

White Bear Lake Comprehensive Planning Study

Study 7A Surface Water Quality Analysis



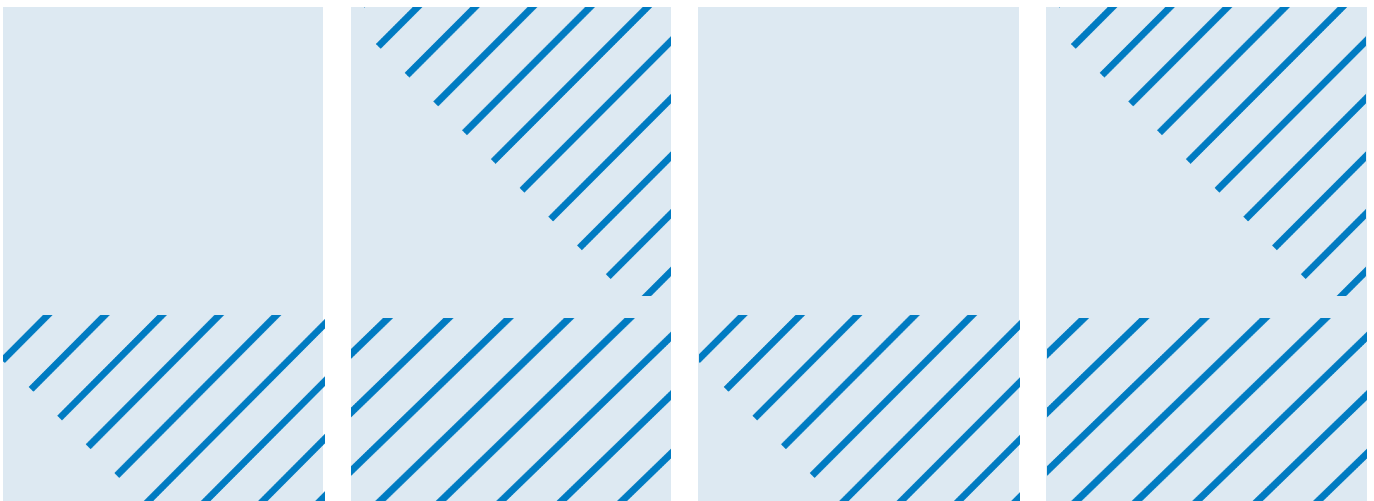
Prepared for
Metropolitan Council Environmental Services

Prepared by
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July 2026

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Certification

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly licensed Professional Engineer under the laws of the state of Minnesota.



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7/9/2026
Date



Study 7A Surface Water Quality Analysis

July 2026

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Abbreviations

95% UCL	95% upper confidence limit of the mean concentration
AIS	aquatic invasive species
AMC	antecedent moisture content
BMP	best management practices
CLP	curly leaf pondweed
CN	Curve Number
COPC(s)	chemical(s) of potential concern
CRWD	Capitol Region Watershed District
DOC	dissolved organic carbon
ELCR	excess lifetime cancer risk
EPA	Environmental Protection Agency
EPCs	exposure point concentrations
FeCl	Ferric chloride
FIBI	Fish Index of Biological Integrity
FQI	Floristic Quality Index
HBV	Health-Based Values
HI	hazard index
HQ	hazard quotient
HRL	Health Risk Limits
IESF	iron-enhanced sand filters
MCES	Metropolitan Council Environmental Services
MCL	Maximum Contaminant Level
MDH	Minnesota Department of Health
MGD	million gallons per day
MnDNR	Minnesota Department of Natural Resources
MPCA	Minnesota Pollution Control Agency
MRCC	Midwestern Regional Climate Center
MSP	Minneapolis-St. Paul International Airport
NAVD88	North American Vertical Datum 1988
NCP	National Contingency Plan
NPDWR	National Primary Drinking Water Regulations
MCL	Maximum Contaminant Levels
NURP	National Urban Runoff Program
O&M	operation and maintenance
OHWL	Ordinary High Water Level
P8	P8 Urban Catchment Model
PFBA	Perfluoro butanoic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctanesulfonic acid
RBSLs	risk-based screening levels
RCPW	Ramsey County Public Works
RCWD	Rice Creek Watershed District
RME	reasonable maximum exposure
RSL	regional screening levels
SLRA	screening level risk assessment

SMCL	Secondary Maximum Contaminant Levels
SPRWS	St. Paul Regional Water Services
TALU	MPCA Tiered Aquatic Life Uses
TC	time of concentration
TKN	total Kjeldahl nitrogen
TOC	total organic carbon
USEPA	U.S. Environmental Protection Agency
USGS	United States Geological Survey
VLAWMO	Vadnais Lake Area Watershed Management Organization
WHO	World Health Organization

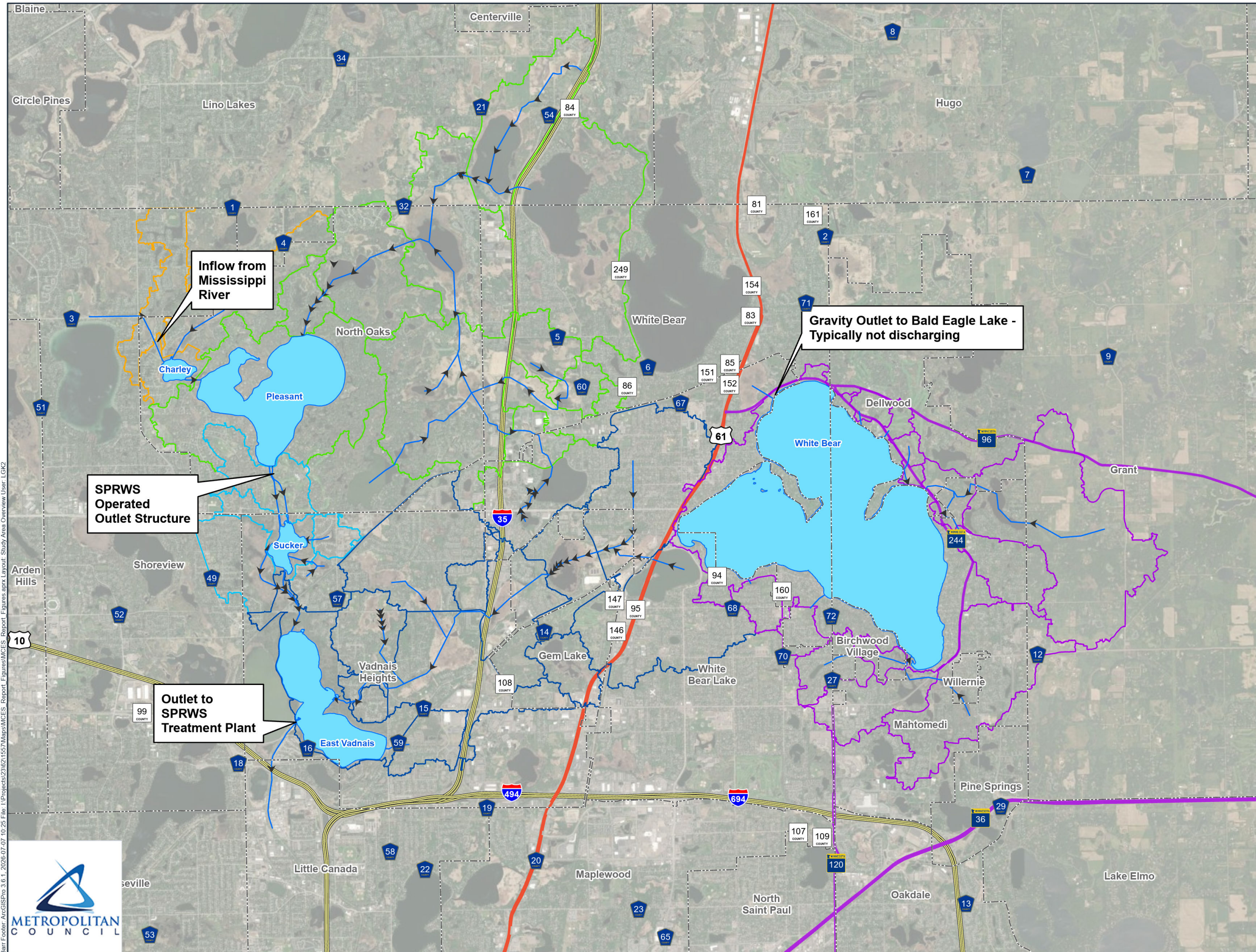
Executive Summary

The Metropolitan Council Environmental Services (MCES) is leading a regional planning effort to develop a comprehensive drinking water management plan to help ensure that communities in the White Bear Lake area have access to sufficient safe drinking water to allow for municipal growth while simultaneously safeguarding the sustainability of surface water and groundwater resources for future supply.

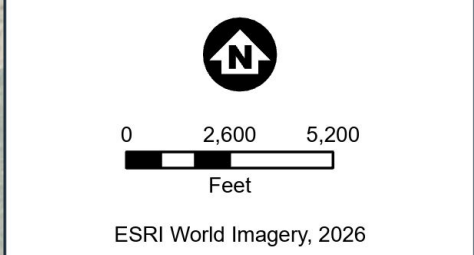
The purpose of Study 7A (the surface water quality study) is to inform a larger scope of work related to modeling the potential impacts to surface water quality that may be caused by increasing the flow of Mississippi River water through the St. Paul Regional Water Services (SPRWS) chain of lakes, which includes Charley Lake, Pleasant Lake, Sucker Lake, and East Vadnais Lake. Additionally, the study includes an evaluation of White Bear Lake. The increase in flow is being considered to augment White Bear Lake water levels and/or supplement the water supply of the 14 communities whose existing groundwater supplies are tied to White Bear Lake's water levels.

The ultimate goal of the surface water modeling effort was to collect comprehensive water quality data to inform the identification of potential water quality parameters of concern and to develop lake water quality models that can be used to assess existing and future water quality conditions under various future use scenarios. The study will be used to provide decision support for water resource management strategies related to lake treatment and augmentation of White Bear Lake.

Figure EX-1 shows the overview of the study area. A brief summary of the scope of the work and results is included in the following sections.



- Municipal Boundary
- Study Lakes
- Flowlines
- Subwatersheds
 - Charley
 - Pleasant
 - Sucker
 - East Vadnais
 - White Bear Lake
- Streets and Highways
 - Interstate Highway
 - US Highway
 - State Trunk Highway



Study Area Overview
MCES White Bear
Lake Study 7A

FIGURE EX-1

BARR

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Data Collection

This task included compilation of historically available studies and information to support the development of the watershed and surface water quality modeling and analysis including watershed, lake, and water quality information available from a variety of agencies and organizations including St. Paul Regional Water Services (SPRWS), Vadnais Lakes Area Watershed Management Organization (VLAWMO), Rice Creek Watershed District (RCWD), Ramsey County Public Works (RCPW), the Minnesota Department of Natural Resources (MnDNR), Metropolitan Council Environmental Services (MCES), and participating communities. Additionally, data collection included development of a surface water quality monitoring plan for the study lakes that was executed by SPRWS, VLAWMO, and RCPW in 2025 to collect a broader range of water quality constituents based on feedback from several agencies. This data was collected to help inform eutrophication modeling and at a planning level, help identify other constituents of concern as it relates to drinking water quality and ecological impact.

Summary of Goals and Standards and Statistical Analysis of Data

This task summarized existing water quality and ecological goals/standards/guidelines for the surface waters within the SPRWS chain of lakes and White Bear Lake, as well as drinking water standards and guidelines from the United States Environmental Protection Agency (EPA) and the Minnesota Department of Health since White Bear Lake is hydraulically connected to the underlying Prairie du Chien-Jordan aquifer that is the primary drinking water source for 13 of the White Bear Lake area communities.. These surface water body goals/standards/guidelines, along with the monitoring data and modeling results, were used when evaluating the impact of the various water use and augmentation scenarios on the water bodies to determine the possible impacts from both a water quality and ecological perspective.

Watershed Modeling

This task developed a watershed model using P8 Urban Catchment Model (P8) application, version 3.5. This model was used to predict the generation and transport of sediment and associated pollutants mobilized by stormwater runoff in urban watersheds to each of the study lakes. Using this application, Barr developed a water quality model for the study area watersheds to each study lake using current impervious coverage data and a particle file that represents and generates the median pollutant loads and concentrations as there was limited data available for watershed flow or other monitoring data for calibration. These results were used to estimate watershed runoff volumes and pollutant loads to the study lakes to inform and support the lake water quality modeling.

Lake Model Development

To evaluate the impact of future changes to flow magnitude and pollutant load on the SPRWS chain of lakes and possible augmentation of White Bear Lake, two different models were developed for this effort. These models included:

- CE-QUAL-W2, version 4.5 – a 2D hydrodynamic and water quality (eutrophication) model developed by Portland State University that includes a complete water balance leveraging lake bathymetry, surface inputs (from the watershed or upstream lakes), groundwater inputs and outputs, direct precipitation and evaporation, and surface outflows through the lake outlet. The model also considers a variety of lake water quality parameters including total phosphorus, internal phosphorus loading, total nitrogen, temperature, stratification, dissolved oxygen, total and dissolved organic carbon, and phytoplankton growth (chlorophyll a), including cyanobacteria

- A mass balance model for non-eutrophication parameters: Leveraging the same lake morphology used to develop the CE-QUAL-W2 model and the calibrated water balances from the CE-QUAL-W2 model for each study lake, a mass balance spreadsheet model was developed to calculate the effect of changes in Mississippi River flows and loads on non-eutrophication parameters as they move through the SPRWS chain of lakes system, as well as in White Bear Lake. The selection of the non-eutrophication parameters for the mass balance modeling was based on the 2025 monitoring data, first considering if the data was detected at the Mississippi River and if detected in the downstream SPRWS chain of lakes and if the downstream lake concentrations were above the concentrations observed in White Bear Lake.

The lake water quality models were calibrated for the 2025 data and results were typically summarized for the growing season (June 1-September 30) to align with the state eutrophication standards. These tools were then used to evaluate the effect of future flow and load scenarios as part of Study 7A to understand the lake eutrophication response as a function of these flows and loads as well as potential changes in other water quality to help identify possible pollutants of concern and mitigation needs.

Scenario Evaluation

Using the calibrated CE-QUAL-W2 model for eutrophication parameters and the calibrated mass balance models for the non-eutrophication parameters, we determined the water quality results for nine flow and augmentation scenarios defined by the projected summer peak community water demands as provided by MCES and the estimated augmentation rate for White Bear Lake from the MnDNR. This effort focused on dry (2021) baseline conditions as these are the conditions in which White Bear Lake would most likely be augmented. The baseline dry model run reflects the dry conditions assuming the existing SPRWS demand as used for Scenarios 2 and 3 (but does not include any augmentation flow) to serve as the baseline for comparison to determine the impact of the future flow scenarios. In addition to determining concentration differences as a screening tool to identify potential impacts, the mass balance will be used to determine the lake water quality responses for high-risk constituents to determine the magnitude of their impacts for each scenario. The nine scenarios are outlined below:

- Scenario 1: SPRWS supplies water to all communities that resulted in the highest projected water demands with treated surface water (no White Bear Lake augmentation)
 - 1A: Existing Conditions
 - 1B: 2050
 - 1C: Ultimate
- Scenario 2: SPRWS supplies water to its own customers only and the augmentation of White Bear Lake from Sucker Lake (surrounding communities remain on groundwater supplies)
 - 1A: Existing Conditions
 - 1B: 2050
 - 1C: Ultimate
- Scenario 3: SPRWS supplies water to its own customers only and Augmentation of White Bear Lake from East Vadnais Lake (surrounding communities remain on groundwater supplies)
 - 1A: Existing Conditions
 - 1B: 2050
 - 1C: Ultimate

Table EX-1 provides a summary of the estimated daily river inflows for the calibration period, the baseline dry conditions, and the 9 scenarios, based on projected summer peak community water demands as

provided by MCES. Also included are the daily augmentation flow rates to White Bear Lake for Scenarios 2 and 3 as well as the daily flowrate to the SPRWS treatment plant.

Table EX-1 Scenario Flow Summary (MGD)

	Calibration (2025)	Baseline (2021) Dry	Scenario 1	Scenario 2	Scenario 3
Pumping From River (including water supply and/or augmentation flows)	22.5	42.4	1A: 56.5 1B: 69.8 1C: 76.2	2A: 46.5 2B: 52.9 2C: 55.7	2A: 46.5 2B: 52.9 2C: 55.7
Augmentation Flow	N/A	N/A	N/A	2A: 4.3 2B: 4.3 2C: 4.3	2A: 4.3 2B: 4.3 2C: 4.3
Flow to SPRWS Treatment Plant	45.6	50.2	1A: 64.7 1B: 78.3 1C: 84.7	2A: 50.2 2B: 56.6 2C: 59.6	2A: 50.2 2B: 56.6 2C: 59.6

The modeling highlights that as water travels through the SPRWS chain of lakes, the system generally retains most pollutants and reduces the impact of pollutant inputs from the Mississippi River as flows move downstream, with observed reductions in concentrations. This is especially true of pollutants associated with particulate being more affected by system processes than dissolved ones. This retention through the system becomes more pronounced downstream, with East Vadnais Lake consistently demonstrating the lowest concentrations for most pollutants.

Generally, the results from the scenario modeling indicated that Scenario 1 resulted in the most significant change in the SPRWS chain of lakes. Scenario 2, which draws augmentation water from Sucker Lake, results in the most significant impact to White Bear Lake. And given White Bear Lake's large size and volume, it appears to be a fairly resilient system that can handle some additional pollutant loading from augmentation without a significant change in water quality.

Sensitivity Analysis

After the scenario modeling was completed, we performed a sensitivity analysis with higher loads at the Mississippi River for select parameters based on the results of the data review and scenario modeling. For eutrophication parameters, we used the CE-QUAL-W2 model and scaling of the Mississippi River inflow chemistry to result in growing season averages reflecting the 99th percentile concentrations based on the full period of record for the Mississippi River using the data leveraged in this study. For dissolved oxygen, we assumed the 1st percentile concentrations as low dissolved oxygen is typically more critical for water quality. These conditions represent a worst-case scenario based on the available data to assess the potential response of the system to changes in these factors, focusing on the two scenarios that resulted in the worst case response from the scenario modeling. These scenarios included:

- Scenario 1C: Ultimate flow conditions to supply the identified communities with drinking water from the SPRWS system. This scenario resulted in the most significant water quality change in East Vadnais, including declines in the hypolimnetic dissolved oxygen levels.
- Scenario 2C: Augmentation of White Bear Lake from Sucker Lake resulted in the most significant water quality change in White Bear Lake.

For non-eutrophication parameters, we used the scenario mass balance model to conduct the sensitivity analysis using the Mississippi River concentrations at the 99th percentile from the full period of data for all scenarios and parameters that were modeled.

Under high-pollutant conditions in the Mississippi River, the chain of lakes experiences more stress than under more average to typical conditions. This is most apparent in the upstream lakes that first receive the river flows and loads. However, we continue to see the general trend of pollutant removals through the chain of lakes through natural settling, biological uptake, and chemical transformation processes that reduce pollutant concentrations as water moves downstream with pollutant concentrations typically the lowest when water reaches East Vadnais Lake.

Some parameters likely have more variability in the Mississippi River flows, so under worse case conditions, can have a more significant impact on the anticipated change in the water quality in the SPRWS chain of lakes. Those parameters with more significant change from baseline conditions included:

- Nutrients (Total Phosphorus and Total Nitrogen)
- Total Organic Carbon
- Chlorophyll a
- Total suspended solids
- Total dissolved solids
- Total aluminum
- Total copper
- Total manganese
- Sulfate
- Chlorine dioxide
- Gross alpha and gross beta (radiation)
- Radium 226/228
- Microplastics

For the White Bear Lake augmentation scenarios, especially Scenario 2, White Bear Lake appeared to be most responsive to the following parameters with more significant change when comparing the sensitivity results to the original scenario assessment for more typical conditions:

- Total suspended solids
- Total copper
- Total manganese
- Sulfate
- Radium 226

Leveraging the sensitivity model run that resulted in the most significant impact to the water quality in the SPRWS chain of lakes (for Scenario 1C), we went through a high-level exercise to evaluate the possible additional dosing that might be needed in these future scenarios for the ferric chloride system at the Mississippi River and at East Vadnais Lake, that suggests with future pollutant loading, dosing will need to increase. We also used the CE-QUAL-W2 model to evaluate dosing impacts to the oxygenation systems in Pleasant Lake and East Vadnais Lake.

This was a planning level assessment intended to help inform the mitigation plan for the SPRWS chain of lakes as well as treatment of augmentation flows to White Bear Lake. This analysis is for planning purposes only and does not constitute design of a system.

Risk Assessment

A risk assessment was conducted using the available 2025 water quality data collected as part of Study 7A. This assessment quantified the potential health risks associated with hypothetical municipal exposure to chemicals in the surface water of East Vadnais Lake and White Bear Lake if untreated surface water was used as municipal tap water to help identify, at a planning level, possible contaminants of concern to consider as part of the mitigation planning. In reality, surface water from East Vadnais Lake is treated at the SPRWS water treatment plant following all appropriate drinking water treatment methods, and the final treated water is regularly tested in accordance with the Minnesota Department of Health for compliance with MDH Human Health-Based Water Guidance values (MDH, 2026) and EPA drinking water standards. Also, White Bear Lake naturally recharges the surrounding groundwater aquifer that serves as the source water for several community water systems and private wells in the area. As the surface water of White Bear Lake passes through the underlying soil on its way to recharge the groundwater aquifer, its chemistry is likely to change through filtration and the geochemistry of the surrounding soil.

The risk assessment consisted of a screening level assessment to identify a subset of chemicals (i.e., chemicals of potential concern or COPCs) in the surface water of each source lake that could contribute to health risks if untreated surface water or groundwater that was under the direct influence of untreated surface water was used as tap water by residents. Any chemical with a maximum detected concentration greater than a conservative human-health risk-based screening levels (RBSL) was identified as a COPC and evaluated further in the quantitative risk assessment.

The quantitative human health risk assessment for the municipal tap water exposure pathway was performed using the USEPA Regional Screen Level (RSL) calculator (USEPA, 2024) that quantifies potential cancer risks and noncancer hazards associated with hypothetical municipal exposure to COPCs in the surface water of East Vadnais Lake and White Bear Lake with the goal of flagging those parameters of most concern to public health.

For East Vadnais Lake, the parameters flagged as COPCs and had a quantitative health risk assessment performed included the following. Those that are **bold** had health risk quotients that exceeded the acceptable ratio.

- Fluoride
- **Phosphorus**
- Manganese
- **Perfluorooctanesulfonic acid (PFOS)**

For White Bear Lake, the parameters flagged as COPCs and had a quantitative health risk assessment performed included the following. Those that are **bold** had health risk quotients that exceeded the acceptable ratio.

- **Chlorine dioxide**
- **Chlorine (total residual)**
- Fluoride

- **Phosphorus**
- Arsenic
- Manganese
- Thallium
- **Perfluorooctanoic acid (PFOA)**

Mitigation Plan

Based on the results of the scenario modeling and sensitivity analysis as well as the results of the risk assessment conducted above, we have summarized the major takeaways to inform the development of a conceptual mitigation plan to prevent, treat, and address potential contaminants of concern in the SPRWS chain of lakes, as well as the augmentation of White Bear Lake. This includes both eutrophication and non-eutrophication parameters as well as consideration of the potential treatment needs for aquatic invasive species (AIS) present in the system, including zebra mussel veligers (known to be present in these systems), as well as available information on requirements to prevent transfer of other possible AIS species of concern in Minnesota.

The mitigation plan represents the most critical outcome of Study 7A, translating the modeling and risk assessment into targeted, actionable strategies designed to ensure water quality protection, regulatory compliance, and operational flexibility under future system demands.

Additional Water Quality Monitoring

2025 data was collected to inform the modeling and provide a screening look at potential contaminants of concern and their concentrations through the system. However, for many parameters (beyond eutrophication parameters and metals which were monitored monthly), this sampling was limited to 2 samples within each lake in June and September 2025 to help identify potential contaminants of concern to inform this study and mitigation plan.

If one of the scenarios evaluated as part of Study 7A were to be selected to move forward for implementation, we would recommend additional monitoring of select parameters to reduce uncertainty, inform design, and guide operations, including:

- Monitoring with increased frequency of the eutrophication-related parameters at the river and through the chain of lakes and White Bear Lake as well as the non-eutrophication parameters, especially those flagged as parameters of potential concern as part of this assessment and for treatment of augmentation of White Bear Lake as outlined in more detail in Section 8.1.3.1. This will more accurately capture variability in these parameters, and include:
- For additional testing, ensuring all laboratory reporting limits are at or below the drinking water standards and regulatory values for surface water samples and looking into a possible low bias in the total phosphorus data tested at the SPRWS laboratory.
- Additionally, monitoring of key tributaries into each lake, including both flow and pollutants, can help better characterize these major inflows into the lakes and inform the possible impacts on the lake management strategies and inform future modifications.
- In light of potential changes in eutrophication conditions especially along the SPRWS chain of lakes and the fact that Pleasant Lake is currently listed as impaired and Charley and Sucker Lakes could also be listed as impaired, the anticipated increases in loading should be reviewed

against existing operating permits held by SPRWS for the management of the drinking water supply. Typically, there are limitations on new or expanded discharges to impaired resources; however, it is possible that existing permits held by SPRWS could allow for the expected increases in flows or loads from the Mississippi River for the various scenarios.

Ferric Chloride Treatment

Based on the estimated increases in loading for the possible future flow conditions, it is likely that the SPRWS will need to increase the ferric chloride dosing at the Mississippi River and East Vadnais if it is decided that any of the scenarios evaluated as part of Study 7A are recommended and progress to the implementation phase (see Section 6.4 for additional detail). In general, in the ultimate water demand scenario (Scenario 1C), ferric chloride dosing from the baseline dry condition would need to increase by 80% including both SPRWS and all additional communities' demands. If only considering the additional communities, ferric chloride dosing would need to increase by 25% if the river is at more typical conditions and 50% increase if the rivers is at high sustained pollutant concentrations; however, it is not likely that the Mississippi River will remain at these high levels for the entirety of the growing season and dosing at a higher rate would likely be temporary.

We would recommend that SPRWS consider the following as it relates to the river inflow treatment:

- Perform a more complete seasonal flow and water quality of the Mississippi River Fridley data to better understand the variability in water quality seasonally and with flow conditions may drive dosing, and to understand how this could affect ferric chloride dosing.
- Continue Ferric Chloride treatment of river inflows and East Vadnais. Evaluate modification to the existing system to allow for increased dosing compensatory with anticipated future flows and loads. Given the possible magnitude of the increase in dosing, it may not be possible to dose at the anticipated rates, and the system sizing could be limited by floc formation, precipitation, and anticipated accumulation in Charley Lake and East Vadnais Lake. Charley Lake often exceeds the surface water standard for iron under the existing dosing conditions, but iron levels in East Vadnais Lake typically meet the surface water standard.
- Jar testing of the river inflows seasonally and during a variety of flow conditions to better understand variability and actual dosing needs would be recommended.
- Outline system operations and decisions surrounding changes in dosing. There may be ways to incorporate real-time monitoring and automate adjustments to the dosing system to optimize the system.
- Evaluate whether increased dosing using ferric chloride at the river would be allowed in light of monitoring data indicating Charlie Lake is often exceeding surface water standards for Iron.

Oxygenation Systems

SPRWS operates oxygen injection systems in the hypolimnion of Pleasant Lake and East Vadnais Lakes to maintain targeted oxygen levels (~5 mg/L). In Pleasant Lake, the 2025 monitoring profile data at Pleasant Lake suggests that the hypolimnion is anoxic for much of the growing season, and it does not appear that the existing system is delivering the oxygen as intended to the deep holes within the lake or that the existing system is underdosed. Monitoring and modeling of East Vadnais suggests that the oxygen system is doing an adequate job of maintaining oxygen levels in the hypolimnion for existing conditions.

The dissolved oxygen profiles for all scenarios and sensitivity runs also show that increased loads will continue to exacerbate the anoxic conditions in the hypolimnion. These conditions result in increased internal phosphorus loads from the lake bottom sediments and may lead to other redox chemical reactions.

Although we performed the modeling exercise to inform possible order of magnitude change in the oxygenation system dosing as a result of future scenarios, there are limitations and uncertainty in the dosing and model predictions.

For Pleasant Lake, the modeling exercise indicates that the existing dosing (based on 2025 dosing) from SPRWS could be sufficient for the future loading. However, for East Vadnais Lake, the oxygen system may need to increase in the dosing during the growing season from existing conditions (2025 dosing) by a factor of approximately 2.25. The analysis performed suggests that under existing conditions, SPRWS may need to nearly double the oxygen dosing (as applied in 2025) to manage climatic variability in the existing system. The additional oxygen dosing required as a result of the ultimate community flows for Scenario 1C is a factor of ~0.25 when compared to 2025 dosing. However, based on the scenario flow summary, about 33% of the increase in flow would be the result of ultimate water supply demand from the other White Bear Lake communities and the remainder of that increase is due to the expected growth in the SPRWS service area.

The following are considerations for the future operations of both the Pleasant Lake and East Vadnais Lake oxygenation systems. These tasks could be done during the preliminary design phase for the proposed lake augmentation system, connecting communities to SPRWS water treatment plant or a separate regional water treatment plant.

- Confirmation that the existing system is delivering oxygen to the hypolimnion as designed and making any additional modifications to improve the existing system performance.
- Testing of the sediment oxygen demand seasonally and across years to better understand variability in the oxygen demand, as well as at each of the deep hole locations within the lakes that could inform modifications to system operations and dosing. This could include collection of gridded dissolved oxygen profile data across each lake during system operations to understand the spatial impact of the oxygenation system on dissolved oxygen levels in the hypolimnion.
- For Pleasant Lake, where water quality is typically poor and internal loading from the lake bottom sediment is expected to increase with increased flow and loads to the lake, further evaluation should be completed to decide if an individual alum treatment of lake bottom sediments could be effective at permanently binding phosphorus and helping control internal loads in Pleasant Lake along with the oxygenation system.
- Evaluate opportunities to modify oxygenation system and dosing based on additional information and accommodate possible increases dosing related to possible future implementation scenarios. Any modifications to the oxygenation system should be closely evaluated as the expansion of the existing diffuser systems could lead to unintended mixing of the lake which is not desired. Maintaining stratification is important to keep elevated phosphorus levels in the hypolimnion from reaching the lake surface waters.
- Modify the CE-QUAL-W2 model code to more accurately capture the existing system diffuser operations and the impact of modifications, including increases in oxygen dosing, numbers of diffusers, and impact on mixing.

Treatment of Augmentation Flows to White Bear Lake

Although the modeling demonstrated that White Bear Lake is resilient to increased loads from augmentation, the modeling demonstrated that drawing water from Sucker Lake will have more of a negative impact on White Bear Lake than using water from East Vadnais Lake. As a result, we would recommend that East Vadnais Lake be the source of water if augmentation of White Bear Lake were part of the long-term implementation plan.

Additionally, regardless of source, we would still recommend treatment to protect White Bear Lake long-term from variability in the quality of the Mississippi River flows and the SPRWS chain of lakes to ensure no degradation of White Bear Lake water quality and protection of the aquatic ecosystem.

Table EX-2 summarizes the mitigation plan for treatment of augmentation flows to White Bear Lake based on this water quality assessment. The treatment outlined is primarily based on the estimated White Bear Lake response assuming East Vadnais Lake is the augmentation source, the scenario evaluation and sensitivity response, and the risk assessment. This mitigation plan does not account for the impact of any potential modifications to the SPRWS systems, including the ferric chloride dosing at the Mississippi River, the oxygenation at Pleasant Lake, and the ferric chloride/oxygenation at East Vadnais Lake, which could result in an improvement in water quality through the chain of lakes with increases in flows and pollutant loads.

Additionally, for parameters listed as no targeted treatment, we have identified that the anticipated change in White Bear Lake water quality is generally insignificant, the estimated concentrations meet current surface water or drinking water standards, and are not expected to impact the aquatic ecosystem at the estimated levels. Although these parameters do not need targeted treatment specific to their removal, it is possible that they will experience some level of removal by treatment process selected to achieve the other targeted reductions.

Also, a water treatment pilot study should be done during both warm and cold weather conditions to confirm the treatment process that will be needed to mitigate the lake augmentation water or for a new regional surface water treatment plant.

Table EX-2 Mitigation Plan Summary for White Bear Lake Augmentation

Parameter	East Vadnais Lake Concentrations	White Bear Lake Concentrations	Recommended Level of Treatment of Augmentation Water to White Bear Lake
Total Phosphorus	0.023 mg/L (0.005 – 0.125 mg/L)	0.018 mg/L (0.006 – 0.173 mg/L)	Maintain discharge concentrations <0.020 mg/L*
Total Nitrogen	0.77 mg/L (0.52 – 1.28 mg/L)	0.72 mg/L (0.1 – 2.2 mg/L)	Maintain discharge concentrations <0.9 mg/L*
Chlorophyll a	7.8 ug/L (<1.0 – 74.1 ug/L)	4.0 ug/L (<1.0 – 22.1 ug/L)	Maintain discharge concentrations <9.0 ug/L
Total Organic Carbon	8.63 mg/L (7.25 – 10 mg/L)	4.6 mg/L (4.2 – 5.2 mg/L)	Maintain discharge concentrations <4.6 mg/L*
Dissolved Oxygen	9.0 mg/L (5.3 – 11.3 mg/L)	9.2 mg/L (5.7 – 13.9 mg/L)	Maintain discharge concentrations >7 mg/L*
Total Suspended Solids	1.8 mg/L (0<1.0 – 3.25 mg/L)	2.0 mg/L (<1.0 – 15 mg/L)	Maintain discharge concentrations <2.0 mg/L*
Total Dissolved Solids	223 mg/L	180 mg/L (166-191 mg/L)	No Targeted Treatment
Chlorides	35.2 mg/L (29.9 – 43.5 mg/L)	33.7 mg/L (16.8 – 57.0 mg/L)	No Targeted Treatment
Hardness	140.9 mg/L (95.4 – 165.5 mg/L)	92.1 mg/L (82.4 – 92.1 mg/L)	No Targeted Treatment
Alkalinity	134.4 mg/L (110.9 – 160.2 mg/L)	88.3 mg/L (55.5 – 113.5 mg/L)	No Targeted Treatment
Arsenic	1.0 ug/L (<1.0 – 1.5 ug/L)	2.1 ug/L (1.2 – 3.0 ug/L)	No Targeted Treatment
Aluminum	4.1 ug/L (0.4 – 12.0 ug/L)	23.8 ug/L (<10 – 52.7 ug/L)	No Targeted Treatment
Barium	48.3 ug/L (46.4 – 49.7 ug/L)	40.2 ug/L (38.5 – 42.3 ug/L)	No Targeted Treatment
Calcium	34.3 mg/L (26.7 – 41.1 mg/L)	20.6 mg/L (19.0 – 22.1 mg/L)	No Targeted Treatment
Copper	2.7 ug/L (1.1 – 13.6 ug/L)	(1.4 – 2.2 ug/L)	No Targeted Treatment*
Fluoride	0.094 mg/L (0.08 – 0.11 mg/L)	0.085 mg/L (0.065 – 0.115 mg/L)	No Targeted Treatment
Magnesium	14.4 mg/L (10.9 – 15.9 mg/L)	9.5 mg/L (9.2 – 10.4 mg/L)	No Targeted Treatment*
Manganese	0.097 mg/L (0.005 – 1.668 mg/L)	0.035 mg/L (<0.01 – 0.090 mg/L)	No Targeted Treatment
Sulfate	8.3 mg/L (<2.0 –30.5 mg/L)	3.3 mg/L (1.5 –10 mg/L)	Maintain discharge concentrations <3.3 mg/L*
Chlorine Dioxide	<0.2 mg/L	(<0.2 – 0.38 mg/L)	No Targeted Treatment (further evaluation)
Gross Alpha Radiation	1.7 pCi/L (1.2 – 2.2 pCi/L)	1.4 pCi/L (0.5 – 2.3 pCi/L)	No Targeted Treatment
Gross Beta Radiation	3.8 pCi/L (2.0 – 3.8 pCi/L)	4.1 pCi/L (3.0 – 5.1 pCi/L)	No Targeted Treatment
Radium 226	0.24 pCi/L (0.07– 0.4 pCi/L)	(0.05 pCi/L)	No Targeted Treatment
Radium 228	0.4 pCi/L (0.06 – 0.8 pCi/L)	0.64 pCi/L (0.01 – 1.26 pCi/L)	No Targeted Treatment
Microplastics	872 mmp/L (653 – 1090 mmp/L)	1190 mmp/L (1124 – 1257 mmp/L)	No Targeted Treatment*
PFOA	<2.0 ng/L	6.2 ng/L (5.6 – 10.4 ng/L)	No Targeted Treatment (further evaluation)
PFOS	1.9 ng/L	<1.8 ng/L	No Targeted Treatment (further evaluation)
Thallium	(<0.15 – 0.18 ug/L)	(<0.15 ug/L)	No Targeted Treatment (further evaluation)
Residual Chlorine	<0.1 mg/L	(<0.1 – 0.11 mg/L)	No Targeted Treatment (further evaluation)
Aquatic Invasive Species			Filtration down to ≤35 microns (per MnDNR Guidance)

*SPRWS modifications to ferric chloride and oxygenation system dosing to accommodate increased flows and load could help achieve these targeted treatment levels or treatment for other parameters could provide treatment for a non-targeted parameter.

1 Introduction

1.1 White Bear Lake Comprehensive Planning Study

The Metropolitan Council Environmental Services (MCES) is leading a regional planning effort to develop a comprehensive drinking water management plan to help ensure that communities in the White Bear Lake area have access to sufficient, safe drinking water to allow for municipal growth while simultaneously safeguarding the sustainability of surface water and groundwater resources for future supply.

The goals of the comprehensive plan are to:

- 1) Evaluate methods for conserving and recharging groundwater in the area
- 2) Determine which existing groundwater supply wells, if converted to surface water sources, could be most effective at ensuring water supply sustainability
- 3) Identify a long-term plan for the conversion of groundwater wells to surface water sources, including governance and concept-level engineering
- 4) Include policy and funding recommendations for the conversion from groundwater supply wells to the other recommended sources, as well as local wastewater treatment and recharge
- 5) Complete the study by June 30, 2027

This regional planning effort includes numerous studies looking at water supply alternatives for the White Bear Lake area and surrounding communities.

1.2 Past Studies

The White Bear Lake Comprehensive planning project is building off of work completed in previous studies, including:

- [Feasibility Assessment of Approaches to Water Sustainability in the Northeast Metro \(Metropolitan Council, 2014\)](#)
- [Report to the Minnesota State Legislature: Concept Cost Report for Augmentation of White Bear Lake with Surface Water \(DNR, 2016\)](#)
- [DNR Analysis: Current Groundwater Use Is Sustainable But Does Affect White Bear Lake \(DNR, 2018\)](#)
- [Modeling Analyses Required by Ramsey County District Court Order 62-CV-13-2414, Parts 3.A\) and 3.C\) \(PDF\) \(DNR, 2018\)](#)
- [Conceptual Drinking Water Supply Plan: Long-term options for the East Metropolitan Area \(PDF\) \(MPCA / DNR, 2021\)](#)
- [Groundwater Model for the North and East Metro Groundwater Management Area \(DNR, n.d.\)](#)
- [Forecast Methodology for the White Bear Lake Area Communities \(Metropolitan Council, 2025\)](#)

For additional information, see the [White Bear Lake Comprehensive Plan Work Group website](#).

1.3 Study 7A Surface Water Quality Study

The purpose of Study 7A (the surface water quality study) is to inform a larger scope of work related to modeling the potential impacts to surface water quality that may be caused by increasing the flow of Mississippi River water through the St. Paul Regional Water Services (SPRWS) chain of lakes, which includes Charley Lake, Pleasant Lake, Sucker Lake, and East Vadnais Lake. Additionally, the study includes an evaluation of White Bear Lake. The increase in flow is being considered to augment White Bear Lake water levels and/or supplement the water supply of the 14 communities whose existing groundwater supplies are tied to White Bear Lake's water levels. The study area for Study 7A is shown in Figure 1-1.

The ultimate goal of the surface water modeling effort was to collect comprehensive water quality data to inform the identification of potential water quality parameters of concern and to develop lake water quality models that can be used to assess existing and future water quality conditions under various future use scenarios. The study will be used to provide decision support for water resource management strategies related to lake treatment and augmentation.

The Study 7A scope included several main tasks that were completed in three (3) phases, listed below and summarized in the following report.

Phase 1 Data Review and Goal Setting

Task 1: Water Quality Data Review and Monitoring Recommendations

Task 2: Identify Water Quality Goals and Standards for Surface Waters and Drinking Water

Task 3: Recommendations for Revisions to Task Order 7A Scope

Phase 2 Water Quality Analysis

Task 1: Laboratory Analysis

Task 2: Laboratory Data QC Review and EQUIS Database Entry

Phase 3 Surface Water Quality Analysis

Task 1: Management, Data Collection, and Review

Task 2: Projected Community Water Demands Review

Task 3: Water Quality Goals

Task 4: Watershed Modeling

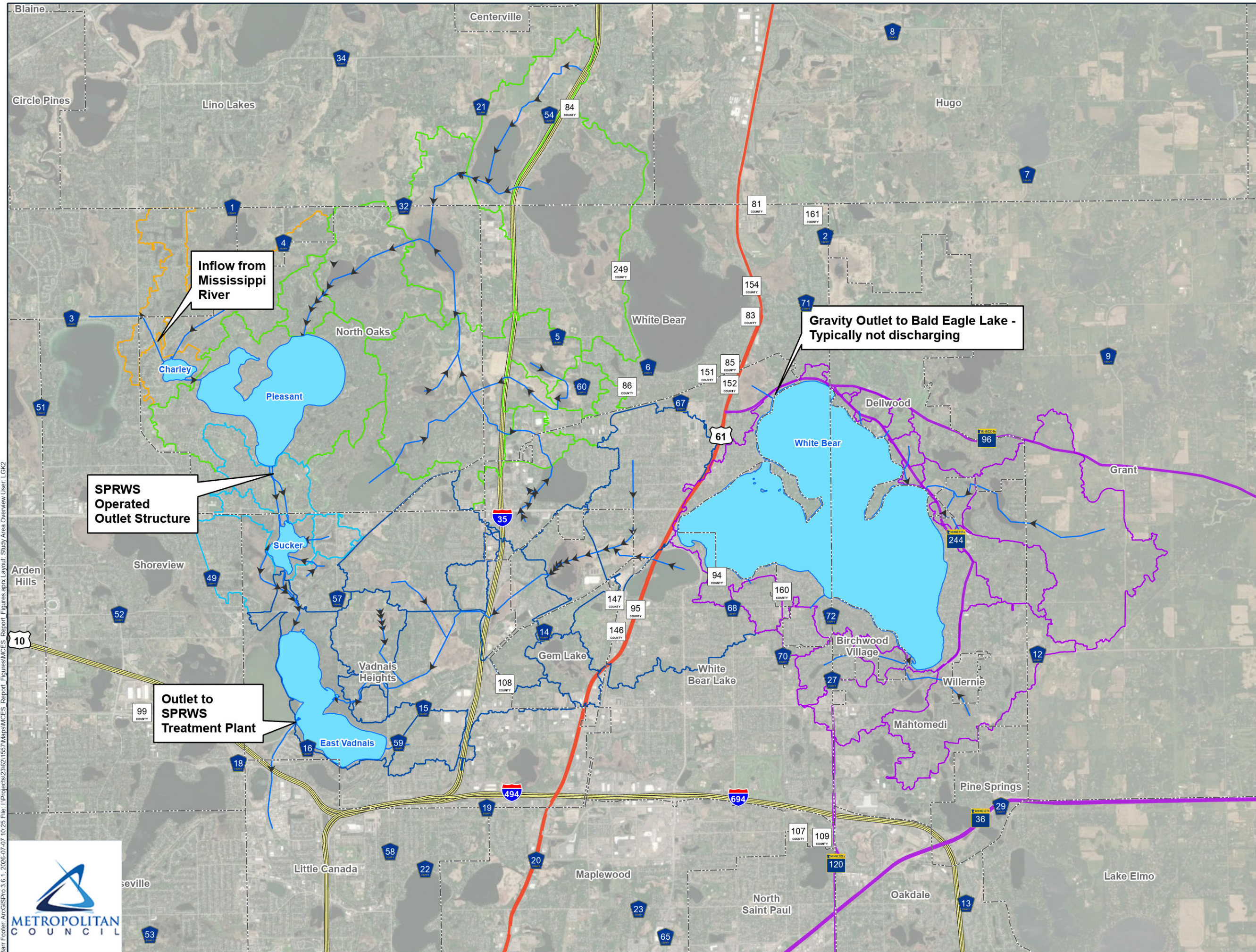
Task 5: Surface Water Quality Modeling and Analysis

Task 6: Risk Assessment

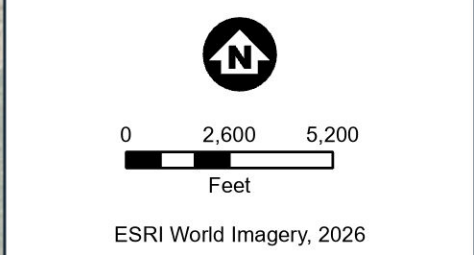
Task 7: Mitigation Plan

Task 8: Reporting

Task 9: Public Outreach



- Municipal Boundary
- Study Lakes
- Flowlines
- Subwatersheds
 - Charley
 - Pleasant
 - Sucker
 - East Vadnais
 - White Bear Lake
- Streets and Highways
 - Interstate Highway
 - US Highway
 - State Trunk Highway



Study Area Overview
MCES White Bear
Lake Study 7A

FIGURE 1-1

BARR

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2 Data Collection

The following section summarizes the data compiled and collected to support the development of the surface water quality modeling and analysis, considering increased flow of Mississippi River water flow through the SPRWS chain of lakes, reflecting existing and future water supply scenarios, and the potential for augmentation of White Bear Lake water levels. To support this effort, relevant datasets were compiled to inform modeling and analysis of potential water quality impacts associated with lake level augmentation and water supply supplementation scenarios.

This includes the following data sets:

- Water Quality (historic and 2025 data)
- LiDAR Topography
- Lake Bathymetry
- Lake Levels
- Mississippi River – Fridley Pumping Rates/Volumes
- Ferric Chloride and Oxygen Dosing
- Climate and Precipitation Data
- Storm Sewer and Water Body Outlet Information
- Subwatersheds (as available from other organizations and agencies)
- Lake Storage and Hydraulic Rating Curves
- Groundwater Augmentation Flow Rates
- Project Community Water Demands
- Macrophyte/Aquatic Plant Data
- Aquatic Invasive Species
- Fisheries Data
- Zooplankton

2.1 Historic Data & Review

As part of the first phase of the work, Barr reviewed the historical water quality data and studies for the Mississippi River, the SPRWS chain of lakes (which includes Charley Lake, Pleasant Lake, Sucker Lake, and East Vadnais Lake), and White Bear Lake. The intent of this review was to assess the adequacy of the historical monitoring data for modeling purposes and other technical analysis anticipated for the next

phase of work, inform recommendations for the 2025 monitoring programs, and support revisions to the Task Order 7A Phase 2 scope of work.

The waterbodies included in this study are routinely monitored by multiple agencies, and existing datasets formed the foundation of the Phase 1 data review. The list below is a high-level summary of information available, categorized by organization supplying the data. The following sections provide additional summaries of the available data:

SPRWS

Water Quality (Mississippi River, Pleasant Lake, East Vadnais)

Lake Level (Pleasant Lake, East Vadnais)

Pumping from the Mississippi River

Ferric Chloride Dosing (Mississippi River, East Vadnais)

Oxygenation System Dosing (Pleasant Lake, East Vadnais)

Outlet/Rating Curve Information (Pleasant Lake, East Vadnais)

Vadnais Lake Area Watershed Management Organization (VLAWMO)

Water Quality (basic lake eutrophication parameters (Charley Lake, Pleasant Lake, Sucker Lake, and East Vadnais Lake)

Bathymetric data (Charley Lake, Pleasant Lake, Sucker Lake, and East Vadnais Lake)

Macrophyte/Aquatic Plant Survey (Charley Lake, Pleasant Lake, Sucker Lake, and East Vadnais Lake)

Ramsey County Public Works (RCPW)

Water quality (White Bear Lake)

Zooplankton/Phytoplankton (White Bear Lake)

MCES

Water Quality (Mississippi River)

Minnesota Department of Natural Resources (MnDNR)

Aquatic Invasive Species infestation/status

Fisheries Data

White Bear Lake Rating Curve

Lake Level Data (as available for MnDNR Lake Finder)

Where available, historical data was leveraged from the MPCA's public water quality database for the monitoring stations that align with the locations of the SPRWS and VLAWMO monitoring stations (Table 2-1).

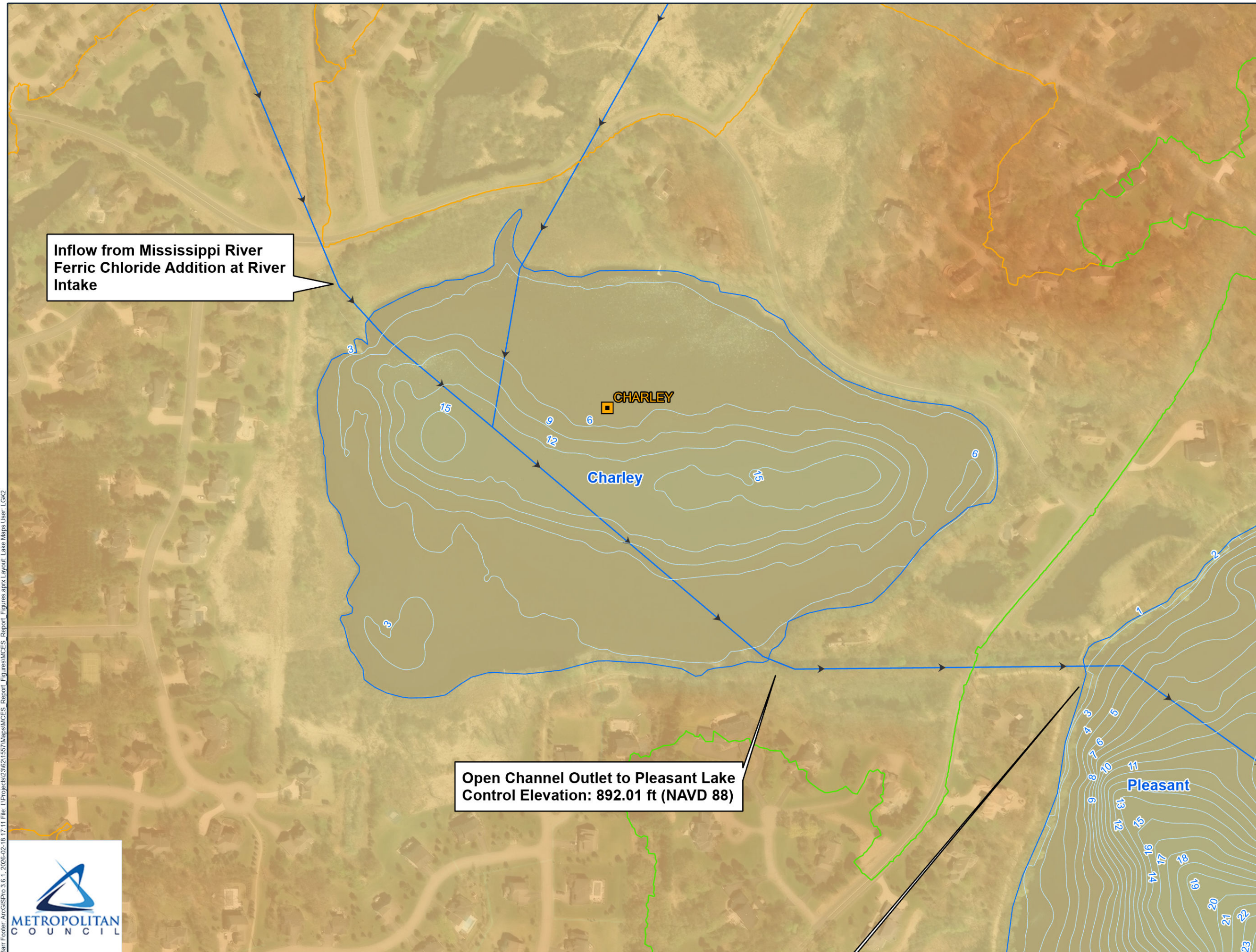
Additional datasets not available through the MPCA were provided directly by SPRWS and other participating agencies.

Table 2-1 Water Quality Station Summary from Study Lakes

Station	Agency
MISSISSIPPI RIVER FRIDLEY	SPRWS/MCES
CHARLEY	VLAWMO
PLEASANT EAST	SPRWS
PLEASANT WEST	SPRWS
PLEASANT VLAWMO	VLAWMO
SUCKER NORTH	SPRWS
SUCKER SOUTH	VLAWMO
EAST VADNAIS NORTH	SPRWS
EAST VADNAIS SOUTH	SPRWS
EAST VADNAIS VLAWMO	VLAWMO
WHITE BEAR LAKE 229	RCPW
WHITE BEAR LAKE 230	RCPW
WHITE BEAR LAKE 231	RCPW
WHITE BEAR LAKE 234	RCPW

Maps showing the available spatial data compiled for each study lake, including topography, subwatersheds, general flow patterns, bathymetry, monitoring locations, ferric chloride and oxygen system additions (if applicable), and outlet locations and control elevations are summarized in Figure 2-1 through Figure 2-5. These figures are ordered from upstream to downstream through the SPRWS chain of lakes system, followed by White Bear Lake.

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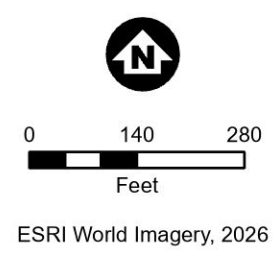


Inflow from Mississippi River
Ferric Chloride Addition at River
Intake

Open Channel Outlet to Pleasant Lake
Control Elevation: 892.01 ft (NAVD 88)



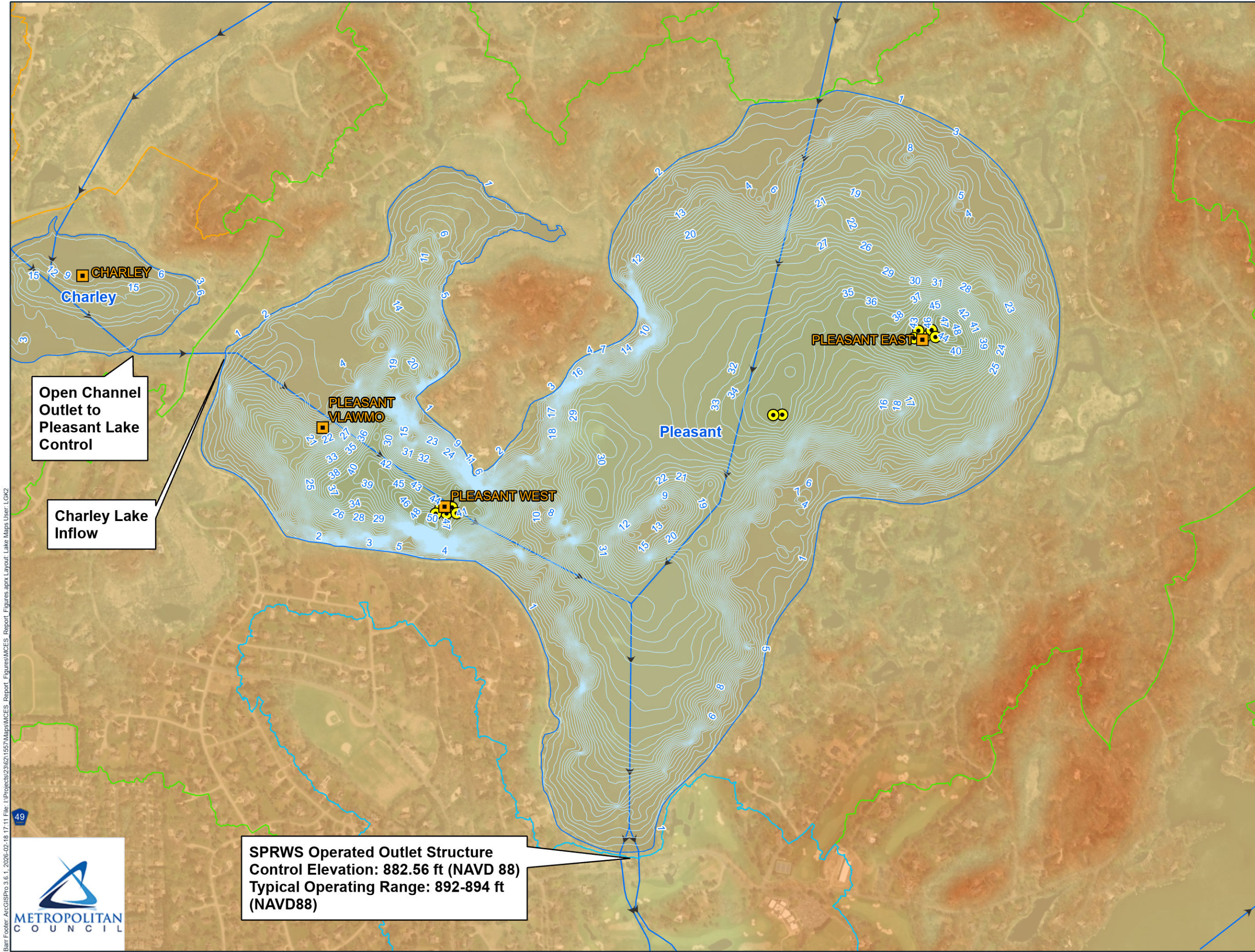
- Study Lakes
- Surface Water Quality Monitoring Stations (Approx)
- Bathymetry (feet)
- Flowlines
- Subwatersheds**
 - Charley
 - Pleasant
 - Sucker
 - East Vadnais
 - White Bear Lake
- Elevation (NAVD88, USft)**
 - 1103
 - 635



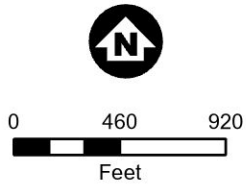
Charley Lake
MCES White Bear
Lake Study 7A

FIGURE 2-1





- Study Lakes
- Surface Water Quality Monitoring Stations (Approx)
- Oxygen Injection Locations
- Bathymetry (feet)
- Flowlines
- Subwatersheds
 - Charley
 - Pleasant
 - Sucker
 - East Vadnais
 - White Bear Lake
- Elevation (NAVD88, USft)
 - 1103
 - 635



ESRI World Imagery, 2026

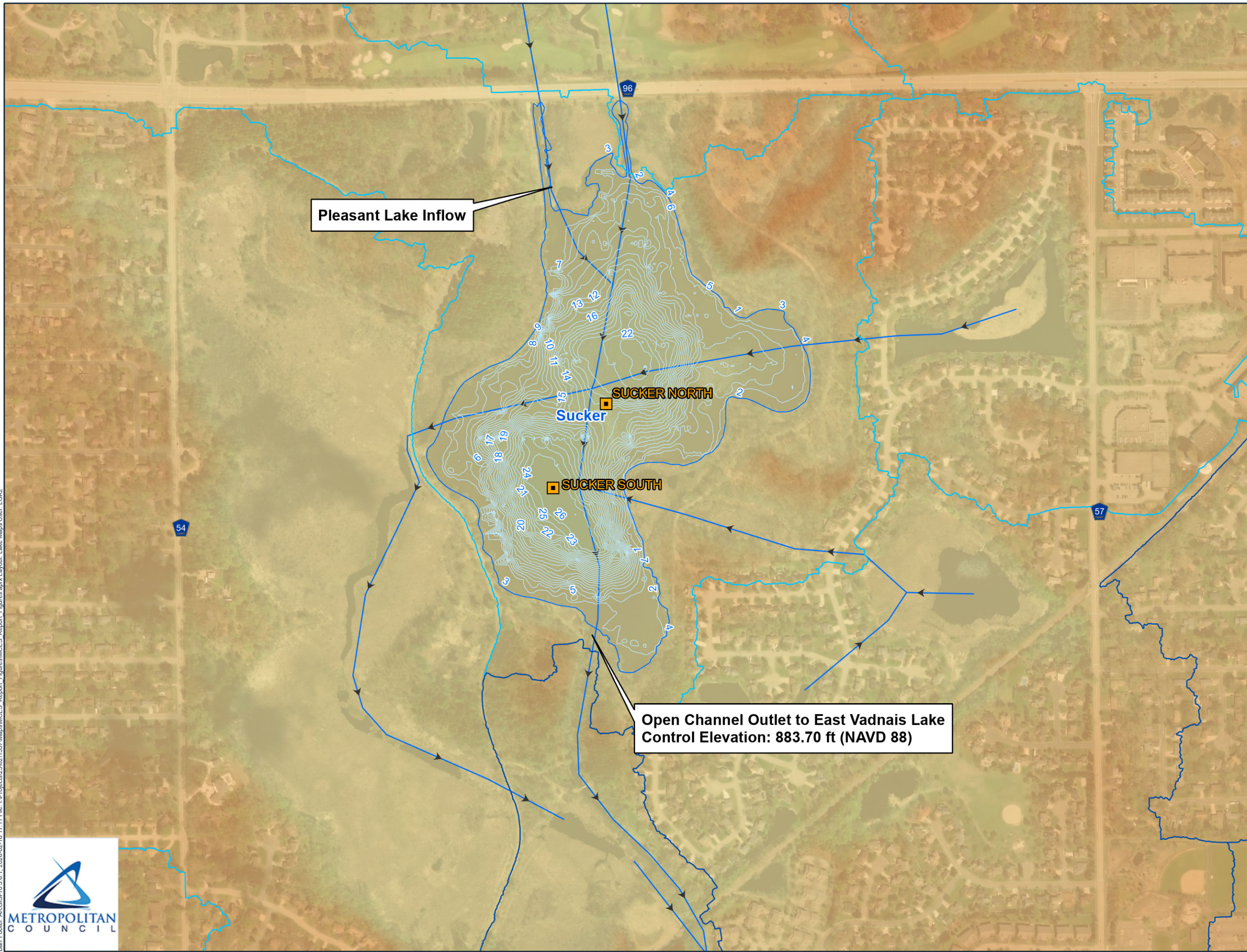
Pleasant Lake
MCES White Bear
Lake Study 7A

FIGURE 2-2

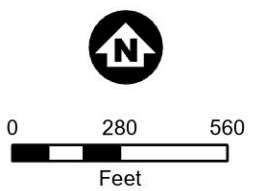


SPRWS Operated Outlet Structure
Control Elevation: 882.56 ft (NAVD 88)
Typical Operating Range: 892-894 ft (NAVD88)

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- Study Lakes
- Surface Water Quality
- Monitoring Stations (Approx)
- Bathymetry (feet)
- Flowlines
- Subwatersheds**
 - Charley
 - Pleasant
 - Sucker
 - East Vadnais
 - White Bear Lake
- Elevation (NAVD88, USft)**
 - 1103
 - 635



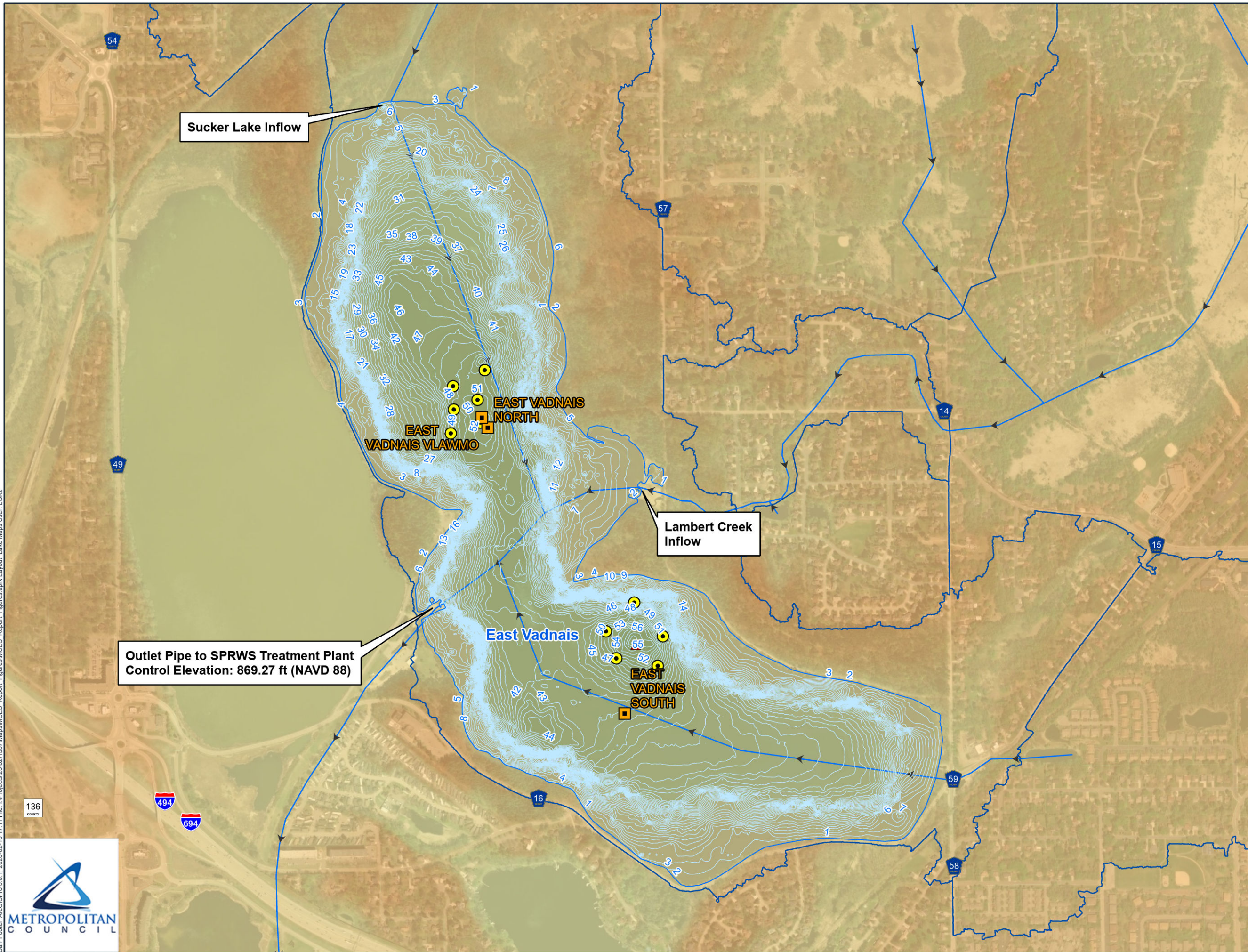
ESRI World Imagery, 2026

Sucker Lake
MCES White Bear
Lake Study 7A

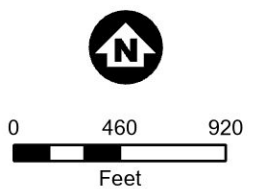
FIGURE 2-3



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- Study Lakes
- Ferric Chloride
- Surface Water Quality Monitoring Stations (Approx)
- Ferric Chloride and Oxygen Injection Locations
- Bathymetry (feet)
- Flowlines
- Subwatersheds**
 - Charley
 - Pleasant
 - Sucker
 - East Vadnais
 - White Bear Lake
- Elevation (NAVD88, USft)**
 - 1103
 - 635



ESRI World Imagery, 2026

East Vadnais Lake
MCES White Bear
Lake Study 7A

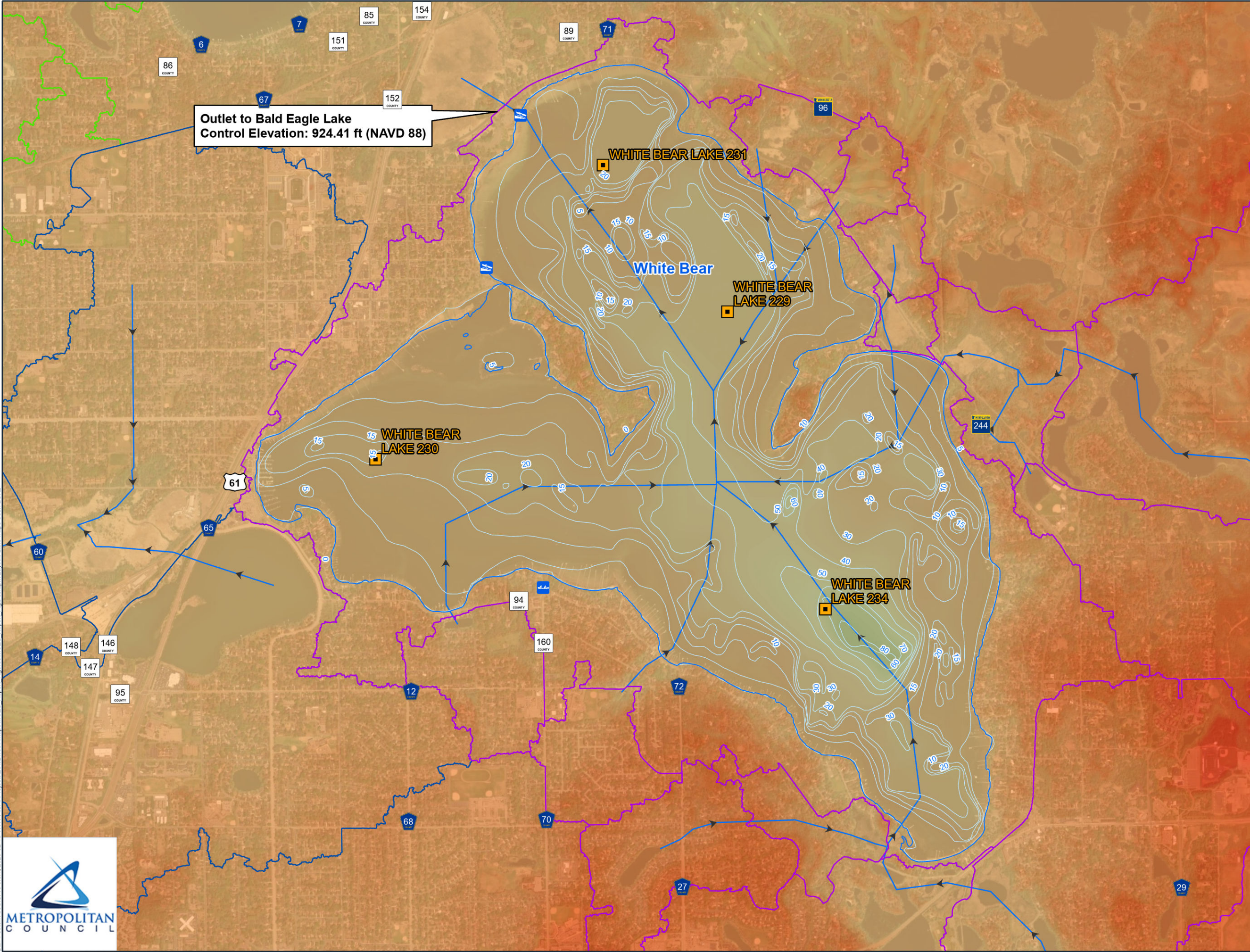
FIGURE 2-4



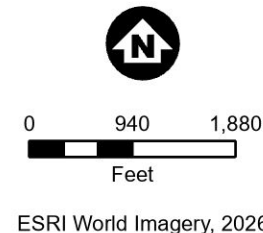
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COUNTY



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- Study Lakes
- Surface Water Quality
- Monitoring Stations (Approx)
- Bathymetry (feet)
- Flowlines
- Water Access Sites**
 - Carry-in
 - Trailer Launch
- Subwatersheds**
 - Charley
 - Pleasant
 - Sucker
 - East Vadnais
 - White Bear Lake
- Elevation (NAVD88, USft)**
 - 1103
 - 635



White Bear Lake
MCES White Bear
Lake Study 7A

FIGURE 2-5



2.2 2025 Monitoring Plan

The 2025 monitoring plan was developed for the study waterbodies to supplement existing datasets and monitoring parameters typically collected by VLAWMO, SPRWS, and RCPW, and address key data gaps identified during the Phase 1 review.

