Project 1007 Focused Investigation Progress Report - Segment 2

June 2021 — Minnesota Pollution Control Agency

Historic and Current Surface and Ground Water Flow from ODS

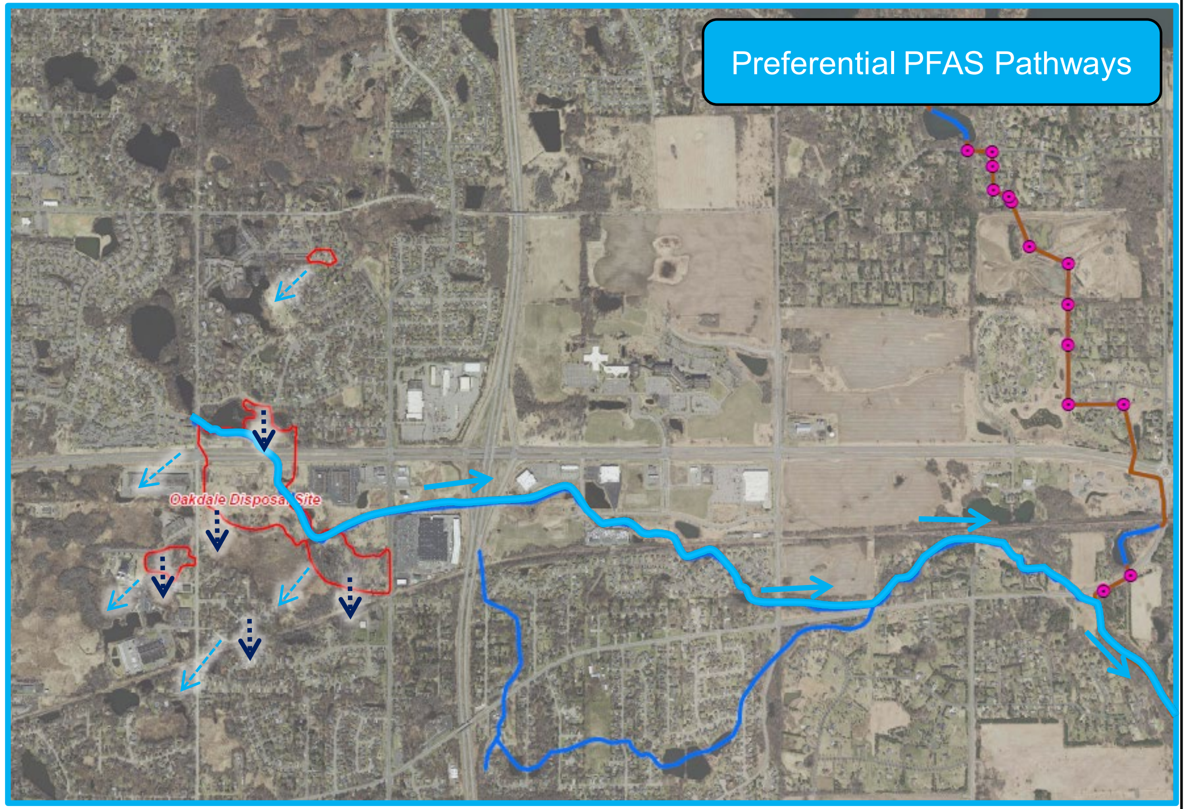
Oakdale Disposal Site History

From the early 1950's through to present day, the 3M facility in Cottage Grove, Minnesota has produced commercial products containing PFAS compounds. Both liquid and solid wastes generated from the perfluorochemical production process were disposed of at the production facility in Cottage Grove as well as several other disposal sites including the Oakdale Disposal Site (ODS).

ODS, which consists of three disposal areas, Eberle (approximately 2 acres), Brockman (approximately 5 acres), and Abresch (approximately 55 acres), accepted a variety of industrial wastes from the late 1940's until the 1960's. From 1956 until 1960*, the three areas received PFAS-containing wastes, with the Abresch location receiving the majority of the waste. 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 1980's, following the detection of VOC-impacted shallow groundwater, portions of the disposal areas were excavated, contaminated materials and soils were disposed of offsite, and 39 multi-aquifer wells were sealed. In addition, a 12 well pump-out system was installed at ODS.

In 2010, in response to the reported PFAS impacts, the pump-out system was expanded to 24 wells. However, PFAS impacts in the subsurface had already migrated far beyond the original boundaries of the VOC-impacted area into Lake Elmo and West Lakeland. In addition, Raleigh Creek continues to flow through ODS and is likely the primary current and historic surface PFAS migration pathway.

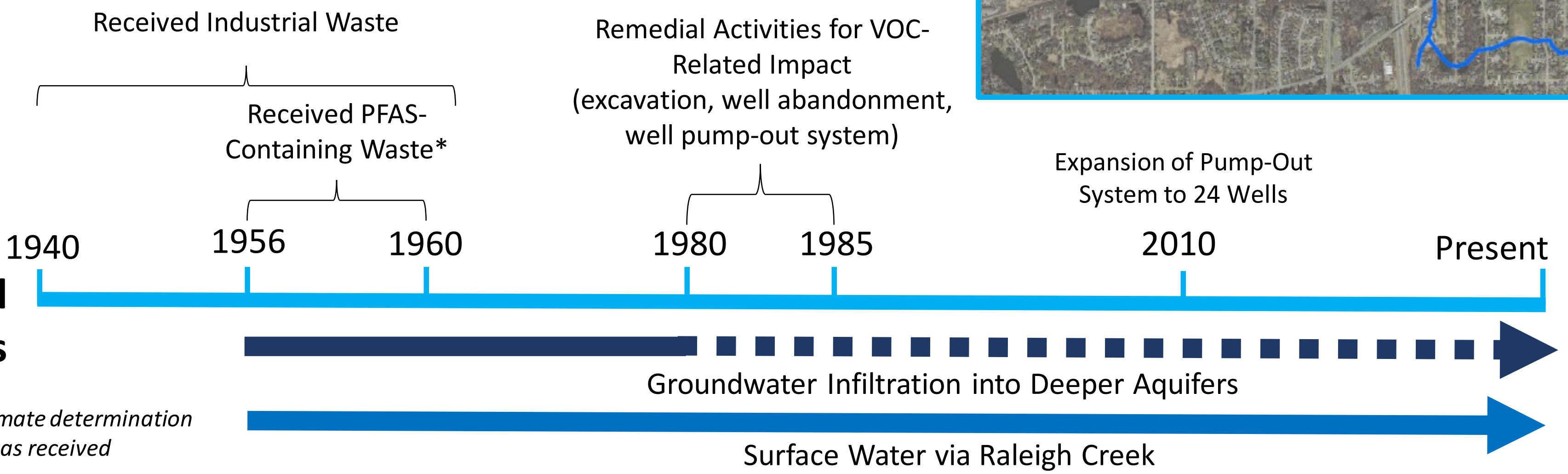


Legend

- Known Surface Water Flow Path
- Potential Historic Runoff Direction
- Known Historic Groundwater Infiltration (possibly still occurring)

Activities at ODS

Preferential PFAS Pathways



**1956-1960 is an approximate determination of the date range waste was received*

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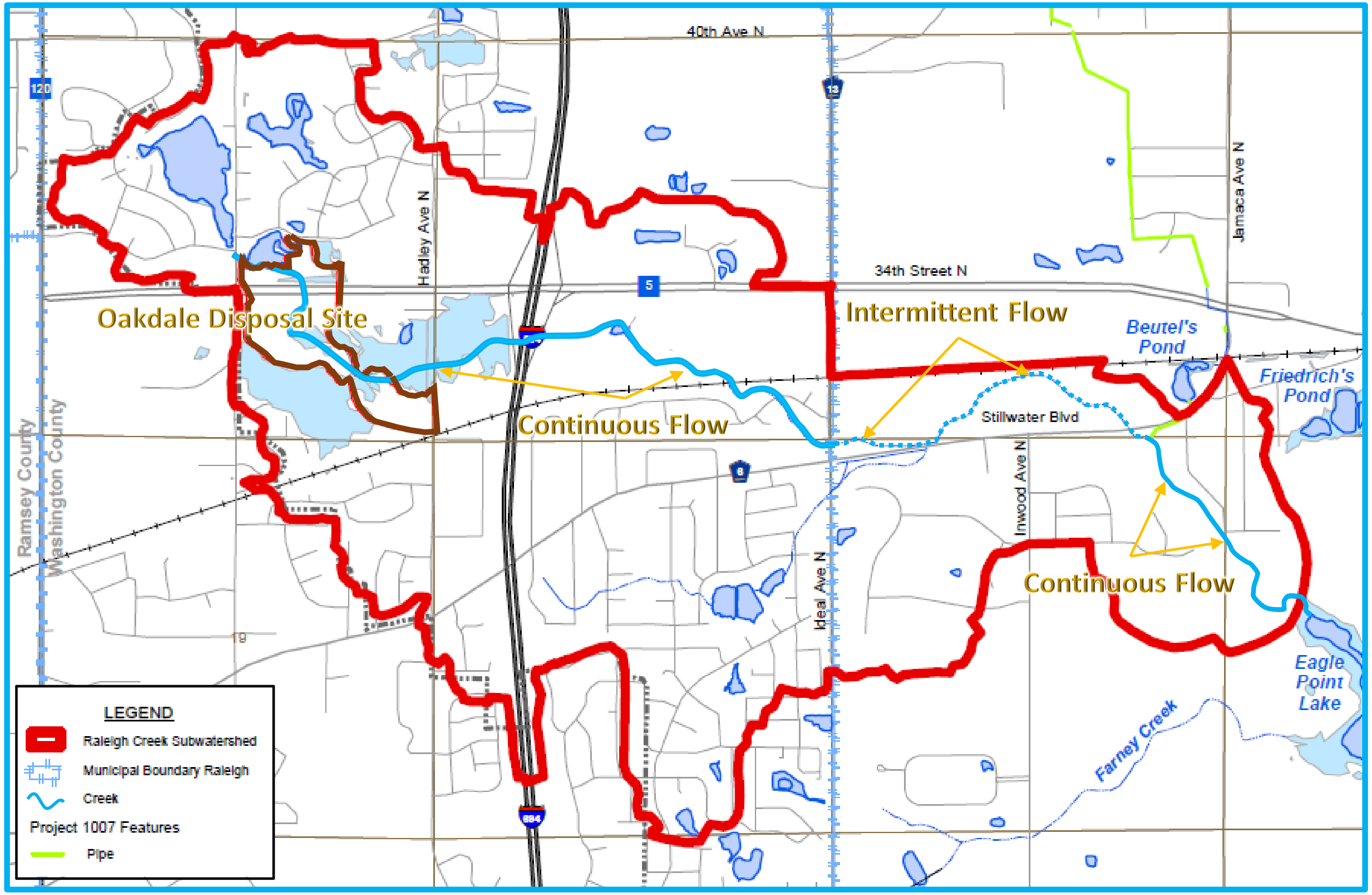
Introduction: Segment 2 Surface Water System



Surface Water Flow Path

The primary surface water flow path in Segment 2 is Raleigh Creek, the headwaters of which is immediately northwest of the former Oakdale Disposal Site (ODS).

Raleigh Creek flows west to east and passes through a series of wetlands and small ponds. These wetlands and ponds have PFAS impacts in sediment that is likely contributing to surface water impacts and infiltrating into the subsurface.

Between ODS and Ideal Avenue, the creek flow is perennial, though much of the creek freezes in the winter months. Raleigh Creek flow downstream of Ideal Avenue is restricted due to the culvert elevations and flood mitigation structure at the intersection of Raleigh Creek and the road. Between Ideal Avenue Wetland Complex (IAWC) and Tablyn Park, Raleigh Creek is dependent on precipitation and as a result is routinely dry.

The combination of the restricted downstream flow and the ponds naturally present at IAWC, make the wetland complex uniquely suited to facilitate the infiltration of PFAS-impacted surface waters from ODS into the subsurface.

After the confluence with the Project 1007 conveyance system at Tablyn Park, Raleigh Creek continues to the southeast to the Lake Elmo Park Reserve and discharges to the northwestern inlet to Eagle Point Lake. Due to the continual input from P1007, this portion of Raleigh Creek is perennial.

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Comparison of Two Source Areas: Oakdale Disposal Site V.S. WCL

Disposal Site-Specific PFAS-Containing Waste

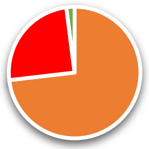
The Oakdale Disposal Site (ODS) accepted liquid and solid industrial waste, while the Washington County Landfill (WCL) accepted a variety of industrial and wastewater treatment plant waste. The PFAS contamination associated with these two historic waste streams is made up of different PFAS compounds, 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

ODS
PFOS-Dominant

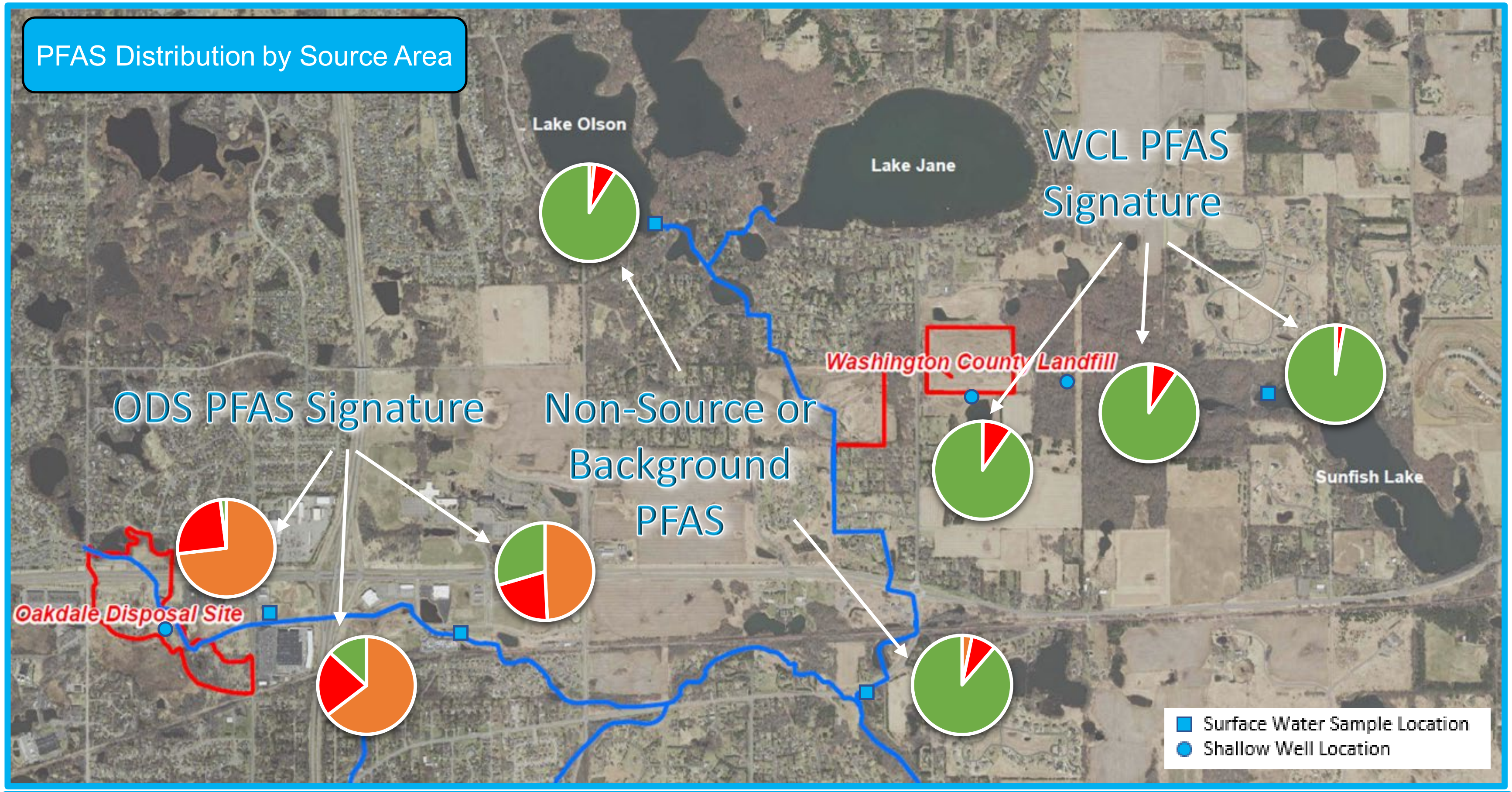


Non-Source or
Background PFAS*

WCL
PFBA-Dominant

■ PFOS ■ PFOA ■ PFBA

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



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, fate and transport and source mixing.

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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Surface Water Results: PFAS

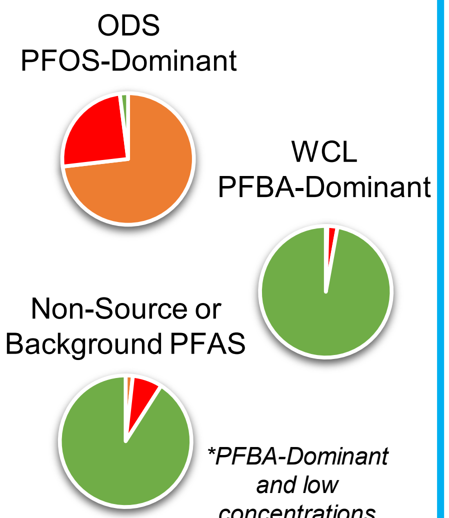
Surface Water Flow Path

<u>Finding:</u> Overall, PFOS concentrations are the highest closest to ODS and decrease steadily the farther away from the source area. Locations with the lowest PFOS concentrations in Segment 2 do not directly receive discharge from ODS (OD1, RC8, RC16, and RC14).

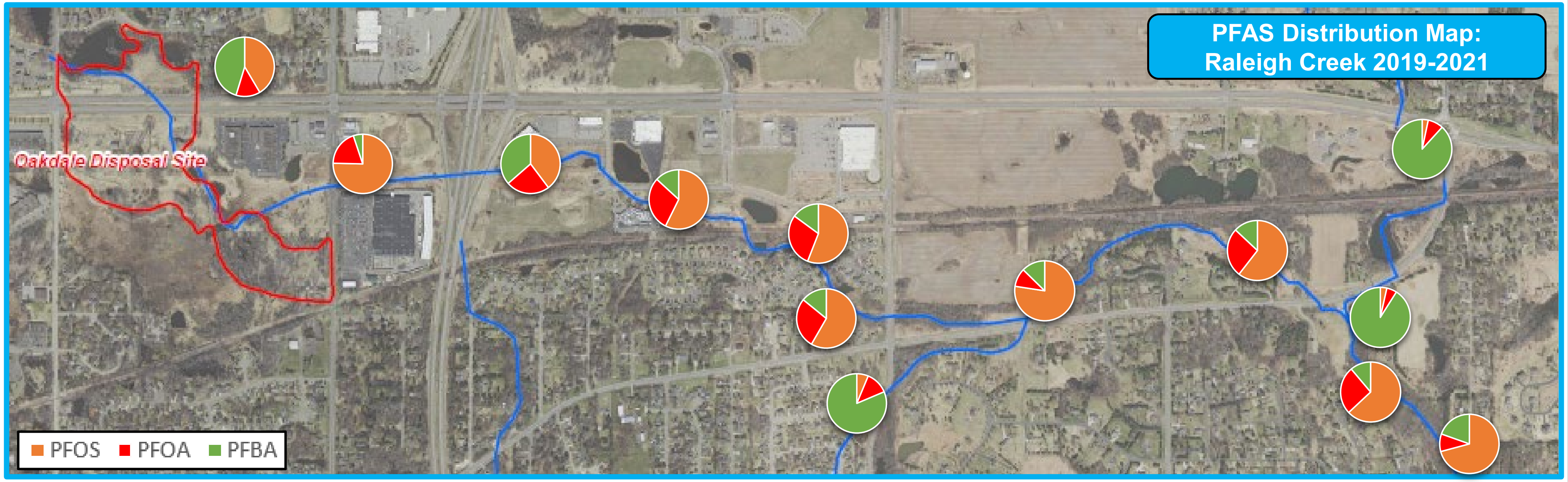
In addition to overall lower PFOS concentrations, locations that are <u>not</u> hydrologically connected to ODS have a distinctly different distribution of PFAS compounds as compared to Raleigh Creek. Impacts at these locations more likely reflect background PFAS impacts rather than a known source.

***Further assessment of the southeastern tributary of Raleigh Creek (i.e., upstream of RC8) is planned for the near future.*

Typical PFAS Distributions



**PFBA-Dominant and low concentrations*



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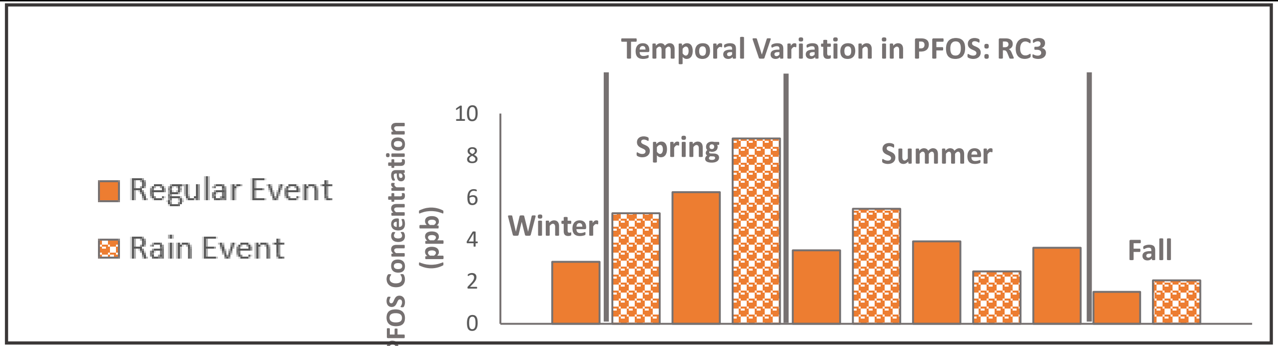
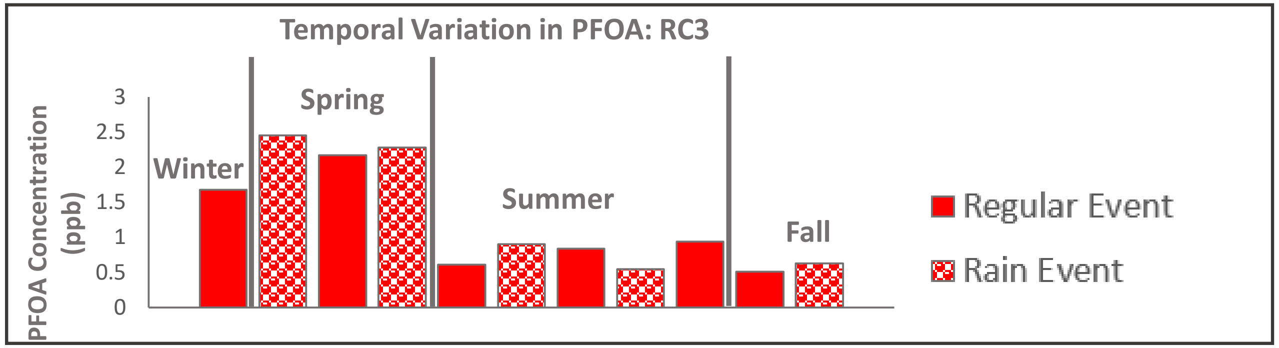
Surface Water Results: Seasonal Variation in PFAS at Source



Finding: PFOS and PFOA fluctuate inconsistently following precipitation events.

Potential causes of this variability in response to rain events is discussed below.

Farther away from the source area along Raleigh Creek, this variability in PFAS concentrations continues. However, the amount of fluctuation appears to be less with greater distance from the source area.

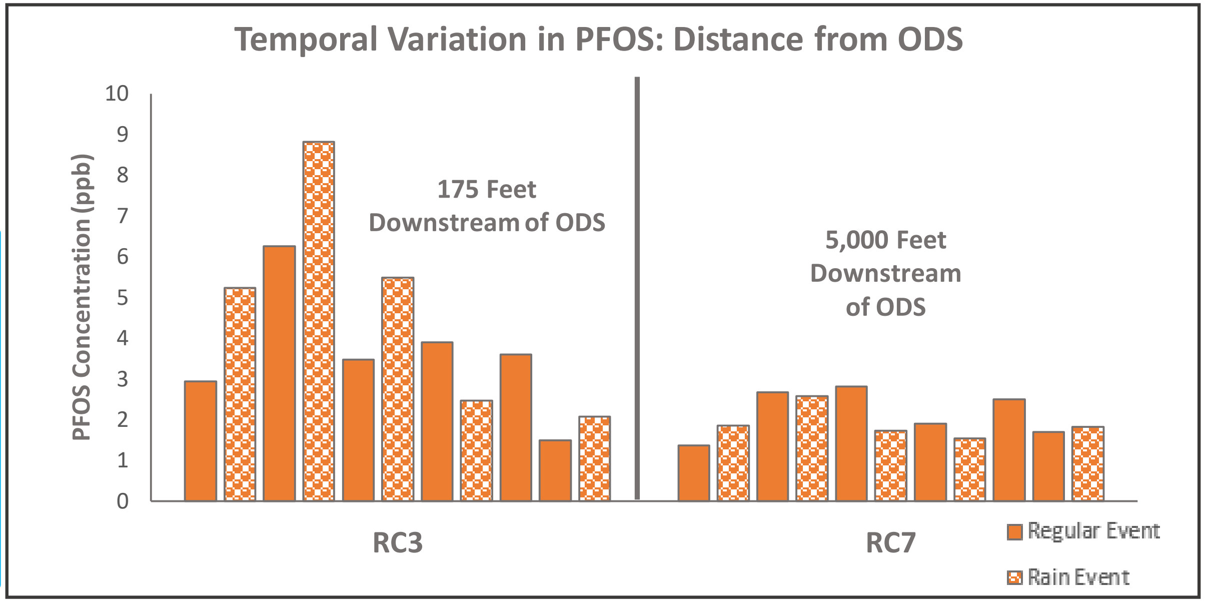


Decrease in PFAS Factors

- Addition of rain to surface water
- Addition of surface runoff from other unimpacted locations (i.e., roadways, parking lots, etc.)
- Frequency, Duration, and Amount of Rainfall

Increase in PFAS Factors

- Release of PFAS trapped from surficial sediments at ODS.
- Connection of otherwise disconnected PFAS-impacted waters (i.e., isolated wetlands, small ponds, etc.)
- Frequency, Duration, and Amount of Rainfall



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Raleigh Creek Flow Path Morphology

High Flow Conditions

During high flow conditions, either due to a precipitation event or sustained intermittent rain events, surface water in Raleigh flows uninterrupted from ODS to the confluence with the P1007 Conveyance. Surface flow downstream of the confluence continue southeast to Lake Elmo Park Reserve into Eagle Point Lake.

