compounds will be significantly lower.

Typical PFAS Distribution: ODS vs WCL



Key difference between non-source and WCL is lower concentrations.

PFAS Distribution by Source Area



Future Chemometrics Forensic Analysis

By applying multivariate statistical tools such as principal component analysis, hierarchical clustering, and logarithmic transformations to chemistry data using PFAS Chemometrics as a forensics tool, potential source area signatures can be identified and separated by subtle variations to provide powerful forensic interpretations. This will aid in future understanding of partitioning, source mixing, and PFAS fate and transport.

Future data analysis will use the above tools to refine the CSM and develop a deeper understanding of how PFAS is behaving in the surface and subsurface features of Project 1007.

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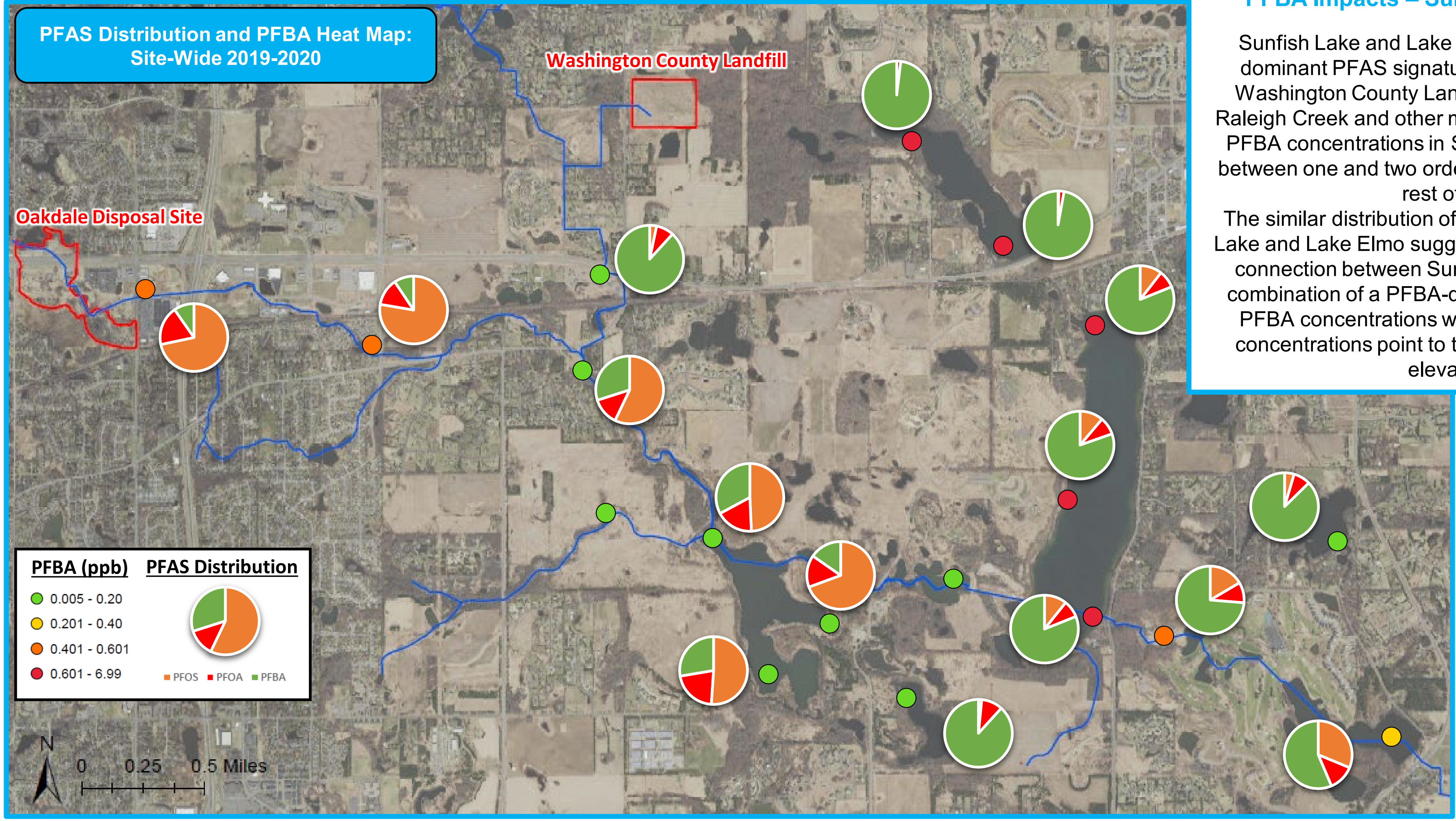
Site-Wide Surface Water Results: Distribution of PFAS Impacts and PFBA

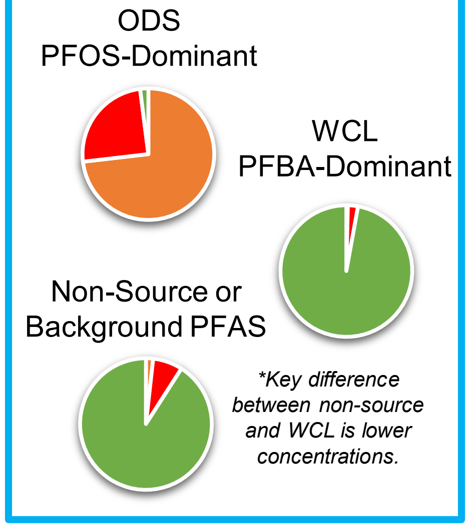


PFBA Impacts – Sunfish Lake and Lake Elmo

Sunfish Lake and Lake Elmo both have distinct PFBA-dominant PFAS signatures similar to impacts from the Washington County Landfill (WCL). When compared to Raleigh Creek and other major water bodies in the corridor, PFBA concentrations in Sunfish Lake and Lake Elmo are between one and two orders of magnitude greater than the rest of the corridor.

The similar distribution of PFAS impacts between Sunfish Lake and Lake Elmo suggests a groundwater-surface water connection between Sunfish Lake and Lake Elmo. This combination of a PFBA-dominant signature and elevated PFBA concentrations when compared site-wide PFBA concentrations point to the WCL as the source of these elevated impacts.

Typical PFAS Distributions



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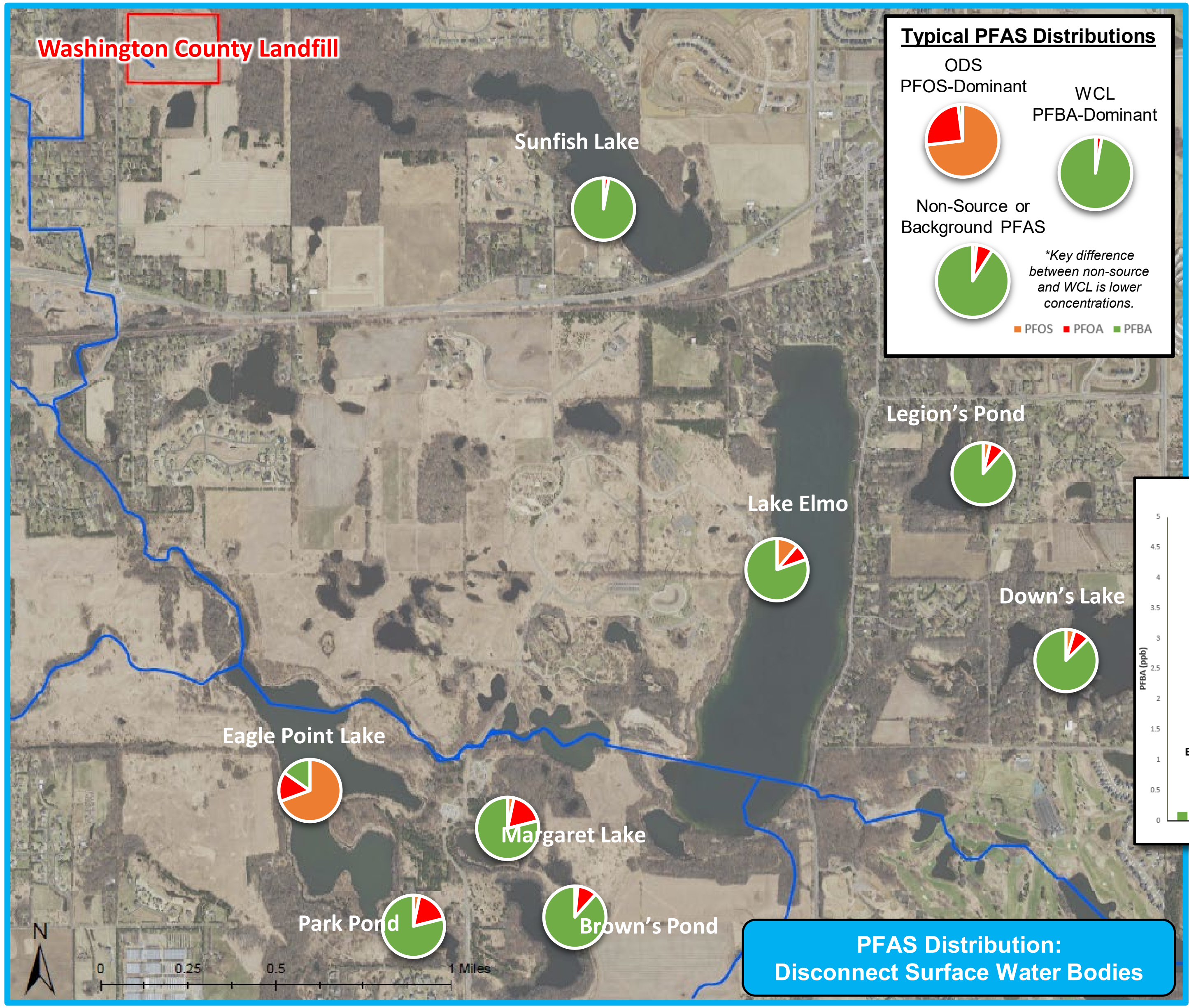
Other Associated Water Bodies in Segment 5