Additional monitoring in 2025 was conducted by SPRWS, VLAWMO, and Ramsey County within their respective waterbodies. In general, based on the information provided by the MCES related to the 2025 monitoring program, it was assumed that current monitoring organizations would sample the same parameters, frequency, and depth as collected in 2024 as part of their routine monitoring efforts and that samples for additional water quality parameters would augment the standard monitoring programs to provide a more comprehensive look at water quality for Study 7A.

Generally, the water quality parameters being monitored could be grouped into several major categories, including:

- Eutrophication and key model input parameters
- Metals, including those that have historically been monitored and those with corresponding drinking water standards
- Anthropogenic Synthetic Organic Chemicals, including:
 - Pesticides
 - PCBs
 - PAHs,
 - PFAS (PFOA, PFOS, PFBS, PFHxS, PFNA, GenX (EPA PFAS hazard index chemicals)
- Other synthetic organic chemicals of variable composition (e.g., other endocrine disruptors, microplastics, etc.)

The 2025 monitoring plan was created through coordination with participating agencies and based on the needs of the modeling and other technical analysis anticipated for the study, as well as the following input gathered through this Phase 1 process:

- Stakeholder and agency meeting on 4/10/2025 - agencies provided input of contaminants of concern, existing monitoring programs, and staff capabilities for additional sampling requirements
- Follow-up meetings with monitoring agency staff on 4/17/2025 and 4/18/2025
- The subworkgroup meeting on 4/22/2025
- Meeting with MDH laboratory staff on 4/25/2025 and follow-up correspondence
- The work group meeting on 4/29/2025
- Numerous email and phone correspondence with RMB Laboratories and Pace Analytical regarding the laboratory capacity, methods, and testing costs

- Review and feedback on the draft monitoring plan by the three monitoring organizations as emailed out on 5/8/2025, reflecting any follow-up comments received from monitoring organizations and analytical laboratories through 5/27/2028

A meeting was held on 4/10/2025 with stakeholders and agency staff to discuss the study, goals, preliminary recommendations for 2025 monitoring, and conversation around any specific concerns, parameters, or questions the various organizations might have as it relates to Study 7A. The intent of this feedback was to inform the 2025 monitoring recommendations and recommended revisions to the Phase 2 scope of work. Feedback from the 4/10/2025 stakeholder and agency meeting indicated concern about the impact of all types of pollutants on increased flow through the chain of lakes and on White Bear Lake, with augmentation on both water quality and ecology. Nine (9) feedback responses were received; however, this feedback did not call out specific parameters of concern or emerging contaminants that the study should focus on to help narrow down the focus to the 2025 monitoring program. A complete summary of the meeting minutes and the table of the input received in follow-up to the meeting is included as Appendix 1.

The following is a summary of the main agency feedback received:

- There is concern about potential water quality impacts on the chain of lakes from increased flows and the reduction in water quality in White Bear Lake and the underlying Jordan aquifer due to the presence of increased groundwater/surface water interaction near White Bear Lake (per interaction quantified during USGS study).
- Introducing new sources of contamination risk to White Bear Lake is a concern. All possible pollutants/contaminants should be considered to assess their impacts on lake health, drinking water supply, aeration system, and treatment system operations.
- Primary concerns include eutrophication parameters (P & N), but heavy metals, iron, chloride, PFAS, pharmaceuticals, and microplastics are also of concern. Lakes should be tested for all drinking water parameters to establish baseline concentrations and add any parameters that MnDNR/MDH lab can offer for contaminants of emerging concern
- Ecological concerns include increased likelihood of Harmful Algal Blooms (HABs) and the impact on SPRWS intake, introduction of new AIS genotypes (e.g. Eurasian watermilfoil [*Myriophyllum spicatum*]) and changes to food sources (chl *a*) and pH levels on the zebra mussel (*Dreissena polymorpha*) carrying capacity of White Bear Lake, changes in other non-eutrophication parameters (not related to nutrients/clarity) altering the White Bear Lake macrophyte community (water color, lake sediment chemistry)
- Numerous questions arose about the level of treatment required: What is the impact on White Bear Lake if there were no treatment? What is the minimum level of treatment needed for augmentation water to maintain water quality and/or prevent AIS transfer? What level of water treatment (i.e., incoming concentrations) would be required to ensure zero impact to eutrophication parameters? What is the impact of adding water that is “too clean” into White Bear Lake? Watershed analysis of the VLAWMO/Chain of Lakes is important due to its significant contribution to total pumped water to SPRWS (~40% in 2024).
- Questions related to impact of increased flows on shoreline erosion, travel time from the Mississippi River to the Chain of Lakes and White Bear Lake, water residence time in each lake, reaction time for augmentation of White Bear Lake.

Based on the feedback from the agencies, in addition to the list of the parameters required for the modeling and the recommended metals, Barr compiled a list of other parameters that currently have

established drinking water standards. To help focus this effort, this initial list includes those parameters that have an established Environmental Protection Agency (EPA) Maximum Contaminant Level (MCLs) and Minnesota Department of Health (MDH) Health Risk Limits (HRL).

Additionally, there was interest in contaminants of emerging concern, including endocrine disruptors, pharmaceuticals, and microplastics, though no specific parameters were identified. In addition to the drinking water standards, we reviewed the 2018 Minnesota Pollution Control Agency (MPCA)/United States Geological Survey (USGS) study *Contaminants of emerging concern in urban stormwater: Spatiotemporal patterns and removal by iron-enhanced sand filters (IESFs)* that evaluated contaminants of emerging concern in surface water and stormwater systems in the Twin Cities metropolitan area. Based on review of this study, we considered a list of chemical parameters that were present in more than 25% of the samples collected during the study and cross-referenced that against the drinking water standard list. Although a handful of these parameters currently have EPA/MDH standards, more than 40 additional parameters were identified for possible consideration to include in the 2025 monitoring program. Barr coordinated with several analytical laboratories, including RMB Laboratories, Pace Analytical, and the MDH laboratories, to understand testing capabilities for the initial list of parameters as outlined above. Additionally, we also reached out to two other commercial labs related to the testing of cyanotoxins (Greenwater Labs) and microplastics (ALS Labs, used by the Capitol Region Watershed District (CRWD) in a recent microplastic study of several surface waters). Based on this feedback, not all of the proposed parameters were able to be tested at these laboratories, and the list of anthropogenic synthetic organic chemicals and contaminants of emerging concern was reduced to include only those that could be tested by the analytical laboratories we were coordinating with on surface water (i.e. non-drinking water) samples.

The 2025 monitoring plan was based on stakeholder input, reviewed by MCES and monitoring organizations. Surface water quality modeling needs, laboratory capabilities, monitoring staff availability, agencies' concerns, and overall project budget were evaluated to identify a monitoring plan that met study needs while remaining realistic given available resources. The primary goal of this additional monitoring was to determine which parameters are present at levels relevant to modeling and to allow for comparison of conditions across study lakes. As a result, parameters such as PFAS, drinking water–related constituents, and other emerging contaminants were monitored at a limited frequency, with two sampling events over the season. As collected, the 2025 data provide a planning-level look at possible water quality parameters of concern in the Mississippi River, the SPRWS chain of lakes, and White Bear Lake to inform the possible impact of the proposed community water demand and augmentation scenarios on surface water quality. However, we recommend that a more comprehensive monitoring program targeting select parameters, including more frequent sampling through the system, be performed to inform final design and permitting of any future projects.

A summary of the 2025 monitoring parameters included in the study is provided in Table 2-2. The complete monitoring plan is included as an Excel file in Appendix 2.

Table 2-2 Summary of 2025 Water Quality Monitoring Parameters

Category	Parameter	General Frequency
Eutrophication/Modeling Parameters	Total Phosphorus (mg/L) (Low Level)	Monthly
	Total Dissolved Phosphorus (mg/L) (Low Level; field filtered)	Monthly
	Total Dissolved Phosphorus (mg/L) (Low Level; lab filtered)	Monthly
	Ortho-P (mg/L) (field filtered)	Monthly
	Ortho-P (mg/L) (lab filtered)	Monthly
	Nitrate+Nitrite (mg/L)	Monthly
	TKN (mg/L)	Monthly
	Ammonia (mg/L)	Monthly
	Chlorophyll a (mg/L)	Monthly
	Secchi disk depth (m)	Monthly
	Turbidity (NTU)	Monthly
	Color (color units)	Monthly
	Total Suspended Solids (mg/L)	Monthly
	Total Dissolved Solids (mg/L)	Monthly
	pH (S.U.)	Monthly
	Temperature	Monthly
	Dissolved oxygen (mg/L)	Monthly
	Specific Conductance	Monthly
	Chloride (mg/L)	Monthly
	Total Organic Carbon (mg/L)	Monthly
	Dissolved Organic Carbon (mg/L) - field filtered	Monthly
	Dissolved Organic Carbon (mg/L) - lab filtered	Monthly
	Hardness (mg/L, CaCO ₃)	Monthly
	Alkalinity (mg/L)	Monthly
Phytoplankton/Cyanotoxin Testing	Phytoplankton Speciation	Monthly
	Microcystins/Nodularins	July, August, September
	Cylindrospermopsin	July, August, September
	Anatoxin-a	July, August, September
	Saxitoxins	July, August, September
Metals	Antimony (mg/L)	Monthly

Category	Parameter	General Frequency
	Arsenic (mg/L)	Monthly
	Aluminum (mg/L)	Monthly
	Barium (mg/L)	Monthly
	Beryllium (mg/L)	Monthly
	Bromide (mg/L)	Monthly
	Cadmium (mg/L)	Monthly
	Calcium (mg/L)	Monthly
	Chromium (III and VI) (mg/L)	Monthly
	Copper (mg/L)	Monthly
	Fluoride (mg/L)	Monthly
	Iron (mg/L)	Monthly
	Lead (mg/L)	Monthly
	Magnesium (mg/L)	Monthly
	Manganese (mg/L)	Monthly
	Mercury (inorganic) (mg/L)	Monthly
	Nickel (mg/L)	Monthly
	Selenium (mg/L)	Monthly
	Silver (mg/L)	Monthly
	Sulfide (mg/L)	Monthly
	Sulfate (mg/L)	Monthly
	Thallium (mg/L)	Monthly
	Zinc (mg/L)	Monthly
Bacteria	Total Coliform	Monthly
	Fecal Coliform	Monthly
	E. coli	Monthly
Viruses	Cryptosporidium	June, September
	Giardia lamblia	June, September
	Legionella	June, September
PFAS	HFPO-DA (ng/L)	June, September
	PFBS (ng/L)	June, September
	PFHxS (ng/L)	June, September
	PFNA (ng/L)	June, September
	PFOA (ng/L)	June, September
	PFOS (ng/L)	June, September
	Hazard index (HFPO-DA, PFBS, PFHxS, and PFNA)	June, September
	PFBA (ng/L)	June, September

Category	Parameter	General Frequency
Other Parameters with Drinking Water Standards	PFHxA (ng/L)	June, September
	Alachlor (mg/L)	June, September
	Aldicarb (mg/L)	June, September
	Asbestos (MFL)	June, September
	Atrazine (mg/L)	June, September
	Benzene (mg/L)	June, September
	Benzo(a)pyrene (PAHs)(mg/L)	June, September
	Bromate (mg/L)	June, September
	Bromodichloromethane (mg/L)	June, September
	Bromoform (mg/L)	June, September
	Carbofuran (mg/L)	June, September
	Carbon tetrachloride (mg/L)	June, September
	Chloramines (as Cl ₂) (mg/L)	June, September
	Chlordane (mg/L)	June, September
	Chlorine (as Cl ₂) (mg/L)	June, September
	Chlorine dioxide (as ClO ₂) (mg/L)	June, September
	Chlorobenzene (mg/L)	June, September
	Chloroform (mg/L)	June, September
	2,4-D (mg/L)	June, September
	Dalapon (mg/L)	June, September
	1,2-Dibromo-3-chloropropane (DBCP) (mg/L)	June, September
	o-Dichlorobenzene (mg/L)	June, September
	p-Dichlorobenzene (mg/L)	June, September
	1,2-Dichloroethane (mg/L)	June, September
	1,1-Dichloroethylene (mg/L)	June, September
	cis-1,2-Dichloroethylene (mg/L)	June, September
	trans-1,2-Dichloroethylene (mg/L)	June, September
	Dichloromethane (mg/L)	June, September
	1,2-Dichloropropane (mg/L)	June, September
	Di(2-ethylhexyl)adipate (mg/L)	June, September
	Di(2-ethylhexyl)phthalate (mg/L)	June, September
	Dinoseb (mg/L)	June, September
	Dioxin (2,3,7,8-TCDD) (mg/L)	June, September
	Endothall (mg/L)	June, September
	Endrin (mg/L)	June, September
	Ethylbenzene (mg/L)	June, September

Category	Parameter	General Frequency
	Ethylene dibromide (mg/L)	June, September
	Glyphosate (mg/L)	June, September
	Haloacetic acids (HAA5) (mg/L)	June, September
	Heptachlor (mg/L)	June, September
	Heptachlor epoxide (mg/L)	June, September
	Hexachlorobenzene (mg/L)	June, September
	Hexachloro-cyclopentadiene (mg/L)	June, September
	Lindane (mg/L)	June, September
	Methoxychlor (mg/L)	June, September
	Oxamyl (Vydate) (mg/L)	June, September
	Pentachlorophenol (mg/L)	June, September
	Picloram (mg/L)	June, September
	Polychlorinated biphenyls (PCBs) (mg/L)	June, September
	Simazine (mg/L)	June, September
	Styrene (mg/L)	June, September
	Tetrachloroethylene (mg/L)	June, September
	Toluene (mg/L)	June, September
	Total Trihalomethanes (TTHMs) (mg/L)	June, September
	Toxaphene (mg/L)	June, September
	2,4,5-TP (Silvex) (mg/L)	June, September
	1,2,4-Trichlorobenzene (mg/L)	June, September
	1,1,1-Trichloroethane (mg/L)	June, September
	1,1,2-Trichloroethane (mg/L)	June, September
	Trichloroethylene (mg/L)	June, September
	Vinyl chloride (mg/L)	June, September
	Xylenes (total) (mg/L)	June, September
	Alpha particles (pCi/L)	June, September
	Beta particles and photon emitters (millirems per year)	June, September
	Radium 226 and Radium 228 (combined, pCi/L)	June, September
	Uranium (ug/L)	June, September
Other Contaminants of Emerging Concern	Metolachlor	June, September
	Isophorone	June, September
	Prometon	June, September
	Pyrene	June, September
	Acetochlor	June, September
	Fluoranthene	June, September

Category	Parameter	General Frequency
	Dimethenamid	June, September
	Phenanthrene	June, September
	Propazine	June, September
	Triclopyr	June, September
	Carbazole	June, September
Microplastics	Microplastics	June, September

Ultimately, the first round of sampling was conducted by monitoring organizations starting the week of May 19, 2025, and included the lakes; the SPRWS sampling at the Mississippi River was already completed before this plan was finalized, so the first complete round of sampling at the river was conducted in June 2025. The dates of the samples collected varied from water body to water body, depending on the sampling collection schedule by each monitoring organization (e.g., all samples may have been collected in May, but not necessarily on the same date). Sampling occurred at the frequency outlined in the monitoring plan, with the last samples being collected in October 2025.

2.3 Elevation and Bathymetric Data

Bathymetric contours for most study lakes were obtained from VLAWMO, while bathymetry for White Bear Lake was sourced from the Minnesota Department of Natural Resources' (MnDNR) statewide database. Table 2-3 summarizes the data sources and survey dates used in the study. Bathymetry data were combined with surface elevations sourced from Anoka, Ramsey, and Washington counties' 2022 USGS LiDAR to create a complete elevation surface that can be leveraged for watershed and lake model development.

Table 2-3 Bathymetry Data Sources for Study Lakes

Lake	Source	Year Collected
Charley	VLAWMO	2017
Pleasant	VLAWMO	2023
Sucker	VLAWMO	2020
East Vadnais	VLAWMO	2020
White Bear Lake	MnDNR	1978

2.4 Lake Level Data

All historic lake level data through 2025 was compiled from multiple sources, including MnDNR Lake Finder and by request from SPRWS. Lake level data was converted to vertical datum NAVD88 to be used in watershed and surface water quality modeling. In 2025, SPRWS staff monitored elevations in Charley, Pleasant, Sucker, and East Vadnais for additional data to be used in these modeling efforts. White Bear

Lake 2025 lake level data was available from the MnDNR Lake Finder. The 2025 elevation data (in feet NAVD88) is shown in Figure 2-6.

Water levels in Charley Lake track similarly to Pleasant Lake and are influenced by Pleasant Lake downstream if above the control elevation of the Charley Lake outlet channel. Similarly, Sucker Lake water levels track similarly to East Vadnais Lake levels, again, often being influenced by the downstream lake.

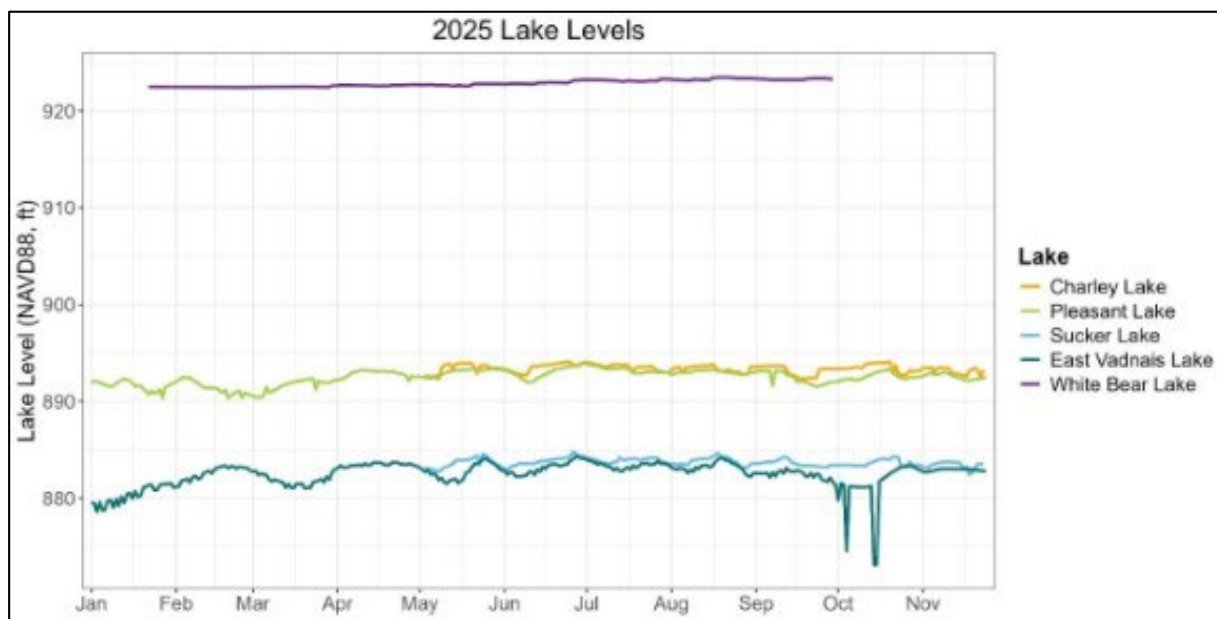


Figure 2-6 2025 Lake Elevations

2.4.1 Long Term Water Level Fluctuations

Additionally, Barr reviewed all available water level data for the study water bodies. A water level summary with elevations presented in feet NAVD88 is available in Table 2-4, including the control elevation, Ordinary High Water Level (OHWL), minimum, average, and maximum water levels, the range in water level fluctuations (between minimum and maximum water levels), and the typical operating range (as applicable to Pleasant Lake).

Table 2-4 Water Level Summary for Study Lakes

Lake	Control Elevation (ft)	OHWL	Min WSEL	Min WSEL Year	Average WSEL	Max WSEL	Range in Water Level Fluctuation (ft)	SPRWS Typical Operating Range (ft)
Charley	892.01	895.0	892.3	2025	893.4	894.0	1.7	
Pleasant	882.56	893.9	889.6	2021	892.7	894.4	4.8	892 - 894
Sucker	883.70	884.3	881.2	1987	883.7	884.8	3.6	
East Vadnais	869.27	Not Listed by MnDNR	873.0	2021	882.6	885.7	12.7	
White Bear Lake	924.41	924.9	918.8	2013	923.1	926.7	7.9	

2.5 Mississippi River – Fridley Pumping Data

SPRWS manages the pumping station located on the Mississippi River at Fridley to pump water from the Mississippi River into the chain of lakes. The outfall from the river pumping system first discharges into Charley Lake at the northwest corner of the lake.

SPRWS-provided monthly total pumping volumes were available from 2015 through February 2025, and daily totals were available from February through November 2025. Annual pumping totals are shown in Figure 2-7. The total annual volume for 2025 does not include December pumping.

Based on the 2015-2025 pumping data from SPRWS, the average daily pumping rate was 28.0 MGD (ranging from 0 MGD to 67.6 MGD). The average daily pumping rate during the growing season (June through September) is 34.6 MGD (ranging from 0 MGD to 61.4 MGD). The daily pumping totals from the Mississippi River at Fridley for 2025 were converted to the appropriate flow units for use in the lake modeling.

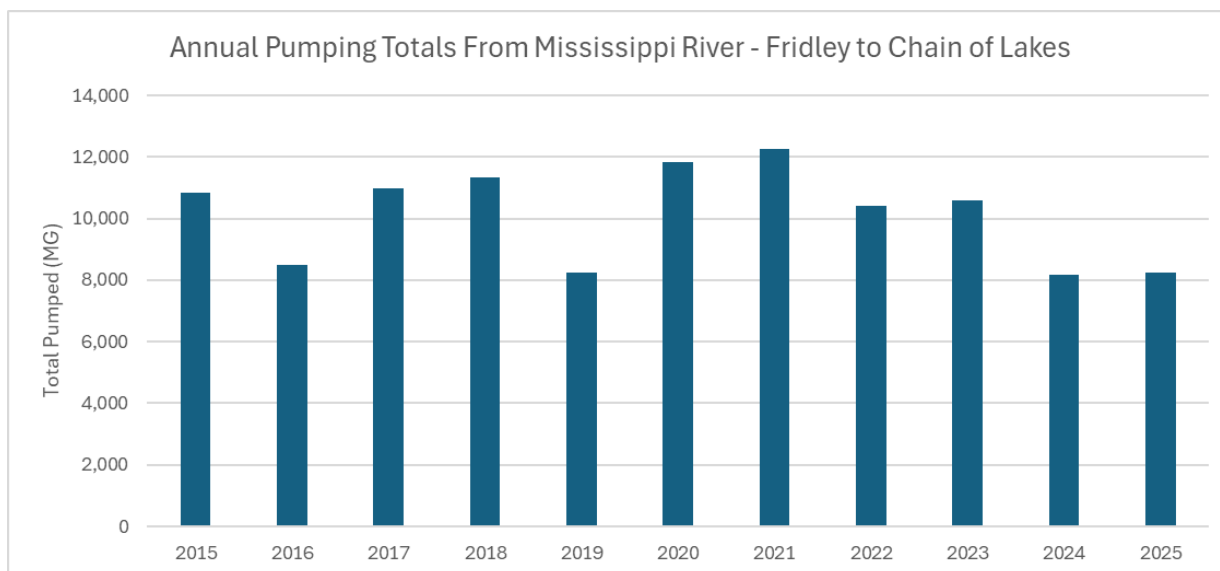


Figure 2-7 Annual Pumping Totals from Mississippi River – Fridley to Chain of Lakes

2.6 Ferric Chloride, Oxygen, and Copper Sulfate Injection Systems

SPRWS operates multiple water quality treatment injection systems that are present throughout the SPRWS chain of lakes, including liquid oxygen, ferric chloride, and copper sulfate.

2.6.1 Oxygen Injection System

Liquid oxygen injection systems are present at three locations in Pleasant Lake and two locations in East Vadnais. Pure oxygen is pumped into deep holes (hypolimnion) within these lakes with the goal of controlling internal phosphorus loading by maintaining oxic conditions at the sediment-water interface, which limits the release of phosphorus from sediments under reducing conditions. Per design information provided by SPRWS, the target is to maintain hypolimnetic oxygen concentrations of 5 mg/L or greater. These systems are operated year round.

In June 2025, Moberly Engineering performed inspection and maintenance work on both the Pleasant Lake and East Vadnais Lake Oxygen Injection System for SPRWS. On Pleasant Lake, this included hose replacement, cleaning of clogged diffuser orifices, and repair to the oxygen supply line near the shoreline, suggesting that oxygen was not being fed into Pleasant Lake hypolimnion during that time. In East Vadnais, work included replacing anchors and areas of corrosion (due to FeCl feed) and hose replacement.

Chemical and system specifications were provided by SPRWS along with injection records from 2015 to 2025. For Pleasant Lake, the monthly long-term average dosing is about 78,000 pounds per month (ranging from 40 to 224,400 pounds per month). For East Vadnais Lake, the monthly long-term average dosing is about 53,000 pounds per month (ranging from 3,600 to 255,000 pounds per month). The 2025 monthly dosing data is summarized in Table 2-5.

Table 2-5 2025 Oxygen System Dosing

Month	Pleasant Lake (lbs)	East Vadnais (lbs)
January	47,504	67,476
February	45,071	Error
March	46,782	4,056
April	45,375	38,156
May	33,194	47,081
June	64,609	42,961
July	60,749	87,353
August	Error	Error
September	208,048	67,233
October	42,588	480
November	15,833	43,202
December	No data	

2.6.2 Ferric Chloride System

Ferric chloride (FeCl) liquid injection systems are present at the Fridley pumping station along the conveyance from the Mississippi River to Charley Lake and alongside the oxygen injection system in the two deep basins of East Vadnais. These injection systems function as nutrient-binding and flocculating agents for drinking water management.

Dosing at the river operates April through October is typically based on the pumping flow rates as well as rain events and total phosphorus/orthophosphorus concentrations at the river, targeting a ferric dose of 0.3 to 2.5 ppm. Dosing at East Vadnais is similar to the river with a similar operating season and dosing related to flow rates at the river with a slightly higher dosing target of 0.3 to 4.0 ppm, that is also influenced by oxygen dosing, total phosphorus/orthophosphorus, and algal toxin levels.

In June 2025, Moberly Engineering performed inspection and maintenance work on the East Vadnais Lake ferric chloride system that included replacing anchors and areas of corrosion (due to FeCl feed) and hose replacement.

Data was provided by SPRWS and included chemical specifications as well as injection records from 2015 to 2025. For the Mississippi River, the long term monthly average dosing is about 7,000 pounds per month (ranging from 0 to 42,000 pounds per month). For East Vadnais Lake, the long term monthly average dosing is about 13,000 pounds per month (ranging from 0 to 52,000 pounds per month). The 2025 data is summarized in Table 2-6.

Table 2-6 2025 Ferric Chloride Dosing

Month	Mississippi River - Fridley (lbs)	East Vadnais (lbs)
January	10,010	1,154
February	0	218
March	0	1,247
April	0	0
May	Error	Error
June	14,570	1,558
July	39,310	18,244
August	Error	10,662
September	Error	26,960
October	12,866	17,224
November	3,797	1,496
December	No data	

2.6.3 Copper Sulfate

Finally, copper sulfate has been used in East Vadnais gatehouse to control the infestation and spread of zebra mussels, an aquatic invasive species (AIS). Dosing data was provided by SPRWS and typically occurs from April through October, with a targeted concentration of 0.06 to 0.12 ppm as Copper. Copper sulfate has been used at East Vadnais Lake from 2016 to 2021 and in 2023. Per the data provided, SPRWS did not use copper sulfate in East Vadnais in 2024 or 2025.

Pleasant Lake has also been dosed with copper sulfate but there is no permanent dosing system installed at the outlet gatehouse. There is not a consistent treatment program at this location. A temporary system is set-up, but usage is variable based on trial permits from the state of Minnesota.

2.7 Climate Data

Hourly climate data were required to support both watershed and surface water modeling as part of this study. This included precipitation data as well as the following other climatic parameters:

- Air temperature
- Relative humidity
- Dew point
- Atmospheric pressure
- Cloud cover
- Wind speed
- Wind direction

2.7.1 Precipitation

Precipitation data for the 2024–2025 period were obtained from the Midwestern Regional Climate Center (MRCC). A network of climate stations surrounding the study area was reviewed (Figure 2-8) considering location, data resolution (hourly vs. daily), etc.

Ultimately, hourly precipitation data were sourced from the Minneapolis-St. Paul International Airport (MSP) station, while daily precipitation data from surrounding local stations were used to adjust the hourly record to produce similar total precipitation depths as the local gages. Local gages were selected based on proximity to the study area and completeness of the data record. Monthly precipitation totals from four local stations (White Bear Lake 1.7 S, White Bear Lake 2.6 W, Falcon Heights 0.8 NE, and University of MN St. Paul) were averaged and used to adjust the hourly MSP precipitation data for local climate conditions (locally adjusted).

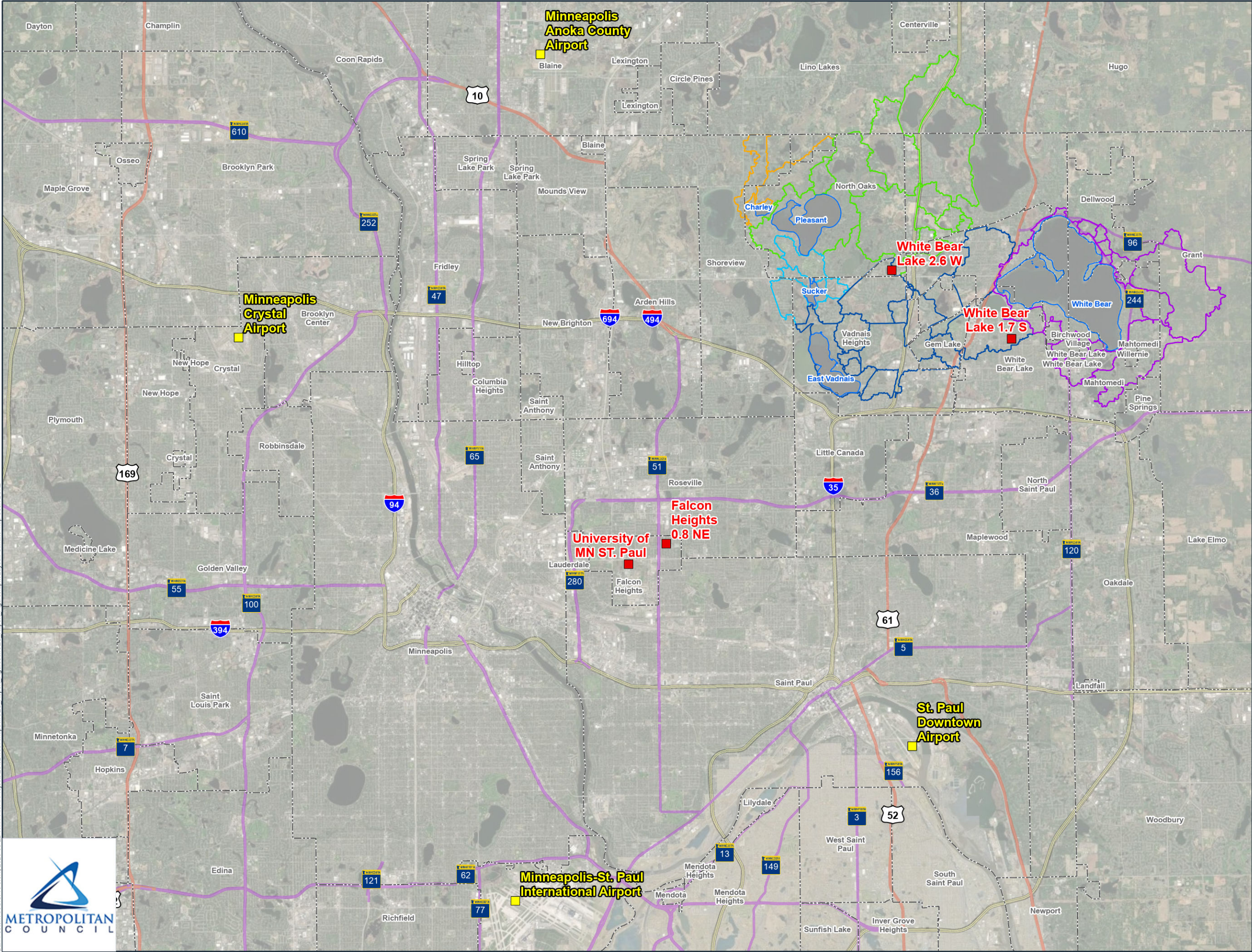
Annual precipitation totals of the hourly precipitation for the study area are summarized in Table 2-7.

Table 2-7 Annual Precipitation Totals for P8 Models

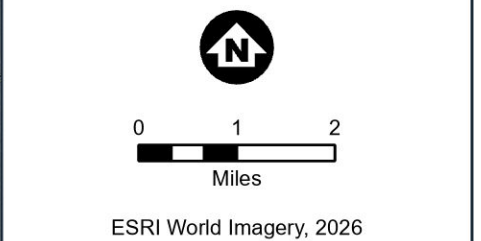
Year	Total Annual Precipitation (in)	
	MSP	Locally Adjusted
2024	36.5	38.0
2025 ¹	28.1	33.8

[1] 2025 data only includes dates up to 12/1/2025.

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- Municipal Boundary
- Study Lakes
- Subwatersheds
 - Charley
 - Pleasant
 - Sucker
 - East Vadnais
 - White Bear Lake
- Climate Data Gages
 - Daily
 - Hourly
- Streets and Highways
 - Interstate Highway
 - US Highway
 - State Trunk Highway



Climate Data Map
MCES White Bear
Lake Study 7A

FIGURE 2-8

BARR



2.7.1.1 Dry Precipitation Conditions

The MnDNR and U.S. Drought Monitor define moderate to severe drought conditions as precipitation at or below the 10th percentile of historical annual totals. Using this criterion and feedback from a meeting reviewing assumptions with MCES, SPRWS, and MnDNR staff, annual precipitation records from the MSP station were evaluated for the most recent 30-year climate period (1990–2020). This analysis identified a 10th percentile annual precipitation threshold of 25.66 inches (Table 2-8).

Following discussion with MCES, SPRWS, and MnDNR staff, recent climate years were examined to determine a year that fell near this 10th percentile. This approach allowed the use of an actual observed temporal distribution of precipitation events rather than applying a uniform scaling factor to the 2025 local precipitation data.

Annual precipitation at MSP in 2021 totaled 25.96 inches, aligning with the calculated 10th percentile threshold, and was therefore selected to represent drought conditions. This also aligns with the lowest observed water levels in both Pleasant Lake and East Vadnais Lake.

Precipitation and temperature from MSP for 2021 were used to develop “dry” climate scenario inputs for the in-lake and watershed model simulations.

Table 2-8 MSP Precipitation Percentiles from 1990-2020

Percentile	Total Annual Precipitation (in)
10 th	25.66
25 th	28.58
50 th	32.36
75 th	34.28
90 th	36.69

2.7.2 Other Climate Data

Additional climate variables were required for surface water modeling, including:

- Air temperature
- Relative humidity
- Dew point
- Atmospheric pressure
- Cloud cover
- Wind speed
- Wind direction

Wind speed and direction were used to estimate solar radiation and evaporation. Because complete records for these parameters were not available at stations closer to the study area, hourly climate data were sourced from the MSP station using the MRCC.

Following a meeting with MCES, SPRWS, and MnDNR staff regarding assumptions, MnDNR provided 2025 monthly estimates for evaporation from White Bear Lake mass transfer model using monthly water temperature data as fitted to University of Minnesota data (MnDNR, 2025; Xiao, K, 2018). This was used to inform the calibration of White Bear Lake.

2.8 Storm Sewer and Outlet Information

2.8.1 Community Request

Storm sewer information was requested from participating communities and watershed districts for incorporation into modeling processes and to help with the development of watershed divides and flow direction. Additionally, for the ponds, wetlands, and waterbodies included in the P8 watershed model, targeted outlet information was requested from the communities and watersheds. Available GIS datasets, record drawings, and as-built plans, as provided by the member communities, were reviewed and used where provided to define storm sewer networks, outlets, and associated structures.

2.8.2 Survey

Where storm sewer or outlet information was incomplete or unavailable through community and watershed district data requests, CBS² was contracted to conduct supplemental surveys of these outlets. These efforts focused on identifying and documenting missing culvert locations, sizes, inverts, outlets, and other hydraulic controls needed to most accurately capture the outlet control elevation and hydraulics for the P8 water quality model to each of the study waterbodies.

2.9 Subwatersheds

Subwatershed layers were also requested from Ramsey County, watersheds (RCWD, VLAWMO), and cities within the watersheds contributing to the study lakes. Additionally, we obtained the MnDNR watersheds for the study area.

Ultimately, these watersheds were used to verify auto-delineated subwatersheds generated during the P8 water quality modeling development (see further discussion in Section 4.1.1).

2.10 Lake Rating Curves

CBS² developed draft rating curves for the study lakes surveyed, including Charley, Pleasant, Sucker, and East Vadnais. Survey data and available drawings were used to develop HydroCAD models, which were utilized to generate lake rating curves assuming free outfall conditions and to be leveraged to develop rating curve input for the lake water quality models. Further review showed that actual lake outlet behavior is influenced by outlet operations and downstream water levels.

Charley Lake's water surface elevations and discharge conditions are influenced by Pleasant Lake outflow, as the two systems are hydraulically connected and typically exhibit similar water levels. As a result, discharge from Charley Lake is often affected by downstream conditions at Pleasant Lake.

Pleasant Lake's outlet is a gated system that is operated by SPRWS staff. The discharge rating curve was updated to reflect typical outlet operations by SPRWS, where the outlet is generally reduced to 15–25% open rather than fully open as assumed in the initial modeling. SPRWS staff adjust the outlet opening daily in response to lake water levels, trying to maintain water levels in the 892.0 – 894.0 ft (NAVD88) range. In addition, outlet performance at Pleasant Lake can be intermittently affected by screen blockage from aquatic vegetation and zebra mussels, which is estimated through the reduced outflow percentage.

Similar to how Pleasant Lake typically impacts water levels and discharge on Charley Lake, downstream control considerations apply to Sucker and East Vadnais Lakes as well. Sucker Lake water levels are typically impacted by water levels on East Vadnais. Therefore, the tailwater impacts were used to adjust rating curves for Sucker Lake.

East Vadnais Lake has a gravity pipe outlet system that drains south to the SPRWS water treatment facility, where automated valves control flow into the treatment system. These valves were recently replaced, and no information was provided on the valves' specific operations in 2025. For this study, we assumed the water levels and gravity discharge from East Vadnais Lake are under free outfall conditions and are not impacted by valve operations.

RCWD provided an XP-SWMM model of White Bear Lake that could be used to develop a discharge rating curve for White Bear Lake. Additionally, the MnDNR had a rating curve developed for White Bear Lake from past studies related to the lake. Ultimately, we leveraged an updated rating curve developed by Kimley-Horn as part of a separate study for the MCES White Bear Lake Comprehensive Planning Study. This rating curve was based on survey data and hydraulic modeling. Based on a comparison of water levels against the outlet invert elevation, White Bear Lake is typically landlocked and frequently does not experience surface discharge due to water levels remaining below the outlet structure. It has been noted that approximately 80-85% percent of White Bear Lake's outflow occurs via groundwater exchange rather than surface discharge.

2.11 Groundwater Augmentation Alignment, Flow Rates, and Exchange

Past modeling effort by the MnDNR evaluating the potential augmentation of White Bear Lake suggested that the goal of augmentation would be to leverage an augmentation system to maintain water levels on the lake at or above 922.0 ft, which would not be operating during the winter months. The 922.0 ft elevation is the MnDNR's established protective lake elevation that is required to maintain the lake's ecosystem and allow recreation. Past assessments have considered drawing augmentation from both Sucker Lake and East Vadnais via two different alignments. SEH provided the historic alignments of the augmentation pipe routes identified during the original 2016 study.

Based on the MnDNR estimated augmentation flow rate from the past groundwater modeling efforts and direction from MCES staff, the initial assumptions in the Study 7A scope of work assumed that the groundwater augmentation flow rates would be based on the estimates from MnDNR groundwater modeling and a 50% factor of safety (up to a maximum continuous pumping rate of 1,170 MGY). Over a 6-month augmentation period, this is equivalent to a daily flow rate of 6.4 MGD.

Additionally, we reviewed the storage curve based on the bathymetric data for White Bear Lake to gain an understanding of the lake's response to the proposed augmentation flow rate relative to the proposed in-lake model run period (May – October). Based on the White Bear Lake volume within one foot of the

augmentation target elevation of 922 (+/- 1 ft), the volume in the lake at that elevation is ~2300 ac-ft of storage. Taking into account evaporative and groundwater loss as well as average watershed inflows, we estimated that during the typical in-lake model run period, augmentation of White Bear Lake would need to be considered as a constant flow into White Bear Lake to help sustain water levels, especially during dry conditions.

The augmentation flow rates and the assessment of continuous pumping were reviewed with MCES, SPRWS, and MCES staff at a meeting. Based on this conversation, the estimated augmentation flow rate was revised to 780 MGY over a 6-month augmentation period. This is equivalent to a daily flow rate of 4.2 MGD. This is the augmentation flow rate that will be used during the scenario analysis evaluation. See Section 6 for further discussion of the Scenario Evaluation for additional details and information.

2.12 Project Community Water Demands

MCES provided estimates of community water demand for the three proposed future water demand scenarios for summer peak usage conditions. As provided, it is assumed that the water demand projections are reflective of the water supply flow rate anticipated from East Vadnais Lake to the SPRWS water treatment plant and not the inflow from the Mississippi River.

Barr reviewed and summarized the summer peak water demands as identified by MCES by community and for the following scenarios:

- Scenario 1: SPRWS supplies water to all communities that resulted in the highest projected water demands with treated surface water (no White Bear Lake augmentation)
 - A: Existing Conditions
 - B: 2050
 - C: Ultimate
- Scenario 2: SPRWS supplies water to its own customers only and augmentation of White Bear Lake from Sucker Lake (surrounding communities remain on groundwater supplies)
 - A: Existing Conditions
 - B: 2050
 - C: Ultimate
- Scenario 3: SPRWS supplies water to its own customers only and augmentation of White Bear Lake from East Vadnais Lake (surrounding communities remain on groundwater supplies)
 - A: Existing Conditions
 - B: 2050
 - C: Ultimate

The water users included in Scenario 1 are listed below:

- SPRWS

- Mahtomedi
- North Oaks
- North St. Paul
- Saputo Dairy Foods
- Shoreview
- Vadnais Heights
- White Bear Lake
- White Bear Township (north and south systems)
- Lake Elmo

The average daily and average peak summer usage for each scenario by community are summarized in Table 2-9. The average daily and average peak summer usage for each scenario, along with the estimated daily augmentation flow rate, are summarized in Table 2-10.

Table 2-9 Daily Summer Peak Water Demand Summary by Community and Scenario

Community	A - Existing Daily Demand			B - 2050 Daily Demand			C - Ultimate Daily Demand		
	Annual Average Daily Usage (gallons/day)	Average Peak Summer Daily Usage (gallons/day)	Summer Peaking Factor	Annual Average Daily Usage (gallons/day)	Average Peak Summer Daily Usage (gallons/day)	Summer Peaking Factor	Annual Average Daily Usage (gallons/day)	Average Peak Summer Daily Usage (gallons/day)	Summer Peaking Factor
SPRWS	39,662,223	49,704,733	1.25	44,886,944	56,252,358	1.25	47,126,725	59,059,254	1.25
Mahtomedi	650,879	1,026,768	1.58	879,671	1,387,690	1.58	1,011,044	1,594,932	1.58
North Oaks	0	0		1,566,411	2,407,369	1.54	1,566,411	2,407,369	1.54
North St. Paul	1,002,947	1,309,079	1.31	1,059,809	1,383,298	1.31	1,059,809	1,383,298	1.31
Shoreview	2,330,949	3,533,417	1.52	2,624,063	3,977,739	1.52	3,201,760	4,853,452	1.52
Vadnais Heights	1,256,147	1,907,937	1.52	1,430,471	2,172,714	1.52	1,911,627	2,903,534	1.52
White Bear Lake	2,093,622	2,862,834	1.37	2,284,547	3,123,906	1.37	3,068,351	4,195,686	1.37
White Bear Township (North & South System)	1,180,084	1,925,845	1.63	1,084,936	1,770,568	1.63	1,134,252	1,851,048	1.63
Lake Elmo	735,066	1,380,655	1.88	2,448,267	4,598,516	1.88	2,791,184	5,242,608	1.88
Saputo Dairy Foods	526,000	526,000	1.00	526,000	526,000	1.00	526,000	526,000	1.00
Total Usage	49,437,917	64,177,268	1.30	58,791,119	77,600,158	1.32	63,397,163	84,017,181	1.33
Difference from Existing Conditions (gallons/day)	0	0		9,353,202	13,422,890		13,959,246	19,839,913	
Increase from Existing Conditions (%)	0.0	0.0		18.9	20.9		28.2	30.9	

Table 2-10 Daily Water Demand and Augmentation Rates by Scenario

Scenario	A – Existing Water Demand			B – 2050 Water Demand			C – Ultimate Water Demand		
	Potable Water Demand - Average Daily (gal/day)	Potable Water Demand - Summer Peak Daily (gal/day) Jun-Aug	Average Augmentation (gal/day)	Potable Water Demand - Average Daily (gal/day)	Potable Water Demand - Summer Peak Daily (gal/day) Jun-Aug	Average Augmentation (gal/day)	Potable Water Demand - Average Daily (gal/day)	Potable Water Demand - Summer Peak Daily (gal/day) Jun-Aug	Average Augmentation (gal/day)
Scenario 1: Water Supply to SPRWS and the surrounding communities - no White Bear Lake augmentation	49,437,917	64,177,268	0	58,791,119	77,600,158	0	63,397,163	84,017,181	0
Scenario 2: Water Supply to SPRWS and Augmentation of White Bear Lake from Sucker Lake - surrounding communities remain on groundwater supplies	39,662,223	49,704,733	4,239,130	44,886,944	56,252,358	4,239,130	47,126,725	59,059,254	4,239,130
Scenario 3: Water Supply to SPRWS and Augmentation of White Bear Lake from East Vadnais Lake - surrounding communities remain on groundwater supplies	39,662,223	49,704,733	4,239,130	44,886,944	56,252,358	4,239,130	47,126,725	59,059,254	4,239,130

2.13 Ecological Data

Ecological data for the study lakes were provided by participating agencies, primarily VLAWMO, RCPW, and the MnDNR. However, available data were limited and varied by lake. This data was used to identify key ecological concerns and to help inform treatment levels considered under the various flow and augmentation scenarios.

2.13.1 Macrophytes

Floristic Quality Index (FQI) and macrophyte richness have been evaluated for all study lakes to assess aquatic plant community condition.

Charley, Pleasant, and East Vadnais Lakes have FQI and richness metrics below target thresholds, while Sucker Lake is at its target threshold, suggesting these lakes have impaired plant communities.

On the other hand, White Bear Lake has a plant FQI that is above the threshold, indicating the lake has high biological significance.

2.13.2 Aquatic Invasive Species

All study lakes are designated by the MnDNR as infested with at least one aquatic invasive species (AIS). Table 2-11 summarizes the presence and listing years of invasive species found in each study lake.

All study lakes are infested with zebra mussels, and all lakes except Charley are officially infested with Eurasian water milfoil.

Although curly leaf pondweed (CLP, *Potamogeton crispus*) is not identified as an AIS by the MnDNR, infestations of CLP can affect water quality, and its presence is often considered when determining lake vegetation management. CLP presence was determined from macrophyte surveys included in 2024 VLAWMO reports for Charley, Pleasant, Sucker, and East Vadnais (VLAWMO, 2024a-c). A point intercept survey conducted in 2023 for White Bear Lake also identified CLP presence; however, the CLP infestation year for the study lakes is unknown (Blue Water Science, 2024).

AIS infestation and dominance can influence both plant community structure and overall ecological function.

Table 2-11 Aquatic Invasive Species Present in Study Lakes

Lake	Zebra mussel presence	Year Listed as Infested	Eurasian watermilfoil presence	Year Listed as Infested	Curly Leaf Pondweed presence
Charley	Yes	2007	No	--	Yes
Pleasant	Yes	2007	Yes	2010	Yes
Sucker	Yes	2007	Yes	1996	Yes
East Vadnais	Yes	2007	Yes	1995	Yes
White Bear Lake	Yes	2014	Yes	1995	Yes

2.13.3 Fisheries

White Bear Lake is the only lake that was evaluated for the Fish Index of Biological Integrity (FIBI) and is considered a general-use lake.

Fisheries data for the remaining lakes are more limited. However, recent management and survey efforts provide some context for current conditions. Carp are present in both Pleasant Lake and Sucker Lake; however, recent removal efforts in Pleasant Lake between 2023 and 2024 substantially reduced carp abundance and biomass (Carp Solutions, 2025). Intermittent MnDNR fisheries surveys have been conducted in Sucker Lake and East Vadnais Lake, with the most recent survey being done in 2005 and 2014, respectively. Bluegill were the most abundant species surveyed in Sucker Lake, while Walleyes and Northern Pike were abundant in East Vadnais Lake (VLAWMO, 2024c).

All study lakes are impaired for mercury in fish tissues except for Charley Lake, which was not evaluated.

2.13.4 Phytoplankton

Historical phytoplankton data was extremely limited for all study lakes, except White Bear Lake, which had available data dating back to 2005. Additional phytoplankton analysis was included in the 2025 monitoring plan to better understand potential changes in algal communities following evaluation of the flow and augmentation scenarios.

2.13.4.1 2025 Phytoplankton Data

Phytoplankton data was provided by RCPW for all study lakes, except Charley Lake, in 2025.

Phytoplankton counts and assemblage composition indicate blue-green algae (cyanobacteria) dominate the algal community during the majority of the growing season in all sampled lakes (see Figure 2-9). Summaries of phytoplankton abundance are shown in Figure 2-10.

Sucker Lake and East Vadnais Lake had lower algal abundance compared to Pleasant Lake. Most lakes exhibited peak algal counts during mid to late summer. However, White Bear Lake experienced a pronounced peak in May, dominated by golden algae (chrysophyta) with total algal counts reaching 17,000 units/mL (Figure 2-10). Following this early-season bloom, algal levels remained low throughout the summer in White Bear Lake, not exceeding 400 units/mL.

Cyanobacteria concentrations in all sampled lakes were below the World Health Organization (WHO) thresholds for adverse health effects.

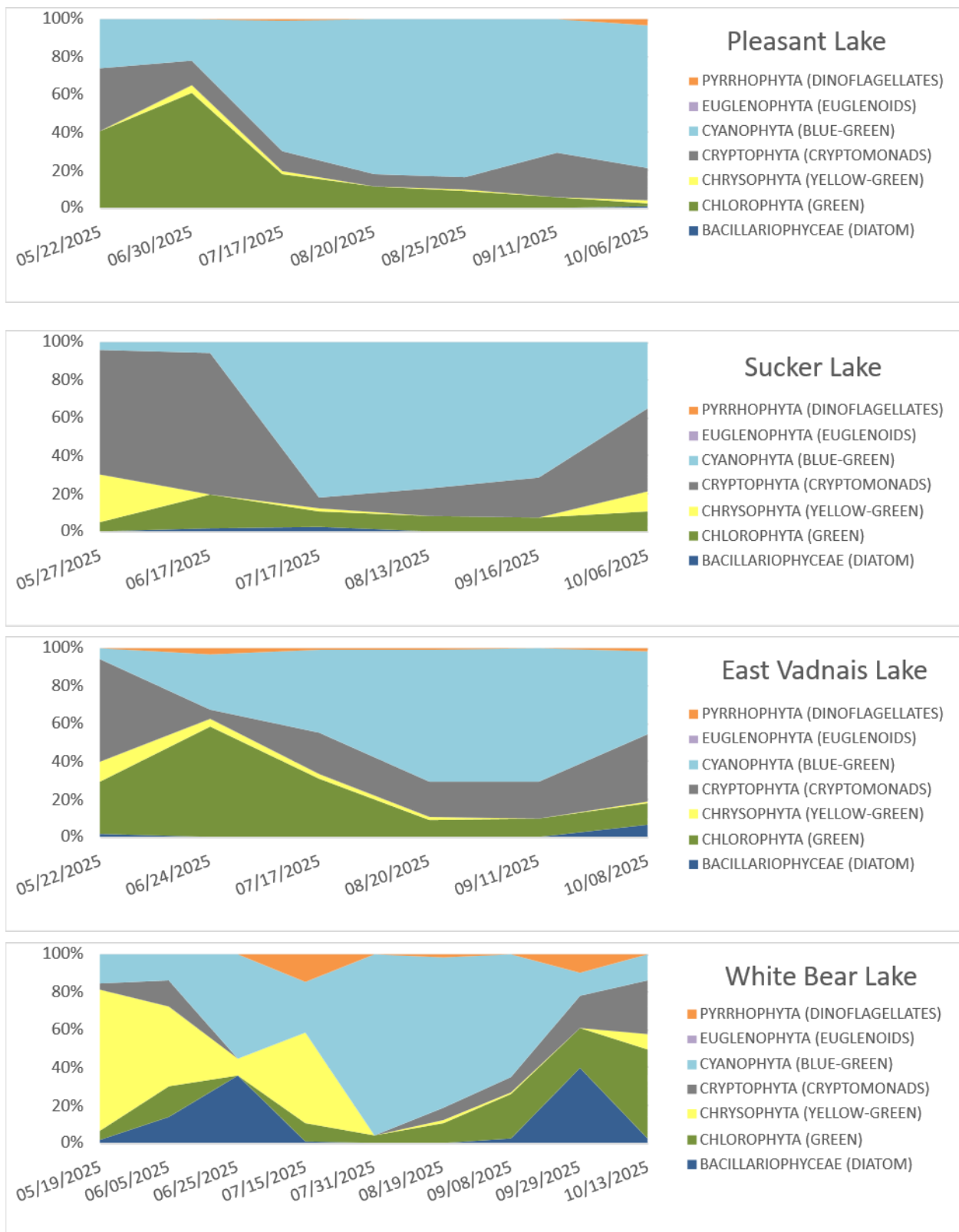


Figure 2-9 Phytoplankton Dominance in Study Lakes in 2025.

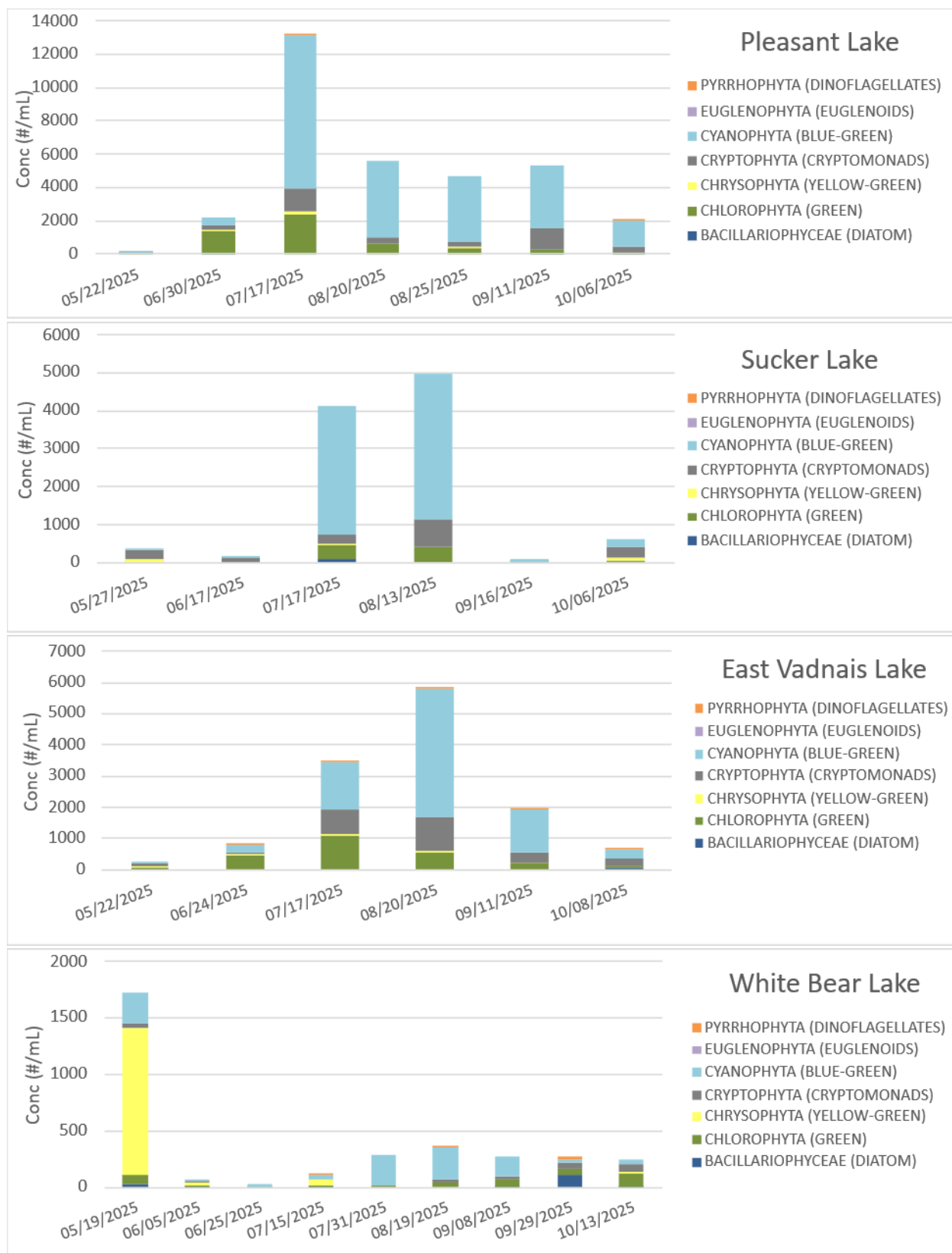


Figure 2-10 Phytoplankton Abundance in Study Lakes in 2025.

2.13.4.2 Cyanotoxin Testing

Cyanotoxin data was provided by MCES for East Vadnais, Pleasant, and Sucker Lakes. East Vadnais Lake was monitored for microcystin, anatoxin-a, and cylindrospermopsin from 2018 through 2022. Cylindrospermopsin was not detected during the monitoring period, while the other cyanotoxins were detected intermittently, with microcystin concentrations peaking at 2.5 µg/L in late 2019 and anatoxin-a concentrations peaking at 0.17 µg/L in late 2018.

Our understanding was that for both East Vadnais Lake at the intake and White Bear Lake at the beaches, there would be cyanotoxins monitored as part of a separate Minnesota Department of Health pilot program, based on feedback from SPRWS and Ramsey County Public Works staff. However, cyanotoxin data was not available from MDH at the time of this report.

As part of the MCES Study 7A monitoring effort, only three cyanotoxin sampling events were conducted in Pleasant and Sucker Lakes during 2025 (July, August, September). In Pleasant Lake, anatoxin-a was detected in mid-July at a concentration of 0.17 µg/L, while microcystin and cylindrospermopsin were not detected. No cyanotoxins were detected in Sucker Lake during the 2025 monitoring period. Cyanotoxin concentrations in all monitored lakes were below the Minnesota Pollution Control Agencies' (MPCA) guidelines for swimming advisories.

2.13.5 Zooplankton

Zooplankton data was not collected as part of this study; however, historical zooplankton data was available for White Bear Lake and was provided by Ramsey County. Historical zooplankton counts indicate a diverse zooplankton community in White Bear Lake, with the taxonomic group nauplii (immature copepods) dominating the zooplankton assemblage during most years of monitoring (Figure 2-11).

White Bear Lake was listed on the infested waters list for zebra mussels in 2014. Following this, zooplankton counts decreased in White Bear Lake and continued to be dominated by smaller-bodied taxa such as nauplii, consistent with research on zebra mussel infestation impacts on zooplankton communities (Cattoor et al., 2025). However, results also indicate an increase in overall zooplankton abundance in 2023 and 2024, comparable to pre-infestation counts. Results from 2023 also include the highest annual average density of *Daphnia* since monitoring began, which is a large-bodied zooplankton and an important food source for higher trophic levels.

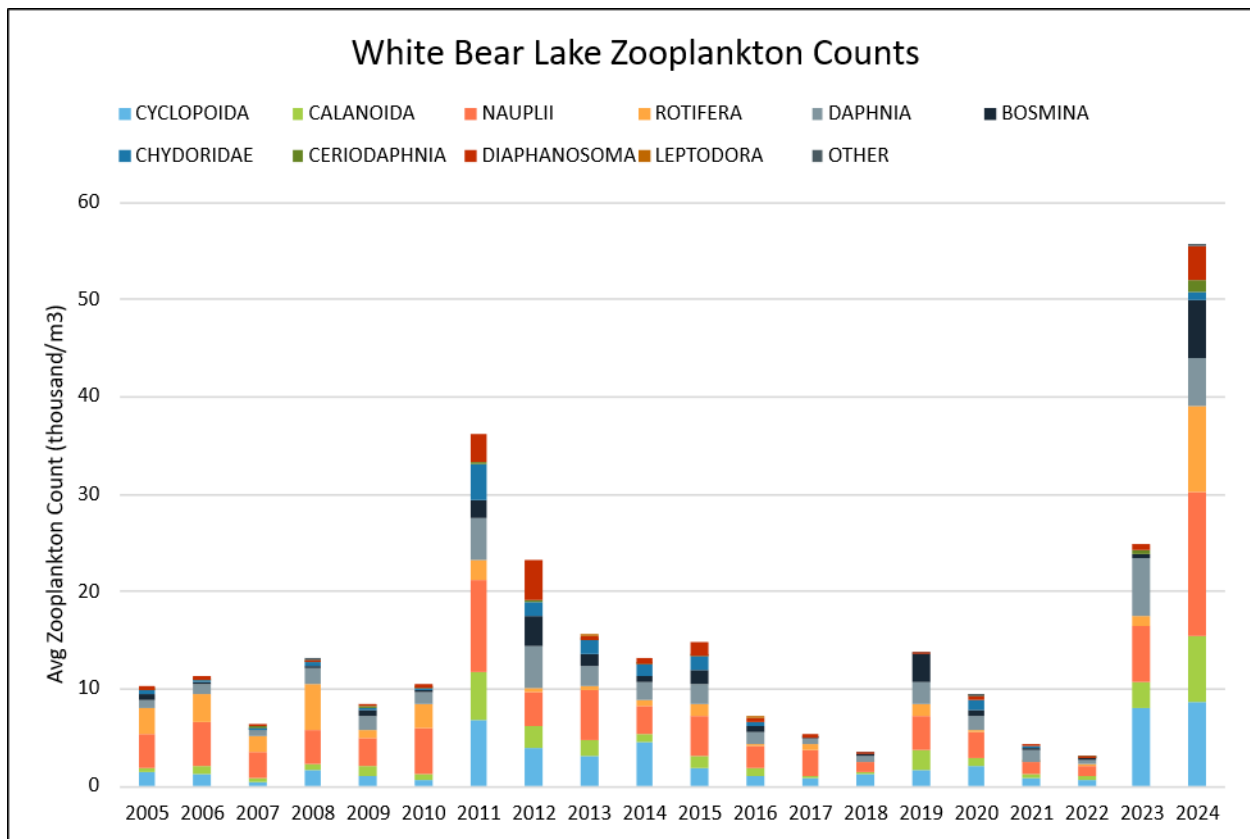


Figure 2-11 Zooplankton Densities in White Bear Lake from 2005-2024.

3 Historic Water Quality and Goals and Standards

3.1 Goals and Standards

Barr summarized existing water quality and ecological goals/standards/guidelines for the surface waters within the SPRWS chain of lakes and White Bear Lake, as well as drinking water standards and guidelines that exist. These surface water body goals/standards/guidelines, along with the monitoring data and modeling results were used when evaluating the impact of the various water use and augmentation scenarios on the water bodies to determine the impact from both a water quality and ecological perspective.

The following sections summarize the existing water quality and ecological goals/standards/guidelines and results for the study lakes.

3.1.1 Lake Surface Water Standards

Existing standards, goals, guidelines, and thresholds that apply to the SPRWS chain of lakes and White Bear Lake were compiled. This included reviewing the following:

- Minnesota Pollution Control Agency (MPCA) water quality standards (Minn. Rule Chapters 7050 and 7052), which include:
 - Lake eutrophication standards
 - Aquatic life and recreation beneficial uses
- Minnesota Department of Natural Resources (MNDNR) Lake Plant Eutrophication Index of Biological Integrity (IBI) Thresholds
- MNDNR Lake Fish Index of Biotic Integrity (FIBI) Thresholds
- MPCA Tiered Aquatic Life Uses (TALU) framework for lakes
- World Health Organization (WHO) Cyanobacteria Thresholds
- MPCA Cyanotoxin Levels for Swimming Advisories
- MPCA PFOS protective values for fish consumption
- Minnesota Department of Health (MDH) Fish Consumption Guidance
- Review of USGS Groundwater and Surface Water Interaction near White Bear Lake, through 2011, with focus on water quality

The beneficial use classifications for the chain of lakes, including Charley, Pleasant, Sucker, and East Vadnais Lake, are Class 1 (Domestic Consumption) and Class 2 (Aquatic Life and Recreation). White Bear Lake is classified as a Class 2 water body.

Table 3-1 includes a summary of the various existing eutrophication and ecological goals/standards/thresholds. Included in the summary table is the use classification, as well as an estimate of the current status of each water body relative to the established goals/standards/thresholds based on

recent 2025 enhanced monitoring data. Table 3-2 summarizes non-eutrophication surface water quality standards set by the state.

Table 3-1 Summary of Eutrophication and Ecological Goals/Standards/Thresholds

Goal/Standard	Category Details	Water Body				
		Charley Lake	Pleasant Lake	Sucker Lake	East Vadnais Lake	White Bear Lake
MN Rule Chapters 7050 and 7052 Eutrophication Standards	Use Classification	1C / 2Bd	1C / 2Bd	1C / 2Bd	1C / 2Bd	2B
	Public Access / Beach	NA	NA	NA	NA	Public Access & Beach
	Ecoregion	North Central Hardwood Forest	North Central Hardwood Forest	North Central Hardwood Forest	North Central Hardwood Forest	North Central Hardwood Forest
	Shallow/Deep	Deep	Deep	Deep	Deep	Deep
	Total Phosphorus (µg/L)	≤ 40	≤ 40	≤ 40	≤ 40	≤ 40
	Chlorophyll a (µg/L)	≤ 14	≤ 14	≤ 14	≤ 14	≤ 14
	Secchi disk depth (m)	> 1.4	> 1.4	> 1.4	> 1.4	> 1.4
	Eutrophication Goal Status ¹	Exceeding Standards TP = 98 Chla = 20 Secchi depth = 2	On MPCA Impaired Waters List TP = 60 Chla = 13 Secchi depth = 2	At/Exceeding Standards TP = 46 Chla = 14 Secchi depth = 3	Below standards TP = 25 Chla = 5 Secchi depth = 3	Below standards TP = 20 Chla = 4 Secchi depth = 4
MNDNR Lake Fish Index of Biotic Integrity (FIBI) Thresholds	FIBI Lake type	Not evaluated	Not evaluated	Not evaluated	Not evaluated	Deep lake with complex shoreline (Group 2)
	FIBI Impairment threshold	NA	NA	NA	NA	45
	FIBI Exceptional threshold	NA	NA	NA	NA	64
MPCA Tiered Aquatic Life Uses (TALU) framework for lakes	Tier Exception or General Use	General Use	General Use	General Use	General Use	General Use
	Fish Community Goal Status	Not evaluated	Not evaluated	Not evaluated	Not evaluated	Above impairment threshold FIBI = 64
Minnesota Department of Natural Resources (MNDNR) Lake Plant Eutrophication Index of Biological Integrity (IBI) Thresholds	Macrophyte Richness	11	12	11	12	12
	Plant FQI Threshold	17.8	18.6	18.6	18.6	18.6
	Plant Community Goal Status	Below threshold Impaired plant community Plant FQI = 11	Below threshold Impaired plant community Plant FQI = 18	Below threshold Impaired plant community Plant FQI = 18	Below threshold Impaired plant community Plant FQI = 16	Above threshold High Biological Significance Plant FQI = 31
MnDNR Aquatic Invasive Species Infested Waters List	Infested Waters List	Infested Zebra mussels	Infested Zebra mussels, Eurasian Watermilfoil	Infested Zebra mussels, Eurasian Watermilfoil	Infested Zebra mussels, Eurasian Watermilfoil	Infested Zebra mussels, Eurasian Watermilfoil
World Health Organization (WHO) Cyanobacteria Thresholds	Low prob of adverse health effects (cyanobacteria cells/mL)	20,000 - 100,000	20,000 - 100,000	20,000 - 100,000	20,000 - 100,000	20,000 - 100,000
	Moderate prob of adverse health effects (cyanobacteria cells/mL)	> 100,000	> 100,000	> 100,000	> 100,000	> 100,000
	High prob of adverse health effects	cyanobacteria scums in areas where whole-body contact or risk of ingestion occur	cyanobacteria scums in areas where whole-body contact or risk of ingestion occur	cyanobacteria scums in areas where whole-body contact or risk of ingestion occur	cyanobacteria scums in areas where whole-body contact or risk of ingestion occur	cyanobacteria scums in areas where whole-body contact or risk of ingestion occur
MPCA Cyanotoxin Levels for Swimming Advisories	Microcystin (µg/L)	≤ 6	≤ 6	≤ 6	≤ 6	≤ 6
	Cylindrospermopsin (µg/L)	≤ 15	≤ 15	≤ 15	≤ 15	≤ 15
	Anatoxin-a (µg/L)	≤ 7	≤ 7	≤ 7	≤ 7	≤ 7
	Algal Community Goal Status ¹	No data	Cyanobacteria counts below WHO's advisory threshold Cyanotoxins below MPCA's swimming advisories	Cyanobacteria counts below WHO's advisory threshold Cyanotoxins below MPCA's swimming advisories	Cyanobacteria counts below WHO's advisory threshold Cyanotoxins below MPCA's swimming advisories	Cyanobacteria counts below WHO's advisory threshold Cyanotoxins below MPCA's swimming advisories
Minnesota Department of Health (MDH) Fish Consumption Guidance	Mercury, total in fish tissue (mg/kg)	0.2	0.2	0.2	0.2	0.2
	Site specific guidance	NA	NA	Limit Bullhead fish consumption to 1 meal/week (men), 1 meal/month (women & children)	NA	NA
	Fish Consumption Goal Status On impaired Waters List for Mercury in Fish Tissue	Not evaluated	Impaired	Impaired	Impaired	Impaired

[1] Goal status updated with available 2025 data

Table 3-2 Summary of Non-Eutrophication Surface Water Goals/Standards/Thresholds

Goal/ Standard	Category Details	Water Body				
		Charley Lake	Pleasant Lake	Sucker Lake	East Vadnais Lake	White Bear Lake
MPCA PFOS protective values	PFOS fish tissue (ng/g)	0.37	0.37	0.37	0.37	0.37
	PFOS surface water (ng/L)	0.05	0.05	0.05	0.05	0.05
	PFBS surface water (ng/L)	350	350	350	350	350
	PFBA surface water (ng/L)	10000	10000	10000	10000	10000
	PFHxS surface water (ng/L)	36	36	36	36	36
	PFHxA surface water (ng/L)	950	950	950	950	950
	PFOA surface water (ng/L)	88	88	88	88	88
	PFAS Goal Status ¹	Available 2025 all well below surface water standards	Available 2025 all well below surface water standards	Available 2025 all well below surface water standards	Available 2025 all well below surface water standards	Available 2025 all well below surface water standards
Emerging Contaminants	Chloride (mg/L) chronic standard	230	230	230	230	230
	Chloride (mg/L) acute standard	860	860	860	860	860
	E. coli (CFU/100 mL)	< 126	< 126	< 126	< 126	< 126
	Others (TBD)	TBD	TBD	TBD	TBD	TBD
	Emerging Contaminants Goal Status	Pending analysis	Pending analysis	Pending analysis	Pending analysis	Pending analysis
MN Rule Chapters 7050 and 7052 Physiochemical Parameters	Chlorine, total residual (µg/L) chronic standard	11	11	11	11	11
	Ammonia unionized as N (µg/L)	40	40	40	40	40
	Nitrate/Nitrite, as N (mg/L)	10	10	10	10	NA
	Nitrate as N (mg/L)	10	10	10	10	NA
	Nitrite as N (mg/L)	1	1	1	1	NA
	Arsenic (µg/L) chronic standard	2	2	2	2	53
	Aluminum (µg/L) chronic standard	125	125	125	125	125
	Sulfate (mg/L)	250	250	250	250	NA
	Manganese (µg/L)	50	50	50	50	NA
	Barium (µg/L)	2,000	2,000	2,000	2,000	NA
	Cadmium (µg/L) chronic standard	exp.(0.7852[ln(total hardness mg/L)]-3.490)	exp.(0.7852[ln(total hardness mg/L)]-3.490)	exp.(0.7852[ln(total hardness mg/L)]-3.490)	exp.(0.7852[ln(total hardness mg/L)]-3.490)	exp.(0.7852[ln(total hardness mg/L)]-3.490)
	Chromium +3 (µg/L) chronic standard	exp.(0.819[ln(total hardness mg/L)]+1.561)	exp.(0.819[ln(total hardness mg/L)]+1.561)	exp.(0.819[ln(total hardness mg/L)]+1.561)	exp.(0.819[ln(total hardness mg/L)]+1.561)	exp.(0.819[ln(total hardness mg/L)]+1.561)
	Chromium +6 (µg/L) chronic standard	11	11	11	11	11
	Copper (µg/L) chronic standard	exp.(0.620[ln(total hardness mg/L)]-0.570)	exp.(0.620[ln(total hardness mg/L)]-0.570)	exp.(0.620[ln(total hardness mg/L)]-0.570)	exp.(0.620[ln(total hardness mg/L)]-0.570)	exp.(0.620[ln(total hardness mg/L)]-0.570)

Goal/ Standard	Category Details	Water Body				
		Charley Lake	Pleasant Lake	Sucker Lake	East Vadnais Lake	White Bear Lake
	Lead (µg/L) chronic standard	exp.(1.273[ln(total hardness mg/L)]-4.705)	exp.(1.273[ln(total hardness mg/L)]-4.705)	exp.(1.273[ln(total hardness mg/L)]-4.705)	exp.(1.273[ln(total hardness mg/L)]-4.705)	exp.(1.273[ln(total hardness mg/L)]-4.705)
	Nickle (µg/L) chronic standard	exp.(0.846[ln(total hardness mg/L)]+1.1645)	exp.(0.846[ln(total hardness mg/L)]+1.1645)	exp.(0.846[ln(total hardness mg/L)]+1.1645)	exp.(0.846[ln(total hardness mg/L)]+1.1645)	exp.(0.846[ln(total hardness mg/L)]+1.1645)
	Zinc (µg/L) chronic standard	exp.(0.8473[ln(total hardness mg/L)]+0.7615)	exp.(0.8473[ln(total hardness mg/L)]+0.7615)	exp.(0.8473[ln(total hardness mg/L)]+0.7615)	exp.(0.8473[ln(total hardness mg/L)]+0.7615)	exp.(0.8473[ln(total hardness mg/L)]+0.7615)
	Iron (µg/L)	300	300	300	300	NA
	Mercury (ng/L)	6.9	6.9	6.9	6.9	6.9
	Color (Pt-Co)	15	15	15	15	NA
	TSS (mg/L)	30	30	30	30	30
	Dissolved oxygen (mg/L)	5	5	5	5	5
	pH	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-9
	Temperature (°F)	< 3 above natural temp, always < 86	<3 above natural temp, always < 86	< 3 above natural temp, always < 86	< 3 above natural temp, always < 86	< 3 above natural temp, always < 86
	Physiochemical Goal Status	Pending analysis	Pending analysis	Pending analysis	Pending analysis	Pending analysis

[1] Goal status updated with available 2025 data

3.1.2 Drinking Water Standards

Barr identified and summarized the current drinking water quality standards and guidelines for the system, including review of the following:

- EPA Drinking Water Standards (MCLs and SMCLs)
 - Title 40 Code of Federal Regulations
 - Part 141: National Primary Drinking Water Regulations (NPDWR MCLs)
 - Part 142: National Primary Drinking Water Regulations Implementation
 - Secondary Drinking Water Standards: Guidance for Nuisance Chemicals (SMCLs)
- Minnesota Department of Health (MDH) Human Health-Based Water Guidance (specifically where parameters overlapped with EPA MCLs and SMCLs)
 - Health Risk Limits (HRLs)
 - Health-Based Values (HBVs)

These goals/standards/thresholds are summarized in Table 3-3 for a variety of parameters, with a focus on those that have both EPA and MDH standards or were included in the historic monitoring data.