Finding: A continuously flowing Raleigh Creek not only allows for the transport of PFAS-impacted waters downstream into other water bodies but also potential infiltration of PFAS-impacted waters between Ideal Ave and Tablyn Park.

Low Flow Conditions

During dry periods, either due to lack of sufficient precipitation or winter freezing, flow from ODS along Raleigh Creek does not continue east of the IAWC. The IAWC ponds are regularly the extent of the perennial portion of Raleigh Creek partially due to the culvert elevations and flood control structure that inhibits flow from exiting IAWC below a certain elevation.

Finding: The effect of a disconnected Raleigh Creek is not only the restriction of downstream transport of PFAS-impacted waters to other water bodies, but also the facilitation of possible infiltration from the Ideal Avenue Wetland Complex into the subsurface.

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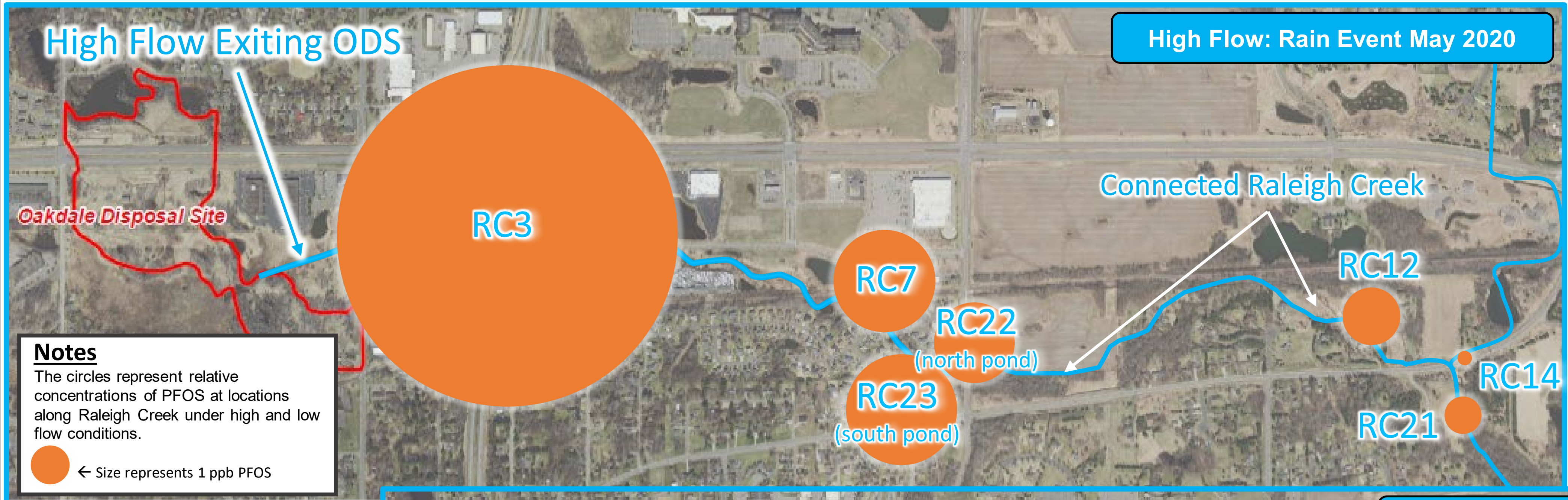
Surface Water Results: PFOS Variation due to Flow Conditions



PFOS Fluctuation

Variations in PFOS concentrations in surface water are influenced, in part, by the amount of flow leaving ODS.

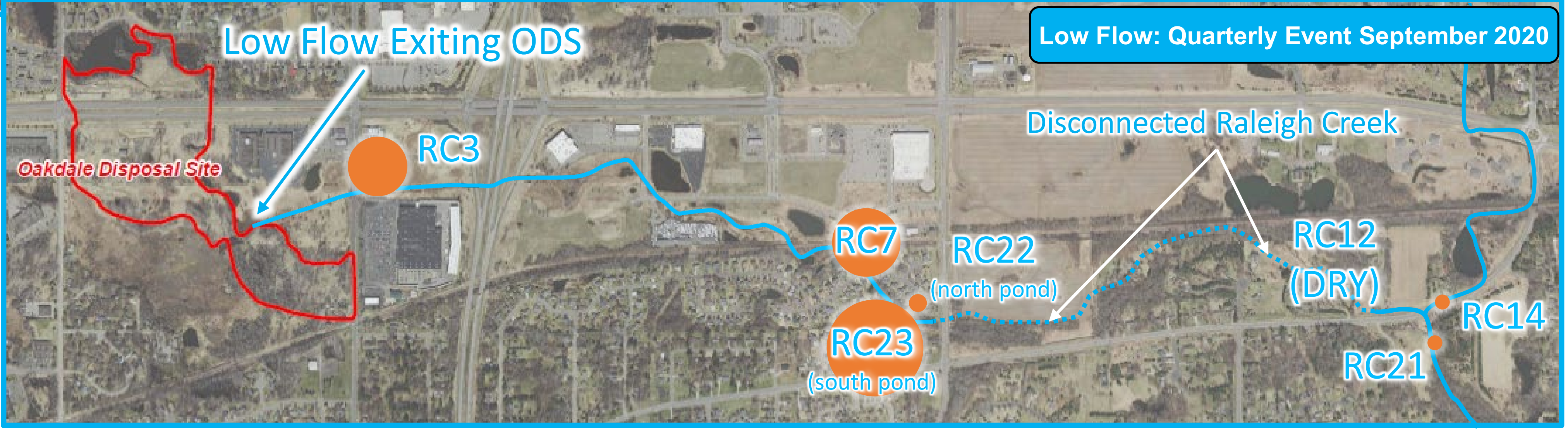
<u>Finding:</u> Greater variation occurs within close proximity to ODS (RC3), while with increased distance from the source area, PFOS in Raleigh Creek appears to remain largely stable.

At the confluence with P1007 (RC21), PFOS concentrations are much higher in high flow conditions.

Surface Water Flow Path

High flow conditions either due to seasonality or precipitation events can allow for two key hydrologic occurrences in Segment 2:

- Increase in PFAS-impacted water exiting ODS and entering Raleigh Creek.
- Connection of Raleigh Creek east of Ideal Avenue, allowing for the transport of PFAS-impacted waters downstream.



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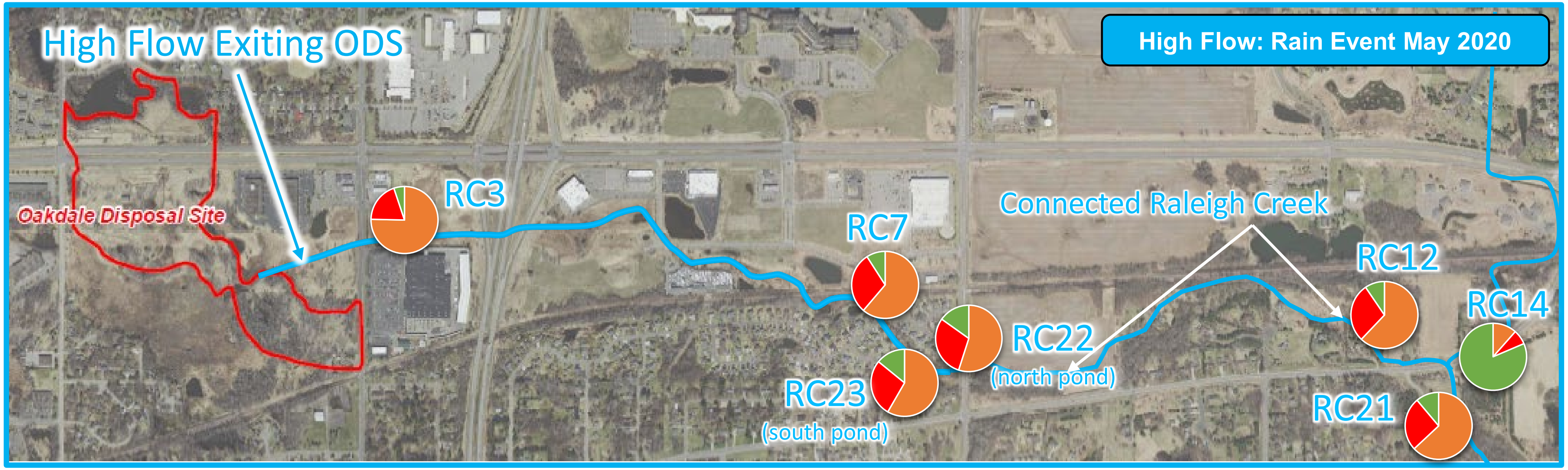
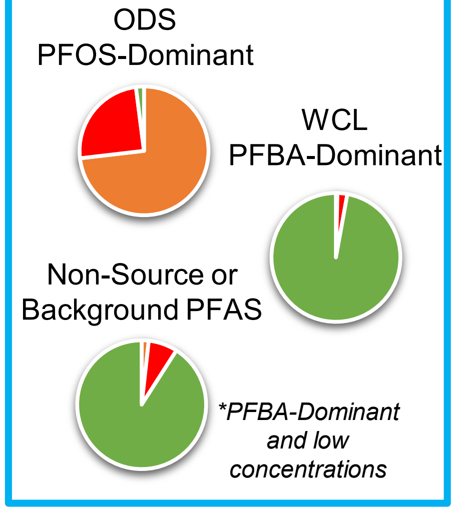
Surface Water Results: Distribution of PFAS Compounds in Varying Flow Conditions

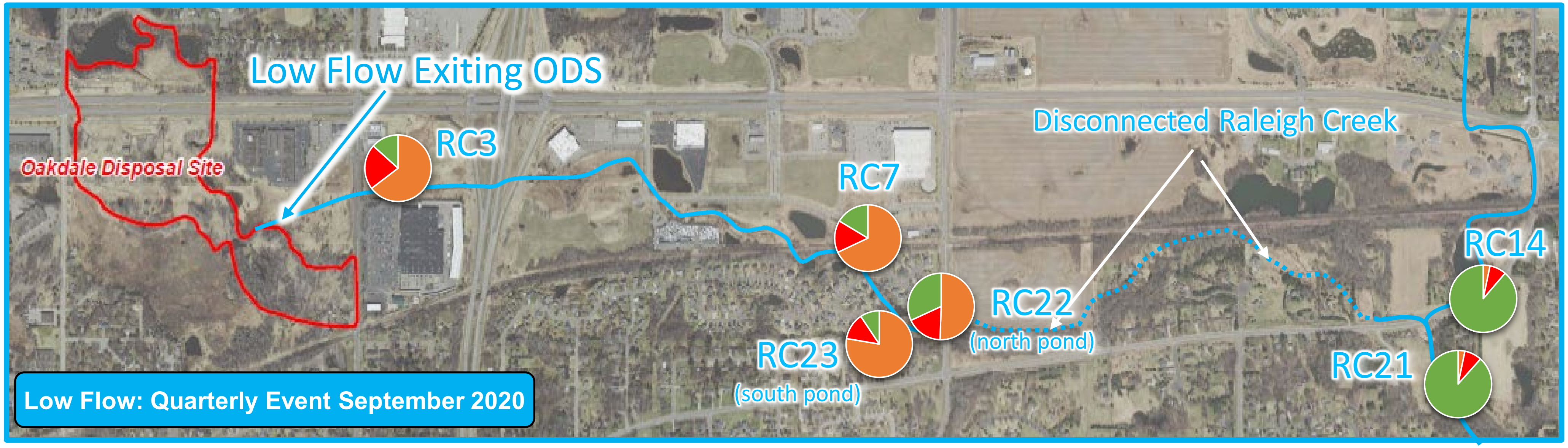


Typical PFAS Distributions



PFAS Distribution

Finding: During high flow conditions, Raleigh Creek is fully connected between ODS and the Confluence resulting in a PFOS-dominant signature throughout the creek. During low flow conditions, the system is completely cuts off downstream of Ideal Ave. Where water is still present (i.e., downstream of Tablyn Park), the PFAS signature shifts completely to a PFBA-dominant signature (as demonstrated at RC21).



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Historic Surface Water Sampling in Raleigh Creek: 2010-2020

Historic Sampling at Segment 2

In 2010, a well pump-out system at ODS was expanded from a system of 12 wells to 24 in an effort to control the release of PFAS-impacted waters from ODS. Prior to this expansion, surface water sampling was conducted once in 2006 by 3M. Since the expansion in 2010, several locations downstream of ODS have been sampled on a routine basis by 3M. Five of these locations, RC3, RC5, RC7, RC10, and RC13, corresponde with surface water locations also sampled by AECOM in 2019 and 2020 and are presented in the map below.

Note: AECOM sample IDs RC3, RC5, RC7, RC10, and RC13 correspond to 3M sample locations SW01, SW12, SW13, SW14, and SW15, respectively.

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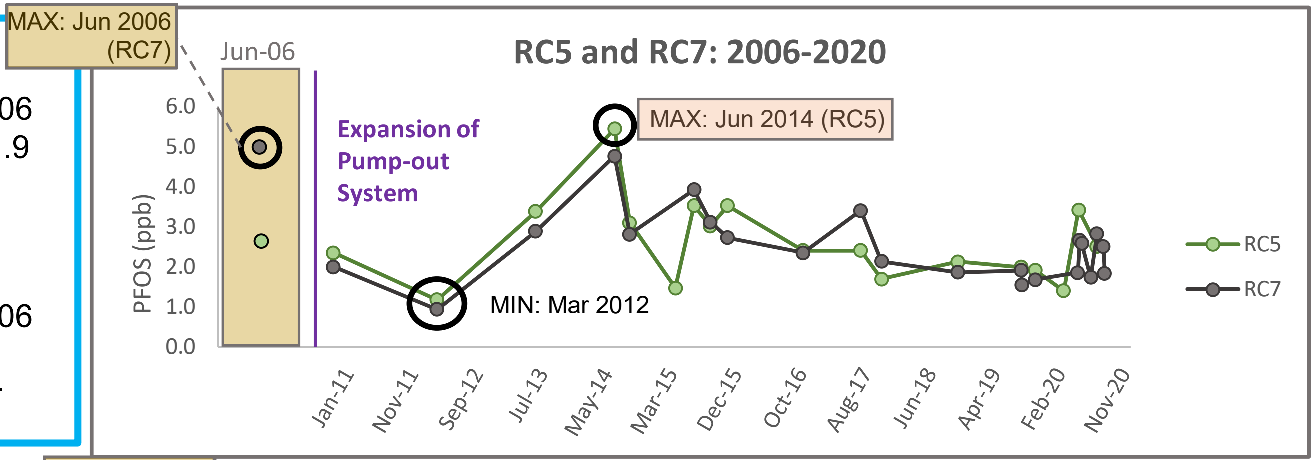
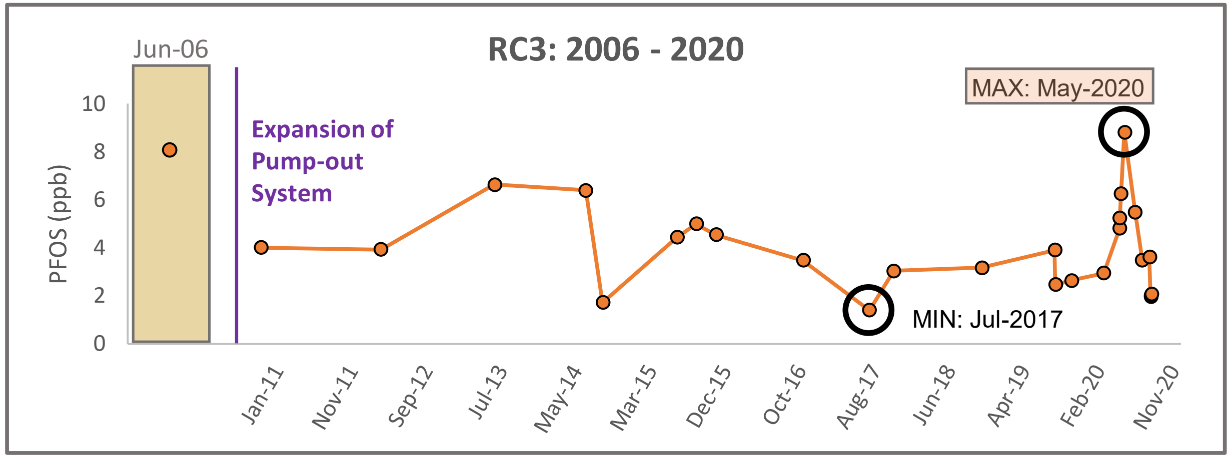
Historic Surface Water Trends Over Time: PFOS

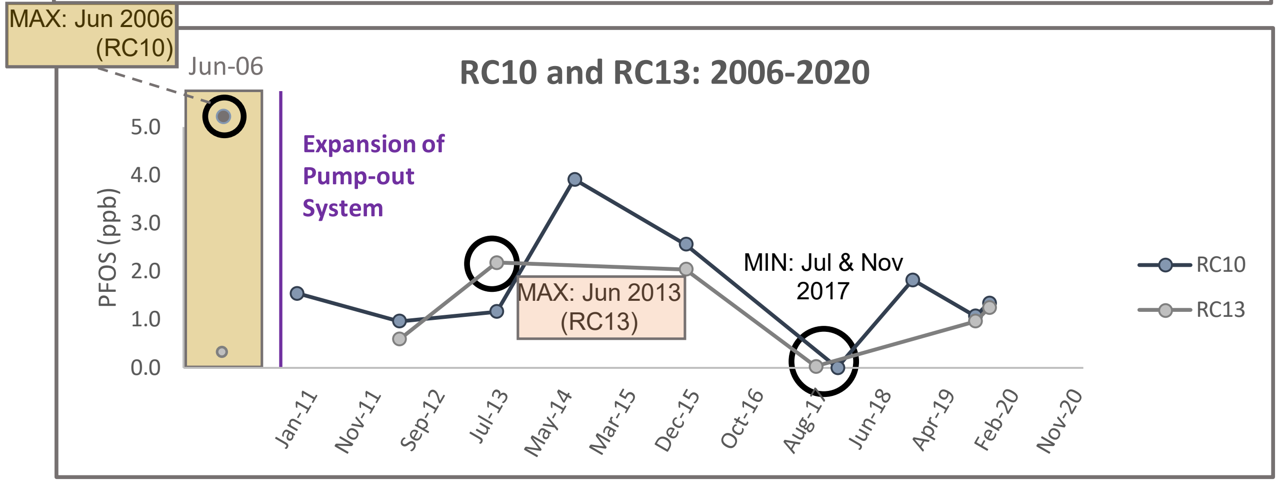
2006 Pre-Pumpout Well Expansion Analysis

According to data provided by MPCA, the first surface water sampling event in 2006 identified PFOS concentrations in Raleigh Creek ranging from 0.2 ppb at RC13 (1.9 miles downstream of ODS) to 8 ppb at RC3 (175 feet downstream of ODS).

- RC7 and RC10 – highest historical PFOS concentrations reported in 2006
- RC3, RC5, and RC13 – highest historic PFOS concentrations reported after 2006
- RC3 (closes to ODS) – highest historic PFOS concentration reported in 2020







2011-2020 Post-Pumpout Analysis: RC3

The maximum PFOS concentration at RC3, the closest sampling point to ODS, was reported in May of 2020. According to Man-Kendall Analysis (run by AECOM for post-expansion data only), since the expansion of the pump-out system in 2010, RC3 has not seen a statistically significant decreasing trend.

2011-2020 Post-Pumpout Analysis: RC5, RC7, RC10, RC13

According to Man-Kendall Analysis (run by AECOM for post-expansion data only), since the expansion of the pump-out system in 2010, none of the above locations have seen a statistically significant decreasing trend. While the maximum recorded PFOS at RC7 and RC10 was in 2006, maximum PFOS at RC5 and RC13 were measured in 2014 and 2013, respectively.

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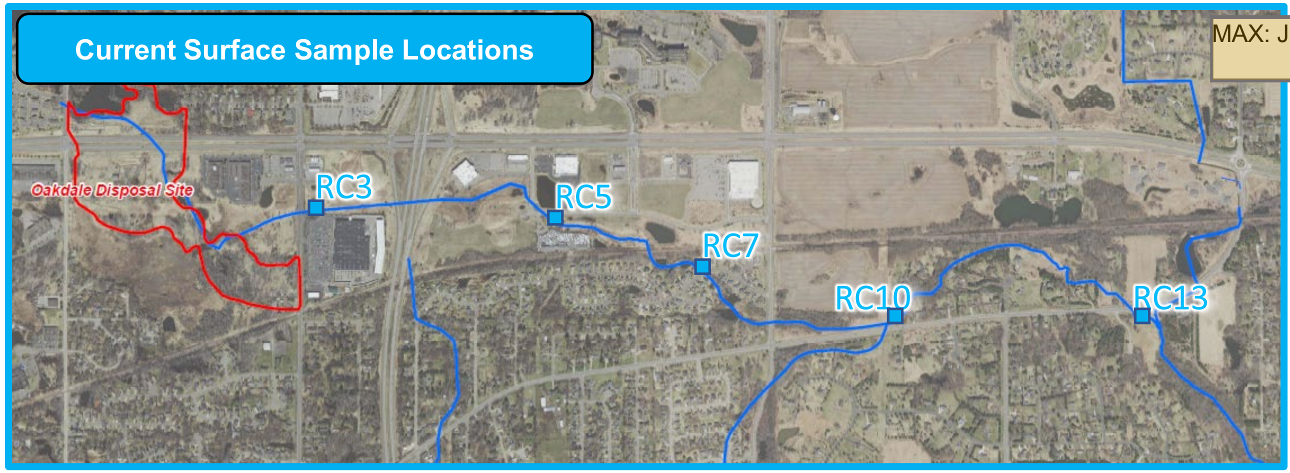
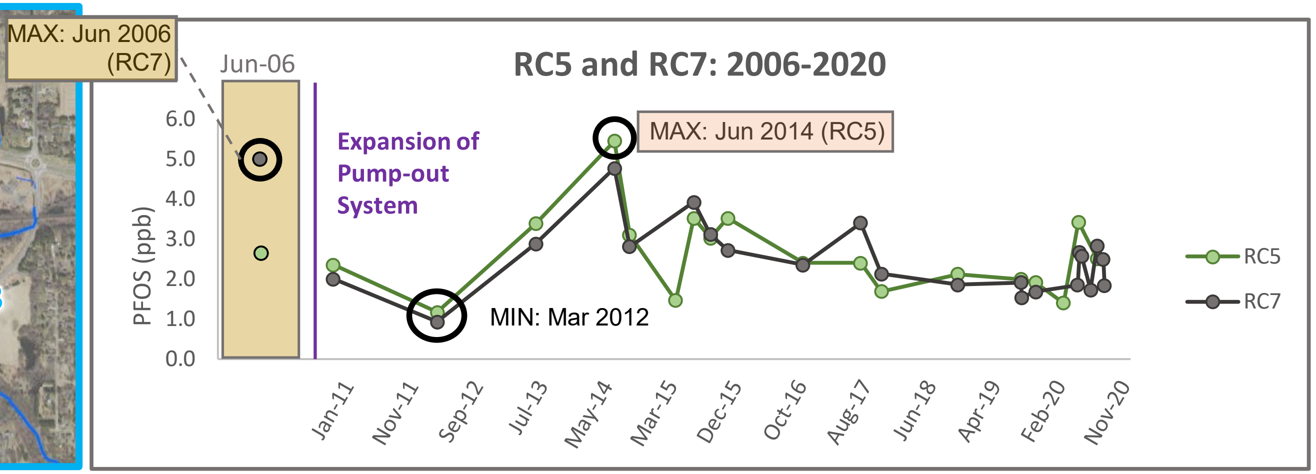
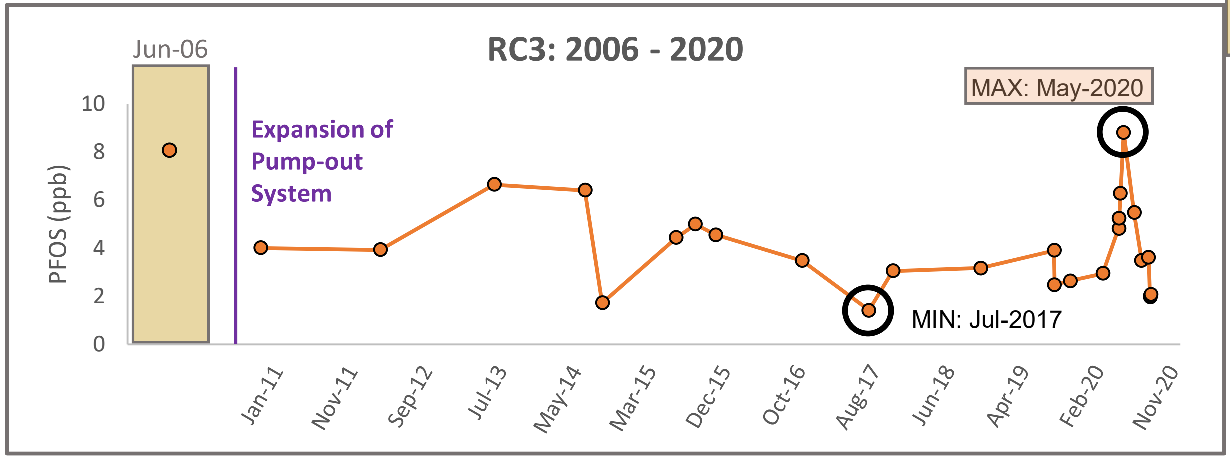
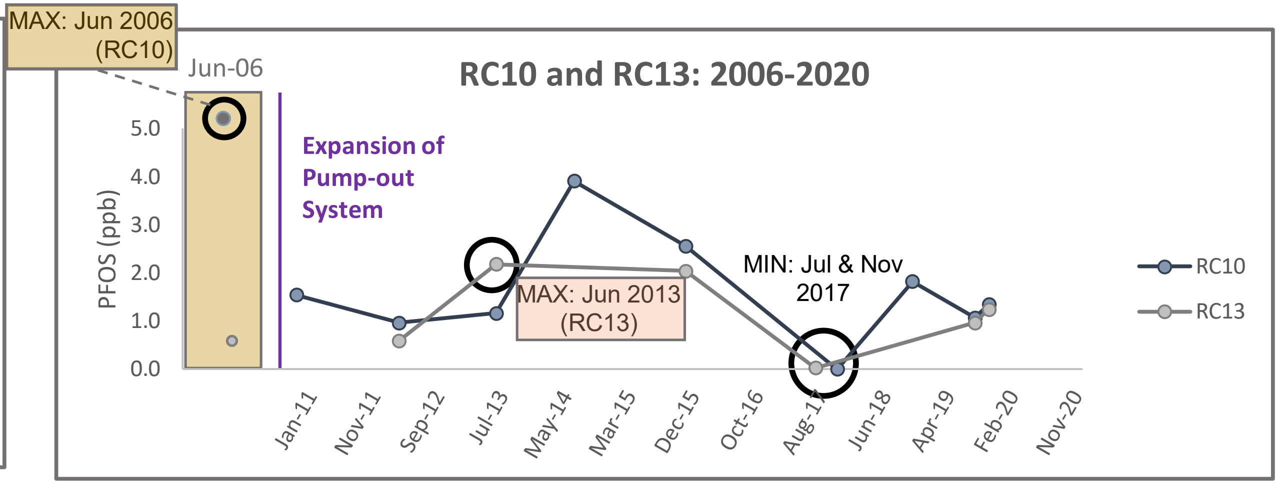
Historic Surface Water: Available Data









Surface Water Data at ODS

At the current time, the only surface water data available is from downstream of the Oakdale Disposal Site (ODS). In 2020, surface water samples were collected within the original extent of ODS. Once that data has been made available, it will be reviewed in conjunction with the downstream data.