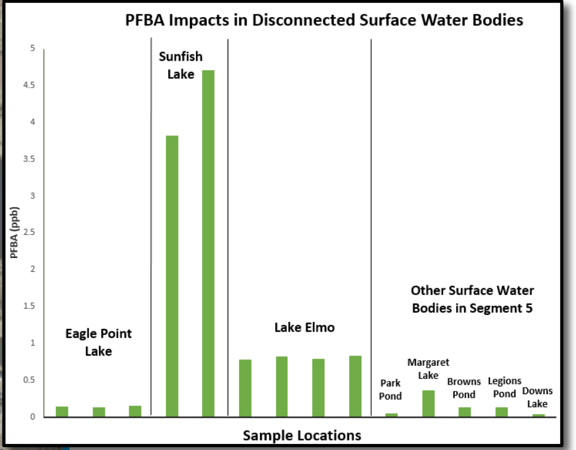
PFAS Distribution: Disconnect Surface Water Bodies

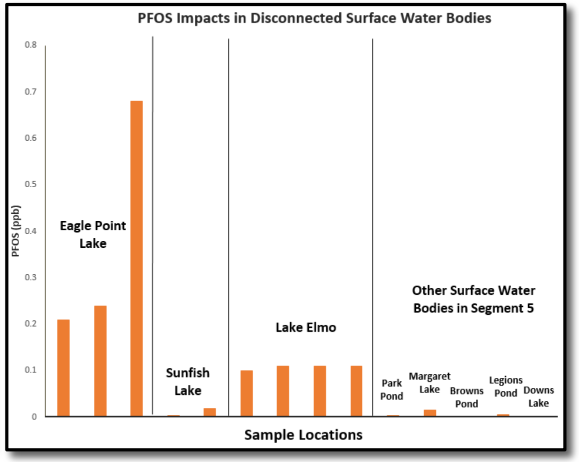
PFAS Impacts: Disconnected Surface Water Bodies

Brown's Pond, Margaret Lake and Park Pond are located southeast of Eagle Point Lake. Down's Lake and Legion's Pond are located east of Lake Elmo. These five small, disconnected water bodies were sampled to determine the extent of impacts outside of the main Project 1007 surface water flow path to assess surface-groundwater connections with Eagle Point Lake, Sunfish Lake, and Lake Elmo.

Like Lake Elmo and Sunfish Lake, PFBA is the dominant compound in all five smaller, disconnected water bodies. However, the concentrations of PFBA in the five water bodies are one and two orders of magnitude lower than Lake Elmo and Sunfish Lake, respectively.

With respect to PFOS, all five water bodies are in exceedance of the Site-Specific Water Quality Criteria for PFOS (0.00005 ppb) but are an order of magnitude lower in concentration than Lake Elmo and more than two orders of magnitude lower than that of Eagle Point Lake. Site-wide, PFAS concentrations in these five water bodies are among the lowest in surface water bodies.





Findings

The combination of overall low PFAS concentrations and a PFBA-dominant distribution of PFAS compounds suggest the PFAS impacts in these water bodies are non-source associated or background conditions.

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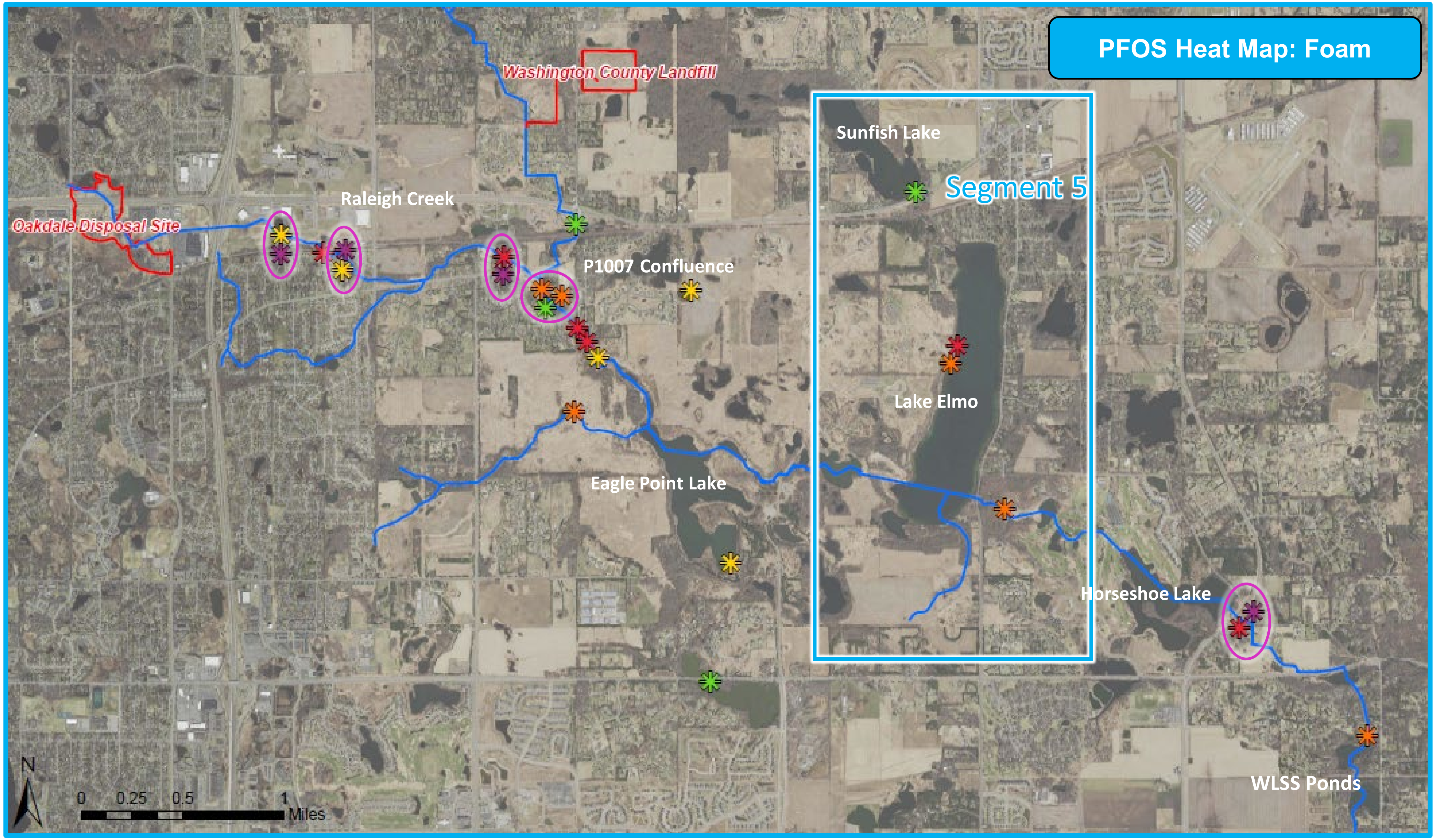
Site-Wide Foam Results: PFOS



Legend

PFOS in Foam (ppb)

- 1.1 - 7.9
- 8.00 - 49.9
- 50.0 - 299.9
- 300.0 - 2,999.9
- 3,000.0 - 30,000.0

Circled symbols denote targeted repeat foam sample locations

Foam in Segment 5

Foam has been observed rarely in Segment 5 along the shores of Lake Elmo and Sunfish Lake and only with high wind conditions. The locations with foam vary depending on wind direction, but the types and appearances of foam have been consistently fresh, fluffy, and lighter in color.

PFOS concentrations in Lake Elmo foam were moderate in magnitude, but the enrichment factors were among the highest in the overall corridor. Sunfish Lake foam had the lowest concentration of PFOS in foam in the corridor.

Foam Formation in Segment 5

Requirements for PFAS-Containing Foam Formation and Accumulation

Turbulence

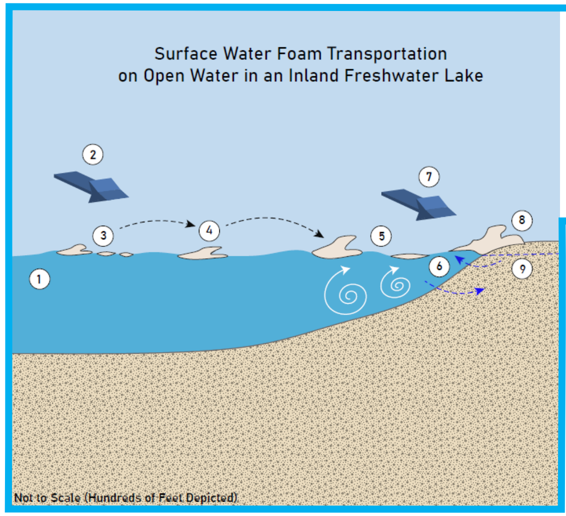
Air must be mixed into the water column for foam to form. In Segment 5, this turbulence was the result of agitation from waves from wind currents or the use of watercraft.