3.1.3 Possible Augmentation Impacts to the Groundwater and Underlying Aquifer

One of the goals of the MCES Study 7A is to understand the impact of augmentation of water levels and water quality on White Bear Lake under future scenarios. With higher water levels in the lake, there will be increased head on the underlying aquifer. That, along with possible changes in water quality in White Bear Lake due to the augmentation, may result in changes to the geochemistry of the aquifer. The USGS study from 2013 (summarized below), documented that the downgradient wells in both the glacial and Jordan aquifers are classified as groundwater under the direct influence of surface water.

3.1.3.1 U.S. Geological Survey (USGS) Scientific Investigations Report 2013-5044

In 2013, the [USGS published a study](#) evaluating the connection between White Bear Lake and the Prairie du Chien-Jordan aquifer. The study determined that increases in groundwater withdrawals and lower precipitation were able to explain the low water levels on White Bear Lake. Groundwater withdrawals have more than doubled from the Prairie du Chien-Jordan aquifer from 1980 – 2010. A regression model showed that groundwater withdrawals have been the primary reason for dropping water levels.

Additionally, through temperature analysis, hydraulic-head differences, seepage meter measurements, and water quality analysis of pore water, the study showed that groundwater is flowing into White Bear Lake from the shallow glacial aquifer from the northeast and south and from below the lake.

The study also concluded that White Bear Lake water is potentially discharging into the Jordan aquifer toward the northwest, a water balance showing a potential discharge of 2.8-4.5 inches per month from lake to aquifer. The hydraulic-head differences between White Bear Lake and the Jordan aquifer

increased during summer months, indicating more leakage from the lake to the aquifer. Wells in both glacial aquifers and Jordan aquifers downgradient of White Bear Lake showed signs of surface water (stable isotope analyses), classifying these as "groundwater under the direct influence of surface water," and could result in high water treatment needs and costs because of increased risk of pathogens. The study also indicated that dissolution of lakebed material (exacerbated by low pH & dissolved oxygen) could increase lake water discharge to Jordan aquifers.

Table 3-3 Summary of Drinking Water Quality Standards/Limits

Category	Category Details	National Primary Drinking Water Regulations (NPDWR) EPA Maximum Contaminant Levels (MCLs)	National Secondary Drinking Water Standards EPA Secondary Maximum Contaminant Levels (SMCLs)	Minnesota Department of Health (MDH) Human Health-Based Water Guidance HRL = Health Risk Limits; HBV = Health-Based Values
Eutrophication/ Modeling Parameters	Total Phosphorus (mg/L)			
	Total Dissolved Phosphorus (mg/L)			
	Ortho-P (mg/L)			
	Nitrate+Nitrite (mg/L)	10 (nitrate, measured as nitrogen) 1 (nitrite, measured as nitrogen)		10 (nitrate) (HRL)
	TKN (mg/L)			
	Ammonia (mg/L)			
	Chlorophyll a (mg/L)			
	Secchi disk depth (m)			
	Turbidity (NTU)	0.3		
	Color (color units)		15	
	Total Suspended Solids (mg/L)			
	Total Dissolved Solids (mg/L)		500	
	pH (S.U.)		6.5 - 8.5	
	Temperature			
	Dissolved oxygen (mg/L)			
	Specific Conductance			
	Chloride (mg/L)		250	
	Total Organic Carbon (mg/L)			
	Dissolved Organic Carbon (mg/L)			
	Hardness (mg/L, CaCO3)			
	Alkalinity (mg/L)			
Phytoplankton/ Cyanotoxin Testing	Phytoplankton			
	Cyanotoxins			
Metals	Antimony (mg/L)	0.006		0.006 (HRL)
	Arsenic (mg/L)	0.01		
	Aluminum (mg/L)		0.05	
	Barium (mg/L)	2		2 (HRL)
	Beryllium (mg/L)	0.004		0.00008 (HRL)
	Bromide (mg/L)			
	Cadmium (mg/L)	0.005		0.0005 (HRL)
	Calcium (mg/L)			
	Chromium (III and VI) (mg/L)	0.1 (total)		20 (Chromium III, HRL) 0.1 (Chromium VI, HRL)
	Copper (mg/L)	1.3	1	
	Cyanide (as free cyanide) (mg/L)	0.2		0.1 (HRL)
	Fluoride (mg/L)	4	2	
	Iron (mg/L)		0.3	
	Lead (mg/L)	0.01		
	Magnesium (mg/L)			
	Manganese (mg/L)		0.05	0.1 (HRL)
	Mercury (inorganic) (mg/L)	0.002		
	Nickel (mg/L)			0.1 (HRL)
	Selenium (mg/L)	0.05		0.03 (HRL)
	Silver (mg/L)		0.1	0.03 (HRL)
	Sulfur (as sulfate, sulfide and total sulfur)			
	Sulfate (mg/L)		250	
	Thallium (mg/L)	0.002		
	Zinc (mg/L)		5	2 (HRL)

Category	Category Details	National Primary Drinking Water Regulations (NPDWR) EPA Maximum Contaminant Levels (MCLs)	National Secondary Drinking Water Standards EPA Secondary Maximum Contaminant Levels (SMCLs)	Minnesota Department of Health (MDH) Human Health-Based Water Guidance HRL = Health Risk Limits; HBV = Health-Based Values
Bacteria	Total Coliform	No more than 5.0% samples total coliform-positive (TC-positive) in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month.)		
	Fecal Coliform	Every sample that has total coliform must be analyzed for either fecal coliforms or E. coli if two consecutive TC-positive samples, and one is also positive for E.coli fecal coliforms, system has an acute MCL violation.		
	<i>E. coli</i>	Every sample that has total coliform must be analyzed for either fecal coliforms or E. coli if two consecutive TC-positive samples, and one is also positive for E.coli fecal coliforms, system has an acute MCL violation.		
	Heterotrophic plate count (HPC)	No more than 500 bacterial colonies per milliliter		
Viruses	<i>Cryptosporidium</i>	99 percent removal for systems that filter. Unfiltered systems are required to include Cryptosporidium in their existing watershed control provisions.		
	<i>Giardia lamblia</i>	99.9 percent removal/inactivation		
	<i>Legionella</i>	No limit, but EPA believes that if Giardia and viruses are removed/inactivated, according to the treatment techniques in the surface water treatment rule, Legionella will also be controlled.		
	Viruses (enteric)	99.9 percent removal/inactivation		
PFAS	HFPO-DA (ng/L)	10		
	PFBS (ng/L)	2000 (as part of hazard index)		100 (HRL)
	PFHxS (ng/L)	10		47 (HRL)
	PFNA (ng/L)	10		
	PFOA (ng/L)	4		0.0079 (HBV)
	PFOS (ng/L)	4		2.3 (HBV)
	Hazard index (HFPO-DA, PFBS, PFHxS, and PFNA)	1 (unitless)		
	PFBA (ng/L)			7000 (HRL)
Other Parameters with Drinking Water Standards	PFHxA (ng/L)			200 (HRL)
	Acrylamide (mg/L)	TT		0.002 (HRL)
	Alachlor (mg/L)	0.002		0.009 (HRL)
	Aldicarb (mg/L)	0.003		0.001 (HRL)
	Asbestos (MFL)	7		
	Atrazine (mg/L)	0.003		0.003 (HRL)
	Benzene (mg/L)	0.005		0.002 (HRL)
	Benzo(a)pyrene (PAHs)(mg/L)	0.0002		0.0001 (HRL)
	Bromate (mg/L)	0.01		
	Bromodichloromethane (mg/L)	0.08		0.003 (HRL)
	Bromoform (mg/L)	0.08		0.04 (HRL)
	Carbofuran (mg/L)	0.04		
	Carbon tetrachloride (mg/L)	0.005		0.001 (HRL)
	Chloramines (as Cl2) (mg/L)	4.0 (Maximum Residual Disinfectant Level)		
	Chlordane (mg/L)	0.002		
	Chlorine (as Cl2) (mg/L)	4.0 (Maximum Residual Disinfectant Level)		

Category	Category Details	National Primary Drinking Water Regulations (NPDWR) EPA Maximum Contaminant Levels (MCLs)	National Secondary Drinking Water Standards EPA Secondary Maximum Contaminant Levels (SMCLs)	Minnesota Department of Health (MDH) Human Health-Based Water Guidance HRL = Health Risk Limits; HBV = Health-Based Values
	Chlorine dioxide (as ClO2) (mg/L)	0.8 (Maximum Residual Disinfectant Level)		
	Chlorite (mg/L)	1		
	Chlorobenzene (mg/L)	0.1		0.1 (HRL)
	Chloroform (mg/L)	0.08		0.02 (HRL)
	2,4-D (mg/L)	0.07		0.03 (HRL)
	Dalapon (mg/L)	0.2		
	1,2-Dibromo-3-chloropropane (DBCP) (mg/L)	0.0002		
	o-Dichlorobenzene (mg/L)	0.6		
	p-Dichlorobenzene (mg/L)	0.075		
	1,2-Dichloroethane (mg/L)	0.005		0.001 (HRL)
	1,1-Dichloroethylene (mg/L)	0.007		0.2 (HRL)
	cis-1,2-Dichloroethylene (mg/L)	0.07		
	trans-1,2,Dichloroethylene (mg/L)	0.1		
	Dichloromethane (mg/L)	0.005		0.01 (HRL)
	1,2-Dichloropropane (mg/L)	0.005		0.003 (HRL)
	Di(2-ethylhexyl)adipate (mg/L)	0.4		
	Di(2-ethylhexyl)phthalate (mg/L)	0.006		0.007 (HRL)
	Dinoseb (mg/L)	0.007		0.008 (HRL)
	Dioxin (2,3,7,8-TCDD) (mg/L)	0.00000003		
	Diquat (mg/L)	0.02		
	Endothall (mg/L)	0.1		
	Endrin (mg/L)	0.002		
	Ethylbenzene (mg/L)	0.7		0.04 (HRL)
	Ethylene dibromide (mg/L)	0.00005		0.000004 (HRL)
	Glyphosate (mg/L)	0.7		0.5 (HRL)
	Haloacetic acids (HAA5) (mg/L)	0.06		
	Heptachlor (mg/L)	0.0004		0.00008 (HRL)
	Heptachlor epoxide (mg/L)	0.0002		0.00004 (HRL)
	Hexachlorobenzene (mg/L)	0.001		0.0002 (HRL)
	Hexachloro-cyclopentadiene (mg/L)	0.05		
	Lindane (mg/L)	0.0002		
	Methoxychlor (mg/L)	0.04		
	Monochloroacetic acid (mg/L)	0.06		
	Oxamyl (Vydate) (mg/L)	0.2		
	Pentachlorophenol (mg/L)	0.001		0.0003 (HRL)
	Picloram (mg/L)	0.5		0.5 (HRL)
	Polychlorinated biphenyls (PCBs) (mg/L)	0.0005		0.00004 (HRL)
	Simazine (mg/L)	0.004		0.004 (HRL)
	Styrene (mg/L)	0.1		
	TCDD, 2,3,7,8- (Dioxin) (mg/L)	0.00000003		
	Tetrachloroethylene (mg/L)	0.005		0.004 (HRL)
	Toluene (mg/L)	1		0.07 (HRL)
	Total Trihalomethanes (TTHMs) (mg/L)	0.08		
	Toxaphene (mg/L)	0.003		0.0003 (HRL)
	2,4,5-TP (Silvex) (mg/L)	0.05		
	1,2,4-Trichlorobenzene (mg/L)	0.07		0.1 (HRL)
	1,1,1-Trichloroethane (mg/L)	0.2		5 (HRL)
	1,1,2-Trichloroethane (mg/L)	0.005		0.003 (HRL)
	Trichloroethylene (mg/L)	0.005		
	Vinyl chloride (mg/L)	0.002		0.0002 (HRL)
	Xylenes (total) (mg/L)	10		0.3 (HRL)
	Alpha particles (pCi/L)	15		
	Beta particles and photon emitters (millirems per year)	4		
	Radium 226 and Radium 228 (combined, pCi/L)	5		
	Uranium (ug/L)	30		
Additional Contaminants of Emerging Concern Observed in	Methyl-1H-benzotriazole			
	Cotinine			
	N, N-Diethyl-m-toluamide (DEET)			0.2 (HRL)

Category	Category Details	National Primary Drinking Water Regulations (NPDWR) EPA Maximum Contaminant Levels (MCLs)	National Secondary Drinking Water Standards EPA Secondary Maximum Contaminant Levels (SMCLs)	Minnesota Department of Health (MDH) Human Health-Based Water Guidance HRL = Health Risk Limits; HBV = Health-Based Values
Surface/Storm Water in 2018 MPCA/USGS Study	Tributyl phosphate			0.004 (HRL)
	Nicotine			
	Caffeine			
	Lidocane			
	2-Hydroxy-4-isopropylamino-6-ethylamino-s-triazine (OIET)			
	Metolachlor			0.3 (HRL)
	Isophorone			
	2-Chloro-4-isopropylamino-6-amino-s-triazine (CIAT)			
	Acetaminophen			
	Menthol			
	Metformin			
	Prometon			0.1 (HRL)
	beta-Sitosterol			
	2-Chloro-6-ethylamino-4-amino-s-triazine (CEAT)			
	5-Methyl-1H-benzotriazole			
	9,10-Anthraquinone			
	2-Hydroxy-4-isopropylamino-6-amino-s-triazine (OIAT)			
	Chlorodiamino-s-triazine (CAAT)			
	Indole			
	Cholesterol			
	Tris(2-butoxyethyl) phosphate (TBEP)			0.03 (HRL)
	Pyrene			0.05 (HRL)
	Carbendazim			
	2-Chloro-N-(2-ethyl-6-methylphenyl)acetamide (CEMPA)			
	Acetochlor			0.02 (HRL)
	Azoxystrobin			
	Diuron			
	N-(3,4-Dichlorophenyl)-N0-methylurea (DCMU)			
	Fluoranthene			0.07 (HRL)
	Tebuconazole			
	Bisphenol A			
	Dimethenamid			
	Triphenyl phosphate			
	Camphor			
	Sulfentrazone			0.06 (HBV)
	Tris(dichloroisopropyl) phosphate (TDIP)			
	Phenanthrene			
	2,6-Dimethylnaphthalene			
	Propazine			
	Triclopyr			
	Carbazole			
Microplastics	Microplastics			

3.2 Statistical Analysis and Exceedances

Barr completed a statistical analysis of historic and 2025 water quality data for comparison to goals and standards. Parameters not meeting goals or standards were identified, and conditions were compared between the Mississippi River and among lakes for parameters that may pose risks to human health, aquatic recreation, and aquatic life (including fisheries, aquatic plants, aquatic macroinvertebrates, and other aquatic organisms). This evaluation also identified parameters that may require treatment prior to augmentation of White Bear Lake, informing discussions with regulatory authorities and verification of compliance with state water quality standards and non-degradation requirements. Appendix 3 includes the statistical summaries completed for this study, including the following Excel files:

- Summary Statistics (SummaryStatistics.xlsx)
- Outliers (OutlierReport.xlsx)
- Exceedance Screening (ExceedanceTables.xlsx)
- Percentiles (SummaryStatisticsPercentiles.xlsx)
- Confidence Intervals (ConfidenceIntervals.xlsx)

Methods for the calculation of summary statistics, percentiles, confidence intervals, outliers, and exceedances are provided in the “Notes” tab of each Excel file.

The notes for summary statistics describe some values that were dropped from consideration for summary statistics and other nuances related to the calculation of summary statistics when some values are below reporting detection limits. Summary statistics were calculated (1) for the entire period of record for each site/chemical/fraction combination with sufficient data, (2) for all of 2025, and (3) for the 2025 growing season for select site/chemical/fraction combinations. Each analysis period is presented in a separate tab in the Excel appendix. The Mississippi River is listed as MISSISSIPPI FRIDLEY in the appendix; the SPRWS chain of lakes sites are listed as CHARLEY, PLEASANT WEST, PLEASANT EAST, PLEASANT VLAWMO, SUCKER NORTH, SUCKER SOUTH, EAST VADNAIS NORTH, EAST VADNAIS VLAWMO, and EAST VADNAIS SOUTH in the appendix; the White Bear Lake sites are listed as WHITE BEAR LAKE 229, WHITE BEAR LAKE 230, WHITE BEAR LAKE 231, and WHITE BEAR LAKE 234.

Barr examined the data for potential outliers, which are values that are extremely high or low compared to the bulk of the data. Outliers can represent physically plausible and process-driven values, expected extremes, or represent values where an error occurred in laboratory or data processing. Methods for the identification of outliers are provided in the “Notes” tab. Outliers were retained for screening-level interpretation unless there was clear evidence of data quality issues. Outliers were evaluated primarily to identify potential data quality issues or episodic or process-driven conditions rather than to exclude data from summary statistics. See the notes in the Excel appendices for more details. Outliers were not removed from summary statistics or exceedance screening.

The summary statistics describe the overall distribution of observed concentrations for the given period at each site. The summary statistics are intended to provide context for general water quality conditions. Barr also evaluated exceedances of U.S. Environmental Protection Agency (USEPA) national primary drinking water regulations (maximum contaminant levels), USEPA secondary drinking water standards, Minnesota Department of Health human health-based water guidance, and WHITE BEAR LAKE project-

specific criteria. Methods for the exceedance screening are provided in the “Notes” tab. Exceedances for the period of record, 2025, and the 2025 growing season for select site/chemical/fraction combinations are provided in additional tabs of the Excel file.

3.2.1 Key Takeaways & Observations

Summary statistics and exceedance screening provide screening-level context for spatial and temporal patterns in water quality across the Mississippi River, the SPRWS chain of lakes, and White Bear Lake. Results are intended to support identification of parameters most relevant to modeling sensitivity, treatment feasibility, and regulatory considerations, rather than to predict future conditions under altered flow scenarios. Observed differences among sites and periods may reflect a combination of source-water quality, in-lake processes, seasonality, sampling design, and analytical limitations. At the screening level, multiple conservative indicators (that is, indicators primarily reflecting source water and not primarily controlled by in-lake biological feedbacks), chloride, arsenic, alkalinity, organic carbon, and color, show consistent source-water differences between White Bear Lake and the Mississippi River, indicating that augmentation could possibly impact White Bear Lake water-quality conditions through augmentation from the SPRWS chain of lakes. However, as Mississippi River flows move through the SPRWS chain of lakes, these water quality conditions may change as a result of the individual lake dynamics, and this expected change should be explicitly considered in the calibration, baseline, and scenario modeling.

The following statements refer to the mean value for each chemical/site combination for a particular period of analysis (2025 or the period of record), recognizing that the period of record varies by site and parameter.

3.2.1.1 Parameters Likely to Be Diluted by Augmentation

For chloride, the WHITE BEAR LAKE 234 site (52.8 mg/l) is more than double that of the Mississippi River (22.3 mg/l). This pattern, while not as extreme, holds for the period of record at these sites (WHITE BEAR LAKE 234 mean chloride 1998–2025 is 34.5 mg/l, Mississippi River mean chloride 2019–2025 is 22.8 mg/l). This suggests that, under conditions where White Bear Lake is augmented from the SPRWS chain of lakes, this could result in dilution of chloride in White Bear Lake, assuming no offsetting in-lake or watershed sources.

For arsenic in 2025, White Bear Lake concentrations are higher than the Mississippi River (WHITE BEAR LAKE 229 2.1 ug/l, WHITE BEAR LAKE 234 2.0 ug/l, Mississippi River 1.7 ug/l). This pattern holds for the period of record. Augmentation could reduce arsenic in White Bear Lake. Potential exceedances of arsenic occur in Charley (2025) and Pleasant East (2021). These are individual sample exceedances compared to chronic White Bear Lake exceedances; however, they are relevant given the human-health-based nature of the applicable criterion.

3.2.1.2 Parameters Likely to Increase with Augmentation

For sulfate in 2025, White Bear Lake (sites 229 and 234) is lower in mean concentration than the other sites with data: Mississippi River, Charley, Pleasant Lake, Sucker South, East Vadnais North, and East Vadnais South. This pattern is consistent with the potential for increased sulfate under augmentation scenarios, which is relevant to treatment aesthetics (taste) and corrosion considerations; however, levels are typical of most freshwater systems and would likely not affect corrosion at the levels observed.

For alkalinity in 2025, mean alkalinity is higher in the Mississippi River (181.4 mg/l) and the SPRWS chain of lakes than it is at the White Bear Lake sites (82.7 mg/l at WHITE BEAR LAKE 234). This pattern holds

for the period of record. This suggests augmentation could increase buffering capacity in White Bear Lake, which can help neutralize pH from acid rain and metal speciation. Generally, the ranges observed in the system are within typical ranges for freshwater systems.

Similarly, fluoride, barium, calcium, magnesium, and hardness exhibit conservative behavior and reflect source-water chemistry; augmentation could increase these constituents in White Bear Lake, although concentrations are generally well below health-based thresholds and are not expected to be limiting.

For dissolved organic carbon (DOC) and total organic carbon (TOC) in 2025, White Bear Lake means are lower than Mississippi/chain (WHITE BEAR LAKE 234 DOC 4.9 mg/l, Mississippi DOC 9.8 mg/l; WHITE BEAR LAKE 234 TOC 4.60 mg/l, Mississippi TOC 10.1 mg/l). This pattern holds for the period of record. This suggests that augmentation could increase total and dissolved organic carbon exposure in White Bear Lake, which is relevant for drinking-water treatability (e.g., precursor considerations).

For color in 2025, White Bear Lake is much lower in mean color units (WHITE BEAR LAKE 234 8.8 color units) than the Mississippi (87 color units), a pattern that holds for the period of record. In addition, frequent exceedances of color relative to USEPA secondary drinking water standards were observed at the Mississippi River and SPRWS chain-of-lakes sites. Augmentation could increase color in White Bear Lake and become an aesthetic concern and potential treatment issue.

3.2.1.3 Parameters Whose Response Depends on In-lake Processes

For chlorophyll-a (pheophytin-adjusted) in 2025, White Bear Lake mean concentrations are lower than those observed in the Mississippi River, with the highest concentrations observed in Charley (WHITE BEAR LAKE 234 3.9 ug/l, Mississippi River 8.7 ug/l, Charley 19.4 ug/l). In addition, for the period of record, there are numerous exceedances at Charley, Pleasant, Sucker, East Vadnais, and White Bear Lake sites.

Over the period of record, numerous Secchi disc measurements fall below the state standards for Charley, Pleasant West, Pleasant East, Pleasant VLAWMO, Sucker North, Sucker South, East Vadnais North, and East Vadnais South. These, combined with the color and chlorophyll a results, indicate the potential for aesthetic concerns related to possible reduced clarity.

3.2.1.4 Parameters Primarily Relevant to Treatment

Iron and manganese exhibit more frequent exceedances of human health-based water guidance and project-specific criteria than most other non-eutrophication parameters. Manganese exhibited frequent exceedances across multiple sites over the period of record, including the Mississippi River and portions of the SPRWS chain of lakes. These exceedances are relevant from a drinking-water treatment and aesthetic perspective and are likely influenced by redox conditions rather than external loading alone. As a result, manganese could be interpreted as a treatment-relevant parameter that may be sensitive to changes in dissolved oxygen and mixing under augmentation scenarios. However, the levels observed in White Bear Lake is typically well below the levels of typical concern in a freshwater system.

Bacterial indicators and radiological parameters exhibit exceedances typical of surface waters and are relevant primarily from a treatment and regulatory compliance perspective rather than as drivers of lake response.

3.2.1.5 Nutrients as Drivers of Lake Response

For nutrients, summary statistics and exceedance screening indicate that phosphorus-related parameters are key drivers of water-quality conditions across the system. Total phosphorus (dissolved and total fractions) and orthophosphate show higher mean concentrations and exceedances of state standards at Charley Lake and portions of the SPRWS chain of lakes than at White Bear Lake. Over the period of record, numerous total phosphorus exceedances occur at Charley, Pleasant, Sucker, East Vadnais, and White Bear Lake sites, indicating that phosphorus is a system-wide driver of eutrophication risk across the study area.

In contrast, nitrate plus nitrite concentrations are generally lower and show fewer exceedances relative to phosphorus, suggesting nitrogen is less frequently a criteria-driven concern in surface waters, although it remains important for nutrient balance and algal response. Ammonia did not exceed applicable criteria during 2025 or over the period of record.

While summary statistics and exceedance screening identify phosphorus and related response indicators (chlorophyll a and Secchi depth) as key drivers, the ultimate lake response to altered flow and residence time depends on the interaction of nutrient loading, light availability, mixing, and internal cycling. Therefore, CE-QUAL-W2 and mass balance modeling are needed to further evaluate how augmentation scenarios may alter eutrophication dynamics, algal biomass, and clarity beyond what can be inferred from historical statistics alone.

3.2.1.6 Other Parameters

The remaining trace metals, PFAS, cyanotoxins, and organic contaminants were summarized and screened, and did not exhibit consistent spatial patterns or frequent exceedances that would appear to influence augmentation decisions.

PFAS data availability is limited to White Bear Lake and East Vadnais Lake. White Bear Lake is designated as a low-PFAS Lake. Classification of East Vadnais Lake in relation to PFAS is pending full analysis of all available data by the MPCA. However, but review of the available data from 2025 suggests that East Vadnais Lake may also be classified as a low PFAS Lake.

3.3 Lake Eutrophication & Ecological Summary

Water quality data was compiled and evaluated in relation to MPCA's eutrophication standards for the North Central Hardwood Forest Ecoregion. All study lakes are classified as deep lakes, with maximum depths exceeding 15 feet. Eutrophication parameters were evaluated for the June through September growing season to be consistent with state assessment methods. Surface samples included measurements collected from 0-3 meters in depth to leverage SPRWS's long-term monitoring data, which typically included a sample at 3 meters. These depths were used instead of the standard 0-2 m range because all study lakes have well-mixed epilimnions, meaning surface water conditions are relatively uniform throughout this upper layer and well represented by the slightly deeper 0-3 m sampling range.

It should be noted that the Mississippi-Fridley sampling station is located along the river and therefore does not have the same lake-based standards as the other study lakes. However, it has been analyzed alongside the lake standards for comparison purposes.

The MPCA's eutrophication standards include three parameters: total phosphorus, chlorophyll a, and Secchi depth, which measures transparency. Eutrophication parameters were plotted using boxplots in

order to visualize the study lake's historical ranges and compare them to state standards. Each boxplot displays the median (center horizontal line), the 25th and 75th percentiles (the lower and upper hinges), and whiskers that extend to 3 times the interquartile range (IQR) above or below these quartiles. Data points outside this range are shown as outliers. Three times the IQR was used instead of the standard 1.5 (Tukey's fences) to identify outliers because water quality data is naturally right-skewed, and increasing this factor reduces false positives (see Appendix 3 for a more detailed description of outlier identification). The boxplots also include an X representing the 2025 growing season average and a horizontal black dotted line representing the MPCA's standard for the associated parameter.

Total phosphorus results indicate that several of the study lakes exceeded the state standard of 0.04 mg/L (40 ug/L) (Figure 3-1). Both historic medians and 2025 averages fell above the state standard for Charley, Pleasant, and Sucker Lakes, while East Vadnais and White Bear Lake stations were consistently below the state standard.

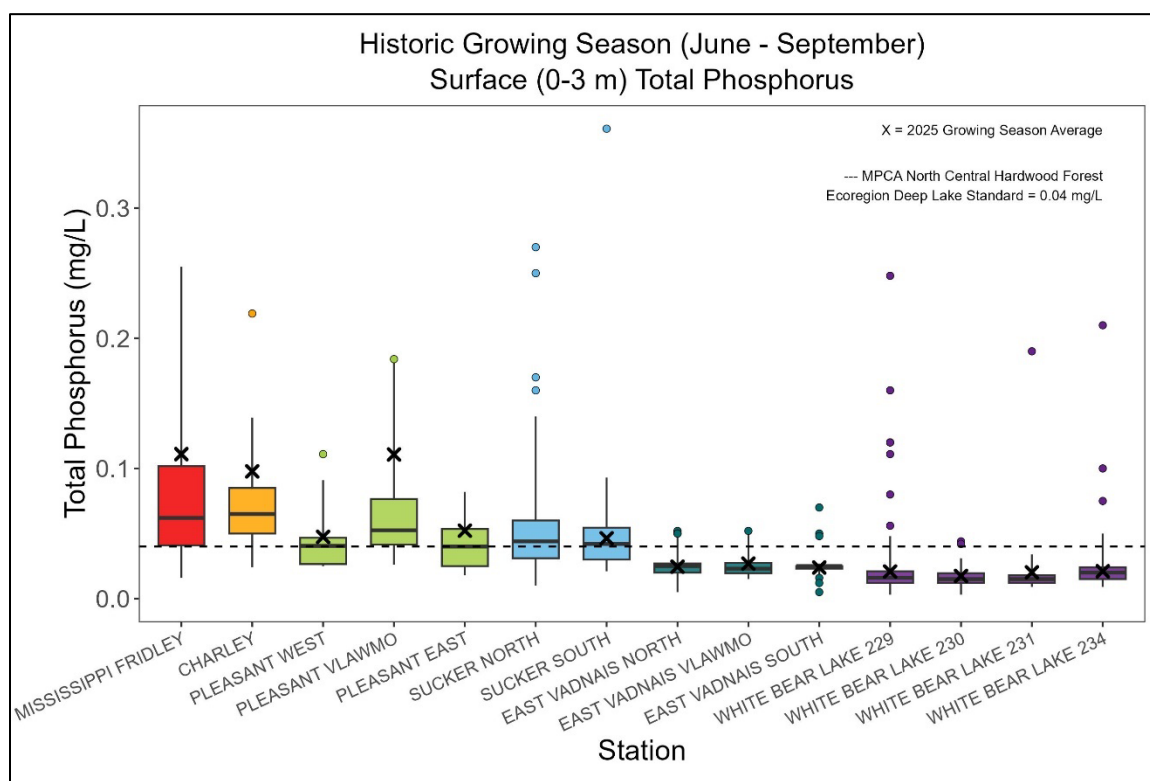


Figure 3-1 Historic Total Phosphorus Measurements in Study Lakes

Chlorophyll a results follow a similar pattern, where East Vadnais and White Bear Lake stations consistently fell below the eutrophication standard of 14 $\mu\text{g/L}$ (Figure 3-2). Charley's historical chlorophyll a median value was also below the state standard; however, the 2025 average exceeded it. Pleasant and Sucker Lake stations showed more variable results, with some exceeding the standard in 2025 while other stations remained below it.

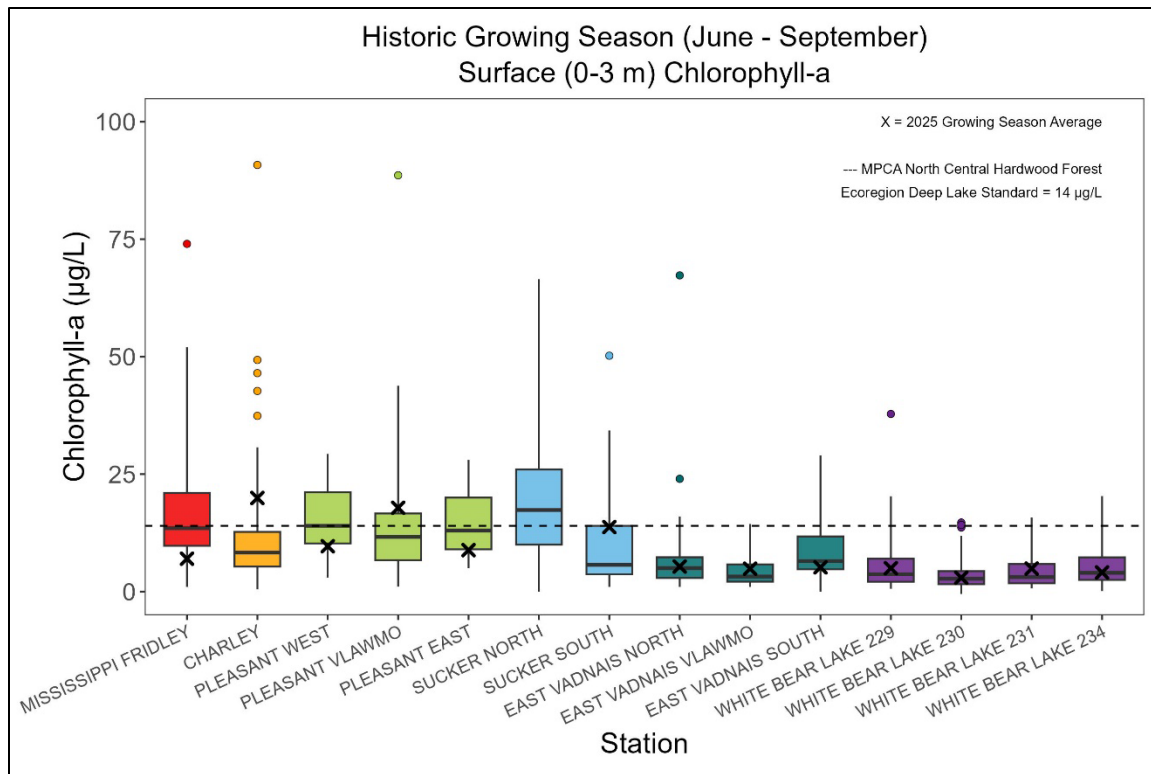


Figure 3-2 Historic chlorophyll a Measurements in Study Lakes

Secchi depth transparency results show that most lakes are meeting the state standard for transparency (Figure 3-3). Charley Lake was the only study lake with a historical median Secchi depth that did not meet the state standard of 1.4 m. All other study lakes met the standard based on both historical median values and 2025 averages. Consistent with other eutrophication parameters, White Bear Lake exhibited higher water clarity relative to the other study lakes.

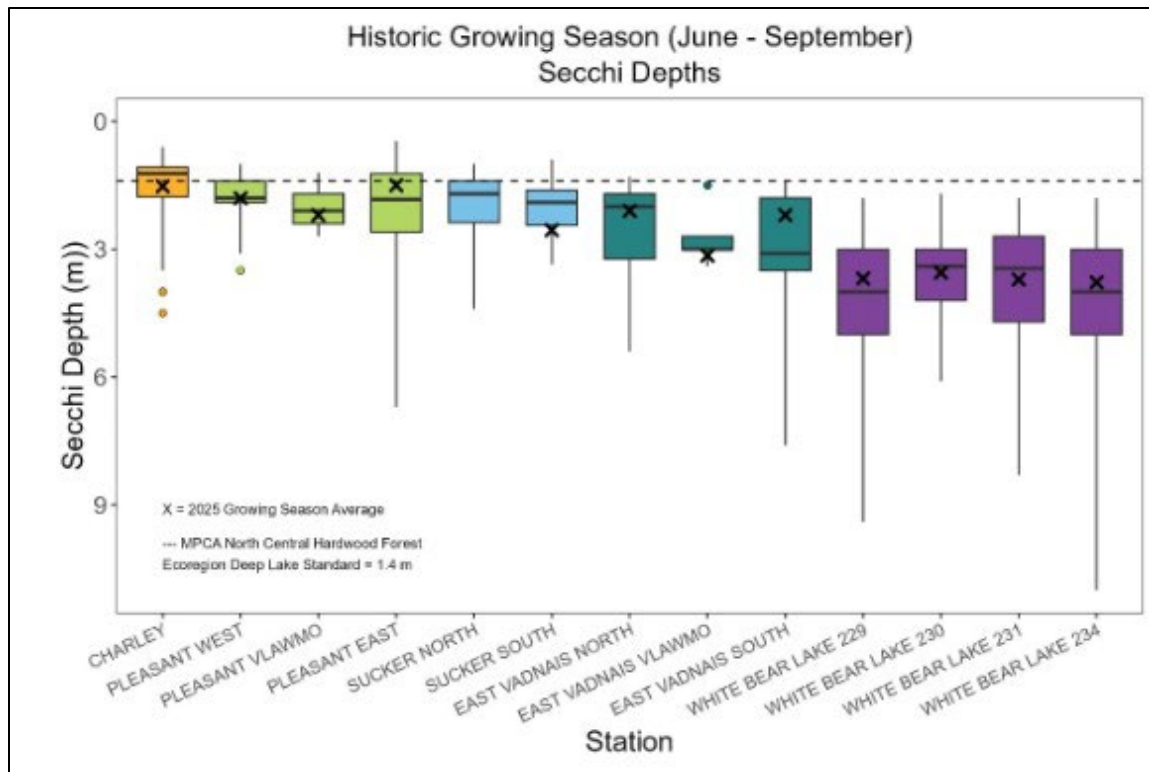


Figure 3-3 Historic Secchi Depth Measurements in Study Lakes

3.3.1 Lake Water Quality Relationships

The historic water quality data was leveraged to develop eutrophication relationships for the study lakes in order to compare observed conditions to established state standard relationships, estimate Secchi depth response as a result of the predicted modeling, and to inform the development of non-degradation thresholds. Prior work by Heiskary and Wilson (2005) established a statewide approach for setting lake nutrient criteria. In this study, a large statewide dataset was compiled to evaluate the relationships between the eutrophication parameters; total phosphorus, chlorophyll a, and Secchi depth. Using regression analysis on log-transformed growing season averages, the study quantified how changes in phosphorus concentrations are associated with changes in algal biomass and water clarity.

Following this approach, growing season averages for each eutrophication parameter were calculated for the study lakes, log-transformed, and used to develop regression relationships. Kaplan-Meier statistics were used on years with censored data, and outliers were removed prior to growing season average calculations. It is important to note that although the reference study used approximately 90 lakes total, the authors intentionally excluded urban lakes in order for the relationships to reflect baseline nutrient response dynamics. As a result, lakes with substantial human influence or altered ecological processes may deviate from these reference relationships. Many of the lakes included in this study, especially those along the SPRWS chain of lakes, differ from those reference conditions, as they are influenced by developed watersheds, aquatic invasive species, pumping from the Mississippi River, and, in some cases, active water quality management associated with drinking water requirements within the SPRWS chain of lakes, including the addition of Ferric Chloride and Oxygen injection systems. As a result, regression relationships for the study lakes often diverged from the standard patterns.

Overall, the study lakes showed a weaker response of chlorophyll a and Secchi depth to total phosphorus compared to reference relationships. This is seen in a lower intercept for the chlorophyll a vs total phosphorus plots and a higher intercept in the Secchi depth vs total phosphorus and chlorophyll a plots. In other words, chlorophyll a and Secchi depths remained relatively similar across a range of total phosphorus values, indicating a limited predictive power of total phosphorus. Chlorophyll a vs Secchi depth was often the strongest relationship; however, all relationships are considered quite weak (low R^2) with substantial variability.

Additionally, all lakes are infested with zebra mussels, which can substantially alter eutrophication dynamics by reducing phytoplankton biomass and increasing water clarity through filter feeding and impact water quality relationships.

Only White Bear Lake has sufficient data before and after zebra mussel infestation, so we evaluated the relationships using all data, as well as pre and post-zebra mussel infestation, to assess how infestation has influenced eutrophication relationships over time.

The water quality relationships for all the study lakes are included in Appendix 4.

3.4 Non-Degradation and Site-Specific Considerations

The method from Heiskary and Wilson (2005) was used for East Vadnais and White Bear Lake in order to inform site-specific considerations and non-degradation thresholds, as both lakes have historically exhibited high water quality that is consistently below state standards. Because of this, a more restrictive threshold is needed to define non-degradation than the current state standard and protect their beneficial uses, and protect macrophyte and fish communities by ensuring the lakes stay in a clear water state.

Because the regression relationships were weak, additional analysis was needed to define non-degradation thresholds for these lakes. Using the calibrated CE-QUAL-W2 surface water quality model, scenarios with increased external total phosphorus and nitrogen loading were simulated to understand each system's sensitivity to increased nutrient loads. These simulations were used to identify the loading levels at which meaningful shifts in water quality are expected to occur.

3.4.1 East Vadnais

Similar to other study lakes, East Vadnais eutrophication relationships were less affected by higher TP values on chlorophyll a and Secchi depth (Figure 3-4). This is likely caused by the river flows, water quality treatment from the SPRWS management system, and the prevalent zebra mussel infestation.

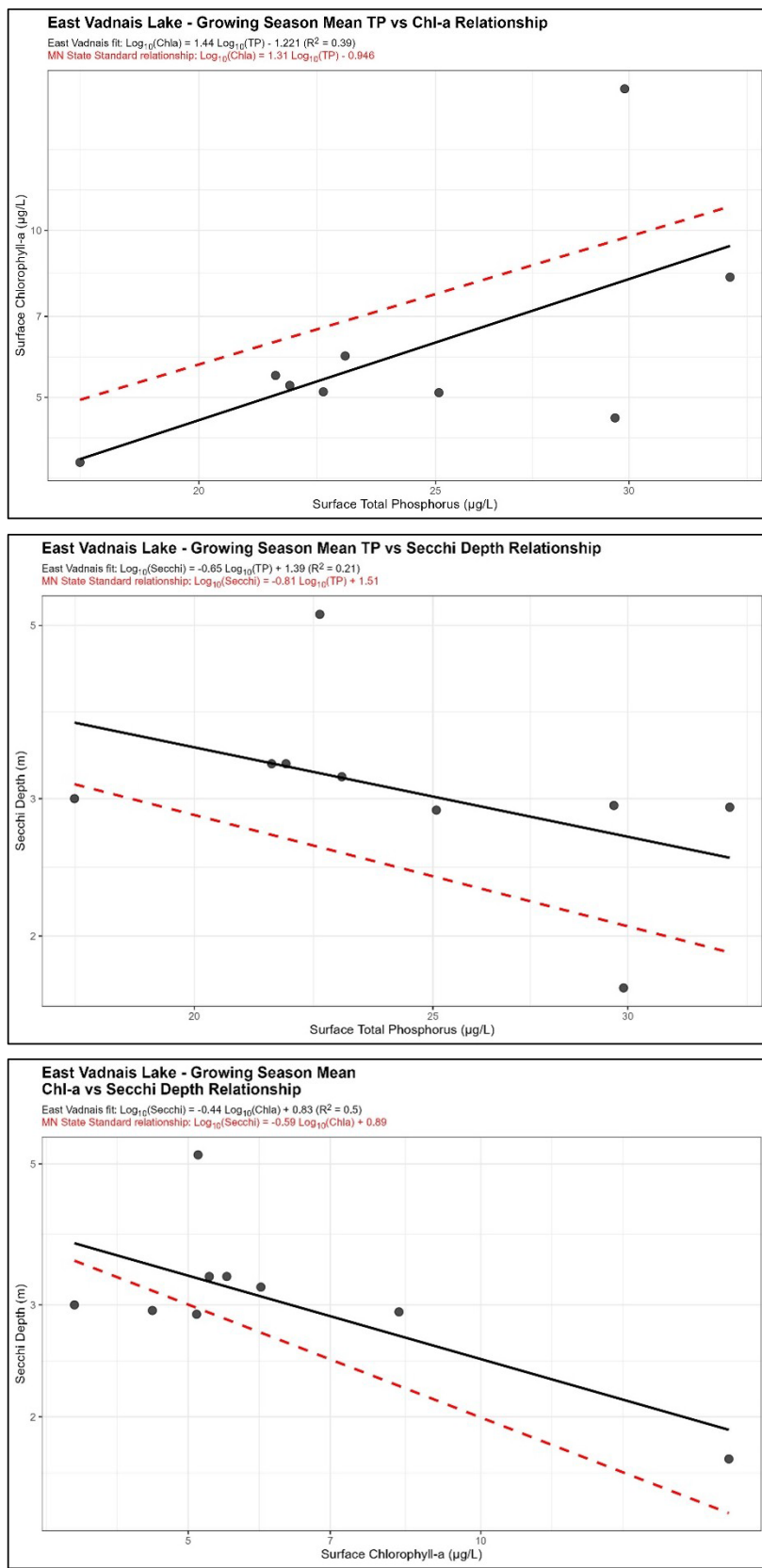


Figure 3-4 East Vadnais Eutrophication Regression Relationships

3.4.1.1 Loading Response Evaluation

The calibrated (2025) CE-QUAL-W2 model was used to evaluate loading response to increased external nutrient loads to East Vadnais Lake. This evaluation was performed by scaling the watershed runoff total phosphorus and total nitrogen loading concentrations by an equivalent factor that resulted in increased external loads to the lake.

The modeling summarized the increase in the total phosphorus and total nitrogen growing season loads from existing (2025) conditions to East Vadnais Lake, as well as the corresponding change in the total phosphorus and chlorophyll a concentration. The estimated change in Secchi depth was estimated using the lake water quality relationship between chlorophyll a and Secchi depth as developed for East Vadnais Lake.

Figure 3-5 shows the resulting total phosphorus and chlorophyll a concentrations (primary axis) and Secchi depth (secondary axis) plotted against the increase in the growing season load. Also included in this plot is the MPCA deep lake standards for these same parameters.

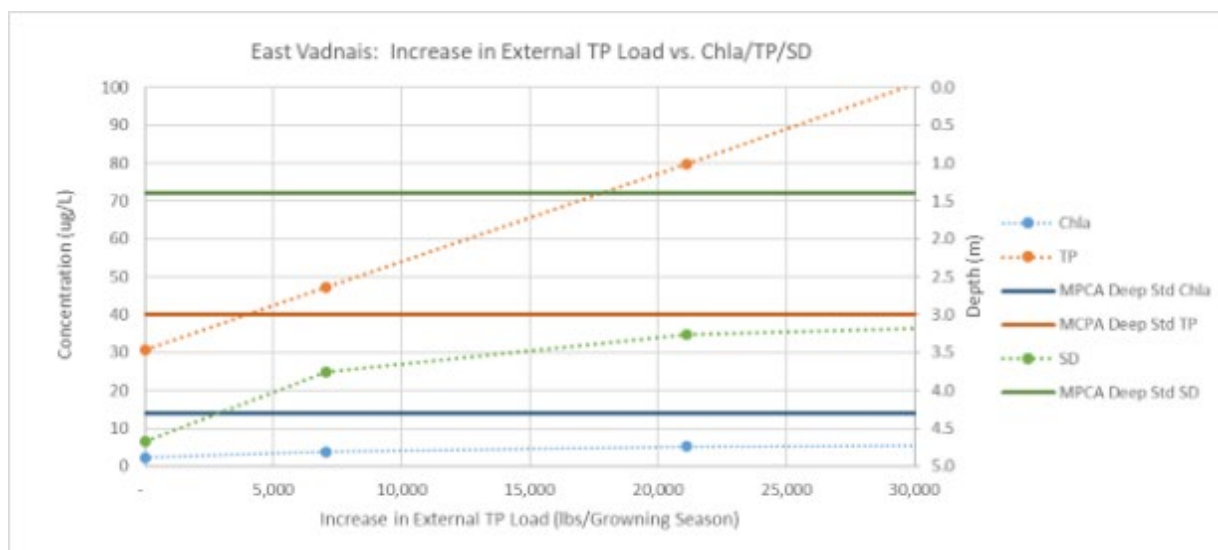


Figure 3-5 East Vadnais Lake Total Phosphorus Loading Response Summary

The modeling exercise indicates that East Vadnais Lake could sustain some increased growing season total phosphorus loads without a significant change in the resulting chlorophyll a concentrations and transparency.

For example, East Vadnais Lake would need to experience an increase in the external total phosphorus load by approximately 4,500 pounds per growing season for the lake to reach the deep lake standards for total phosphorus. Even at the deep lake standard for total phosphorus, both chlorophyll a and Secchi depth transparency only shows slight decreases in water quality, and both still continue to meet the state water quality standards.

The modeling result is similar to what is observed in the water quality relationships based on the East Vadnais Lake monitoring data. This suggests that East Vadnais Lake could have capacity to accept some additional total phosphorus load without significant change in water quality.

3.4.2 White Bear Lake

White Bear Lake eutrophication regression patterns were consistent with East Vadnais Lake. When analyzed pre- and post-zebra mussel infestation, relationships often were stronger in the post-infestation samples; however, variability was still substantial. Slopes were somewhat less steep prior to zebra mussel infestation; however, post-infestation relationships appear to be influenced by persistently low chlorophyll a concentrations, possibly driven by zebra mussel filter feeding. Among the evaluated relationships, chlorophyll a versus Secchi depth was the strongest, with a relatively high R^2 value ($R^2 = 0.72$) in the post-infestation data (Figure 3-6).

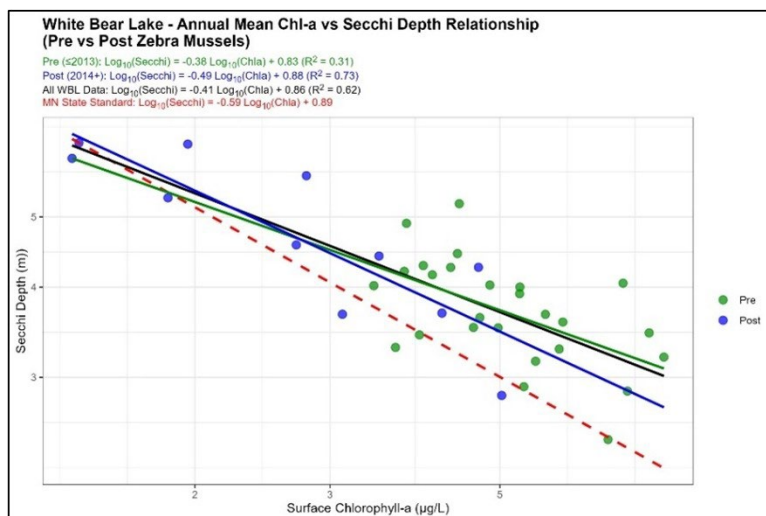
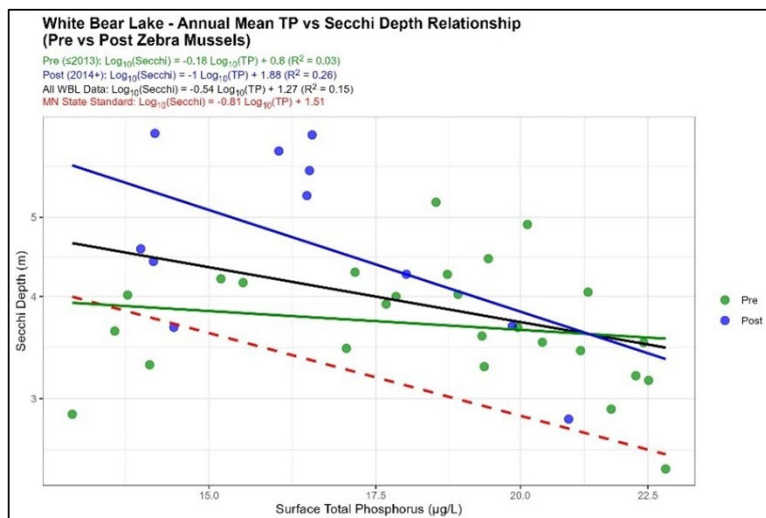
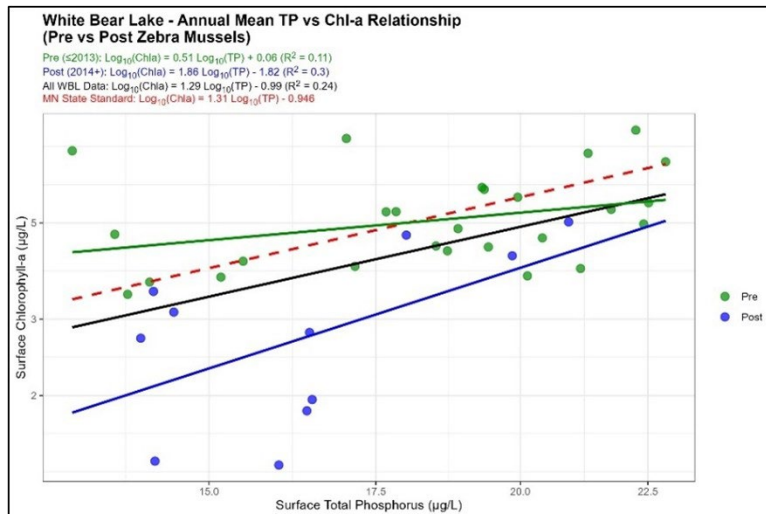


Figure 3-6 White Bear Lake Eutrophication Regression Relationships Pre and Post Zebra Mussel Infestation

3.4.2.1 Loading Response Evaluation

The calibrated (2025) CE-QUAL-W2 model was used to evaluate loading response to increased nutrient loads to White Bear Lake. This evaluation was performed scaling the watershed runoff total phosphorus and total nitrogen loading concentrations by an equivalent factor that resulted in increased external loads to the lake.

The modeling summarized the increase in the total phosphorus and total nitrogen growing season loads from existing (2025) conditions to White Bear Lake as well as the corresponding change in the total phosphorus and chlorophyll a concentration. The estimated change in Secchi depth was estimated using the lake water quality relationship between chlorophyll a and Secchi depth, as developed for White Bear Lake for the period after zebra mussel infestation.

Figure 3-7 shows the resulting total phosphorus and chlorophyll a concentrations (primary axis) and Secchi depth (secondary axis) plotted against the increase in the growing season load. Also included in this plot is the MPCA deep lake standards for these same parameters.

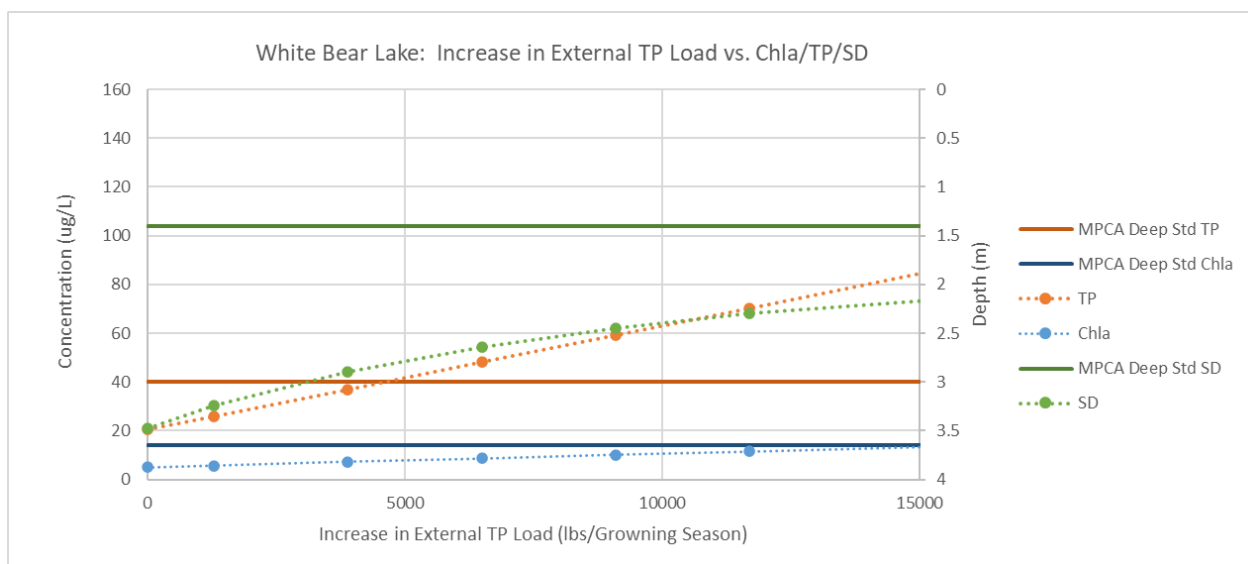


Figure 3-7 White Bear Lake Total Phosphorus Loading Response Summary

The modeling exercise indicates that White Bear Lake total phosphorus concentrations would respond more quickly to increased external loading during the growing season but could sustain some increased growing season total phosphorus loads without a significant change in the resulting chlorophyll a concentrations and transparency.

For example, White Bear Lake would need to experience an increase in the total phosphorus load by just under 5,000 pounds per growing season for the lake to reach the current deep lake standards for total phosphorus. Even at the deep lake standard for total phosphorus, both chlorophyll a and Secchi depth transparency only shows slight decreases in water quality and both still continue to meet the state water quality standards. For White Bear Lake to reach the deep lake standard for chlorophyll a, the lake would need to see an increase in total phosphorus loads by as much as 15,000 pounds per growing season.

The modeling result is similar to what is observed in the water quality relationships based on the White Bear Lake monitoring data, which do not show strong chlorophyll a or Secchi depth response to total phosphorus.

This suggests that White Bear Lake could have capacity to accept some additional total phosphorus load without significant change in water quality.

4 Watershed Modeling

The SPRWS chain of lakes and White Bear Lake's watersheds were modeled using the P8 Urban Catchment Model (P8) application, version 3.5. P8 is a water quality model used to predict the generation and transport of sediment and associated pollutants mobilized by stormwater runoff in urban watersheds. Using this application, Barr developed a water quality model for the study area watersheds to each study lake to estimate watershed runoff volumes and pollutant loads to the study lakes. Although P8 limits the number of model features (maximum of 75 water quality devices and 250 subwatersheds per model); we were able to develop a single P8 model to cover the entire project area. Development of the P8 model is discussed in more detail in the following subsections.

Figure 4-1 shows the P8 watersheds divides, flow patterns, and water bodies modeled as P8 devices for each of the study lake watersheds.

4.1 Hydrology

Model hydrology governs the generation of runoff volume within a watershed during rainfall events, as well as the rate and timing at which this runoff is conveyed to the hydraulic network, including pipes and water quality best management practices (BMPs) within the watershed. P8 serves as a water quality model specifically developed for the long-term simulation of watershed runoff and pollutant transport. For this study, P8 hydrologic outputs (runoff volumes and flow time series at key lake inflow locations) were summarized for use as inputs to the subsequent in-lake modeling and scenario evaluation.

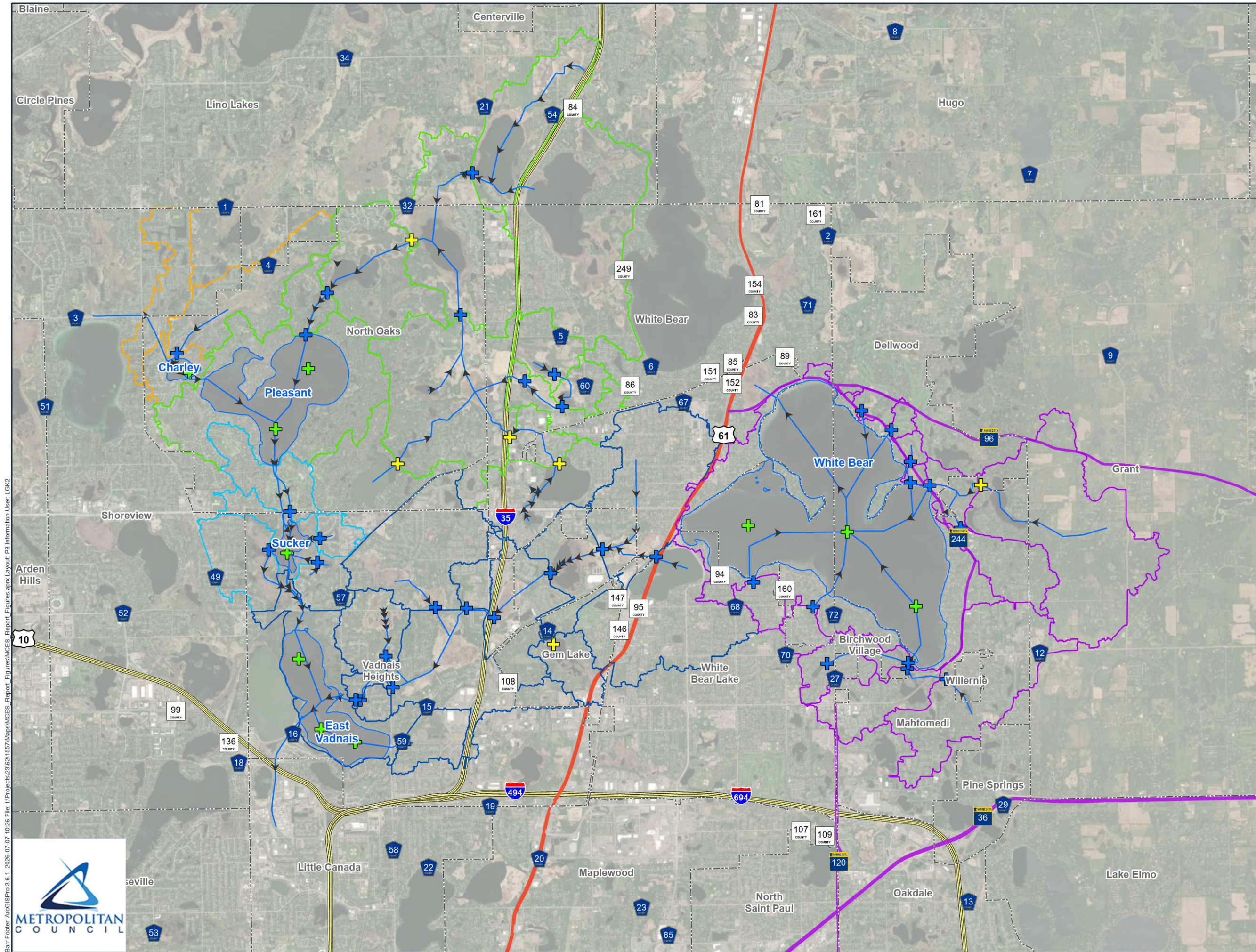
4.1.1 Subwatershed Delineation

Barr autogenerated 46 subwatersheds in the study area leveraging the most current LiDAR data available along with any available storm sewer data provided by the communities. Watersheds were delineated to the water bodies (lake, wetland, pond) that were to be modeled as a P8 device as well as to the ultimate study lakes. These subwatersheds were reviewed and compared against historic watersheds from the RCWD, VLAWMO, and the MnDNR.

Barr assigned an individual identification number in GIS to each P8 subwatershed aligning the receiving water body. An additional attribute field in the GIS database identifies the downstream P8 device to which the subwatershed was routed. These attributes support consistent model bookkeeping and facilitate tracing and summarizing inflows delivered to each study lake.

4.1.2 Subwatershed Inputs

For subwatershed inputs, P8 generates runoff using the SCS Curve Number (CN) methodology. Runoff from impervious areas starts after the cumulative storm rainfall exceeds the specified impervious depression storage, and thereafter the runoff rate equals the rainfall intensity. These methods require the calculation of watershed area, pervious CN, directly and indirectly-connected impervious fractions, and impervious depression storage.



- Study Lakes
- Municipal Boundary
- Flowlines
- P8 Devices**
 - General Device
 - Pond
 - Pipe/Lake Inflow
- Subwatersheds**
 - Charley
 - Pleasant
 - Sucker
 - East Vadnais
 - White Bear Lake
- Streets and Highways**
 - Interstate Highway
 - US Highway
 - State Trunk Highway



0 2,600 5,200
Feet

ESRI World Imagery, 2026

P8 Model Information
MCES White Bear
Lake Study 7A

FIGURE 4-1



4.1.2.1 Watershed and Impervious Area

To estimate the total watershed area to be used in P8, we utilized the subwatersheds delineated above. However, P8 will incorrectly generate pollutant loading from areas of open water, overestimating pollutant loading model-wide. To make sure that the model does not generate pollutant loads using the lake and other open water surfaces, we leveraged the open water area from the 2015 University of Minnesota Land Cover dataset for the Twin Cities Metropolitan area. The P8 subwatershed area entered into P8 reflects the total watershed area less the open water area within the subwatershed.

For the P8 model, Barr determined the total impervious area within each P8 subwatershed based on the two different impervious area datasets that were available for the project area:

- Ramsey County Total Imperviousness (2021) – applied to watersheds fully within Ramsey County
- University of Minnesota Total Imperviousness (2015) – watersheds that were fully outside or straddling Ramsey County

For similar reasons as noted above for the total watershed area, P8 does not include open water surfaces in the estimate of the imperviousness for a subwatersheds. P8 generates pollutant loading (i.e., EMC concentration loading and pollutant buildup and wash-off) from all impervious surfaces, meaning that if open water “impervious” area is included, P8 will incorrectly generate pollutant loading from these open water surfaces, overestimating pollutant loading model wide.

The total impervious area for each subwatershed was then summed and divided by the P8 subwatershed area (not including open water area).

The impervious depression storage determines the volume of rainfall abstracted by impervious surfaces before runoff occurs. The impervious depression storage was set to the P8 default of 0.02 inches.

4.1.2.2 Curve Number

The Curve Number (CN) is an empirical parameter used to predict the potential for runoff from a surface. Typically, the CN applied to a watershed is determined by land use or surface type (e.g., lawn, residential, street or parking lot, etc.) and the infiltration potential of underlying soils. Using the SSURGO soils hydrologic soils groups for each subwatershed and a pervious CN for turf open space in good condition, we area-weighted the CN by soil type for each subwatershed.

4.1.2.3 Watershed Routing

In P8, runoff generated from P8 subwatersheds is routed to hydraulic devices, such as pipes, ponds, infiltration basins, and swales, from which model results may be extracted. Each P8 subwatershed is assigned an outflow device named similarly to the subwatershed.

The outflow device assigned to each P8 subwatershed was determined by the hydraulic routing network based on GIS data provided by communities, MnDNR public watercourse data, LiDAR data, survey, and past information received during the study.

4.1.2.4 Precipitation and Temperature

P8 reads hourly precipitation and daily average temperature data to model a continuous simulation of watershed hydrology and pollutant transport. The lake modeling and calibration are focused on the 2025

growing season, and hourly precipitation data was compiled from MSP International Airport and scaled based on local daily data for 2024 and 2025. Daily average temperature data was also compiled from the MSP International Airport data.

The P8 model was run for the period 10/1/2024 through 10/31/2025 to support the in-lake model calibration.

4.1.2.5 Snowmelt, Evapotranspiration, and Runoff

Snowfall, the generation of snowpack, and snowmelt are modeled processes in P8. Depending on daily-average air temperature, precipitation events in P8 are modeled as either rainfall or snowfall. Over winter and spring months, snowfall accumulates across the watershed as snowpack. As the daily-average air temperature begins to rise in the spring, accumulated snowpack is converted into snowmelt (i.e., runoff). All model parameters related to snowfall, snowpack, and snowmelt were left at default values.

The amount of runoff generated by a precipitation event is impacted by the antecedent moisture content (AMC) of the soil. P8 assumes either AMC2 (typical runoff potential) or AMC3 (highest runoff potential), depending on factors such as how much precipitation has been applied to the watershed over the last five days and whether or not the soil is frozen. Because AMC2 is the typical soil condition assumed by P8, pervious curve numbers applied throughout the watershed reflect AMC2 soil conditions. Default values were assumed for all parameters related to AMC calculation in P8.

4.2 Pollutant Loading

Runoff generated from the pervious and impervious surfaces throughout the watershed by precipitation events mobilizes sediment and the associated pollutant loadings. The rate at which sediment particles accumulate throughout the watershed, as well as the ability of particles to be removed by water quality BMPs via filtration and settling, is defined by particle characteristic assumptions, the associated water quality components related to those particles, and assumptions related to street sweeping operations that are assigned in the P8 model. Pollutant load outputs were summarized to support comparison among modeled scenarios and to provide consistent external loading inputs for downstream lake water quality evaluations.