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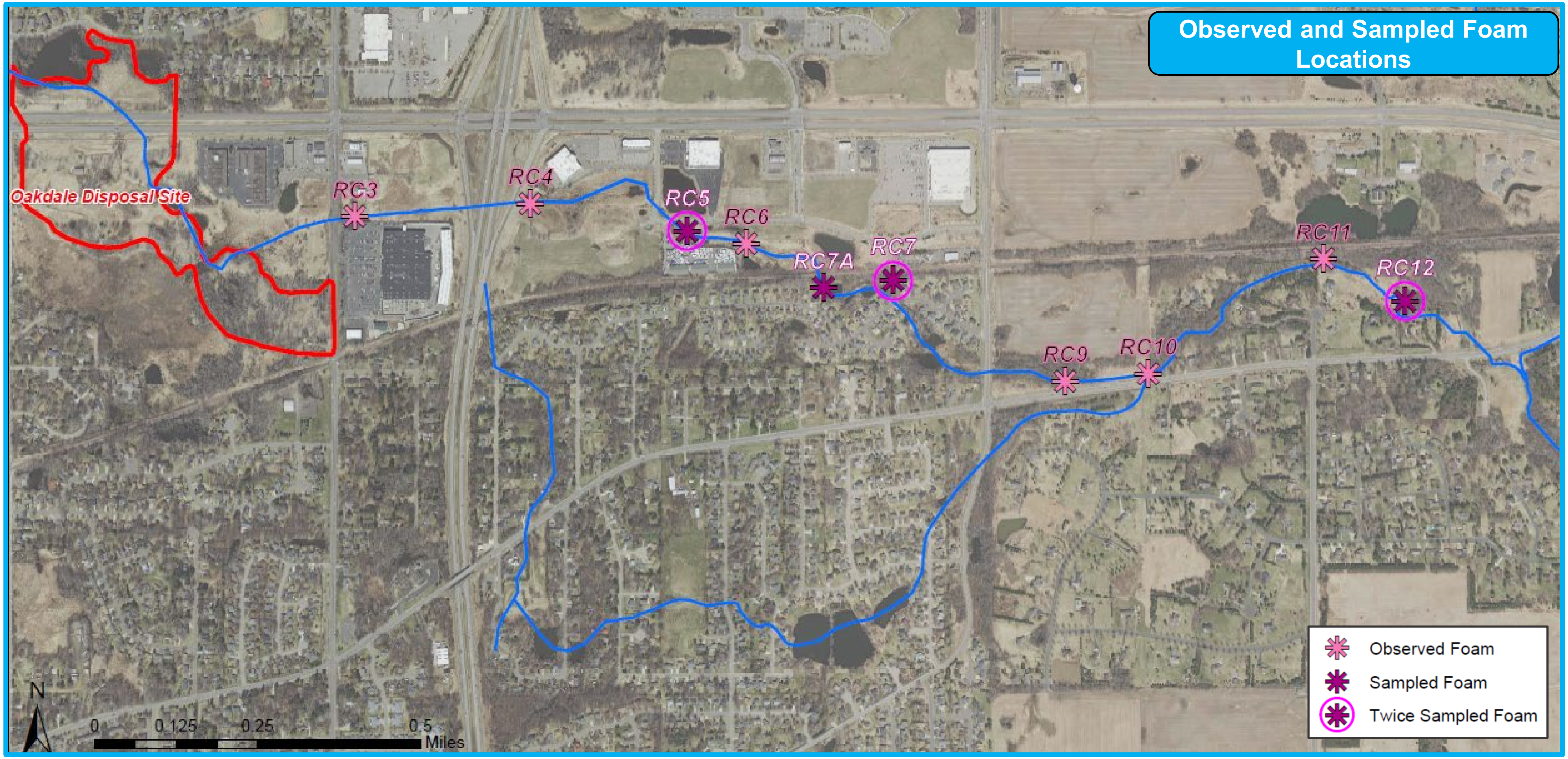
Foam in Segment 2



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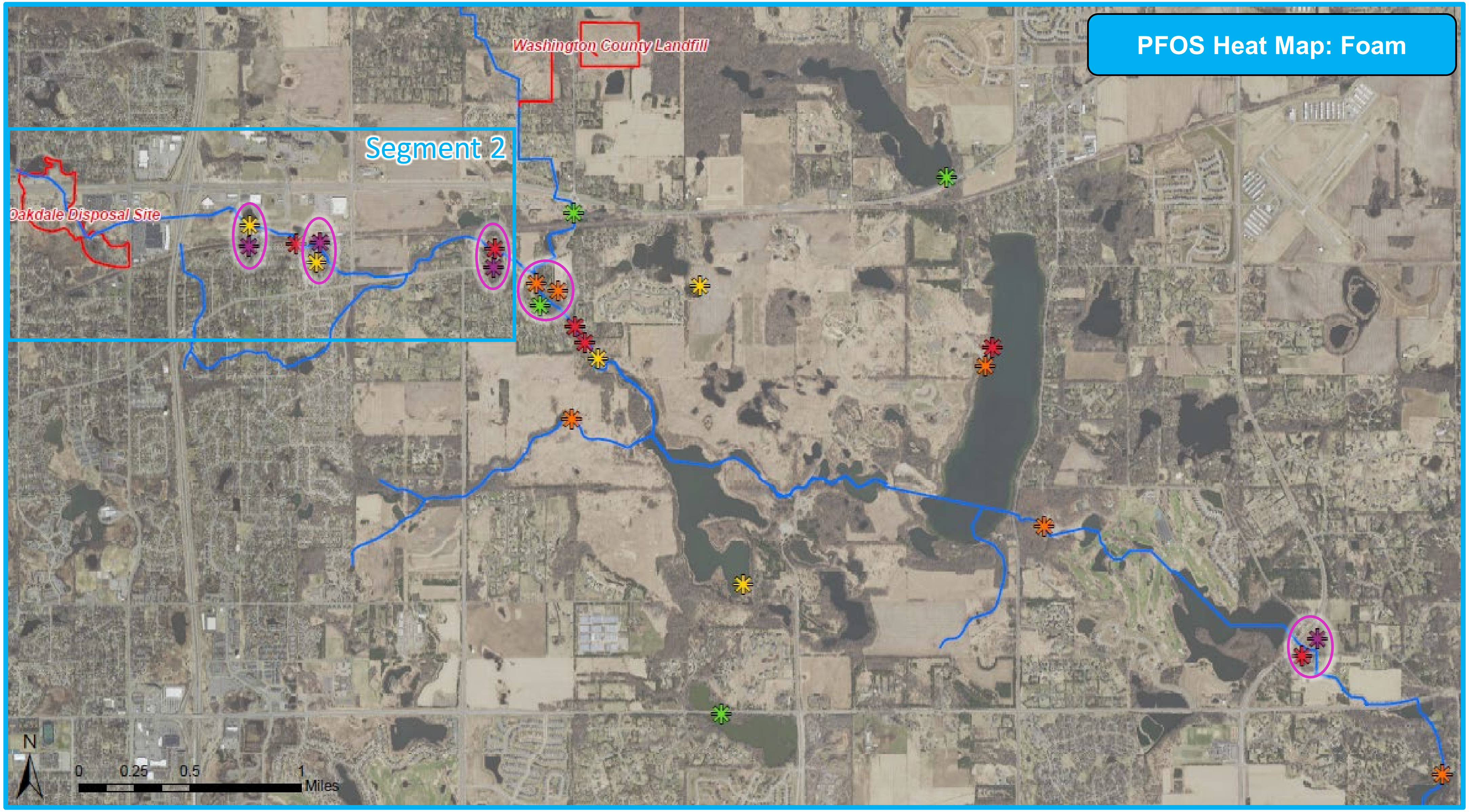
Site-Wide Foam Results: PFOS



Legend

PFOS (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 repeat foam sample locations

Foam in Segment 2

Foam has been routinely observed along Raleigh Creek in Segment 2. The locations with foam and types of foam observed are variable, largely depending on flow conditions.

PFOS in foam in Segment 2 is generally higher when compared to the other locations in the corridor.

Foam Formation in Raleigh Creek

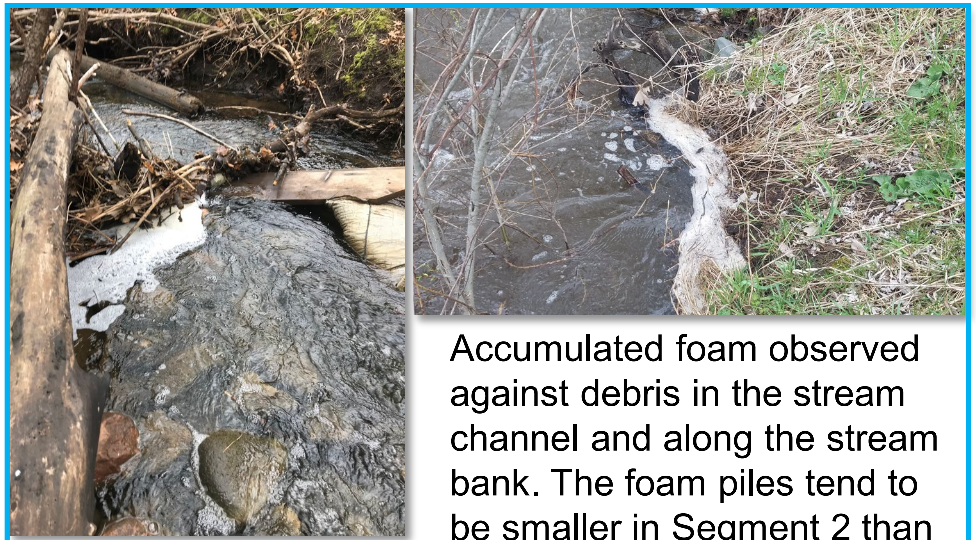
Requirements for PFAS-Containing Foam Formation and Accumulation

Turbulence
Air must be mixed into the water column for foam to form. In Segment 2, this is most often caused by water flowing over rocks, trees, or other debris in the stream. The water level greatly affects the locations of turbulence.

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 condense back into the stream. In Segment 2, foam was found to accumulate along the stream banks, debris, blocks of ice, and vegetation growing in the stream channel.

PFAS Concentrations in Surface Water
Foam will naturally form regardless of the presence of PFAS. However, it is not well understood 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.

Shallow water flowing over rocks in the channel created turbulence and foam bubbles in Raleigh Creek.



Accumulated foam observed against debris in the stream channel and along the stream bank. The foam piles tend to be smaller in Segment 2 than those observed elsewhere.

Types of Foam

Foam in Segment 2

The foam observed and sampled in Segment 2 had several different appearances. The type of foam observed was not tied to an exact location, precipitation events, or seasons with the exception of frozen foam.

The different types of foam typically observed in Segment 2 are presented in this slide. Foam can present itself in any one of these types or as a combination.

Frozen
Occurs when foam accumulates against ice or snow and then freezes in place. Can range in appearance from bubbles to frozen piles.

Wrinkled
Foam bubbles that flow over a biosheen or thin layer of ice and then accumulate into thin layers that gather against and on top of each other, forming a wrinkled appearance. This foam is frequently discolored due to the organic matter.

Fluffy
Accumulated piles are larger and whiter in appearance, though some discoloring can occur. Can be more stable than other foam types. Fluffy foam condenses into a smaller liquid volume than other foam types, indicating the presence of more air.

Floating (not accumulating)
Foam bubbles that do not accumulate either because they condense too quickly or because there is no location for accumulation to occur. This foam cannot be isolated from the surface water and thus has not been sampled.

Deflated (old)
Typically thin, in smaller quantities, and discolored with organic matter present. Not actively reaccumulating.

Actively Generating and Accumulating (fresh)
Foam observed as actively accumulating. The accumulated foam can have a wide range of appearances from thin bubbles to fluffy piles. This foam is typically whiter than other types.

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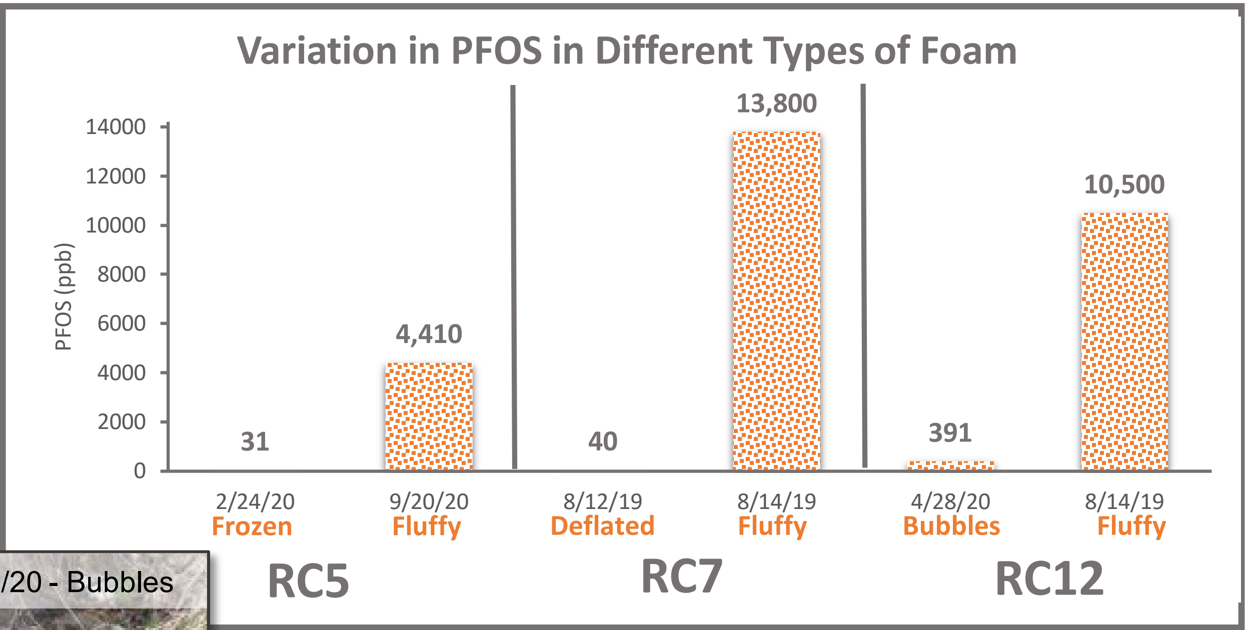
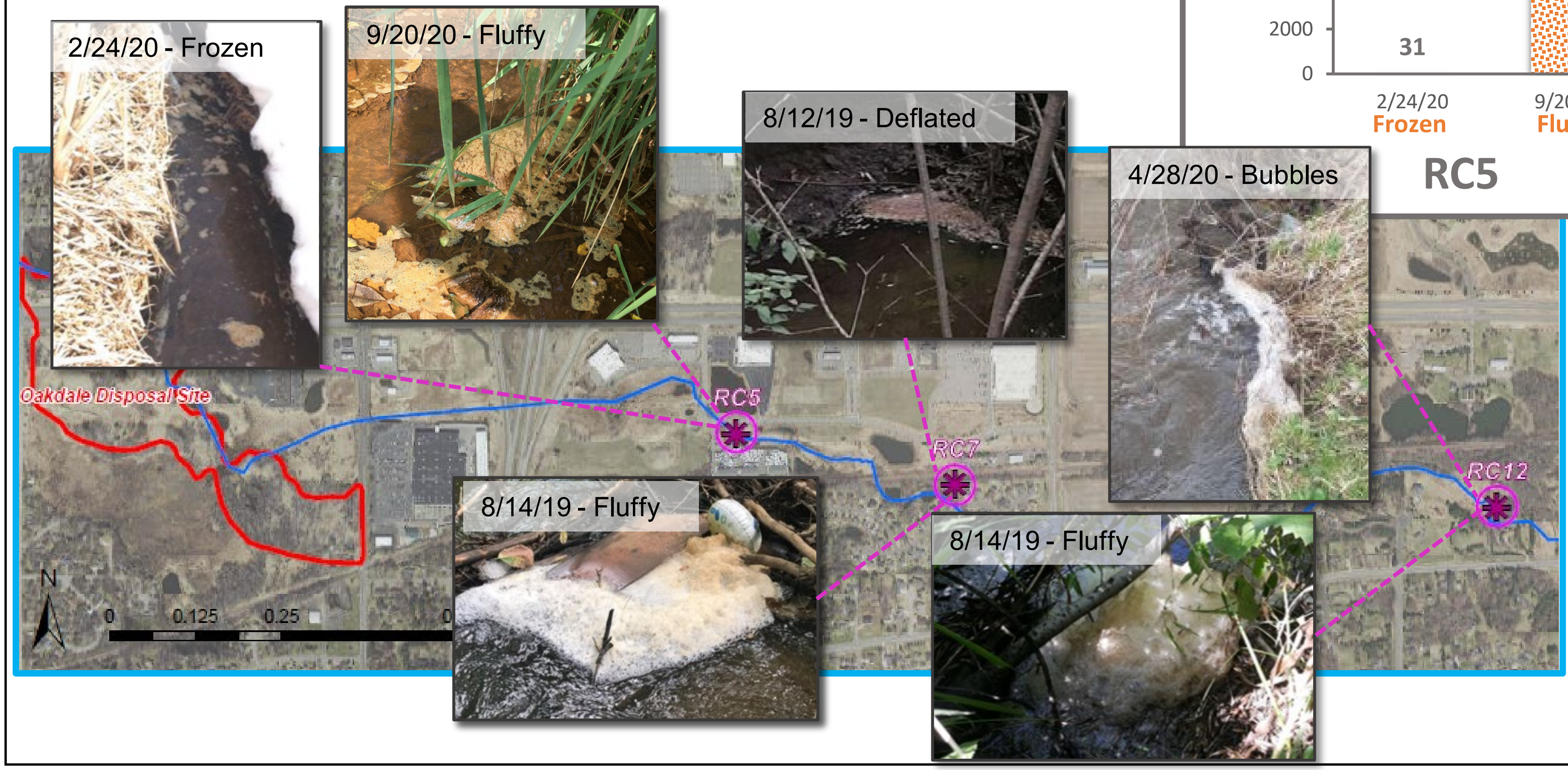
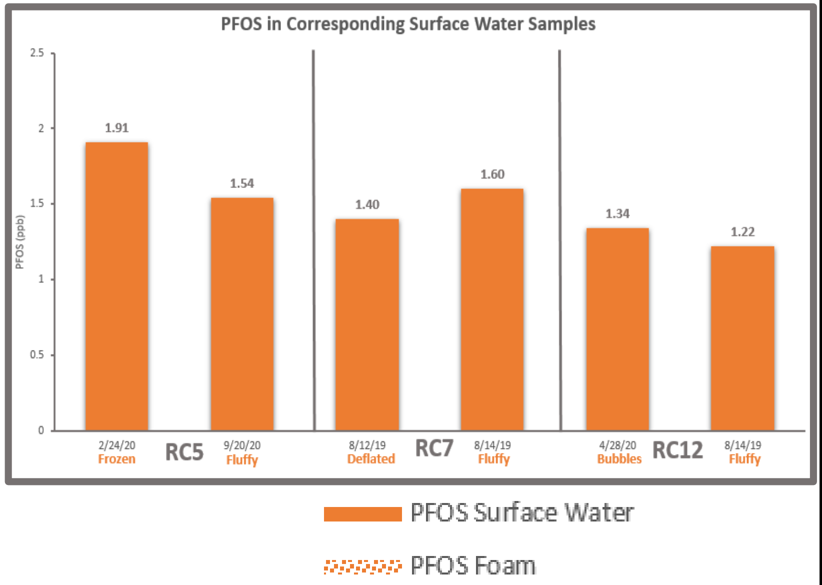
Variation in PFOS due to Foam Type

Foam Type

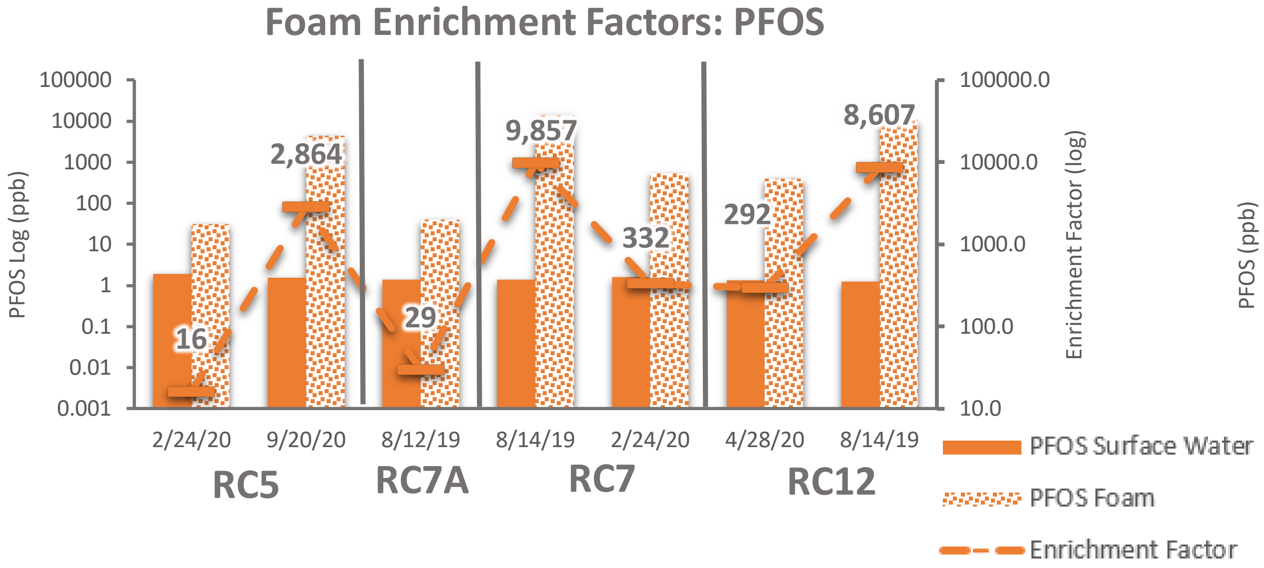
At three locations in Segment 2 (RC5, RC7, and RC12), foam was collected and analyzed for PFAS twice to assess potential variation in PFAS due to variation in foam type. At each location, a “fluffy” foam sample was collected to compare against a “thin” foam type. PFOS concentrations from the larger and fluffier piles of foam were between 2 and 3 orders of magnitude greater than their thinner counterparts. The corresponding surface water samples had negligible variation in PFOS, suggesting that the PFAS enrichment in foam can be highly variable due to the environmental conditions.

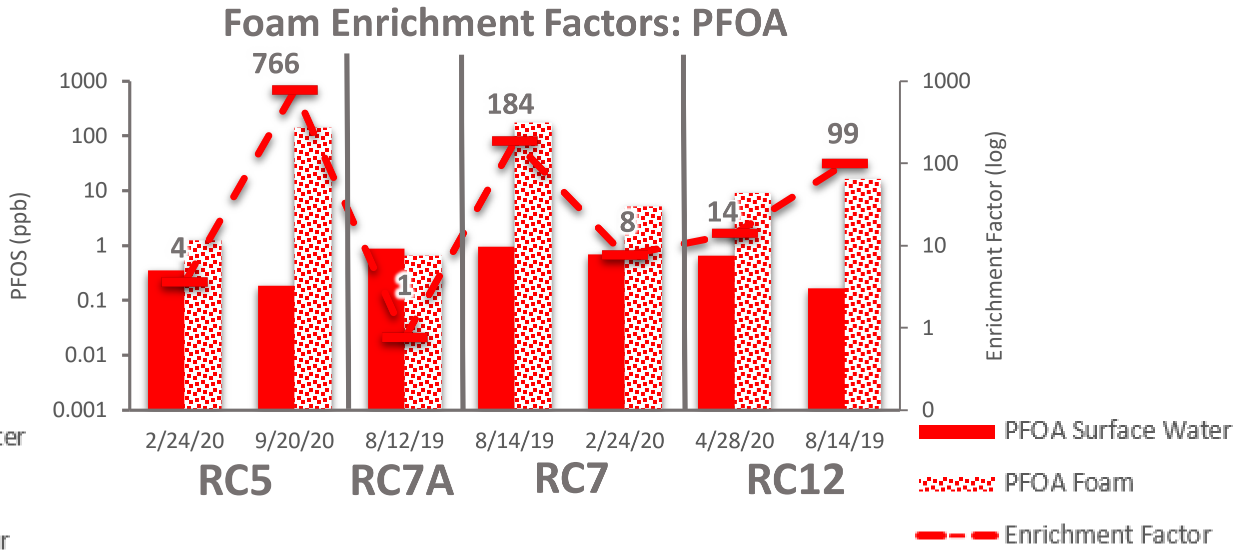






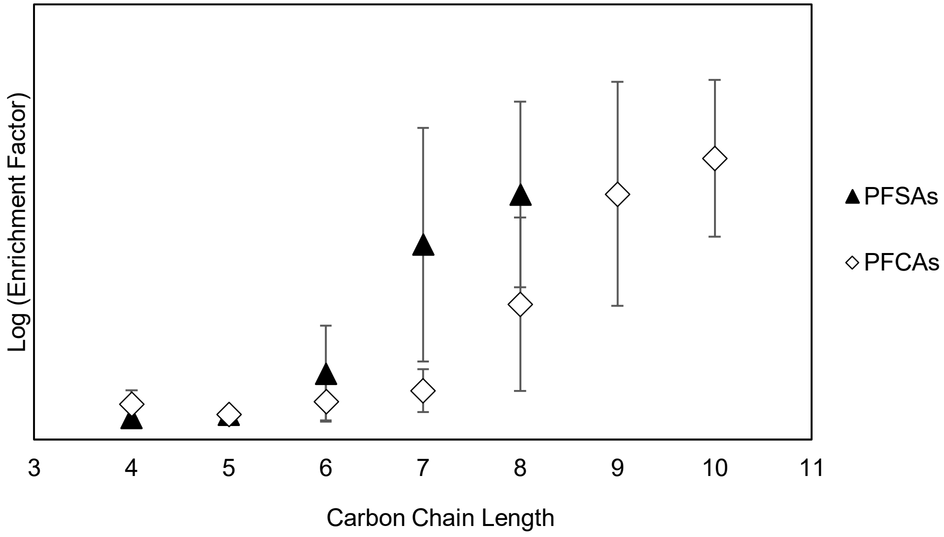
Foam: Enrichment Factors





Findings

- An enrichment factor is the ratio of the PFAS concentration in the foam to that in the water.
- Foam enrichment factors of PFOS ranged from 16 to nearly 10,000. Foam enrichment factors for PFOA were notably less, ranging from just over 1 to 766.
- Enrichment factors from the same location can vary significantly as well (up to two orders of magnitude of difference).
- Foam samples were overwhelmingly comprised of long-chain PFSAs and PFCAs, up to 97% of PFAS compounds in a sample.
- Longer chain PFAS compounds like PFOA, PFOSA, and N-EtFOSA tend to enrich or preferentially separate into the foam more than shorter chain compounds like PFBA and PFBS because they are more hydrophobic.