Solid Substrate for Foam to Accumulate Against

After generation, the foam bubbles must have a solid substrate in relatively calmer water to accumulate along or against. Without accumulation, the foam bubbles will collapse back into the water column. In Segment 5, foam was found to accumulate along the lake shores as well as under and against docks. The larger, fluffier piles of foam were observed in locations sheltered by wind, such as under docks.

PFAS Concentrations in Surface Water

Foam will naturally form regardless of the presence of PFAS. However, it is not well understood how the presence of PFAS in water affects foam formation. It is also not well understood how much PFAS will preferentially separate (enrich) into the foam relative to the PFAS in the corresponding surface water.



Depiction of the physical process of wind-generated foam and the subsequent accumulation on shore.

Accumulated foam observed along the shore (above and left) and below a dock (bottom). Foam in Segment 5 tends to be whiter and contain little to no organic matter. The types of foam observed in Segment 5 were the product of wind-generation and were very similar in appearance.

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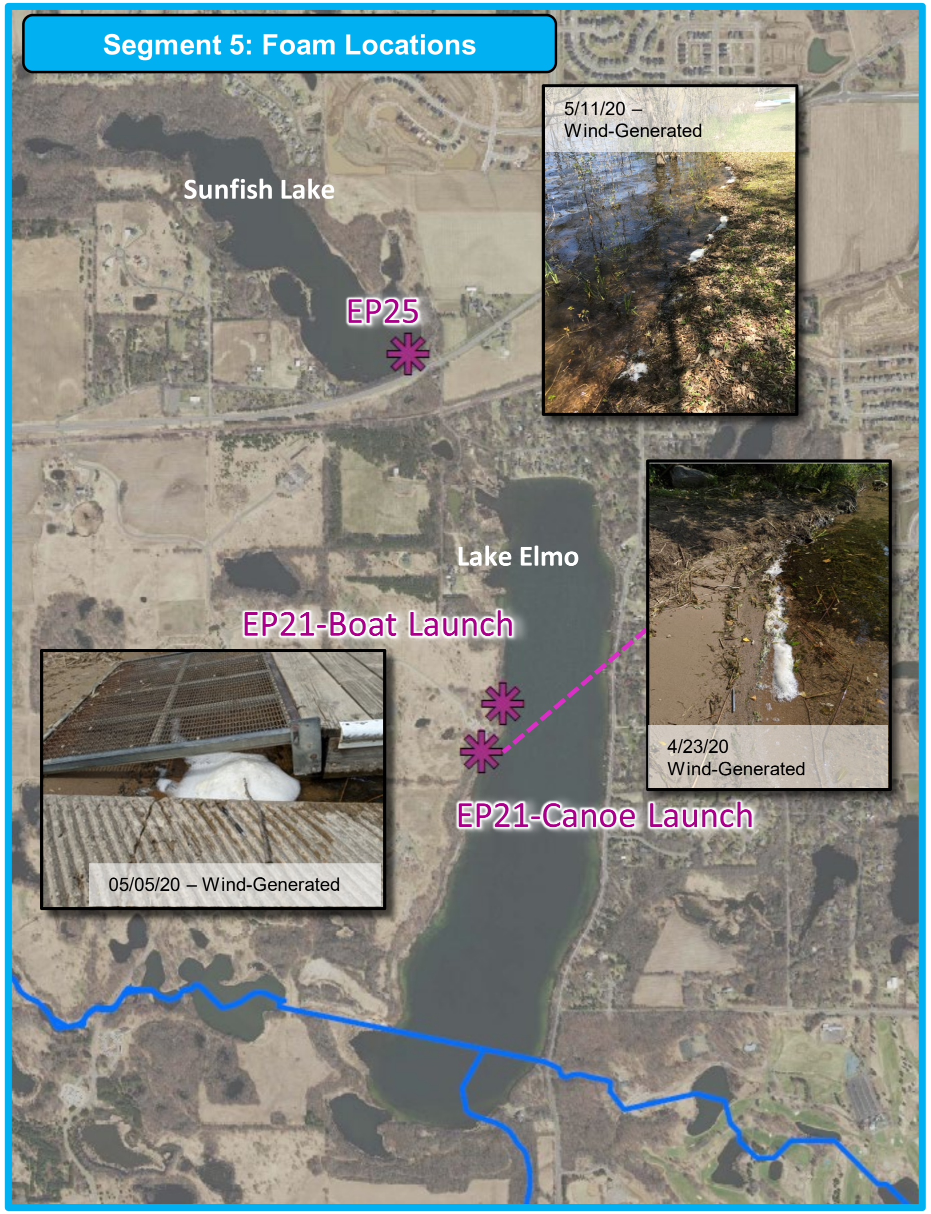
Foam Segment 5: Results and Enrichment Factors

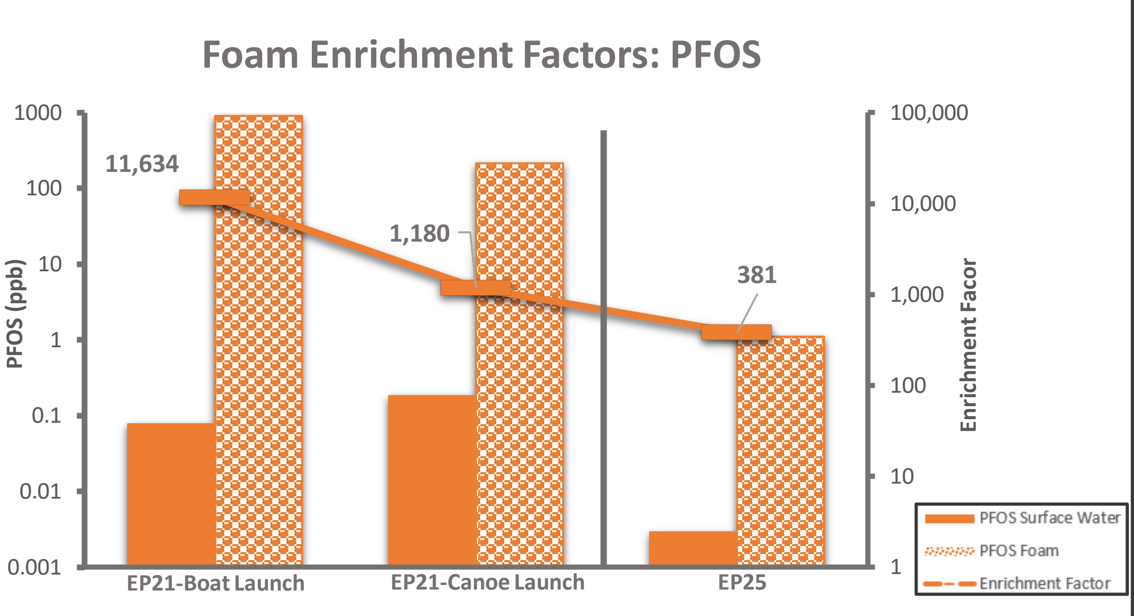
Segment 5: Foam Locations



Findings: PFOS Results

Site-wide, the foam sample from Sunfish Lake (EP25) had the lowest PFOS concentration, while PFOS concentrations in foam from Lake Elmo were among the higher samples.

As in other segments in the corridor, PFOS concentrations in foam sampled from the same location can vary in magnitude.

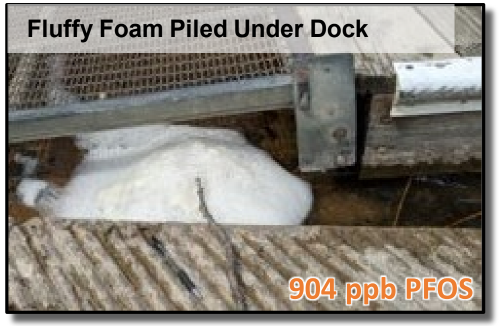


Findings: Enrichment Factors and Foam Type

An enrichment factor is the ratio of the PFAS concentration in the foam to that in the water.

In comparing the two foam samples from eastern portion of Lake Elmo, the enrichment factor increased by an order of magnitude. Both samples are wind-generated, fresh foam. However, as in Segments 2 and 6, the foam sample with the higher PFOS and higher enrichment factors is the fluffier foam.