4.2.1 Particle Characteristics

Sediment characteristics (such as settling velocity, filtration efficiency, mass accumulation rate, etc.) can vary greatly based on the size of individual sediment particles. For this reason, P8 models up to five particle sizes (referred to as particle fractions). The P8 default particle file, NURP50, was developed from National Urban Runoff Program (NURP) studies (USEPA, 1986) and reflects the median (50th percentile) sediment characteristics of all monitored sites. Barr applied the NURP50 particle file and default settings to the study area models to define particle characteristics of the five particle fractions, or classes, which are based on particle size and varying settling velocities. Each particle class is associated with representative percentiles ranging from P0 (representative of dissolved pollutants), P10, P30, P50, and P80 (coarsest particle fraction). NURP50 was used as a screening-level/default particle characterization in the absence of site-specific particle size distribution data for the full study area.

4.2.2 Water Quality Components

The concentration of water quality pollutants (such as TP, lead, total Kjeldahl nitrogen (TKN), etc.) associated with each particle fraction is defined by water quality component assumptions applied in P8.

For example, if the particle composition of TP associated with a particle class is 5,000 mg/kg, then the model assumes that 5,000 mg of TP is transported for every kilogram of that particle class transported. Because the pollutant particle composition associated with sediment can vary greatly depending on sediment size, P8 allows a unique pollutant particle composition (mg/kg) to be applied to each particle class. Barr utilized the NURP50 particle file default water quality component parameters.

4.2.3 Street Sweeping

Street sweeping practices can reduce the buildup of sediment on street surfaces between precipitation events. P8 allows the user to define impervious areas as either “swept” (road surfaces that are swept) or “unswept” (roads and other impervious surfaces that are not swept). The buildup of sediment on “swept” surfaces is reduced based on the sweeping schedule assigned (number of sweeping operations per week) and the sweeper efficiency applied to each sediment particle class. For the study area, the P8 street sweeping routine was not utilized. As a result, modeled sediment accumulation and associated loads do not reflect potential reductions from municipal sweeping programs.

4.3 Devices

4.3.1 Water Quality Treatment Devices

In P8, runoff generated from subwatersheds, along with associated sediment and pollutant loads, is routed to devices that determine how and where flow is hydraulically routed throughout the model. Pipe devices are used for routing and do not provide any runoff volume reduction or water quality treatment, while devices representing water quality treatment BMPs (e.g., ponds, infiltration basins, etc.) have the potential to remove runoff volume and pollutants via particle settling and filtration. Pipe devices were also used at key lake inflow locations to summarize flow and loads delivered to each study lake. Following model runs (including the dry-condition rerun), lake inflow devices were traced to verify contributing areas and to support consistent inflow summaries for downstream lake modeling.

The inputs for each P8 device (e.g., pond, general device) were developed from information provided by the communities (GIS or construction drawings), an outlet survey completed for this study, and past studies. Storage information for the water bodies was generated based on the available LiDAR and bathymetric data (as available), drawings (if available), and National Wetland Inventory information (to estimate a typical depth of the water body if no bathymetric information or drawing information was available).

4.3.1.1 Ponds

Ponds are storage areas with a permanent pool (i.e., dead storage) and a flood pool (i.e., live storage), a defined normal outlet, and overflow. Ponds are typically used to model open water ponds with a simple outlet structure, and P8 requires that the outlet from a pond device be modeled using one of the following five options:

- Orifice (used to model flared end sections, culverts, and pipes)
- Weir
- Riser
- None (no normal outlet)

- Flood pool drawdown time (user specifies time required to drain from flood pool to permanent pool)

Particle scale removal factor, which is set to 1 by default in P8, is used to adjust the particle settling efficiency of a given BMP. Based on the typical depth of the pond, we adjust the particle scale removal factor down if the estimated pond depths are less than 3 feet to account for reduced settling and possible resuspension of material. For ponds with normal depths between 2-3 feet, we used a particle scale removal factor of 0.6 and if less than 2 feet, we use a factor of 0.3.

Ponds with complex outlet structures (e.g. extended detention outlets, pumps) are typically modeled as general devices that allow for the application of a user-defined rating curve. Most of the devices in the project area were modeled as ponds.

4.3.1.2 General Devices

General devices are the most versatile of the P8 device options, allowing the user to input elevation and area along with corresponding discharges for infiltration, normal flow, and overflow. Due to this flexibility, general devices are ideal for modeling:

- Ponds with complex outlets, including pumps
- Lakes, wetlands, or ponds that may have normal water levels that are observed below the outlet elevations at times
- Flow splitters (e.g., structures that divert low flows in one direction while allowing high flows to bypass)

Barr utilized general devices for water bodies that had historic water level monitoring data that suggested the water levels would drop below the outlet elevation at times to capture the water level variability in the system, especially during extended dry periods. PC-SWMM was leveraged to develop the hydraulic discharge curve for the water bodies being modeled as general devices to help capture the outlet hydraulics of more complex systems. A low infiltration rate (0.0001 in/hr) was applied over the area of the water bodies to allow for water level fluctuation within the range historically observed.

Similar to pond devices, the particle scale removal factor, which is set to 1 by default in P8 is used to adjust the particle settling efficiency of a given BMP. Based on the typical depth of the pond, we adjust the particle scale removal factor down if the estimated pond depths are less than 3 feet to account for reduced settling and possible resuspension of material. For ponds with normal depths between 2-3 feet, we used a particle scale removal factor of 0.6, and if less than 2 feet, we used a factor of 0.3.

4.3.1.3 Infiltration Basins

Although users can use both ponds and general devices to model infiltration practices, the P8 model also includes an infiltration basin device that can be used to model infiltration practices, especially those that do not have complicated outlet structures or hydraulics. Infiltration devices were not used in the P8 watershed study area.

4.3.1.4 Pipes

Pipes are the most basic of the P8 device options, only providing routing and time of concentration (TC) inputs. For this study area, pipes are used for the following purposes:

- Summarizing discharge to the study lakes to be used as an input to the more detailed lake modeling

Because the pipe devices are only being used to summarize the model results as inflows to the lake model and are not critical to hydraulic routing, the TC was calculated based on alignment with the model timestep.

4.4 Model Parameters and Continuity

The P8 model requires a variety of input parameters in addition to watershed, pollutant loading, and device data. These parameters define the length of simulation and job control conditions, such as the time step calculation. The parameters selected for the P8 models are discussed in this section. P8 parameters not discussed in this section were left at the default settings as defined in P8 version 3.5.

- Time steps per hour – This parameter defines the number of calculations performed per model hour. The model was set to run at 20 time steps per hour. This selection was based on two factors:
 - 1) The number of time steps required to eliminate hydraulic continuity errors greater than 2 percent. Continuity error reports were reviewed following model runs, and timestep settings were adjusted as needed to maintain acceptable continuity prior to extracting inflow summaries used in downstream modeling.
 - 2) In P8, the TC value in any device must be consistent with the model time step (i.e. the TC value must be in an increment that matches the model time step).
- Passes through Storm File (Warm up period) – A warm up period in the storm file was required because the model assumes that water in the dead storage of ponds contains no water or pollutants. Consequently, the first pass through the storm file results in lower pollutant loading than occurs after the warm up period. For the P8 model, the model was set to do five (5) pass through the storm file, before keeping the model results. The length of the warm-up period is based on the model run period, but typically ranges from at least one to several years. Model input files and run versions were saved using scenario-specific folders/naming conventions to preserve traceability of routing edits, climate inputs, and traced output summaries.

4.5 Model Results

4.5.1 2025 Model Results

There was no specific stormwater flow and water quality monitoring data collected with the study area watersheds as part of this study or provided by the communities to allow for P8 model calibration. However, watershed loading results were reviewed against typical values for urban stormwater runoff and the watershed conditions to confirm reasonable watershed loads and orders of magnitude.

Because the in-lake model was calibrated to 2025 conditions, the P8 model was run for the period from 10/1/2024 through 10/31/2025. The hourly output from the P8 model was then used to generate hourly watershed inflow volumes, concentrations, and loads (via traced lake pipe devices) that were then used as inputs for the in-lake water quality models for each respective lake. Subwatershed boundaries and routing were reviewed to support later extraction of lake inflow summaries. Initial P8 output was used

during the initial hydrodynamic calibration runs of the in-lake models; however, any modifications to these flows as part of the calibration process is further discussed in Section 5.1.

Table 4-1 summarizes the 2025 P8 watershed runoff results for the study lakes.

Table 4-1 P8 Watershed Runoff Results for 2025

Water Year (10/1/2024 - 9/30/2025)									
Lake	Watershed Area (ac)	P8 Watershed Area (ac)	Precipitation (in)	Watershed Runoff (acft)	Runoff Coefficient	Total Phosphorus Load (lbs)	Average Total Phosphorus Concentration (mg/L)	Total Suspended Solids Load (lbs)	Average Total Suspended Solids Concentration (mg/L)
Charley	778	466	36.51	289	0.20	132	0.168	22821	29
Pleasant	7196	4588		2916	0.21	1047	0.132	121068	15
Sucker	1195	979		670	0.23	280	0.154	34666	19
East Vadnais	6095	4669		4838	0.34	1688	0.129	125984	10
White Bear Lake	7334	4296		2874	0.22	1348	0.173	231160	30
In-Lake Modeling Period (5/1/2025-10/31/2025)									
Lake	Watershed Area (ac)	P8 Watershed Area (ac)	Precipitation (in)	Watershed Runoff (acft)	Runoff Coefficient	Total Phosphorus Load (lbs)	Average Total Phosphorus Concentration (mg/L)	Total Suspended Solids Load (lbs)	Average Total Suspended Solids Concentration (mg/L)
Charley	778	466	26.46	210	0.20	95	0.166	15983	28
Pleasant	7196	4588		2260	0.22	793	0.129	85344	14
Sucker	1195	979		478	0.22	200	0.154	24586	19
East Vadnais	6095	4669		3541	0.34	1234	0.128	91256	9
White Bear Lake	7334	4296		2102	0.22	973	0.171	163264	29

4.6 2021 Dry Precipitation Model Results

To reflect the dry conditions, the model was run using the hourly 2021 precipitation and temperature data (reflective of the 10th percentile precipitation) for the MSP International Airport was run through the P8 model. Table 4-2 summarizes the 2021 (Dry Condition) P8 watershed runoff results for the study lakes.

Table 4-2 P8 Watershed Runoff Results for 2021 (Dry Conditions)

Water Year (10/1/2020 - 9/30/2021)									
Lake	Watershed Area (ac)	P8 Watershed Area (ac)	Precipitation (in)	Watershed Runoff (acft)	Runoff Coefficient	Total Phosphorus Load (lbs)	Average Total Phosphorus Concentration (mg/L)	Total Suspended Solids Load (lbs)	Average Total Suspended Solids Concentration (mg/L)
Charley	778	466	27.24	211	0.12	100	0.175	18457	32
Pleasant	7196	4588		2154	0.13	778	0.133	97055	17
Sucker	1195	979		513	0.19	214	0.154	26764	19
East Vadnais	6095	4669		3541	0.26	1226	0.128	92469	10
White Bear Lake	7334	4296		2108	0.13	1013	0.177	182927	32
In-Lake Modeling Period (5/1/2021-10/30/2021)									
Lake	Watershed Area (ac)	P8 Watershed Area (ac)	Precipitation (in)	Watershed Runoff (acft)	Runoff Coefficient	Total Phosphorus Load (lbs)	Average Total Phosphorus Concentration (mg/L)	Total Suspended Solids Load (lbs)	Average Total Suspended Solids Concentration (mg/L)
Charley	778	466	16.65	139	0.13	72	0.189	14388	38
Pleasant	7196	4588		1467	0.15	554	0.139	75770	19
Sucker	1195	979		337	0.20	150	0.164	20901	23
East Vadnais	6095	4669		2350	0.28	849	0.133	72535	11
White Bear Lake	7334	4296		1413	0.14	731	0.191	143063	37

5 Lake Model Development and Calibration

To evaluate the impact of future changes to flow magnitude on the SPRWS chain of lakes and possible augmentation of White Bear Lake, two different models were developed for this effort for Charley Lake, Pleasant Lake, Sucker Lake, East Vadnais Lake, and White Bear Lake. These models include:

- CE-QUAL-W2 – a 2D hydrodynamic and water quality (eutrophication) model developed by [Portland State University](#)
- A mass balance model for non-eutrophication parameters.

5.1 CEQUAL W2 In-Lake Model for Eutrophication Parameters

5.1.1 Model Development

The CE-QUAL-W2 model, version 4.5, was developed for Charley Lake, Pleasant Lake, Sucker Lake, East Vadnais Lake, and White Bear Lake to model the effect of nutrients and solids originating from the Mississippi River and the contributing watersheds on the water quality. We leveraged the various datasets summarized above to estimate the appropriate lake morphometry, water balance, and water quality inputs.

This program includes a complete water balance leveraging lake bathymetry, surface inputs (from the watershed or upstream lakes), groundwater inputs and outputs, direct precipitation and evaporation, and surface outflows through the lake outlet. The model also considers a variety of lake water quality parameters including total phosphorus, internal phosphorus loading, total nitrogen, temperature, stratification, dissolved oxygen, total and dissolved organic carbon, and phytoplankton growth (chlorophyll a), including cyanobacteria.

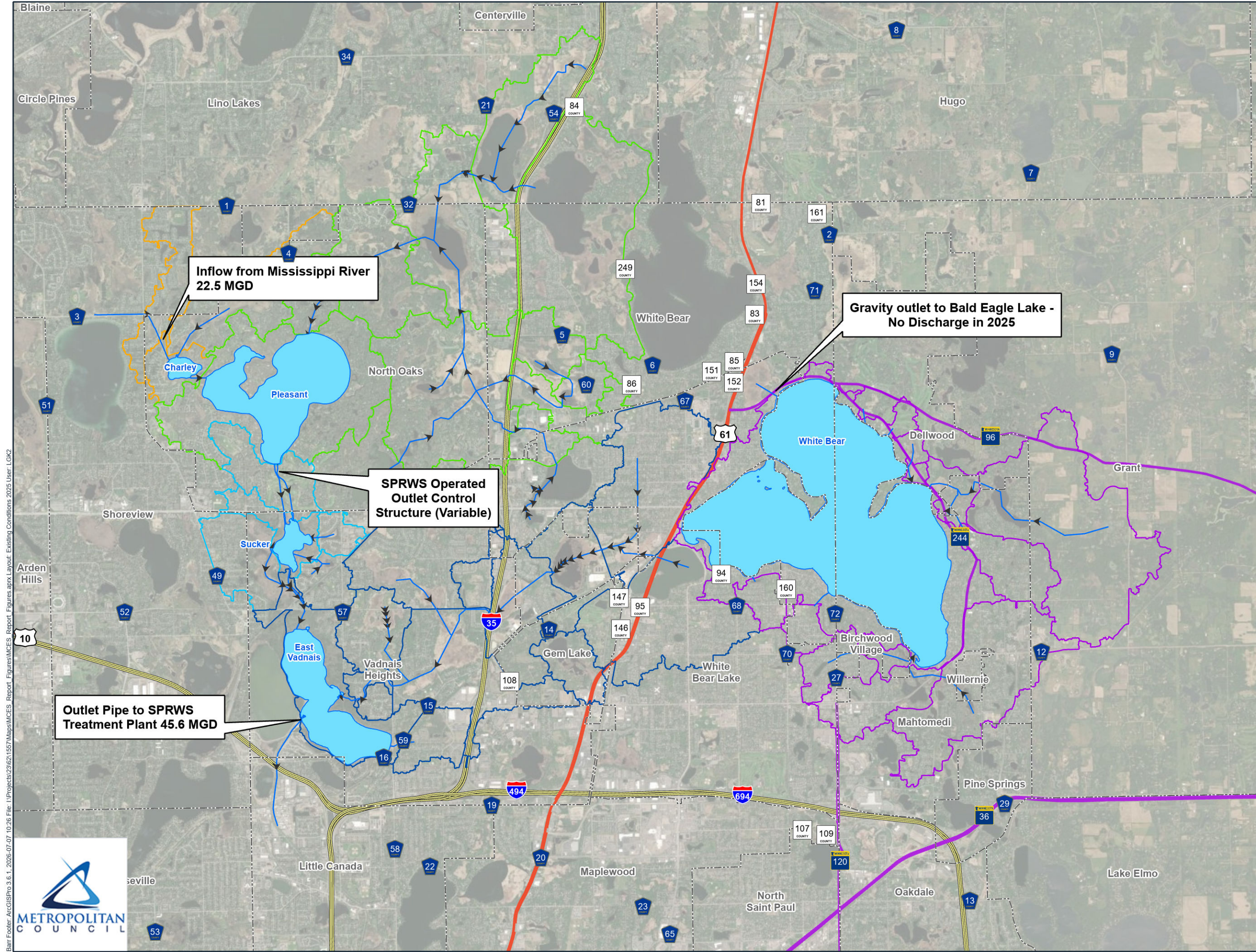
A map showing the existing (2025) watershed and flow conditions for the calibration growing season (June – September, presented as an average in million gallons per day (MGD)) is shown in Figure 5-1.

Appendix 5 provides a more detailed description of the model development and calibration process and results, including time series plots comparing modeling predictions to observed water quality data.

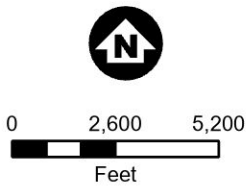
However, in general, a CE-QUAL-W2 model of each lake was developed for the SPRWS chain of lakes as well as White Bear Lake. The model leveraged the following information to inform the inputs to the model (further details about these data sources are included in Section 2 above):

- Lake bathymetry data
- Lake surface outlet information includes survey data, rating curves, information from SPRWS regarding the manual operation of outlets (for Pleasant Lake), and daily discharge data from East Vadnais to the SPRWS treatment plant.
- Flow, temperature, and water chemistry inputs from the Mississippi River into the SPRWS chain of lakes, including 2025, were collected by SPRWS and MCES
- Flow and water chemistry inputs from the watershed runoff to all lakes at key inflow locations,
- Flow from East Vadnais to the SPRWS water treatment plant,

- Oxygen and ferric chloride dosing data from SPRWS
- Climate data (precipitation, windspeed and direction, air temperature, dewpoint, and cloud cover) and evaporation and groundwater exchange information for White Bear Lake from the MnDNR, and
- Initial (in-lake water column) conditions chemistry for each lake. In-lake water quality data in 2025 was collected by SPRWS, VLAWMO, and Ramsey County Public Works. Historic data was also leveraged to inform assumptions for water quality inputs and fractions of pollutant to inform inputs to the model.



- Municipal Boundary
- Study Lakes
- Flowlines
- Subwatersheds
 - Charley
 - Pleasant
 - Sucker
 - East Vadnais
 - White Bear Lake
- Streets and Highways
 - Interstate Highway
 - US Highway
 - State Trunk Highway



ESRI World Imagery, 2026

Existing Conditions 2025
MCES White Bear
Lake Study 7A

FIGURE 5-1

BARR

Barr Footer ArcGISPro 3.6.1, 2025-07-07 10:26 File: \\Projects\\23621\\Maps\\MCES_Report_Figures.aprx Layout: Existing Conditions 2025 User: LGK2



5.1.2 Model Calibration

The CE-QUAL-W2 model calibration process proceeded stepwise with a water balance, lake temperature, water quality constituents (e.g., nutrients), and then model-derived constituents such as phytoplankton (e.g., chlorophyll a) and dissolved oxygen. The calibration process for each step was generally completed from upstream to downstream through the SPRWS chain of lakes as the flow and pollutant loads from one lake were routed to the next lake downstream.

The model was calibrated for the May 7 through October 10, 2025 period for the Charley, Pleasant, Sucker, and East Vadnais chain of lakes, and from May 19 through October 6, 2025. The model start date was dictated by the date on which in-lake monitoring data was available to set model initial conditions. To summarize the model results for calibration and evaluation purposes, we selected a point within each lake model domain that reflects one of the historic monitoring locations and deep hole locations to provide for consistent comparison approaches. Results were summarized for the June 1 through September 30 time period to align with Minnesota eutrophication standards.

Ultimately, the calibrated CE-QUAL-W2 model is an appropriate tool that can be used to evaluate the effect of future flow and load scenarios as part of Study 7A to understand the lake eutrophication response as a function of these flows and loads. The model can be used to accurately predict the effect of external and internal phosphorus and nitrogen loads on in-lake concentrations of phosphorus and nitrogen as well as chlorophyll a response to changes in loading as a result of the anticipated increased flows and augmentation of White Bear Lake.

5.1.2.1 Water Balance Calibration

Changes in lake water level are directly related to changes in lake water volume. In addition to using the lake bathymetric data, the model tracks inflows and outflows through each lake to estimate lake volume and water levels.

The main inflows tracked for this effort included:

- Water pumped from the Mississippi River (and discharges from each respective upstream lake in the SPRWS chain of lakes),
- Watershed runoff, and
- Direct precipitation

The main losses of water for this model:

- Evaporation from the lake surfaces,
- Discharge through the surface outlets,
- Net groundwater exchange (applicable to White Bear Lake only)
- Ultimately, the water discharged from East Vadnais Lake to the SPRWS water treatment plant.

The predicted water levels were then compared to the observed water levels for 2025 to confirm that the model accurately captured the average water levels and water level fluctuations during the calibration period. Table 5-1 summarizes the average water level based on the monitoring and modeled elevations. Table 5-2 provides a summary of the growing season water balance for each lake, summarized in MGD.

Table 5-1 2025 Growing Season Average Water Elevation Summary

Lake	Lake Elevation (ft NAVD88)	
	Model	Measured
Charley	893.5	893.4
Pleasant	892.9	892.9
Sucker	882.5	883.7
East Vadnais	882.5	883.0
White Bear	923.1	923.2

Table 5-2 2025 Growing Season Water Balance Summary (in MGD)

Water Balance Term	Charley	Pleasant	Sucker	East Vadnais	White Bear
Flow From River (MGD)	22.5	0.0	0.0	0.0	0.0
Flow Upstream Lakes (MGD)	0.0	22.8	28.6	30.0	0.0
Direct Precipitation (MGD)	0.2	2.9	0.3	1.9	11.5
Watershed Runoff (MGD)	0.5	5.0	1.1	13.0	4.7
WBL Augmentation (MGD)	0.0	0.0	0.0	0.0	0.0
Surface Discharge (MGD)	-22.8	-28.9	-30.0	0.0	0.0
Evaporation (MGD)	-0.2	-2.8	-0.3	-1.6	-10.5
Net Groundwater Outflow (MGD)	0.0	0.0	0.0	0.0	-2.4
Flow to SPRWS Treatment Plan (MGD)	0.0	0.0	0.0	-45.6	0.0

5.1.2.2 Lake Water Quality Calibration

Following the water balance calibration, we worked through the process of calibrating lake temperature, then water quality constituents (e.g., nutrients (total phosphorus, total nitrogen, total carbon, etc.), and then model-derived constituents such as phytoplankton (e.g., chlorophyll a) and dissolved oxygen.

To capture the anticipated lake stratification and anticipated turnover, lake water temperatures were calibrated by changing the wind sheltering coefficient for each lake, which changes how wind affects mixing and convective and evaporative heat loss.

Nutrient calibration was largely a function of modifying parameters that controlled phosphorus and nitrogen internal loading; watershed loading and loading from the Mississippi River were not modified as part of the calibration process.

Phytoplankton calibration (which ultimately translates to chlorophyll a concentrations) for Charley, Pleasant, Sucker, and East Vadnais Lake was achieved by modifying Michaelis-Menten coefficients for maximum growth and nutrient limitation (e.g., half-saturation coefficients). To calibrate White Bear Lake, two phytoplankton types were modeled to simulate algae that are representative of green algae and nitrogen-fixing cyanobacteria. Intermittent nitrogen and phosphorus limitation are responsible for the

timing of observed phytoplankton populations and the magnitude and timing of growth in White Bear Lake. Calibration was achieved by allowing for nitrogen fixation (cyanobacteria), application of different half-saturation coefficients and light sensitivities for the green algae and cyanobacteria groups.

Table 5-3 summarizes the nutrient growing season concentrations based on the 2025 calibration.

Table 5-3 2025 Growing Season Nutrient Calibration

Lake	Total Phosphorus (mg/L)		Total Nitrogen (mg/L)		Chl a (ug/L)	
	Model	Measured	Model	Measured	Model	Measured
Charley	0.096	0.096	1.6	1.55	30	22
Pleasant	0.087	0.091	1.3	1.11	11.0	19
Sucker	0.039	0.040	0.9	1.06	4.3	10
East Vadnais	0.029	0.028	0.8	0.79	2.6	4.6
White Bear	0.020	0.019	0.7	0.62	4.7	4.6

Table 5-4 includes a summary of the 2025 growing season total phosphorus mass balance terms, including inflows and outflows in pounds per growing season.

Table 5-4 2025 Growing Season Total Phosphorus Loads

Term	Charley	Pleasant	Sucker	East Vadnais	White Bear
Flow From River (lbs/GS)	2781	0	0	0	0
Flow From Upstream Lakes (lbs/GS)	0	2087	2605	1293	0
Watershed Runoff (lbs/GS)	271	629	597	7371	1439
Internal Load from Sediments (lbs/GS)	518	1527	635	3516	3554
WBL Augmentation (lbs/GS)	0	0	0	0	0
Surface Discharge (lbs/GS)	2084	2605	1293	0	0
Net Groundwater Outflow (lbs/GS)	0	0	0	0	50
Flow to SPRWS Treatment Plant (lbs/GS)	0	0	0	2525	0
Flux to Sediments (lbs/GS)	721	172	794	4398	2733

Using the average whole lake area for the calibration period, we estimated the calibrated total phosphorus internal loading rate for each study lake. These loading rates are summarized in Table 5-5. These internal loading rates generally align with typical internal loading rates for many Twin Cities metropolitan area lakes (Huser et. al., 2009; Pilgrim et. al., 2007).

Table 5-5 2025 Total Phosphorus Internal Loading Rates

Estimated Internal Phosphorus Loading Rates (mg/m ² /day)	Charley	Pleasant	Sucker	East Vadnais	White Bear
Calibration	14.4	2.3	10.3	8.7	1.4

5.2 Mass Balance Model for Non-Eutrophication Parameters

5.2.1 Model Development

Leveraging the same lake morphology used to develop the CE-QUAL-W2 model and the calibrated water balances from the CE-QUAL-W2 model for each study lake, a mass balance spreadsheet model was developed to calculate the effect of changes in Mississippi River flows and loads on non-eutrophication parameters as they move through the SPRWS chain of lakes system, as well as in White Bear Lake. This mass balance model was used to provide estimates of water quality parameters as a function of lake morphology, constituent loading, and constituent losses. Once calibrated to the 2025 data, this model was used as a tool to predict the change in estimated water quality in each lake in the SPRWS chain of lakes as a result in changes in flows, pollutant loads, and possible augmentation scenarios.

This mass balance model considers all constituent loads from external sources (e.g., watershed runoff, flows from the upstream lake or Mississippi River), losses through the surface outlet or discharges to groundwater (if applicable), and an estimate of constituent capture and removal for each lake system using an empirical coefficient called the retention coefficient.

5.2.1.1 Selection of Non-Eutrophication Water Quality Parameters

Parameters that were modeled using the mass balance model were dependent on the results of the monitoring conducted in 2025, along with selection criteria for non-eutrophication parameters to be modeled, as follows:

- if the mean of the parameter could not be calculated for the Mississippi River, either because there were few (or no) observations or 80% or more of the observations were censored, the parameter will not be modeled, and
- if the mean of the parameter at the Mississippi River is less than the mean of Sucker South, the East Vadnais sites, and White Bear Lake sites (when a mean exists at one or more of those sites), the parameter will not be modeled,
- if the mean of the parameters exists for the Mississippi River, but there are no means at any of the other sites for comparison, the parameter will not be modeled, and
- the parameter will be modeled if the mean of parameter exists for the Mississippi River and the other conditions do not apply; in addition
- parameters where one or more of the Sucker South and East Vadnais sites had a mean larger than one or more of the White Bear Lakes sites were considered for modeling and
- parameters where Sucker South and all East Vadnais sites were missing means but there was a mean for at least one White Bear Lake were considered for modeling.

The final list of non-eutrophication water quality parameters that were evaluated using the mass balance model is summarized in Table 5-6.

Table 5-6 Non-Eutrophication Parameters

Parameter	Comments on Selection Criteria
Solids, total suspended	Detected at the Mississippi River and concentration above downstream lakes
Solids, total dissolved	Detected at the Mississippi River and concentration above downstream lakes
Chloride	Detected at the Mississippi River
Hardness, as CaCO ₃	Detected at the Mississippi River and concentration above downstream lakes
Alkalinity, total, as CaCO ₃	Detected at the Mississippi River and concentration above downstream lakes
Arsenic	Detected at the Mississippi River and concentration above downstream lakes
Aluminum	Detected at the Mississippi River and concentration above downstream lakes
Barium	Detected at the Mississippi River and concentration above downstream lakes
Copper	Detected at the Mississippi River and concentration above downstream lakes
Flouride	Detected at the Mississippi River and concentration above downstream lakes
Magnesium	Detected at the Mississippi River and concentration above downstream lakes
Manganese	Detected at the Mississippi River and concentration above downstream lakes
Sulfate, as SO ₄	Detected at the Mississippi River and concentration above downstream lakes
Chlorine dioxide	Detected at the Mississippi River and concentration above downstream lakes
Gross Alpha (radiation)	Detected at the Mississippi River and concentration above downstream lakes
Gross Beta (radiation)	Detected at the Mississippi River and concentration above downstream lakes
Radium 226	Detected at the Mississippi River and concentration above downstream lakes
Radium 228	Detected at the Mississippi River and concentration above downstream lakes
Micro plastic particles, total	Detected at the Mississippi River and concentration above downstream lakes
Calcium	No 2025 samples for the Mississippi River; however, Sucker South, East Vadnais North, and East Vadnais South had mean higher than the mean at White Bear Lake 234.

Examples of water quality parameters that were screened out for mass balance modeling purposes included the following:

- Zinc was detected at the Mississippi River, but was not modeled, as the mean concentration was lower than downstream lakes
- Perfluoro butanoic acid (PFBA) was detected at the Mississippi River but were not modeled as the mean concentration was lower than downstream lakes.
- Atrazine was detected at the Mississippi River (although 80% censored), but was not detected (100% censored) at all downstream lakes and therefore was not modeled.

5.2.2 Model Calibration

To calibrate the mass balance model for the non-eutrophication parameters, the calibrated water balance from the 2025 CE-QUAL-W2 model was used to estimate the inflow and outflow water loads for the growing season (6/1/2025 through 9/30/2025). Key parameters included for the water balance included the following inflows and outflows:

- Inflows:
 - Watershed Runoff
 - Direct Precipitation
 - Flow from the Mississippi River (Charley Lake) or upstream lakes (Pleasant, Sucker, East Vadnais Lakes).
- Outflows:
 - Surface outflow
 - Evaporation
 - Net Loss to Groundwater (groundwater loss term only applicable to White Bear Lake)

Using the water volumes from CE-QUAL-W2, we then selected the appropriate water quality concentrations to apply to each term in the water balance. This included the following assumptions:

- We assumed there was no atmospheric deposition or loading due to direct precipitation for any of the non-eutrophication water quality parameters.
- We used the average 2025 concentration for the Mississippi River Fridley for the inflow concentration from the Mississippi River.
- For in-lake concentration, we used the average 2025 concentrations for each lake. Where concentrations for parameters do not exist, values were determined by ratios with other parameters, linear regression, or interpolation using upstream and/or downstream sites, or using the mean from previous years.
- No stormwater or watershed runoff monitoring was completed for this study. To estimate the 2025 watershed inflow concentrations, we used the P8 model to estimate the total suspended solids and total copper concentrations for the watershed runoff, as the P8 NURP50 particle file tracks these pollutants and estimates runoff concentration.
- For the remaining non-eutrophication parameters, we leveraged the [National Water Quality Monitoring Council Water Quality Portal](#) to estimate the runoff concentrations using average water quality data for streams in Ramsey and Washington Counties, Minnesota (NWQMC, 2026). Due to limited data for Minnesota for Gross Alpha (radiation), Gross Beta (radiation), Radium 226, and Radium 228, we used the average stream flow concentrations based on the entire US dataset.
- For Microplastics concentrations in the watershed runoff, we leveraged stream results from the CRWD Microplastics sampling report for 2020 to 2025 (CRWD 2025).

- We assumed no loss of pollutants due to evaporation.
- For losses via the surface outlet or to the net loss to groundwater, we assume the 2025 average lake concentration to estimate the load leaving the lake.

To estimate a pollutant retention coefficient for each lake and each water quality parameter, we initially leveraged the approach from Dillon and Rigler (1974) that used a steady state mass balance model to describe the fraction of external pollutant loading that was retained within a lake. The retention coefficient is expressed as a function of lake morphometry (depth, surface area, volume) and the hydraulic residence time (**Equation 1**). The retention coefficient was estimated based on the following equation that considers the mass off pollutant outflow in relation to the sum of all pollutant inflows.

$$R_{exp} = 1 - \frac{q_o [P]_o}{\sum q_i [P]_i}$$

Where R_{exp} is the retention coefficient, q_o is the outflow discharge volume, ($\text{g}\cdot\text{m}^3$), $[P]_o$ is the outflow concentration, q_i is the inflow volumes, and $[P]_i$ is the inflow concentrations.

Equation 1 Retention coefficient equation from Dillon and Rigler (1974).

Once the retention coefficient was calculated, the following equation (Equation 2) was applied to predict the pollutant concentration:

$$[P] = \frac{L(1 - R_{exp})}{\bar{z}_p}$$

Where $[P]$ is the concentration ($\text{g}\cdot\text{m}^3$) in the water, L is the loading ($\text{g}\cdot\text{m}^3 \cdot \text{yr}$), R_{exp} is the retention coefficient, z is the lake's mean depth (m), and p is the replenishment coefficient or the fraction of the water volume lost annually through the outflow.

Equation 2 Predicted concentration equation from Dillon and Rigler (1974).

In general, the Dillon and Rigler equation worked well at estimating the retention coefficient and predicting all non-eutrophication pollutant concentrations in the SPRWS chain of lakes. However, because of the generally landlocked nature and long residence time of White Bear Lake, for most parameters, the Dillon and Rigler empirical relationship did not typically result in retention coefficients and predicted concentrations that accurately reflected the concentrations observed in White Bear Lake.

In general, we made the following assumptions during the mass balance calibration process based on our understanding of each non-eutrophication parameters, including if the parameters are typically conservative/non-reactionary and typical chemistry and possible response in lake systems and conditions.

- If a retention coefficient predicted was slightly negative for SPRWS chain of lakes, we assumed the retention coefficient was zero (conservative, no retention). This modification was made for all parameters when a negative occurred, with the exception of Total Manganese in Pleasant Lake.

- This lake is highly anoxic in the hypolimnion and manganese is likely released from the bottom sediments during these conditions. Therefore, a negative retention coefficient is accurate.
- For parameters where we expected White Bear Lake to retain pollutants similar to the SPRWS chain of lakes, we back calculated what the retention coefficient should be to accurately predict the 2025 lake concentration. This approach was used for total suspended solids, aluminum, copper, manganese, sulfate, & radium 226.
- For the remaining non-eutrophication White Bear Lake parameters, we used a simple mass balance equation to predict the lake concentration based on the mass in the lake as well as the inflows and outflows from the lake during the model period (Equation 3). This conservatively assumes there is no pollutant retention in White Bear Lake for these parameters.

$$C_t = \frac{W_0 + W_{in} - W_{out}}{V}$$

Where C_t is the concentration of the substance in the lake at time (mg/L), W_0 is the starting (initial) mass load (kg) in the lake, W_{in} is the inflow mass load (kg) in the lake, W_{out} is the outflow mass load (kg), and V is the lake volume (m³).

Equation 1 Simple mass balance.

5.2.2.1 Model Calibration Results

Table 5-7 summarizes the mass balance model calibration results for the 2025 period, including the retention coefficient or approach (if using the simple mass balance approach to predict concentration), observed pollutant concentration, and predicted pollutant concentration for each.

Table 5-7 2025 Mass Balance Calibration Results for Non-Eutrophication Parameters

Parameters	Unit	Charley Lake			Pleasant Lake			Sucker Lake			East Vadnais Lake			White Bear Lake		
		Retention Coefficient/ Approach	Observed	Predicted	Retention Coefficient/ Approach	Observed	Predicted	Retention Coefficient/ Approach	Observed	Predicted	Retention Coefficient/ Approach	Observed	Predicted	Retention Coefficient/ Approach	Observed	Predicted
Solids, total suspended	mg/l	0.64	3.98	3.94	0.33	3.70	3.37	0.48	2.18	2.16	0.61	1.61	1.56	0.65	3.63	3.60
Solids, total dissolved	mg/l	0.00	274	262	0.01	246	224	0.02	238	236	0.00	223	204	SMB	180	188
Chloride	mg/l	0.00	26.54	22.77	0.07	26.99	24.57	0.00	29.80	27.19	0.00	36.00	31.93	SMB	52.23	53.00
Hardness, as CaCO3	mg/l	0.04	199	197	0.11	164	150	0.00	169	161	0.10	141	136	SMB	92	96
Alkalinity, total, as CaCO3	mg/l	0.01	181	179	0.11	150	137	0.00	151	148	0.01	142	137	SMB	83	87
Arsenic, Total	mg/l	0.00	0.0017	0.0016	0.19	0.0013	0.0011	0.00	0.0014	0.0012	0.00	0.0014	0.0012	SMB	0.0020	0.0020
Aluminum, Total	mg/l	0.77	0.0164	0.0163	0.91	0.0025	0.0023	0.55	0.0025	0.0025	0.91	0.0026	0.0025	0.64	0.0118	0.0117
Barium, Total	mg/l	0.09	0.057	0.056	0.00	0.052	0.044	0.00	0.050	0.050	0.00	0.048	0.037	SMB	0.040	0.040
Calcium, Total	mg/l	0.00	48.27	46.24	0.14	39.23	35.73	0.00	39.69	38.64	0.11	34.33	33.19	SMB	20.69	21.94
Copper, Total	mg/l	0.19	0.0035	0.0035	0.69	0.0018	0.0017	0.37	0.0015	0.0015	0.27	0.0042	0.0041	0.83	0.0014	0.0014
Fluoride	mg/l	0.09	0.112	0.111	0.10	0.112	0.102	0.14	0.098	0.097	0.23	0.094	0.091	SMB	0.085	0.091
Magnesium, Total	mg/l	0.24	19.07	18.87	0.12	16.12	14.68	0.00	17.03	15.92	0.13	14.40	13.92	SMB	9.53	10.07
Manganese, Total	mg/l	0.37	0.084	0.083	-0.73	0.233	0.212	0.72	0.067	0.067	0.78	0.034	0.033	0.72	0.036	0.040
Sulfate, as SO4	mg/l	0.00	14.77	14.11	0.49	9.86	8.98	0.00	12.95	10.92	0.62	8.25	7.98	0.76	3.89	3.93
Chlorine dioxide	mg/l	0.00	0.446	0.439	0.00	0.430	0.320	0.28	0.295	0.293	0.48	0.100	0.097	SMB	0.380	0.372
Gross Alpha (radiation)	pCi/l	0.07	2.41	2.38	0.19	1.59	1.45	0.00	2.21	1.52	0.00	1.72	1.51	SMB	1.39	1.38
Gross Beta (radiation)	pCi/l	0.00	3.91	3.87	0.00	3.70	2.90	0.00	4.02	3.52	0.00	3.84	2.71	SMB	4.06	4.00
Radium 226	pCi/l	0.10	0.258	0.256	0.38	0.250	0.227	0.00	1.770	0.363	0.84	0.241	0.233	0.88	0.049	0.050
Radium 228	pCi/l	0.00	0.821	0.813	0.00	0.843	0.734	0.89	0.093	0.092	0.00	0.430	0.314	SMB	0.635	0.658
Micro plastic particles, total	mpp/l	0.17	4905	4854	0.85	570	519	0.00	7288	520	0.82	872	843	SMB	1191	1174

Note: SMB = Simple mass balance. See Equation 3

6 Scenario Evaluation

Using the calibrated CE-QUAL-W2 model for eutrophication parameters and the calibrated mass balance models for the non-eutrophication parameters, we determined the water quality results for nine flow and augmentation scenarios defined by the projected summer peak community water demands as provided by MCES and the estimated augmentation rate for White Bear Lake from the MnDNR. In addition to determining concentration differences as a screening tool to identify potential impacts, the mass balance will be used to determine the lake water quality responses for high-risk constituents to determine the magnitude of their impacts for each scenario.

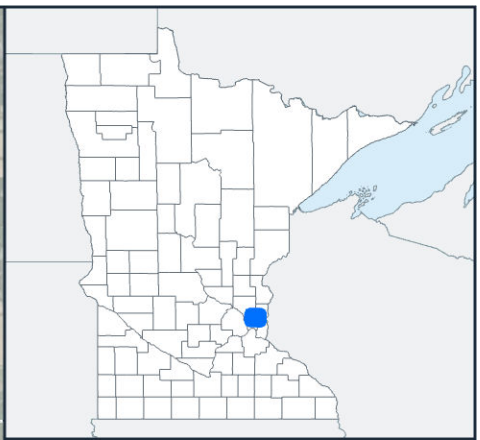
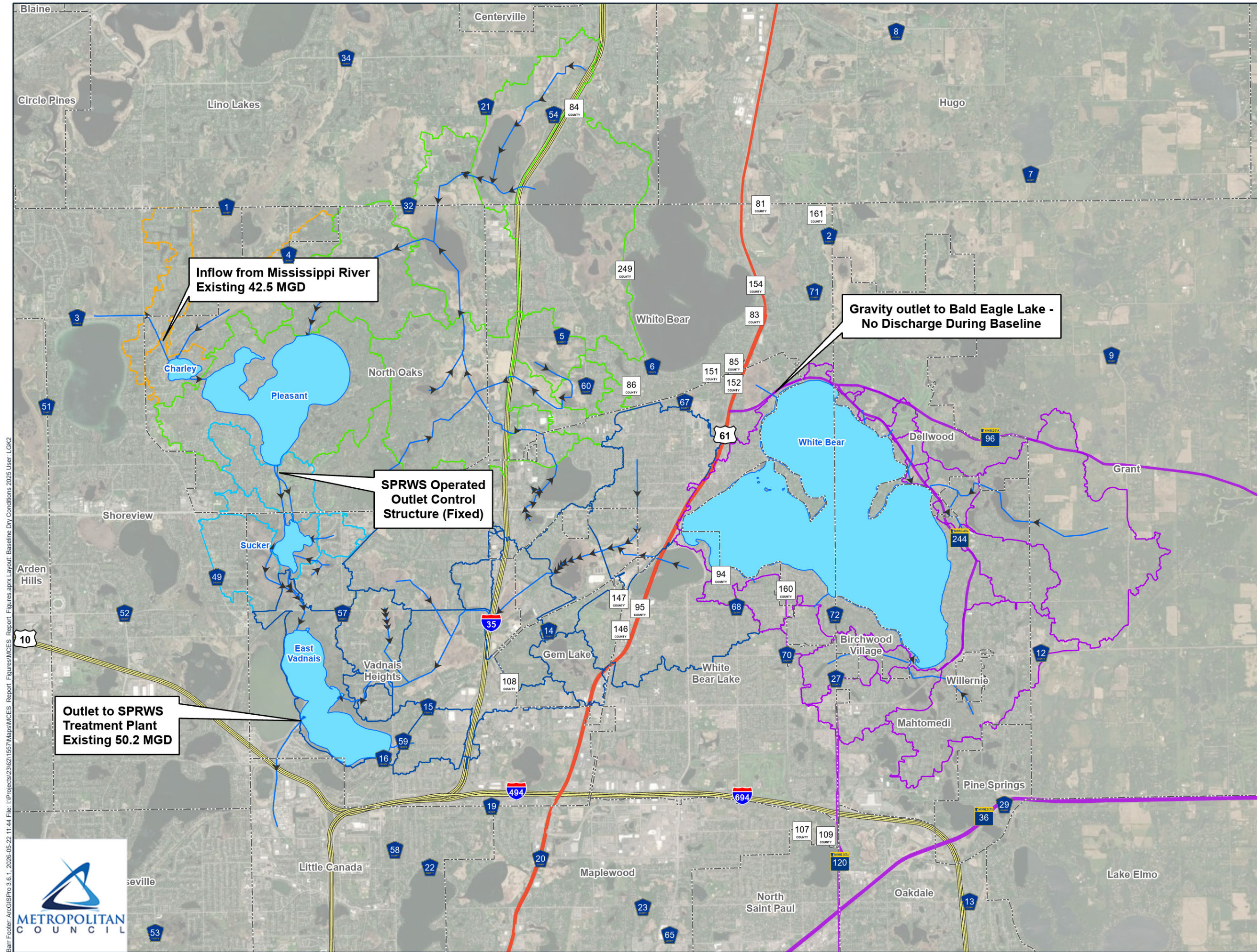
To limit the number of modeling scenarios, we assumed the modeling scenarios will consider precipitation and runoff for a dry climatic year, which can be expected to require the highest flow rates from the Mississippi River and the rate of augmentation for White Bear Lake.

In addition to the nine scenarios, we also developed a dry (2021) baseline condition model run based on the calibrated CE-QUAL-W2 and mass balance model, dry climatic and watershed runoff conditions to allow for a relative comparison of the scenarios to a baseline condition without the future pumping scenarios or augmentation.

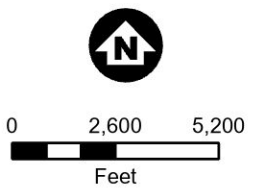
The nine scenarios are outlined below:

- Scenario 1: SPRWS supplies water to all communities that resulted in the highest projected water demands with treated surface water (no White Bear Lake augmentation)
 - 1A: Existing Conditions
 - 1B: 2050
 - 1C: Ultimate
- Scenario 2: SPRWS supplies water to its own customers only and the augmentation of White Bear Lake from Sucker Lake (surrounding communities remain on groundwater supplies)
 - 1A: Existing Conditions
 - 1B: 2050
 - 1C: Ultimate
- Scenario 3: SPRWS supplies water to its own customers only and augmentation of White Bear Lake from East Vadnais Lake (surrounding communities remain on groundwater supplies)
 - 1A: Existing Conditions
 - 1B: 2050
 - 1C: Ultimate

Figure 6-1 through Figure 6-4 show the baseline conditions as well as the three scenarios, including the daily flow summaries for pumping from the Mississippi River, discharge to the SPRWS treatment plant, and augmentation flows to White Bear Lake (applicable for Scenarios 2 & 3 only).



- Municipal Boundary
- Study Lakes
- Flowlines
- Subwatersheds
 - Charley
 - Pleasant
 - Sucker
 - East Vadnais
 - White Bear Lake
- Streets and Highways
 - Interstate Highway
 - US Highway
 - State Trunk Highway

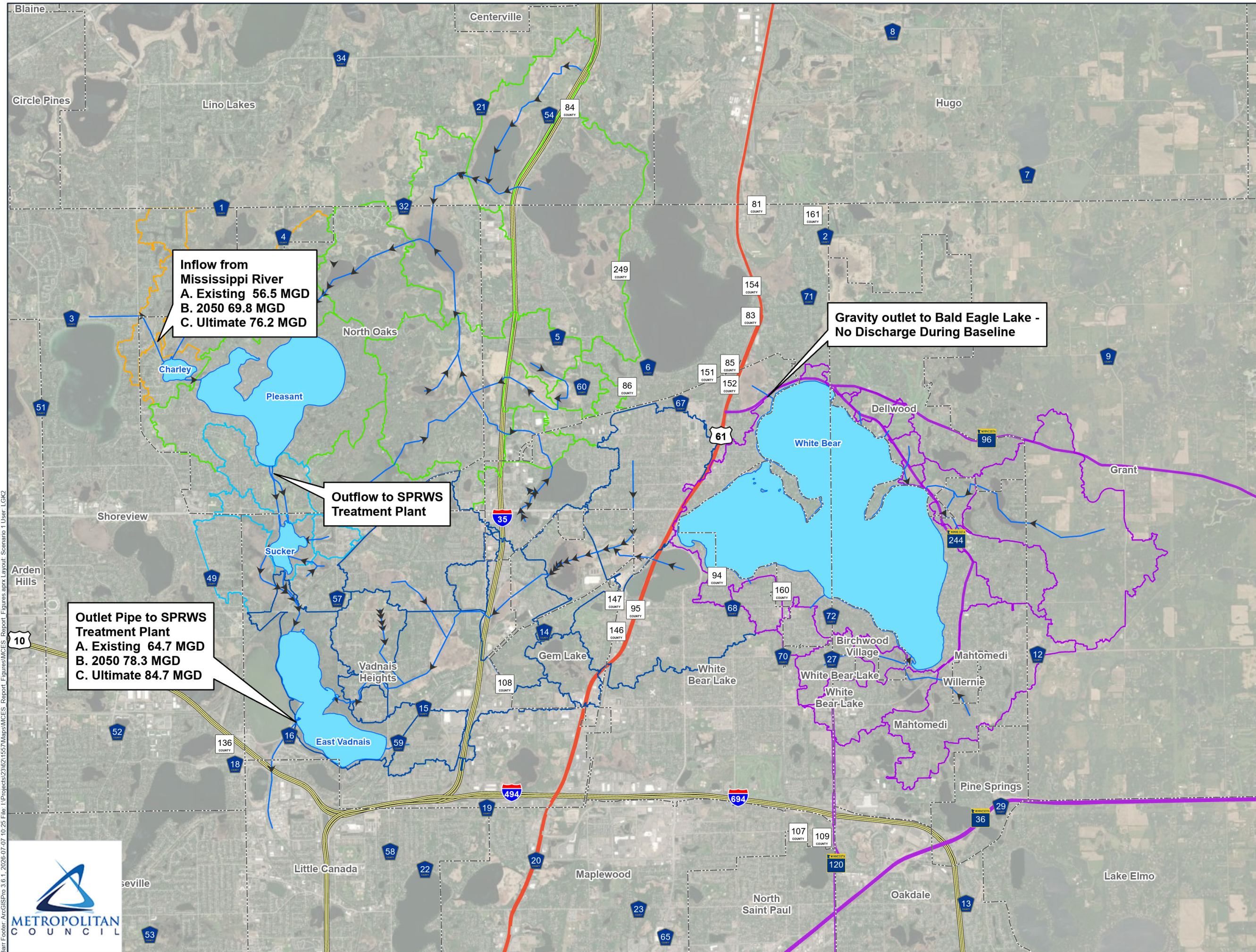


ESRI World Imagery, 2026

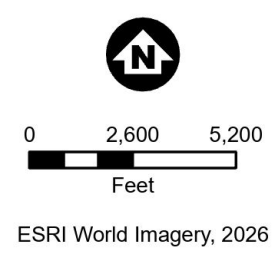
Baseline Dry Conditions 2025
MCES White Bear
Lake Study 7A

FIGURE 6-1





- Municipal Boundary
- Study Lakes
- Flowlines
- Subwatersheds
 - Charley
 - Pleasant
 - Sucker
 - East Vadnais
 - White Bear Lake
- Streets and Highways
 - Interstate Highway
 - US Highway
 - State Trunk Highway



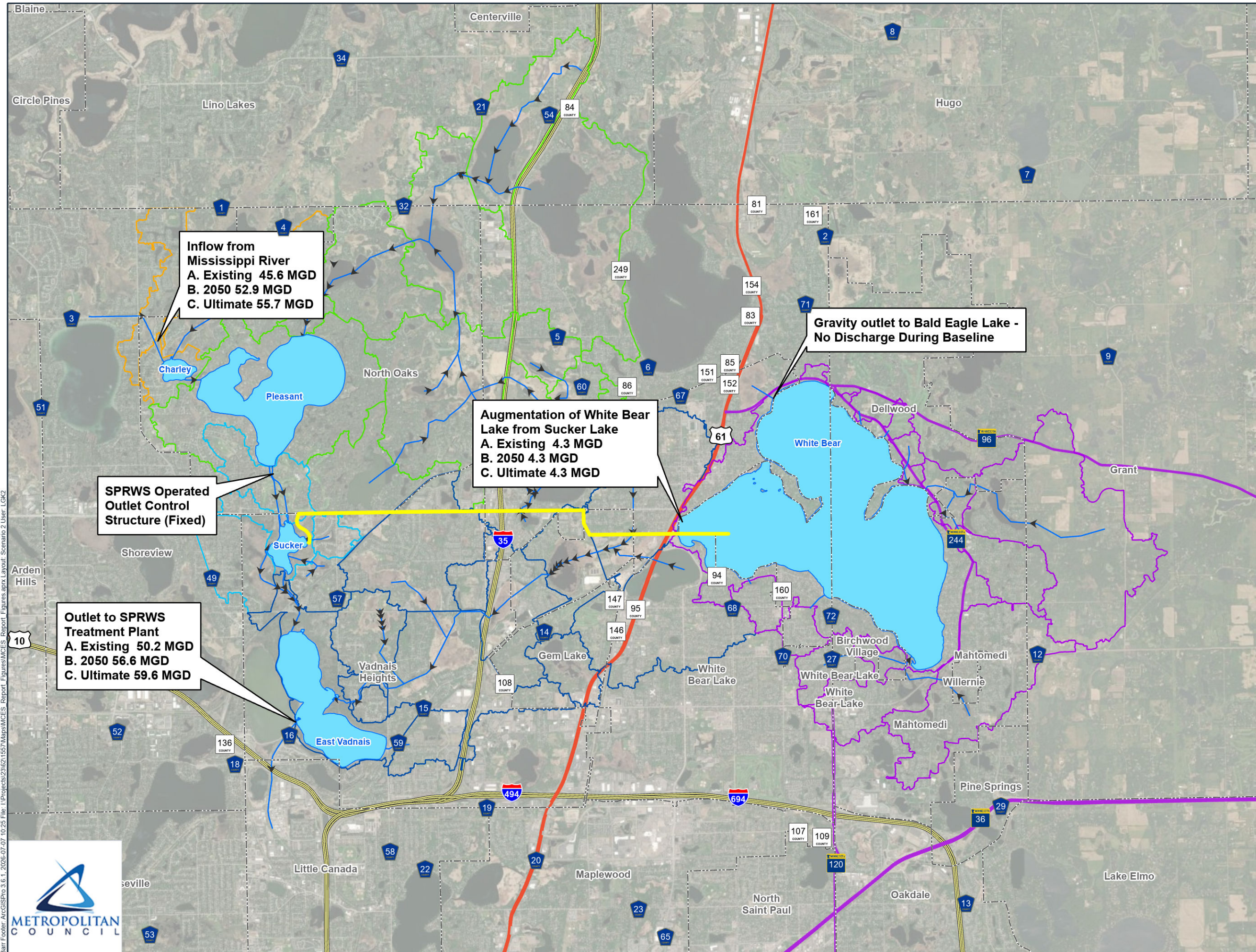
Scenario 1
MCES White Bear
Lake Study 7A

FIGURE 6-2

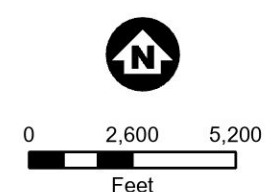
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- Municipal Boundary
- Study Lakes
- Flowlines
- Augmentation Alignment
- Subwatersheds
 - Charley
 - Pleasant
 - Sucker
 - East Vadnais
 - White Bear Lake
- Streets and Highways
 - Interstate Highway
 - US Highway
 - State Trunk Highway



ESRI World Imagery, 2026

Scenario 2
MCES White Bear Lake Study 7A

FIGURE 6-3



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6.1 Scenario Input Assumptions

To evaluate the scenarios and generate the associated inputs for the CE-QUAL-W2 and mass balance models, we reviewed and finalized the key assumptions with MCES, SPRWS, and MnDNR staff.

The following is a summary of the key assumptions related to the scenario evaluation:

- To reflect dry precipitation conditions, the 2021 hourly precipitation data set (reflective of the 10th percentile for the most recent 30-year climate normal at MSP airport) was leveraged to estimate direct precipitation on the lake surface areas during the model run (see Section 2.7.1.1).
- Other climatic data for the 2021 dry conditions, including air temperature, dew point, wind speed and direction, and cloud cover, were entered into the CE-QUAL-W2 model and evaporative losses from the lake surface for the SPRWS chain of lakes. For White Bear Lake, the evaporative loss coefficients applied during calibration to align with the MnDNR evaporation rates were applied to these dry climatic conditions.
- Additionally, the P8 model was run for this dry climatic period to estimate the watershed runoff volume to each lake (see Section 4.6).
- Based on lake level analysis and discussion with SPRWS and MCES staff, we selected the appropriate starting elevation for each water body for the in-lake model run as summarized below (in meters and ft NAVD88).
 - Charley Lake: 271.88 m (892.0 ft)
 - Pleasant Lake: 271.88 m (892.0 ft)
 - Sucker Lake: 267.83 m (878.7 ft)
 - East Vadnais: 267.83 m (878.7 ft)
 - White Bear Lake: 281.03 m (922.0 ft)
- Based on the future water demand projections provided by MCES for the 9 scenarios (see Section 2.12), we assumed this reflected a constant flow rate to be delivered from East Vadnais Lake to the SPRWS water treatment plant. We developed constant flow time series for use in the lake model. For the dry baseline conditions run, we assumed an existing water demand flow rate similar to Scenarios 2A and 3A, which reflects the SPRWS existing demand estimate (but does not include any White Bear Lake augmentation flows).
- Based on direction from the MnDNR, we assumed the White Bear Lake augmentation rate would be equivalent to 780 million gallons over a 6-month period (May through October). This is equivalent to a constant flow of ~4.3 MGD. We developed constant flow time series for use in the lake model to reflect the augmentation flow from either Sucker Lake or East Vadnais to White Bear Lake in Scenarios 2 and 3, respectively.
- To estimate the flow from the Mississippi River, we initially back-calculated a flow time series from the river to the SPRWS Chain of Lakes using the following general approach:

- Flow from the Mississippi = Water Demand Projection + Augmentation + Net Environmental Loss (e.g. evaporation + loss to groundwater - direct precipitation etc.) – Watershed Runoff.
- After an initial run was completed, we increased the initial river pumping estimate by 0.3 m³/s to generally maintain water levels and prevent significant drops in water levels through the SPRWS chain of lakes system.
- We assumed that there would be no changes to the lake outlets/rating curves. However, for Pleasant Lake, we assumed that the gated outlet (which is manually operated by SPRWS was variable during the 2025 calibration) was set at a constant condition for the scenario analysis. Using the range in the 2025 settings required for the lake level calibration, we assumed that the lake would be maintained at the lower end of the typical operating range during drought conditions allowing more water to pass through to East Vadnais for water supply. .
- No changes to the calibrated inputs related to the ferric chloride and oxygenation systems.
- Augmentation water was drawn from the epilimnion (surface waters) of Sucker and East Vadnais Lakes and there was no treatment of the augmentation water and pollutant loads prior to discharge to White Bear Lake.
- Assumed pollutant concentrations at the Mississippi River was the same as 2025 calibration.
- Assumed pollutant concentrations in the watershed runoff was based on the dry (2021) P8 model run for those parameters that are modeled directly in P8 and assumed to be the same as the 2025 calibration for other parameters..

6.2 Scenario Results

The following sections outline the results of the scenario analysis using the calibrated CE-QUAL-W2 model for eutrophication parameters and the mass balance model for the non-eutrophication parameters.

6.2.1 CE-QUAL-W2 Results for Eutrophication Parameters

The CE-QUAL-W2 model was run for the baseline dry and nine flow scenarios. The results from the CE-QUAL-W2 model for the calibration run (2025), the baseline dry (2021) condition run, and the nine scenarios is included in Appendix 6. This summary includes time series plots for the model run period for each lake at a surface point representative of a historic monitoring location, including the results for the following parameters:

- Lake Level
- Total Phosphorus
- Chlorophyll a
- Secchi Depth (estimated based on eutrophication relationships for each individual lake)
- Total Nitrogen
- Total Organic Carbon

- Dissolved Oxygen

Also included in the appendix are monthly dissolved oxygen profile plots for each lake during the growing season months (June – September), showing the impact of the proposed scenarios on the dissolved oxygen concentrations throughout the lake profile.

The following sections include further evaluation of the model results, including discussion of the results of the scenario analysis, summary of the impact of different flow scenarios on the growing season water balance, relative water level change, growing season load summaries to each lake, and the resulting average growing season pollutant concentrations for each lake, with a focus on the key eutrophication parameters.

6.2.1.1 Changes in Water Balance

To understand the impact of increased flows from the Mississippi River through the SPRWS chain of lakes system due to future water demand and/or augmentation flows for White Bear Lake, the growing season water balance for each lake was summarized based on the CE-QUAL-W2 outputs. Table 6-1 through Table 6-3 include summaries of the growing season water balances to each lake in MGD. This includes the calibration (2025), baseline (2021) dry, and the nine water demand scenarios.

Table 6-1 Growing Season Water Balance Summary (in MGD) – Scenario 1

Growing Season Water Balance Summaries Inflow and Outflow in MGD Scenarios 1A-1C	Calibration (2025)					Baseline (2021) Dry					Scenario 1A					Scenario 1B					Scenario 1C				
	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear
Flow From River (MGD)	22.5	0.0	0.0	0.0	0.0	42.4	0.0	0.0	0.0	0.0	56.5	0.0	0.0	0.0	0.0	69.8	0.0	0.0	0.0	0.0	76.2	0.0	0.0	0.0	0.0
Flow From Upstream Lakes (MGD)	0.0	22.8	28.6	30.0	0.0	0.0	42.4	43.3	43.7	0.0	0.0	56.5	57.4	57.9	0.0	0.0	69.8	70.8	71.3	0.0	0.0	76.2	77.1	77.7	0.0
Direct Precipitation (MGD)	0.2	2.9	0.3	1.9	11.5	0.1	1.6	0.1	1.0	5.8	0.1	1.6	0.1	1.0	5.8	0.1	1.6	0.1	1.0	5.8	0.1	1.6	0.1	1.0	5.8
Watershed Runoff (MGD)	0.5	5.0	1.1	13.0	4.7	0.2	2.7	0.6	6.8	2.4	0.2	2.7	0.6	6.8	2.4	0.2	2.7	0.6	6.8	2.4	0.2	2.7	0.6	6.8	2.4
WBL Augmentation (MGD)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surface Discharge (MGD)	-22.8	-28.9	-30.0	0.0	0.0	-42.4	-43.2	-43.7	0.0	0.0	-56.5	-57.4	-57.9	0.0	0.0	-69.8	-70.7	-71.3	0.0	0.0	-76.2	-77.0	-77.7	0.0	0.0
Evaporation (MGD)	-0.2	-2.8	-0.3	-1.6	-10.5	-0.3	-3.4	-0.2	-1.5	-12.8	-0.3	-3.4	-0.2	-1.5	-12.8	-0.3	-3.4	-0.2	-1.5	-12.8	-0.3	-3.4	-0.2	-1.4	-12.8
Net Groundwater Outflow (MGD)	0.0	0.0	0.0	0.0	-2.4	0.0	0.0	0.0	0.0	-2.4	0.0	0.0	0.0	0.0	-2.4	0.0	0.0	0.0	0.0	-2.4	0.0	0.0	0.0	0.0	-2.4
Flow to SPRWS Treatment Plant (MGD)	0.0	0.0	0.0	-45.6	0.0	0.0	0.0	0.0	-50.2	0.0	0.0	0.0	0.0	-64.7	0.0	0.0	0.0	0.0	-78.3	0.0	0.0	0.0	0.0	-84.7	0.0

Table 6-2 Growing Season Water Balance Summary (in MGD) – Scenario 2

Growing Season Water Balance Summaries Inflow and Outflow in MGD Scenarios 1A-1C	Calibration (2025)					Baseline					Scenario 2A					Scenario 2B					Scenario 2C				
	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear
Flow From River (MGD)	22.5	0.0	0.0	0.0	0.0	42.4	0.0	0.0	0.0	0.0	46.5	0.0	0.0	0.0	0.0	52.9	0.0	0.0	0.0	0.0	55.7	0.0	0.0	0.0	0.0
Flow From Upstream Lakes (MGD)	0.0	22.8	28.6	30.0	0.0	0.0	42.4	43.3	43.7	0.0	0.0	46.5	47.4	43.6	0.0	0.0	52.9	53.8	50.0	0.0	0.0	55.7	56.6	52.8	0.0
Direct Precipitation (MGD)	0.2	2.9	0.3	1.9	11.5	0.1	1.6	0.1	1.0	5.8	0.1	1.6	0.1	1.0	5.8	0.1	1.6	0.1	1.0	5.8	0.1	1.6	0.1	1.0	5.8
Watershed Runoff (MGD)	0.5	5.0	1.1	13.0	4.7	0.2	2.7	0.6	6.8	2.4	0.2	2.7	0.6	6.8	2.4	0.2	2.7	0.6	6.8	2.4	0.2	2.7	0.6	6.8	2.4
WBL Augmentation (MGD)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-4.3	0.0	4.3	0.0	0.0	-4.3	0.0	4.3	0.0	0.0	-4.3	0.0	4.3
Surface Discharge (MGD)	-22.8	-28.9	-30.0	0.0	0.0	-42.4	-43.2	-43.7	0.0	0.0	-46.5	-47.3	-43.6	0.0	0.0	-52.9	-53.7	-50.0	0.0	0.0	-55.7	-56.5	-52.8	0.0	0.0
Evaporation (MGD)	-0.2	-2.8	-0.3	-1.6	-10.5	-0.3	-3.4	-0.2	-1.5	-12.8	-0.3	-3.4	-0.2	-1.5	-13.0	-0.3	-3.4	-0.2	-1.5	-13.0	-0.3	-3.4	-0.2	-1.5	-13.0
Net Groundwater Outflow (MGD)	0.0	0.0	0.0	0.0	-2.4	0.0	0.0	0.0	0.0	-2.4	0.0	0.0	0.0	0.0	-2.4	0.0	0.0	0.0	0.0	-2.4	0.0	0.0	0.0	0.0	-2.4
Flow to SPRWS Treatment Plant (MGD)	0.0	0.0	0.0	-45.6	0.0	0.0	0.0	0.0	-50.2	0.0	0.0	0.0	0.0	-50.2	0.0	0.0	0.0	0.0	-56.6	0.0	0.0	0.0	0.0	-59.6	0.0

Table 6-3 Growing Season Water Balance Summary (in MGD) – Scenario 3

Growing Season Water Balance Summaries Inflow and Outflow in MGD Scenarios 1A-1C	Calibration (2025)					Baseline (2021) Dry					Scenario 3A					Scenario 3B					Scenario3C				
	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear
Flow From River (MGD)	22.5	0.0	0.0	0.0	0.0	42.4	0.0	0.0	0.0	0.0	46.5	0.0	0.0	0.0	0.0	52.9	0.0	0.0	0.0	0.0	55.7	0.0	0.0	0.0	0.0
Flow From Upstream Lakes (MGD)	0.0	22.8	28.6	30.0	0.0	0.0	42.4	43.3	43.7	0.0	0.0	46.5	47.4	47.9	0.0	0.0	52.9	53.8	54.3	0.0	0.0	55.7	56.6	57.1	0.0
Direct Precipitation (MGD)	0.2	2.9	0.3	1.9	11.5	0.1	1.6	0.1	1.0	5.8	0.1	1.6	0.1	1.0	5.8	0.1	1.6	0.1	1.0	5.8	0.1	1.6	0.1	1.0	5.8
Watershed Runoff (MGD)	0.5	5.0	1.1	13.0	4.7	0.2	2.7	0.6	6.8	2.4	0.2	2.7	0.6	6.8	2.4	0.2	2.7	0.6	6.8	2.4	0.2	2.7	0.6	6.8	2.4
WBL Augmentation (MGD)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-4.3	4.3	0.0	0.0	0.0	-4.3	4.3	0.0	0.0	0.0	-4.3	4.3
Surface Discharge (MGD)	-22.8	-28.9	-30.0	0.0	0.0	-42.4	-43.2	-43.7	0.0	0.0	-46.5	-47.3	-47.9	0.0	0.0	-52.9	-53.7	-54.3	0.0	0.0	-55.7	-56.5	-57.1	0.0	0.0
Evaporation (MGD)	-0.2	-2.8	-0.3	-1.6	-10.5	-0.3	-3.4	-0.2	-1.5	-12.8	-0.3	-3.4	-0.2	-1.5	-13.0	-0.3	-3.4	-0.2	-1.5	-13.0	-0.3	-3.4	-0.2	-1.5	-13.0
Net Groundwater Outflow (MGD)	0.0	0.0	0.0	0.0	-2.4	0.0	0.0	0.0	0.0	-2.4	0.0	0.0	0.0	0.0	-2.4	0.0	0.0	0.0	0.0	-2.4	0.0	0.0	0.0	0.0	-2.4
Flow to SPRWS Treatment Plant (MGD)	0.0	0.0	0.0	-45.6	0.0	0.0	0.0	0.0	-50.2	0.0	0.0	0.0	0.0	-50.2	0.0	0.0	0.0	0.0	-56.6	0.0	0.0	0.0	0.0	-59.6	0.0

In general, for existing conditions, inflows into the SPRWS chain of lakes is dominated by flows from the Mississippi River. Direct precipitation is typically less than 10% of the existing water balance with watershed loads typically less than 30% of the inflows to the lakes, with watershed inflows ranging from 2% (Charley) to 29% (East Vadnais) during the calibration period to 1% (Charley) to 13% (East Vadnais). Additionally, these lakes are flowthrough lakes with the majority of water leaving the lake system through the surface outlet and ultimately draining to the SPRWS water treatment plant.

However, based on the growing season modeling for White Bear Lake, direct precipitation is the dominant inflow (~70%) during the growing season while watershed runoff makes up just under 30% of the growing season inflow volume. During all model runs, including calibration, White Bear Lake was essentially landlocked with no surface outflow, and most water (~80-85%) leaves the White Bear Lake system via evaporation, with the remainder of outflow through recharge to the groundwater (~15-20%).

When looking at the impact of the different flow scenarios on the growing season water balances, there is a shift in the water balance as the flows from the Mississippi River become a larger portion of the anticipated flows through the SPRWS chain of lakes system. This is especially true of the ultimate water demand scenarios (e.g., Scenarios 1C, 2C, 3C) that reflect the highest anticipated water demand at full development conditions.

For the two augmentation scenarios, augmentation outflows from Sucker and East Vadnais Lake to White Bear Lake account for less than 10% of the outflow from these systems, while as an inflow to White Bear Lake, this accounts for over 30% of the growing season inflow volume to the lake.

6.2.1.2 Relative Change in Water Levels

To understand the impact of increased flows from the Mississippi River through the SPRWS chain of lakes system due to future water demand and/or augmentation flows for White Bear Lake, the estimated water levels for each water body for each scenario were compared to the baseline dry estimated water levels. This provides an understanding of the relative impact of these increased flows through the chain of lakes system and White Bear Lake.

For all baseline (2021) dry scenario runs, the starting elevations of the lakes were selected to be on the low end of their operating ranges, based on direction from SPRWS staff related to these assumptions.

Table 6-4 summarizes the average water surface elevation and relative change in the growing season average water surface elevation when compared to the baseline dry (2021) results for each of the lakes for the calibration conditions (2025), baseline, and the nine future water flow scenarios.

The water levels on the SPRWS chain of lakes system is highly managed by SPRWS operations, including the volume of pumping from the Mississippi River into the system, manual opening and closing of the gated outlet at Pleasant Lake, and the inflow into the SPRWS treatment plant. However, to be consistent with our approach to modeling the scenarios, several assumptions for scenario modeling ultimately impact the predicted water levels, including the following:

- Discharge to the SPRWS treatment plant from East Vadnais and the augmentation of White Bear Lake (from either Sucker Lake or East Vadnais) are assumed to be constant flows for the baseline dry conditions (as applicable) as well as for all the scenario runs.