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Site-Wide Surface Sediment Results: PFOS

Sediment in Segment 2

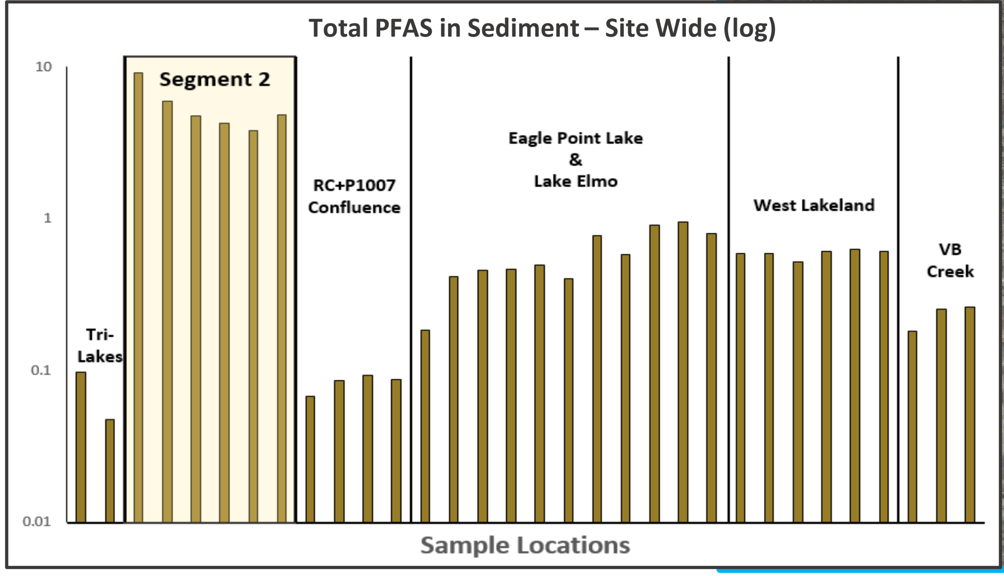
PFAS in sediment in Segment 2 is generally higher than anywhere else in the corridor, with nearly every sampling location exceeding the 5-day per week Site-Specific Sediment Screening Value (SDCV) of 54 ppb.

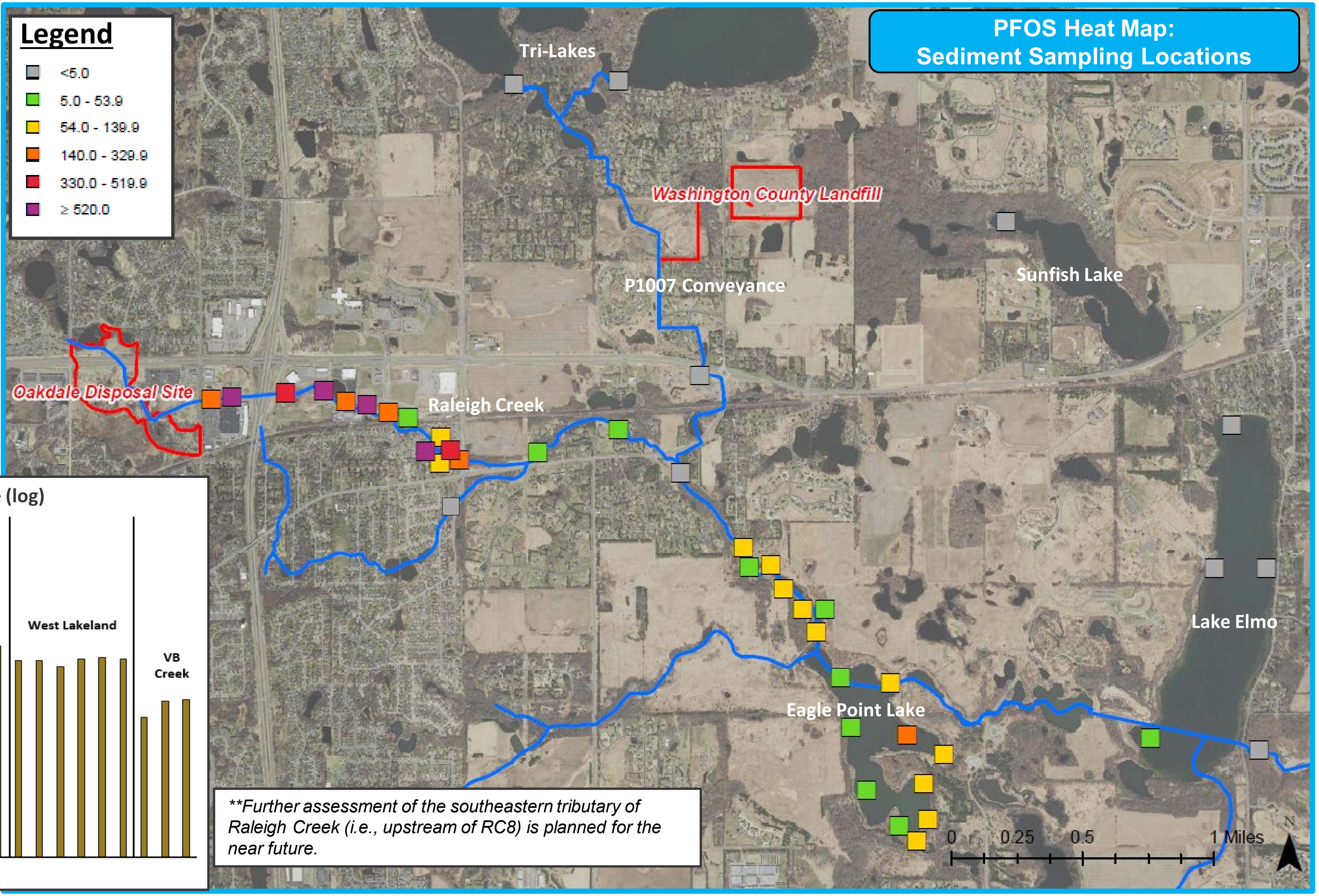
Factors that may influence the sorption and retention of PFAS include:

Depositional Environment and Flow Path Morphology

Total Organic Carbon Content

Proximity to Source





***Further assessment of the southeastern tributary of Raleigh Creek (i.e., upstream of RC8) is planned for the near future.*

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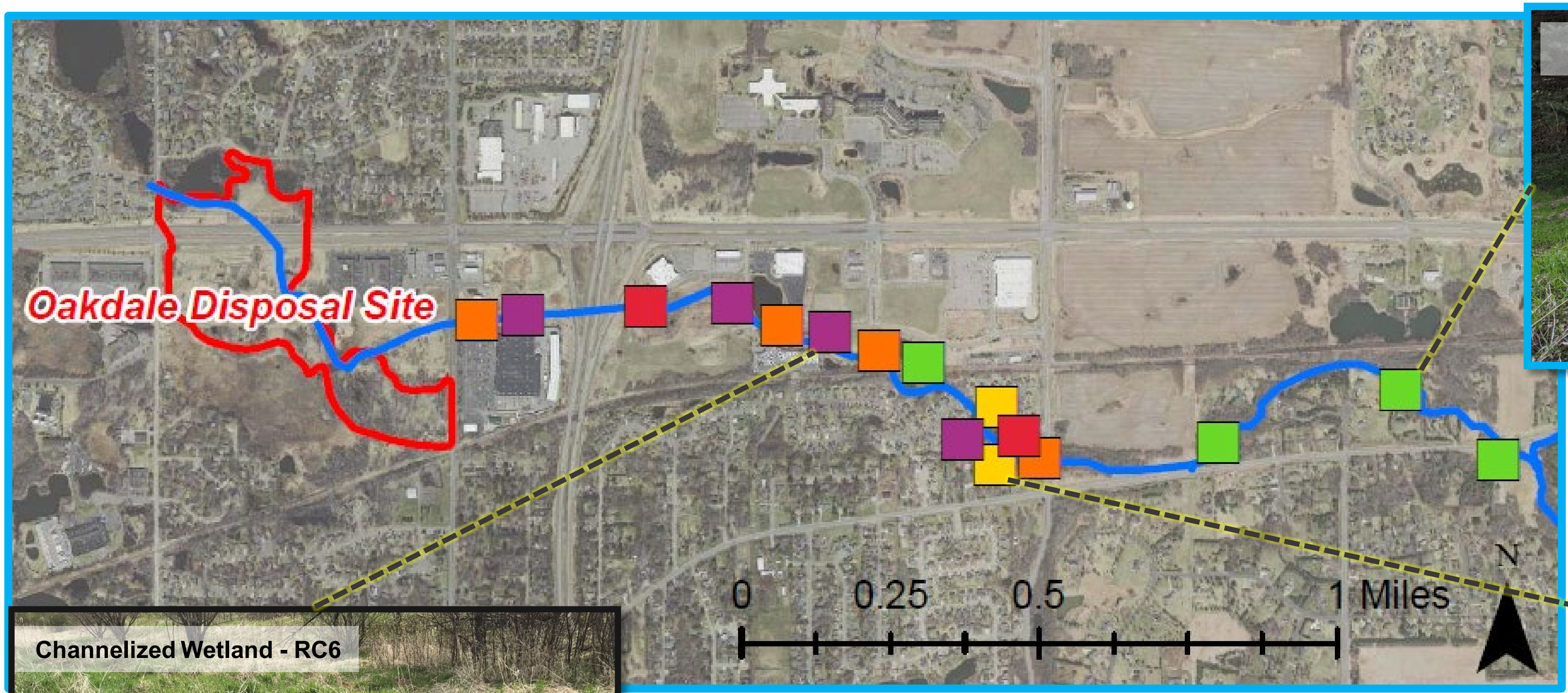
Segment 2 Sediment Impacts: Depositional Environment



Depositional Environment

Segment 2 includes of a variety of depositional environments including channelized wetlands, ponded wetlands, and incised channels. Further, flow within Segment 2 is intermittent to the east of Ideal Avenue.

Finding: The lowest PFAS sediment impacts appear to be in the incised channels, where flow is intermittent. Conversely, the highest PFAS impacts are in areas where Raleigh Creek flows through the channelized wetlands and flow is typically year-round.

Legend

- <5.0
- 5.0 - 53.9
- 54.0 - 139.9
- 140.0 - 329.9
- 330.0 - 519.9
- ≥ 520.0

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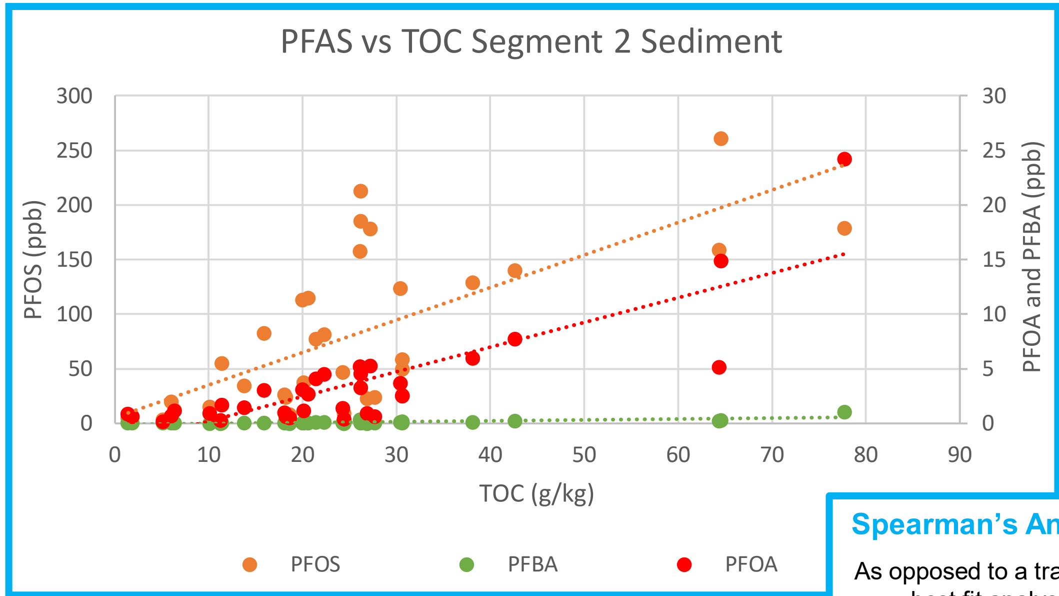
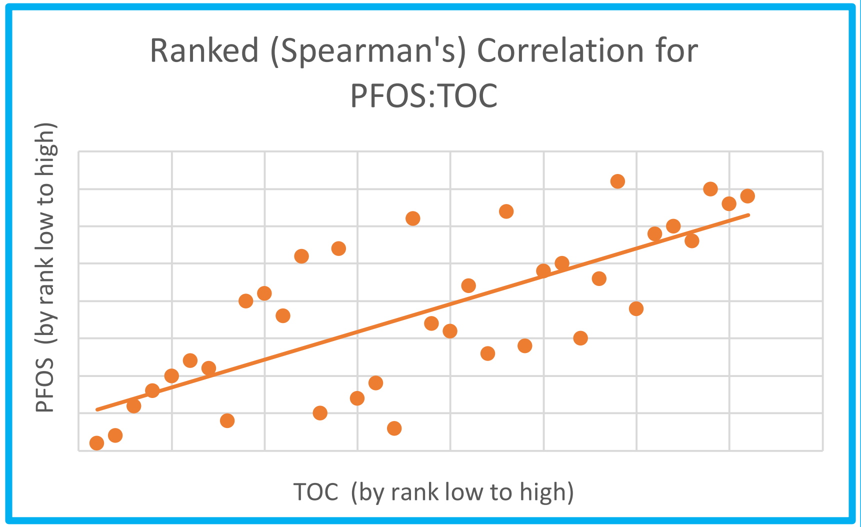
Sediment Impacts: Total Organic Content





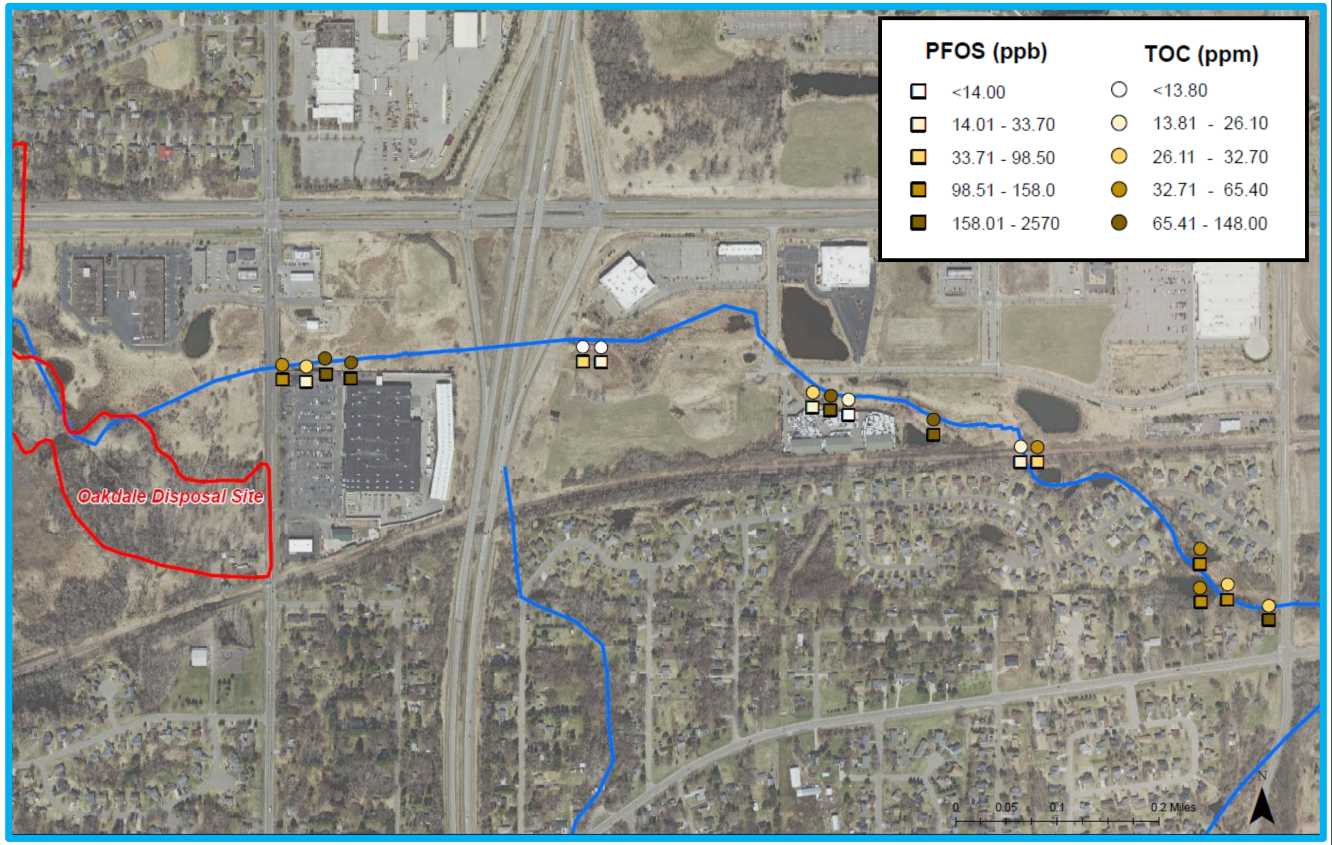
Spearman's Analysis

As opposed to a traditional best fit analysis, Spearman's normalizes the data by ranking each variable from low to high (and renumbering them in order) before calculating correlation. As a result, both variables are represented by numbers of the same scale (e.g., 1 - 30 rank versus the full range of PFOS and TOC concentrations), resulting in a calculation of only the statistical strength of one variable's correlation to another. In this case, a strong positive correlation of PFOS to TOC is shown in the Ranked Spearman's Correlation graph.

Organic Content

Organic content may have a causal influence on elevated concentrations of PFAS in sediment.

Finding: When looking at the statistical relationship between PFAS impacts and TOC, variations in PFOS, PFOA, PFBA, and PFHxS have statistically significant, strong positive correlation to TOC.

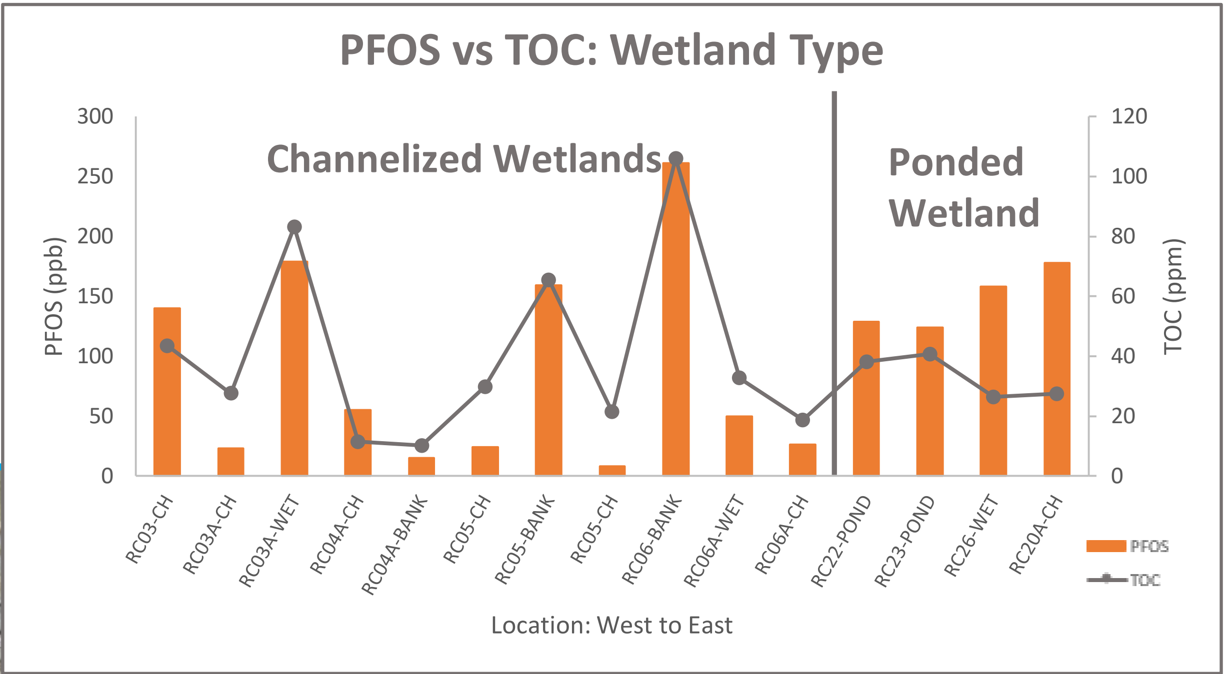


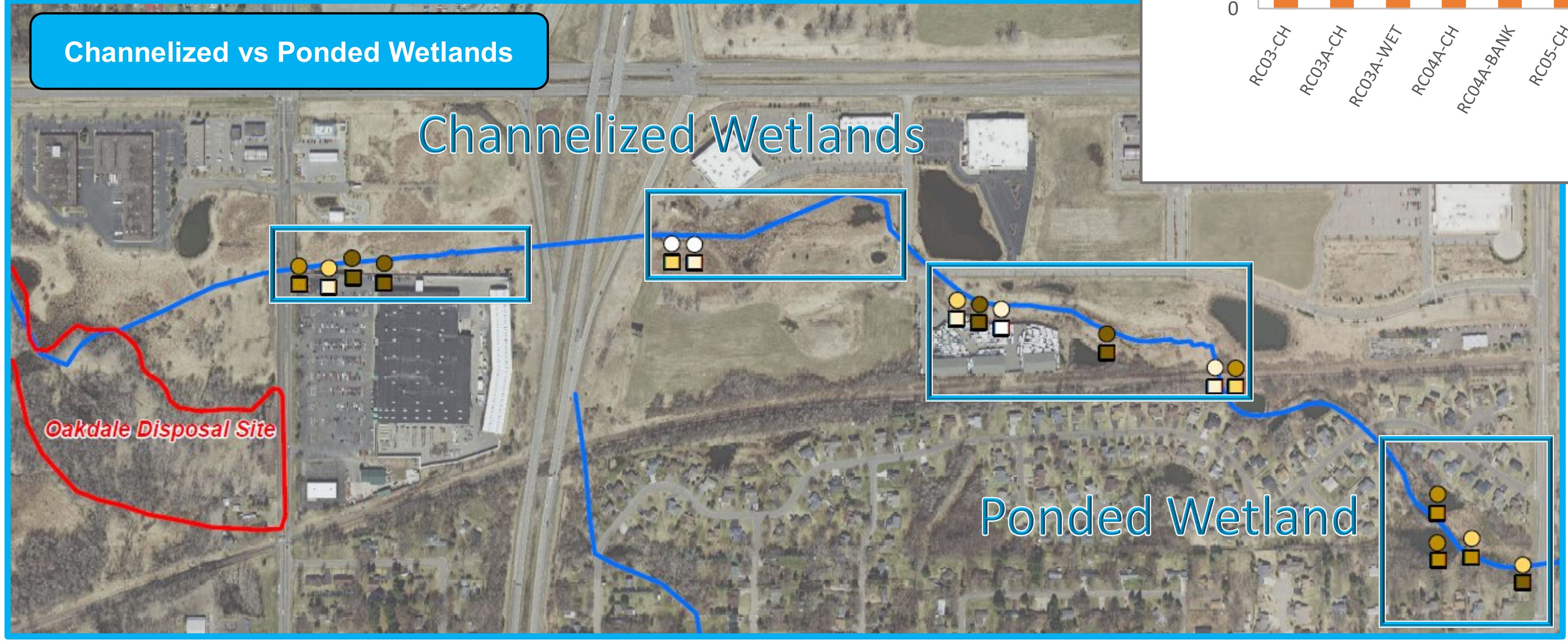
Segment 2 Sediment Impacts: Depositional Environment (cont.)

Ponded Wetlands vs Channelized Wetlands

In channelized wetlands, PFOS and TOC have a statistically significant strong correlation, indicating the variation in PFOS in these wetlands is primarily a result of variation in TOC. However, in the ponded wetlands at Ideal Avenue Wetland Complex (IAWC), the correlation between PFOS and TOC is less apparent. Despite the greater distance from the source area, the ratio of PFOS:TOC is consistently higher in IAWC, indicating that other variables are enabling increased sediment retention of PFAS at this specific wetland complex. The flood control structure at Ideal Avenue reduces drainage from the wetland complex, resulting in shallow stagnant water to remain at the wetland complex for longer periods of time.

Finding: This unique depositional environment may allow for increased sorption of PFAS within these ponded wetlands.





Legend and Notes

PFOS (ppb)	TOC (ppm)
<14.00	<13.80
14.01 - 33.70	13.81 - 26.10
33.71 - 98.50	26.11 - 32.70
98.51 - 158.0	32.71 - 65.40
158.01 - 2570	65.41 - 148.00

CH – sample collected from within main channel
BANK – sample collected from bank of channel
WET – sample collected from wetland area (off-channel)
POND – sample collected from within pond

RC3B-WET sample excluded from graph for scale purposes but is included in figures and statistical analysis.