Lake Elmo Foam Types



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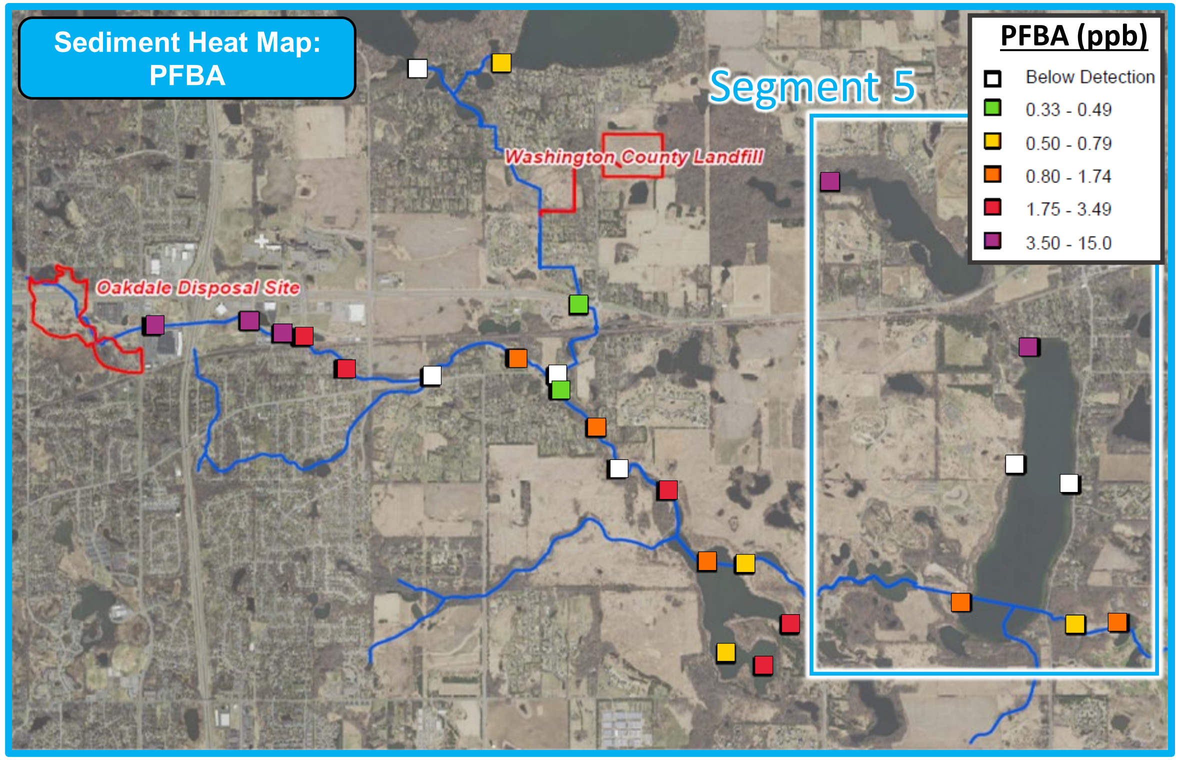
Segment 5 Sediment Results

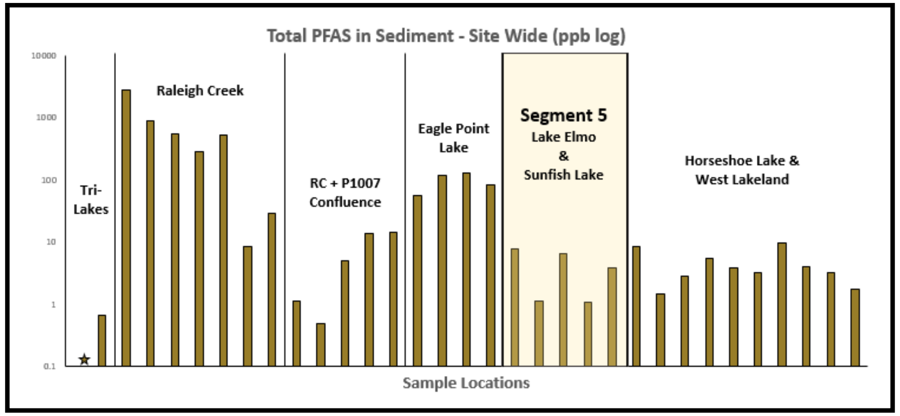


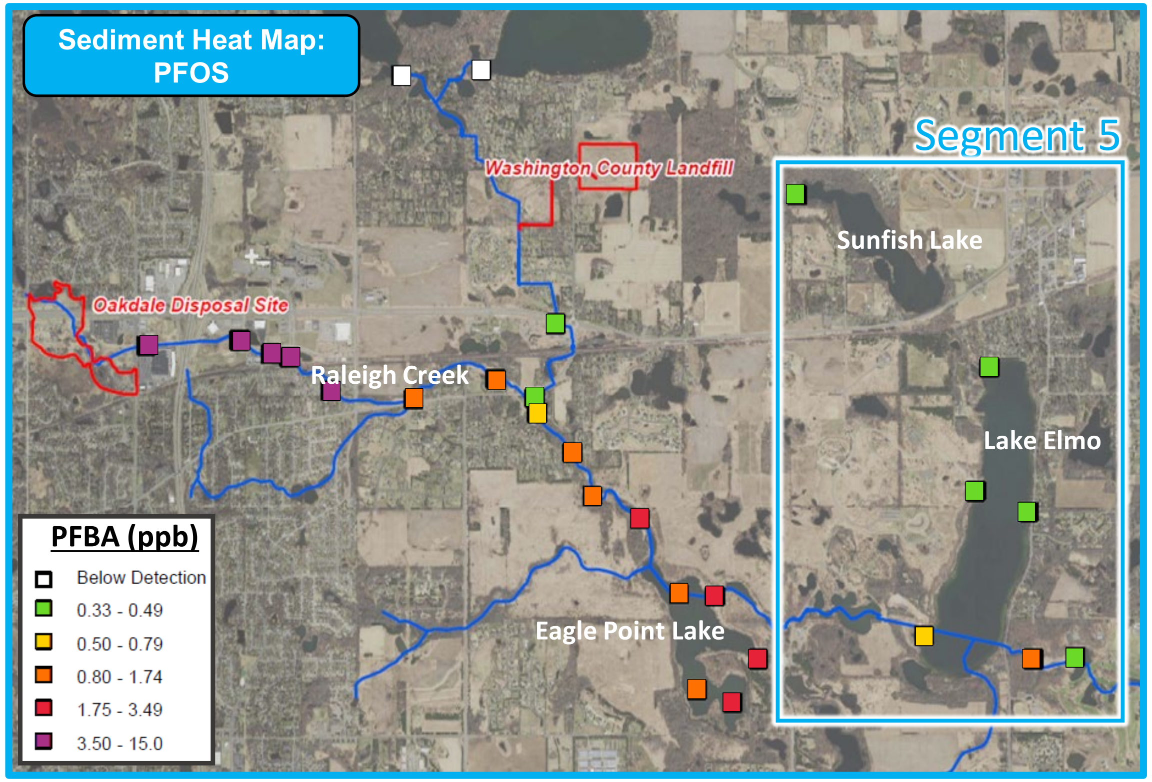
PFBA vs PFOS in Sediment

Concentrations of PFBA in sediment in Sunfish Lake and northern Lake Elmo, which are both in close proximity to the Washington County Landfill (WCL), are among the highest in the corridor. Only sediment collected in the western portion of Raleigh Creek, located immediately downstream of the Oakdale Disposal Site (ODS), had higher concentrations of PFBA. However, while PFOS sediment concentrations in this portion of Raleigh Creek are the highest in the corridor, sampled sediment in Sunfish Lake and north Lake Elmo have among the lowest concentrations of PFOS corridor-wide. The opposing maximum PFBA and PFOS sediment concentrations between these two areas point to proximity to source area as the largest contributing factor to PFAS impacts and suggests two distinct source areas, one with elevated PFOS impacts (ODS) and one with elevated PFBA impacts (WCL).

PFAS in Sediment in Segment 5 vs Site-Wide

PFAS in sediment in Segment 5 is relatively lower than elsewhere in the corridor. All sediment samples are below the MPCA 2-Day and 5-Day per Week Site-Specific Sediment Screening Values (SDSVs) for PFOS of 140 ug/kg and 54 ug/kg, respectively.





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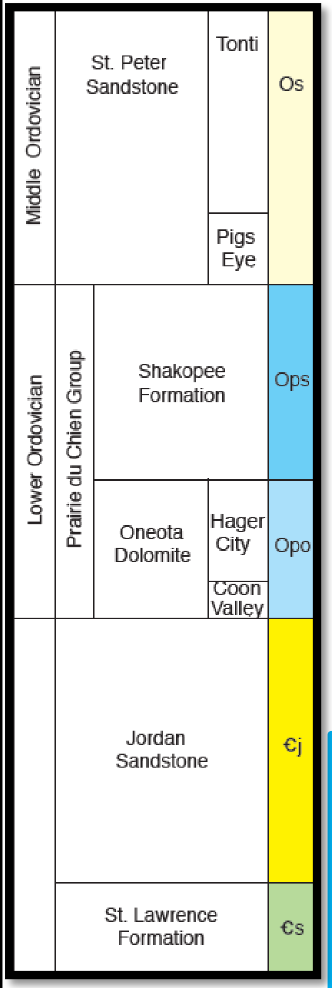
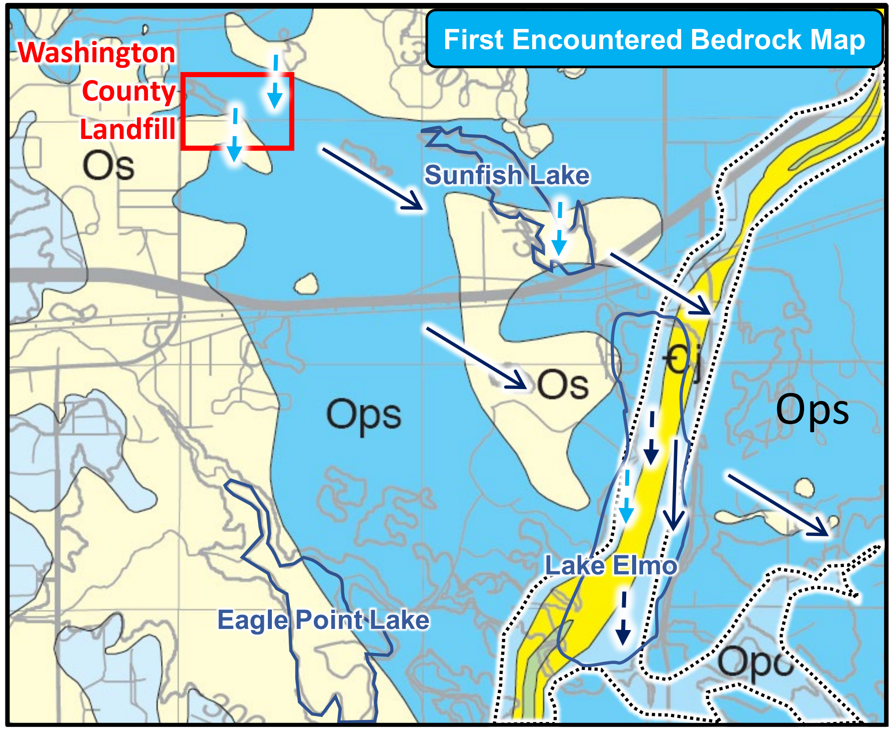
From the Surface to the Subsurface