- We developed a consistent approach for estimating a fairly constant pumping rate from the Mississippi River with the goal of providing enough flow to support the discharge to the SPRWS treatment plant and augmentation of White Bear Lake while generally sustaining constant water levels. However, SPRWS could increase pumping from the river if determined that additional flows would be needed based on the water levels in the system. As a result of these operations (which are not fully captured in our scenario evaluation approach), the flows into and out of the chain of lakes system would typically be more variable from day to day and could result in more fluctuations in water levels (and pollutant loading) from day to day.
- For the Pleasant Lake outlet, SPRWS staff are manually adjusting the outlet on a daily basis to maintain water levels and provide sufficient discharge for water supply needs. We assumed that the outlet rating curve was set at a fixed open position, resulting in water levels around the lower end of the typical operating range based on the model calibration settings and feedback from SPRWS staff.

With regards to average changes we are estimating, on Charley and Pleasant Lake, we are seeing a slight increase in the water levels during the growing season on the order of 0.1 – 0.2 ft, depending on the flow scenario, with the assumption that the Pleasant Lake outlet was set at a fixed opening condition resulting in water levels at the lower end of the operating range.

For the scenarios, we are seeing a decline in the average water elevations (-0.2 to -0.9 feet) in the Sucker and East Vadnais system compared to baseline conditions. This is likely a result of our approach to estimating the pumping from the Mississippi River and the constant, increased demand from East Vadnais, especially during higher use scenarios.

For White Bear Lake, there are no impacts during Scenario 1 (where no augmentation is occurring). During the baseline dry and Scenario 1 model runs, the water level time series for White Bear Lake shows a consistent decline in water surface elevation over the growing season. During Scenarios 2 and 3, where White Bear Lake is being augmented by a constant pumping rate, the water levels are generally sustained at the starting elevation of the model run period.

Although the CE-QUAL-W2 model does allow for water balance and hydrodynamic calibration, it is not as sophisticated as a true hydrologic and hydraulic model. As such, the changes in water levels are relative to baseline conditions to understand the magnitude of impact on average lake water levels. Additionally, these results should not be used to analyze the hydraulic capacity of the outlet and conveyance system relative to anticipated future flows.

Table 6-4 Average Water Levels and Relative Change Compared to Baseline (2021) Conditions

Scenario	Charley Lake		Pleasant Lake		Sucker Lake/East Vadnais Lake		White Bear Lake	
	Level (ft)	Change (ft)	Level (ft)	Change (ft)	Level (ft)	Change (ft)	Level (ft)	Change (ft)
Calibrated (2025)	893.5	-0.4	892.9	0.7	882.5	4.6	923.1	1.6
Baseline (2021)	893.9	0.0	892.2	0.0	877.9	0.0	921.5	0.0
Scenario 1A	894.0	0.1	892.3	0.1	877.5	-0.4	921.5	0.0
Scenario 1B	894.1	0.2	892.3	0.2	877.1	-0.8	921.5	0.0
Scenario 1C	894.1	0.2	892.4	0.2	877.0	-0.9	921.5	0.0
Scenario 2A	893.9	0.0	892.2	0.0	877.8	-0.2	921.9	0.4
Scenario 2B	894.0	0.1	892.2	0.1	877.7	-0.3	921.9	0.4
Scenario 2C	894.0	0.1	892.3	0.1	877.5	-0.5	921.9	0.4
Scenario 3A	893.9	0.0	892.2	0.0	877.8	-0.2	921.9	0.4
Scenario 3B	894.0	0.1	892.2	0.1	877.7	-0.3	921.9	0.4
Scenario 3C	894.0	0.1	892.3	0.1	877.5	-0.5	921.9	0.4

6.2.1.3 Changes in Pollutant Loads and Concentrations

To understand the impact of increased flows and pollutant loads from the Mississippi River through the SPRWS chain of lakes system due to future water demands and/or augmentation flows for White Bear Lake, the results of the CE-QUAL-W2 model were leveraged to evaluate changes in the growing season pollutant loads to the lakes as well as the resulting pollutant concentration in the lakes.

Pollutant Loading Summaries

Similar to calibration, we summarized the growing season total phosphorus loads to each lake using the CE-QUAL-W2 model results for the calibration (2025) event, baseline dry (2021), and the nine scenarios. Table 6-5, Table 6-6, and Table 6-7 summarize the results for Scenarios 1, 2, and 3, respectively. Additionally, Table 6-8 summarizes the estimated change in the growing season phosphorus loads to each lake due to the additional pumping from the Mississippi River, augmentation, and possible changes in internal loading when compared to the baseline dry (2021) conditions.

Table 6-5 Growing Season Total Phosphorus Load Summary (in pounds/growing season) – Scenario 1

Growing Season Total Phosphorus Load Summaries (lbs/GS) Scenarios 1A-1C	Calibration (2025)					Baseline (2021) Dry					Scenario 1A					Scenario 1B					Scenario 1C				
	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear
Flow From River (lbs/GS)	2781	0	0	0	0	5097	0	0	0	0	6793	0	0	0	0	8391	0	0	0	0	9157	0	0	0	0
Flow From Upstream Lakes (lbs/GS)	0	2087	2605	1293	0	0	3754	3649	1787	0	0	5319	4891	2742	0	0	6862	6103	3845	0	0	7599	6682	4374	0
Watershed Runoff (lbs/GS)	271	629	597	7371	1439	134	242	124	1519	177	134	242	124	1520	177	134	242	124	1520	177	134	242	124	1520	177
Internal Load from Sediments (lbs/GS)	518	1527	635	3516	3554	735	1555	294	2252	3935	824	1667	307	2447	3935	903	1753	322	2627	3935	926	1772	328	2699	3935
WBL Augmentation (lbs/GS)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surface Discharge (lbs/GS)	2084	2605	1293	0	0	3748	3649	1787	0	0	5310	4891	2742	0	0	6851	6103	3845	0	0	7586	6682	4374	0	0
Net Groundwater Outflow (lbs/GS)	0	0	0	0	50	0	0	0	0	43	0	0	0	0	43	0	0	0	0	43	0	0	0	0	43
Flow to SPRWS Treatment Plant (lbs/GS)	0	0	0	2525	0	0	0	0	1349	0	0	0	0	1902	0	0	0	0	2484	0	0	0	0	2769	0
Flux to Sediments (lbs/GS)	721	172	794	4398	2733	1104	171	367	2809	2351	1233	189	411	3278	2351	1309	206	458	3739	2351	1342	216	480	3956	2351

Table 6-6 Growing Season Total Phosphorus Load Summary (in pounds/growing season) – Scenario 2

Growing Season Total Phosphorus Load Summaries Scenarios 2A-2C	Calibration (2025)					Baseline (2021) Dry					Scenario 2A					Scenario 2B					Scenario 2C				
	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear
Flow From River (lbs/GS)	2781	0	0	0	0	5097	0	0	0	0	5588	0	0	0	0	6357	0	0	0	0	6689	0	0	0	0
Flow From Upstream Lakes (lbs/GS)	0	2087	2605	1293	0	0	3754	3649	1787	0	0	4202	4006	1820	0	0	4911	4568	2245	0	0	5223	4815	2462	0
Watershed Runoff (lbs/GS)	271	629	597	7371	1439	134	242	124	1519	177	134	242	124	1519	177	134	242	124	1519	177	134	242	124	1520	177
Internal Load from Sediments (lbs/GS)	518	1527	635	3516	3554	735	1555	294	2252	3935	764	1591	293	2287	4032	804	1644	302	2382	4056	819	1666	302	2419	4047
WBL Augmentation (lbs/GS)	0	0	0	0	0	0	0	0	0	0	0	0	178	0	178	0	0	192	0	192	0	0	199	0	199
Surface Discharge (lbs/GS)	2084	2605	1293	0	0	3748	3649	1787	0	0	4195	4006	1820	0	0	4902	4568	2245	0	0	5213	4815	2462	0	0
Net Groundwater Outflow (lbs/GS)	0	0	0	0	50	0	0	0	0	43	0	0	0	0	43	0	0	0	0	43	0	0	0	0	43
Flow to SPRWS Treatment Plant (lbs/GS)	0	0	0	2525	0	0	0	0	1349	0	0	0	0	1394	0	0	0	0	1628	0	0	0	0	1743	0
Flux to Sediments (lbs/GS)	721	172	794	4398	2733	1104	171	367	2809	2351	1146	176	371	2897	2464	1204	184	394	3111	2472	1226	187	400	3204	2477

Table 6-7 Growing Season Total Phosphorus Load Summary (in pounds/growing season) – Scenario 3

Growing Season Total Phosphorus Load Summaries Scenarios 3A-3C	Calibration (2025)					Baseline (2021) Dry					Scenario 3A					Scenario 3B					Scenario 3C				
	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear
Flow From River (lbs/GS)	2781	0	0	0	0	5097	0	0	0	0	5588	0	0	0	0	6357	0	0	0	0	6689	0	0	0	0
Flow From Upstream Lakes (lbs/GS)	0	2087	2605	1293	0	0	3754	3649	1787	0	0	4202	4006	2053	0	0	4911	4568	2499	0	0	5223	4815	2707	0
Watershed Runoff (lbs/GS)	271	629	597	7371	1439	134	242	124	1519	177	134	242	124	1519	177	134	242	124	1519	177	134	242	124	1520	177
Internal Load from Sediments (lbs/GS)	518	1527	635	3516	3554	735	1555	294	2252	3935	764	1591	296	2311	3988	804	1644	305	2403	4024	819	1666	305	2440	4015
WBL Augmentation (lbs/GS)	0	0	0	0	0	0	0	0	0	0	0	0	0	109	109	0	0	0	114	114	0	0	0	117	117
Surface Discharge (lbs/GS)	2084	2605	1293	0	0	3748	3649	1787	0	0	4195	4006	2053	0	0	4902	4568	2499	0	0	5213	4815	2707	0	0
Net Groundwater Outflow (lbs/GS)	0	0	0	0	50	0	0	0	0	43	0	0	0	0	43	0	0	0	0	43	0	0	0	0	43
Flow to SPRWS Treatment Plant (lbs/GS)	0	0	0	2525	0	0	0	0	1349	0	0	0	0	1387	0	0	0	0	1626	0	0	0	0	1743	0
Flux to Sediments (lbs/GS)	721	172	794	4398	2733	1104	171	367	2809	2351	1146	176	378	2950	2392	1204	184	401	3162	2402	1226	187	407	3255	2402

Table 6-8 Change in Total Phosphorus Loads From Baseline Due to Increased River Pumping, Augmentation, and Internal Loads

Growing Season Total Phosphorus Load Summaries Scenarios 1A-1C	Scenario 1A					Scenario 1B					Scenario 1C				
	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear
Flow From River (lbs/GS)	1697	0	0	0	0	3295	0	0	0	0	4060	0	0	0	0
Flow From Upstream Lakes (lbs/GS)	0	1565	1241	955	0	0	3108	2454	2058	0	0	3845	3033	2586	0
Internal Load from Sediments (lbs/GS)	89	113	13	195	0	168	198	28	375	0	190	217	34	447	0
WBL Augmentation (lbs/GS)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Growing Season Total Phosphorus Load Summaries Scenarios 2A-2C	Scenario 2A					Scenario 2B					Scenario 2C				
	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear
Flow From River (lbs/GS)	491	0	0	0	0	1260	0	0	0	0	1592	0	0	0	0
Flow From Upstream Lakes (lbs/GS)	0	448	357	33	0	0	1157	919	458	0	0	1469	1166	674	0
Internal Load from Sediments (lbs/GS)	29	36	-1	35	96	69	89	8	130	121	84	111	8	168	112
WBL Augmentation (lbs/GS)	0	0	178	0	178	0	0	192	0	192	0	0	199	0	199
Growing Season Total Phosphorus Load Summaries Scenarios 3A-3C	Scenario 3A					Scenario 3B					Scenario 3C				
	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear	Charley	Pleasant	Sucker	East Vadnais	White Bear
Flow From River (lbs/GS)	491	0	0	0	0	1260	0	0	0	0	1260	0	0	0	0
Flow From Upstream Lakes (lbs/GS)	0	448	357	266	0	0	1157	919	712	0	0	1157	919	712	0
Internal Load from Sediments (lbs/GS)	29	36	2	60	53	69	89	11	151	89	69	89	11	151	89
WBL Augmentation (lbs/GS)	0	0	0	109	109	0	0	0	114	114	0	0	0	114	114

Pollutant Concentration Summaries

Additionally, we developed growing season average surface water concentrations for the main eutrophication parameters for each water body. These were compiled for each water body for each scenario compared to the baseline dry estimated water quality concentrations to understand the estimated change in water quality.

Because of the CE-QUAL-W2 model structure that breaks each lake into upstream to downstream segments and vertical layers, the original calibration summaries pulled data from a defined vertical layer and segment in the model that generally reflected the top 2 meters based on the 2025 water level fluctuations. However, for the scenario runs where water levels were expected to start at a lower elevation and respond to higher flows, we wanted to be consistent with the vertical location in the profile we were pulling the model results from for comparative purposes. For nearly all parameters, there is variability in the concentrations as you move down the vertical profiles. To be consistent with what layer and location we were pulling the model results from for comparison purposes, we summarized results at the same segments that represented the deep hole/historic monitoring location used for calibration, but selected at the top of the estimated water surface at that point.

Additionally, we compared the resulting water quality concentrations against the 95th confidence interval range for the growing season means for each parameter for each lake to understand how the 2025 calibration year compared to the historic data sets, as well as how the water quality response for the baseline dry and scenarios fell within the historical range of water quality to help identify potentially significant changes in water quality. However, it is important to note that for some parameters in 2025 (calibration period), the growing season average for parameters like total phosphorus and total nitrogen, the observed concentrations in the Mississippi River, Charley Lake, and Pleasant Lake were high, and the observed data was outside the 95th confidence interval before evaluating the scenarios.

Table 6-9 through Table 6-13 summarize the estimated average growing season Mississippi River concentration for each scenario model run, as well as the resulting average growing season concentrations in the SPRWS chain of lakes and White Bear Lake for total phosphorus, chlorophyll a, Secchi depth, total nitrogen, and dissolved oxygen, respectively.

Table 6-9 Total Phosphorus Concentrations and Relative Change Compared to Baseline (2021) Conditions

Scenario	Mississippi River		Charley Lake		Pleasant Lake		Sucker Lake		East Vadnais Lake		White Bear Lake	
	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline
Calibrated (2025)	0.117	0.0	0.097	6.8	0.089	6.2	0.043	5.6	0.041	67.9	0.020	16.2
Baseline (2021)	0.117	0.0	0.091	0.0	0.084	0.0	0.041	0.0	0.024	0.0	0.0176	0.0
Scenario 1A	0.117	0.0	0.096	5.5	0.085	1.2	0.047	15.8	0.027	11.8	0.0176	0.0
Scenario 1B	0.117	0.0	0.100	9.8	0.086	2.8	0.054	32.0	0.030	23.1	0.0176	0.0
Scenario 1C	0.117	0.0	0.101	11.2	0.087	3.3	0.056	37.9	0.031	27.5	0.0176	0.0
Scenario 2A	0.117	0.0	0.092	1.8	0.084	0.4	0.041	2.2	0.025	1.3	0.0179	1.7
Scenario 2B	0.117	0.0	0.095	4.3	0.085	0.9	0.045	9.9	0.026	6.6	0.0179	1.7
Scenario 2C	0.117	0.0	0.096	5.2	0.085	1.2	0.046	14.1	0.027	9.2	0.0179	1.8
Scenario 3A	0.117	0.0	0.092	1.8	0.084	0.4	0.043	5.0	0.025	3.6	0.0175	-0.3
Scenario 3B	0.117	0.0	0.095	4.3	0.085	0.9	0.046	12.7	0.026	8.5	0.0176	-0.2
Scenario 3C	0.117	0.0	0.096	5.2	0.085	1.2	0.047	16.1	0.027	11.5	0.0176	-0.2
95% Confidence Interval for growing season mean based on period of record data	0.064		0.065		0.044		0.047		0.022		0.018	
	0.088		0.074		0.055		0.058		0.025		0.020	

Table 6-10 Chlorophyll a Concentrations and Relative Change Compared to Baseline (2021) Conditions

Scenario	Mississippi River		Charley Lake		Pleasant Lake		Sucker Lake		East Vadnais Lake		White Bear Lake	
	Average (ug/L)	% Change from Baseline	Average (ug/L)	% Change from Baseline	Average (ug/L)	% Change from Baseline	Average (ug/L)	% Change from Baseline	Average (ug/L)	% Change from Baseline	Average (ug/L)	% Change from Baseline
Calibrated (2025)	7.1	0.0	3.0	-34.3	11.0	-18.3	4.2	-46.1	4.0	-53.9	4.9	-4.0
Baseline (2021)	7.1	0.0	4.6	0.0	13.4	0.0	7.8	0.0	8.8	0.0	5.1	0.0
Scenario 1A	7.1	0.0	5.1	9.0	9.9	-26.4	6.8	-13.1	9.6	9.3	5.1	0.0
Scenario 1B	7.1	0.0	5.3	15.1	8.6	-36.0	5.7	-26.8	9.9	12.5	5.1	0.0
Scenario 1C	7.1	0.0	5.4	17.4	8.3	-38.3	5.3	-32.4	9.9	12.4	5.1	0.0
Scenario 2A	7.1	0.0	4.8	2.9	12.1	-9.9	7.5	-4.1	8.8	0.1	5.2	3.4
Scenario 2B	7.1	0.0	5.0	7.0	10.5	-21.6	7.1	-9.9	9.2	4.5	5.3	3.8
Scenario 2C	7.1	0.0	5.0	8.5	10.0	-25.6	6.7	-14.4	9.3	5.9	5.3	4.0
Scenario 3A	7.1	0.0	4.8	2.9	12.1	-9.9	7.6	-3.5	9.1	3.9	5.1	0.0
Scenario 3B	7.1	0.0	5.0	7.0	10.5	-21.6	7.1	-9.6	9.4	7.7	5.1	0.6
Scenario 3C	7.1	0.0	5.0	8.5	10.0	-25.6	6.8	-13.0	9.6	9.2	5.1	0.6
95% Confidence Interval for growing season mean based on period of record data	13.2		9.1		12.8		15.4		4.9		4.5	
	23.1		12.7		17.2		19.1		9.5		4.9	

Table 6-11 Secchi Depth and Relative Change Compared to Baseline (2021) Conditions

Scenario	Mississippi River		Charley Lake		Pleasant Lake		Sucker Lake		East Vadnais Lake		White Bear Lake	
	Average (m)	% Change from Baseline	Average (m)	% Change from Baseline	Average (m)	% Change from Baseline	Average (m)	% Change from Baseline	Average (m)	% Change from Baseline	Average (m)	% Change from Baseline
Calibrated (2025)	N/A	N/A	1.0	-5.6	2.0	1.8	1.9	-2.5	3.7	40.6	3.5	2.0
Baseline (2021)	N/A	N/A	1.0	0.0	1.9	0.0	2.0	0.0	2.6	0.0	3.4	0.0
Scenario 1A	N/A	N/A	1.0	-4.6	2.0	2.8	1.9	-6.5	2.5	-3.8	3.4	0.0
Scenario 1B	N/A	N/A	1.0	-7.9	2.0	4.1	1.8	-12.0	2.5	-5.0	3.4	0.0
Scenario 1C	N/A	N/A	0.9	-8.9	2.0	4.4	1.7	-13.7	2.5	-5.0	3.4	0.0
Scenario 2A	N/A	N/A	1.0	-1.6	2.0	0.9	2.0	-1.0	2.6	0.0	3.4	-1.6
Scenario 2B	N/A	N/A	1.0	-3.6	2.0	2.2	1.9	-4.2	2.6	-1.9	3.4	-1.8
Scenario 2C	N/A	N/A	1.0	-4.4	2.0	2.7	1.9	-5.9	2.5	-2.5	3.4	-1.9
Scenario 3A	N/A	N/A	1.0	-1.6	2.0	0.9	2.0	-2.2	2.6	-1.7	3.4	0.0
Scenario 3B	N/A	N/A	1.0	-3.6	2.0	2.2	1.9	-5.3	2.5	-3.2	3.4	-0.3
Scenario 3C	N/A	N/A	1.0	-4.4	2.0	2.7	1.9	-6.6	2.5	-3.8	3.4	-0.3
95% Confidence Interval for growing season mean based on period of record data	N/A	N/A	1.4		2.1		1.8		2.8		3.9	
	N/A	N/A	1.7		2.3		2.1		3.4		4.1	

Table 6-12 Total Nitrogen Concentrations and Relative Change Compared to Baseline (2021) Conditions

Scenario	Mississippi River		Charley Lake		Pleasant Lake		Sucker Lake		East Vadnais Lake		White Bear Lake	
	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline
Calibrated (2025)	2.0	0.0	1.6	-6.9	1.4	-11.6	0.9	-9.2	0.9	13.0	0.7	-0.1
Baseline (2021)	2.0	0.0	1.8	0.0	1.6	0.0	1.0	0.0	0.8	0.0	0.7	0.0
Scenario 1A	2.0	0.0	1.8	3.3	1.7	6.4	1.2	17.7	1.0	17.4	0.7	0.0
Scenario 1B	2.0	0.0	1.9	5.9	1.7	11.1	1.4	32.6	1.1	32.6	0.7	0.0
Scenario 1C	2.0	0.0	1.9	6.7	1.8	12.7	1.4	38.0	1.1	38.9	0.7	0.0
Scenario 2A	2.0	0.0	1.8	1.1	1.6	2.1	1.1	3.5	0.9	3.3	0.7	-0.2
Scenario 2B	2.0	0.0	1.8	2.6	1.6	5.0	1.2	11.8	0.9	11.1	0.7	0.1
Scenario 2C	2.0	0.0	1.8	3.2	1.7	6.1	1.2	16.0	0.9	14.5	0.7	0.2
Scenario 3A	2.0	0.0	1.8	1.1	1.6	2.1	1.1	5.5	0.9	5.4	0.7	-1.4
Scenario 3B	2.0	0.0	1.8	2.6	1.6	5.0	1.2	13.8	0.9	13.1	0.7	-1.3
Scenario 3C	2.0	0.0	1.8	3.2	1.7	6.1	1.2	17.3	1.0	16.5	0.7	-1.3
95% Confidence Interval for growing season mean based on period of record data	1.3		1.2		0.8		1.0		1.1		0.7	
	1.7		1.5		1.1		1.4		0.8		0.8	

Table 6-13 Dissolved Oxygen Concentrations and Relative Change Compared to Baseline (2021) Conditions

Scenario	Mississippi River		Charley Lake		Pleasant Lake		Sucker Lake		East Vadnais Lake		White Bear Lake	
	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline
Calibrated (2025)	8.4	0.0	7.5	5.0	7.4	5.8	5.9	24.2	6.3	18.7	9.0	5.1
Baseline (2021)	8.4	0.0	7.1	0.0	7.0	0.0	4.8	0.0	5.3	0.0	8.6	0.0
Scenario 1A	8.4	0.0	7.0	-1.0	6.9	-1.6	4.2	-11.3	4.6	-13.0	8.6	0.0
Scenario 1B	8.4	0.0	7.0	-1.3	6.8	-2.5	3.8	-19.9	4.0	-25.3	8.6	0.0
Scenario 1C	8.4	0.0	7.0	-1.0	6.8	-2.7	3.8	-21.1	3.7	-29.8	8.6	0.0
Scenario 2A	8.4	0.0	7.1	-0.4	7.0	-0.6	4.7	-2.1	5.2	-2.3	8.6	-0.1
Scenario 2B	8.4	0.0	7.0	-0.8	6.9	-1.2	4.4	-7.7	4.9	-8.3	8.6	-0.1
Scenario 2C	8.4	0.0	7.0	-0.9	6.9	-1.6	4.3	-9.9	4.8	-10.7	8.6	-0.1
Scenario 3A	8.4	0.0	7.1	-0.4	7.0	-0.6	4.6	-3.8	5.1	-3.9	8.6	0.0
Scenario 3B	8.4	0.0	7.0	-0.8	6.9	-1.2	4.3	-9.1	4.8	-9.7	8.6	0.0
Scenario 3C	8.4	0.0	7.0	-0.9	6.9	-1.6	4.2	-11.0	4.7	-12.4	8.6	-0.1
95% Confidence Interval for growing season mean based on sample data for period of record	8.8		6.6		8.4		6.7		8.6		8.8	
	9.6		7.4		9.0		7.6		9.0		8.9	

6.2.1.4 Key Takeaways for Eutrophication Parameters

Based on the CE-QUAL-W2 modeling, we summarized the relative change in the water surface elevations in each of the water bodies when compared to the baseline conditions modeling. Assuming constant flows through the system, the average change in the water levels of the SPRWS chain of lakes was within the normal variability with the historic system water level data and operations and does not indicate concern about shoreline impacts. However, as previously mentioned, a hydraulic model of the lake outlets and conveyance channels should be used to fully understand the hydraulic conveyance capacity of the SPRWS chain of lakes system relative to the anticipated future flows if one of these approaches is selected for long-term implementation. The slight increase in the average water surface elevation with the augmentation of White Bear Lake compared to baseline conditions indicates that the augmentation flow rate will help sustain the water levels on White Bear Lake during dry conditions, but may not result in increased water levels during the growing season during dry climatic conditions and peak evaporative losses.

In addition to slight impacts to the water levels on the SPRWS chain of lakes, the increased flow through the system also reduces the residence time for each of the lakes. However, with the addition of volume to White Bear Lake (in a condition where the water levels are below the surface outlet and the lake is generally landlocked), the augmentation results in an increase in the residence time.

In all scenarios, we are seeing increases in not only the volumes to each of the SPRWS chain of lakes, but also the pollutant loads due to the increased flows and resulting loads. In general, the increased loading does impact the predicted water quality in the SPRWS chain of lakes. Scenarios 1A through 1C have the most significant water quality response due to the highest flows and loads from the Mississippi River as a result of needing to provide increased water supply for not only the SPRWS system but also the additional communities around White Bear Lake. However, there is also moderate water quality degradation on the SPRWS chain of lakes as a result of the increased loads from Scenarios 2A-2C and 3A-3C, which includes both the flows for the SPRWS system demand as well as the augmentation flows for White Bear Lake.

Although we expect possible increases in chlorophyll a levels in some of the lakes (e.g., Charley and East Vadnais), in other lakes, the modeling suggests a possible reduction in the chlorophyll a concentrations. For the lakes, we are seeing a possible increase; the concentrations in these lakes generally remain low, and the predicted concentrations are typically within the 95th confidence interval for growing season averages, so we would not expect algal blooms to be significantly different than have historically occurred. It is important to note that the study lakes do not have strong relationships between total phosphorus or chlorophyll a and Secchi depth, so most change in transparency is anticipated to be small (typically less than 5% change). This is likely due to flow from the Mississippi River (that can result in low residence times), the high manipulation of the system with the addition of ferric chloride, oxygen, and outlet operations, and the presence of AIS such as zebra mussels.

Although White Bear Lake has the most significant responses to augmentation from Sucker Lake as reflected by Scenario 2, the general impact of the augmentation on the lake water quality is typically very small (e.g., less than 5% change for most eutrophication parameters), suggesting that, given its size and volume, White Bear Lake system is highly resilient to the additional loading from augmentation.

A summary of the main takeaways related to the eutrophication parameters for each lake is provided in Table 6-14.

Table 6-14 Summary of Significant Eutrophication Parameter Findings for Scenario Evaluation

Lake	Key Findings
Charley	- Shows increase in total phosphorus concentrations for all scenarios, but most impacted in Scenario 1 (especially Scenario 1C (increase from baseline by ~11%)). Anticipated to exceed state water quality standard. - Shows increase in chlorophyll a concentration for all scenarios, but most impacted in Scenario 1 (especially Scenario 1C (increase from baseline by ~17%)). Anticipated to meet state water quality standard. - Shows slight increases in total nitrogen concentrations for all scenarios, but most impacted in Scenario 1 (especially Scenario 1C (increase from baseline by ~7%)) - Shows slight decline in surface dissolved oxygen concentrations for all scenarios, but most impacted in Scenario 1 (decrease from baseline by ~1-2%). However, the dissolved oxygen profiles for Charley Lake suggest the lake is not strongly stratified and is fairly well mixed throughout the growing season with dissolved oxygen levels above 6 mg/L.
Pleasant	- Shows slight increases in total phosphorus concentrations for all scenarios, but most impacted in Scenario 1 (especially Scenario 1C (increase from baseline by ~2-3%)). Anticipated to exceed state water quality standard. - Shows reduced chlorophyll a concentrations for the higher flows in Scenario 1 and the 2050 and ultimate water demand Scenarios 2B/C and 3B/C; however, in the lower flows in Scenarios 2A and 3A, we are seeing higher chlorophyll a concentrations (increase from baseline by ~10%)) but below the 95th confidence interval for growing season averages. Anticipated to meet state water quality standard. - Shows slight increases in total nitrogen concentrations for all scenarios, but most impacted in Scenario 1 (especially Scenario 1C (increase from baseline by ~13%)) - Shows slight decline in surface dissolved oxygen concentrations for all scenarios, but most impacted in Scenario 1 (decrease from baseline by ~2-3%). However, the dissolved oxygen profiles for Pleasant Lake suggest that even during the baseline dry conditions as well as all scenarios, the hypolimnion of the lake will go anoxic for the entire growing season without confirmation that the existing oxygenation system is delivering oxygen as intended and providing additional dosing to achieve the targeted oxygen levels in the hypolimnion (5 mg/L). As a result of these anoxic conditions, the model results are showing increased internal phosphorus loading from the sediments from the baseline conditions, increasing by 113-217 pounds per growing season.
Sucker	- Shows significant increases in total phosphorus concentrations for all scenarios, but most impacted in Scenario 1 (especially Scenario 1C (increase from baseline by ~38%)). Anticipated to exceed state water quality standard. - Sucker shows reduced chlorophyll a concentration for the higher flows in all scenarios when compared to the baseline conditions. Anticipated to meet state water quality standard. - Shows increases in total nitrogen concentrations especially for Scenario 1 (especially Scenario 1C (increase from baseline by ~38%)). - Shows decline in surface dissolved oxygen concentrations for many scenarios, but most impacted in Scenario 1 (decrease from baseline by ~21%). However, the dissolved oxygen profiles for Sucker Lake suggest that even during the baseline dry conditions as well as all scenarios, the hypolimnion of the lake will go anoxic for the entire growing season. As a result of these anoxic conditions, the model results are showing increased internal phosphorus loading from the sediments from the baseline conditions, increasing by 13-34 pounds per growing season.

Lake	Key Findings
East Vadnais	- Shows significant increases in total phosphorus concentrations for all scenarios, but most impacted in Scenario 1 (especially Scenario 1C (increase from baseline by ~28%)). Anticipated to meet state water quality standard with growing season average concentrations typically below 0.031 mg/L. - East Vadnais shows increased chlorophyll a concentration for all scenarios when compared to the baseline conditions (especially Scenario 1C (increase from baseline by ~12-13%)). Anticipated to meet state water quality standard with growing season average concentrations typically below 9.9 ug/L. - Shows significant increases in total nitrogen concentrations especially for Scenario 1 (especially Scenario 1C (increase from baseline by ~39%)). - Shows decline in surface dissolved oxygen concentrations for all scenarios, but most impacted in Scenario 1 (decrease from baseline by ~30%). However, the dissolved oxygen profiles for East Vadnais Lake suggest that even with the operation of the oxygen injection system at the existing dosing during the baseline dry conditions as well as all scenarios, the hypolimnion of the lake will drop below the targeted oxygen levels in the hypolimnion (5 mg/L), typically in the 0-2 mg/L range. As a result of these anoxic conditions, the model results are showing increased internal phosphorus loading from the sediments from the baseline conditions, increasing by 195-447 pounds per growing season.
White Bear	- With augmentation from both Sucker and East Vadnais, White Bear Lake shows minimal change in the estimated total phosphorus concentrations for Scenarios 2 and 3; however, Scenario 2 that draws augmentation water from Sucker Lake results in more impact than Scenario 3 (with an increase from baseline by ~1-2%). Anticipated to meet state water quality standard with growing season average concentrations typically below 0.018 mg/L. - Similar to total phosphorus, Scenario 2 shows the largest increase in chlorophyll a concentrations when compared to the baseline conditions (increase from baseline by ~3-4%). Anticipated to meet state water quality standard with growing season average concentrations typically below 5.3 ug/L. - With augmentation from both Sucker and East Vadnais, White Bear Lake shows minimal change in the estimated total nitrogen concentrations for Scenarios 2 and 3; however, Scenario 2 that draws augmentation water from Sucker Lake results in more impact than Scenario 3 (with an increase from baseline by ~0-1%). - Shows no change in surface dissolved oxygen concentrations from either Scenario 2 or 3. The dissolved oxygen profiles for White Bear Lake suggest that even during baseline dry conditions, the hypolimnion may have lower oxygen concentrations than observed in the calibration/monitoring data, but there is very slight difference between the baseline dry conditions and Scenarios 2 and 3. The model results are showing increased internal phosphorus loading from the sediments from the baseline conditions, increasing by 96 – 145 pounds per growing season.

6.2.2 Mass Balance Results for Non-Eutrophication Parameters

The calibrated mass balance model was run for the baseline dry (2021) conditions as well as nine flow scenarios, leveraging the growing season water balance data from the CE-QUAL-W2 model runs. The output summary from the mass balance model for the calibration run (2025), the baseline dry (2021) condition run, and the nine water demand and augmentation scenarios is included in Appendix 7. This includes tables organized by water quality parameter that summarize the estimated average growing season concentration for the calibration and baseline dry runs, as well as the various scenarios by lake.

6.2.2.1 Scenario Analysis Results for Non-Eutrophication Parameters

The predicted pollutant concentrations reveal a clear spatial pattern in how different lakes respond to changes in flow and average loading conditions in the Mississippi River as water flows from upstream to downstream. Charley Lake, being closest to the Mississippi River source, consistently shows concentrations that closely track the river input with little to no changes across scenarios. Generally, as water moves through the system, Pleasant and Sucker Lakes show intermediate and often similar responses, with concentrations generally declining from the river source. East Vadnais Lake, positioned furthest downstream in the chain, consistently shows the lowest concentrations of pollutants in the SPRWS chain of lakes.

Generally, when comparing changes in water quality to the baseline dry conditions, we are not seeing major changes in water quality as a result of the increased flows and loads from the Mississippi River system. As water progresses through the sequence of lakes from the Mississippi River to East Vadnais Lake, the most significant changes are observed in particulate-associated constituents due to settling, retention, and removal processes as water travels through the system. These include total suspended solids, total aluminum, total arsenic, total barium, total calcium, total magnesium, total fluoride, radium 226, and microplastic particles. Sulfate, hardness, chlorine dioxide, gross alpha and gross beta radiation, and radium 228 also generally show a decrease through the chain of lakes. The remaining pollutants that are dissolved or more conservative in nature have minimal change from the Mississippi River to East Vadnais, including total dissolved solids, chlorides, and alkalinity. The exceptions to this longitudinal trend are that total manganese is variable through the system, seeing an increase in the concentrations in Pleasant Lake, and total copper, which is lowest in Sucker Lake.

White Bear Lake overall generally shows lower concentrations than the Mississippi River and chain of lakes for most parameters. However, White Bear Lake exhibits higher concentrations than the chain of lakes for chloride (which is more than double the concentration found in any of the chain lakes) and total arsenic.

Differences in scenario concentrations compared to the baselines for the lakes ranged from slightly positive to substantially negative, becoming more extreme through the chain of lakes, indicating the system's ability to buffer average concentrations of pollutants, sometimes even better than baseline.

Within each future water demand scenario, the progression from "A" (Existing) to "B" (2050) to "C" (Ultimate) shows consistently little divergence from each other and similar trends, although the highest flow scenario "C" typically results in the most impact.

Under Scenario 1, the SPRWS chain of lakes experiences the most significant increase in flows and pollutant loads from the Mississippi River, with most increases in concentrations of many constituents relative to baseline, especially total dissolved solids, hardness, alkalinity, and some metals. However, the anticipated increases in resulting lake concentrations from Scenario 1 are typically small (e.g., less than 5% increase from baseline conditions). However, for some parameters, we are seeing the more significant increase in lake concentrations at East Vadnais Lake, including:

- Total barium, with an 8% increase from baseline conditions
- Chlorine dioxide, with a 12% increase from baseline conditions
- Gross alpha (radiation), with a 10% increase from baseline conditions

- Gross beta (radiation), with a 10% increase from baseline conditions
- Microplastics, with a 12% increase from baseline conditions

Scenarios 2 and 3 have smaller increases in flows and pollutant loads when compared to Scenario 1, so the anticipated impact on the water quality of the SPRWS chain of lakes is smaller than expected in Scenario 1. Scenario 2 draws White Bear Lake augmentation water from Sucker Lake before it has passed through the full chain of lakes, resulting in more significant impacts to White Bear Lake compared to the baseline and Scenario 3, which draws augmentation water from East Vadnais Lake. In Scenario 2, for many parameters, the expected change in the White Bear Lake concentrations due to augmentation is typically small (less than 5% change from baseline conditions). The parameters that we are seeing the most significant impacts to on White Bear Lake for Scenario 2 include:

- Total suspended solids, with an 8-9% increase from baseline
- Total dissolved solids, with a 5% increase from baseline
- Hardness, with a 6-7% increase from baseline
- Alkalinity, with a 6-7% increase from baseline
- Total calcium, with a 6-7% increase from baseline
- Total copper, with a 5-6% increase from baseline
- Total magnesium, with a 6-7% increase from baseline
- Total manganese, with a 19-20% increase from baseline
- Sulfate, with a 29-30% increase from baseline
- Radium 226, with a 27-28% increase from baseline

Although the percent change from baseline conditions is significant for several of these parameters, the estimated concentration for the scenarios is still typically considered to be low, and for some parameters is less than the concentrations observed in the lake in 2025, suggesting that this change is within the natural variability of the lake. Given White Bear Lake's large size and volume, it appears to be a resilient system that can handle some additional pollutant loading without a significant change in water quality.

Scenario 3 draws augmentation water from East Vadnais Lake that has undergone additional settling through the full chain of lakes and also benefits from the ferric chloride and oxygenation occurring in East Vadnais Lake. This results in lower pollutant delivery to White Bear Lake than in Scenario 2. In general, the pollutant concentrations in White Bear Lake for Scenario 3 are very similar to the baseline dry conditions and, in some cases, show a slight decrease in concentrations as a result of dilution effect if concentrations in East Vadnais are expected to be lower than the concentrations in White Bear Lake. This is true for the following parameters:

- Total suspended solids
- Total aluminum
- Total calcium

- Total copper
- Fluoride
- Total manganese
- Sulfate
- Radium 226/228

Table 6-15 summarizes the specific key takeaways of the scenario evaluation and corresponding lake water quality response, organized by water quality parameter.

Table 6-15 Summary of Significant Pollutant Findings for Scenario Evaluation for Non-Eutrophication Parameters

Parameter	Scenario Response Summary
Solids, total suspended	TSS concentrations decrease though chain of lakes and do not show significant change in any Scenario; White Bear TSS concentrations are similar to Sucker and East Vadnais and most significantly impacted during Scenario 2
Solids, total dissolved	TDS concentrations show slight decrease though chain of lakes and do not show significant change in any Scenario; TDS concentrations in White Bear lower than Sucker and East Vadnais and are most significantly impacted under Scenario 2
Chloride	Chloride concentrations generally consistent through the chain of lakes though highest in East Vadnais and does not show any significant change in any scenarios; White Bear Lake concentration higher than the chain of lakes and shows limited impact during Scenario 2
Hardness, as CaCO ₃	Hardness decreases though chain of lakes and does not show significant change in any Scenario; White Bear hardness typically less than the chain of lakes and is most impacted during Scenario 2
Alkalinity, total, as CaCO ₃	Alkalinity decreases though chain of lakes and does not show significant change in any Scenario; White Bear alkalinity typically less than the chain of lakes and is most impacted during Scenario 2
Arsenic, Total	Arsenic concentrations show slight decrease though chain of lakes and does not show significant change in any Scenario; Arsenic concentrations in White Bear are typically higher than Sucker and East Vadnais and shows limited impact under Scenario 2
Aluminum, Total	Aluminum concentrations show slight decrease though chain of lakes and does not show significant change in any Scenario; Aluminum concentrations in White Bear are typically higher than Sucker and East Vadnais and shows limited impact under Scenario 2
Barium, Total	Barium decreases though chain of lakes and shows the most significant change in East Vadnais as part of Scenario 1; White Bear barium concentrations typically less than Sucker and East Vadnais and shows limited impact during Scenario 2
Calcium, Total	Calcium concentrations show slight decrease though chain of lakes and does not show significant change in any Scenario; Calcium concentrations in White Bear are lower than Sucker and East Vadnais and is most significantly impacted under Scenario 2
Copper, Total	Copper concentrations show slight decrease though chain of lakes until East Vadnais where increases are observed; however, does not show significant change in any Scenario; Copper concentrations in White Bear are lower than Sucker and East Vadnais and is most significantly impacted under Scenario 2
Fluoride	Fluoride concentrations generally decrease through the chain of lakes and does not show significant change in any Scenario; White Bear Lake concentration typically similar to Sucker and higher than East Vadnais and limited impact during Scenario 2
Magnesium, Total	Magnesium concentrations decrease though chain of lakes and does not show significant change in any Scenario; White Bear magnesium concentrations are less than Sucker and East Vadnais and most significantly impacted during Scenario 2
Manganese, Total	Manganese concentrations generally decrease though chain of lakes although concentrations are highest in Pleasant and does not show significant change in any Scenario; White Bear manganese concentrations are less than Sucker and similar to East Vadnais and most significantly impacted during Scenario 2
Sulfate, as SO ₄	Sulfate concentrations decrease though chain of lakes and does not show significant change in any Scenario; White Bear sulfate concentrations are lower than both Sucker and East Vadnais and most significantly impacted during Scenario 2
Chlorine dioxide	Chlorine dioxide concentrations decrease though chain of lakes and does not show significant change in any Scenario; White Bear chlorine concentrations are lower than both Sucker and East Vadnais and shows limited impact during Scenario 2

Parameter	Scenario Response Summary
Gross Alpha (radiation)	Gross Alpha (radiation) generally shows a decline through chain of lakes and shows the most significant change in East Vadnais as part of Scenario 1; White Bear Lake generally lower than the chain of lakes and shows limited impact during Scenario 2
Gross Beta (radiation)	Gross Beta (radiation) generally shows a decline through chain of lakes and shows the most significant change in East Vadnais as part of Scenario 1; White Bear Lake generally higher than the chain of lakes and shows limited impact during Scenario 2
Radium 226	Radium 226 generally constant through chain of lakes, though Sucker is the highest, and does not show significant change in any Scenario; White Bear Lake generally higher than the chain of lakes and shows limited impact during Scenario 2
Radium 228	Radium 228 generally constant through chain of lakes, though an increase is observed from Sucker to East Vadnais, and does not show significant change in any Scenario; White Bear Lake generally higher than the chain of lakes and shows limited impact during Scenario 2
Micro plastic particles, total	Microplastics generally shows a decline through chain of lakes and shows the most significant change in East Vadnais as part of Scenario 1; White Bear Lake typically higher than the chain of lakes and shows limited impact during Scenario 2

6.2.2.2 Key Takeaways from Scenario Mass Balance Modeling

The model highlights that as water travels through the SPRWS chain of lakes, the system generally retains pollutants and reduces the impact of pollutant inputs from the Mississippi River as flows move downstream, with observed reductions in concentrations. This is especially true of pollutants associated with particulate being more affected by system processes than dissolved ones. This retention through the system becomes more pronounced downstream, with East Vadnais Lake consistently demonstrating the lowest concentrations for most pollutants.

Scenario 1, which increases flows through the SPRWS chain of lakes to accommodate an expanded water services area to many of the White Bear Lake communities (but does not augment White Bear Lake), has a more significant impact on the water quality in the SPRWS chain of lakes than the flows for Scenarios 2 and 3. For most pollutants, the anticipated increases are typically small, with more significant increases in lake concentrations at East Vadnais Lake for barium, chlorine dioxide, gross alpha and beta radiation, and microplastics.

For Scenarios 2 and 3, include the flows for the SPRWS service area and the anticipated flows for White Bear Lake augmentation, drawing from either Sucker Lake or East Vadnais Lake. Scenario 2 results in more significant impacts to White Bear Lake when compared to Scenario 3, increasing concentrations for the following parameters: total suspended solids, total dissolved solids, hardness, alkalinity, calcium, copper, magnesium, manganese, sulfate, and radium 226. Augmentation from East Vadnais Lake (Scenario 3) results in less impact to White Bear Lake by allowing water to move through the entire SPRWS chain, resulting in maximum pollutant settling and retention, and benefiting from the ferric chloride and oxygenation that is occurring in East Vadnais Lake.

Overall, the model results show that increasing water demands from existing ("A") to future ("B" and "C") scenarios has little effect on predicted concentrations in White Bear Lake, especially under augmentation scenarios. And given White Bear Lake's large size and volume, it appears to be a fairly resilient system that can handle some additional pollutant loading from augmentation without a significant change in water quality.

Elevated chloride and arsenic concentrations in White Bear Lake under existing conditions are likely attributed to groundwater impacts/flow through, local watershed contributions, and evaporation effects, rather than the influence of Mississippi River or SPRWS system flows.

6.3 Sensitivity Analysis

After the scenario modeling was completed, we performed a sensitivity analysis with higher loads at the Mississippi River for select parameters based on the results of the data review and scenario modeling outlined in the sections above.

6.3.1 CE-QUAL-W2 Sensitivity for Eutrophication Parameters

For the eutrophication parameters, we leveraged the CE-QUAL-W2 models to perform the sensitivity analysis. Based on the results of the scenario modeling above, we selected the two scenario runs that resulted in the worst water quality in the SPRWS chain of lakes as well as the most significant change in water quality in White Bear Lake to further evaluate the system sensitivity. This included both surface concentrations as well as dissolved oxygen profiles to estimate the magnitude of impact on the water bodies if higher loads are experienced in the future and determine if the change will cause a significant degradation in water quality. Results of the sensitivity runs are included in Appendix 8.

The scenario models used for the sensitivity analysis included:

- Scenario 1C: Ultimate flow conditions to supply the identified communities with drinking water from the SPRWS system. This scenario resulted in the most significant water quality change in East Vadnais, including declines in the hypolimnetic dissolved oxygen levels.
- Scenario 2C: Augmentation of White Bear Lake from Sucker Lake resulted in the most significant water quality change in White Bear Lake.

This included scaling up the Mississippi River flow concentrations for the following parameters:

- Total Phosphorus
- Chlorophyll a
- Total Nitrogen
- Total Organic Carbon
- Dissolved Oxygen
- Total Dissolved Solids

For this assessment, we scaled the 2025 concentrations in the Mississippi River to reflect the temporal distribution of the river flow concentrations, while the resulting growing season average reflected the 99th percentile concentrations based on the full period of record for the Mississippi River using the data leveraged in this study. For dissolved oxygen, we assumed the 1st percentile concentrations as low dissolved oxygen is typically more critical for water quality. These conditions represent a worst-case scenario based on the available data to assess the response of the system to changes in these factors.

Table 6-16 summarizes the average growing season concentrations for the Mississippi River for the sensitivity runs using the CE-QUAL-W2 model for the evaluation of the eutrophication parameters.

Table 6-16 Mississippi River Pollutant Scaling for Sensitivity Evaluation for Eutrophication Parameters

Parameter	Unit	Mississippi River Growing Season Average Concentration - Calibration (2025)	Mississippi River Growing Season Average Concentration - Sensitivity	Sensitivity Scaling Factor
Phosphorus, total, as P	mg/l	0.117	0.160	1.36
Nitrogen, total	mg/l	2.0	3.4	1.74
Chlorophyll a, pheophytin-adjusted	ug/l	7.1	64.9	9.08
Solids, total dissolved	mg/l	307	355	1.16
Dissolved oxygen	mg/l	8.4	7.7	0.92
Carbon, total organic	mg/l	15.0	15.3	1.02

6.3.1.1 Sensitivity Analysis Results for Eutrophication Parameters

Table 6-17 through Table 6-21 summarize the estimated average growing season Mississippi River concentration for the two sensitivity runs performed using the CE-QUAL-W2 model and the resulting average growing season concentrations in the SPRWS chain of lakes and White Bear Lake for total phosphorus, chlorophyll a, Secchi depth, total nitrogen, and dissolved oxygen, respectively.

Table 6-17 Sensitivity Total Phosphorus Concentrations and Relative Change Compared to Baseline (2021) Conditions

Scenario	Mississippi River		Charley Lake		Pleasant Lake		Sucker Lake		East Vadnais Lake		White Bear Lake	
	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline
Baseline (2021)	0.117	0.0	0.091	0.0	0.084	0.0	0.041	0.0	0.024	0.0	0.0176	0.0
Scenario 1C - Sensitivity	0.160	36.3	0.150	65.1	0.125	48.4	0.079	94.9	0.040	63.4	0.018	0.0
Scenario 2C - Sensitivity	0.160	36.3	0.142	56.0	0.119	41.0	0.062	52.4	0.032	32.9	0.018	2.0
95% Confidence Interval for growing season mean based on period of record data	0.064		0.065		0.044		0.047		0.022		0.018	
	0.088		0.074		0.055		0.058		0.025		0.020	

Table 6-18 Sensitivity Chlorophyll a Concentrations and Relative Change Compared to Baseline (2021) Conditions

Scenario	Mississippi River		Charley Lake		Pleasant Lake		Sucker Lake		East Vadnais Lake		White Bear Lake	
	Average (ug/L)	% Change from Baseline	Average (ug/L)	% Change from Baseline	Average (ug/L)	% Change from Baseline	Average (ug/L)	% Change from Baseline	Average (ug/L)	% Change from Baseline	Average (ug/L)	% Change from Baseline
Baseline (2021)	7.1	0.0	4.6	0.0	13.4	0.0	7.8	0.0	8.8	0.0	5.1	0.0
Scenario 1C - Sensitivity	64.9	808.4	48.7	950.9	48.1	337.5	15.9	103.2	19.2	118.9	5.1	0.0
Scenario 2C - Sensitivity	64.9	808.4	44.8	867.0	42.5	287.1	14.9	90.7	15.4	75.1	5.4	7.5
95% Confidence Interval for growing season mean based on period of record data	13.2		9.1		12.8		15.4		4.9		4.5	
	23.1		12.7		17.2		19.1		9.5		4.9	

Table 6-19 Sensitivity Secchi Depth and Relative Change Compared to Baseline (2021) Conditions

Scenario	Mississippi River		Charley Lake		Pleasant Lake		Sucker Lake		East Vadnais Lake		White Bear Lake	
	Average (m)	% Change from Baseline	Average (m)	% Change from Baseline	Average (m)	% Change from Baseline	Average (m)	% Change from Baseline	Average (m)	% Change from Baseline	Average (m)	% Change from Baseline
Baseline (2021)	N/A	N/A	1.0	0.0	1.9	0.0	2.0	0.0	2.6	0.0	3.4	0.0
Scenario 1C - Sensitivity	N/A	N/A	0.7	-35.7	1.7	-10.8	1.5	-26.4	1.8	-29.2	3.4	0.0
Scenario 2C - Sensitivity	N/A	N/A	0.7	-32.4	1.8	-9.8	1.6	-17.6	2.0	-21.8	3.3	-3.5
95% Confidence Interval for growing season mean based on period of record data	N/A	N/A	1.4		2.1		1.8		2.8		3.9	
	N/A	N/A	1.7		2.3		2.1		3.4		4.1	

Table 6-20 Sensitivity Total Nitrogen Concentrations and Relative Change Compared to Baseline (2021) Conditions

Scenario	Mississippi River		Charley Lake		Pleasant Lake		Sucker Lake		East Vadnais Lake		White Bear Lake	
	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline
Baseline (2021)	2.0	0.0	1.8	0.0	1.6	0.0	1.0	0.0	0.8	0.0	0.7	0.0
Scenario 1C - Sensitivity	3.4	74.0	3.9	122.1	3.1	101.9	2.5	140.7	1.9	135.4	0.7	0.0
Scenario 2C - Sensitivity	3.4	74.0	3.8	115.0	2.9	84.7	2.0	92.0	1.5	82.1	0.7	1.9
95% Confidence Interval for growing season mean based on period of record data	1.3		1.2		0.8		1.0		1.1		0.7	
	1.7		1.5		1.1		1.4		0.8		0.8	

Table 6-21 Sensitivity Dissolved Oxygen Concentrations and Relative Change Compared to Baseline (2021) Conditions

Scenario	Mississippi River		Charley Lake		Pleasant Lake		Sucker Lake		East Vadnais Lake		White Bear Lake	
	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline	Average (mg/L)	% Change from Baseline
Baseline (2021)	8.4	0.0	7.1	0.0	7.0	0.0	4.8	0.0	5.3	0.0	8.6	0.0
Scenario 1C - Sensitivity	7.7	-8.0	6.5	-8.8	6.4	-8.6	3.2	-32.7	3.6	-31.4	7.7	0.0
Scenario 2C - Sensitivity	7.7	-8.0	6.6	-7.7	6.6	-6.5	3.8	-21.1	4.5	-14.6	7.7	0.0
95% Confidence Interval for growing season mean based on sample data for period of record	8.8		6.6		8.4		6.7		8.6		8.8	

6.3.1.2 Key Takeaways for Eutrophication Parameters

Based on the sensitivity analysis for the eutrophication parameters for Scenarios 1C and 2C, following are a few additional takeaways related to a “worst case” responses in the lakes, assuming that the Mississippi River is at sustained high concentrations for the various parameters throughout the growing season:

- In relation to total phosphorus, we see consistently higher concentrations in all the SPRWS chain of lakes, with all lakes, including East Vadnais Lake, exceeding the state water quality standards, especially for Scenario 1C. When looking at Scenario 2C and the impact of the high river concentrations on augmentation at White Bear Lake, there is minimal impact on total phosphorus concentrations, with only a 2% increase from baseline dry conditions, and the lake still meets state water quality standards. This is likely the result of removal of total phosphorus through the chain of lakes before the withdrawal from Sucker Lake and the significant volume of White Bear Lake.
- The river has a wide range in the chlorophyll a concentrations. If the river is elevated at extremely high levels for the entire growing season, we could expect the SPRWS chain of lakes water bodies to experience significant algal blooms, and similar to total phosphorus, all the lakes may possibly exceed the state water quality standards. However, when looking at Scenario 2C, there is minimal impact on chlorophyll a concentrations in White Bear Lake, with ~7-8% increase from baseline dry conditions (but still well below the state water quality standards).
- For Scenario 1C, total nitrogen levels in the SPRWS chain of lakes could double from the baseline conditions concentrations. However, for Scenario 2C, there is minimal impact on the total nitrogen concentrations in White Bear Lake, with ~2% increase from baseline conditions, as there is a decrease in nitrogen concentrations as the flows move through the chain of lakes. Similar to total phosphorus, this is likely the result of removal of total phosphorus through the chain of lakes before the withdrawal at Sucker Lake and the significant volume of White Bear Lake.
- In general, for the baseline dry conditions model, we see a slight reduction in dissolved oxygen concentrations at the lake surface as well as along the depth profiles of the lakes. For the SPRWS chain of lakes, Scenario 1C has the most significant impact on the hypolimnetic oxygen levels in the lakes, although all scenarios show reduced hypolimnetic oxygen levels compared to baseline conditions. The phosphorus load summaries from the modeling show increasing internal phosphorus loads from the sediments as a result of the lower oxygen levels and longer periods of anoxia in some lakes.

6.3.2 Mass Balance Sensitivity for Non-Eutrophication Parameters

For non-eutrophication parameters, we used the scenario mass balance model to conduct the sensitivity analysis. This allowed us to evaluate all scenarios and parameters through the model. Using Mississippi River concentrations at the 99th percentile from the full period of data included in this study, we predicted scenario concentrations and compared them with baseline dry (2021) scenario conditions calculated using mean concentrations. This comparison helped us estimate the relative change in scenario concentrations under high concentration pollutants from the Mississippi River compared to the calibration

(2025) conditions. The output summary from the mass balance model used for the sensitivity analysis of the nine water demand and augmentation scenarios is included in Appendix 9.

6.3.2.1 Sensitivity Analysis Results for Non-Eutrophication Parameters

The predicted scenario concentrations under high Mississippi River pollutant conditions for Scenario 1A follow similar patterns through the lakes, scenarios, and future water demands as average pollutant conditions. However, we are seeing more significant responses for several parameters in these sensitivity runs in the SPRWS chain of lakes. This is true in the sensitivity response at White Bear Lake as well.

Table 6-22 summarizes key takeaways from the sensitivity analysis based on the mass balance modeling for the non-eutrophication parameters.

Table 6-22 Summary of Significant Pollutant Findings for Sensitivity Evaluation for Non-Eutrophication Parameters

Parameter	Sensitivity Response Summary
Solids, total suspended	TSS concentrations decrease though chain of lakes but show significant change from baseline by more than doubling for Charley, Pleasant, and Sucker and for East Vadnais increasing to over 50% in all scenarios; White Bear TSS concentrations are most significantly impacted during Scenario 2, increasing to 20% change (up from 8-9% as part of scenario assessment)
Solids, total dissolved	TDS concentrations show slight decrease though chain of lakes but show significant change from baseline increasing to 30-35% in all scenarios; TDS concentrations in White Bear are most significantly impacted under Scenario 2, increasing to 6-7% change (up from 5% as part of scenario assessment)
Chloride	Chloride concentrations generally consistent through the chain of lakes though highest in East Vadnais and show that concentrations could be double baseline conditions for all scenarios; White Bear Lake concentration higher than the chain of lakes and shows limited impact during Scenario 2
Hardness, as CaCO ₃	Hardness decreases though chain of lakes but show significant change from baseline, increasing to 10-12% in all scenarios; White Bear hardness typically less than the chain of lakes and is most impacted during Scenario 2, increasing to 7-8% change (up from 6-7% as part of scenario assessment)
Alkalinity, total, as CaCO ₃	Alkalinity decreases though chain of lakes but show significant change from baseline, increasing to 10-13% in all scenarios; White Bear alkalinity typically less than the chain of lakes and is most impacted during Scenario 2, increasing to 7-8% change (up from 6-7% as part of scenario assessment)
Arsenic, Total	Arsenic concentrations show slight decrease though chain of lakes and does not show significant change in any Scenario; Arsenic concentrations in White Bear are typically higher than Sucker and East Vadnais and shows limited impact under Scenario 2
Aluminum, Total	Aluminum concentrations show slight decrease though chain of lakes but show significant change from baseline by more than doubling for lakes through the chain of lakes; Aluminum concentrations in White Bear are typically higher than Sucker and East Vadnais and shows limited impact under Scenario 2
Barium, Total	Barium decreases though chain of lakes but show significant change from baseline, increasing to 10-12% in all scenarios; White Bear barium concentrations typically less than Sucker and East Vadnais and increasing to 5-6% change (up from 4-5% as part of scenario assessment)
Calcium, Total	Calcium concentrations show slight decrease though chain of lakes but show significant change from baseline, increasing to 9-12% in all scenarios; Calcium concentrations in White Bear are lower than Sucker and East Vadnais and increasing to 7-8% change (up from 6-7% as part of scenario assessment)
Copper, Total	Copper concentrations show slight decrease though chain of lakes until East Vadnais where increases are observed but show significant change from baseline by more than 2-4 times for Charley, Pleasant, and Sucker and for East Vadnais increasing to over 50% in all scenarios; Copper concentrations in White Bear are lower than Sucker and East Vadnais and is most significantly impacted under Scenario 2 increasing to 24% change (up from 5-6% as part of scenario assessment)
Fluoride	Fluoride concentrations generally decrease through the chain of lakes but show significant change from baseline increasing to 11-15% in all scenarios; White Bear Lake concentration typically similar to Sucker and higher than East Vadnais and limited impact during Scenario 2 with a similar response to the scenario assessment (with an increase of 6-7% change from baseline)

Parameter	Sensitivity Response Summary
Magnesium, Total	Magnesium concentrations decrease through chain of lakes and does not show significant change in any Scenario; White Bear magnesium concentrations are less than Sucker and East Vadnais and most significantly impacted during Scenario 2 increasing to 6-7% change (up from 0-1% as part of scenario assessment)
Manganese, Total	Manganese concentrations generally decrease through chain of lakes although concentrations are highest in Pleasant but show significant change from baseline increasing to 400-1000% in all scenarios; White Bear manganese concentrations are less than Sucker and similar to East Vadnais and most significantly impacted during Scenario 2 increasing to 200% change (up from 19-20% as part of scenario assessment)
Sulfate, as SO ₄	Sulfate concentrations decrease through chain of lakes but show significant change from baseline increasing to 100-250% in all scenarios; White Bear sulfate concentrations are lower than both Sucker and East Vadnais and most significantly impacted during Scenario 2 increasing to 88-89% change (up from 29-30% as part of scenario assessment)
Chlorine dioxide	Chlorine dioxide concentrations decrease through chain of lakes but show significant change from baseline increasing to 45-65% in all scenarios; White Bear sulfate concentrations are lower than both Sucker and East Vadnais and shows limited impact during Scenario 2
Gross Alpha (radiation)	Gross Alpha (radiation) generally shows a decline through chain of lakes but show significant change from baseline increasing to 75-95% in all scenarios; White Bear Lake generally lower than the chain of lakes and shows limited impact during Scenario 2 increasing to 8-9% change (up from 4-5% as part of scenario assessment)
Gross Beta (radiation)	Gross Beta (radiation) generally shows a decline through chain of lakes but show significant change from baseline increasing to 6-75% in all scenarios; White Bear Lake generally higher than the chain of lakes and during Scenario 2 increasing to 5-6% change (up from 3-4% as part of scenario assessment)
Radium 226	Radium 226 generally constant through chain of lakes, though Sucker is the highest, but show significant change from baseline increasing to 18-96% in all scenarios; White Bear Lake shows limited impact during Scenario 2 increasing to 47-49% change (up from 27-28% as part of scenario assessment)
Radium 228	Radium 228 generally constant through chain of lakes, though an increase is observed from Sucker to East Vadnais, but show significant change from baseline increasing to 10-82% in all scenarios; White Bear Lake shows limited impact during Scenario 2
Micro plastic particles, total	Microplastics generally shows a decline through chain of lakes but show significant change from baseline increasing to 150-180% in all scenarios; White Bear Lake typically higher than the chain of lakes and shows limited impact during Scenario 2 increasing to 5-6% change (up from ~2% as part of scenario assessment)

6.3.2.2 Key Takeaways from Scenario Mass Balance Modeling

The sensitivity analysis allows us to understand the possible lake response assuming the Mississippi River was at its worst water quality for a sustained period of time to understand if there are specific parameters that the SPRWS chain of lakes system and White Bear Lake are more responsive to during these extreme conditions to help focus mitigation efforts.

Key takeaways and observations from the sensitivity analysis include the following:

- Under high-pollutant conditions in the Mississippi River, the chain of lakes experiences more stress than under more average to typical conditions. Concentrations through the scenarios at the sites are obviously higher when using the 99th percentile of pollutants in the Mississippi River than the average. This is most apparent in the upstream lakes. However, we continue to see the

general trend of pollutant removals through the chain of lakes, with concentrations typically the lowest when water reaches East Vadnais Lake.

- Some parameters likely have more variability in the Mississippi River flows so under worse case conditions, can have a more significant impact on the anticipated change in the water quality in the SPRWS chain of lakes. Those parameters with more significant change from baseline conditions included:
 - Total suspended solids
 - Total dissolved solids
 - Total aluminum
 - Total copper
 - Total manganese
 - Sulfate
 - Chlorine dioxide
 - Gross alpha and gross beta (radiation)
 - Radium 226/228
 - Microplastics
- For the White Bear Lake augmentation scenarios, especially Scenario 2, White Bear Lake appeared to be most responsive to the following parameters with more significant change when comparing the sensitivity results to the original scenario assessment for more typical conditions:
 - Total suspended solids
 - Total copper
 - Total manganese
 - Sulfate
 - Radium 226

6.4 Evaluation of Oxygen and Ferric Chloride Injection Systems

6.4.1 Oxygenation System Considerations

In response to a request from SPRWS, we leveraged the CE-QUAL-W2 lake model for the sensitivity run for the SPRWS chain of lakes system (Sensitivity Run for Scenario 1C that resulted in the “worst case” water quality in the SPRWS chain of lakes) to evaluate and estimate the anticipated scaling factor for oxygen system dosing from existing conditions to achieve the targeted hypolimnetic dissolved oxygen concentration in Pleasant Lake and East Vadnais Lake only.

As mentioned in the model calibration summary, the CE-QUAL-W2 model is not designed to simulate the effect of pure oxygen bubbles, which are added at the lake bottom and then rise and dissolve while traveling upward in the water column. This has the effect of less oxygen addition to the bottom waters and more oxygen addition to waters mid-depth on the hypolimnion. In East Vadnais, a model workaround was implemented where oxygen was injected in the model at a range of depths in the hypolimnion to simulate the bubble plume dissolution process. In Pleasant Lake, information on 2025 repairs suggested that the system may not have been delivering oxygen to the hypolimnion in May and June, and the 2025 dissolved oxygen profile data for both the east and west Pleasant Lake monitoring stations showed that the Pleasant Lake hypolimnion was anoxic for the entire growing season; as such, we did not include oxygenation in the lake for calibration. For this exercise, we added oxygen dosing at the two main deep holes in the Pleasant Lake hypolimnion and used the 2025 dosing data provided to inform this assessment.

We went through a dosing exercise scaling the existing oxygen into the hypolimnion of each lake until we hit a target dissolved oxygen concentration of 5 mg/L in the hypolimnion. This was based on the average of the entire dissolved oxygen profile concentrations from below the thermocline down to the bottom of the lake. General dosing curves were generated to help understand the order of magnitude of oxygen dosing factor that may be needed to meet the target as a result of the worst-case future pollutant loading (using the Sensitivity Run for Scenario 1C). The assessment was performed for each lake independently (e.g. dosing estimate for East Vadnais does not reflect any changes to the Pleasant Lake oxygenation system). This evaluation was only performed to understand the possible magnitude of dosing from existing conditions for the highest load scenario and does not include any further design or evaluation of these systems.

To separate out the impact of increased flows due to the possible modifications to the system from the White Bear Lake planning study on the dosing versus increasing flows and demand from SPRWS alone, we used the estimated changes in flow to allocate back the estimates changes in dosing. This flow summary is included in Table 6-23. The estimated daily pumping rates for the existing conditions, reflected in the calibration (2025) and baseline (2021) dry reflect the potential range in the average growing season pumping rates, with the calibration value representing slightly wetter than average pumping rates and the baseline dry reflecting estimated drought conditions pumping. This range (22.5 to 42.4 MGD) generally falls in line with the range in actual growing season daily pumping data provided by SPRWS from 2015 - 2025 (average growing season pumping of 34.6 MGD with a range of 0.0 to 61.4 MGD).

To estimate the increase in pumping due to the scenarios proposed as part of the White Bear Lake planning study rather than natural variability in the existing system operations, we looked at the difference between Scenario 1C (which is the highest flow scenario that results in the worst-case water quality impacts to the SPRWS Chain of Lakes) and the river pumping for baseline conditions. Additionally, we looked at Scenario 3C (which is the highest estimated pumping needed for ultimate SPRWS service area demand along with White Bear Lake augmentation flows assuming pumping from East Vadnais) relative to the river pumping for baseline conditions.

For Scenario 1C, the additional river pumping to supply SPRWS and the other White Bear Lake communities is ~34 MGD. Based on the community flow data, about 30% of the increased flow is the result from the demand for the other communities (not including SPRWS) (see Table 2-9 for further community water demand details). For Scenario 3C, the additional river pumping to supply the SPRWS and the augmentation flows of White Bear Lake is ~13 MGD. Augmentation flows are about 33% of the increase in flow in this scenario.

Table 6-23 Scenario Flow Summary (MGD)

	Calibration (2025)	Baseline (2021) Dry	Scenario 1	Scenario 2	Scenario 3
Pumping From River (including water supply and/or augmentation flows)	22.5	42.4	A: 56.5 B: 69.8 C: 76.2	A: 46.5 B: 52.9 C: 55.7	A: 46.5 B: 52.9 C: 55.7
Augmentation Flow	N/A	N/A	N/A	A: 4.3 B: 4.3 C: 4.3	A: 4.3 B: 4.3 C: 4.3
Flow to SPRWS Treatment Plant	45.6	50.2	A: 64.7 B: 78.3 C: 84.7	A: 50.2 B: 56.6 C: 59.6	A: 50.2 B: 56.6 C: 59.6

6.4.1.1 Pleasant Lake

Figure 6-5 summarizes the order of magnitude oxygen dosing in the Pleasant Lake hypolimnion from existing conditions to achieve the 5 mg/L target concentration in the two main deep holes within the lake, assuming the increased loading from the sensitivity run for Scenario 1C.

Generally, the modeling suggests that applying the existing dosing (based on 2025 data) for Pleasant Lake may be sufficient to achieve the targeted hypolimnetic oxygen levels if appropriately applied and distributed within the hypolimnion.

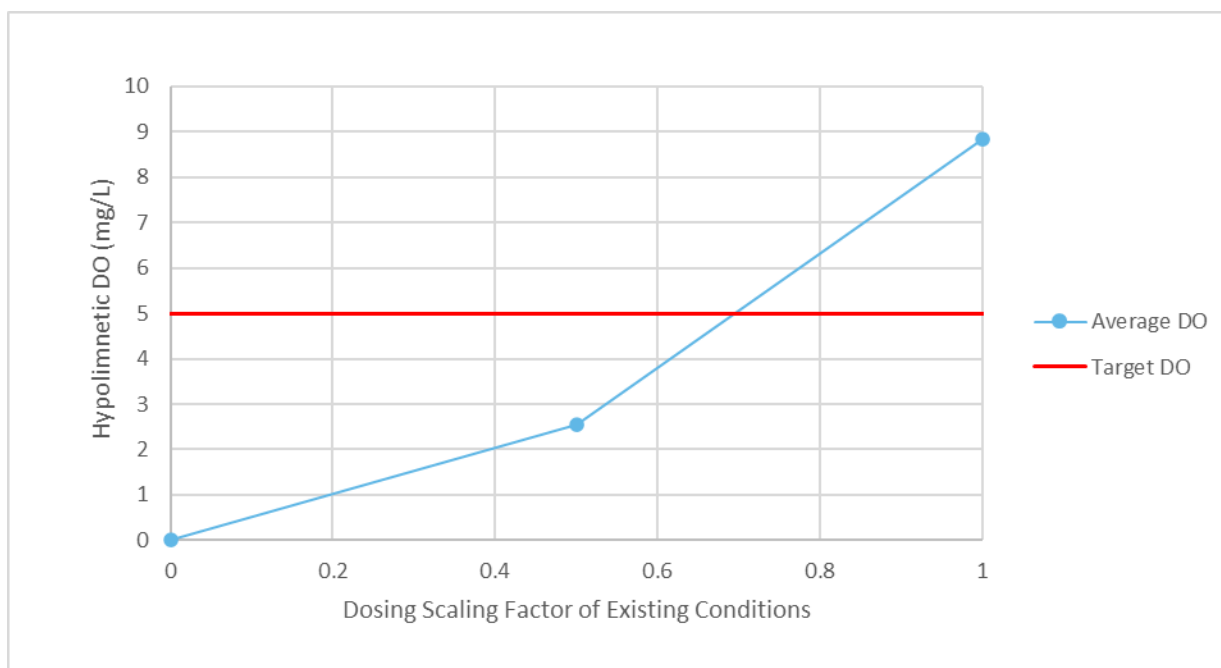


Figure 6-5 Pleasant Lake Oxygen Dosing Scaling Factor for Sensitivity Run for Scenario 1C

6.4.1.2 East Vadnais Lake

Figure 6-6 summarizes the order of magnitude oxygen dosing in the East Vadnais Lake hypolimnion to achieve the 5 mg/L target concentration in the two main deep holes within the lake, assuming the increased loading from the sensitivity run for Scenario 1C.