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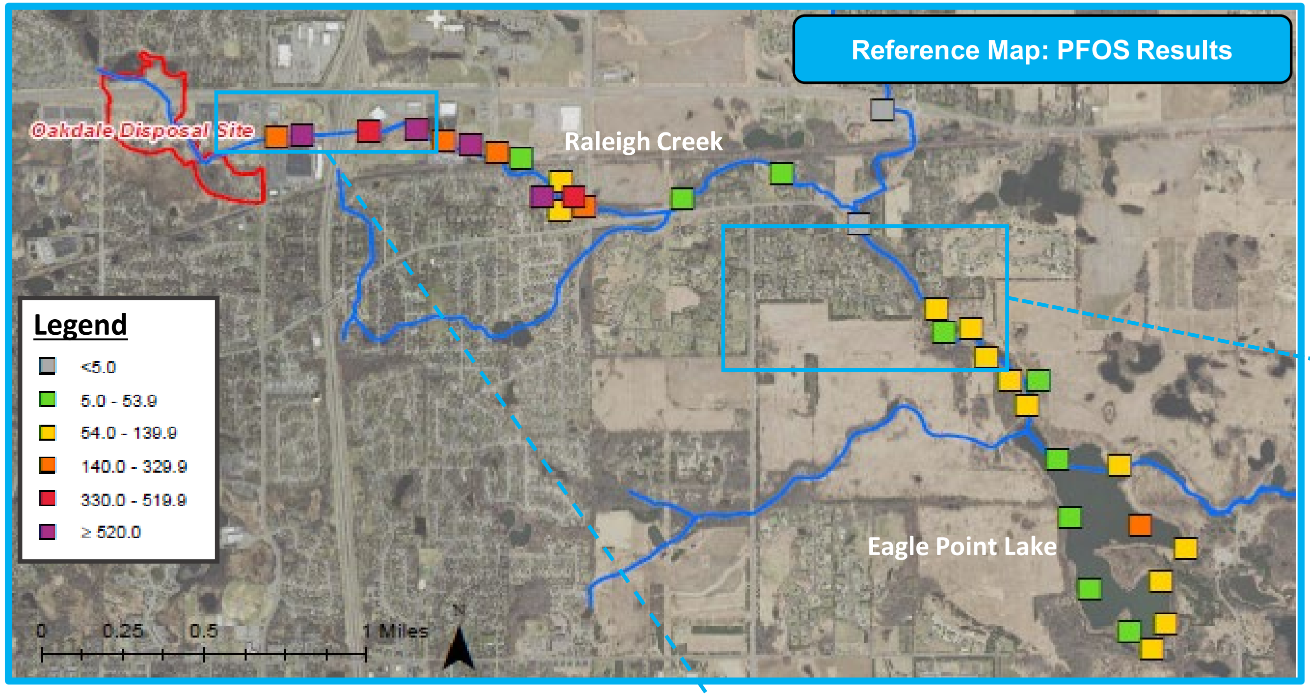
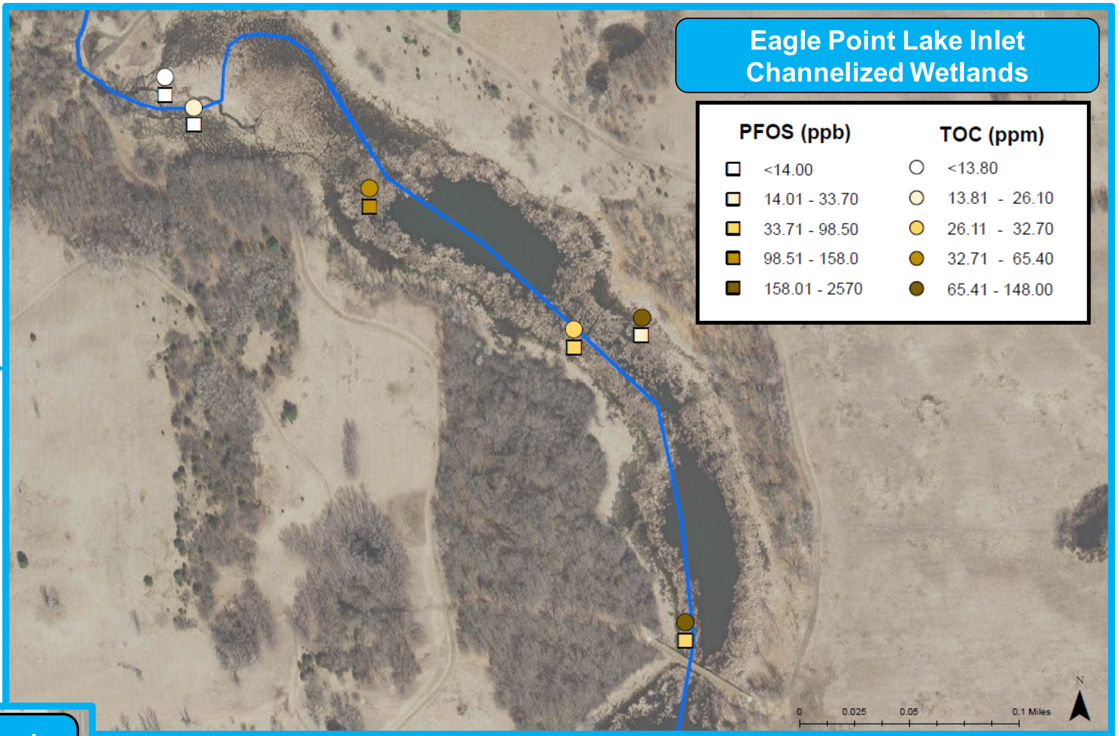
Segment 2 Sediment Impacts: Proximity to Source





Isolating for Proximity to Source Area

As previously shown, PFOS in sediment is generally higher in Segment 2 than in other portions of the corridor. Two locations within the corridor, the western portion of Raleigh Creek in Segment 2 and the inlet to Eagle Point Lake in Segment 4, have very similar depositional environments (channelized wetlands) and a similar range in organic content (up to 150 g/kg).

Finding: However, the PFOS in the channelized wetlands is significantly higher than in any other segment in the system, supporting that proximity to source is the greatest contributing factor to PFAS concentrations in sediments.

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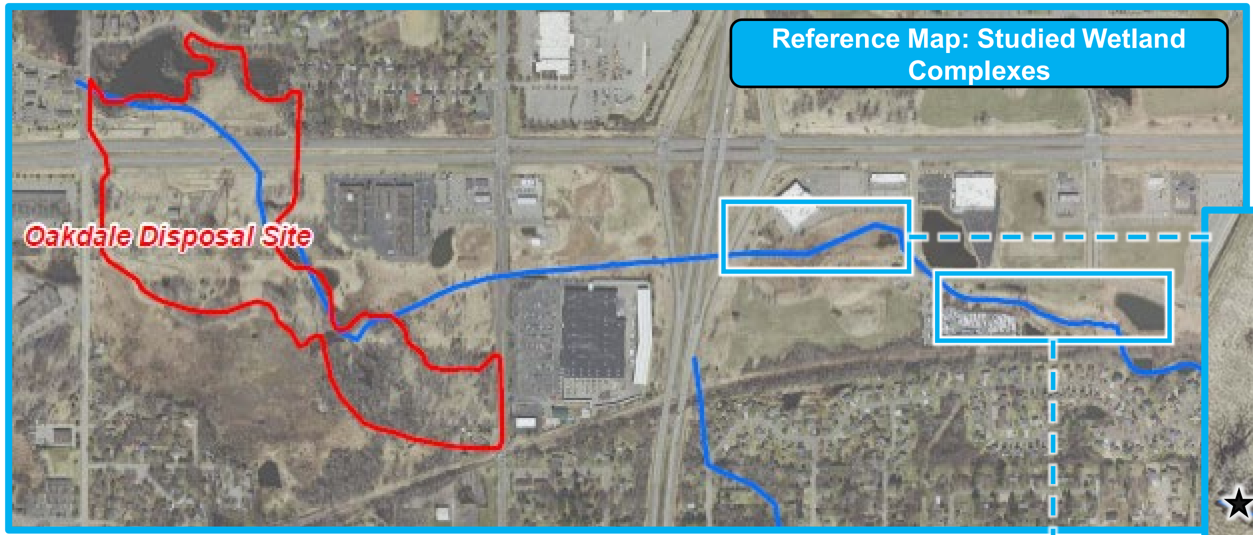
A Closer Look: Channelized Wetland Complexes



Wetland Delineation

Due to the elevated PFOS impacts in areas of high organic content, wetland complexes in Segment 2 were selected for further sediment sampling for delineation purposes. The wetland complex immediately downgradient of ODS (between Hadley Ave. and I-694) has not yet been sampled for delineation.

Note: The wetland complex immediately downgradient of ODS is planned for additional delineation sampling when access is provided by the property owner.

Legend

PFOS (ppb)

- <5.0
- 5.0 - 53.9
- 54.0 - 139.9
- 140.0 - 329.9
- 330.0 - 519.9
- <520.0

- ★ Previously sampled location (0-6 inches)
- ☆ Combined interval sample location (0-24 inches)
- ☆ Combined interval sample location (0-18 inches)

Unless otherwise indicated, each sample represents 0-12 inches.

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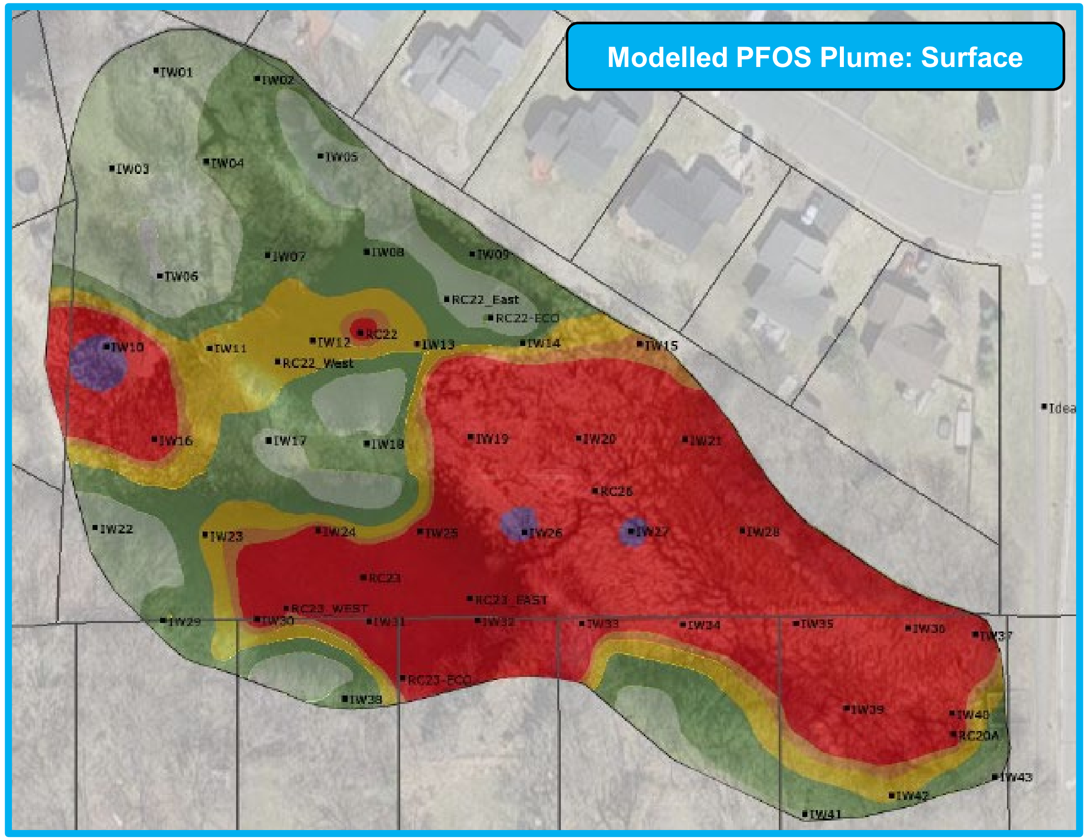
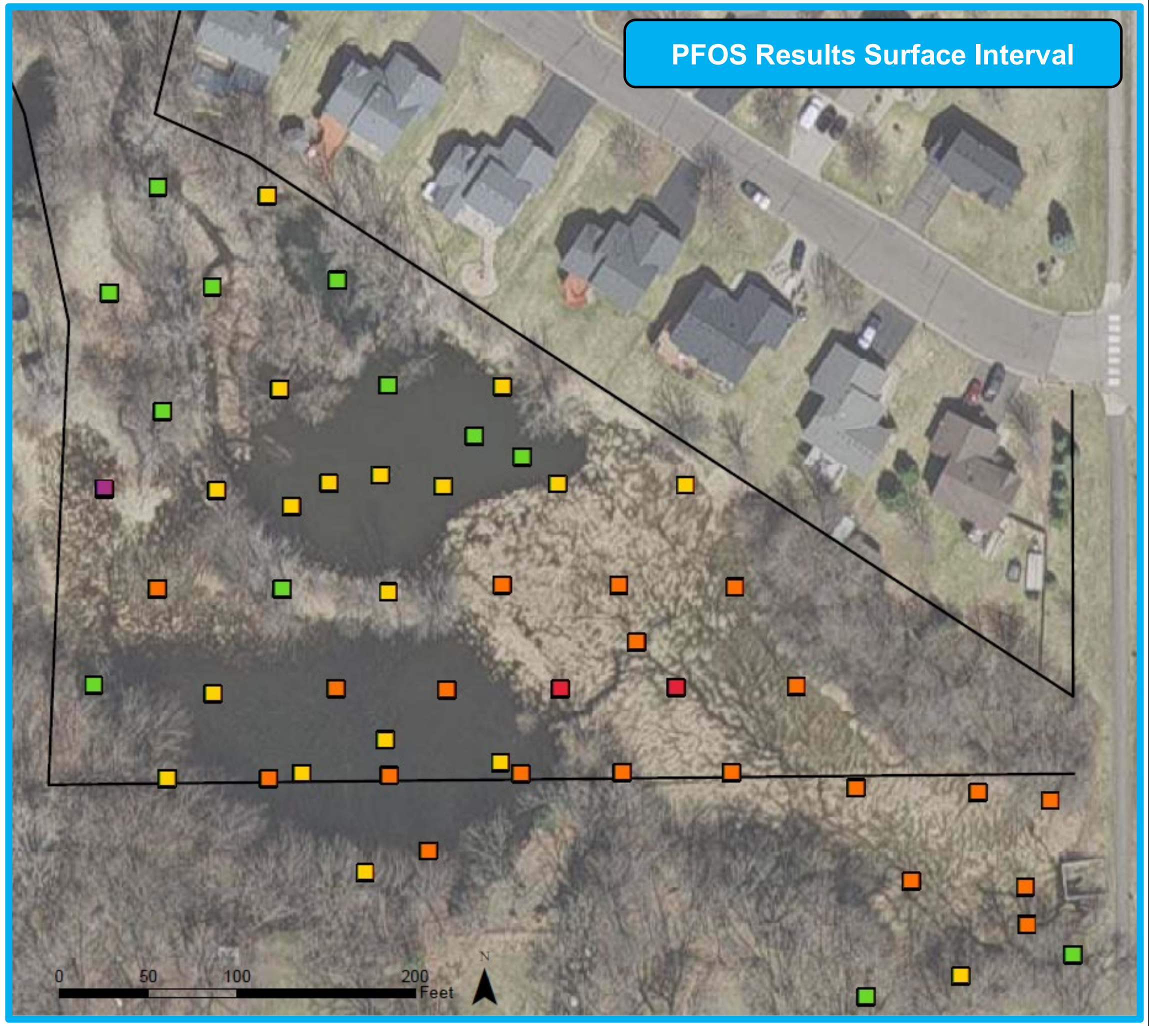
A Closer Look: Ponded Wetland Complex - IAWC

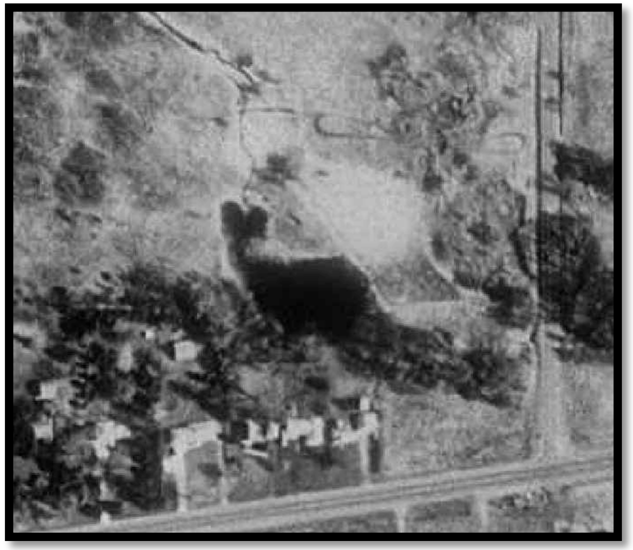
Legend

- <5.0
- 5.0 - 53.9
- 54.0 - 139.9
- 140.0 - 329.9
- 330.0 - 519.9
- ≥ 520.0





A Closer Look: Ponded Wetland Complex – IAWC (cont)

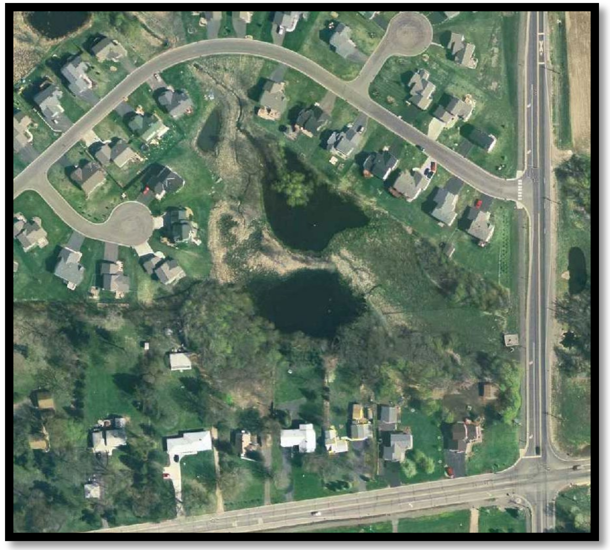


1991: Pre-Development

Only one pond visible (southern pond). Single channel visible running N-S into the pond. Heavy vegetation along the southern/southwestern edge of the pond.

1997: Post-Development

Northern pond now visible and two channels appear to be feeding the southern pond. The new surrounding residential development appears to have restricted the extent of the wetland complex, allowing for the wetland complex to flood more easily and for both ponds to hold water.



2004: Post-Flood Control Structure

Primary inlet channel appears to have shifted east. The flood control structure at Ideal Ave is now visible. Structure was designed to reduce the volume of water discharging downstream of Ideal Ave, resulting in the ponds holding water for longer periods of time.

2020: Current Conditions

Channel continues to feed both ponds. Outlet channel appears more pronounced.

IAWC Development Timeline

- 1940 – 1991: **Pre-Residential Development: One Pond and One Channel**
- 1991 – 1997: **Development of Northern Pond**
- 2001: **Flood Control Structure: Primary Channel Shift**
- 2001 – Present: **Current Conditions: One Channel and Two Ponds**

A Closer Look: Ponded Wetland Complex – IAWC (cont)

Depositional Environment at IAWC

During high flow conditions, intermittent channels within IAWC contain more water flow. With high enough water level, these channels may “overflow”, causing the surrounding wetlands to saturate with water. Since high rain events can cause an influx of PFAS-impacted waters from ODS to Raleigh Creek and the IAWC pond system, the sediment in the areas that experience this “overflow” may have elevated PFAS impacts. Further, given the propensity of PFAS molecules to gather at the air/water interface of surface water, these overflow water paths may act as a preferential transport pathway.

In the figure to the right, potential dispersal zones of water during flooding conditions are presented with buffers. Areas near the intermittent wetland channels (orange plus yellow) are more likely to experience increased sorption of PFAS during flooding conditions (compared to the areas farther away from the intermittent streams).

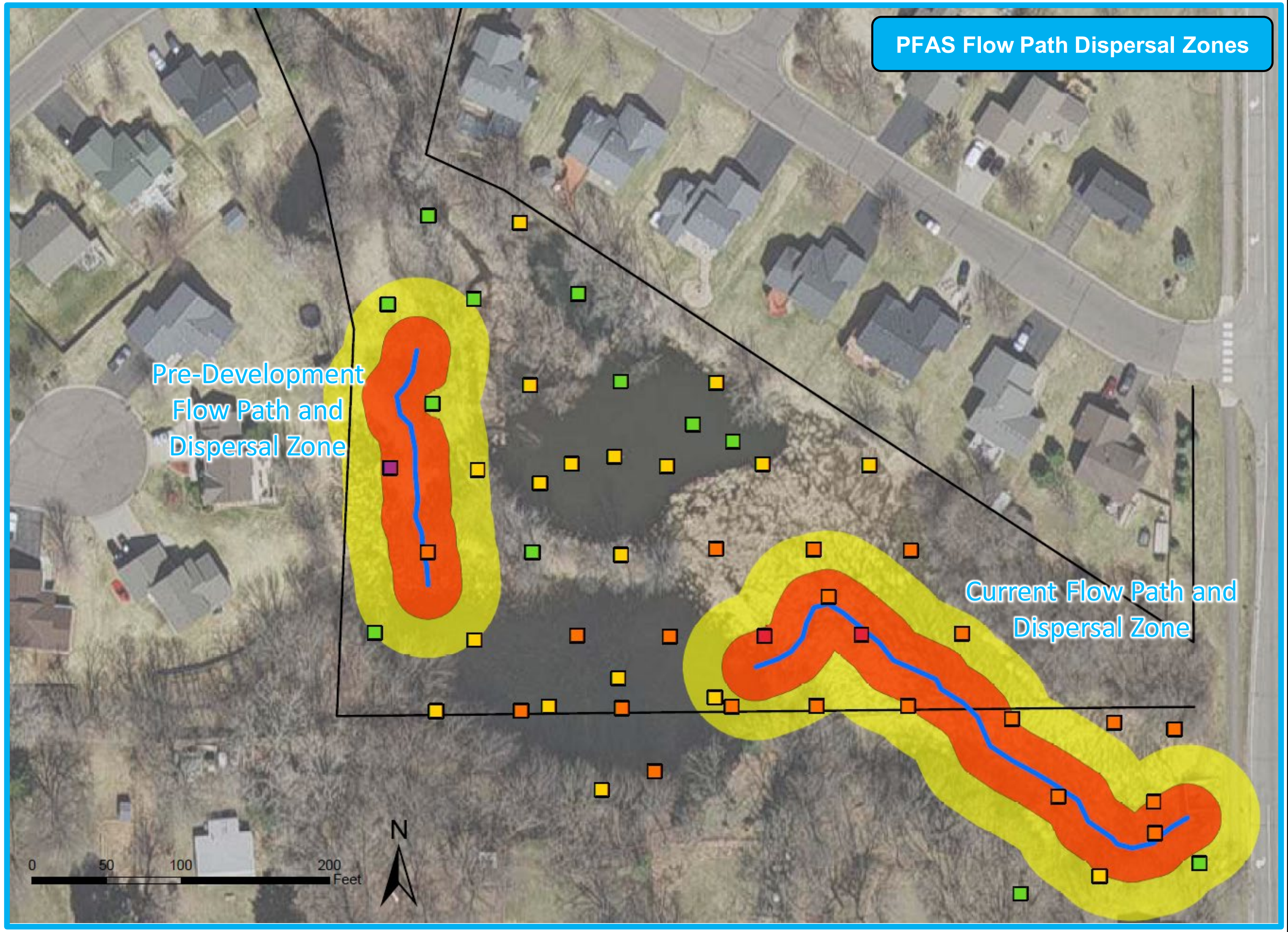
The western dispersal zone existed only prior to the development in the 1990’s. The eastern flow path and dispersal zone likely existed prior to development but has become more pronounced and more likely to experience overflow, potentially allowing for more PFAS deposition into sediments.

Legend

- Intermittent Channelized Wetland
- Private Property Boundary
- Near Intermittent Saturation Buffer
- Far Intermittent Saturation Buffer

PFOS (ppb)

- <5.0
- 5.0 - 53.9
- 54.0 - 139.9
- 140.0 - 329.9
- 330.0 - 519.9
- <520.0



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IAWC PFOS Distribution by Depth: Sediment PFOS Results

Legend

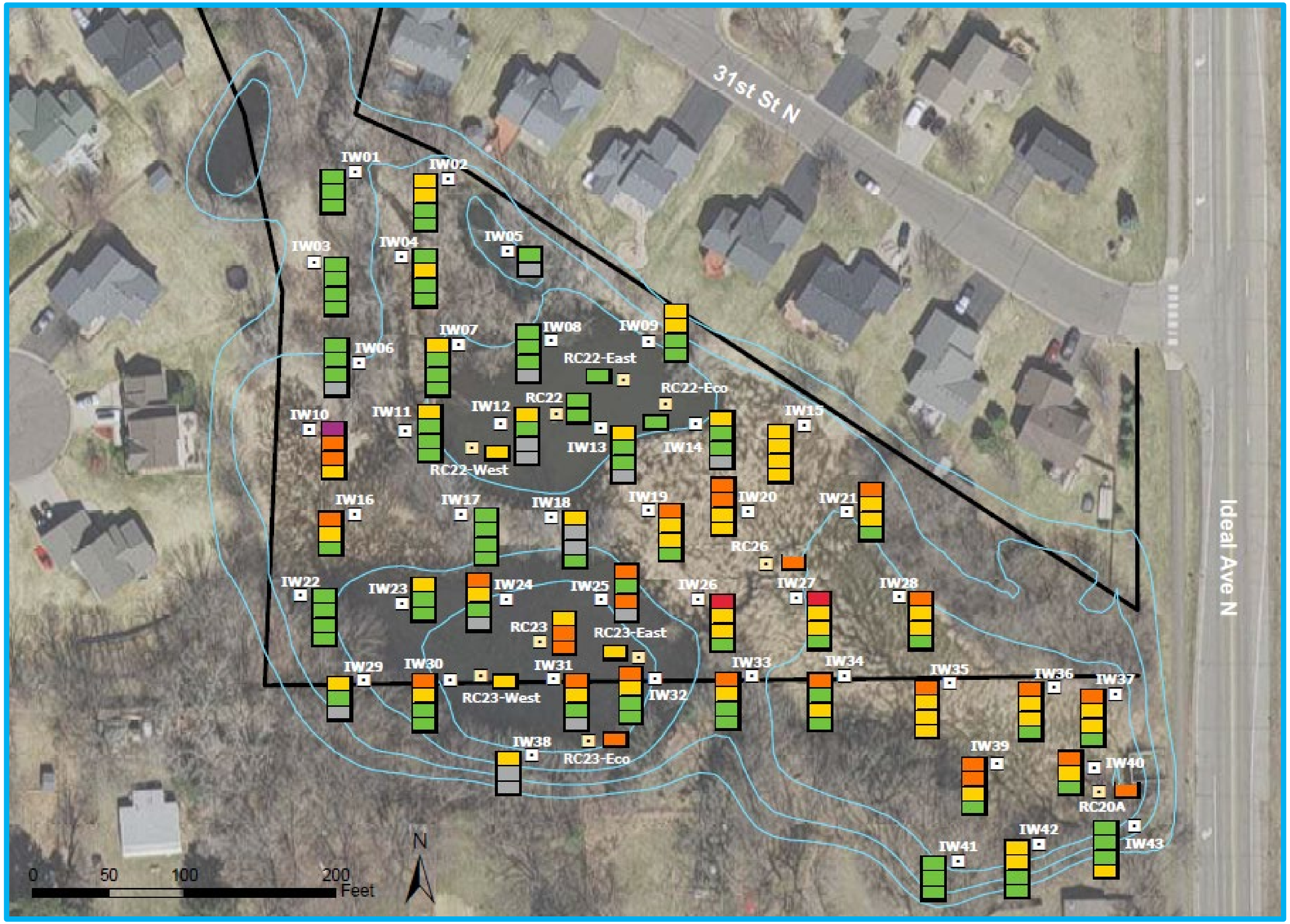
- Multi-Depth Sample Locations (0-4')
- Hand Sample Locations (up to 3')
- 2-ft Elevation Contours
- Private Property Boundary

Probe Depth
0-12"
12-24"
24-36"
36-48"

Auger Depth
0-6"
6-12"
12-18"

PFOS (ppb)

- <5.0
- 5.0 - 53.9
- 54.0 - 139.9
- 140.0 - 329.9
- 330.0 - 519.9
- ≥ 520.0



PFOS Characteristics and Leaching Potential

In addition to the PFAS/TOC relationship previously presented, there are PFAS structural properties such as ionic charge and chain length that affect adsorption to sediment that may limits its ability to migrate or leach downward. As demonstrated by the vertical distribution of PFOS in sediment in the image to the left, PFOS sediment concentrations are predominantly higher is surface samples compared to samples at depth.