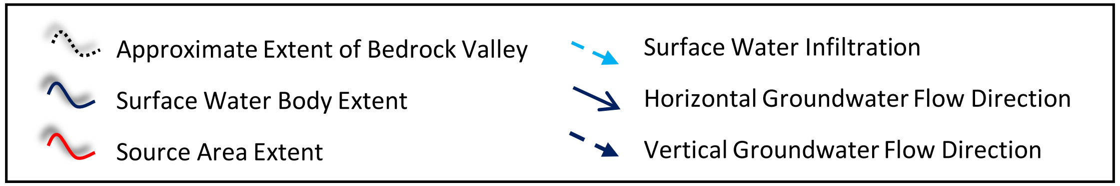




Bedrock Valley: Geology and Hydrogeology

Lake Elmo is situated within a buried bedrock valley, a thin, deeply incised paleochannel comprised of deeply eroded bedrock units filled in with glacial and alluvial sediments. The bedrock valley exposes deeper bedrock aquifers to the surficial sediments and surface water bodies.

As a result of the high conductivity typical of these surficial sediments, groundwater flow within the bedrock valley is both eastward across the valley and downward through the valley. Specifically in Lake Elmo, the absence of the Oneota Dolostone Aquitard, which typically inhibits vertical groundwater flow from the shallow subsurface, allows for a direct connection from the surface to the Jordan Aquifer.



Segment 5: Bedrock Geology and Hydrogeology

The bedrock geology in Segment 5 is diverse and contributes to a hydrogeologically complex system that likely influences PFAS migration from the Washington County Landfill (WCL) and nearby surface water bodies to groundwater.

The Sunfish Lake area is underlain by both the St. Peter Sandstone and Shakopee Dolostone. The St. Peter Aquifer is disconnected throughout the area and thin where present. Due to the lack of confining layers between these units, both the St. Peter and the Shakopee aquifers are connected to the overlying shallow subsurface groundwater and surface water. The Shakopee Aquifer is underlain by the Oneota Dolostone Aquitard, which can be fractured and "leaky." The extent to which the aquitard functions as a barrier to the underlying Jordan Aquifer is not well understood.

Due to the presence of the Bedrock Valley, the first encountered bedrock under Lake Elmo is primarily the Jordan Aquifer. The absence of the overlying bedrock units creates a unique direct connection between surface water and the Jordan Aquifer. Further vertical groundwater migration from the Jordan Aquifer is likely inhibited by the St. Lawrence Aquitard.

These geologic conditions may allow groundwater migration into the Jordan Aquifer through two pathways: through the "leaky" Oneota Aquitard and through the Bedrock Valley.

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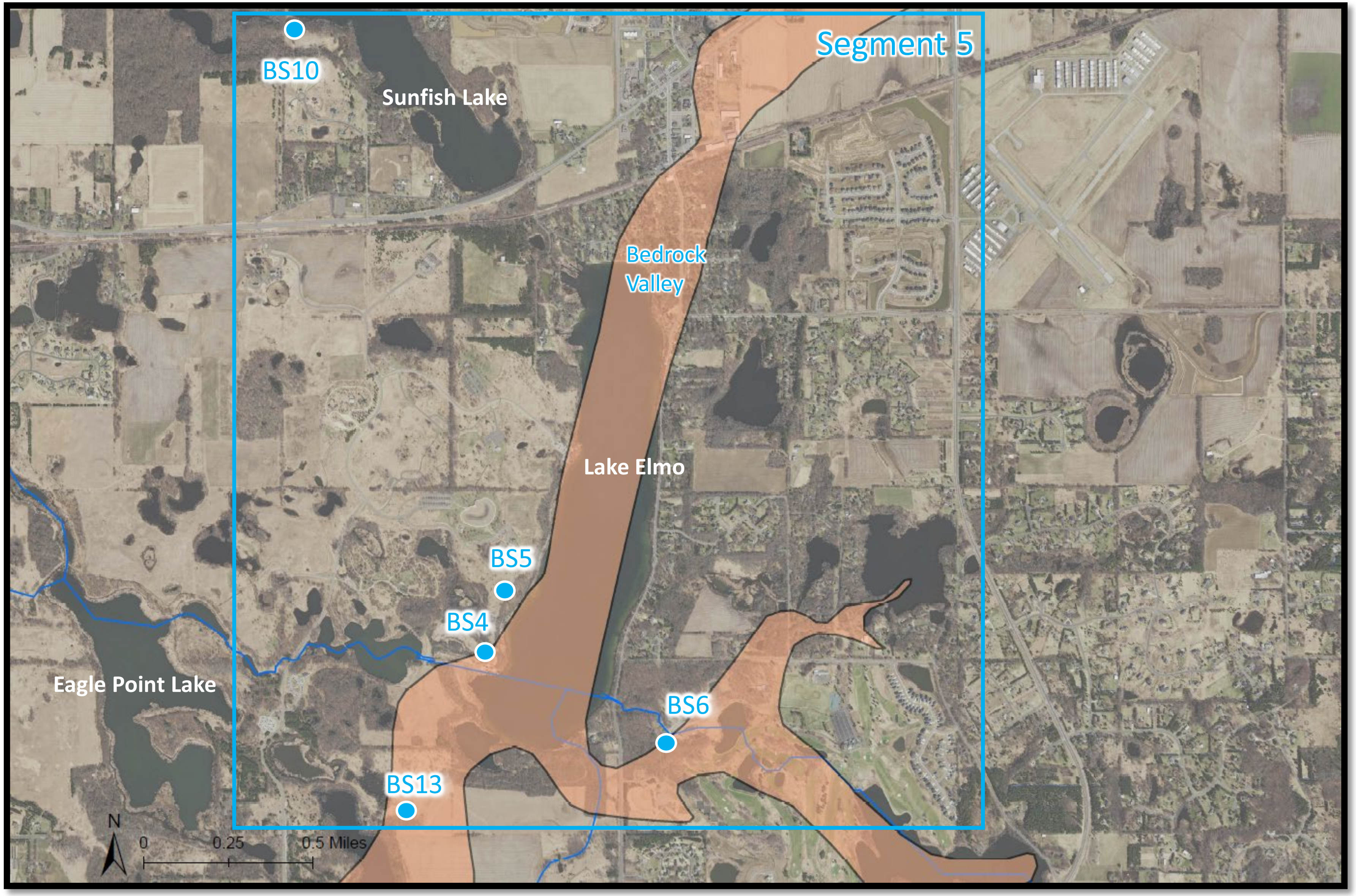
Beta Sites and Features



AECOM Beta Sites

Beta Site 4 (BS4)

MW4A: Oneota Aquitard Well

Beta Site 5 (BS5)

MW5A: Jordan Aquifer Well

MW5B: Shakopee Aquifer Well

(Vertical Aquifer Profile Samples from the Quaternary Aquifer)

Beta Site 6 (BS6)

MW6A: Jordan Aquifer Well

MW6B: Oneota Aquitard Well

MW6C: Quaternary Aquifer Well

MW6D: Quaternary Aquifer Well

Beta Site 10 (BS10)

MW10C: Quaternary Aquifer Well

Beta Site 13 (BS13)