This would require an increase in the dosing during the growing season from existing conditions (2025 dosing) by a factor of approximately 2.25. However, some of this estimated increase in dosing would result from climatic variability and the need for increased river pumping during those conditions. For example, the dry baseline conditions run, which reflects existing lake conditions during a drought period, requires nearly double the pumping from the Mississippi River when compared to the wetter 2025 calibration conditions. The predicted baseline dissolved oxygen profiles in East Vadnais Lake from the dry baseline model runs shows lower dissolved oxygen levels in the hypolimnion (by 1-2 mg/L) during the peak of the growing season than during the wetter calibration period. This suggests that under existing conditions, SPRWS may need to nearly double the oxygen dosing to manage climatic variability in the existing system. The additional oxygen dosing required as a result of the ultimate community flows for Scenario 1C is a factor of ~0.25 when compared to 2025 dosing. However, based on the scenario flow summary, about 33% of the increase in flow would be the result of ultimate water supply demand from the other White Bear Lake communities and the remainder of that increase is due to the expected growth in the SPRWS service area.

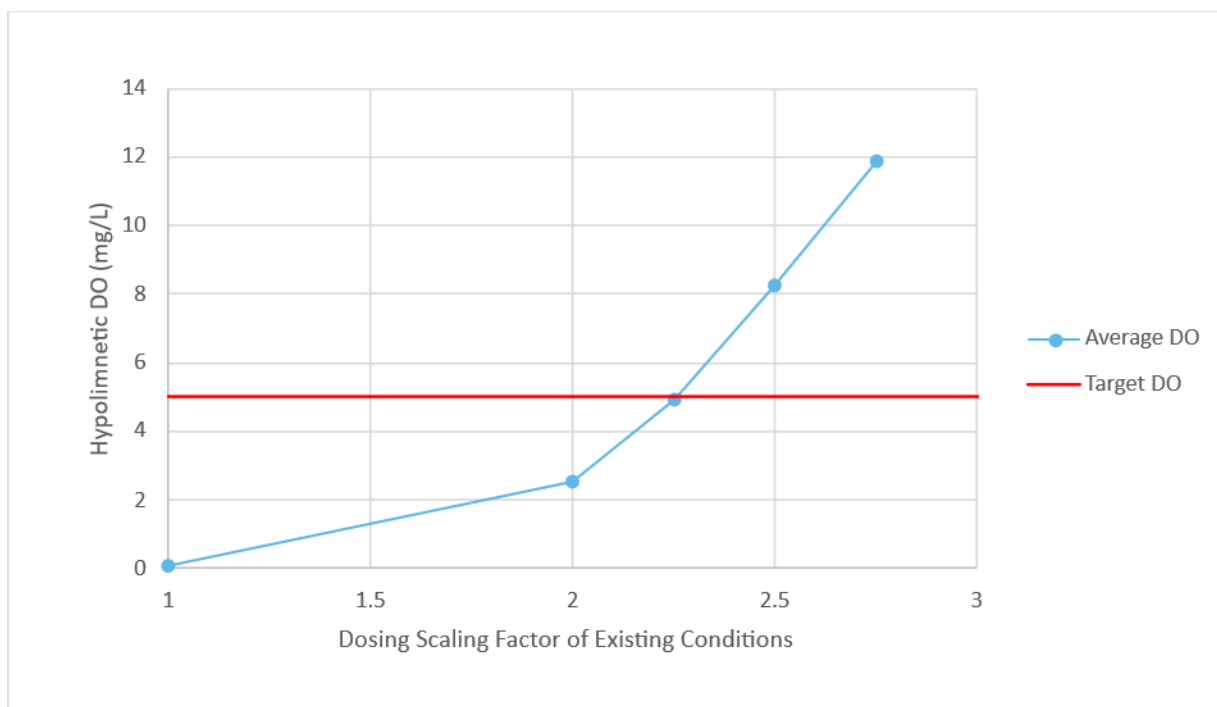


Figure 6-6 East Vadnais Lake Oxygen Dosing Scaling Factor for Sensitivity Run for Scenario 1C

6.4.2 Ferric Chloride System Considerations

We gathered and evaluated operational data recorded by SPRWS staff to determine the historic ferric chloride addition at the Mississippi River and East Vadnais Lake as a function of the mass loading of total phosphorus. We reviewed Mississippi River flow, phosphorus concentrations, and chemical addition data collected during the growing seasons from 2015 to 2025 at the Mississippi River and 2019 to 2025 at East Vadnais Lake. Because of differences in the available data for the locations and gaps in some of the dosing data, especially in the earlier part of the record, we focused on the more complete recent years of data (2020-2025) to inform this dosing assessment, we focused on the growing season (June through September).

Table 6-24 shows a summary of data used to develop the FeCl Solution/TP mass ratio at the Mississippi River. We assumed that the dosing of Ferric Chloride provided by SPRWS per month/year was based on pounds of solution.

Table 6-24 Ferric Chloride Solution/Total Phosphorus Mass Ratio at the Mississippi River Intake

Year	Growing Season Flow from MS (MG)	Growing Season TP (mg/L)	River TP Load (lbs/growing season)	FeCl Solution Added at River (lbs/growing season)	FeCl Solution/TP Ratio (lbs/lbs)
2020	5393	0.0421	1891	18495	10
2021	5337	0.0353	1567	61748	39
2022	5280	0.0424	1864	18700	10
2023	5224	0.0429	1865	39450	21
2024	5167	0.0441 ²	1899 ³	9951 ²	5 ³
2025	5111	0.0904	3848	135837	35
Average (2020-2025)	5,252	0.050	2,156	47,364	20
Revised Average ¹	5,269	0.051	2,207	54,846	23

(1) Revised average for River includes 2020-2023 & 2025

(2) Data recorded deemed unreliable

(3) Calculated value deemed unreliable

Data was not evaluated for years where the data is suspect or incomplete in the most recent years of data. Unreliable data was eliminated for the following reasons:

1. 2024 TP concentration – One data point more than 5 times the historical average and more than twice the second-highest data point recorded.
2. 2024 Ferric data included months of negative addition.

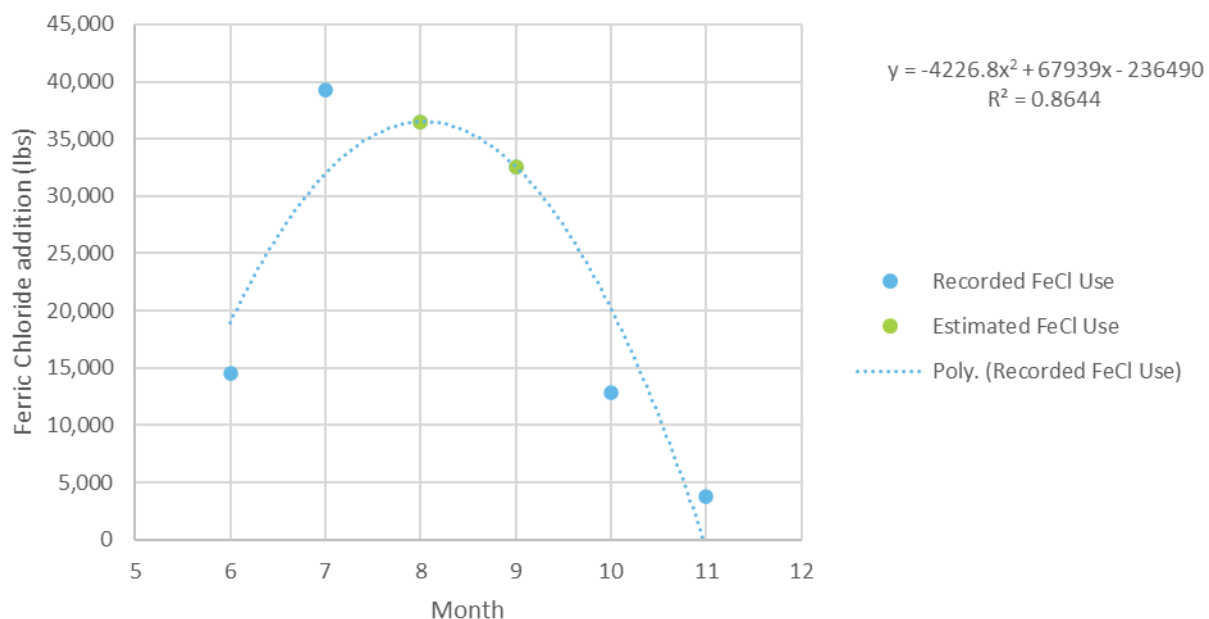


Figure 6-7 2025 Ferric Chloride Addition at Mississippi River Intake

The 2025 Ferric Chloride data included months of “Error” recordings. We eliminated these in favor of an estimate based on additions recorded during other months of the year. A second-order equation was curve fit to recorded data to estimate ferric chloride addition in two months. The 2025 data is shown in Figure 6-7.

Table 6-25 shows a summary of data used to develop the FeCl solution/TP ratio at East Vadnais Lake. We developed the relationship between Mississippi River total phosphorus load into the SPRWS chain of lakes and the dosing at East Vadnais to leverage the dosing ratio to scale the change in dosing at the river based on the scenario modeling for Scenario 1 and sensitivity runs for Scenario 1C.

Table 6-25 Ferric Chloride/Total Phosphorus Mass Ratio at the East Vadnais Lake Addition Point

Year	Growing Season Flow from MS (MG)	Growing Season TP (mg/L)	River TP Load (lbs/growing season)	FeCl Solution Added at East Vadnais (lbs/growing season)	FeCl Solution/TP Ratio (lbs/lbs)
2020	5393	0.0421	1891	1,008 ²	1 ³
2021	5337	0.0353	1567	128,418	82
2022	5280	0.0424	1864	128,510	69
2023	5224	0.0429	1865	148,842	80
2024	5167	0.0441 ²	1899 ³	82,053	43
2025	5111	0.0904	3848	57,424	15
Average (2020- 2025)	5,252	0.050	2,156	91,043	48
Revised Average ¹	5,269	0.051	2,207	109,049	58

(1) Revised average for East Vadnais includes 2021-2025

(2) Data recorded deemed unreliable

(3) Calculated value deemed unreliable

Unreliable data was eliminated for the following reasons:

1. 2020 Ferric data totaled 1,008 pounds with multiple months of zero.
2. FeCl Solution/TP Load Ratio at Mississippi River and East Vadnais Lake Addition Points

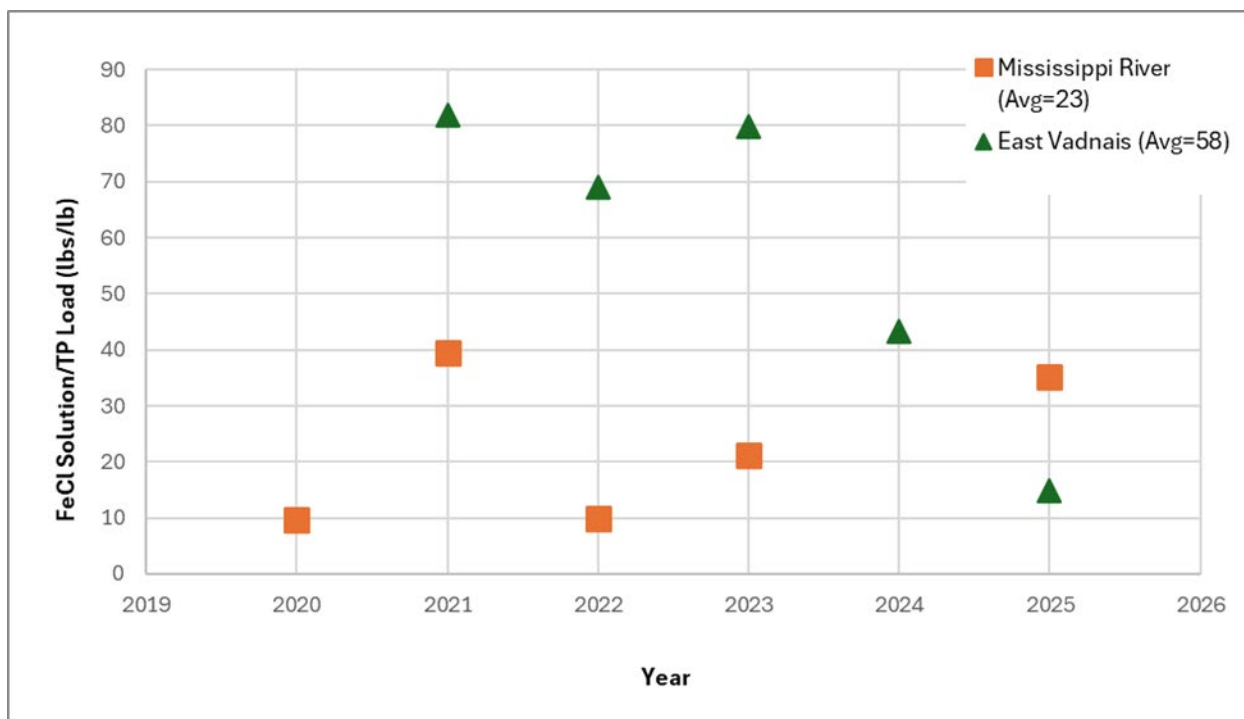


Figure 6-8 FeCl Solution/TP Load Ratio at Mississippi River and East Vadnais Lake Addition Points

The FeCl Solution/TP mass ratio is presented in Figure 6-8. Based on evaluation of recent growing season data, future ferric chloride addition at the Mississippi River can be estimated at 23 lbs/lb of total phosphorus loading. Future ferric chloride addition at East Vadnais Lake can be estimated at 58 lbs/lb of total phosphorus loading.

Using these average dosing rates, we applied this to the estimated increased Mississippi River loads into the SPRWS chain of lakes to estimate the potential magnitude of additional Ferric Chloride dosing at the River and East Vadnais. This evaluation focused on Scenario 1 model runs and the sensitivity runs for Scenario 1C, as these resulted in the highest loads and most significant impacts to the chain of lakes. Additionally, we needed to be able to estimate how much of the increased dosing was the results of the increased demand from the SPRWS service area versus the expansion to include the other White Bear Lake communities (see discussion in Section 6.4.1 and Table 6-23). Table 6-26 summarizes the estimated increases in ferric chloride dosing.

In general, in the ultimate water demand scenario (Scenario 1C), dosing from the baseline dry condition would need to increase by 80% including both SPRWS and all additional communities' demands. If only considering the additional communities, ferric chloride dosing would need to increase by 20-25%. In a worst-case scenario (where the Mississippi River is at its highest pollutant concentrations, Sensitivity – 1C), a more significant increase in ferric chloride dosing may needed (167% increase); however, it is not likely that the Mississippi River will remain at these high levels for the entirety of the growing season and dosing at a higher rate would likely be temporary.

Given the possible magnitude of the increase in dosing, it may not be possible to dose at the anticipated rates, and the system sizing could be limited by floc formation, precipitation, and anticipated accumulation in Charley and Vadnais Lakes. This dosing will need to result in in-lake iron concentrations that meet the

state surface water standards (300 ug/L). Charley Lake data suggests it typically exceeds this standard currently, but the other lakes within the system have average iron concentrations below the standard.

Table 6-26 Estimated Increase in Ferric Chloride Dosing at the Mississippi River and East Vadnais Lake

Growing Season (GS) River Load	Total River Load (lbs/GS)	Increase in River Load (lbs/GS) - Compared to Baseline	River Dosing FeCl Solution/TP Ratio	Total Growing Season FeCl Dosing At River (lbs/GS)	Increase in Growing Season FeCl Dosing At River (lbs/GS) - Compared to Baseline	Increase in Dosing including SPRWS (%)	Increase in Dosing without SPRWS (%)	East Vadnais Dosing FeCl Solution/TP Ratio	Total Growing Season FeCl Dosing At East Vadnais (lbs/GS)	Increase in Growing Season FeCl Dosing At East Vadnais (lbs/GS) - Compared to Baseline	Increase in Dosing including SPRWS (%)	Increase in Dosing without SPRWS (%)
2025 Calibration	2781	0	23	64,249	0	0%	0%	58	160,651	0	0%	0%
Baseline Dry	5097	0	23	117,742	0	0%	0%	58	294,409	0	0%	0%
Scenario 1A	6793	1697	23	156,941	39,199	33%	8%	58	392,424	98,015	33%	8%
Scenario 1B	8391	3295	23	193,858	76,116	65%	18%	58	484,735	190,326	65%	18%
Scenario 1C	9157	4060	23	211,544	93,803	80%	24%	58	528,959	234,550	80%	24%
Scenario 1 C - Sensitivity	13617	8521	23	314,593	196,851	167%	50%	58	786,627	492,218	167%	50%

It is important to note that this exercise is for planning purposes and guidance only. It does not replace the need for the standard practices employed for ferric chloride dosing. This is typically empirically determined or guided by literature values and standard practices using jar testing to quantify the recommended dose.

Should Scenario 1 be selected for future implementation, we would recommend further monitoring and jar testing to be completed to inform the actual dosing required. Also, the river flow is variable as is the water quality, and further analysis should be performed to provide a more detailed look at seasonal and annual variability in the loads from the Mississippi River.

Additionally, further documentation of the ferric chloride system operations and decision points when making changes to the dosing system could be useful and may identify opportunities for more automated control and optimized dosing.

7 Risk Assessment

For the purposes of Study 7A, a risk assessment was conducted to quantify the potential health risks associated with hypothetical municipal exposure to chemicals in the surface water of East Vadnais Lake and White Bear Lake if untreated surface water was used as municipal tap water. In reality, surface water from East Vadnais Lake is treated at the SPRWS water treatment plant following all appropriate drinking water treatment methods, and the final treated water is regularly tested in accordance with the Minnesota Department of Health (MDH) for compliance with Human Health-Based Water Guidance values (MDH, 2026). Also, White Bear Lake naturally recharges the surrounding groundwater aquifer that serves as the source water for several community water systems and private wells in the area. As the surface water of White Bear Lake passes through the underlying soil on its way to recharge the groundwater aquifer, its chemistry is likely to change through filtration and the geochemistry of the surrounding soil.

The risk assessment consisted of a screening level assessment and a quantitative human health risk assessment for the municipal tap water exposure pathway to help identify at a planning level possible contaminants of concern to consider as part of the mitigation planning.

The following sections summarize the risk assessment process and results, and information supporting this assessment is located in Appendix 10.

7.1 Screening Level Risk Assessment

The purpose of the screening level risk assessment (SLRA) was to identify a subset of chemicals (i.e., chemicals of potential concern or COPCs) in the surface water of each source lake that could contribute to health risks if untreated surface water was used as tap water by residents.

The measured concentrations of chemicals in surface water samples collected from East Vadnais Lake and White Bear Lake were screened against conservative human-health risk-based screening levels (RBSLs) for a municipal exposure scenario. Any chemical for which a maximum measured concentration exceeded an RBSL was identified as a COPC, and the risks were evaluated further in the quantitative risk assessment (Section 7.2).

7.1.1 Datasets

The SLRA dataset for East Vadnais Lake consists of the analytical results for surface water samples collected from the East Vadnais North, East Vadnais South, and East Vadnais VLAWMO monitoring stations (Figure 2-4) in 2025. The SLRA dataset for White Bear Lake consists of the analytical results for surface water samples collected from the White Bear Lake monitoring stations 229, 230, 231, and 234 (Figure 2-5) in 2025. The 2025 monitoring data was collected in accordance with the monitoring plan, further discussed in Section 2.2.

The analytical results were screened for data usability based on an evaluation of data qualifiers. The analytical results are considered representative of surface water conditions, and none of the samples were excluded from the SLRA datasets. Data qualifier flags have been retained, and estimated values (e.g., those values marked with the letter J) are evaluated as detections. For each chemical, the maximum detected concentration was used in the SLRA.

7.1.2 Identification of COPCs

The maximum detected concentration of chemicals in surface water samples from East Vadnais Lake and White Bear Lake were screened with the following conservative human-health RBSLs for municipal exposures:

1. U.S. Environmental Protection Agency (USEPA) regional screening levels (RSLs) for municipal tap water (USEPA, 2024) based on a target hazard quotient of 0.1 for noncarcinogens and a target cancer risk of 1E-06 for carcinogens.
2. MDH Human Health-Based Water Guidance values (MDH, 2026).

The results of these comparisons are shown in Appendix 10. Any chemical with a maximum detected concentration greater than an RBSL was identified as a COPC and evaluated further in the quantitative risk assessment (Section 7.2).

As shown on the screening level table for East Vadnais Lake, the maximum measured concentrations of the following chemicals in surface water samples were greater than an RBSL and are considered COPCs for East Vadnais Lake: fluoride, phosphorus (total), manganese, and perfluorooctanesulfonic acid (PFOS). As shown on the screening level table for White Bear Lake, the maximum measured concentrations of the following chemicals in surface water samples were greater than an RBSL and are considered COPCs for White Bear Lake: chlorine dioxide, total residual chlorine, fluoride, phosphorus (total), arsenic, manganese, thallium, and perfluorooctanoic acid (PFOA).

7.2 Quantitative Risk Assessment

This section quantifies the potential cancer risks and noncancer hazards associated with hypothetical municipal exposure to COPCs in the surface water of East Vadnais Lake and White Bear Lake if tap water sourced from each lake were untreated.

Consistent with the National Contingency Plan (NCP; 40 CFR Part 300, §300.430), the USEPA identifies a total excess lifetime cancer risk (ELCR) between 1E-06 (one in one million) and 1E-04 (one in ten thousand) to be within the acceptable risk management range. Therefore, in this quantitative risk assessment, the calculated ELCRs are compared to both the lower and upper limits of the USEPA acceptable risk range (i.e., 1E-06 and 1E-04).

For noncancer health hazards, the NCP states that acceptable exposure levels shall represent concentration levels to which humans, including sensitive subgroups, may be exposed without adverse effect during a lifetime or part of a lifetime, incorporating an adequate margin of safety. The USEPA has defined this acceptable exposure level as a hazard quotient (HQ) or hazard index (HI) less than or equal to 1 (USEPA, 1989). An HQ is the ratio of a single chemical exposure level over a specified period of time to a reference dose for that chemical derived from a similar exposure period (USEPA, 1989). An HI is the sum of more than one HQ for multiple chemicals and/or exposure pathways (USEPA, 1989).

The USEPA RSL calculator (USEPA, 2024) was used to calculate ELCRs, HQs, and HIs for hypothetical municipal tap water exposures. The RSL calculator utilizes the most current USEPA risk assessment methodology, equations, conservative reasonable maximum exposure (RME) variables, and toxicity values. The equations and default exposure variables used in the RSL calculator for municipal tap water exposures are provided in Appendix 10.

7.2.1 Dataset Processing

The datasets used in the quantitative risk assessment were the same as those used for the SLRA (Section 7.1.1). However, rather than using maximum detected concentrations, exposure point concentrations (EPCs) were calculated for each COPC. The statistical methods used to calculate the EPCs were consistent with USEPA guidance (USEPA, 2022) and based on both the total number of samples and the number of detected values within each COPC dataset. For COPCs with at least 8-10 sample results, the EPC was equal to a 95% upper confidence limit of the mean concentration (95% UCL). The ProUCL 5.2 software package (USEPA, 2022) was used to calculate a 95% UCL for each COPC from the surface water data collected from East Vadnais Lake and White Bear Lake in 2025. For COPCs with fewer than eight detected values, the EPC was equal to the maximum detected concentration.

Prior to calculation of the 95% UCLs, each dataset was processed as recommended by ProUCL guidance (USEPA, 2022). This process consisted of the modification of non-detect results and the removal of duplicate sample results. Non-detect values were modified as required by ProUCL by removing all non-numeric characters (e.g., <, laboratory qualifiers) and assigning a detection status value of zero in a separate column of the ProUCL worksheet. Duplicate sample values were removed from the datasets. Documentation of the ProUCL datasets (input) and statistical results (output) for each COPC is provided in Appendix 10.

7.2.2 Potential Source Water Risks and Hazards

The potential human health risks and hazards associated with the hypothetical municipal use of untreated surface water as tap water were evaluated using the USEPA RSL calculator (USEPA, 2024), which calculates risks and hazards from tap water delivered into a residence from a groundwater or surface water source. The resident tap water equations calculate the cumulative risks and hazards from the exposure routes of ingestion, dermal contact, and inhalation.

Using the municipal tap water equations and default variables in the RSL calculator, and the East Vadnais Lake EPCs for each COPC, the following ELCRs, HQs, and HIs were calculated for the hypothetical municipal use of untreated tap water sourced from East Vadnais Lake, as summarized in Table 7-1.

Table 7-1 Risk Assessment Summary for East Vadnais Lake

COPC	Carcinogenic ELCR for Hypothetical Municipal Tap Water Scenario	Noncarcinogenic HQ for Hypothetical Resident Child	Noncarcinogenic HQ for Hypothetical Resident Adult
Fluoride	Not Applicable	0.126	0.0761
Phosphorus	Not Applicable	89.9	54.1
Manganese	Not Applicable	0.800	0.494
Perfluorooctanesulfonic acid (PFOS).	9.63E-07	0.947	0.569
Total Risk/Hazard Index	9.63E-07	91.8	55.2
<i>Acceptable Risk/Hazard</i>	<i>1E-04 to 1E-06 or less</i>	<i>1 or less</i>	<i>1 or less</i>

As summarized above, the ELCR for PFOS is less than the USEPA acceptable risk range (i.e., 1E-06 and 1E-04). The noncancer HQ for phosphorus is greater than the acceptable target of 1 for both hypothetical child and adult residents and constitutes 98% of the HI for both hypothetical child and adult residents. While the noncancer HQs for the other COPCs are less than the acceptable target of 1, the cumulative HI for the other COPCs is greater than the acceptable target of 1 for both hypothetical child and adult residents.

Using the municipal tap water equations and default variables in the RSL calculator, and the White Bear Lake EPCs for each COPC, the following ELCRs, HQs, and HIs were calculated for the hypothetical municipal use of untreated tap water sourced from White Bear Lake, as summarized in Table 7-2.

Table 7-2 Risk Assessment Summary for White Bear Lake

COPC	Carcinogenic ELCR for Hypothetical Municipal Tap Water Scenario	Noncarcinogenic HQ for Hypothetical Resident Child	Noncarcinogenic HQ for Hypothetical Resident Adult
Chlorine dioxide	Not Applicable	912	911
Chlorine (total residual)	Not Applicable	364	364
Fluoride	Not Applicable	0.118	0.0711
Phosphorus	Not Applicable	102	61.5
Arsenic	4.78E-05	0.412	0.248
Manganese	Not Applicable	0.126	0.0779
Thallium	Not Applicable	0.901	0.542
Perfluorooctanoic acid (PFOA)	2.56E-03	11.3	6.8
Total Risk/Hazard Index	2.61E-03	1390	1340
<i>Acceptable Risk/Hazard</i>	<i>1E-04 to 1E-06 or less</i>	<i>1 or less</i>	<i>1 or less</i>

As summarized above, the ELCR for arsenic is less than the USEPA acceptable risk range (i.e., 1E-06 and 1E-04), and the ELCR for PFOA (based on the maximum concentration of two surface water samples) is greater than the USEPA acceptable risk range for hypothetical residents.

The noncancer HQ for phosphorus is greater than the acceptable target of 1 for both hypothetical child and adult residents. The noncancer HQs for chlorine dioxide, total residual chlorine, and PFOA (each based on the maximum concentration of two surface water samples) are greater than the acceptable target of 1 for both hypothetical child and adult residents. The HQs for chlorine dioxide and total residual chlorine constitute 92%-95% of the HI for the hypothetical child and adult residents, respectively.

7.3 Future Considerations

Based on the results of the quantitative risk assessment, future actions to consider for East Vadnais Lake include:

1. Consider testing the treated SPRWS water for the identified East Vadnais Lake COPCs (i.e., fluoride, phosphorus, manganese, and PFOS) for compliance with MDH Human Health-Based Water Guidance values, if such testing is not already being done.

2. Consider additional monitoring of East Vadnais Lake for PFOS, as only two surface water samples were tested for PFOS in 2025.
3. Confirm that reporting limits for future monitoring samples are less than relevant regulatory values.

Based on the results of the quantitative risk assessment, future actions to consider for White Bear Lake include:

1. Consider testing community water systems and private wells in the area for the identified White Bear Lake COPCs (i.e., chlorine dioxide, total residual chlorine, fluoride, phosphorus, arsenic, manganese, thallium, and PFOA) for compliance with MDH Human Health-Based Water Guidance values, if such testing is not already being done.
2. Consider additional monitoring of White Bear Lake for chlorine dioxide, total residual chlorine, and PFOA, as only two surface water samples were tested for these COPCs in 2025.
3. Confirm that reporting limits for future monitoring samples are less than relevant regulatory values.

8 Mitigation Plan

8.1 Summary of Key Considerations for Mitigation

Based on the results of the scenario modeling and sensitivity analysis as well as the results of the risk assessment conducted above, we have summarized the major takeaways to inform the development of a conceptual mitigation plan to prevent, treat, and address potential contaminants of concern in the SPRWS chain of lakes, as well as the augmentation of White Bear Lake. This includes both eutrophication and non-eutrophication parameters as well as consideration of the potential treatment needs for aquatic invasive species (AIS) present in the system, including zebra mussel veligers (known to be present in these systems), as well as available information on requirements to prevent transfer of other possible AIS species of concern in Minnesota.

As part of the mitigation plan development, we considered the results of the various scenarios and sensitivity analysis summarized in the report above, but did not perform any additional in-lake model runs reflecting the potential treatment as outlined in the mitigation plan that follows.

Additionally, the infrastructure improvements for distribution and treatment related to lake augmentation, including their estimated capital and operation and maintenance (O&M) costs, will be evaluated by others as part of a separate study (Study 7B), but will consider the recommendations of this Mitigation Plan to inform the system design and costs.

8.1.1 Conveyance

Although the CE-QUAL-W2 indicates that a significant change in average water levels is not expected for the modeled scenarios, some additional modeling work is needed. If one of the scenarios evaluated in this study is selected for long term implementation, a hydraulic model of lake outlets and conveyance channels should be used to fully understand the hydraulic conveyance capacity of the SPRWS chain of lakes system relative to the anticipated future flows.

Additionally, the current SPRWS system has a lot of manually operated components, and we had to make simplifying assumptions to capture future operations. Moving forward, it will be important to work with SPRWS to better capture the operational variability in the pumping from the Mississippi River, the operations at Pleasant Lake outlet, and even the gate operations, which also flow into the SPRWS treatment plant.

Frequent monitoring of lake levels for all the lakes in the system should be continued. This data can help better capture the variability and response to system operations through the entire chain of lakes and will be important to inform any future management decisions or design modifications.

8.1.2 Lake Response Summary

In general, scenario modeling and sensitivity analysis show that the SPRWS chain of lakes system could experience degraded water quality with the increased flows and pollutant loading, especially if the Mississippi River is experiencing sustained, high pollutant concentrations.

The magnitude of eutrophication responses to increased flows and nutrient loads through the chain of lakes for all the scenarios decreases as water moves through the system, and pollutants are generally retained in the upstream lakes. For phosphorus, Scenario 1 results in the most significant response

Charley Lake, Pleasant Lake, and Sucker Lake, which all currently do not meet state water quality standards for total phosphorus, will experience further increases in growing season concentrations. East Vadnais Lake will also see a possible 10-30% increase in total phosphorus though it is expected that the lake will still meet state water quality standards. For White Bear Lake augmentation scenarios, Scenario 2, which draws water from Sucker Lake, results in a more significant response in White Bear Lake than when drawing water from East Vadnais Lake, which generally has better water quality. The lake response to the estimated increased phosphorus load is limited (1-2% increase from baseline), suggesting that White Bear Lake system is highly resilient to the additional loading from augmentation. This is largely due to the large size and volume of the lake relative to the augmentation flows and estimated increase in loads. Additionally, internal phosphorus loading is the primary driver of water quality in White Bear Lake and the increased loading from augmentation is small relative to internal phosphorus loads.

A similar trend is seen with total nitrogen, with Scenario 1 showing a greater response in the chain of lakes and Scenario 2 showing a slight increase in total nitrogen levels in White Bear Lake. Again, impacts in the upstream lakes (Charley, Pleasant, and Sucker) indicate a more significant response with respect to increased nitrogen levels, with some estimated concentrations falling outside historic ranges while in East Vadnais, though an increase is observed, the resulting concentrations align with historic observations. However, in White Bear Lake, the response to increased nitrogen loads is limited (~1% increase from baseline).

The lake eutrophication relationships for the SPRWS chain of lakes show that there are not strong relationships between elevated phosphorus concentrations and corresponding increases in chlorophyll a (algal) response or reduced Secchi disc transparency. The data was highly variable and had low correlation, likely driven by the Mississippi River flows/low residence times, active outlet management, and the ferric chloride/oxygenation systems used to treat the chain of lakes, as well as the presence of AIS, specifically zebra mussels, in all lakes, which can control algal response and improve transparency even during higher nutrient conditions. White Bear Lake had a stronger correlation between nutrients and phytoplankton (measured as chlorophyll a), but similar to the chain of lakes, chlorophyll a remains low, and transparency remains high, with the anticipated change in water quality. Similarly, White Bear Lake relationships are impacted by zebra mussels.

The CE-QUAL-W2 modeling showed a similar response, with increased loading impacting nutrient levels, but not seeing the same algal response or reduction in clarity. In all scenarios under more normal conditions in the river, we see slight increases in chlorophyll a concentrations, with the most significant increase seen at East Vadnais and a slight increase in White Bear Lake; however, these levels are typically well below the state standards. However, if the river has high chlorophyll concentrations, we might expect to see elevated chlorophyll levels throughout the chain of lakes that could exceed state standards and result in algal blooms throughout the system.

With increased loads including the nutrients and total organic carbon to the lakes' systems, we are seeing declines in dissolved oxygen concentrations at the lake surface as well as in the hypolimnion of the lakes. For many of the lakes, all scenarios show reduced hypolimnetic oxygen levels compared to baseline conditions, with many scenarios showing anoxic conditions. Scenario 1 has the most significant impact on oxygen levels in the chain of lakes. The phosphorus load summaries from the modeling also show increasing internal phosphorus loads from the sediments as a result of the lower oxygen levels and longer periods of anoxia in the lakes. Oxygen response in White Bear Lake due to augmentation is minimal, but adding long term loads of total suspended solids, phosphorus, and total organic carbon to the lake should be treated to similar levels observed in White Bear Lake to protect water quality, to prevent accumulation within the lake and bottom sediments, and to reduce risk for eutrophication into the future.

As part of the scenario and sensitivity modeling, as well as part of the risk assessment, we identified and evaluated other non-eutrophication pollutants to be evaluated based on the 2025 monitoring data. The mass balance modeling response helped identify those parameters where we could expect a more significant response to the proposed changes in flows through the system and augmentation of White Bear Lake. The following is a summary of the anticipated lake response to those parameters, with those in **bold** highlighting those with a more significant response:

- **Total Suspended Solids:** Particulate material suspended in lake water can reduce lake clarity, carry additional pollutants like phosphorus and metals, contribute to algal blooms, and can contribute to low oxygen levels. The modeling suggests that TSS decreases through the chain of lakes, and under more typical river conditions, the additional loads would not result in significant changes in all scenarios evaluated, but when the river has elevated (99th percentile) TSS concentrations, the concentrations could be more than double for Charley, Pleasant, and Sucker, and for East Vadnais, increasing to over 50%. White Bear TSS concentrations are most significantly impacted during Scenario 2, increased by 8-9% at typical conditions, and increases to 20% change from baseline when the river concentrations are elevated. This is more critical in the upstream lakes (Charley and Pleasant), with the concentrations in Sucker, East Vadnais, and White Bear Lake falling within the range of historic variability (95th percentile for growing season average), and overall TSS concentrations throughout the system are fairly low and are expected to remain well below the TSS standards for surface waters.
- **Total Dissolved Solids:** TDS concentrations measure the combined content of all inorganic and organic substances dissolved in water. The modeling suggests that TDS decreases through the chain of lakes, and under more typical river conditions, the additional loads would not result in significant changes in all scenarios evaluated, but when the river has elevated (99th percentile) TDS concentrations, the concentrations could increase by 30-35% in all scenarios. White Bear TDS concentrations are most significantly impacted during Scenario 2, increasing from up to 5% at typical conditions and increasing to 6-7% change from baseline when the river concentrations are elevated. The estimated concentrations will typically fall within the range of historic conditions, although when the river has elevated levels TDS may exceed the historic ranges. There are no surface water standards for TDS, but the chain of lakes concentrations are higher than typically seen in surface waters. However, all estimated concentrations are below the EPA drinking water standards secondary maximum contaminant levels.
- **Chlorides:** Chloride is a naturally occurring ion in lakes, but its concentrations have risen sharply due to anthropogenic sources like road de-icing salts. The modeling suggests that concentrations are generally consistent through the chain of lakes, though highest in East Vadnais, and under more typical river conditions, the estimated change in lake concentrations is not significant, but when the river has elevated (99th percentile) chloride, concentrations could possibly double in all scenarios. White Bear Lake concentrations are typically higher than the chain of lakes and show limited impact during augmentation. Although there are changes from baseline conditions, the resulting lake concentrations are well below the state standards for chronic chloride impairments and are below the EPA drinking water secondary maximum contaminant levels.
- **Hardness:** Water hardness is the measure of dissolved minerals, typically calcium and magnesium, in the water. The modeling suggests that hardness decreases through the chain of lakes, and under more typical river conditions, the additional loads would not result in significant changes in all scenarios evaluated. However, when the river has elevated conditions, hardness could increase by 10-12% in all scenarios. White Bear Lake hardness is most significantly

impacted during Scenario 2, increasing from up to 6-7% at typical conditions and increasing to 7-8% change from baseline when the river concentrations are elevated. Although there are anticipated changes in alkalinity, the resulting concentrations are generally around the upper end of the historic range of variability.

- **Alkalinity:** Alkalinity is a buffer that stabilizes pH and protects aquatic ecosystems. The modeling suggests that alkalinity decreases through the chain of lakes, and under more typical river conditions, the additional loads would not result in significant changes in all scenarios evaluated. However, when the river has elevated conditions, alkalinity could increase by 10-13% in all scenarios; White Bear Lake alkalinity is typically less than the chain of lakes and is most impacted during Scenario 2, increasing to 7-8% change (up from 6-7% as part of scenario assessment when river concentrations were more average). Although there are anticipated changes, the resulting concentrations are generally around the upper end of the historic range of variability and are within the range typically considered optimal for freshwater ecosystems.
- **Arsenic:** Arsenic is a naturally occurring element that can come from both natural processes and human activities. The modeling suggests that arsenic decreases through the chain of lakes, and under more typical river conditions, the additional loads would not result in significant changes in all scenarios evaluated. However, when the river has elevated conditions, arsenic could increase by 35-44% in all scenarios. Arsenic concentrations in White Bear are typically higher than Sucker and East Vadnais and show limited impact under Scenario 2. The concentrations seen in all the lakes are typical of background levels of arsenic and are below the state surface water standard for arsenic. Although it was flagged as a contaminant of potential concern during the risk assessment for White Bear Lake, the health risk quotient was within the acceptable range, and the estimated levels are below the EPA drinking water maximum contaminant levels.
- **Aluminum:** Aluminum can occur naturally or be introduced through human activities, and its presence can have both beneficial and harmful effects depending on concentration, form, and water chemistry. The modeling suggests that aluminum concentrations show a slight decrease through chain of lakes and under more typical river conditions; the additional loads would not result in significant changes in all scenarios evaluated. However, when the river has elevated conditions, the chain of lakes aluminum concentration could more than double. Aluminum concentrations in White Bear Lake are typically higher than Sucker and East Vadnais and shows limited impact under Scenario 2. The increased concentrations estimated for the lakes are generally around the upper end of the historic range of variability, are below the state surface water standard, and are below the EPA drinking water secondary maximum contaminant levels.
- **Barium:** Barium is a metal often found in rocks and soil as well as anthropogenic sources. The modeling suggests that barium decreases through chain of lakes, and under more typical river conditions, the additional loads would not result in significant changes in all scenarios evaluated. However, when the river has elevated conditions, the chain of lake shows significant change from baseline, increasing to 10-12% in all scenarios. In White Bear Lake, the barium concentrations are typically less than Sucker and East Vadnais and increasing to 5-6% change (up from 4-5% when the river conditions were more average) under Scenario 2. The increased concentrations estimated for the lakes are generally around the upper end of the historic range of variability, are below the state surface water standards, and are below the EPA drinking water maximum contaminant levels.

- Calcium: Calcium is a naturally occurring metal in freshwater ecosystems. The modeling suggests that calcium concentrations show slight decreases through chain of lakes and under more typical river conditions, the additional loads would not result in significant changes in all scenarios evaluated. However, when river concentrations are elevated, a more significant change from baseline, increasing to 9-12% in all scenarios. Calcium concentrations in White Bear are lower than Sucker and East Vadnais and increasing to 7-8% change (up from 6-7% under more typical river conditions) under Scenario 2. The increased concentrations estimated for the lakes are generally within or around the upper end of the historic range of variability and align with concentrations seen in higher calcium lake systems.
- Copper: Copper is a naturally occurring trace element that can have both natural and anthropogenic sources. SPRWS has applied copper sulfate in the past in the chain of lakes system to help control zebra mussels (this activity was not included as part of the model inputs as there was limited usage in 2025). The modeling suggests that copper concentrations show slight decrease through chain of lakes until East Vadnais where increases are observed. Under more typical river conditions, the additional loads would not result in significant changes in all scenarios evaluated. However, when the river has elevated conditions, the chain of lakes copper concentration significantly change from baseline by more than 2-4 times for Charley, Pleasant, and Sucker and for East Vadnais increasing to over 50% from baseline conditions in all scenarios. Copper concentrations in White Bear Lake are lower than Sucker and East Vadnais and is most significantly impacted under Scenario 2, increasing from 5-6% during typical river conditions and increasing to 24% change from baseline conditions when river concentrations are elevated. The increased concentrations estimated for the lakes are above the upper end of the historic range of variability, especially in the upstream lakes in the chain of lakes (Charley, Pleasant, Sucker), while the increased concentration in East Vadnais falls within the historic variability. The increased concentrations estimated for the lakes can be above the upper end of the historic range of variability, below the state surface water standard, and concentrations in all lakes are below the EPA drinking water maximum contaminant levels.
- Fluoride: Fluoride comes from both natural and anthropogenic sources in freshwater systems. Fluoride concentrations generally decrease through the chain of lakes but show significant change from baseline increasing to 11-15% in all scenarios when the river concentrations are elevated; White Bear Lake concentrations typically similar to Sucker and higher than East Vadnais and limited impact during Scenario 2 with a similar response to the scenario assessment (with an increase of 6-7% change from baseline). The increased concentrations estimated for the lakes are above the upper end of the historic range of variability and it was also flagged as a contaminant of potential concern during the risk assessment for both East Vadnais and White Bear Lake, though the health risk quotient was within the acceptable range and the estimated average concentrations in all lakes are below the EPA drinking water maximum contaminant levels. These levels are also well below toxicity for aquatic life.
- Magnesium: Magnesium is a naturally occurring element in freshwater systems. The modeling shows that magnesium concentrations decrease through the chain of lakes and does not show significant change in any Scenario when the river is at typical concentrations and when the river has elevated pollutant concentrations, the change from baseline ranges from 11-14% change. White Bear Lake magnesium concentrations are less than Sucker and East Vadnais and most significantly impacted during Scenario 2 increasing to 6-7% change when the river pollutant

concentrations are elevated (up from 0-1% change when river concentrations are more typical). Historic magnesium concentrations in the chain of lake system as well as White Bear Lake are on the higher end of what is typical in most freshwater lakes.

- **Manganese:** Manganese is naturally occurring element that becomes soluble in sediments under anoxic conditions and impacts discoloration and also cause taste and odor issues. The modeling shows that manganese generally decreases through chain of lakes although concentrations are highest in Pleasant Lake. Under typical river concentrations, there is little anticipated change in levels through the SPRWS chain of lakes. However, there is more significant change from baseline increasing to 400-1000% in all scenarios when river concentrations are elevated. White Bear Lake manganese concentrations are less than Sucker and similar to East Vadnais and most significantly impacted during Scenario 2 increasing to 200% change (up from 19-20% as part of scenario assessment) when river concentrations are elevated. However, the predicted levels in White Bear Lake are typically within historic ranges and below levels that would typically cause concern in freshwater lakes. Concentrations in the chain of lakes could exceed the historic variability in these water bodies and under future scenarios, especially when river concentrations are elevated, the estimated concentrations possibly exceed the EPA drinking water secondary maximum contaminant levels and MDH health risk limits. Manganese was also flagged as a contaminant of potential concern during the risk assessment for both East Vadnais and White Bear Lake, though the health risk quotient was within the acceptable range for both lakes.
- **Sulfate:** Sulfate is a naturally occurring anion in freshwater systems that can impact carbon, nitrogen, and phosphorus cycling, iron availability, and other biological processes. The modeling shows that sulfate concentrations generally decrease through the chain of lakes and does not show significant change in any scenario when the river is at typical concentrations. However, when the river has elevated pollutant concentrations, the change from baseline increases to 100-250% in all scenarios. White Bear Lake sulfate concentrations are lower than both Sucker and East Vadnais and most significantly impacted during Scenario 2. During typical conditions, the increase from baseline is 29-30% increase while this change increases to 88-89% when river concentrations are elevated. Concentrations exceed the historic variability in these water bodies in the future scenarios, especially when river concentrations are elevated, but are still typically well below concentrations where there would be ecological concerns in lakes. Additionally, sulfate concentrations are well below the surface water standards and below the EPA drinking water secondary maximum contaminant levels for all lakes.
- **Chlorine Dioxide:** Chlorine dioxide is an oxidizing and disinfecting agent typically used in water and wastewater treatment. The modeling shows that chlorine dioxide concentrations decrease through chain of lakes and with the river at more typical conditions, it generally shows that this is not a significant impact on the chain of lakes though a more significant impact is seen at East Vadnais Lake, increasing up to 12% from baseline. When river pollutant levels are more elevated, we see are more significant change from baseline increasing to 45-65% in all scenarios; White Bear Lake chlorine dioxide monitored concentrations are higher than both Sucker and East Vadnais and shows limited impact during Scenario 2. It was also flagged as a contaminant of potential concern during the risk assessment for White Bear Lake with the health risk quotient being above the acceptable range based on limited available data. Chlorine dioxide concentrations are below the EPA drinking water maximum contaminant levels for all lakes.

- Gross Alpha Radiation: Gross Alpha (radiation) is a measure of radioactivity with a water source often driven by local geology. The modeling shows that Gross Alpha (radiation) generally declines through chain of lakes. When the river is at more average conditions, there is not a significant change in the chain of lakes except there is more of an increase from baseline in East Vadnais Lake. However, when concentrations are elevated, the response shows more significant change from baseline increasing to 75-95% in all scenarios. White Bear Lake generally has lower levels than the chain of lakes. Under normal conditions, it shows limited impact (4-5% increase from baseline) during Scenario 2 but increases to an 8-9% change when river concentrations are elevated. Gross Alpha particles are below the EPA drinking water maximum contaminant levels for all lakes.
- Gross Beta Radiation: Gross Beta (radiation) is a measure of radioactivity with a water source often driven by local geology. The modeling shows that Gross Beta (radiation) generally shows a decline through chain of lakes, though there is an increase in Sucker Lake before declining again in East Vadnais. When the river is at more typical conditions, there is not a significant change in the chain of lakes except there is more of an increase from baseline in East Vadnais Lake. However, when concentrations in the river are elevated, we see a more significant change from baseline in the chain of lakes increasing to 60-75% in all scenarios. White Bear Lake generally has higher levels than the chain of lakes and during Scenario 2, when we see levels that increase from 3-4% from baseline during typical conditions and increase to 5-6% change when the river is elevated. In elevated conditions, Gross Beta particles could exceed the EPA drinking water maximum contaminant levels for all lakes.
- Radium 226: Radium 226 is a naturally occurring radionuclides that is typical from surrounding bedrock, groundwater, and sediments. Radium 226 generally remains constant through chain of lakes, though Sucker Lake typically has the highest levels. The modeling shows that when the river is at more average conditions, there is not significant change from baseline conditions through the chain of lakes for all scenarios; however, if the river is at elevated levels, are more significant response in the lakes is expected, increasing from baseline by 18-96% in all scenarios when the river levels are elevated. White Bear Lake shows a more significant response during Scenario 2 increasing to 47-49% change (up from 27-28% during more average river conditions). In combination with Radium 228, the estimated concentrations for the lakes typically are below the EPA drinking water maximum contaminant levels for all lakes.
- Radium 228: Radium 228 is a naturally occurring radionuclide that is typical from surrounding bedrock, groundwater, and sediments. Radum 228 is generally constant through chain of lakes, though an increase is observed from Sucker to East Vadnais. The modeling shows that during typical conditions the is limited response in the chain of lakes but when the river conditions are elevated, the chain shows a more significant change from baseline increasing to 10-82% in all scenarios. White Bear Lake Radium 226 levels are typically higher than Sucker and East Vadnais Lakes and shows limited impact during Scenario 2. In combination with Radium 226, the estimated concentrations for the lakes typically are below the EPA drinking water maximum contaminant levels for all lakes.
- Microplastics: Microplastics are small pieces of plastic that are typically less than 5 mm in length, coming from a variety of anthropogenic sources. Microplastics generally show a decline through chain of lakes but does show a higher concentration in East Vadnais Lake. When the river is at more typical conditions, the chain of lakes does not show significant response until Sucker and East Vadnais Lakes, where we see increases from 4-15% from baseline. When the river is at

elevated conditions, the chain of lakes show a significant change from baseline with a 150-180% increase in all scenarios. White Bear Lake microplastic concentrations are typically higher than the chain of lakes and show limited impact during Scenario 2 increasing to 5-6% change when river concentrations are elevated (up from ~2% under more typical river concentrations). There are currently no standards for microplastics.

- **PFOA/PFOS:** PFOA was flagged as a contaminant of potential concern during the risk assessment for White Bear Lake and the health risk quotient was above the acceptable range for White Bear Lake. PFOS was also flagged as a contaminant of potential concern during the risk assessment for East Vadnais Lake and the health risk quotient was within the acceptable range for East Vadnais. The risk assessment was based on limited data points in each lake which were collected for screening purposes; however additional monitoring should be performed from the river through the chain of lakes and White Bear Lake to better understand the per- and polyfluoroalkyl substances within these lake systems.
- **Thallium:** Thallium was flagged as a contaminant of potential concern during the risk assessment for White Bear Lake, with the concentrations in the lake exceeding the EPA drinking water maximum contaminant levels. However, the health risk quotient was within the acceptable range for White Bear Lake. The 2025 data meet the state surface water standard are within the range typical of freshwater ecosystems.
- **Total Residual chlorine:** Total Residual Chlorine should typically be undetectable in freshwater ecosystems. This parameter was flagged as a contaminant of potential concern during the risk assessment for White Bear Lake, with the concentrations in the lake meeting the EPA drinking water maximum contaminant levels. The health risk quotient exceeded the acceptable range for White Bear Lake.

8.1.3 Mitigation Plan

Based on the response summary above, the following are potential mitigation strategies that could be considered if one of the scenarios evaluated as part of Study 7A is selected for implementation as part of a long-term water supply strategy for communities in the White Bear Lake area. This includes considerations around additional monitoring, the ferric chloride treatment of the river inflows, the oxygenation system at Pleasant Lake, the ferric chloride and oxygenation system at East Vadnais, and treatment of water prior to augmentation of White Bear Lake.

8.1.3.1 Additional Water Quality Monitoring

2025 data was collected to inform the modeling and provide a screening look at potential contaminants of concern and concentrations through the system. However, for many parameters (beyond eutrophication parameters and metals which were monitored monthly), this sampling was limited to 2 samples within each lake in June and September 2025 to help identify potential contaminants of concern to inform this study and mitigation plan. We would recommend continuing monthly (or more frequent) monitoring of the eutrophication-related parameters at the river and through the lakes. Additionally, more frequent monitoring of the non-eutrophication parameters that were flagged during the mass balance modeling and risk assessment. Ideally samples would be collected monthly at the Mississippi River as well in the chain of lakes and White Bear Lake throughout the season to more accurately capture variability in these parameters. This data would be important to support future project design and evaluation.

For several of the parameters, where surface waters were tested for drinking water parameters, the laboratory reporting limits were above the drinking water standards, which limited our ability to interpret some of the data. Future sampling should confirm reporting limits are less than relevant regulatory values.

In addition to parameters that SPRWS, VLAWMO, and Ramsey County Public Works monitor as part of their program, parameters we recommend for additional monitoring to support future phases of evaluation and design include:

- Total Phosphorus/Orthophosphate (surface and profiles)
- Chlorophyll a
- Total Organic Carbon
- Total Nitrogen
- Dissolved Oxygen (surface and profiles)
- Total Suspended Solids
- Arsenic
- Thallium
- Manganese
- Sulfate
- Chlorine Dioxide
- Chloride (total residual)
- PFOA/PFOS
- Fluoride

We noticed a possible bias in the total phosphorus data with data tested by the SPRWS laboratory appearing consistently lower than samples collected by VLAWMO on the same water body that were sent to RMB laboratories (apparent on Pleasant Lake) and samples collected by MCES on the Mississippi River and tested at the Metropolitan Council Lab. Further QAQC should be completed by SPRWS to confirm their testing methodologies and results to ensure accurate representation of the total phosphorus monitoring data as it informs system operations.

Additionally, monitoring of key tributaries into each lake, including both flow and pollutants, can help better characterize these major inflows into the lakes and inform the possible impacts on the lake management strategies and inform future modifications.

8.1.3.2 Consideration of Increased Loads, Impairments, and Operating Permits

In light of potential changes in eutrophication conditions especially along the SPRWS chain of lakes and the fact that Pleasant Lake is currently listed as impaired and Charley and Sucker Lakes could also be listed as impaired, the anticipated increases in loading should be reviewed against existing operating permits held by SPRWS for the management of the drinking water supply. Typically, there are limitations on new or expanded discharges to impaired resources; however, it is possible that existing permits held by SPRWS could allow for the expected increases in flows or loads from the Mississippi River for the various scenarios.

8.1.3.3 River Inflow Treatment

Ferric chloride is commonly used as a coagulant to remove suspended solids and other pollutants associated with particulates, control turbidity, precipitate phosphates and manganese, and aid in odor

control. SPRWS has historically operated the ferric chloride systems at the Mississippi River to help control phosphorus and other pollutants at the river source.

Based on the estimated increases in loading for the possible future flow conditions as a results of the additional community flows (per Scenario 1C), it is likely the SPRWS will need to increase the dosing at the Mississippi River by approximately 25% beyond what it would need to dose for the SPRWS area demand and climatic variability if the river is at more typical conditions and up to 50% more if the rivers is experiencing sustained high pollutant conditions.

We would recommend that SPRWS consider the following as it relates to the river inflow treatment:

- Perform a more complete seasonal flow and water quality of the Mississippi River Fridley data to better understand the variability in water quality seasonally and with flow conditions may drive dosing and to understand how this could affect ferric chloride dosing.
- Continue Ferric Chloride treatment of river inflows. Evaluate modification to the existing system to allow for increased dosing compensatory with anticipated future flows and loads. Given the possible magnitude of the increase in dosing, it may not be possible to dose at the anticipated rates and the system sizing could be limited by floc formation, precipitation, and anticipated accumulation in Charley Lake.
- Jar testing of the river inflows seasonally and during a variety of flow conditions to better understand variability and actual dosing needs would be recommended.
- Outline system operations and decisions surrounding changes in dosing. There may be ways to incorporate real time monitoring and automate adjustments to the dosing system to optimize the system.
- Evaluate whether increased dosing using ferric chloride would be allowed in light of monitoring data indicating Charlie Lake is often exceeding surface water standards for Iron.

8.1.3.4 Oxygenation System at Pleasant Lake

The oxygen injection system in Pleasant Lake is intended to help maintain the targeted oxygen levels in the hypolimnion of Pleasant Lake; however, 2025 monitoring profile data at Pleasant Lake suggests that the hypolimnion is anoxic for much of the growing season and it does not appear the existing system is delivering the oxygen as intended to the deep holes within the lake or that the existing system is under dosed. The dissolved oxygen profiles for all scenario and sensitivity runs also show that increased loads will continue to exacerbate the anoxic conditions in the hypolimnion. These conditions result in increased internal phosphorus loads from the lake bottom sediments and may lead to other redox chemical reactions.

Although the modeling exercise to inform possible order of magnitude change in the oxygenation system dosing as a result of future scenarios indicates that the existing dosing from SPRWS may be sufficient for the future loading, there are limitations and uncertainty in the dosing and model predictions. That, along with the uncertainty about delivery to the hypolimnion in light of the monitoring data and information from SPRWS, the following are considerations for the future operations of the Pleasant Lake oxygenation system:

- Confirmation that the existing system is delivering oxygen to the hypolimnion as designed and making any additional modifications to improve the existing system performance. This could be completed through collection of dissolved oxygen profiles in a grid over the lake during operation of the oxygenation system to confirm system performance and extents of hypolimnetic oxygenation.
- Testing of the sediment oxygen demand seasonally and across years to better understand variability in the oxygen demand as well as at each of the deep hole locations within the lakes. Given the differences in the main surface inflows to Pleasant Lake (e.g. river flows into the west and larger watershed runoff into the northeast), it is possible there is variability in the loading to and oxygen demand at the different locations within the lake that could inform modifications to system operations and dosing.
- Internal loading from the lake bottom sediment is expected to increase with increased flow and loads to the lake. Along with the modeling results, sediment testing was completed by VLAWMO in 2020 to help understand the mobile phosphorus fractions in Pleasant Lake and the potential for internal loading. This information can be used to inform if an individual alum treatment of lake bottom sediments could be effective at permanently binding phosphorus released from sediments in anoxic conditions, augmenting the performance of the oxygenation system.
- Evaluate opportunities to modify oxygenation system and dosing based on additional information (as outlined above) and accommodate increased dosing related to possible future implementation scenarios. Any modifications to the oxygenation system should be closely evaluated as the expansion of the existing diffuser systems could lead to unintended mixing of the lake. Maintaining stratification is important to keep elevated phosphorus levels in the hypolimnion from reaching the lake surface waters.
- As previously mentioned, the CE-QUAL-W2 model is not designed to simulate the effect of pure oxygen bubbles which are added at the lake bottom and then rise and dissolved while traveling upward in the water column. However, the model code can be modified to incorporate bubble plume modeling to more accurately capture the existing system operations and the impact of modifications including increases in oxygen dosing or numbers of diffusers.

8.1.3.5 Ferric Chloride and Oxygenation System at East Vadnais Lake

SPRWS also uses ferric chloride and an oxygenation system to help maintain oxygen levels in the hypolimnion, remove suspended solids and other pollutants associated with particulates, control turbidity, precipitate phosphates, and aid in odor control at this intake to the water treatment plant.

Based on the estimated increases in loading for the possible future flow conditions as a result of the additional community flows (per Scenario 1C), it is likely the SPRWS will need to increase the dosing at East Vadnais Lake by approximately 25% beyond what it would need to dose for the SPRWS area demand and climatic variability if the river is at more typical conditions and up to 50% more if the river is experiencing sustained high pollutant conditions.

East Vadnais Lake, the oxygen system may need to increase in the dosing during the growing season from existing conditions (2025 dosing) by a factor of approximately 2.25. However, some of this estimated increase in dosing would result from climatic variability and the need for increased river pumping during those conditions. Review of the modeling results suggests that under existing conditions, SPRWS may need to nearly double the oxygen dosing to manage climatic variability in the existing system. The

additional oxygen dosing required as a result of the ultimate community flows for Scenario 1C is a factor of ~0.25 when compared to 2025 dosing. However, based on the scenario flow summary, about 33% of the increase in flow would be the result of ultimate water supply demand from the other White Bear Lake communities and the remainder of that increase is due to the expected growth in the SPRWS service area.

The following are considerations for the future operations of the East Vadnais Lake ferric chloride and oxygenation system:

- Continue Ferric Chloride treatment in East Vadnais Lake. Evaluate modification to the existing system to allow for increased dosing compensatory with anticipated future flows and loads. Given the possible magnitude of the increase in dosing, it may not be possible to dose at the anticipated rates and the system sizing could be limited by floc formation, precipitation, and anticipated accumulation in East Vadnais Lake.
- This could also include jar testing of the hypolimnion from throughout the season and during a variety of flow conditions to better understand anticipated variability.
- Outline system operations and decisions surrounding changes in dosing. There may be ways to incorporate real time monitoring and automate adjustments to the dosing system to optimize the system.
- Although the East Vadnais oxygenation system appears to be doing an adequate job at maintaining more elevated dissolved oxygen levels in the hypolimnion, there may be additional efforts that can be done to improve performance. Confirmation that the existing system is delivering oxygen to the hypolimnion as designed through the collection of dissolved oxygen profiles in a grid over the lake during operation of the oxygenation system to confirm system performance and extents of hypolimnetic oxygenation.
- Testing of the sediment oxygen demand seasonally and across years to better understand variability in the oxygen demand as well as at each of the deep hole locations within the lakes. Given the differences in the main surface inflows to East Vadnais Lake (e.g. river flows through the upstream chain into the north and larger watershed runoff into the east (Lambert Creek) and limited watershed runoff into the south), it is possible there is variability in the loading to and oxygen demand at the different locations within the lake that could information modifications to system operations and dosing.
- Evaluate opportunities to modify oxygenation system and dosing based on additional information (as outlined above) and accommodate increased dosing related to possible future implementation scenarios. Any modifications to the oxygenation system should be closely evaluated as the expansion of the existing diffuser systems could lead to unintended mixing of the lake. There is some evidence of mixing in the dissolved oxygen profile data. Maintaining stratification is important to keep elevated phosphorus levels in the hypolimnion from reaching the lake surface waters.
- As previously mentioned, the CE-QUAL-W2 model is not designed to simulate the effect of pure oxygen bubbles which are added at the lake bottom and then rise and dissolved while traveling upward in the water column. However, the model code can be modified to incorporate bubble plume modeling to more accurately capture the existing system operations and the impact of modifications including increases in oxygen dosing or numbers of diffusers.

8.1.3.6 Treatment of Augmentation Flows to White Bear Lake

Although the modeling demonstrated that White Bear Lake is resilient to increased loads from augmentation, the modeling demonstrated that drawing water from Sucker Lake will have more of a negative impact on White Bear Lake than using water from East Vadnais Lake. As a result, we would recommend that East Vadnais Lake be the source of water if augmentation of White Bear Lake were part of the long-term implementation plan.

Additionally, regardless of source, we would still recommend treatment to protect White Bear Lake long term from variability in the quality of the Mississippi River flows and the SPRWS chain of lakes to ensure no degradation of White Bear Lake water quality and protection of the aquatic ecosystem.

Table 8-1 summarizes the mitigation plan for treatment of augmentation flows to White Bear Lake based on this water quality assessment. The treatment outlined is primarily based on the estimated White Bear Lake response assuming East Vadnais Lake is the augmentation source, the scenario evaluation and sensitivity response, and the risk assessment. This mitigation plan does not account for the impact of any potential modifications to the SPRWS systems, including the ferric chloride dosing at the Mississippi River, the oxygenation at Pleasant Lake, and the ferric chloride/oxygenation at East Vadnais Lake, which could result in an improvement in water quality through the chain of lakes with increases flows and pollutant loads. Additionally, for parameters listed as no targeted treatment, we have identified that the anticipated change in White Bear Lake water quality is generally small, the estimated concentrations meet current surface water or drinking water standards, and are not expected to impact the aquatic ecosystem at the estimated levels. Although these parameters do not need targeted treatment, it is possible that they will experience some level of removal by treatment process selected to achieve the other targeted reductions.

Also, a water treatment pilot study should be done during both warm and cold weather conditions to confirm the treatment process that will be needed to mitigate the lake augmentation water or for a new regional surface water treatment plant

Table 8-1 Mitigation Plan Summary for White Bear Lake Augmentation

Parameter	East Vadnais Lake Concentrations	White Bear Lake Concentrations	Recommended Level of Treatment of Augmentation Water to White Bear Lake
Total Phosphorus	0.023 mg/L (0.005 – 0.125 mg/L)	0.018 mg/L (0.006 – 0.173 mg/L)	Maintain discharge concentrations <0.020 mg/L*
Total Nitrogen	0.77 mg/L (0.52 – 1.28 mg/L)	0.72 mg/L (0.1 – 2.2 mg/L)	Maintain discharge concentrations <0.9 mg/L*
Chlorophyll a	7.8 ug/L (<1.0 – 74.1 ug/L)	4.0 ug/L (<1.0 – 22.1 ug/L)	Maintain discharge concentrations <9.0 ug/L
Total Organic Carbon	8.63 mg/L (7.25 – 10 mg/L)	4.6 mg/L (4.2 – 5.2 mg/L)	Maintain discharge concentrations <4.6 mg/L*
Dissolved Oxygen	9.0 mg/L (5.3 – 11.3 mg/L)	9.2 mg/L (5.7 – 13.9 mg/L)	Maintain discharge concentrations >7 mg/L*
Total Suspended Solids	1.8 mg/L (0<1.0 – 3.25 mg/L)	2.0 mg/L (<1.0 – 15 mg/L)	Maintain discharge concentrations <2.0 mg/L*
Total Dissolved Solids	223 mg/L	180 mg/L (166-191 mg/L)	No Targeted Treatment
Chlorides	35.2 mg/L (29.9 – 43.5 mg/L)	33.7 mg/L (16.8 – 57.0 mg/L)	No Targeted Treatment
Hardness	140.9 mg/L (95.4 – 165.5 mg/L)	92.1 mg/L (82.4 – 92.1 mg/L)	No Targeted Treatment
Alkalinity	134.4 mg/L (110.9 – 160.2 mg/L)	88.3 mg/L (55.5 – 113.5 mg/L)	No Targeted Treatment
Arsenic	1.0 ug/L (<1.0 – 1.5 ug/L)	2.1 ug/L (1.2 – 3.0 ug/L)	No Targeted Treatment
Aluminum	4.1 ug/L (0.4 – 12.0 ug/L)	23.8 ug/L (<10 – 52.7 ug/L)	No Targeted Treatment
Barium	48.3 ug/L (46.4 – 49.7 ug/L)	40.2 ug/L (38.5 – 42.3 ug/L)	No Targeted Treatment
Calcium	34.3 mg/L (26.7 – 41.1 mg/L)	20.6 mg/L (19.0 – 22.1 mg/L)	No Targeted Treatment
Copper	2.7 ug/L (1.1 – 13.6 ug/L)	(1.4 – 2.2 ug/L)	No Targeted Treatment*
Fluoride	0.094 mg/L (0.08 – 0.11 mg/L)	0.085 mg/L (0.065 – 0.115 mg/L)	No Targeted Treatment
Magnesium	14.4 mg/L (10.9 – 15.9 mg/L)	9.5 mg/L (9.2 – 10.4 mg/L)	No Targeted Treatment*
Manganese	0.097 mg/L (0.005 – 1.668 mg/L)	0.035 mg/L (<0.01 – 0.090 mg/L)	No Targeted Treatment*
Sulfate	8.3 mg/L (<2.0 –30.5 mg/L)	3.3 mg/L (1.5 –10 mg/L)	Maintain discharge concentrations <3.3 mg/L*
Chlorine Dioxide	<0.2 mg/L	(<0.2 – 0.38 mg/L)	No Targeted Treatment (further evaluation)
Gross Alpha Radiation	1.7 pCi/L (1.2 – 2.2 pCi/L)	1.4 pCi/L (0.5 – 2.3 pCi/L)	No Targeted Treatment
Gross Beta Radiation	3.8 pCi/L (2.0 – 3.8 pCi/L)	4.1 pCi/L (3.0 – 5.1 pCi/L)	No Targeted Treatment
Radium 226	0.24 pCi/L (0.07– 0.4 pCi/L)	(0.05 pCi/L)	No Targeted Treatment
Radium 228	0.4 pCi/L (0.06 – 0.8 pCi/L)	0.64 pCi/L (0.01 – 1.26 pCi/L)	No Targeted Treatment
Microplastics	872 mmp/L (653 – 1090 mmp/L)	1190 mmp/L (1124 – 1257 mmp/L)	No Targeted Treatment*
PFOA	<2.0 ng/L	6.2 ng/L (5.6 – 10.4 ng/L)	No Targeted Treatment (further evaluation)
PFOS	1.9 ng/L	<1.8 ng/L	No Targeted Treatment (further evaluation)
Thallium	(<0.15 – 0.18 ug/L)	(<0.15 ug/L)	No Targeted Treatment (further evaluation)
Residual Chlorine	<0.1 mg/L	(<0.1 – 0.11 mg/L)	No Targeted Treatment (further evaluation)
Aquatic Invasive Species			Filtration down to ≤35 microns (per MnDNR Guidance)

*SPRWS modifications to ferric chloride and oxygenation system dosing to accommodate increased flows and load could help achieve these targeted treatment levels or treatment for other parameters could provide treatment for a non-targeted parameter

8.1.3.6.1 Aquatic Invasive Species Treatment

Aquatic invasive species, including zebra mussels and Eurasian watermilfoil and the nuisance curly-leaf pondweed, are present in the study lakes and represent a key consideration for lake augmentation activities. As noted previously, state regulations prohibit the transfer of AIS between waterbodies regardless of whether the species are already present. Accordingly, mitigation strategies must be designed to prevent the physical transport of AIS propagules during water conveyance. Filtration is considered the primary and most practical approach to achieve this objective, as it directly removes organisms from the water column prior to transfer.

The Minnesota Department of Natural Resources (MnDNR) requires a Water Appropriation Permit and filtration when withdrawing more than 10,000 gallons of water per day or 1 million gallons per year in order to prevent the transfer of AIS from one water body to another (MnDNR 2022). While adult zebra mussels are relatively immobile, larval veligers are planktonic and range in size from 70 to 200 microns (Cohen 2005, McCartney 2017). Therefore, filtration efforts focus on targeting these early developmental stages, dictating the necessary level of treatment. The MnDNR recommends a filtration pore size of ≤ 35 microns to effectively prevent the transport of zebra mussel veligers.

Designing filtration to this threshold provides a conservative level of protection because it also captures larger AIS propagules. Eurasian watermilfoil is primarily transported as plant fragments, for which the MnDNR requires a minimal filter size of 1,000 microns (MnDNR 2022), and would therefore be effectively removed by filtration meeting zebra mussel criteria. The zebra minimal filter size is also effective for multiple other species that the MnDNR has established and requirement.

Curly-leaf pondweed, while not formally designated as an AIS, is present in the system and can negatively influence water quality. Its primary reproductive structures (turions) are typically associated with sediments and are not commonly suspended in the water column; however, a conservative approach to design assumes that incidental transport may occur during pumping. Available information does not define a minimum turion size threshold, but given their relatively large size compared to zebra mussel veligers, filtration to ≤ 35 microns is expected to also prevent their transfer. This conclusion reflects a conservative, performance-based assumption rather than a documented regulatory criterion.

It is important to note that intake screening alone is not sufficient to meet AIS prevention requirements. Typical intake screens provide coarse filtration (approximately hundreds of microns) and are effective for excluding juvenile and adult mussels but do not remove veligers. As a result, fine filtration downstream of the intake is required to achieve compliance with AIS transfer prevention objectives. Intake screening may still be incorporated as a pre-treatment step to reduce debris loading and protect downstream filtration systems.

Additional treatment approaches for zebra mussels, such as ultraviolet (UV) treatment or chemical treatment, may also be considered. However, these approaches are generally secondary to filtration as they do not meet the requirements of the MN Water Appropriation Permit. UV treatment can reduce reproductive capacity by sterilizing veligers but does not necessarily ensure complete mortality, while chemical treatment requires sufficient contact time and system design considerations that may limit feasibility under high-flow conditions.

In summary, filtration designed to a maximum pore size of ≤ 35 microns is recommended to prevent the transfer of AIS during lake augmentation. This performance threshold is driven by zebra mussel veliger

removal and is expected to provide comprehensive protection against other AIS present in the system, including Eurasian watermilfoil and curly-leaf pondweed.