IAWC PFOS Distribution by Depth: Statistical Exploratory Analysis

PFOS Concentrations With Depth

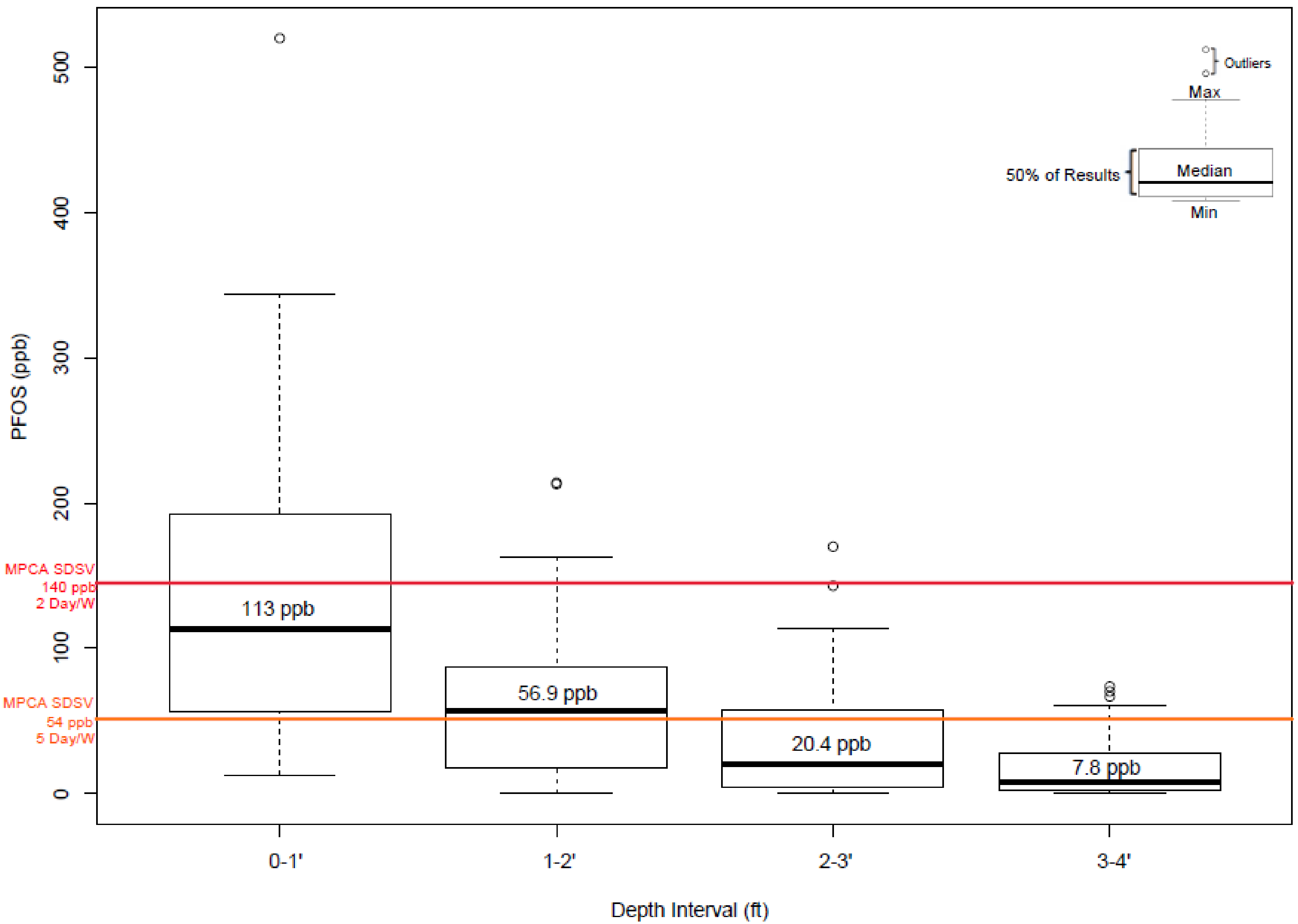
In effort to further evaluate PFOS impacts in sediment, a set of statistical parameters were calculated for the range in PFOS concentrations at each depth interval, including the minimum, maximum, median, mean, and standard deviation (Figure 4). Each depth interval was set for one foot of sediment depth, with the first depth interval representing the surface interval. At most locations, the depth intervals were 0-1 foot, 1-2 feet, 2-3 feet, and 3-4 feet. At the surface depth interval, the median and mean PFOS concentrations are 113 ppb and 134.8 ppb; respectively; at the second interval, 56.9 and 59.3 ppb; at the third interval, 20.4 and 36.1 ppb; at the fourth, interval, 7.8 and 17.7 ppb.

Finding: Not only do PFOS impacts decrease with depth, but the variability of PFOS concentrations within each depth interval also decreases with depth. The true mean value with a 95% Uniform Confidence Level (UCL) for sediment in IAWC within the surface interval is at least 112.7 ppb.

Depth Interval	Minimum	Maximum	Median	Mean	Standard Deviation
1	12.96	520.0	113.00	134.84	101.18
2	0.00	214.0	56.90	59.32	42.32
3	0.00	170.0	20.40	36.12	40.54
4	0.00	73.7	7.81	17.69	20.14

**Values below the laboratory method detection limits were calculated as 0.00 ppb.*

IAWC PFOS Distribution by Depth



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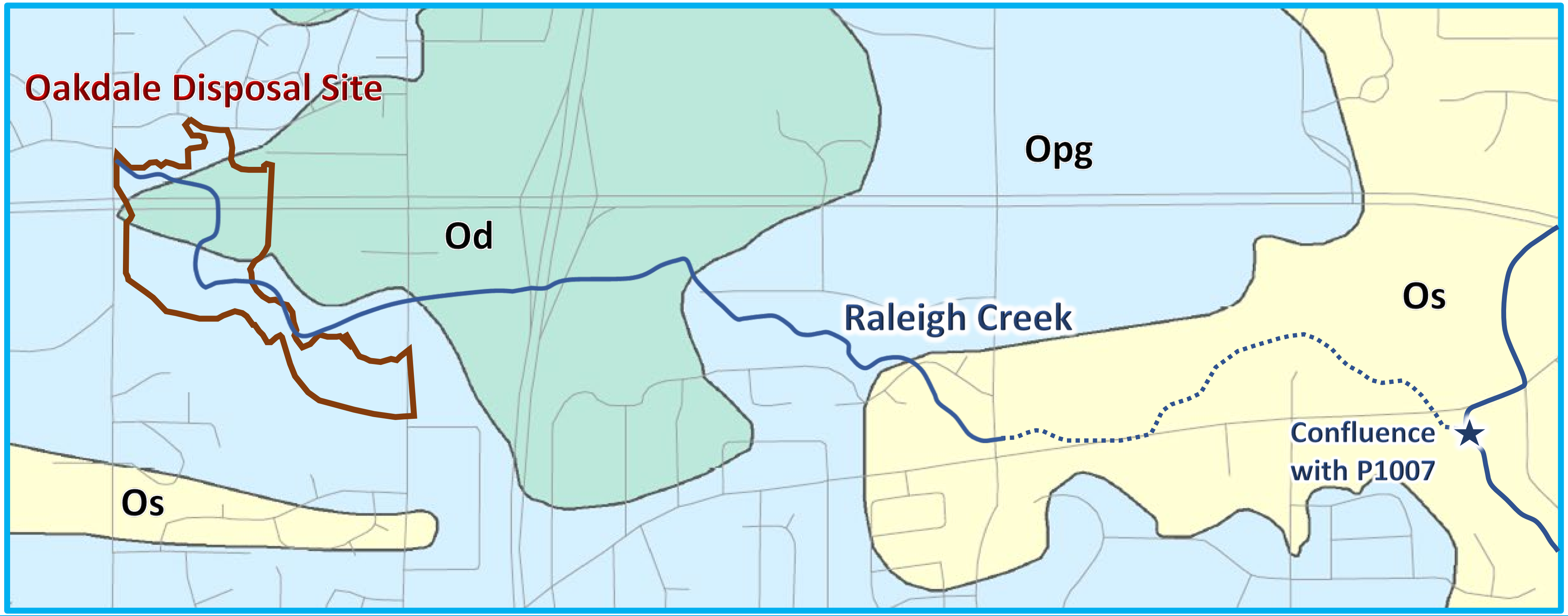
From the Surface to the Subsurface

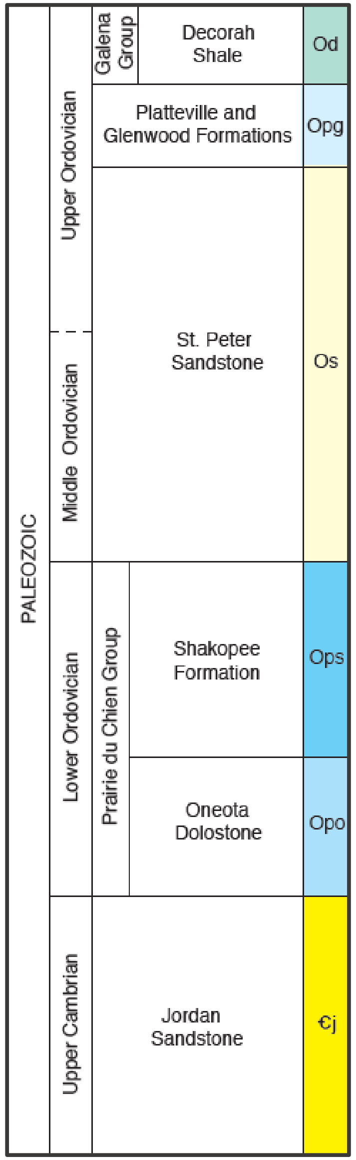


Segment 2 Bedrock Geology and Hydrogeology

The bedrock geology in Segment 2 is diverse and contributes to a hydrogeologically complex system that influences PFAS migration from Raleigh Creek to groundwater. ODS is underlain by both the Decorah Shale, in the northern portion, and the Platteville Limestone Aquifer, in the central and southern portions. The Decorah Shale Aquitard acts as a barrier to downward groundwater migration from the quaternary into lower units, resulting in horizontal groundwater flow to the south, southwest, and southeast until the Decorah is no longer present. Once the Decorah Shale vertically pinches out, the quaternary units are hydrogeologically connected to the Platteville Aquifer. Below the Platteville Limestone is the Glenwood Shale, which is also an aquitard and acts as another barrier to vertical groundwater movement. As a result, groundwater again flows horizontally until the Platteville-Glenwood Formations vertically pinch out and vertical flow to the St Peter Sandstone is uninhibited.

The St Peter Sandstone is underlain by the Shakopee Dolostone Aquifer. This absence of the Platteville-Glenwood Formation, therefore, allows for a direct pathway from surface and shallow quaternary waters to the both St Peter and Shakopee Bedrock aquifers.

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 Sandstone aquifer is not well understood. The hydraulic properties of this lower aquitard will be further assessed with a series of site-wide pumping tests, among other hydrogeologic testing techniques, planned for the late summer and fall of 2021.



**Prairie du Chien and Jordan units not on map.*

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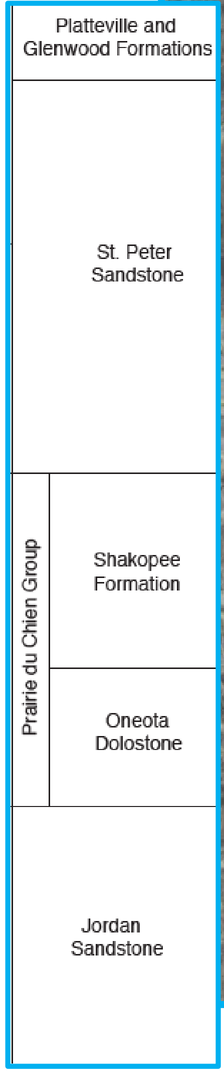
Segment 2: Site Features and Beta Sites



Beta Site Map: Segment 2

AECOM Beta Sites

Beta Site 1 (BS1)

MW1A: Jordan Aquifer Well

MW1B: St Peter Aquifer Well

MW1C: Platteville Aquifer Well

Vertical Aquifer Profile Samples from Quaternary Aquifer, Shakopee Aquifer, and Oneota Aquitard

Beta Site 14 (BS14)

Well Nest Downgradient of IAWC:

MW14A: Jordan Aquifer Well

MW14B: St Peter Aquifer Well

MW14C: Quaternary Aquifer Well

Vertical Aquifer Profile Samples from Shakopee Aquifer and Oneota Aquitard

Well Upgradient of IAWC:

MW14D: Quaternary Aquifer Well

Beta Site 2 (BS2)

MW2A: Jordan Aquifer Well

MW2E: St Peter Aquifer Well

MW2B: Deep Quaternary Aquifer Well

MW2C: Mid Quaternary Aquifer Well

MW2D: Shallow Quaternary Aquifer Well

Vertical Aquifer Profile Samples from Shakopee Aquifer and Oneota Aquitard

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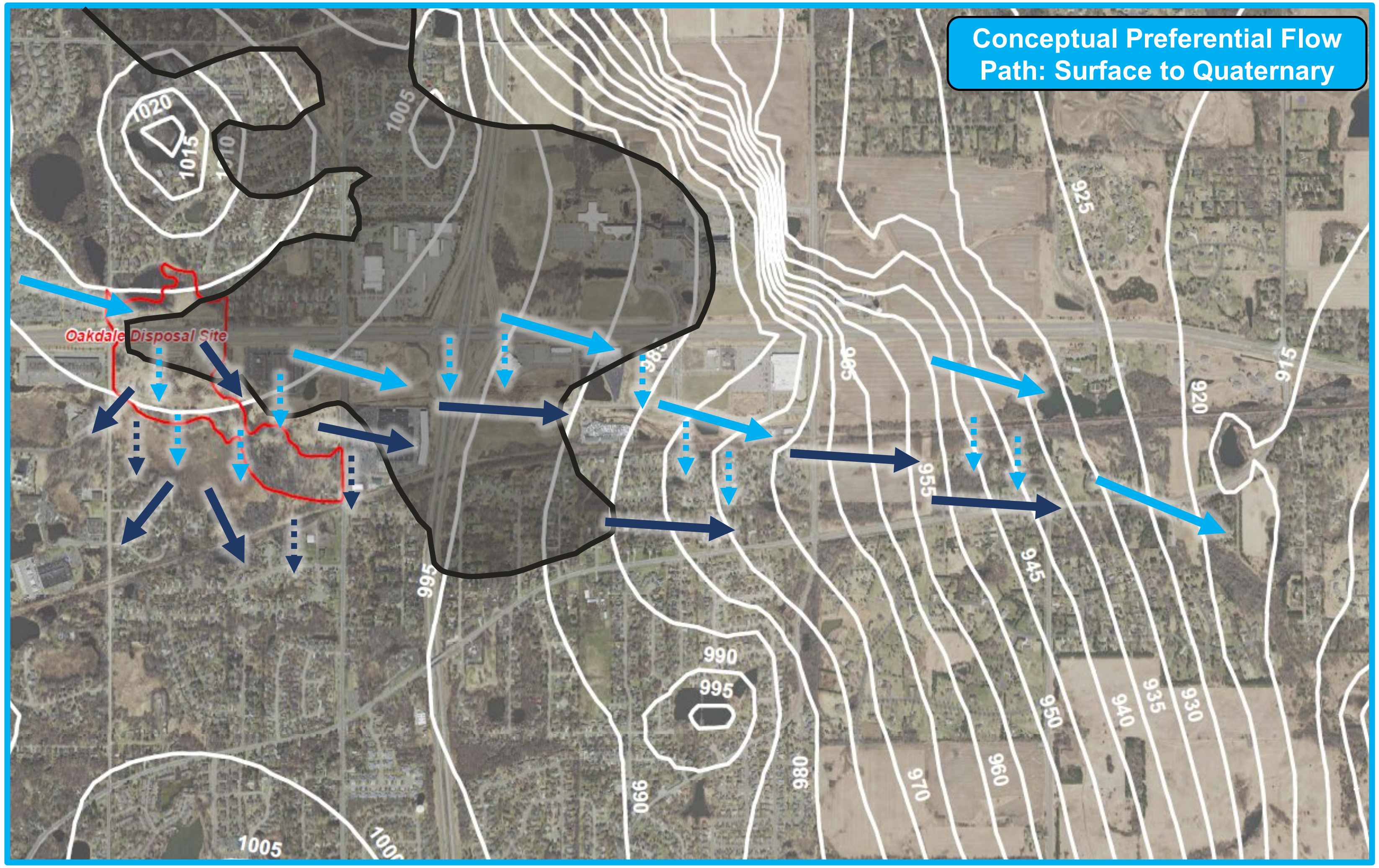
Shallow Quaternary Aquifers: PFAS Preferential Flow Path from Source



Quaternary Water Flow Path

The Oakdale Disposal Site (ODS) is underlain by approximately 40 to 60 feet of quaternary alluvium and undifferentiated glacial deposits, consisting of sands, clays, and gravels. Groundwater flow within the quaternary units effectively pools beneath ODS before migrating to the south, southwest, and southeast. Along the northern portion of the former disposal site, the Decorah Shale underlies these quaternary sediments. Where present, the confining shale units inhibits vertical flow. Once the Decorah pinches out in the southern portion of ODS, groundwater can migrate downward into the Platteville Limestone Aquifer.

East of ODS, surface water flows eastward along Raleigh Creek. Due to the creek's intermittent nature and flow-through wetland systems, surface water in Raleigh Creek likely infiltrates into the quaternary aquifers periodically through Segment 2.

Legend

- Surface Water Flow Direction
- Surface to Groundwater Infiltration
- Horizontal GW Flow: Quaternary
- Vertical GW Migration: Quat to Platteville
- Extent of Decorah Shale
- Quat Potentiometric Surface (5-ft Contours)

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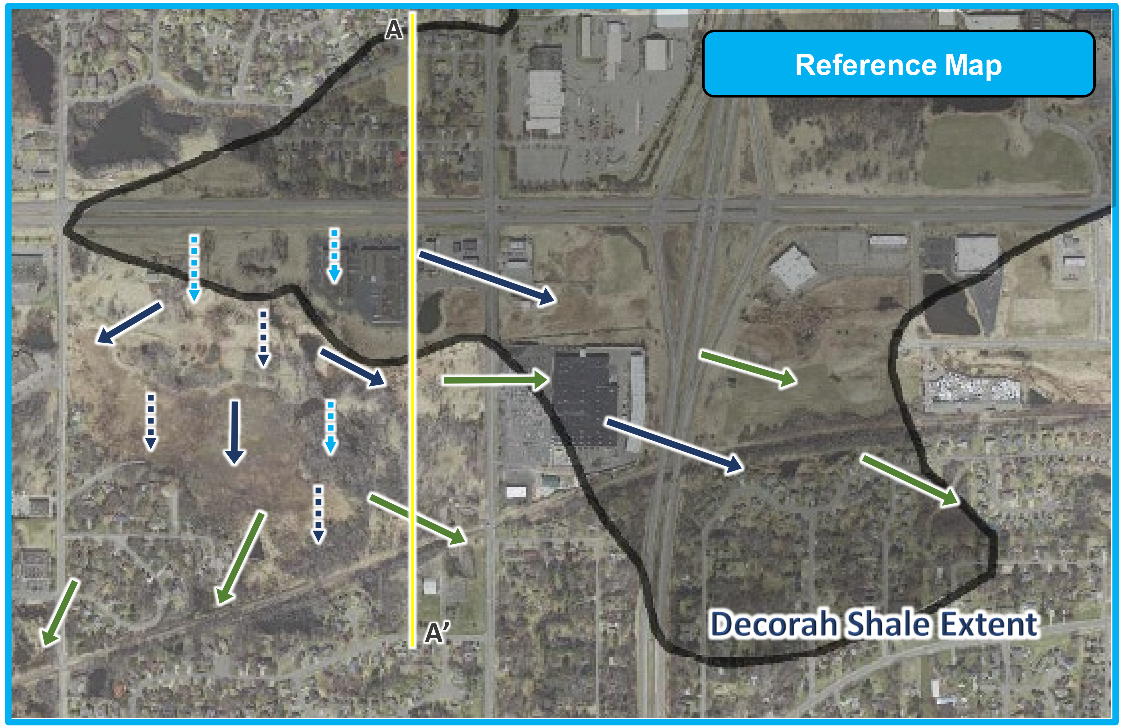
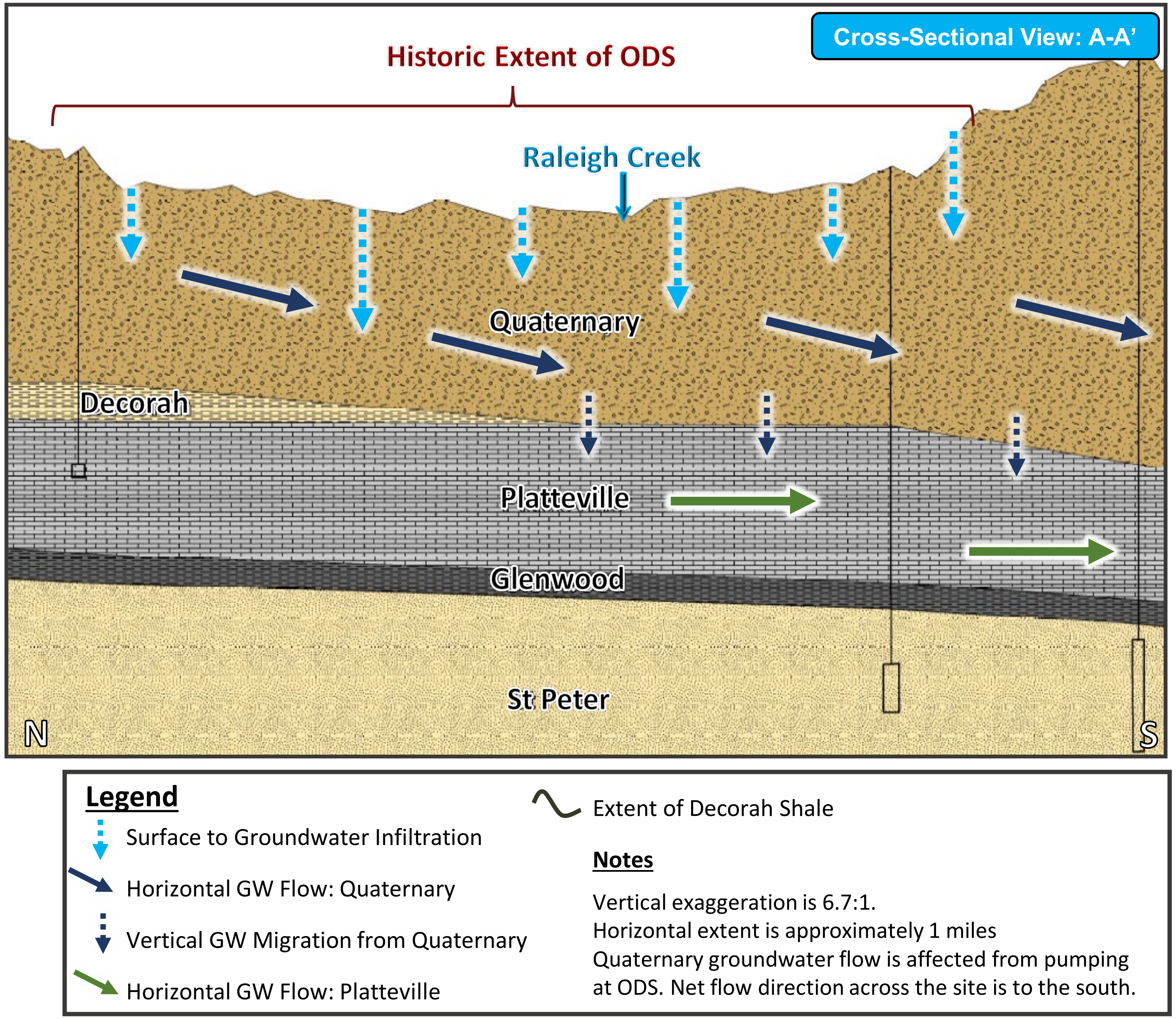
Cross-Sectional View: PFAS Preferential Flow Path at ODS



A Closer Look: Flow from ODS Surface to Platteville

The northern portion of ODS is underlain by the Decorah Shale Aquitard, which acts as a natural barrier to vertical groundwater migration from the quaternary aquifers into the underlying Platteville Limestone Aquifer. Once the Decorah Aquitard pinches out towards the middle of ODS, the quaternary aquifers are hydrogeologically connected to the Platteville Aquifer.