MW13A: Tunnel City Aquifer Well

MW13B: Jordan Aquifer Well

MW13C: Quaternary Aquifer Well

MW13D: Quaternary Aquifer Well

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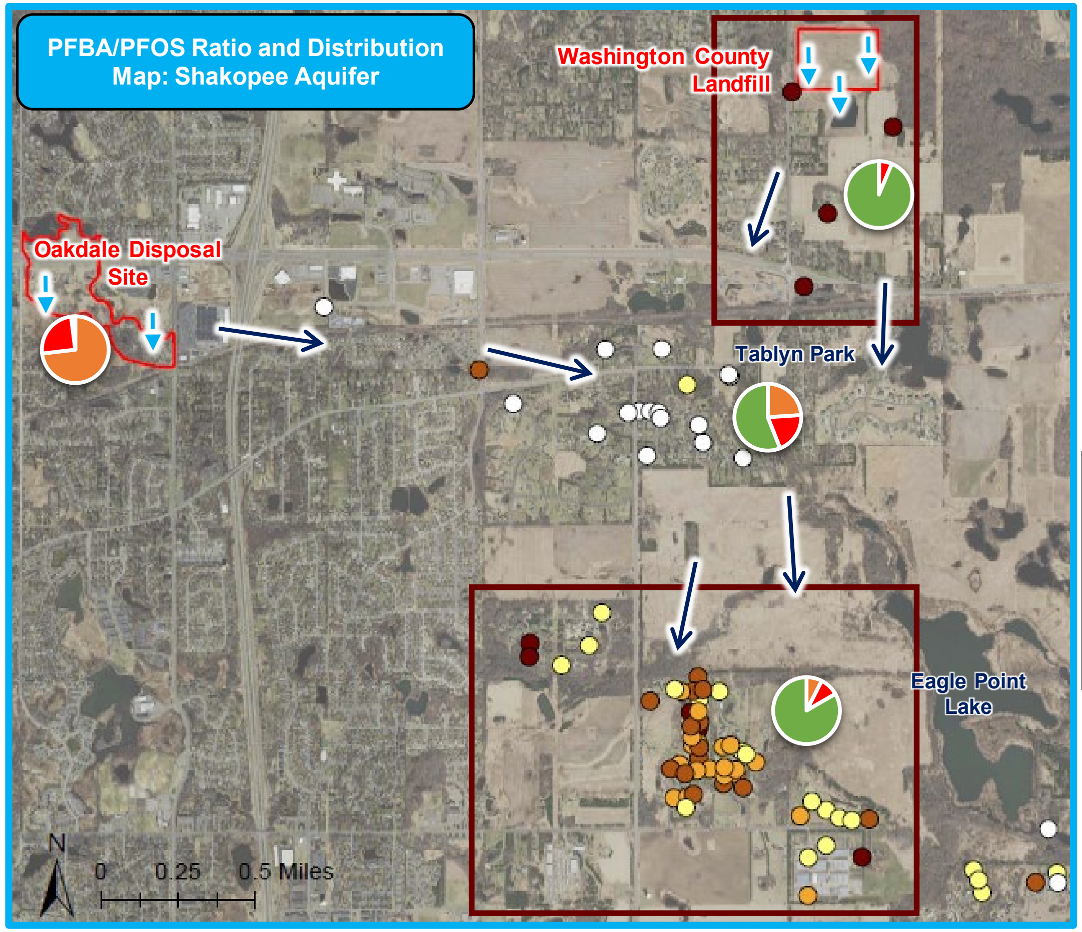
PFAS Preferential Pathway from WCL to the Shakopee Aquifer: Southernly Component

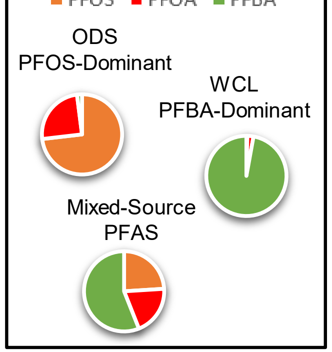
PFBA/PFOS Distribution: WCL to Shakopee Aquifer

The highest PFBA/PFOS ratios occur in the Shakopee Aquifer in close proximity to the Washington County Landfill (WCL). High PFBA/PFOS ratios, resulting in a PFBA-dominant signature, is typical of PFAS impacts associated with WCL. Conversely, near the Oakdale Disposal Site (ODS), the PFBA/PFOS ratio is between three and four orders of magnitude lower due to PFOS-dominant impacts. At Tablyn Park, the PFAS distribution becomes more equal, likely the result of mixing of PFOS-dominant impacts from ODS to the west with PFBA-dominant impacts from WCL to the north. Continuing southward, the PFBA/PFOS ratios increase again and the distribution shifts back to that typical of WCL impacts.

PFBA/PFOS Ratio and Distribution Map: Shakopee Aquifer



Typical PFAS Distributions



PFBA/PFOS Ratio

- 0.3 - 4.0
- 4.1 - 8.0
- 8.1 - 10.0
- 10.1 - 14.0
- 14.1 - 830.0

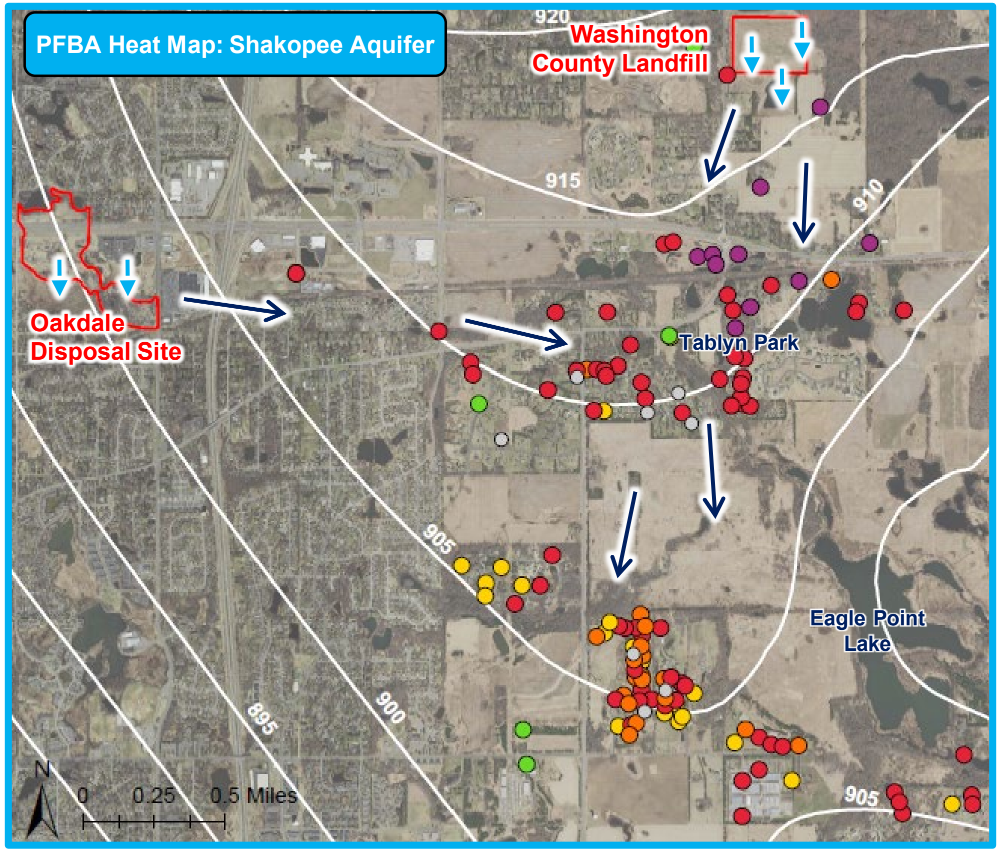
PFBA (ppb)

- Below Detection
- 0.005 - 0.20
- 0.201 - 0.40
- 0.401 - 0.601
- 0.601 - 6.99
- 7.00 - 350

Map Features

- Surface to Ground Infiltration
- Groundwater Flow Direction
- Shakopee Potentiometric Surface (5-ft Contours)