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Vadnais Lake Area Water Management Organization (VLAWMO). 2024c. *Sucker and East Vadnais Lake Review, Ramsey County, MN.*



Appendix 1

Agency Meeting Summary (4/10/2025)



Meeting Minutes MCES Comprehensive Planning Study: Study 7A Agency Meeting

Project: MCES Comprehensive Planning Study: Study 7A Phase 1 (Barr Project: 23/62-1557.00)
Date: April 10, 2025

Attendees (Based on official meeting attendance list)

Brian LeMon (Barr)	Greg Johnson (MCES)	David Weum (MDH)	Matt Kocian (RCWD)
Jennifer Koehler (Barr)	Judy Sventek (MCES)	Danielle Luzinski (MDH)	Brian Corcoran (VLAWMO)
Keith Pilgrim (Barr)	Brian Johnson (MCES)	Jon Hansen (MnDNR)	Phil Belfiori (VLAWMO)
Katie Turpin-Nagel (Barr)	Erik Herberg (MCES)	Dan Scollan (MnDNR)	John Manske (Ramsey County Public Works)
Katie Wolohan (Barr)	CheFei Chen (SPRWS)	Elizabeth Kaufenberg (MPCA)	Paul Kauppi (White Bear Lake)
Jon Strand (CBS ²)	Racquel Vaske (SPRWS)	Laura Lyle (MPCA)	Jim Hauth (Vadnais Heights)
	Justine Roe (SPRWS)	Lauren Larkin (MPCA)	
		William Cole (MPCA)	
		Katy Bock (MPCA)	

Meeting Summary

Meeting Agenda and Presentation Slides: See Attached.

- **Meeting Introduction:** Barr introduced the meeting, explaining that it is part of the early stages of a sub-study under the larger Met Council, [White Bear Lake Comprehensive Planning Study](#). Participants in the meeting included representatives from Met Council, MnDNR, St. Paul Regional Water Services, MDH, MPCA, Vadnais Lake Area Water Management Organization, Rice Creek Watershed District, Ramsey County Public Works, & Cities of White Bear Lake and Vadnais Heights as well as the consultant team (Barr Engineering & CBS²).
- **Study 7A Overview:** Barr provided an overview of Study 7A, which focuses on surface water quality evaluation related to increased water demand/use scenarios and possible lake augmentation of White Bear Lake. Barr explained that the study will involve developing watershed and lake water quality models to evaluate the impact of changes in flow and water quality on the chain of lakes serving the SPRWS system and White Bear Lake.
 - **Phase 1:** Initial tasks include inventorying available monitoring data, making recommendations for monitoring, and understanding existing goals and standards, and aims to ensure the project scope for Phase 2 accurately reflects the necessary tasks needed to consider the major items of concern and answer questions from the stakeholders/agencies as it relates to this surface water study.
 - **Phase 2:** Effort will focus on the technical work including development of watershed and lake water quality models to evaluate future use and lake augmentation scenarios, estimate impacts, and determine what would be required to mitigate impacts. Scope for this effort is still draft.

- **Water Supply System:** The existing SPRWS system pumps water from the Mississippi River at Fridley to the chain of lakes (Charley, Pleasant, Sucker, East Vadnais, to the water treatment plant). The study will include evaluation of future flow/use scenarios, including possible augmentation from either Sucker Lake or East Vadnais Lake to White Bear Lake. MCES has been working with surrounding communities and SPRWS to estimate future use demands and the MnDNR to estimate the White Bear Lake augmentation rates.
- **Monitoring Data and Parameters:** Barr inventoried available data and has made recommendations for the 2025 monitoring that will be essential to inform the modeling process, ensuring accurate calibration and analysis of water quality and ecological impacts. Information required for the lake modeling includes specific WQ parameters phytoplankton data, sediment cores to understand internal loading, lake bathymetry, lake level monitoring, and flow and pumping records from SPRWS at the Mississippi River and at East Vadnais Lake to the water treatment plant. Barr will be coordinating follow-up meetings with monitoring organizations shortly.
- **Existing Goals and Standards:** Barr compiled a summary of the existing goals, standards, and thresholds for the lakes in the study for both water quality and ecological parameters - some lakes are meeting the standards, while others are not. East Vadnais and White Bear Lake are consistently meeting the eutrophication standards and may require more restrictive site-specific standards. All lakes are impacted by AIS, including zebra mussels, and most have Eurasian Watermilfoil present (except Charley).
- **Drinking Water Standards:** Barr summarized the drinking water standards and the importance of monitoring parameters that have both MDH and EPA standards. However, from a surface water standpoint, it will be important to understand if SPRWS has certain thresholds for criteria as it relates to the operations in the drinking water treatment system.
- **Questions and Concerns:** Barr posed several questions to the participants, asking for their specific concerns about increased flow or changes in water quality, additional pollutants to consider, and any other questions they might have.
 - (SPRWS) What's the frequency of the monitoring being proposed?
 - Barr is in process of coordinating meetings with monitoring organizations to review the recommended monitoring in 2025.
 - (MPCA) What are the timelines for implementing some of these objectives, like the site-specific standards for example?
 - Site specific standards may be established for the purpose of the planning level study to evaluate/determine impact (and support nondegradation) of future scenarios being developed by MCES for both water supply and lake augmentation (MnDNR estimated 780 million gallons per year would be needed to augment White Bear Lake)
 - MPCA is in the process of revising our Class 1 drinking water standards right now. Currently, they are the federal mcls. This could be a few years down the line.
 - (VLAWMO) Would like modeling that is selected to be useful for watershed management (e.g. future resiliency studies).
 - From a watershed modeling standing, we are proposing to use P8 to estimate watershed runoff/pollutant loads
 - The intent of the lake modeling is to be able to trace the origin from the Mississippi River through the system to East Vadnais Lake, the drinking water source as well as augmentation of White Bear Lake. There are several things that can happen (settling, decay, uptake by algae, and simulation of algal blooms. The proposed lake models (AEM3D or CEQUAL W2) have not been selected yet and is somewhat dependent on what specific questions are being asked of the study by the stakeholders/agencies, especially in relation to operations/function of the existing oxygenation systems etc.
 - (RCWD) Is augmentation of White Bear Lake a directive from the legislature or a MCES initiative?
 - Augmentation not specifically driven by legislature. Augmentation was identified as part of the Comprehensive Planning Workgroup brainstorming/prioritization

- sessions (14 communities and 4 agencies). There are several other studies looking at other sources of water to possibly augment White Bear Lake and reduce demand on groundwater.
- (Vadnais Heights) Are you interested in the water quality coming from Lambert Creek or just the pumped water from the Mississippi River?
 - We will need to estimate water quality inputs from ALL sources to these lakes including the watershed. However, we aren't going to be able to monitor all inflows, so we will be leveraging the watershed pollutant loading model to estimate those loads along with the pumped loading from the Mississippi River.
 - (MPCA) Is part of the scope of this study to look at groundwater elevation impacts as a result of the lake augmentation? And how that impacts appropriations permits?
 - MCES has been working with Glen Champion at the MnDNR to perform modeling analysis including evaluation of lake augmentation looking at different rates of pumping and what it takes to keep the lake at elevation 922 ft MSL (though can vary by climate conditions). The modeling also considers all the projected water demands we've come up for all the communities too, so we're looking at the effects of the groundwater effects in separate efforts. These efforts and solutions may inform conversations about appropriations associated with growth etc.
 - (MnDNR) For the two arrows showing possible augmentation locations to White Bear Lake, how were these defined? Are there multiple options for intake?
 - The two potential sources (arrows on the map in the slide) were studied as part of the 2016 study, so those will be the initial focus for this study. However, there may be other routes the system can take which will be part of Study 7B, to reevaluate roads/routes to make sure they are the most efficient.
 - (SPRWS) Will you be considering shoreline erosion as part of this study (due to increased flows)?
 - Not explicitly defined in the draft scope currently but the water balance portion of the lake models will estimate water levels on the basins with increased flow.
 - (VLAWMO) North Oaks Association has prioritized shoreline issues on Pleasant Lake and have been in touch with VLAWMO. It may not be a priority for this study, but you may want to consider this as the public might want to understand the various outcomes.
 - (MDH) Will you guys be estimating lake residence times and all the different channel lengths?
 - Yes, we will have a complete water balance on these lakes and will be able to estimate residence time for all the various scenarios.
 - (MCES) There are quite a few variables of things to measure and monitor, and so I'm wondering is would that be part of your conversations that you'll be setting up for next week with the people who are doing monitoring is which ones they currently doing, which ones they'd be adding?
 - Yes. There is a minimum amount of information that is needed to develop/calibrate the models. This data should be collected in 2025. But there may also be specific parameters on some of these broader groupings of chemicals of concerns (beyond what is needed at a minimum for modeling), identified by the stakeholders/agencies that should also be considered. For example, are there specific parameters that SPRWS is specifically concerned about as it relates to operations of the water treatment system? Are there specific chemicals (beyond PFAS) that the MDH is regularly talking about that we should at a minimum understand baseline conditions? There are some things the models can do well, and some they can do less well (limitations on the geochemistry), but the better data we have to inform the modeling, the more accurate we can make the models.
 - (MnDNR) Can you send out the slides and link to the MS Form?
 - Yes (see attached) and following link – Please provide response by end of day Tuesday 4/15:

Subject: MCES Comprehensive Planning Study: Study 7A Phase 1 (Barr Project: 23/62-1557.00)
Date: 4/10/2025

https://forms.office.com/Pages/ResponsePage.aspx?id=fZiHY2hX_EOqgNpTA9zG7Q4JUzSaC2pGtedmutaCcDNUOVZBRVZCRFhIWkZQVjIBWUJSM1E1SUxLQS4u

MCES White Bear Lake Comprehensive Planning Study



**Study 7A – Surface Water Quality Study
Phase 1 - Agency Meeting**

April 10, 2025





Agenda



1. Introductions
2. Overview of MCES Planning Study
3. Discuss Study 7A Scope
4. Review Study 7A study lakes/system
5. Outline Meeting Goals
6. Discuss Anticipated 2025 monitoring
7. Review existing goals/standards/thresholds & possible site-specific criteria
8. Discussion of preliminary questions for stakeholders and agency staff

Introductions

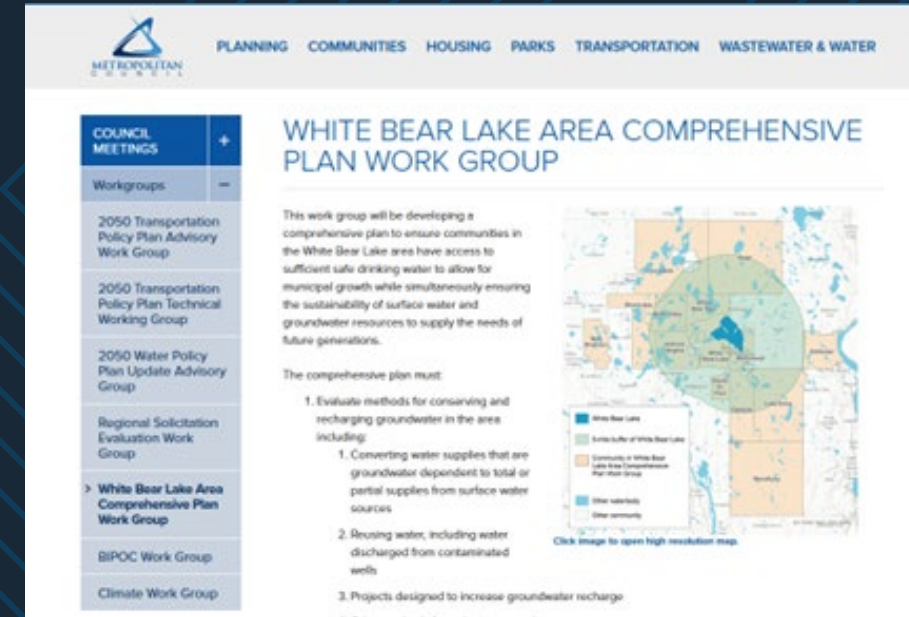


Greg Johnson (MCES)	Racquel Vaske (SPRWS)	Phil Belfiori (VLAWMO)
Judy Sventek (MCES)	CheFei Chen (SPRWS)	Brian Corcoran (VLAWMO)
Brian Johnson (MCES)	Justine Roe (SPRWS)	Matt Kocian (RCWD)
Erik Herberg (MCES)	Karla Peterson (MDH)	John Manske (Ramsey County Public Works)
Jason Moeckel (MnDNR)	David Wedum (MDH)	Paul Kauppi (White Bear Lake)
Dan Scollan (MnDNR)	Danielle Luzinski (MDH)	Brian LeMon (Barr)
April Londo (MnDNR)	Liz Kaufenberg (MPCA)	Jen Koehler (Barr)
Jon Hansen (MnDNR)	Bill Cole (MPCA)	Keith Pilgrim (Barr)
	Megan Hemken (MPCA)	Katie Turpin-Nagel (Barr)
		Jon Strand (CBS ²)

MCES White Bear Lake Comprehensive Plan Work Group



Goal: Develop a comprehensive plan to ensure communities in the White Bear Lake area have access to sufficient safe drinking water to allow for municipal growth while simultaneously ensuring the sustainability of surface water and groundwater resources to supply the needs of future generations.



Current Studies

- Study No. 1 – Redirect stormwater to augment White Bear Lake
- Study No. 3 – Reuse of treated wastewater for industrial & agricultural users
- Study No. 5 – Reuse water discharged from contaminated wells
- Study No. 6 - Treat wastewater and aquifer injection to raise groundwater elevations
- Study No. 7A – Water quality study as it relates to lake augmentation study (Study No. 7B)**
- Study No. 8 – Stormwater collection and infiltration for raise groundwater elevations

Upcoming Studies

- Study No. 2 – Convey treated surface water from SPRWS, a regional surface water treatment, or both to NE communities
- Study No. 9A – Raise outlet elevation of White Bear Lake – evaluation of potential flood impacts
- Study No. 14A – Future community impacts from PFAS groundwater contamination



Study 7A Water quality study related to lake augmentation: Overview of Scope



Study 7A, Phase 1 - Data Review and Goal Summary

- Inventory existing monitoring data
- Recommendations for 2025 monitoring to support model development (Phase 2)
- Summarize existing surface water and drinking waters goals/standards/thresholds
- Stakeholder/Agency review meeting
- Recommended revisions to 2025 monitoring & draft MCES Study 7A phase 2 scope of work





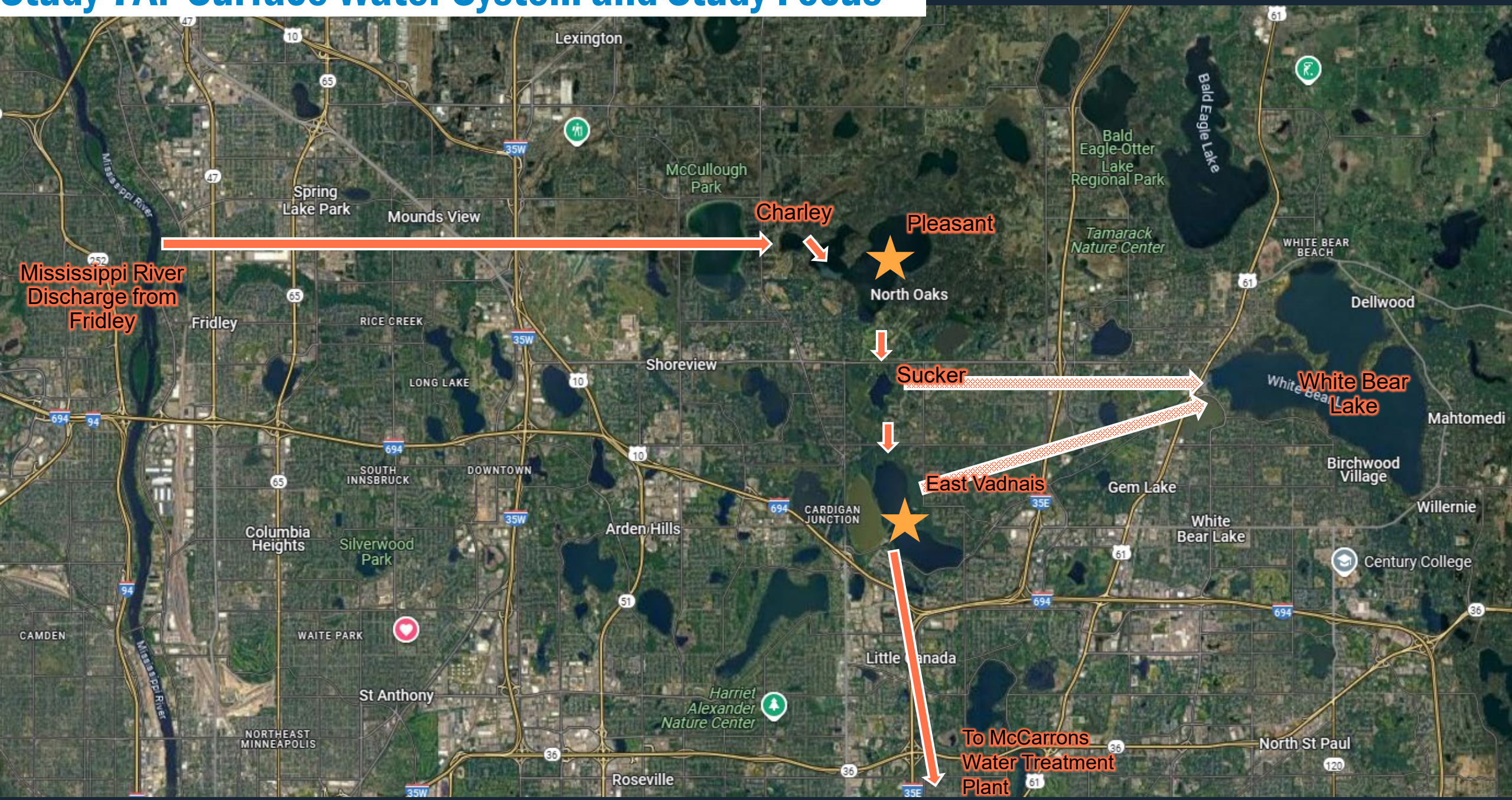
Study 7A Water quality study related to lake augmentation: Overview of Scope (cont.)

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Study 7A, Phase 2 – Calibrated Surface Water Model Development and Evaluation of Future Use Scenarios & Lake Augmentation (DRAFT Scope)

- Watershed modeling to generate runoff volume and estimated pollutant loads to lakes (in combination with river pumping and loads)
- Develop calibrated surface (lake) water quality models for chain of lakes and WBL (considering AEM3D or CEQUAL W2)
- Summarize available water quality monitoring data and compare to goals/standards/thresholds & develop site-specific standards
- Review/use projected demands for current, 2025, 2050, and ultimate development conditions to evaluate impact on lake water quality, including augmentation of WBL
- Sensitivity analysis of higher assumed loading to the lakes
- Conduct a risk assessment for toxics, pesticides, organics, and other toxic substances using Mississippi River data along with injections of ferric chloride by SPRWS
- Develop a mitigation plan to prevent/treat/address contaminants of concern in the chain of lakes prior to augmenting and pumping to WBL
- Reporting and public outreach

Study 7A: Surface Water System and Study Focus



Meeting Goals



In light of the Study 7A scope, gather preliminary input from stakeholders and agency staff related to the evaluation and outcomes from this study that will be used to:

- Inform the 2025 monitoring, and
- Support recommendations to revisions to the draft scope of work for Study 7A, Phase 2



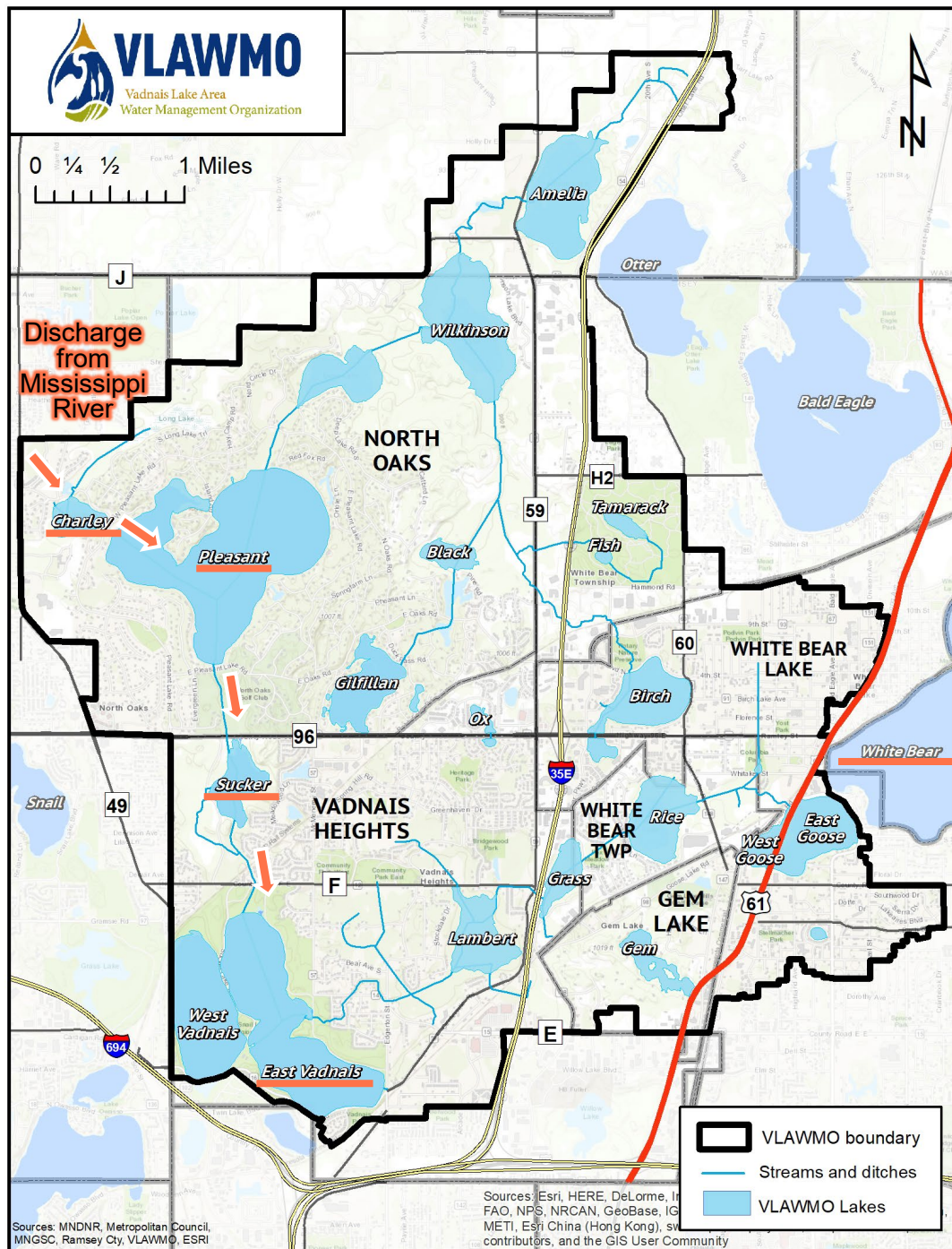


Preliminary Questions for Stakeholders/Agency Staff



From your stakeholder or agency's perspective:

- What **specific concerns do you have about increased flow or changes in water quality** through the chain of lakes for drinking water supply and the augmentation of White Bear Lake?
- Are there **certain pollutants/contaminants of concern you believe should be considered as part of this study** as it relates to: lake health/ecology, drinking water supply, the existing aeration systems, & existing drinking water treatment system? Are there specific pesticides or trace chemicals of emerging concern (like pharmaceuticals, estrogen disrupters, microplastics, etc.) that should be considered?
- What **specific questions would you expect this planning level study to be able to answer** as it relates to: lake impacts (water quality/ecological), operations of the SPRWS drinking water treatment system, corrosion potential in distribution system, & future permitting of the proposed White Bear Lake augmentation system?



Task 1: Monitoring Data Review

- Mississippi River
 - Anoka
 - Fridley
- VLA WMO Lakes
 - Charley Lake
 - Pleasant Lake
 - Sucker Lake
 - East Vadnais Lake
- RCWD Lakes
 - White Bear Lake

Eutrophication monitoring recommendations – Key model input parameters

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WQ Profile Data*

- Grab Samples
 - Phosphorus (*TP, TDP, OP*)
 - Nitrogen (*TKN, N-N, Ammonia*)
 - Chlorophyll-a
- Probe Data
 - Temperature
 - Dissolved Oxygen
 - Specific Conductance
 - pH

WQ Surface Data

- Secchi Disk
- Grab Samples
 - Organic Carbon (*total, dissolved*)
 - Suspended solids (*total, volatile*)
 - Turbidity
 - Alkalinity
 - Hardness
 - Chloride
- Phytoplankton Identification

Lake Bottom Sediment

- Cores and Fractionation (*only completed in Pleasant Lake, recommended for others*)

Lake Bathymetry

- Historic data available for all water bodies (MnDNR/VLAWMO)

Lake Levels

- Historic data limited to WBL, Pleasant, & East Vadnais (*recommended water level monitoring in all basins*)
- Weekly at a minimum; Daily or continuous preferred

Outlet/Discharge

- Survey/rating curve available for WBL and outlet drawings available for Pleasant Lake (*recommended outlet survey for other lakes*)

Flow/Pumping

- Historic data available for pumping from Mississippi River and to SPRWS treatment plant

* River sampling at intakes can be grab samples

Drinking water/Aquatic life monitoring recommendations

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Metals

- Aluminum
- Antimony
- Arsenic
- Barium
- Bromide
- Cadmium
- Calcium
- Chromium (total and hexavalent)
- Copper
- Fluoride
- Iron
- Lead
- Magnesium
- Manganese
- Mercury
- Nickel

Metals (con't)

- Selenium
- Sulfur (as sulfate, sulfide and total sulfur)
- Thallium
- Zinc

Synthetic Organics & Other Trace Chemicals

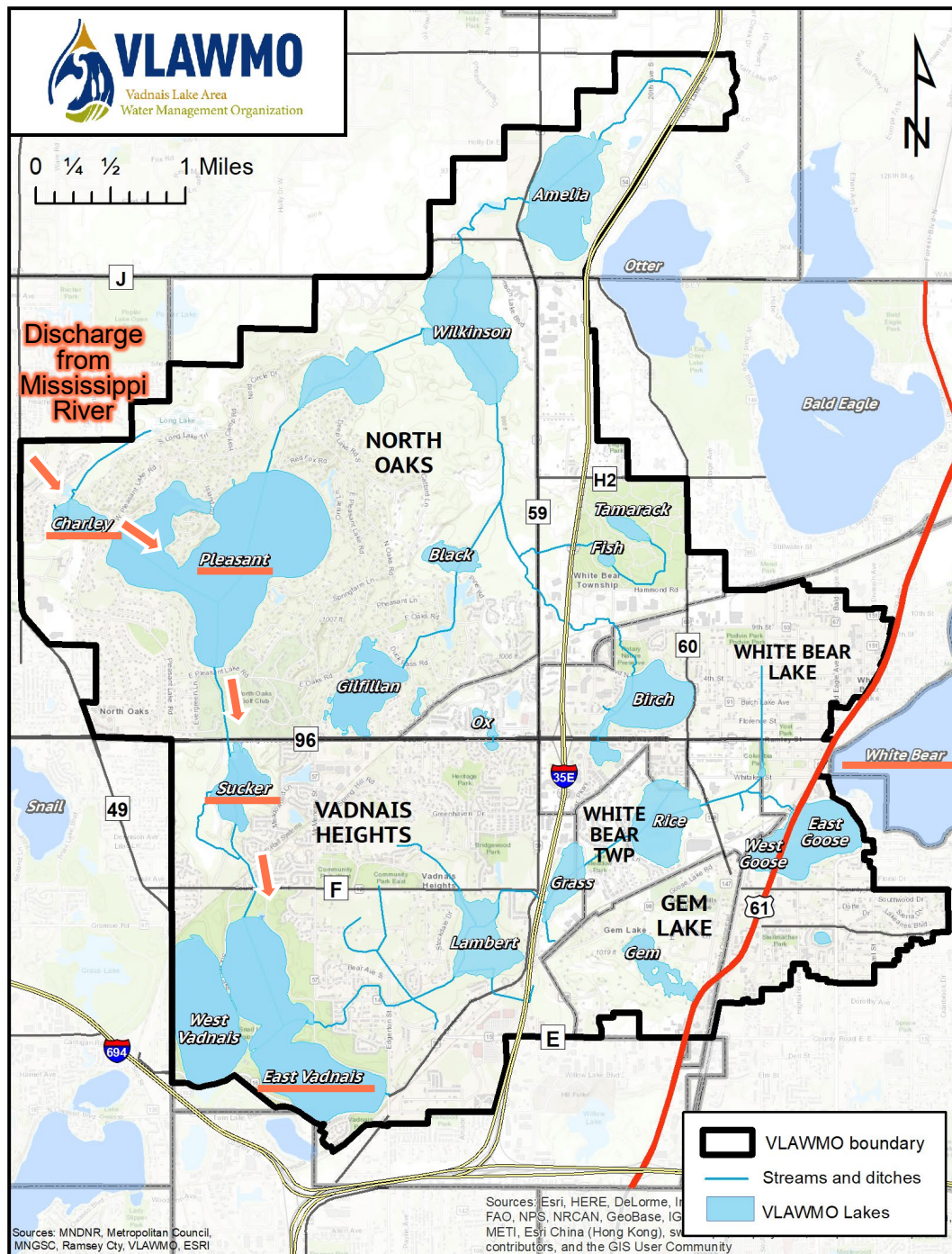
- PFAS (PFOA, PFOS, PFBS, PFHxS, PFNA, GenX (EPA PFAS hazard index chemicals))
- **PCBs?**
- **PAHs?**
- **Pesticides?**
- **Pharmaceuticals?**
- **Estrogen Disruptors?**
- **Microplastics?**
- **Others?**

Bacteria

- Total coliform
- Fecal coliform
- *E. coli*.

Ecological Parameters (Lakes)

- Fisheries (*historic data available for all lakes, no additional monitoring recommended*)
- Phytoplankton (*limited primarily to WBL, recommended for all lakes*)
- Cyanotoxin testing (*limited to microcystin testing at East Vadnais, recommended for all lakes*)
- Zooplankton (*historic data limited to WBL, no additional monitoring recommended*)
- Aquatic plants (*historic surveys completed on all lakes, no additional monitoring recommended*)
- Aquatic Invasive Species (AIS) (*MnDNR data indicates all lakes have zebra mussels, and EWM (except Charley)*)



Task 2: Water Quality Goals/Standards/Thresholds

- Mississippi River
 - Anoka
 - Fridley
- VLawMO Lakes
 - Charley Lake – Shallow (1C/2Bd)
 - Pleasant Lake – Deep (1C/2Bd)
 - Sucker Lake – Shallow (1C/2Bd)
 - East Vadnais Lake – Deep (1C/2Bd)
- RCWD Lakes
 - White Bear Lake – Deep (2B)

Minnesota State Standards, Thresholds, Guidelines - Lakes



- MPCA MN Rule Chapters 7050 and 7052 Eutrophication Standards & Physiochemical Parameters
- MPCA Tiered Aquatic Life Uses (TALU) Framework for Lakes
- MNDNR Fish Index of Biotic Integrity (FIBI) Thresholds for Lakes
- MNDNR Plant Eutrophication Index of Biological Integrity (Plant IBI) Thresholds for Lakes
- MNDNR Aquatic Invasive Species Infested Waters List
- WHO Cyanobacteria Thresholds
- MPCA Cyanotoxin Levels for Swimming Advisories
- MPCA PFAS protective values
- MDH Fish Consumption Guidance



Water Quality Goals - Lakes



Lake	Deep vs. Shallow (Use Class)	Official Public Access	Eutrophication Standards	FIBI	Aquatic Plants	AIS	PFAS Status
Charley	Shallow (1C/2Bd)	N/A	Slightly above standard	Not evaluated	Degraded, below threshold	Zebra mussels	Not evaluated
Pleasant	Deep (1C/2Bd)	N/A	On MPCA Impaired Waters List	Not evaluated	Degraded, below threshold	Zebra mussels, EWM	Not evaluated
Sucker	Shallow (1C/2Bd)	N/A	Slightly above standard	Not evaluated	At threshold	Zebra mussels, EWM	Not evaluated
East Vadnais	Deep (1C/2Bd)	N/A	Well below standard	Not evaluated	Degraded, below threshold	Zebra mussels, EWM	Pending – Low PFAS Lake
White Bear	Deep (2B)	Beach/Boat Ramp	Well below standard	Above impairment threshold	High biological significance	Zebra mussels, EWM	Designated Low PFAS Lake

Site Specific Considerations – East Vadnais and White Bear Lake

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- Eutrophication site-specific standards
 - Leverage historic water quality data records to develop water quality relationships to inform the more stringent/site specific standards to support nondegradation
 - Consider zebra mussel impacts on water quality record and relationships

National/Minnesota Standards, Advisories, Health Risk Limits – Drinking Water



- National Primary Drinking Water Regulations and Implementation - Title 40, Code of Federal Regulations, Part 141 and Part 142
 - EPA Drinking Water Standards (MCLs and SMCLs) and Health Advisories
- Minnesota rules governing public water systems - Minnesota Rules, chapter 4720
- MDH Health Risk Limit Rules (HRLs) for Drinking Water

*** There may be specific goals/targets for East Vadnais Lake that varies from the typical surface water or drinking water goals based on the SPRWS infrastructure and water treatment system*





Preliminary Questions for Stakeholders/Agency Staff

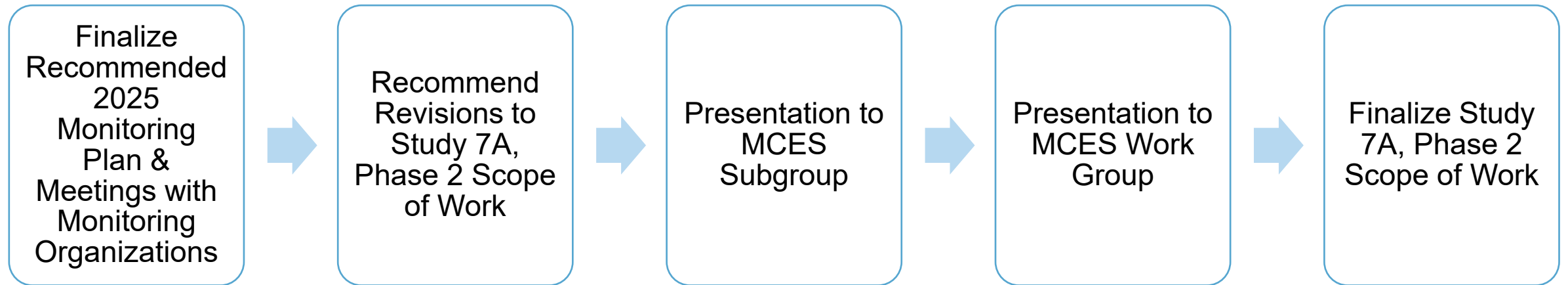


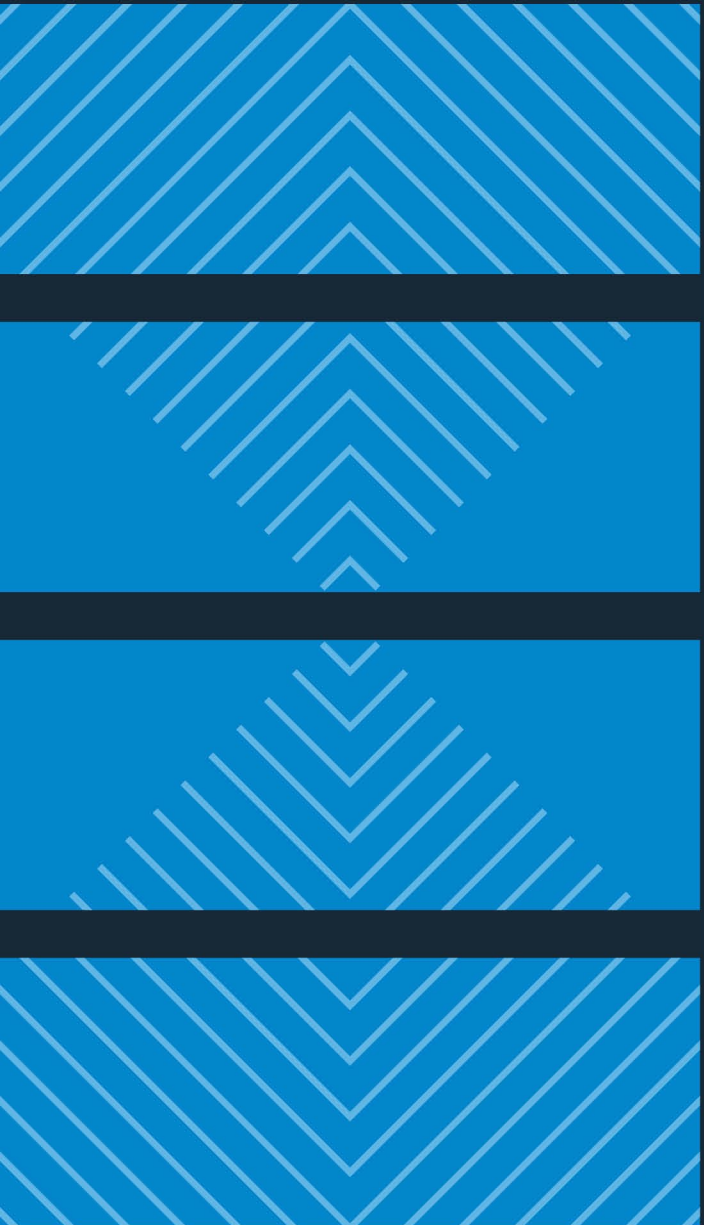
From your stakeholder or agency's perspective:

- What **specific concerns do you have about increased flow or changes in water quality** through the chain of lakes for drinking water supply and the augmentation of White Bear Lake?
- Are there **certain pollutants/contaminants of concern you believe should be considered as part of this study** as it relates to: lake health/ecology, drinking water supply, the existing aeration systems, & existing drinking water treatment system? Are there specific pesticides or trace chemicals of emerging concern (like pharmaceuticals, estrogen disrupters, microplastics, etc.) that should be considered?
- What **specific questions would you expect this planning level study to be able to answer** as it relates to: lake impacts (water quality/ecological), operations of the SPRWS drinking water treatment system, corrosion potential in distribution system, & future permitting of the proposed White Bear Lake augmentation system?

[Please fill in your responses at this MS Form Here.](#) Your Name & Agency/Organization are required. You can submit multiple responses. Please provide your input by end of day Tuesday April 15, 2025.

Next Steps





Jennifer Koehler
jkoehler@barr.com
952-832-2750



Thank you! Any Questions?

Id	Start time	Completion time	Email	Name	Please Enter your Name and Organization/Agency	What specific concerns do you have about increased flow or changes in water quality through the chain of lakes for drinking water supply and the augmentation of White Bear Lake?	Are there certain pollutants/contaminants of concern you believe should be considered as part of this study as it relates to: lake health/ecology, drinking water supply, the existing aeration systems	What specific questions would you expect this planning level study to be able to answer as it relates to: lake impacts (water quality/ecological), operations of the SPRWS aeration & drinking water tre
1	4/10/2025 15:24	4/10/2025 16:00	anonymous		Matt Kocian, Rice Creek Watershed District	RCWD has concerns about water quality impacts to WBL with augmentation. The primary concern is eutrophication parameters (P & N), but also concerns on heavy metals, iron, and chloride. We have concerns AIS introductions - including introductions of new genotypes of existing AIS (e.g. EWM). For the existing zebra mussel population in WBL, altering food sources (chl-a) or pH for shell production could increase the lake's ZM carrying capacity.	In addition to standard eutrophication parameters, please include heavy metals, total iron, and chloride. Yes, contaminants of emerging concern should be included. WBL has a tiny watershed; augmenting water levels by addition from a HUGE watershed could increase the load of all chemicals of emerging concern. PFAS, microplastics, pharm., etc.	If WBL is augmented, what level of water treatment (i.e. incoming concentrations) would be required to ensure zero impact to eutrophication parameters? WBL has an outstanding macrophyte community - dense and very diverse. Is it possible that altering non-eutrophication parameters (not related to clarity) could alter the macrophyte community? Perhaps by altering water color, or changing lake sediment chemistry? What type of treatment would be needed to ensure no introduction of new AIS?
2	4/11/2025 7:59	4/11/2025 8:27	anonymous		John Manske Ramsey County	My concerns are solely for the water quality of White Bear Lake. The 2016-17 intensive monitoring of the lake demonstrated how impressively high the quality of the water was in White Bear. Any augmentation water used for surface water addition in White Bear would need to be purified more than the current level done by SPRWD. Previous studies of White Bear Lake augmentation should be referenced to avoid duplicated efforts.	I'd like to duplicate the parameter list from 2016-17 and would be all for adding any parameters that the DNR/MDH lab can offer for chemicals of emerging concern. We rarely get those parameters measured in routine monitoring due to costs. I believe they can be the most important parameters to measure for a study like this.	Which chemical parameters in White Bear would change if the proposed level of augmentation occurred and how would that potentially affect the lakes health, surface and ground water levels.
3	4/14/2025 13:06	4/14/2025 13:14	anonymous		Greg Johnson - Met Council	Potential water quality effects to the chain of lakes from increased flows and the reduction in water quality in White Bear Lake and drinking water quality in the underlaying Jordan aquifer if the lake augmentation water would be only partially treated for zebra mussels, phosphorus, and suspended solids. Will higher quality water treatment be required for the chain of lakes water for augmentation?	I think Barr's Table 2 list is sufficient. I would like to hear what others suggest though.	What is the minimum level of treatment needed for the chain of lakes augmentation water to maintain the water quality of White Bear Lake, maintain and protect the drinking water quality in the underlaying Jordan aquifer, and potentially treat for emerging contaminants if needed?
4	4/14/2025 11:43	4/14/2025 15:03	anonymous		David Weum - MDH	Primarily my concerns are around impacts to SPRWS and the potential for harmful algal blooms (HABs)	Potentially PFAS and pharmaceuticals. I would need to know more about timeline it takes for WBL water to impact the Jordan aquifer, but I think PFAS would be the only that persistent enough at small levels to be of significant concern to the Jordan. I think the other concerns are impacts to SPRWS's intake.	What current WBL quality is, how much water would need to be pumped into WBL to eliminate the impact of cities pumping (both now and future demand), how impacted WBL would be if we did nothing to treat water from various chain-of-lakes sources, types of treatment (if needed) to water transferred to WBL to not negatively impact the ecology/water quality.
5	4/14/2025 14:58	4/14/2025 15:07	anonymous		MDH - Source Water Protection	MDH has concerns about potentially introducing new sources of contamination risk to White Bear Lake (i.e. potential point source contaminants upstream of the Mississippi/Chain of Lakes would now be spread to White Bear Lake as well). There is also concern about potential contamination spreading faster due to the presence of increased groundwater/surface water interaction near White Bear Lake (see https://pubs.usgs.gov/sir/2013/5044/sir2013-5044.pdf).		Time of travel from the Mississippi River to the Chain of Lakes and White Bear Lake and the approx. residence time of each lake studied.
6	4/14/2025 12:52	4/14/2025 17:38	anonymous		Liz Kaufenberg, MPCA	Ensuring does not negatively impact ability to meet applicable water quality standards, either directly to surface water or indirectly to groundwater. In addition, ensure not new pollutants/higher concentration of existing pollutants are not added to the lake.	Standard water quality standards carried out by state agencies for drinking water, aquatic life, recreation. Specifically, nutrients that could result in lower eutrophication status	What impact will lake augmentation have on communities' ability to supply need for drinking water either via surface water or additional groundwater appropriation permits.
7	4/15/2025 10:39	4/15/2025 10:59	anonymous		Paul Kauppi, City of White Bear Lake	Not sure concerns for the Chain of Lakes, but rather water quality coming into White Bear Lake for augmentation.	Concern for invasive species or other pollutants, ie PFAS, that could enter and change the characteristics of White Bear Lake. Everything considered. Also, if water is too clean, how does that affect the characteristics of WBL.	What is reaction time for augmentation, if low in the spring, how much time needed at acceptable pumping rate to increase water level. Is goal to have level up at freeze up so not low in spring?
8	4/15/2025 14:13	4/15/2025 14:19	anonymous		Brian Corcoran Vadnais Lake Area WMO (VLAWMO)	Will shoreline erosion and water residence time be evaluated?	All possible pollutants/contaminants should be considered to evaluate lake health/ecology, drinking water supply, aeration system and treatment system.	How will the increased flow will impact the existing chain of lakes and any lakes that will be augmented. As well as water quality concerns with both the increased flow and augmentation of other waterbodies. Overall analysis of the VLAWMO watershed (pre vs. post any anticipated proposed projects) is important given, according to SPRWS data, VLAWMO watershed contribution was 41.6% of total pumped from E. Vadnais Lake in 2024. VLAWMO would like to have access any data and modeling etc that may be developed /assembled as part of this Met Council study. Partnership and collaboration approaches should be discussed /brainstormed between Met Council, VLAWMO and member communities to determine if modeling and related H/H study work could also be developed to aid in the planning of anticipated future watershed management projects.
9	4/16/2025 9:07	4/16/2025 11:52	anonymous		Brian Johnson - Metropolitan Council	Concerns would be on the lakes' water quality, ecological structure, and thermal structure. Trophic state, and changes to it, have implications for the lakes' biology, ecology, and recreational use. WBL is listed as impaired for aquatic consumption (mercury in fish tissue). Will augmentation increase toxic metals in WBL and the chain of lakes and its fish? Increased Chloride loading. Changes in the structure of the biology/ecology of the lakes. Changes in the macrophyte, phytoplankton, and zooplankton populations (abundance, densities, species, etc.). Introduction of aquatic invasive species. Changes/increases in harmful algal blooms. Disruption of the thermal structure of WBL (changes in water temperature, disruption of stratification with effects on fish habitat and nutrient cycling). Changes in the lakes' fisheries. Introduction of contaminants/pollutants and animal and plant species in the Mississippi River that are not in White Bear Lake.	Trophic indicators: phosphorus and its species, nitrogen and its species, chlorophyll, organic carbon, iron, turbidity. Choride. E. coli and bacteria. Aquatic invasive species (plants and animals). Heavy metals particularly mercury in water and fish but other heavy metals need to be evaluated as well e.g. As, Cd, Cr, Cu, Pb, and Ni. Organic chemicals such as but not limited to solvents, PCBs, PAHs, pesticides (a full suite analysis can be done). Harmful algal bloom toxins. Emerging contaminants of concern: pharmaceuticals (a fully survey needed?), estrogen disrupters (a full survey needed?), microplastics, PFAS (a full survey needed?). A full survey would be required for these parameters to determine base line conditions, i.e. what is the current state, what is there?	- What would be the adverse effects on WBL with non-treated augmentation water on the lake's water quality, ecological structure, and thermal structure? - What would be the adverse effects on the chain of lakes with increased pass through of Mississippi River water? - What treatment is needed for augmentation water to prevent changes to White Bear Lake's water quality, ecological structure, and thermal structure? - What is the condition of White Bear Lake and the chain of lakes before augmentation and long-term conditions after augmentation begins? - Which parameters will need to be monitored, where, and what frequency to help answer the above questions?



Appendix 2

2025 Monitoring Plan (Excel file)

Data available upon request





Appendix 3

Summary Statistics (Excel files)

Data available upon request





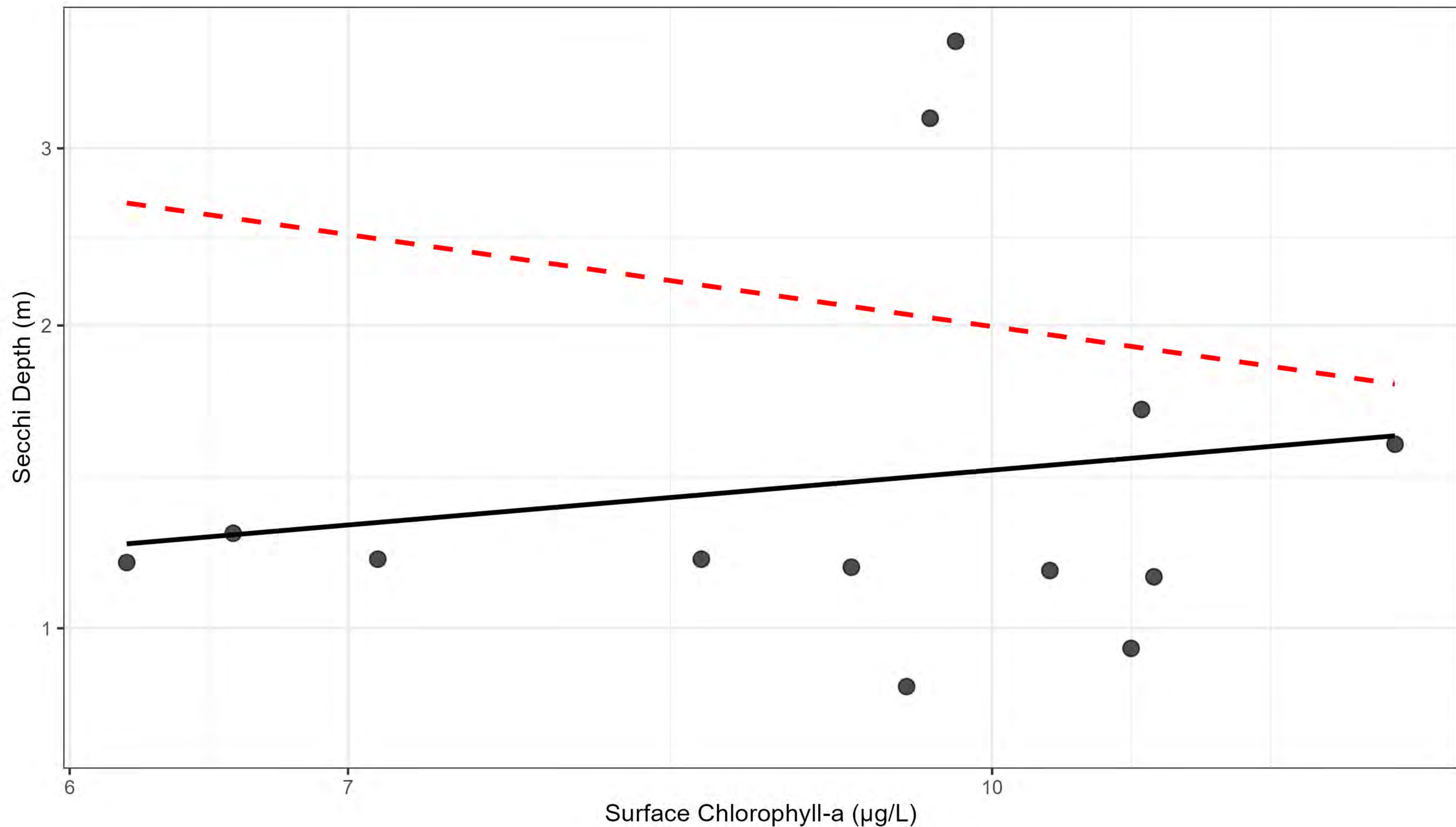
Appendix 4

Lake Water Quality Relationships



Charley Lake - Growing Season Mean Chl-a vs Secchi Depth Relationship

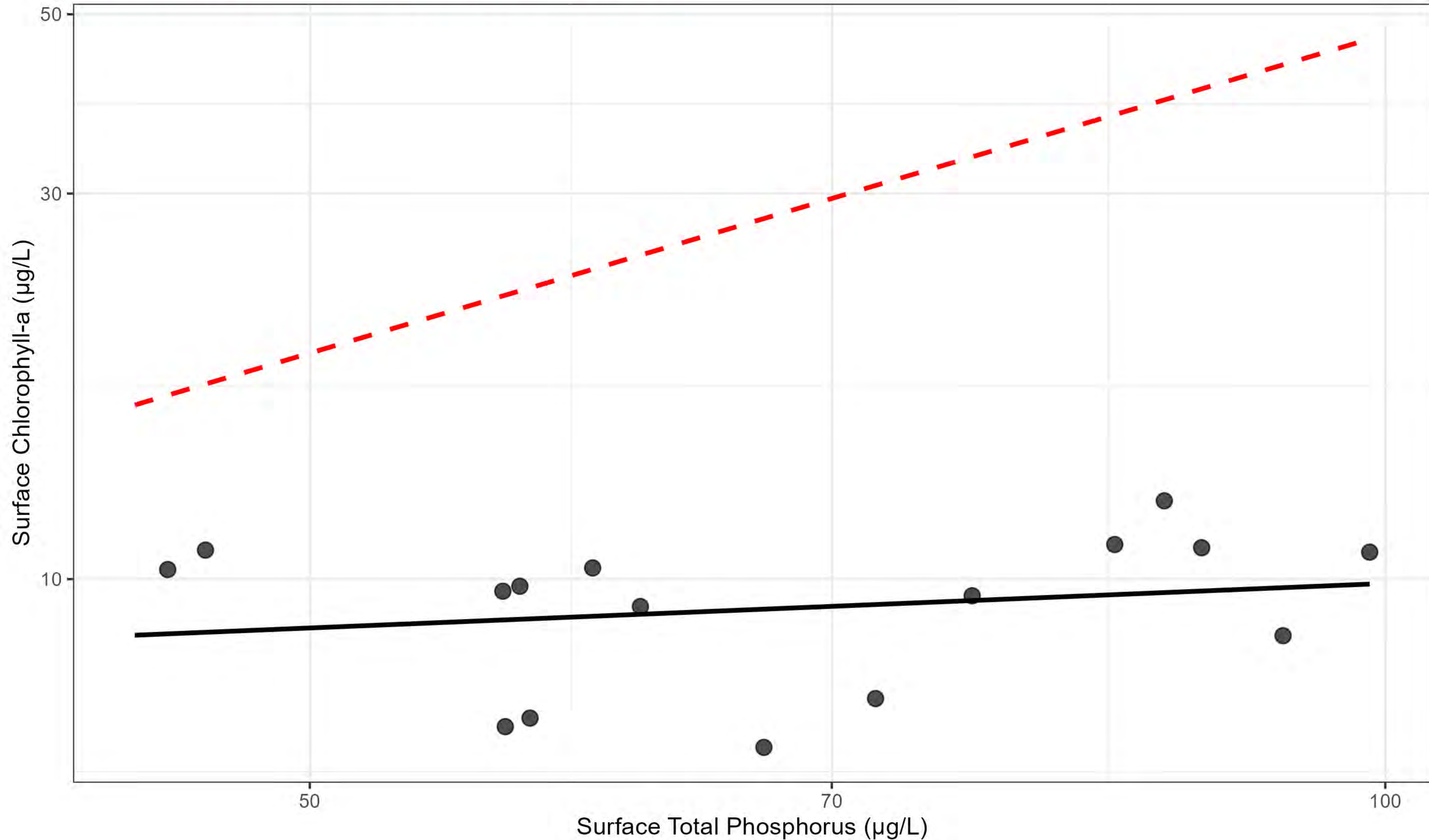
Charley fit: $\text{Log}_{10}(\text{Secchi}) = 0.35 \text{ Log}_{10}(\text{Chla}) + -0.19$ ($R^2 = 0.03$)
MN State Standard relationship: $\text{Log}_{10}(\text{Secchi}) = -0.59 \text{ Log}_{10}(\text{Chla}) + 0.89$



Charley Lake - Growing Season Mean TP vs Chl-a Relationship

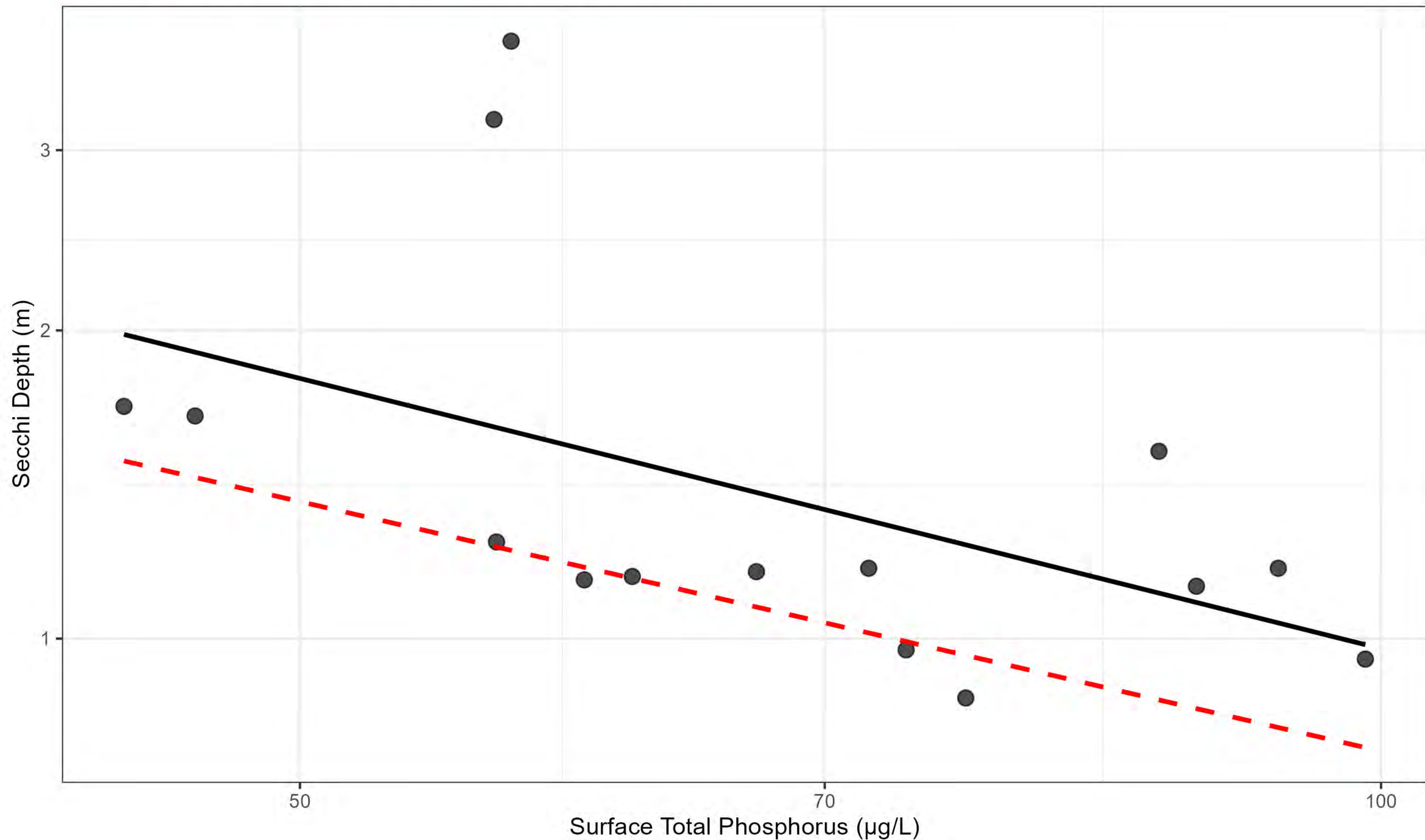
Charley fit: $\text{Log}_{10}(\text{Chla}) = 0.18 \text{ Log}_{10}(\text{TP}) + 0.629$ ($R^2 = 0.04$)

MN State Standard relationship: $\text{Log}_{10}(\text{Chla}) = 1.31 \text{ Log}_{10}(\text{TP}) - 0.946$



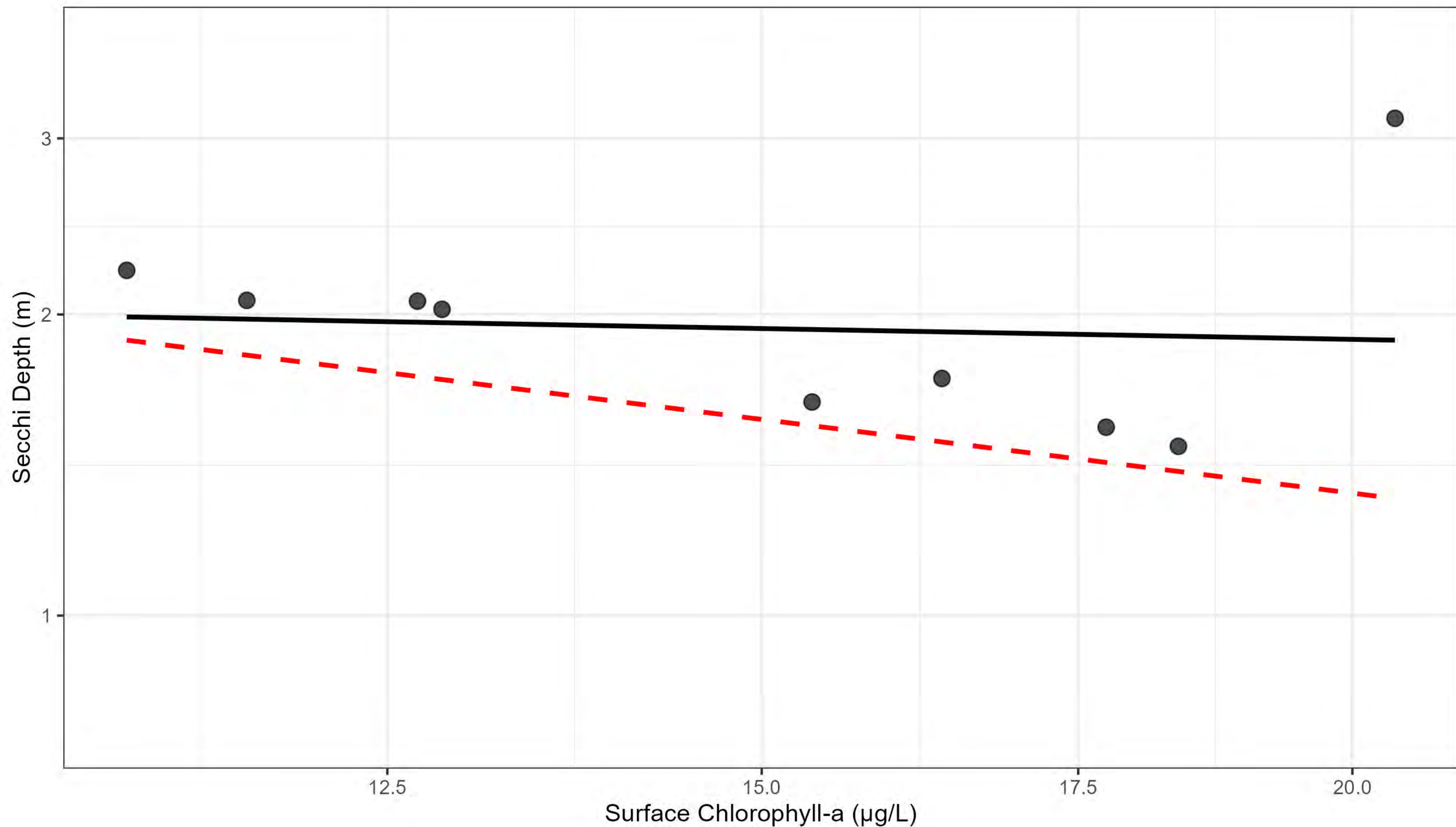
Charley Lake - Growing Season Mean TP vs Secchi Depth Relationship

Charley fit: $\text{Log}_{10}(\text{Secchi}) = -0.88 \text{Log}_{10}(\text{TP}) + 1.74$ ($R^2 = 0.26$)
MN State Standard relationship: $\text{Log}_{10}(\text{Secchi}) = -0.81 \text{Log}_{10}(\text{TP}) + 1.51$



Pleasant Lake - Growing Season Mean Chl-a vs Secchi Depth Relationship

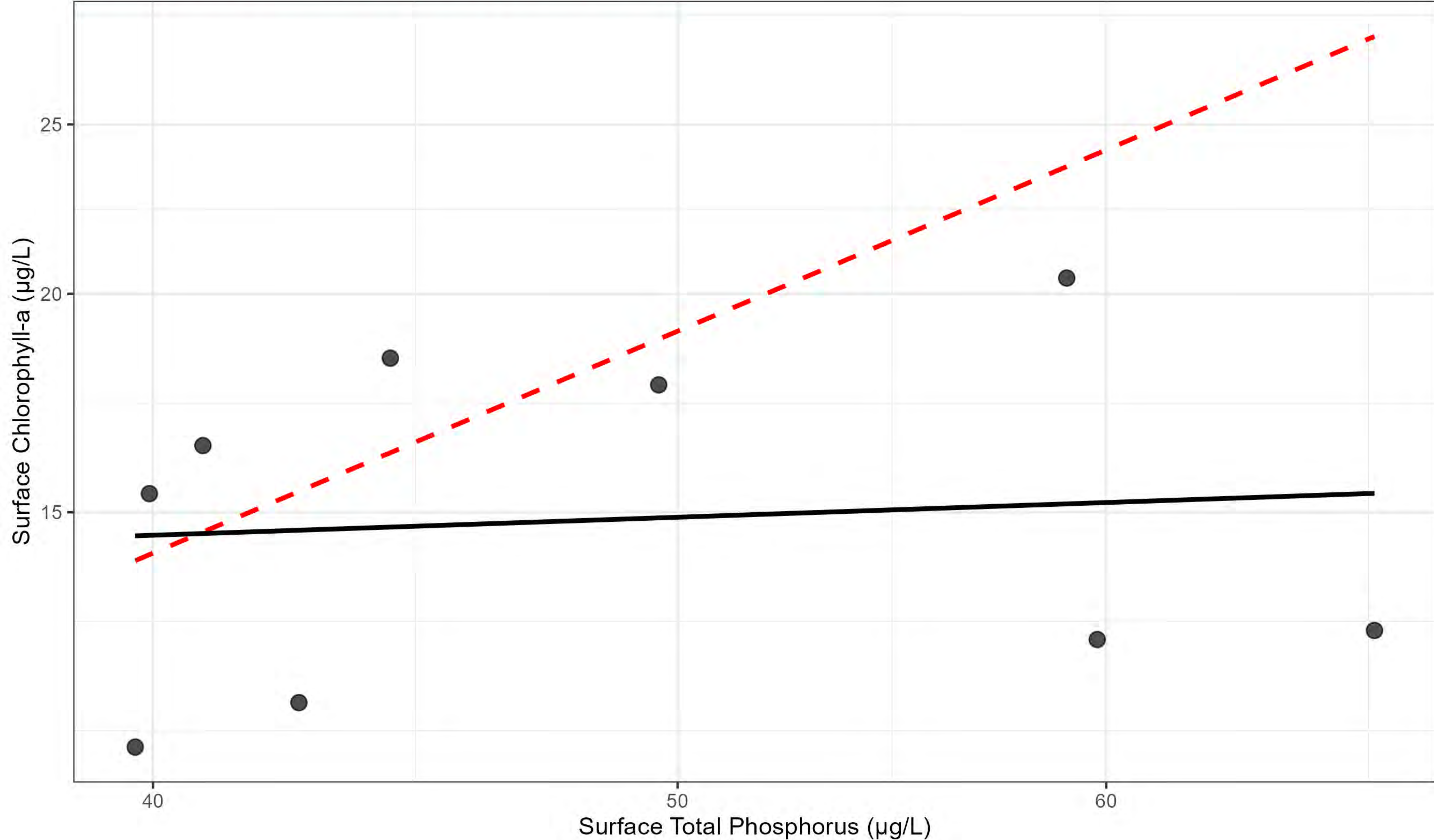
Pleasant fit: $\text{Log}_{10}(\text{Secchi}) = -0.09 \text{Log}_{10}(\text{Chla}) + 0.39$ ($R^2 = 0.01$)
MN State Standard relationship: $\text{Log}_{10}(\text{Secchi}) = -0.59 \text{Log}_{10}(\text{Chla}) + 0.89$



Pleasant Lake - Growing Season Mean TP vs Chl-a Relationship

Pleasant fit: $\text{Log}_{10}(\text{Chla}) = 0.11 \text{ Log}_{10}(\text{TP}) + 0.993$ ($R^2 = 0.01$)

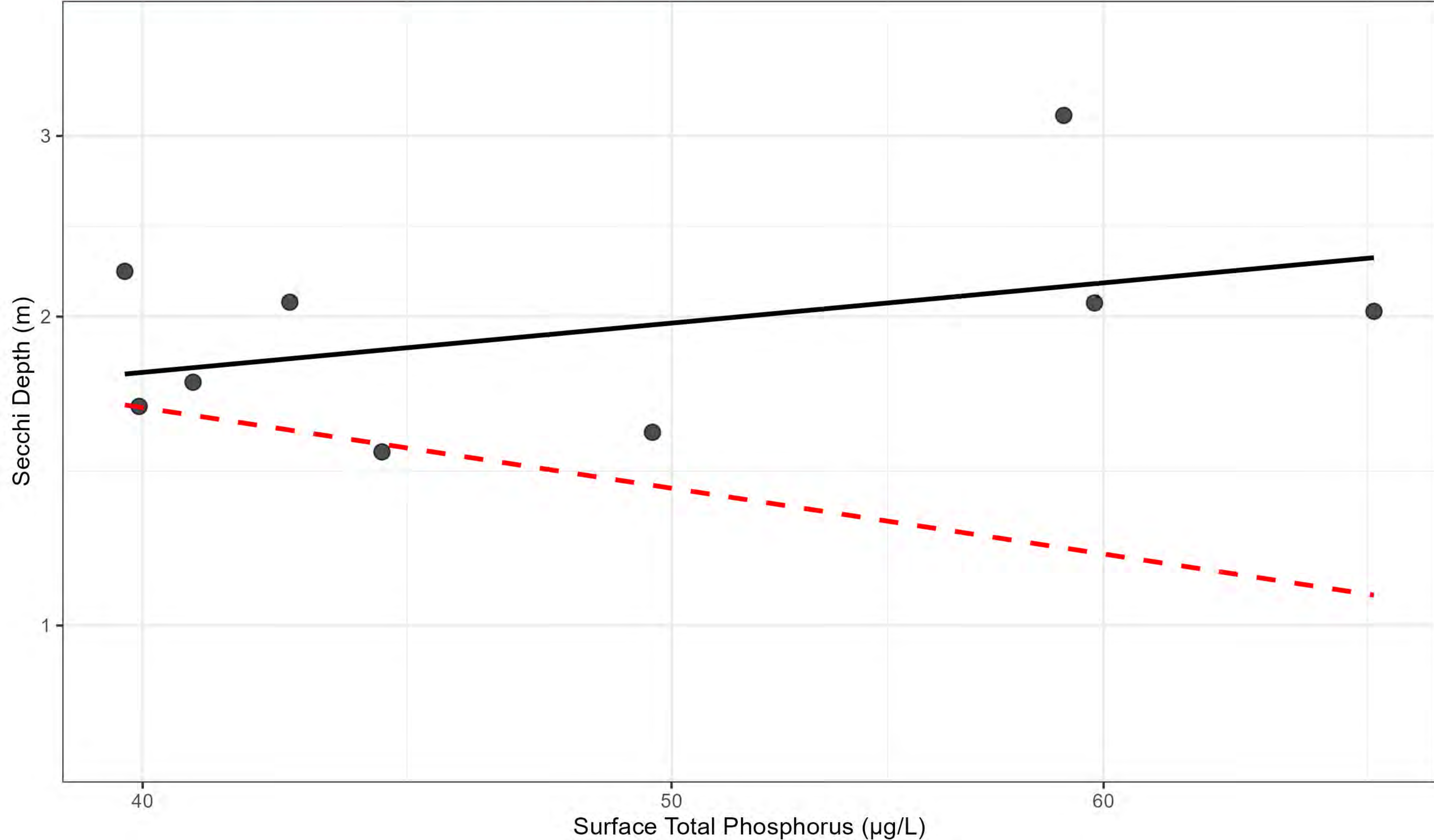
MN State Standard relationship: $\text{Log}_{10}(\text{Chla}) = 1.31 \text{ Log}_{10}(\text{TP}) - 0.946$