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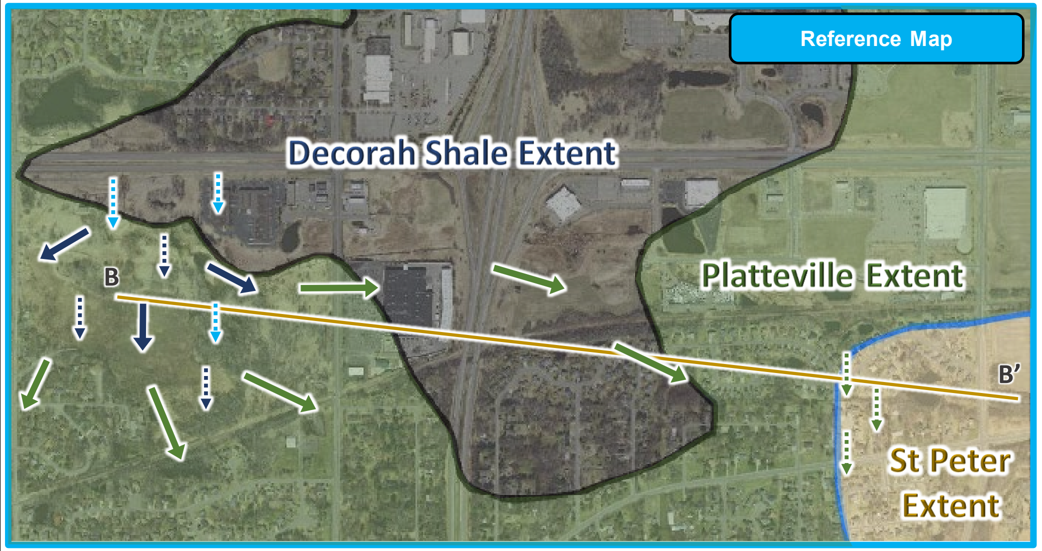
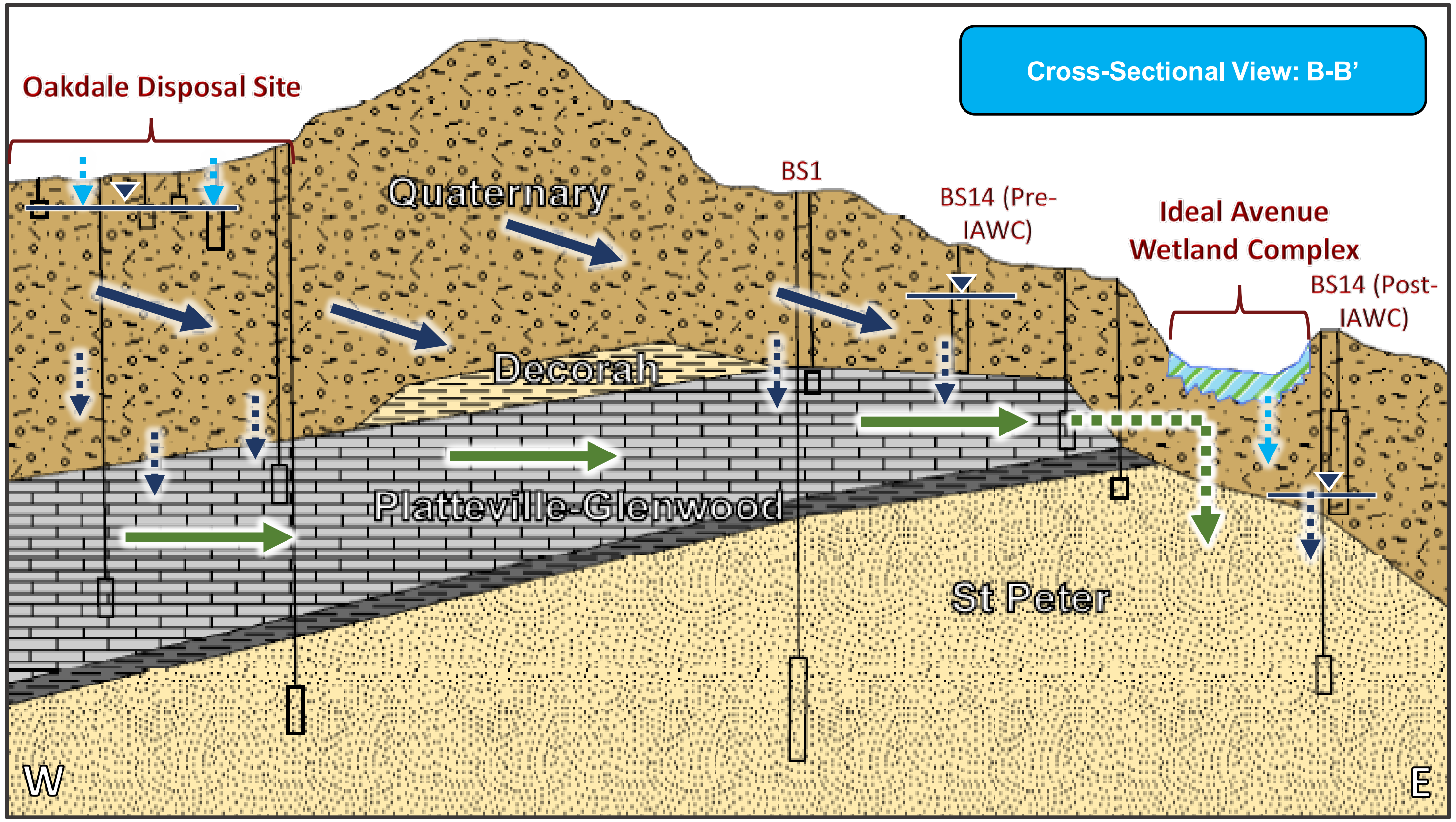
Platteville Aquifer: PFAS Preferential Flow Path from Source



A Closer Look: Platteville Groundwater Flow

Available gauging data from the Platteville aquifer indicates an eastward groundwater flow despite the westerly dip of the geologic unit. This eastward groundwater flow direction starts at the western edge of ODS.

Finding: Since the eastward flow path within the Platteville starts under, or just west of ODS, the source of the contamination in the Platteville is likely *from* ODS. Since the flow path is then to the east until the Platteville-Glenwood Formation pinches out, these impacts likely discharge to the St Peter aquifer.



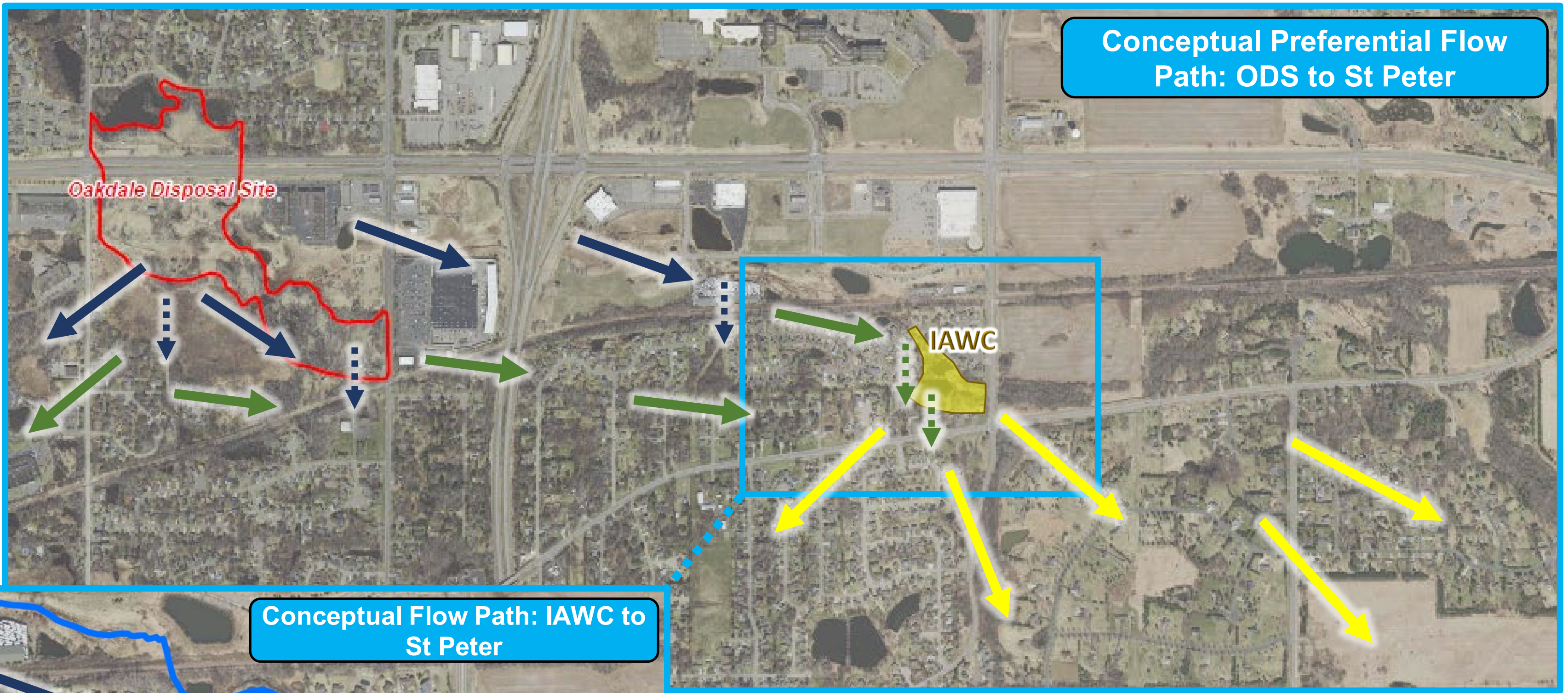
Legend

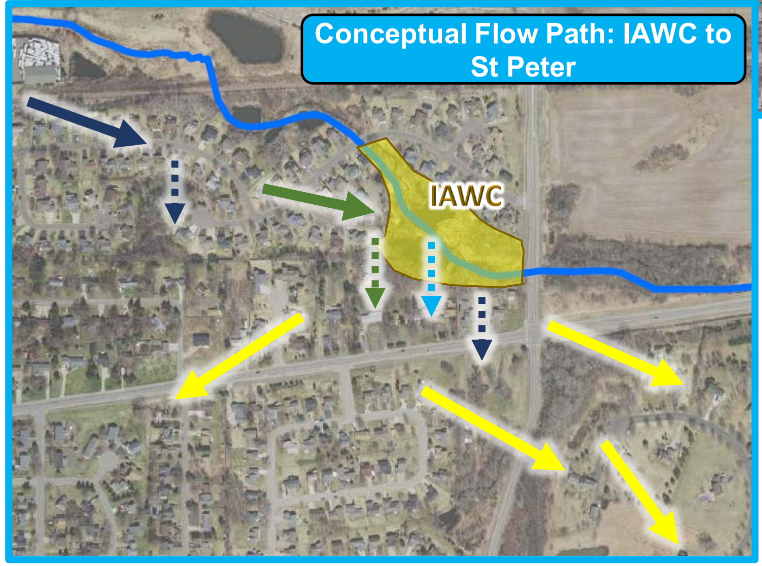
- Surface to Groundwater Infiltration
- Horizontal GW Flow: Quaternary
- Vertical GW Migration from Quaternary
- Horizontal GW Flow: Platteville
- Vertical GW Migration from Platteville
- Extent of Decorah Shale
- Extent of Platteville-Glenwood Formation
- Approx. Water Table (Quaternary)

Notes

Vertical exaggeration is 24.5:1
Horizontal extent is approximately 1.4 miles

St Peter Aquifer: PFAS Preferential Flow Path from Source





Legend

- Surface to Groundwater Infiltration
- Horizontal GW Flow: Quaternary
- Vertical GW Migration from Quaternary
- Horizontal GW Flow: Platteville
- Vertical GW Migration from Platteville
- Horizontal GW Flow: St Peter

Notes

Refer to slides 25-27 for addition details on impacts to sediment in the Ideal Avenue Wetland Complex (IAWC).

PFAS Preferential Flow Path: St Peter Aquifer

From ODS, PFAS-impacted waters may flow to the east via Raleigh Creek towards the Ideal Avenue Wetland Complex (IAWC) as well as through the Quaternary and Platteville Aquifers.

The approximate eastern-most edge of the Platteville-Glenwood Formation is located immediately to the west of the IAWC. This position of the edge of the aquitard overlying the St Peter Aquifer may allow for PFAS-impacted waters from three potential overlying sources:

1) **Impacted surface water from Raleigh Creek and the IAWC system infiltrating downward,**
2) **Impacted groundwater in the quaternary aquifers flowing from the west, and**
3) **Impacted groundwater exiting the Platteville Aquifer.**

Because of the effective groundwater divide within the St Peter aquifer under the approximate location of the edge the Platteville-Glenwood Formation, PFAS-impacted waters in the St Peter aquifer may then continue to the southeast and the southwest, as shown on the next slide in cross-section C-C'.

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St Peter Aquifer: PFAS Preferential Flow Path from Source (cont.)

A Closer Look: IAWC Infiltration

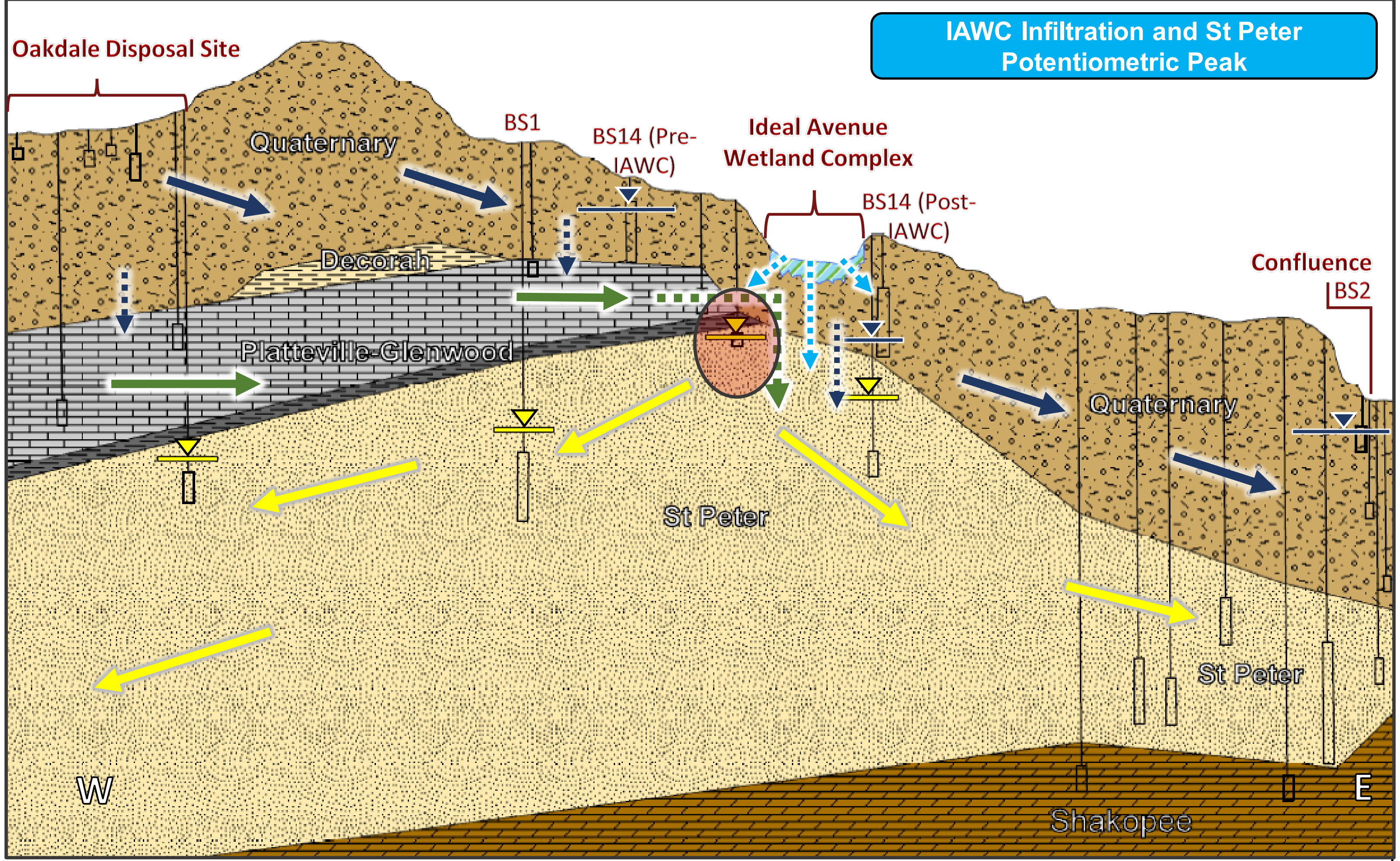
With the restriction of surface water discharge downstream of IAWC, and the steep vertical gradient between surface water and the quaternary aquifer at IAWC, it is likely that much of the ponds' water readily infiltrates into the subsurface.

Due to the absence of the Platteville-Glenwood Formation under IAWC, surface water is thus directly connected to the quaternary and St Peter aquifers, making the ponds and channels a potential secondary source of PFAS to groundwater in both aquifer systems.

A Closer Look: Platteville Recharge to St Peter

According to historic gauging data, a potentiometric "peak" in the St Peter Aquifer is located immediately below the eastern edge of the Platteville Aquifer (see circled area in drawing to the right). According to the Minnesota Geological Survey, this peak may be the result of groundwater from the Platteville Aquifer flowing eastward to the edge of the unit and then cascading downward into the St Peter Aquifer. This secondary input of groundwater to the St Peter elevates the water table enough so that groundwater flow in the St Peter at this location is actually to the east, despite the relative dip of the geologic unit being to the west.

As a result, this location may be a confluence of PFAS-impacted waters from IAWC, Raleigh Creek, the Platteville Aquifer, and the quaternary aquifers.



Legend

- Surface to Groundwater Infiltration
- Horizontal GW Flow: Quaternary
- Vertical GW Migration from Quaternary
- Horizontal GW Flow: Platteville
- Vertical GW Migration from Platteville
- Horizontal GW Flow: St Peter
- Approx. Water Table (Quaternary or St Peter)

Notes

Vertical exaggeration is 24.5:1

Horizontal extent is approximately 2.1 miles

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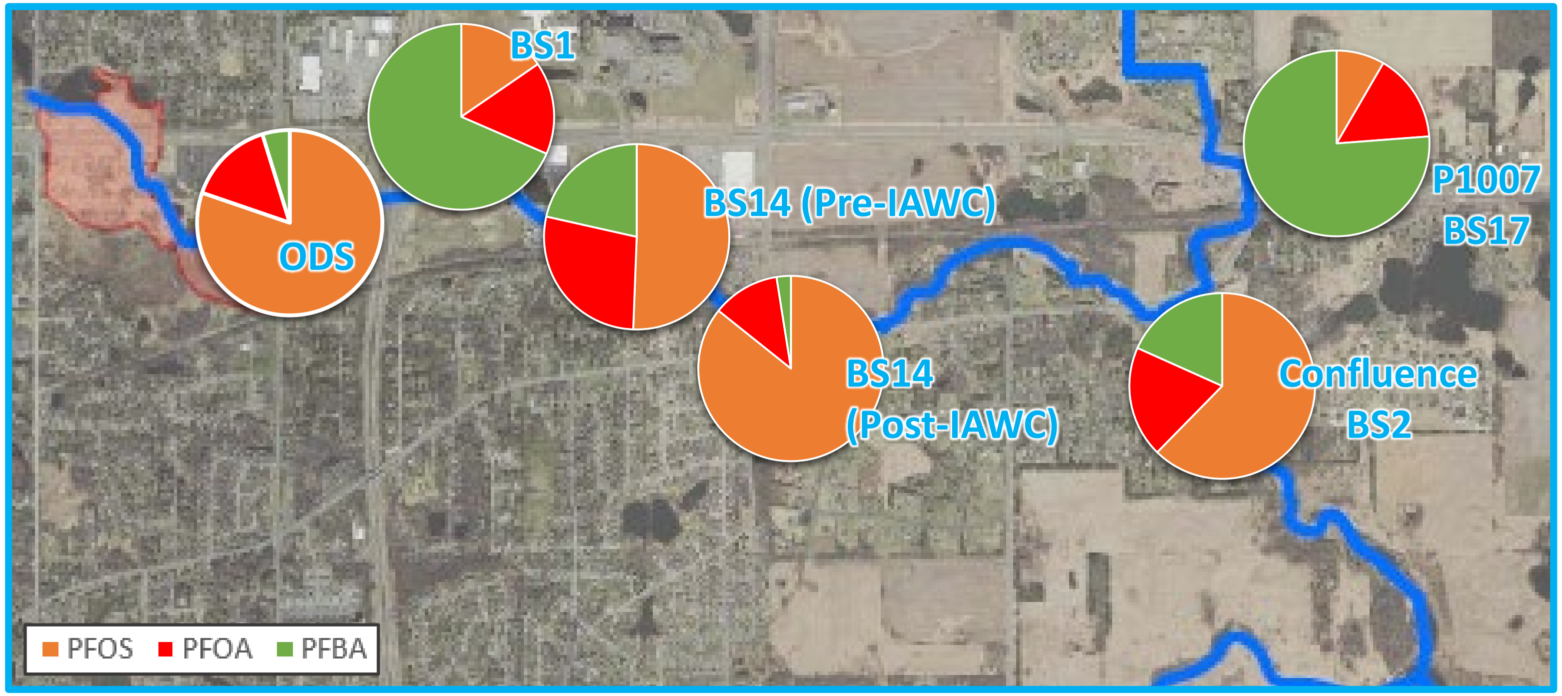
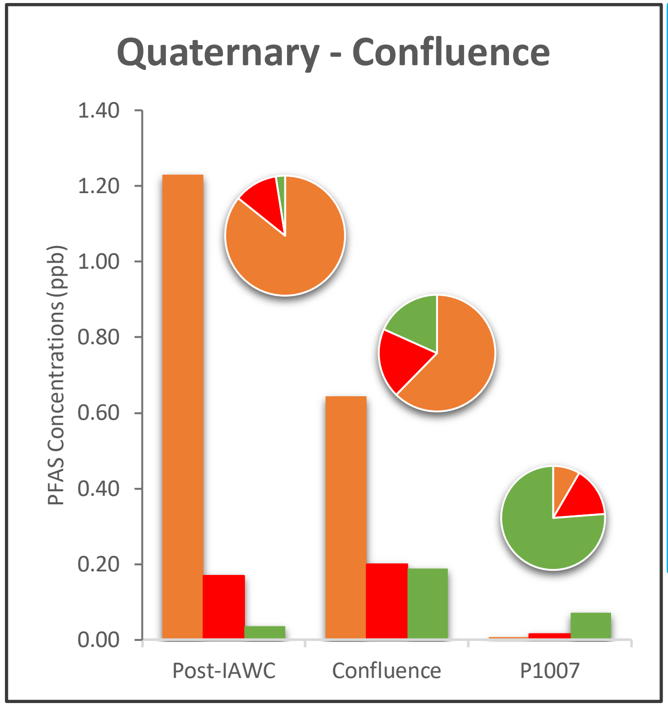
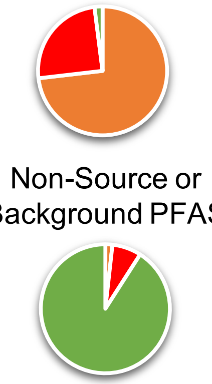
Groundwater Results: Distribution of PFAS Impacts in the Quaternary Aquifer





Typical PFAS Distributions

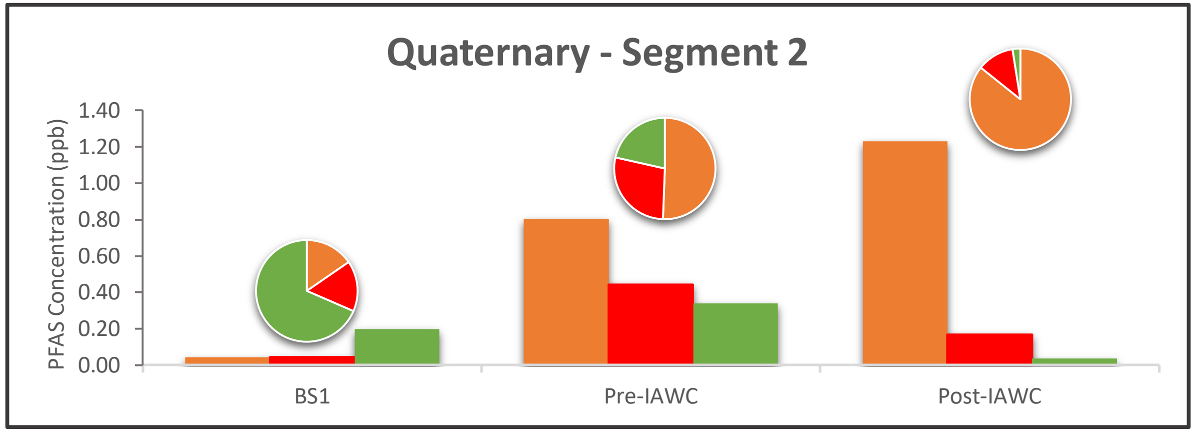
ODS PFOS-Dominant



Non-Source or Background PFAS

A Closer Look: BS1 to IAWC

Finding: From BS1 to downgradient of the IAWC system, quaternary groundwater shifts from PFBA-dominated to PFOS-dominated impacts. This gradual downgradient increase in PFOS concentrations that more closely resemble that of ODS impacts suggests that PFAS-impacted surface water from ODS is travelling eastward via Raleigh Creek and periodically infiltrating into the quaternary aquifers.



A Closer Look: Quaternary at Confluence

Like surface water, quaternary groundwater at the confluence is a mixture of groundwater from the west and the north. The western groundwater input is PFOS-dominant and similar to impacts at ODS, and the northern groundwater input is PFBA-dominant, generally low in PFAS impacts, and not clearly associated with any source areas.

As a result of the mixture of these two inputs, PFAS impacts in quaternary groundwater at the confluence (BS2) see a reduction in PFOS and an increase in PFBA.