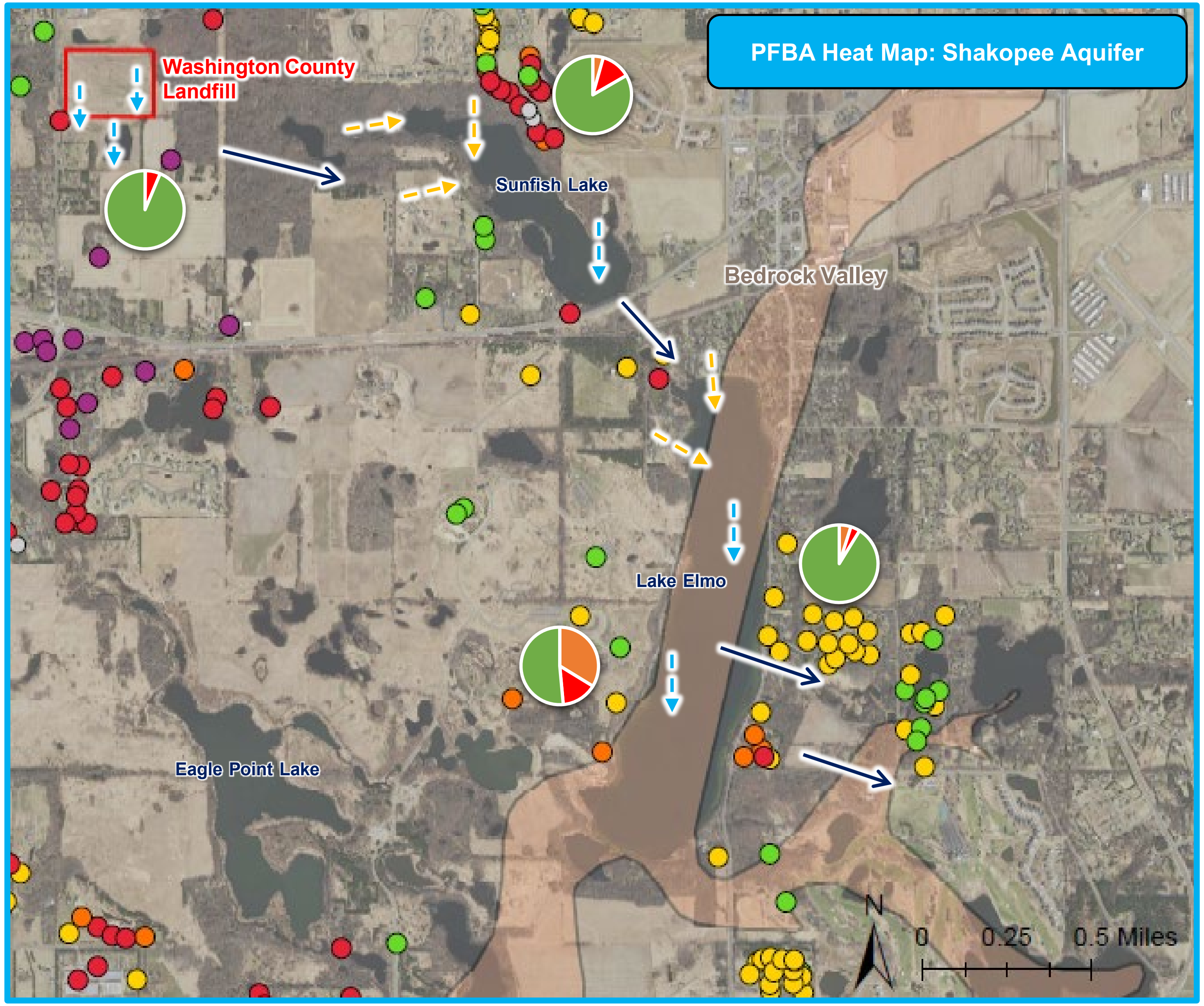
PFBA Heat Map: Shakopee Aquifer



PFBA Impacts in Groundwater: WCL to Shakopee Aquifer

The highest PFBA concentrations are observed in the Shakopee Aquifer at WCL. Moving south, though the PFBA/PFOS ratio decreases, PFBA concentrations remain elevated. Continuing southward, the PFAS distribution in groundwater shifts back to the PFBA-dominant signature due to a reduction in PFOS concentrations while concentrations of PFBA remain elevated. Relative to PFOS and other-longer chained PFAS compounds, PFBA has a smaller molecular size, more hydrophilic nature, and higher water solubility. These chemical properties allow the compound to travel faster and farther in groundwater and likely explain the elevated PFBA impacts beyond the extent of PFOS-dominant impacts to the north.

PFBA Groundwater Results: WCL to the Shakopee Aquifer



PFBA Impacts in Groundwater: WCL to Shakopee Aquifer

Elevated PFBA concentrations in the Shakopee Aquifer with the distinct PFBA-dominant signature typical of the Washington County Landfill (WCL) are observed along the northern portion of Sunfish Lake. The pathway for these impacts is likely the result of surface water infiltration at the landfill, followed by groundwater discharge to the Sunfish Lake. Sunfish Lake is similarly connected via infiltration and groundwater discharge to Lake Elmo, which also has elevated PFBA impacts in surface water. Finally, surface water infiltration from Lake Elmo into the Shakopee Aquifer is likely facilitated by the underlying Bedrock Valley and discussed in the next slide.

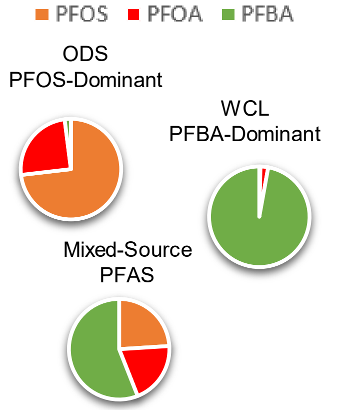
Map Features

- Surface to Ground Infiltration
- Groundwater Flow Direction (Horizontal)
- Groundwater to Surface Discharge

PFBA (ppb)

- Below Detection
- 0.005 - 0.20
- 0.201 - 0.40
- 0.401 - 0.601
- 0.601 - 6.99
- 7.00 - 350

Typical PFAS Distributions



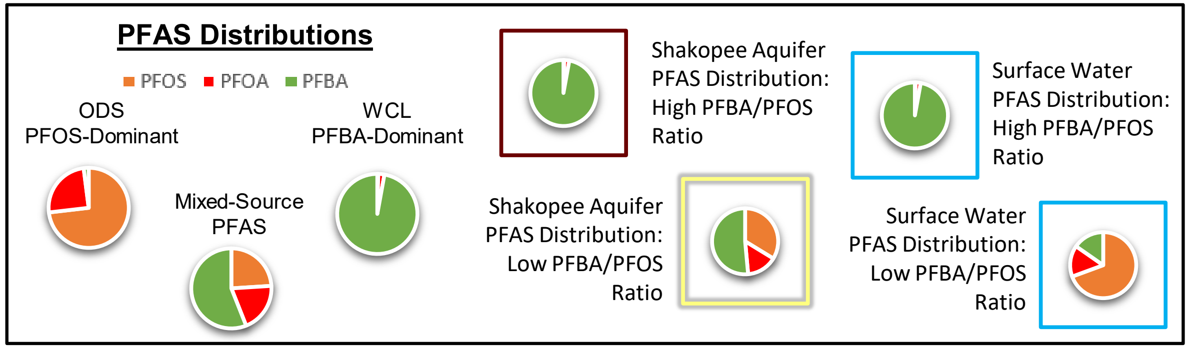
PFBA/PFOS Distribution in Groundwater: WCL to the Bedrock Valley

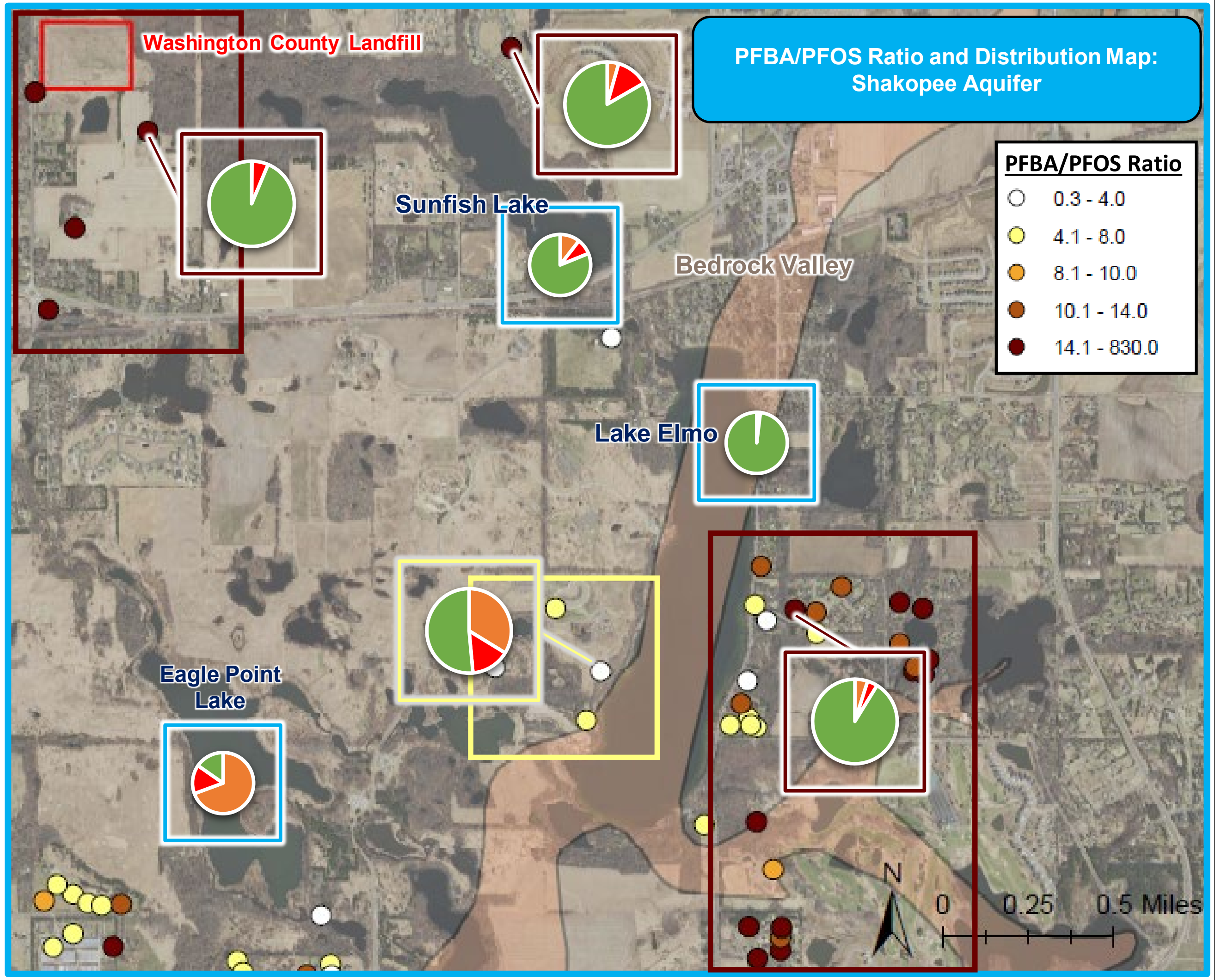
Fate and Transport: WCL to Shakopee Aquifer via Bedrock Valley

The unique hydrogeologic properties of the Bedrock Valley, which is mapped approximately under Lake Elmo, may facilitate the migration of PFAS-impacted waters from Lake Elmo into bedrock aquifers. Though PFBA concentrations are up to two orders of magnitude less on either side of the Bedrock Valley (as shown in the previous slide), groundwater impacts at WCL and east of the Bedrock Valley have elevated PFBA/PFOS ratios, sharing the PFBA-dominant signature characteristic of WCL. Further, PFBA/PFOS ratios from wells west of the Bedrock Valley are up to four orders of magnitude lower that those east of the valley, resulting in a more equal distribution of PFAS compounds. The combination of the similarity between WCL wells and those east of the Bedrock Valley with the dissimilarity between wells west and east of the Bedrock Valley suggest a migration pathway from the WCL, to the Bedrock Valley, and on to the Shakopee Aquifer eastward.

Fate and Transport: Lake Elmo to Shakopee Aquifer via Bedrock Valley

In addition to the shared PFBA-dominant signature observed between Shakopee Aquifer wells, similarly elevated PFBA/PFOS ratios are also observed between Sunfish Lake and Lake Elmo and the Shakopee Aquifer east of the Bedrock Valley, further supporting a connection between these surface water bodies and impacted groundwater downgradient of the Bedrock Valley. Although other variables may influence the PFBA and PFOS distribution in Segment 5, the similarity in ratios between Lake Elmo and groundwater downgradient of Lake Elmo point to the Bedrock Valley as the key in surface and groundwater connection in Segment 5.





Map Features

- Surface to Ground Infiltration
- Groundwater to Surface Discharge
- Groundwater Flow Direction (Horizontal)

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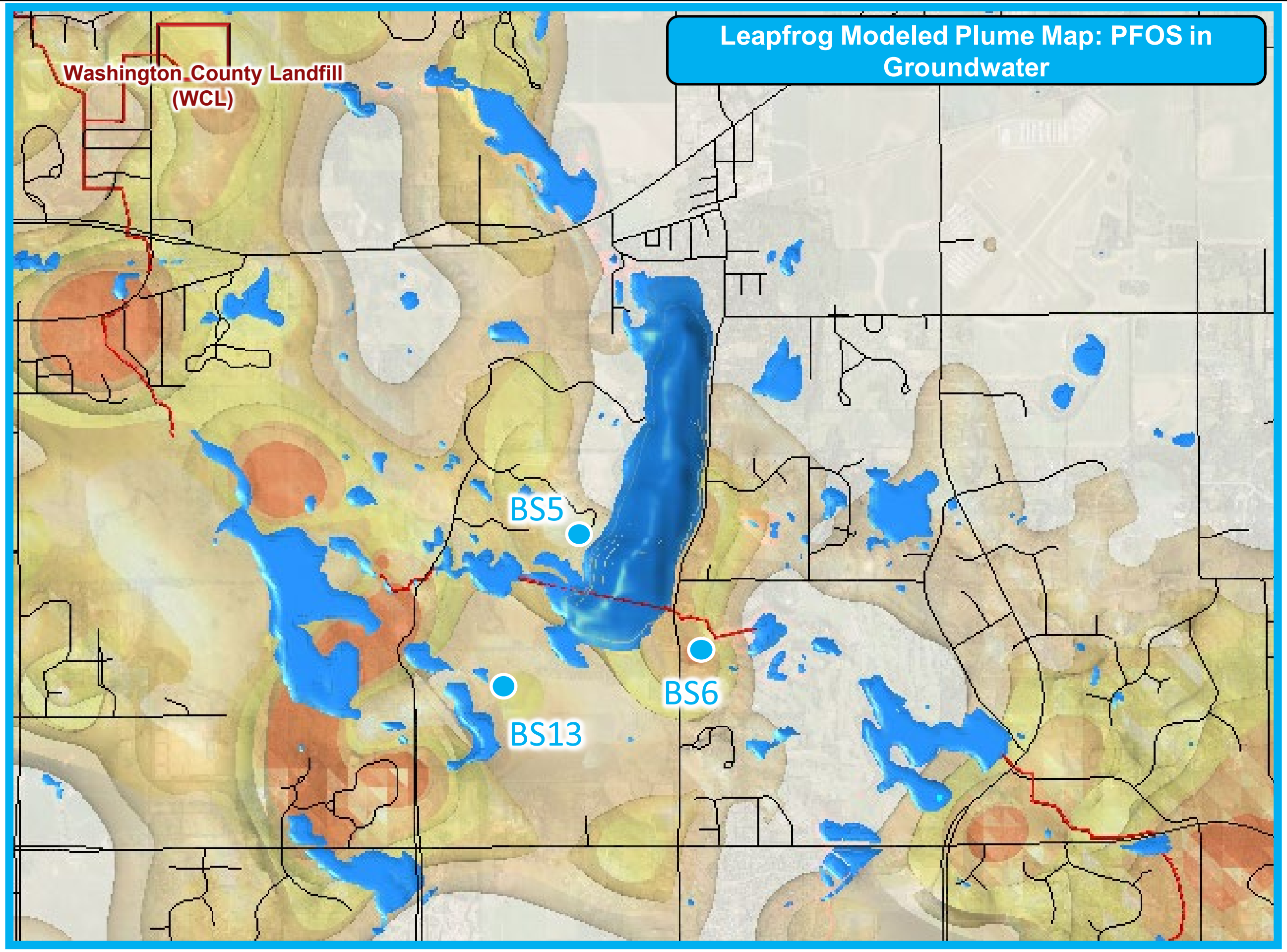
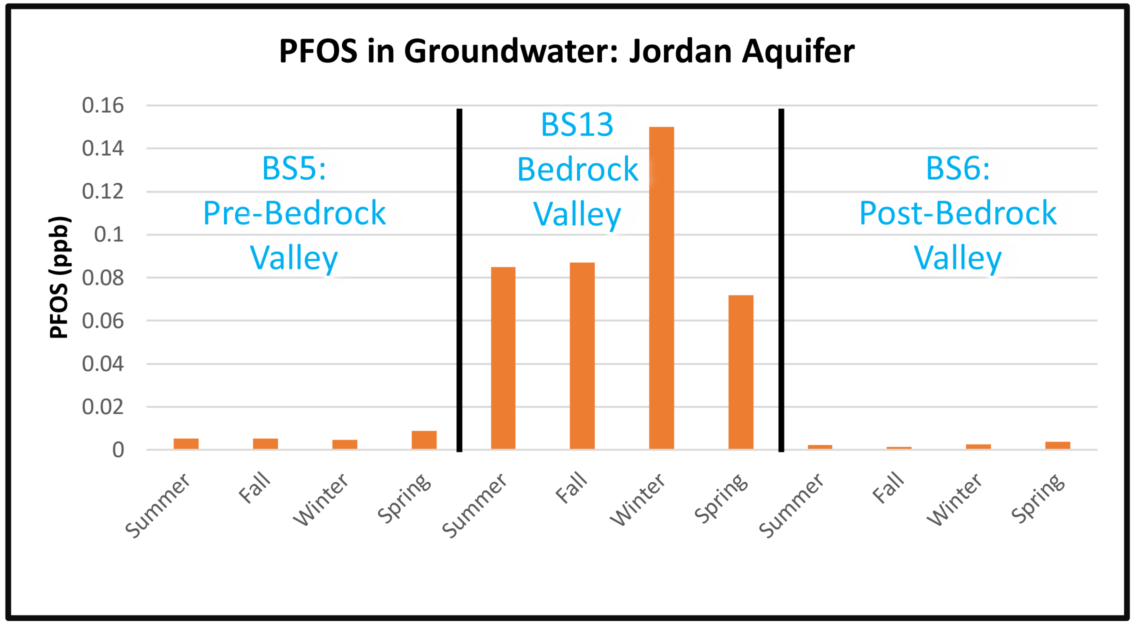
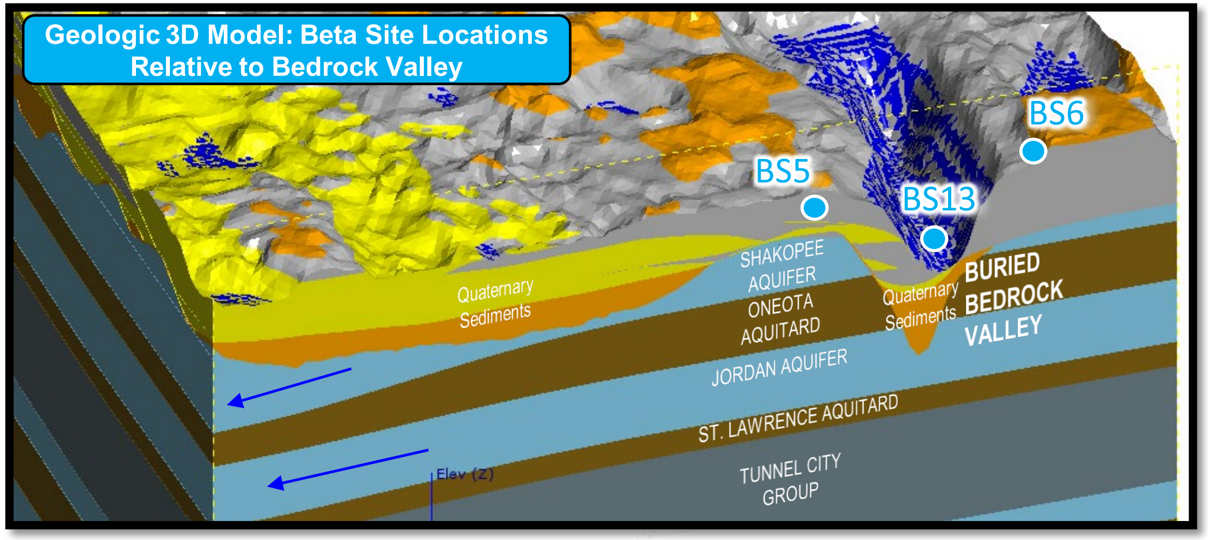
A Closer Look: Groundwater Results and the Bedrock Valley







PFOS in Jordan Aquifer: Bedrock Valley

Quarterly sampling of Jordan Aquifer wells upgradient of, within, and downgradient of the Bedrock Valley have consistently shown notably greater amounts of PFOS within the valley. Although the exact mechanisms and flow dynamics within the Bedrock Valley are not fully understood, these results point to the valley as a contributing factor in the migration of PFAS-impacted waters within the corridor.