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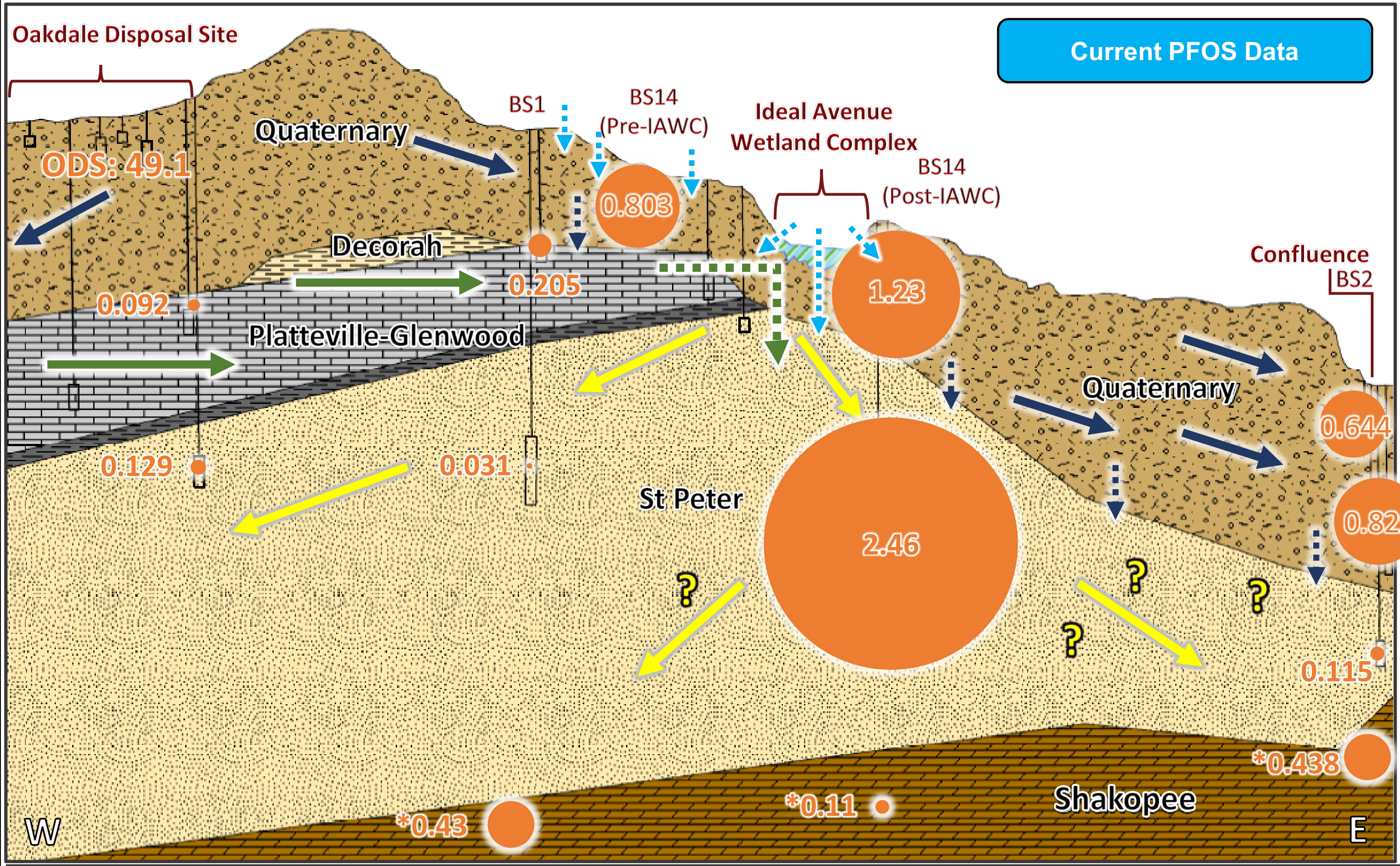
Current Groundwater PFOS Results



Legend
- Surface to Groundwater Infiltration
- Horizontal GW Flow: Quaternary
- Vertical GW Migration from Quaternary
- Horizontal GW Flow: Platteville
- Vertical GW Migration from Platteville
- Horizontal GW Flow: St Peter
- 0.25 ppb PFOS

Notes

Vertical exaggeration is 24.5:1.
Horizontal extent is approximately 2.1 miles.
For illustration purposes, ODS PFOS is not graphically depicted.
All sample results are in ppb (collected between 2020 and 2021).
* Denotes samples collected during drilling.

Current Post-IAWC PFOS Migration Path

Upon review of data collected from current monitoring wells in the St Peter and Quaternary aquifers, it is unclear exactly where the impacted groundwater at BS14 (post-IAWC) is going.
Finding: PFOS concentrations to the east and west of BS14 in the St Peter Aquifer are between one and two orders of magnitude lower than BS14 (post-IAWC). Vertically, PFOS concentrations are again an order of magnitude lower in the underlying Shakopee Aquifer, both directly below BS14 and to the west and east of BS14.

Unknown Flow Path of St Peter Impacts

The lack of active monitoring wells between BS14 and BS2 and south of Segment 2 further complicates the understanding of the migration flow path of the IAWC subsurface impacts. The key to understanding the PFOS flow path may be in evaluating historic data from previously abandoned wells, as presented in the next slide.

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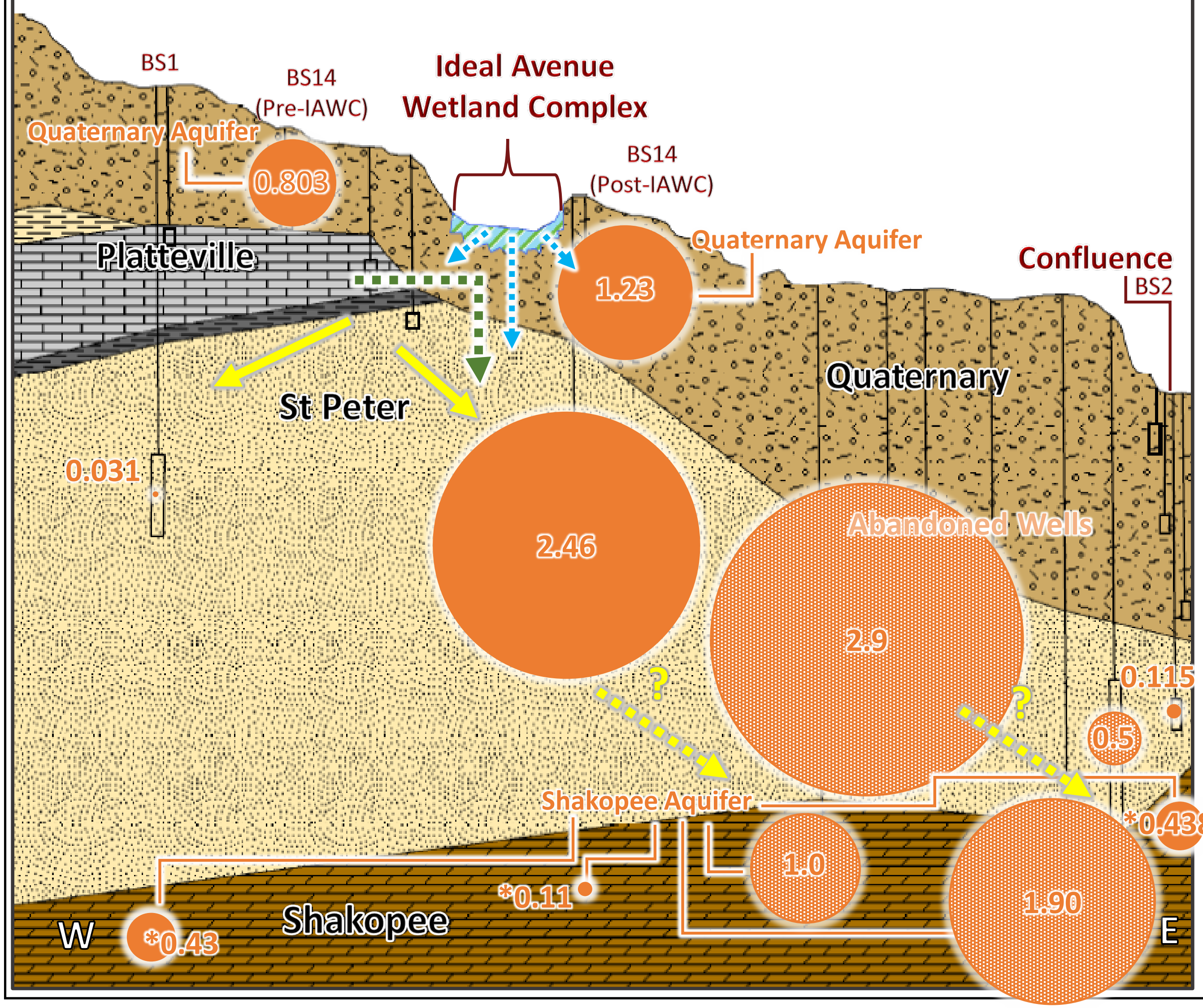
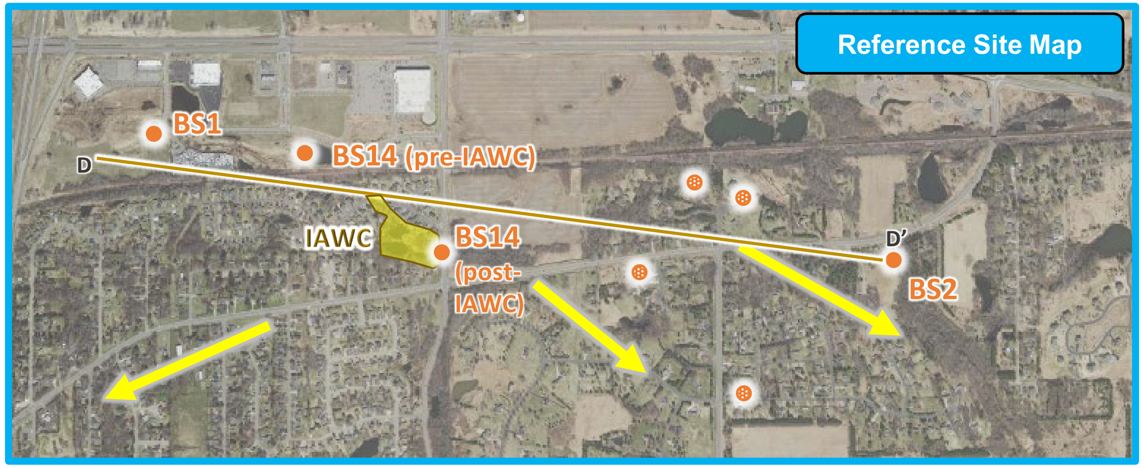
Historic and Current Groundwater Results

Current and Historic PFOS Data



Reference Site Map



Historic Post-IWAC St Peter Migration Path

Historical groundwater data from abandoned wells (provided by MDH) show similar concentrations of PFOS were detected in St Peter and Shakopee wells to the east and southeast in 2006. This suggests that PFAS impacts, at least historically, moved vertically from the St Peter Aquifer into the Shakopee Aquifer. The lack of PFAS impacts in the Shakopee Aquifer at BS2 and BS14 suggests that PFAS impacts in the St Peter Aquifer at BS2 and BS14 are not currently migrating downward. A possible cause for this historic downward migration may be poor well construction or wells constructed through multiple aquifers. It is not yet understood how the impacts in the St Peter Aquifer currently move.

Legend

- Surface to Groundwater Infiltration
- Vertical GW Migration from Platteville
- Horizontal GW Flow: St Peter
- Active Well (sampled 2020-2021)
- Abandoned Well (sampled 2006)

Notes

Vertical exaggeration is 24.5:1.

Horizontal extent is approximately 1.5 miles.

All sample results are in ppb.

Data from 2006 provided by MDH.

* Denotes samples collected during drilling.

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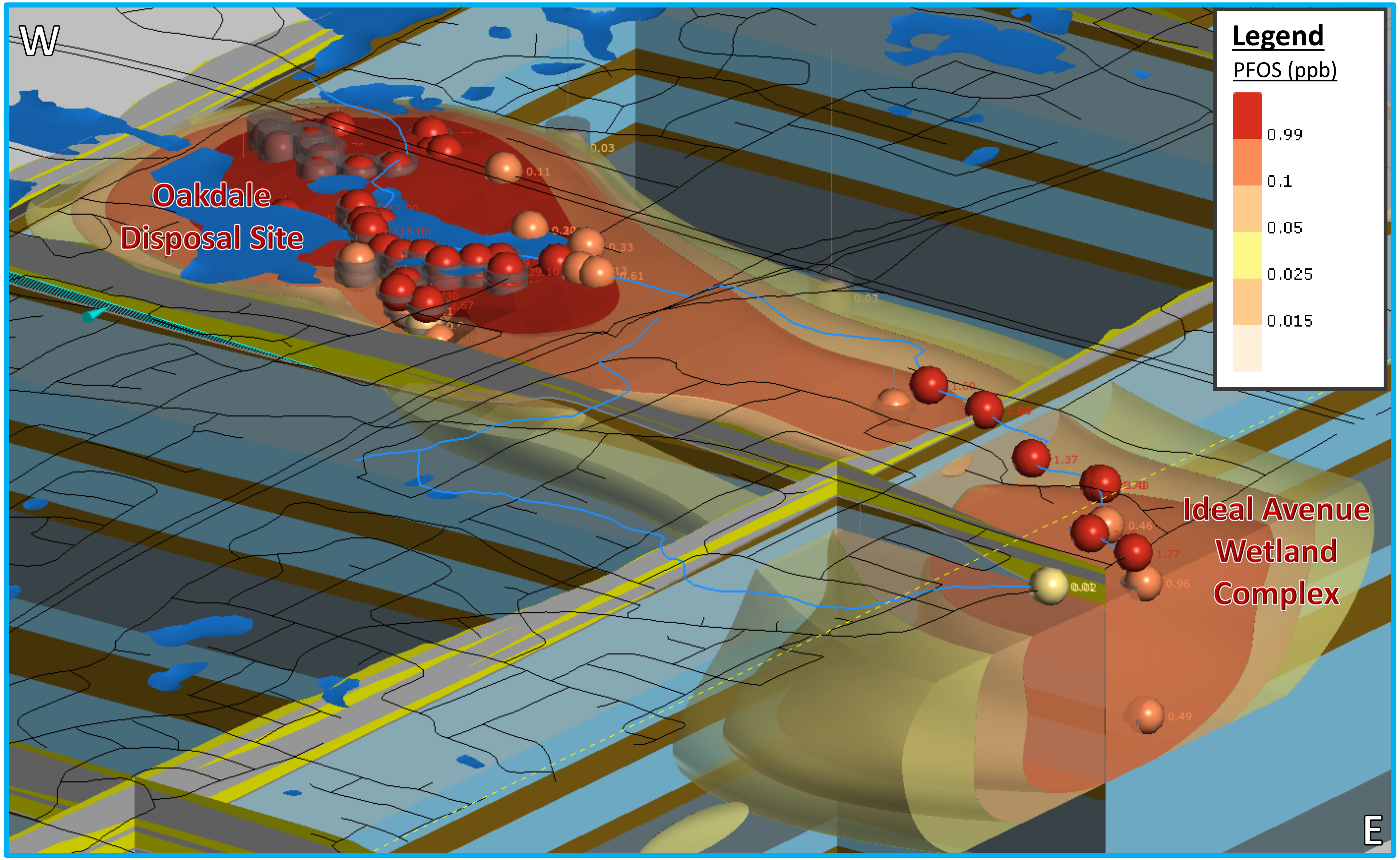
ODS to IWAC: Modelled Plume Surface to Ground



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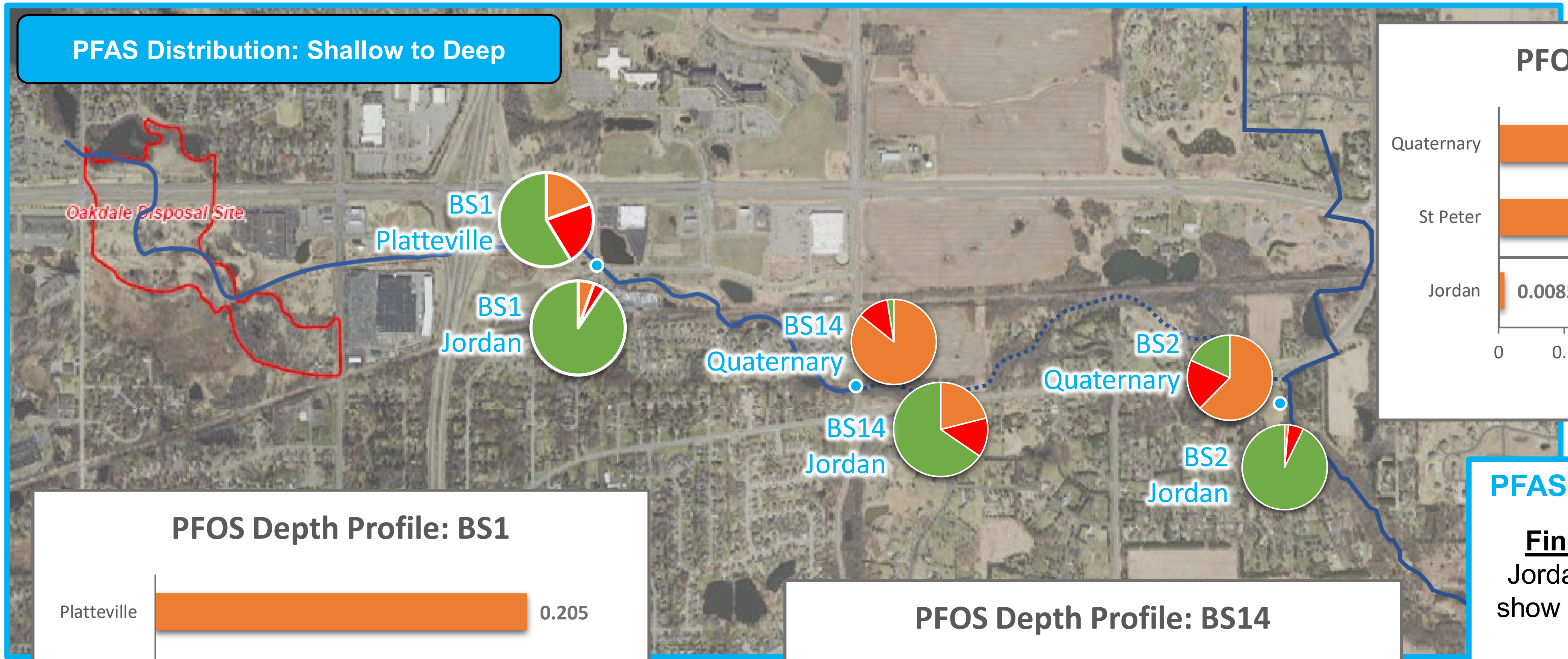
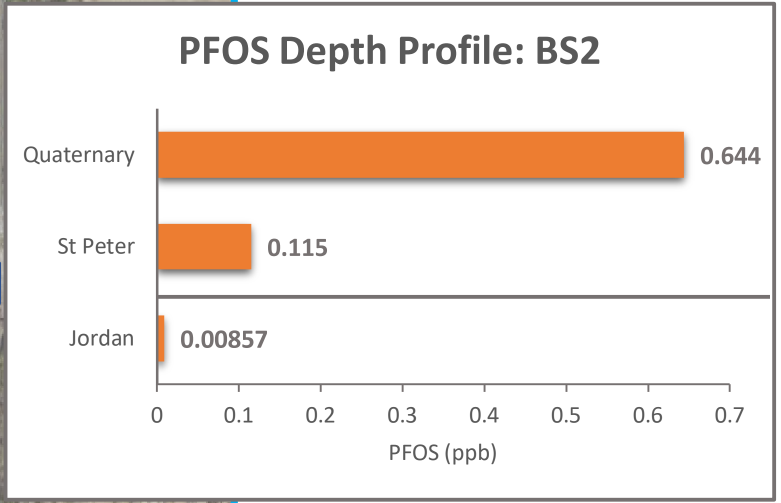
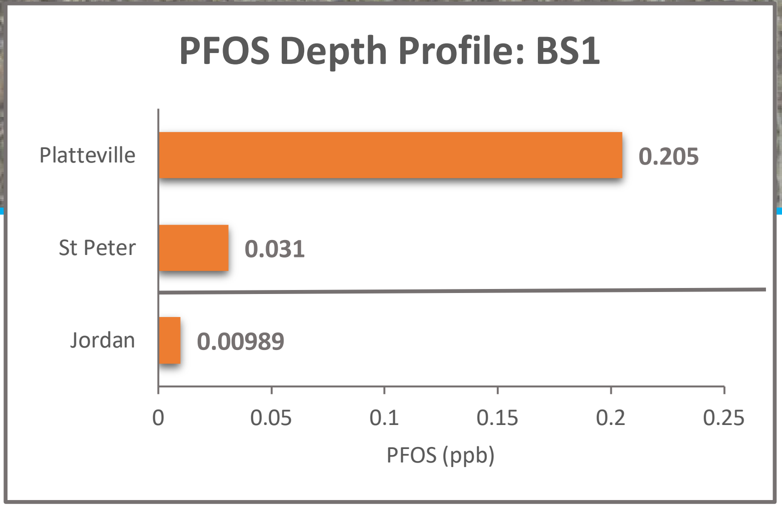
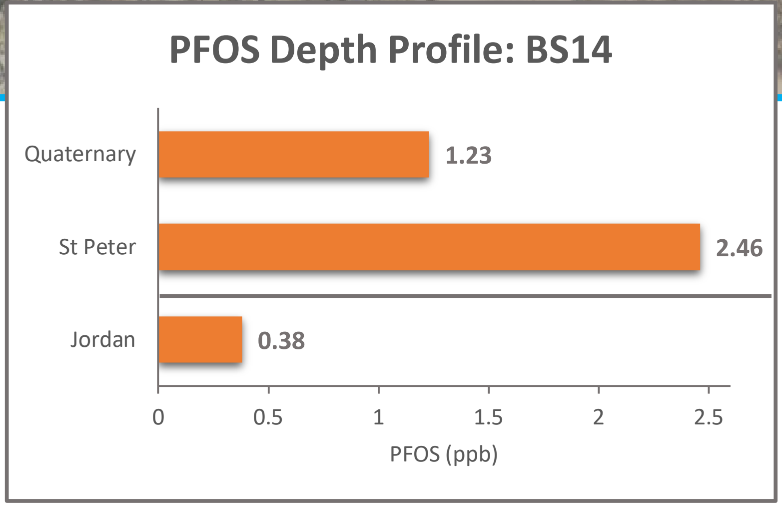
Segment 2: Jordan Aquifer Impacts









PFAS Impacts in the Jordan Aquifer

Finding: Analytical results from the Jordan Aquifer wells within Segment 2 show relatively low PFOS impacts when compared to the overlying aquifers. Additionally, the PFAS impacts are consistently PFBA-dominant. Based on the southwest trending GW flow direction in the Jordan, PFOS impacts in the Jordan in Segment 2 are likely from downward infiltrations from overlying aquifers or source areas to the northeast (i.e., Washington County Landfill that is located northeast of the map extent).

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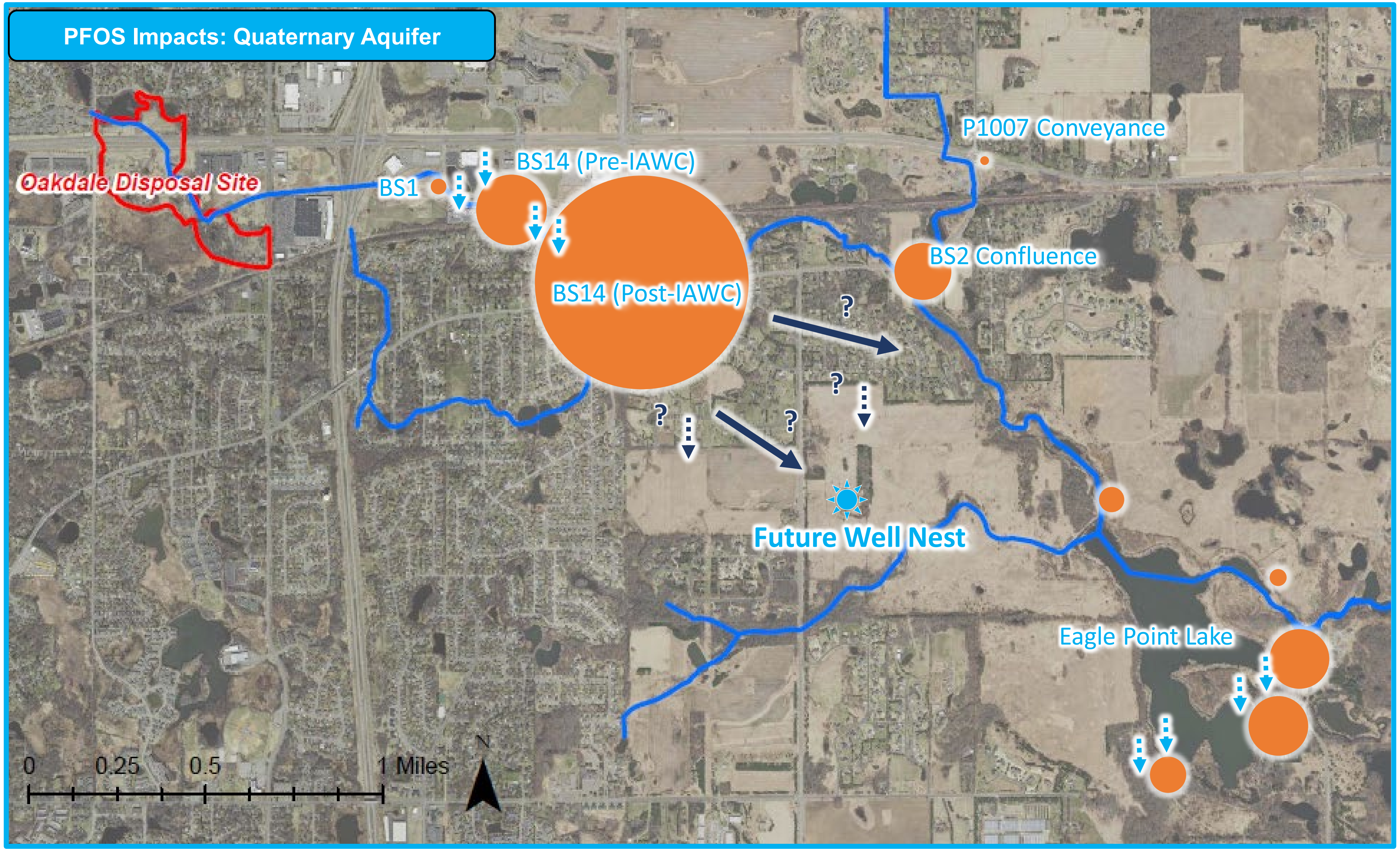
Next Steps



Unknown Flow Path of Impacts from IAWC

Reported concentrations of PFOS at BS14 in both the quaternary and St Peter aquifers are the highest groundwater impacts corridor-wide, second only to impacts at ODS. However, PFOS concentrations to east and west of BS14 (post-IAWC) are between one and two orders of magnitude lower, and vertically, PFOS concentrations are again an order of magnitude lower. To determine where these impacts are going both laterally and vertically, a future well nest is planned to the southeast of IAWC that will target all aquifers.

**ODS annual monitoring data has not been made available since 2019.*

Legend

- Surface to Groundwater Infiltration
- Horizontal GW Flow: Quaternary
- Vertical GW Migration from Quaternary
- 0.25 ppb PFOS

Notes

Sample results from April 2021.