Pleasant Lake - Growing Season Mean TP vs Secchi Depth Relationship

Pleasant fit: $\text{Log}_{10}(\text{Secchi}) = 0.5 \text{Log}_{10}(\text{TP}) + -0.55$ ($R^2 = 0.18$)

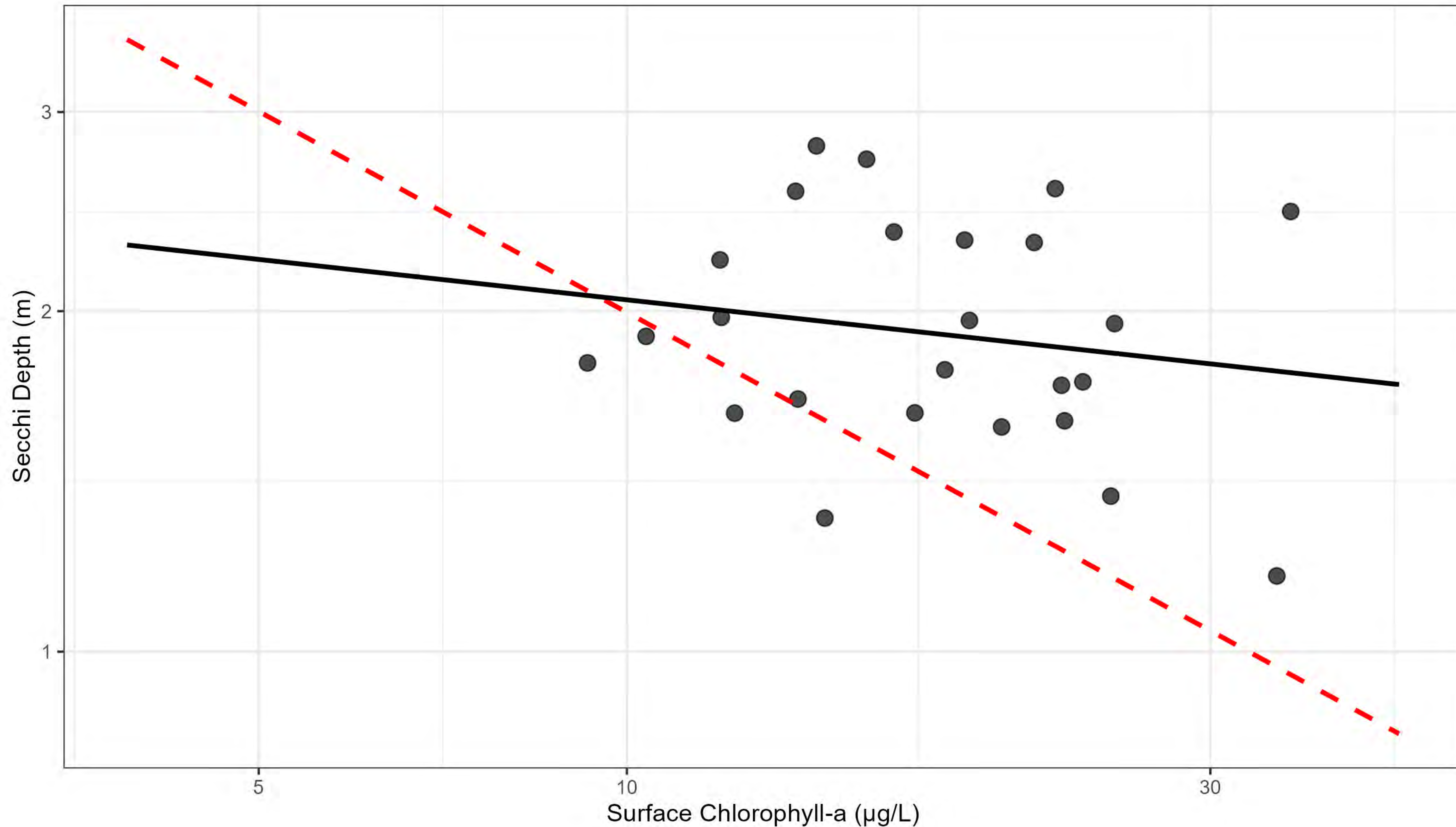
MN State Standard relationship: $\text{Log}_{10}(\text{Secchi}) = -0.81 \text{Log}_{10}(\text{TP}) + 1.51$



Sucker Lake - Growing Season Mean Chl-a vs Secchi Depth Relationship

Sucker fit: $\text{Log}_{10}(\text{Secchi}) = -0.12 \text{Log}_{10}(\text{Chla}) + 0.43$ ($R^2 = 0.03$)

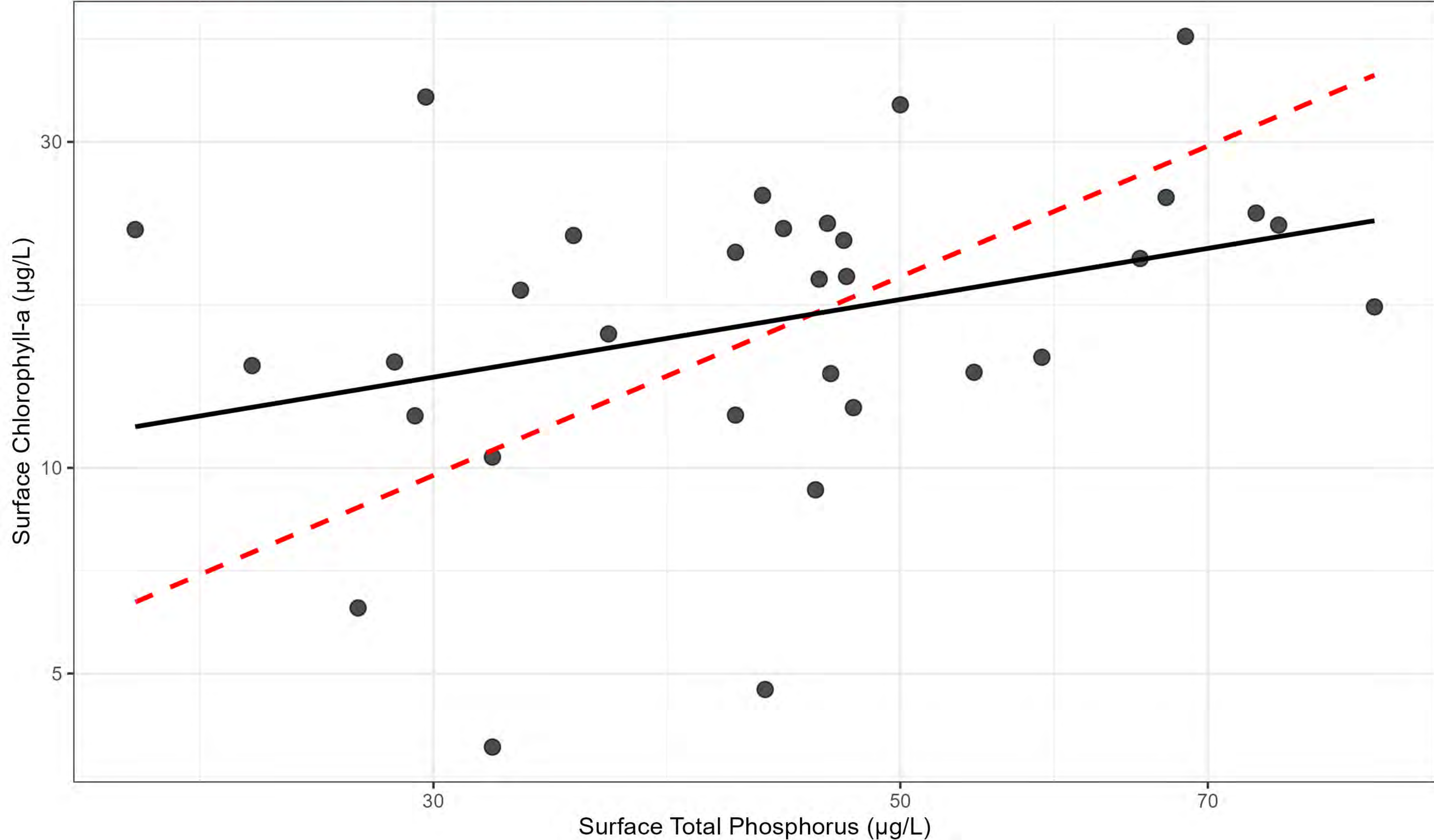
MN State Standard relationship: $\text{Log}_{10}(\text{Secchi}) = -0.59 \text{Log}_{10}(\text{Chla}) + 0.89$



Sucker Lake - Growing Season Mean TP vs Chl-a Relationship

Sucker fit: $\text{Log}_{10}(\text{Chla}) = 0.51 \text{ Log}_{10}(\text{TP}) + 0.376$ ($R^2 = 0.11$)

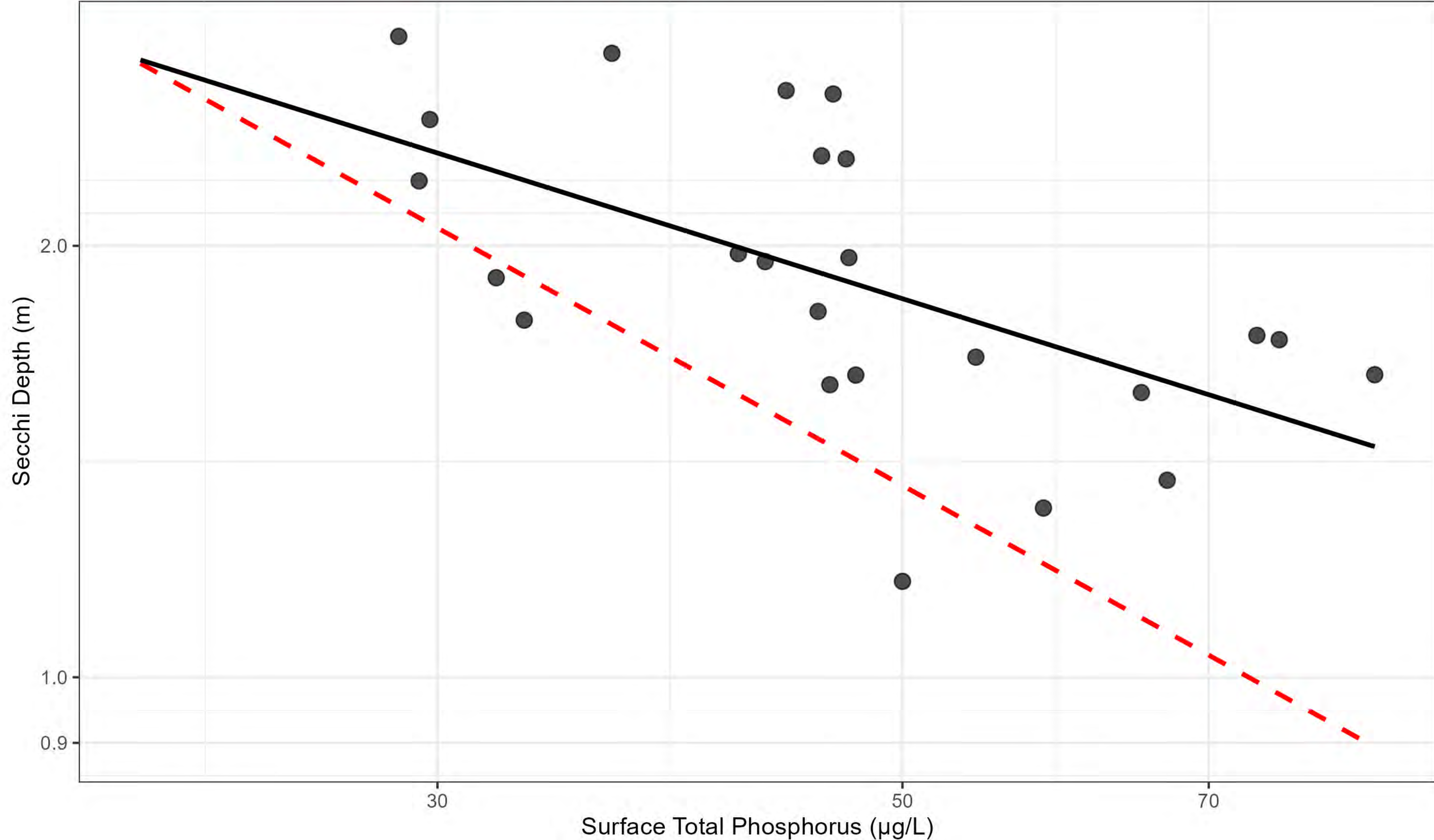
MN State Standard relationship: $\text{Log}_{10}(\text{Chla}) = 1.31 \text{ Log}_{10}(\text{TP}) - 0.946$



Sucker Lake - Growing Season Mean TP vs Secchi Depth Relationship

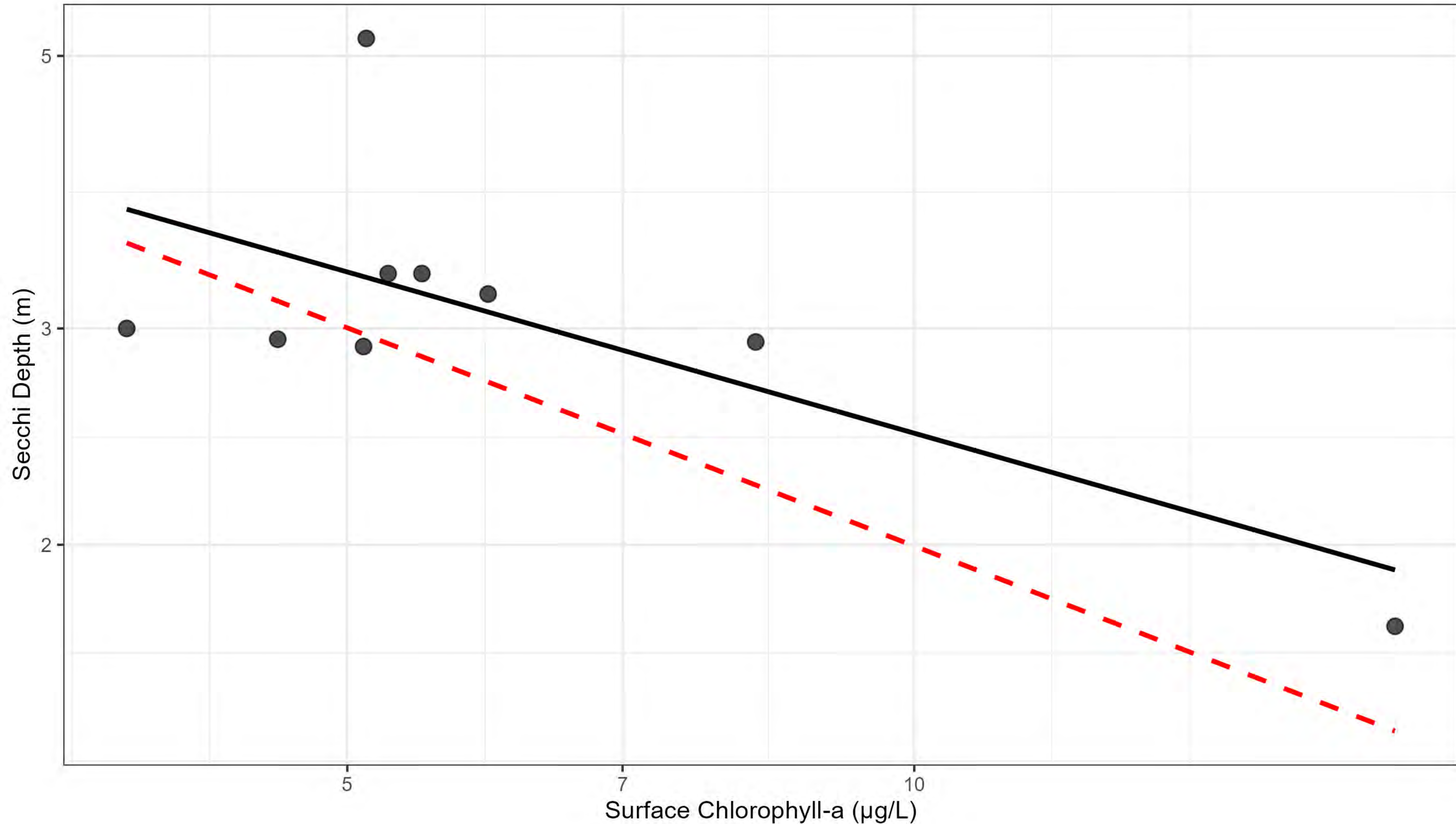
Sucker fit: $\text{Log}_{10}(\text{Secchi}) = -0.46 \text{Log}_{10}(\text{TP}) + 1.04$ ($R^2 = 0.35$)

MN State Standard relationship: $\text{Log}_{10}(\text{Secchi}) = -0.81 \text{Log}_{10}(\text{TP}) + 1.51$



East Vadnais Lake - Growing Season Mean Chl-a vs Secchi Depth Relationship

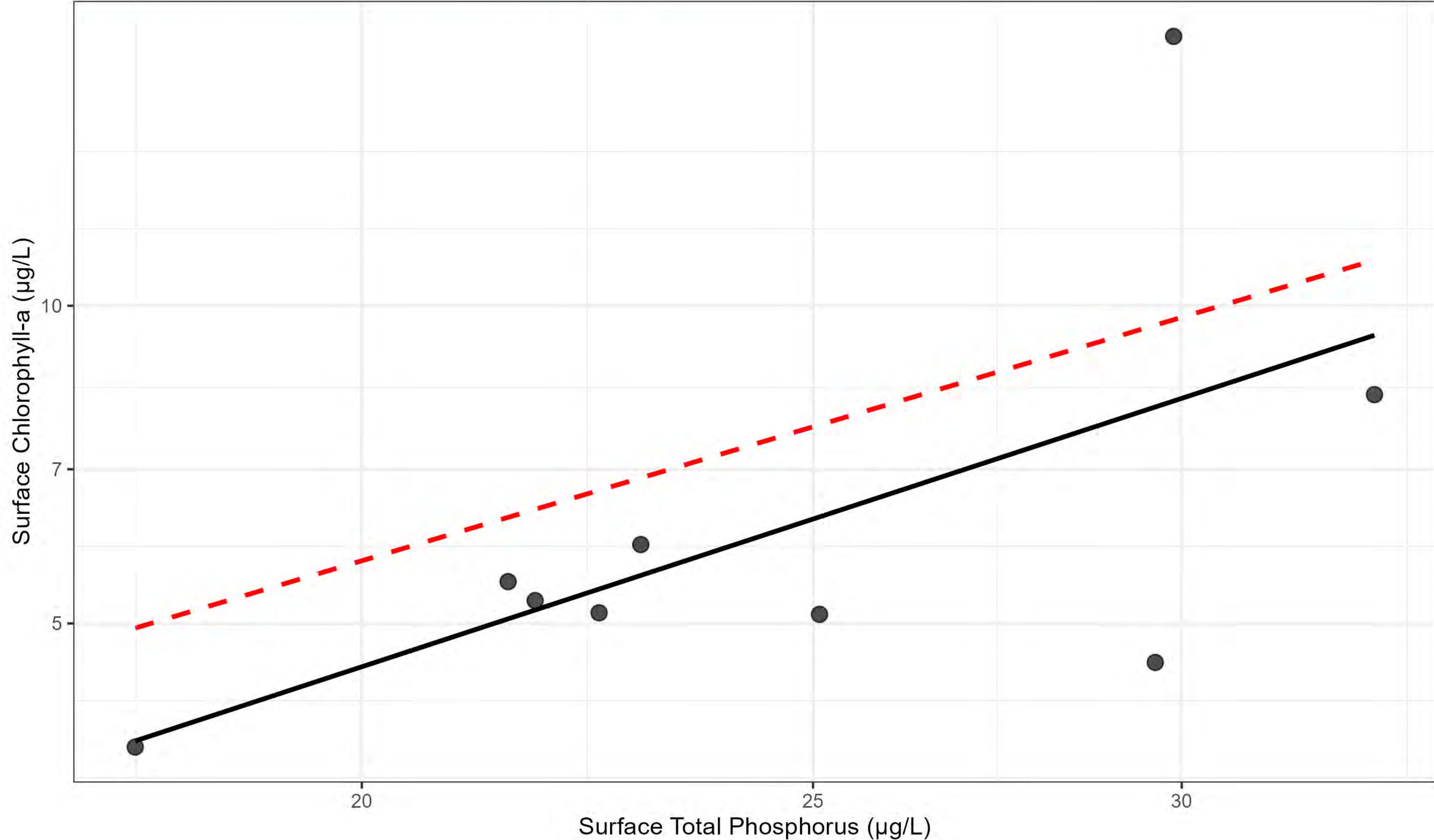
East Vadnais fit: $\text{Log}_{10}(\text{Secchi}) = -0.44 \text{ Log}_{10}(\text{Chla}) + 0.83$ ($R^2 = 0.5$)
MN State Standard relationship: $\text{Log}_{10}(\text{Secchi}) = -0.59 \text{ Log}_{10}(\text{Chla}) + 0.89$



East Vadnais Lake - Growing Season Mean TP vs Chl-a Relationship

East Vadnais fit: $\text{Log}_{10}(\text{Chla}) = 1.44 \text{ Log}_{10}(\text{TP}) - 1.221$ ($R^2 = 0.39$)

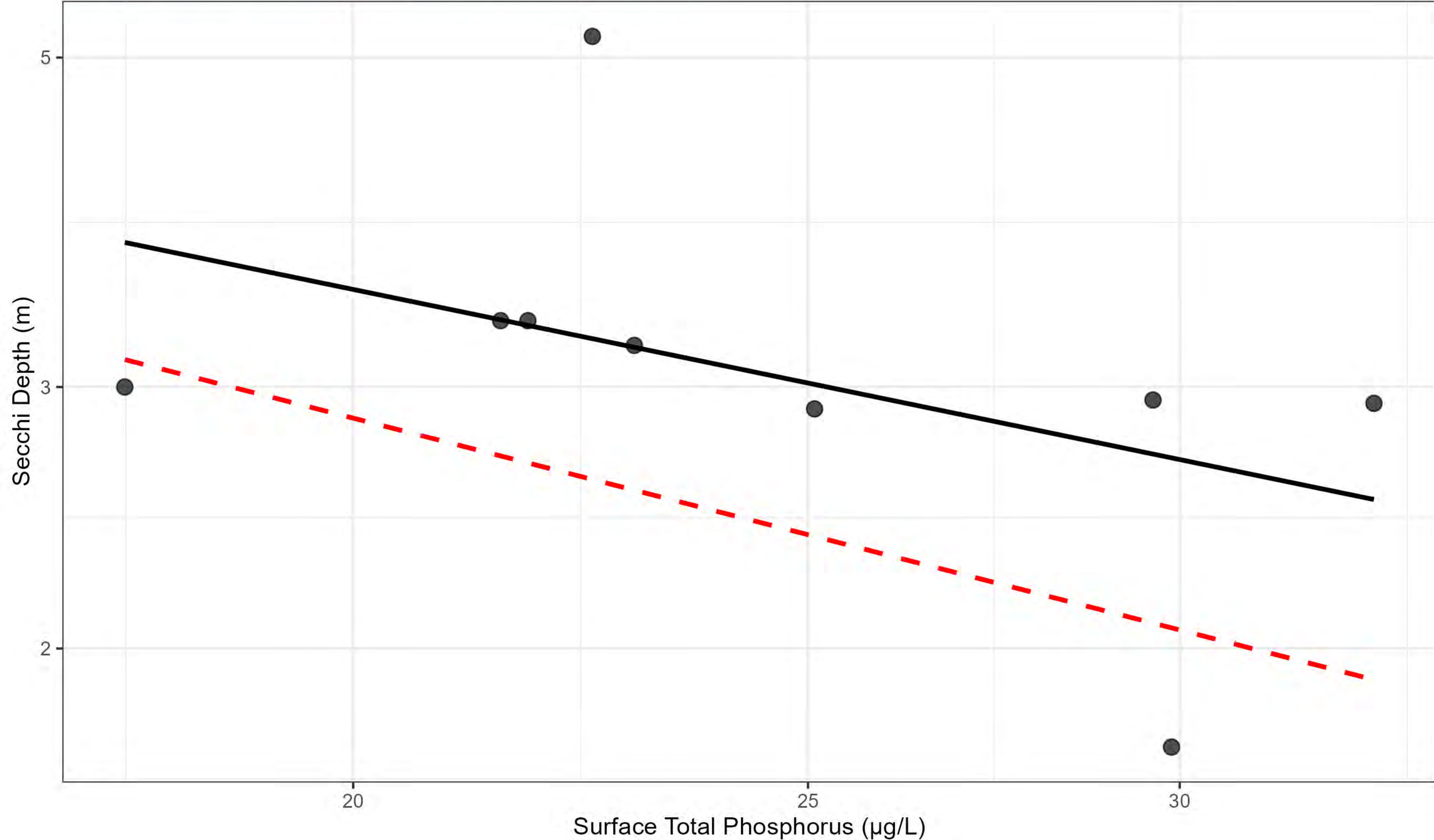
MN State Standard relationship: $\text{Log}_{10}(\text{Chla}) = 1.31 \text{ Log}_{10}(\text{TP}) - 0.946$



East Vadnais Lake - Growing Season Mean TP vs Secchi Depth Relationship

East Vadnais fit: $\text{Log}_{10}(\text{Secchi}) = -0.65 \text{Log}_{10}(\text{TP}) + 1.39$ ($R^2 = 0.21$)

MN State Standard relationship: $\text{Log}_{10}(\text{Secchi}) = -0.81 \text{Log}_{10}(\text{TP}) + 1.51$



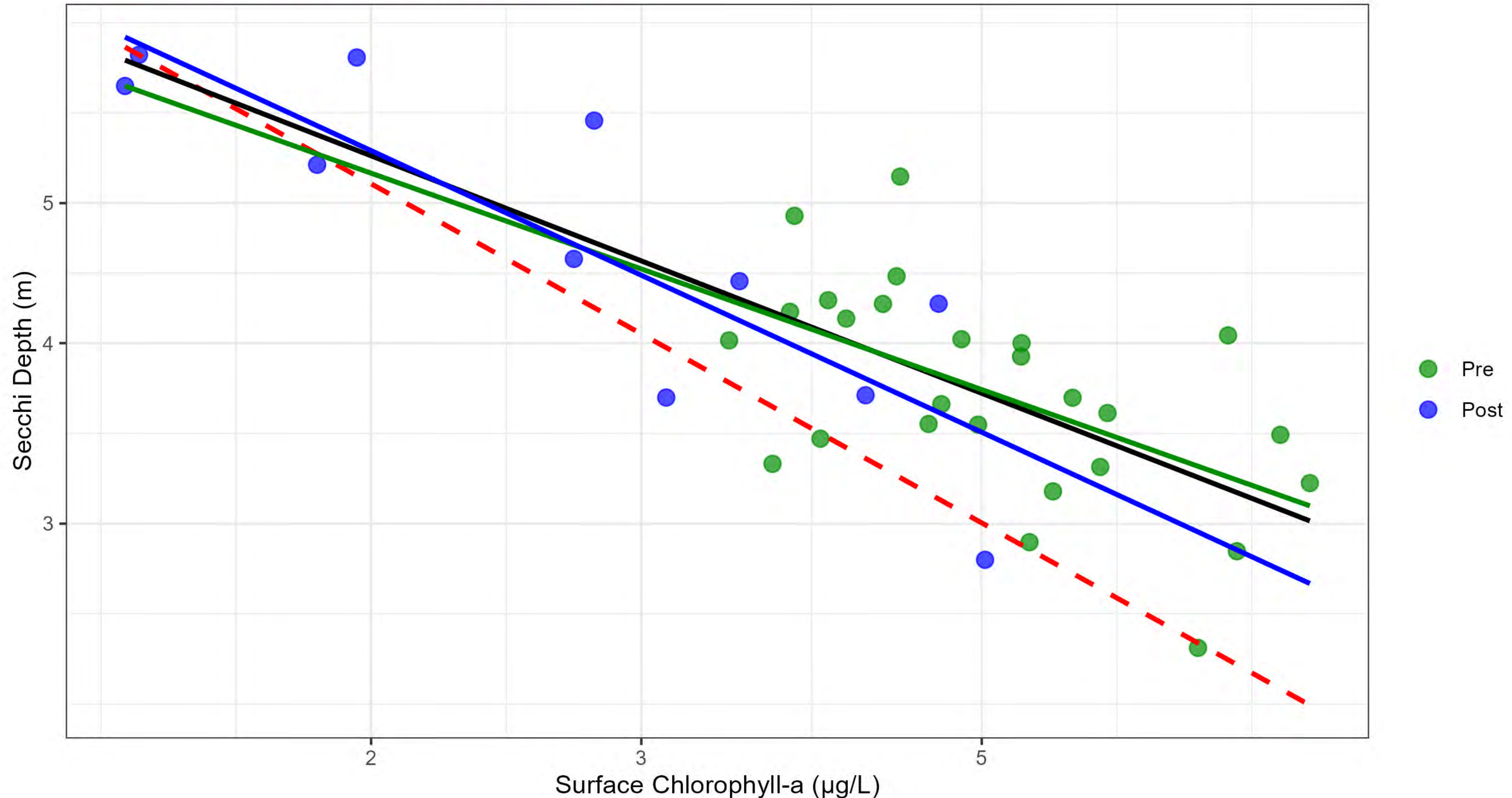
White Bear Lake - Growing Season Mean Chl-a vs Secchi Depth Relationship (Pre vs Post Zebra Mussels)

Pre (≤ 2013): $\text{Log}_{10}(\text{Secchi}) = -0.38 \text{Log}_{10}(\text{Chla}) + 0.83$ ($R^2 = 0.31$)

Post (2014+): $\text{Log}_{10}(\text{Secchi}) = -0.49 \text{Log}_{10}(\text{Chla}) + 0.88$ ($R^2 = 0.73$)

All WBL Data: $\text{Log}_{10}(\text{Secchi}) = -0.41 \text{Log}_{10}(\text{Chla}) + 0.86$ ($R^2 = 0.62$)

MN State Standard: $\text{Log}_{10}(\text{Secchi}) = -0.59 \text{Log}_{10}(\text{Chla}) + 0.89$



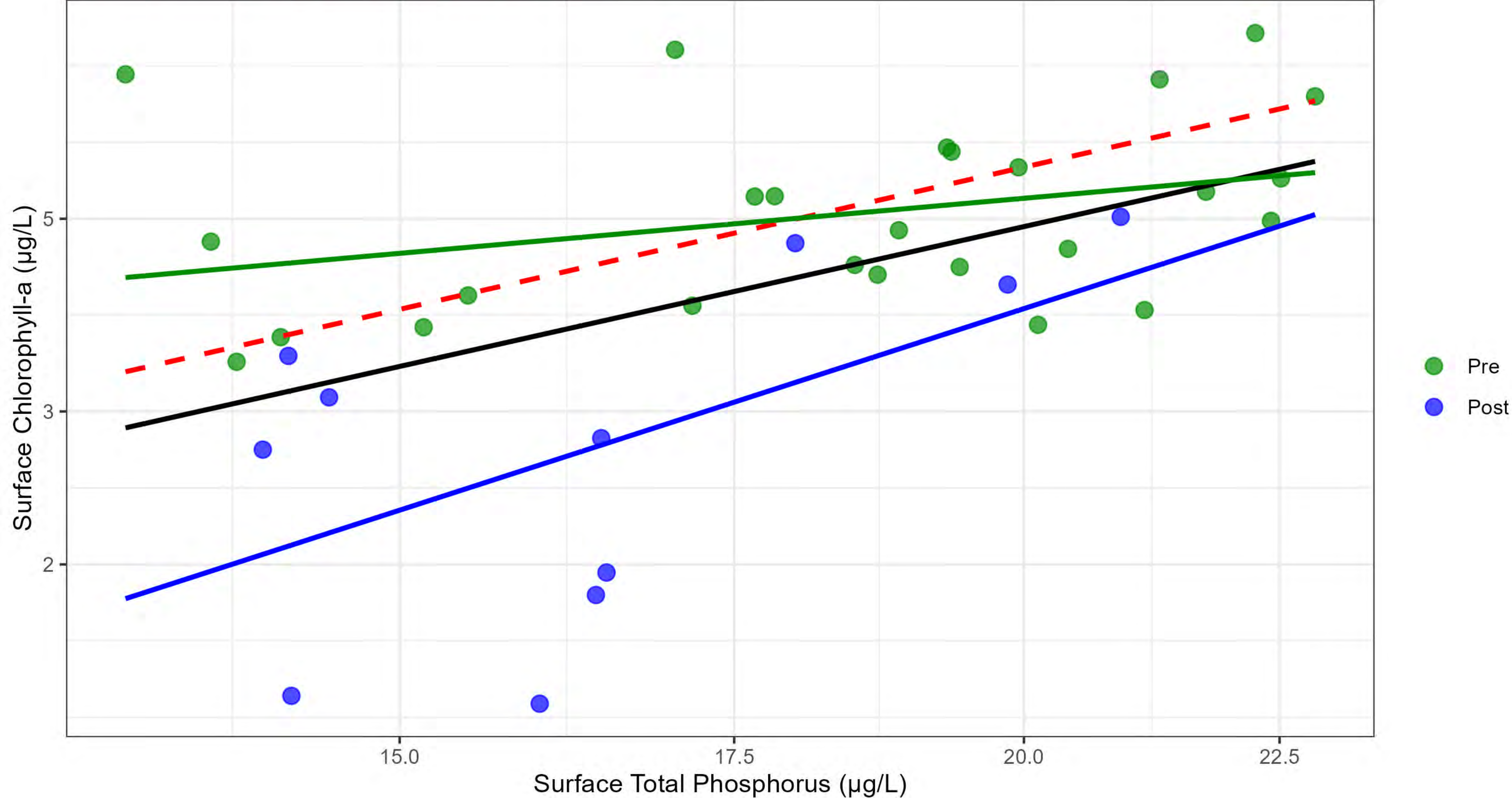
White Bear Lake - Growing Season Mean TP vs Chl-a Relationship (Pre vs Post Zebra Mussels)

Pre (≤2013): $\text{Log}_{10}(\text{Chl-a}) = 0.51 \text{ Log}_{10}(\text{TP}) + 0.06$ ($R^2 = 0.11$)

Post (2014+): $\text{Log}_{10}(\text{Chl-a}) = 1.86 \text{ Log}_{10}(\text{TP}) - 1.82$ ($R^2 = 0.3$)

All WBL Data: $\text{Log}_{10}(\text{Chl-a}) = 1.29 \text{ Log}_{10}(\text{TP}) - 0.99$ ($R^2 = 0.24$)

MN State Standard: $\text{Log}_{10}(\text{Chl-a}) = 1.31 \text{ Log}_{10}(\text{TP}) - 0.946$



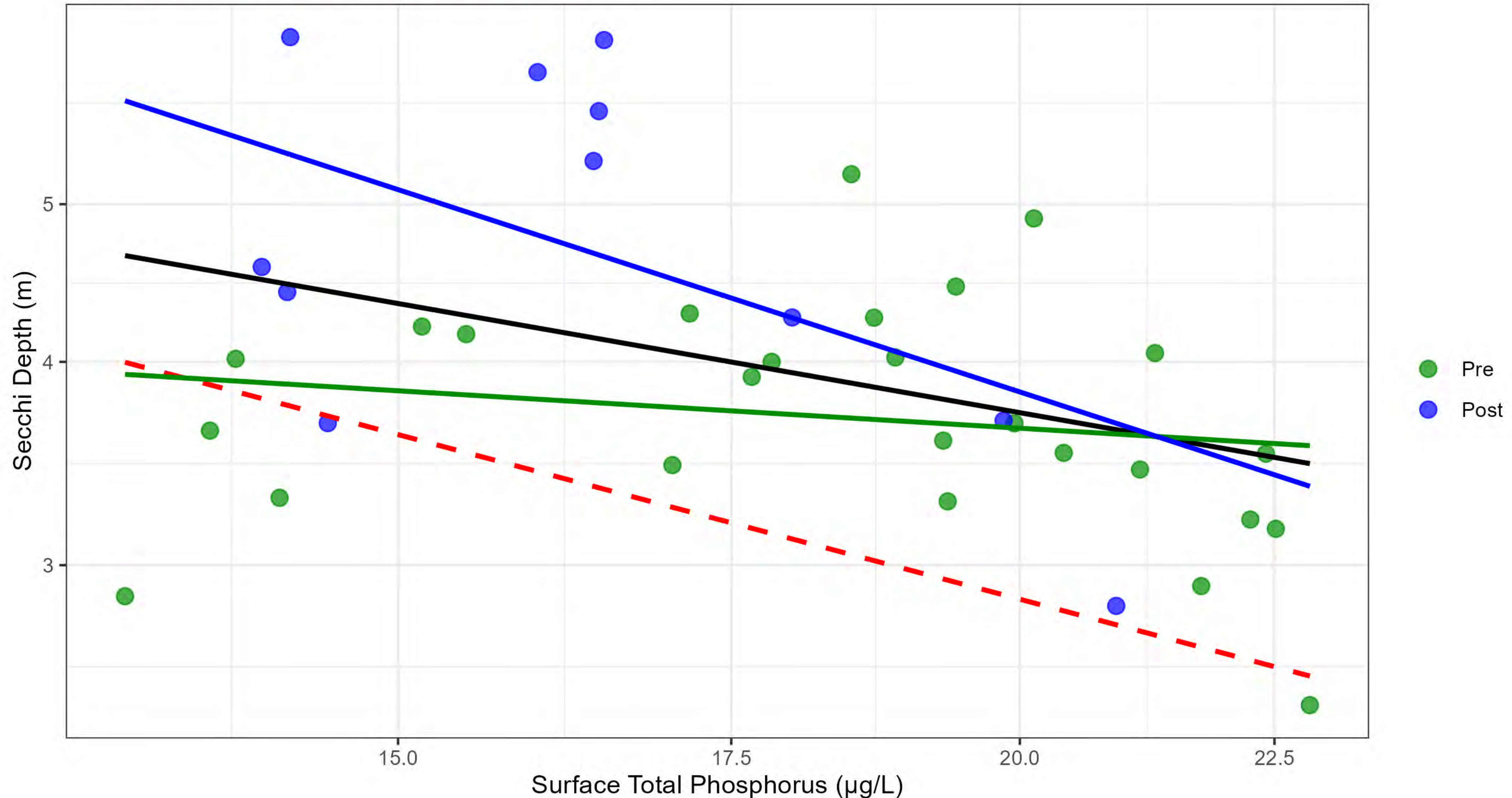
White Bear Lake - Growing Season Mean TP vs Secchi Depth Relationship (Pre vs Post Zebra Mussels)

Pre (≤ 2013): $\text{Log}_{10}(\text{Secchi}) = -0.18 \text{Log}_{10}(\text{TP}) + 0.8$ ($R^2 = 0.03$)

Post (2014+): $\text{Log}_{10}(\text{Secchi}) = -1 \text{Log}_{10}(\text{TP}) + 1.88$ ($R^2 = 0.26$)

All WBL Data: $\text{Log}_{10}(\text{Secchi}) = -0.54 \text{Log}_{10}(\text{TP}) + 1.27$ ($R^2 = 0.15$)

MN State Standard: $\text{Log}_{10}(\text{Secchi}) = -0.81 \text{Log}_{10}(\text{TP}) + 1.51$





Appendix 5

Lake Water Quality Calibration (CE-QUAL-W2)



Model and Model Structure

The CE-QUAL-W2 model (model), version 4.5, housed and maintained by Portland State University ([link](#)), was used to model the effect of nutrients and solids originating from the Mississippi River and the contributing watersheds on the water quality of the Saint Paul Regional Water Services (SPRWS) chain of lakes, including Charley Lake, Pleasant Lake, Sucker Lake, and terminating at East Vadnais Lake, which ultimately discharges to the SPRWS water treatment plant. A separate CE-QUAL-W2 model was also built for White Bear Lake. As part of the calibration process the White Bear model was calibrated separately but later linked for scenario evaluation that included the pumping of water from Sucker Lake or East Vadnais Lake to White Bear Lake. This appendix describes the model building and calibration process for the year 2025; however, additional details about the available data and information leveraged during this model development and calibration process are summarized in the main body of the report.

The CE-QUAL-W2 model is a two-dimensional hydrodynamic and water quality model that includes hydraulic and hydraulic functions that simulate the horizontal and vertical transport of water and constituents (e.g., dissolved and particulate organic carbon, inorganic suspended solids, phosphorus, nitrogen, phytoplankton, dissolved oxygen, salinity, and temperature). The basic structure of the model design for this project includes lakes in series where water and chemistry of the upstream lake is transported to the downstream lakes. The overall modeling design is shown below.

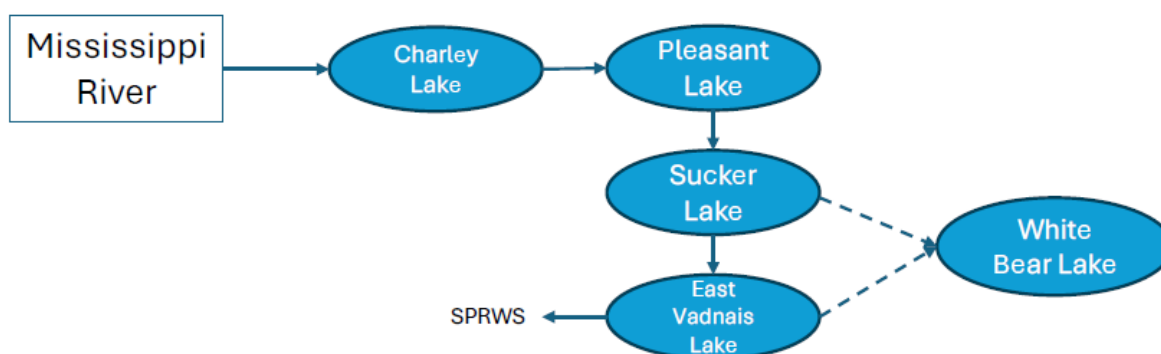


Figure A-1. Basic structure of the CE-QUAL-W2 modeling environment.

Each lake is partitioned into several rectangular shaped segments. These segments include the lake surface area and depth-area structure contained within the segment, based on the bathymetric data available for each lake as described in the main report. This design enables the

model to simulate transport and the timing of water and constituent movement within each lake and through the entire chain.

Additionally, lake outlets were modeled using the available options within the CE-QUAL-W2 model based on outlet survey data, rating curves, information from SPRWS regarding the manual operation of outlets (for Pleasant Lake), and daily discharge data from East Vadnais to the SPRWS treatment plant.

A summary of the model structure is provided in Table A-1 below. Figure A-2 uses East Vadnais Lake as an example of the two-dimensional structure of the CE-QUAL-W2 model grid.

Table A-1. Basic model structure by lake.

Lake	Number of Segments	Number of Branches	Maximum Number of Layers	Layer Width (m)	Bottom Elevation (m)	Primary Inlet	Model Outlet Structure
Charley	8	1	18	0.5	267.67	Miss. River	Weir
Pleasant	16	1	37	0.5	257	Charley Lake	Weir
Sucker	5	1	20	0.5	261.5	Pleasant Lake	Pipe
East Vadnais	25	1	39	0.5	252	Sucker Lake	Pump
White Bear	92	2	53	0.5	257	Watershed Runoff	Weir

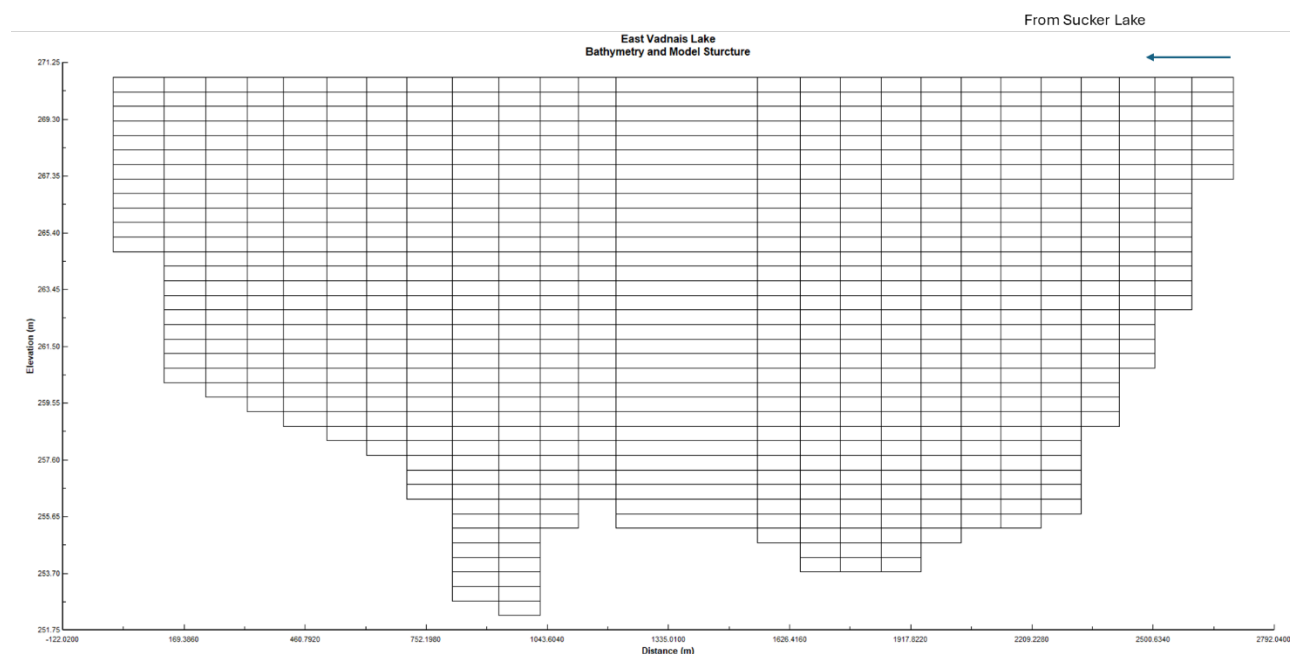


Figure A-2. East Vadnais Lake CE-QUAL-W2 model grid.

The model was calibrated for the May 7 through October 10, 2025 period for the Charley, Pleasant, Sucker, and East Vadnais chain of lakes and from May 19 through October 6, 2025. The model start date was dictated by the date on which in-lake monitoring data was available to set model initial conditions. The model timestep is variable and determined by the model while output is user controlled and was set to report daily. Results were summarized for the June 1 through September 30 time period to align with Minnesota eutrophication standards.

The two-dimensional structure of the model allows the user to identify the location where model results are reported. The reporting locations for each lake were aligned with the modeling locations. Calibration was evaluated for each monitoring location.

Model Inputs

In addition to bathymetric and model structure developments, model inputs for the SPRWS chain of lakes and White Bear Lake models included:

- flow, temperature, and water chemistry inputs from the Mississippi River into the SPRWS chain of lakes, including 2025 was collected by SPRWS and MCES
- flow and water chemistry inputs from the watershed runoff to all lakes at key inflow locations,
- flow from East Vadnais to the SPRWS water treatment plant,
- oxygen and ferric chloride dosing data from SPRWS
- climate data (precipitation, windspeed and direction, air temperature, dewpoint, and cloud cover), and
- initial (in-lake water column) conditions chemistry for each lake. In-lake water quality data in 2025 was collected by SPRWS, Vadnais Lake Area Watershed Management Organization (VLAWMO), and Ramsey County Public Works (see main report for additional details).

Water quality, temperature, and flow data for the Mississippi River are based upon monitoring data for the Mississippi River at Fridley and pumping records provided by Saint Paul Regional Water Services. The Mississippi River data were from the Metropolitan Council Environmental Services (MCES) website (<https://eims.metc.state.mn.us/Site/UM8628>) as well as from data collected by Saint Paul Regional Services as part of this project. The additional data points available from MCES improved the model by also improving the accuracy of loading estimates from the Mississippi River as the MCES dataset included weekly monitoring data.

There also are noted differences in the magnitude of the results for SPRWS and the MCES data in 2025, and it is concluded that the SPRWS data are biased low. For example, for the Mississippi River the mean total phosphorus concentration for June 1 through September 30, 2025 for SPRWS was 0.094 mg/L while the mean value for the MCES dataset for the same period was 0.115 mg/L. For total nitrogen, the mean concentration from May through October monitoring period for the

SPRWS data was 1.66 mg/L while the mean MCES value for the same period was 1.84. Other data used from the MCES data included TSS and VSS data to calculate ISS (inorganic suspended solids) and conductivity to calculate total dissolved solids. There were also notable differences between the SPRWS data and the Vadnais Lakes Area Water Management Organization (VLAMO) data for nutrients and it was also concluded that the SPRWS data was biased low. Nutrient calibration for Charley, Pleasant, Sucker and East Vadnais was based upon the surface measurements provided by VLAWMO.

Watershed runoff flow rates and chemistry for nutrients and solids were estimated from the P8 model except for the chemistry of the northern tributary to Pleasant Lake which was based upon Deep Lake water quality monitoring data collected by the VLAWMO.

The SPRWS adds iron to the Mississippi River intake as well as to Vadnais Lake. These inputs were simulated in the model as iron oxide inputs. The model simulates the effect of iron on phosphorus by adding iron to the concentration of inorganic solids which in turn bind only phosphate. Dissolved organic phosphorus and particulate organic phosphorus are not bound in the model by iron. However, iron in the non-modeling (“real world”) does bind and settle dissolved organic and particulate organic phosphorus. Hence, the representation of iron in the model is imperfect and the predictive capacity of the model with respect to modifications to iron dosing is unreliable.

There are also limitations with the model-representation of the dissolved oxygen injection systems at Pleasant and East Vadnais Lake. Oxygen mass per unit time is injected in the model at user-prescribed depths, however, it is not represented as bubbles but rather as pure dissolved oxygen. Hence, there is much less mixing in the model than there is in the real world since oxygen bubbles rise upward in real-world conditions. Hence, oxygen was injected in the model at multiple lake depths. This led to a uniform concentration of dissolved oxygen in the model in much of the bottom water. Whereas, based upon monitoring data there was greater vertical and later mixing of injected oxygen. Regardless, the general effect of the oxygen injection system was adequately represented in the model and was able to simulate the effect of aeration on important processes such as phosphorus and nitrogen internal loading.

Calibration

The calibration process proceeded stepwise with a water balance, lake temperature, water quality constituents (e.g., nutrients), and then model-derived constituents such as phytoplankton (e.g., chlorophyll *a*) and dissolved oxygen. The calibration for each step was generally completed from upstream to downstream through the SPRWS chain of lakes as the flow and pollutant loads from one lake were routed to the next lake downstream.

Water Level and Water Balance

Changes in lake water level are directly related to changes in lake water volume. In addition to using the lake bathymetric data, the model tracks inflows and outflows through each lake to estimate

lake volume and water levels. For the SPRWS chain of lakes (Charley, Pleasant, Sucker, and East Vadnais), there are three types of water sources, including:

- water pumped from the Mississippi River (and discharges from each respective upstream lake),
- watershed runoff, and
- direct precipitation.

There are also several losses of water including:

- evaporation from the lake surface,
- discharge through the surface outlets, and
- ultimately the water discharged from East Vadnais Lake to the SPRWS water treatment plant.

Ultimately, no groundwater exchange was included for the SPRWS chain of lakes. These inputs and withdrawals were included in the CE-QUAL-W2 model and model-predicted water level was compared to measured values. The calibration process for water levels in the SPRWS chain of lakes included the following:

- outlet rating curve modification (Pleasant Lake) – based on direction from SPRWS staff that this outlet is manually adjusted, we made minor adjustments to the outlet to best represent 2025 water levels
- runoff yield adjustment for Lambert Creek (runoff generated by P8) using a scaling factor of 1.66) to most accurately reflect water surface elevations. This scaling still resulted in accurate runoff coefficients for this watershed given the nature of this watershed. and

For White Bear Lake, the sources of water for the calibration period included:

- watershed runoff, and
- direct precipitation.

There are also several losses of water including:

- evaporation from the lake surface,
- net loss to groundwater, and
- discharge through the surface outlets (though based on observed water levels, there was no surface discharge in 2025)

For White Bear Lake, we initially developed the evaporative losses using the same methodology as for the SPRWS chain of lakes and estimated the net groundwater exchange required for the prediction of water levels. Although results were within acceptable ranges, the parameters that affect evaporative loss in White Bear Lake were modified to fit within the boundaries of evaporative and groundwater losses provided by Minnesota Department of Natural Resources (MnDNR) based on past studies. These modifications resulted in slight adjustment to the net groundwater losses

required. Modifications to evaporative loss and subsequent adjustments to match water levels resulted in the following:

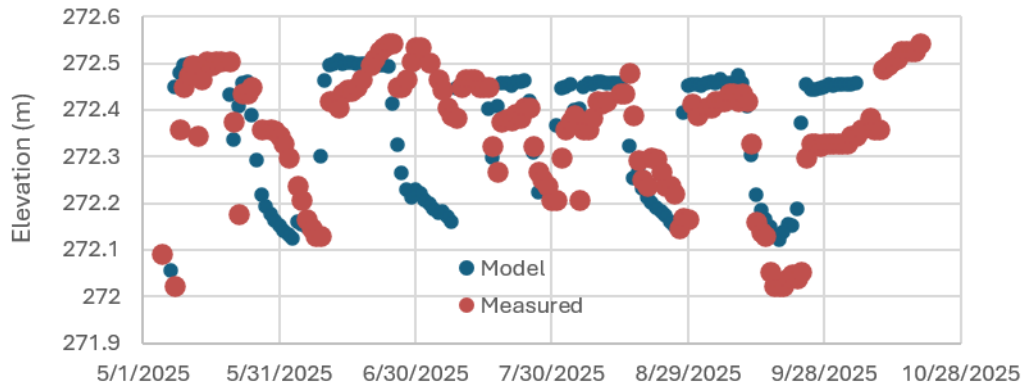
- June through September daily groundwater losses of 9,251 m³ or 7.5 acre-feet/day.
- Average June, July, August and September total monthly evaporative loss of 103.5, 161.5, 144.8, and 94 mm.

Results of the water level calibration are provided in Figure A-3. The overall water balance for the five modeled lakes for the calibration period growing season is provided in Table A-2.

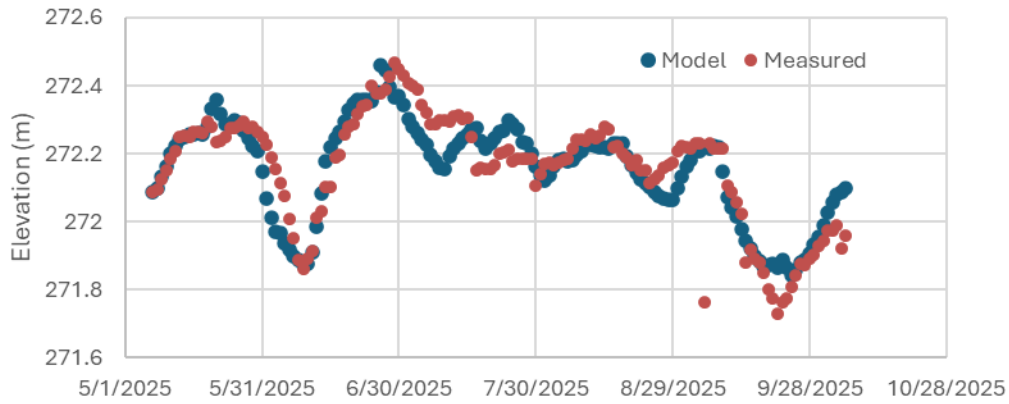
Table A-2. Water balance for the calibrated CE-QUAL-W2 model for growing season 2025.

Water Component	Charley	Pleasant	Sucker	East Vadnais	White Bear
Upstream Lake Inflow (m ³)	10,316,202	10,450,101	13,108,723	13,730,593	-
Direct Precipitation (m ³)	71,199	1,345,659	139,638	869,268	5,271,415
Surface Discharge (m ³)	10,452,893	13,250,367	13,730,593	-	-
Saint Paul Water Utility (m ³)	-	-	-	20,880,947	-
Evaporation (m ³)	109,858	1,300,399	115,785	717,121	4,801,223
Groundwater Outflow (m ³)	-	-	-	-	1,118,880
Watershed Runoff (m ³)	215,016	2,278,796	483,940	5,971,688	2,134,605
Hydraulic Residence Time (days)	3	115	4	56	1,125

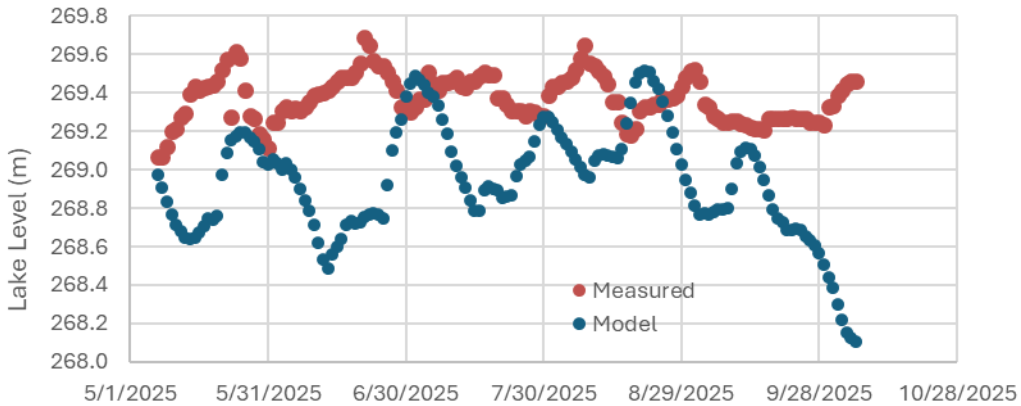
Charley Lake Water Level Calibration



Pleasant Lake Water Level Calibration



Sucker Lake Level Calibration



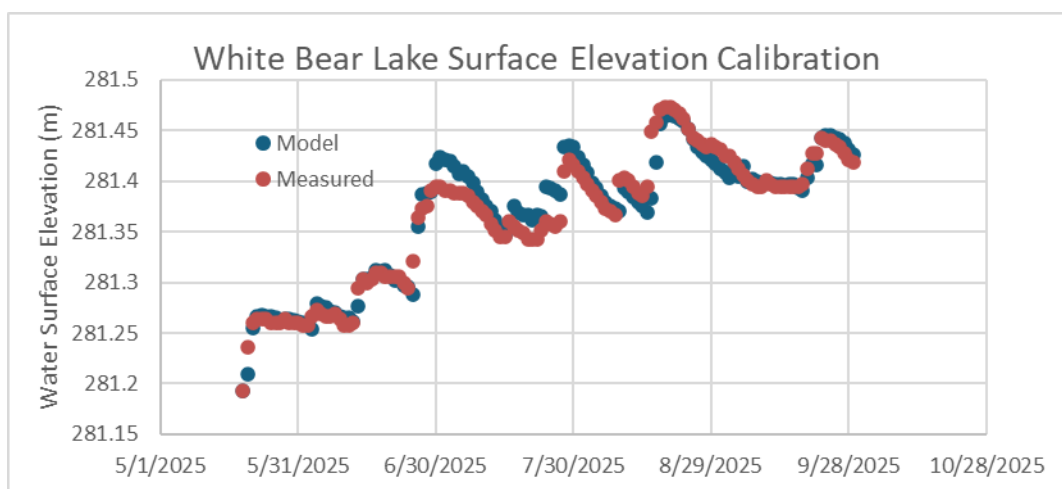
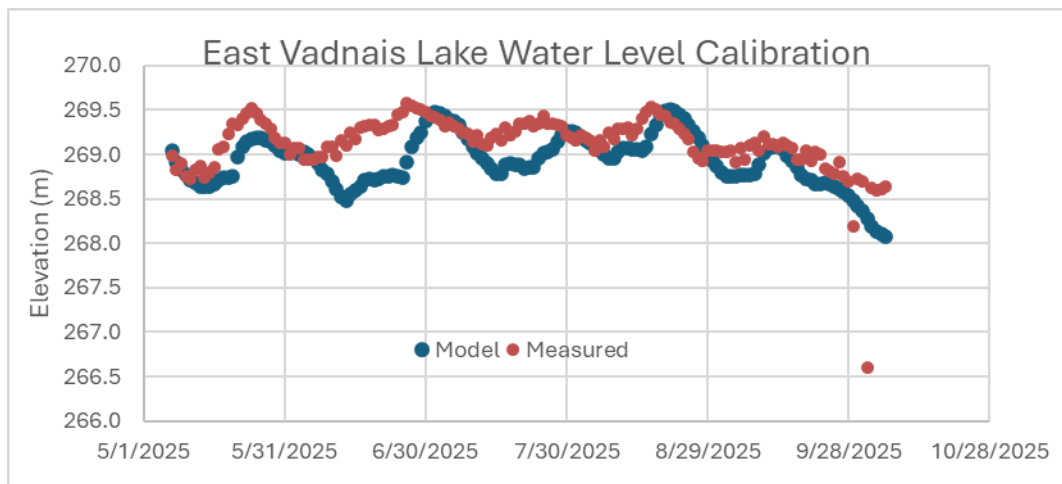
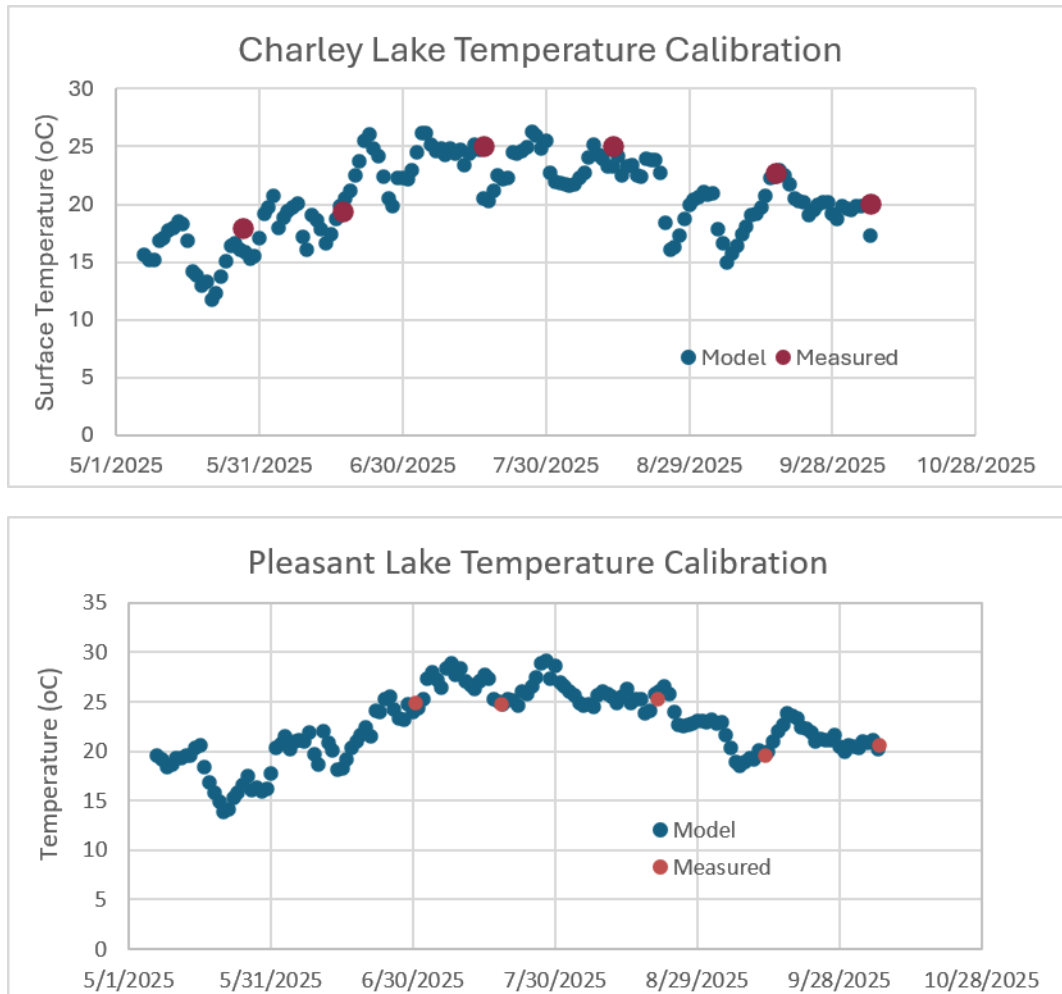


Figure A-3. Water level calibration results for the SPRWS chain of lakes and White Bear Lake.

Temperature

To capture the anticipated lake stratification and anticipated turnover, lake water temperatures were calibrated by changing the wind sheltering coefficient for each lake. This has the effect of changing how wind affects mixing and convective and evaporative heat loss. The results of the temperature calibration are provided in Figure A-4.



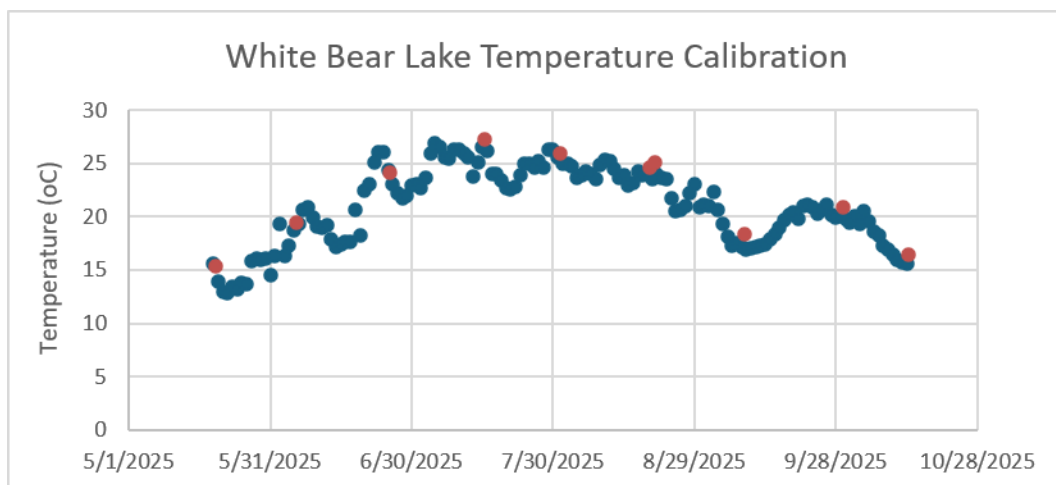
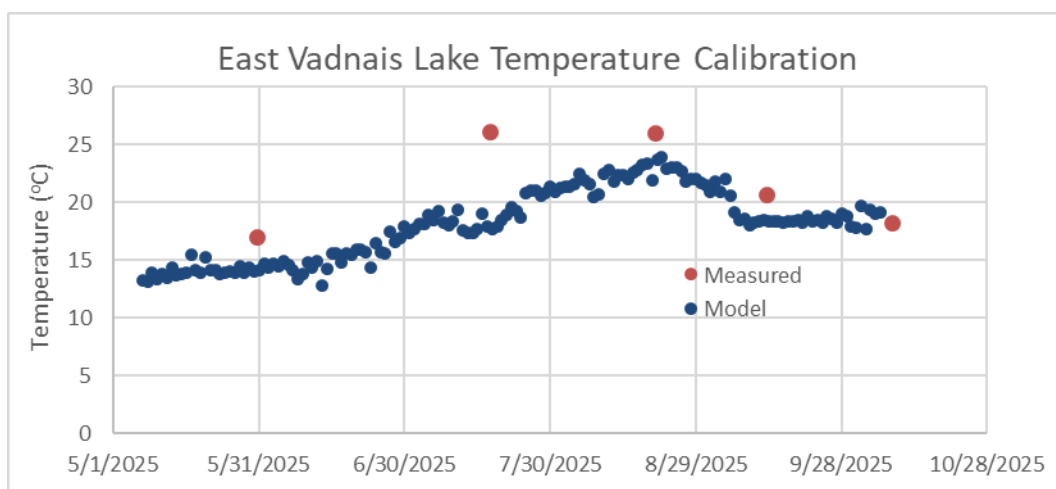
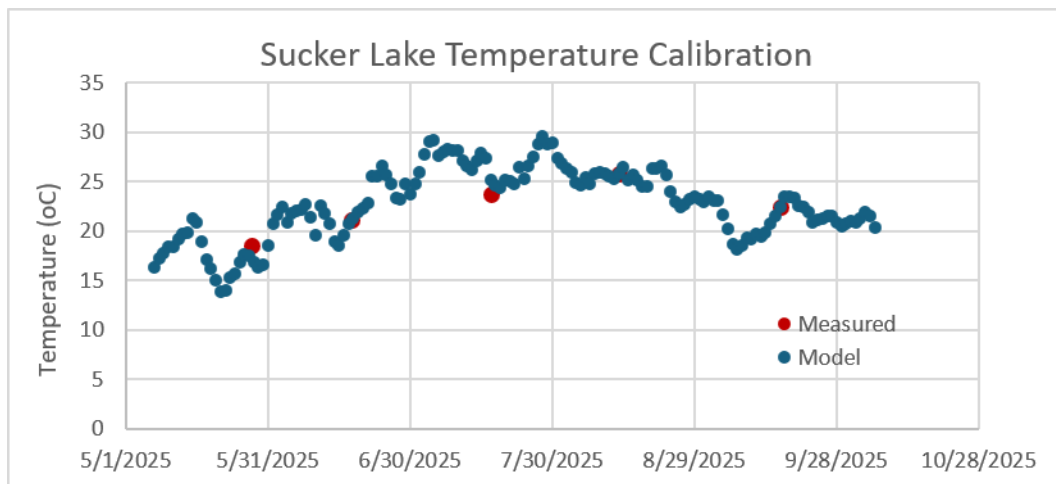


Figure A-4. Temperature calibration results for Charley, Pleasant, Sucker, East Vadnais, and White Bear Lakes

Nutrients, Phytoplankton (Chl *a*), and Total Organic Carbon

Nutrient calibration was largely a function of modifying parameters that controlled phosphorus and nitrogen internal loading; watershed loading and loading from the Mississippi River were not modified as part of the calibration process.

Phytoplankton calibration for Charley, Pleasant, Sucker, and East Vadnais Lake was achieved by modifying Michaelis-Menten coefficients for maximum growth and nutrient limitation (e.g., half saturation coefficients). To calibrate White Bear Lake, two phytoplankton types were modeled to simulate algae that are representative of green algae and nitrogen fixing cyanobacteria. Intermittent nitrogen and phosphorus limitation are responsible for the timing of observed phytoplankton populations and the magnitude and timing of growth in White Bear Lake. Calibration was achieved by allowing for nitrogen fixation (cyanobacteria), application of different half saturation coefficients and light sensitivities for the green algae and cyanobacteria groups.

The overall phosphorus and nitrogen mass balance for the summer period in 2025 is provided in Table A-3. Figures showing a comparison of measured and modeled total phosphorus, total nitrogen, chlorophyll *a*, and total organic carbon in the study lakes are provided in Figure A-5, Figure A-6, Figure A-7, and Figure A-8, respectively.

Table A-5. Phosphorus and nitrogen mass balance for Charley, Pleasant, Sucker-Vadnais, and White Bear Lake. Mass balance period is June 1 through September 30.

Lake	Parameter	Loads (kg)				Losses (kg)		
		Upstream Inflow	Watershed	Internal	Total	Settling	Outflow	Total
Charley	Total Phosphorus	1264	123	236	1623	328	949	1276
	Total Nitrogen	22000	652	3146	25798	3314	17892	21206
Pleasant	Total Phosphorus	949	286	694	1928	78	1281	1359
	Total Nitrogen	17892	956	53294	72142	717	18718	19435
Sucker-Vadnais	Total Phosphorus	1281	3622	1438	6341	2413	1184	3597
	Total Nitrogen	18718	26790	16892	62400	15561	20991	36552
White Bear	Total Phosphorus	0	654	1615	2269	1242	23	1265
	Total Nitrogen	0	3139	11915	15054	7619	730	8349

Table A-6. Comparison of average June 1 through September 30 model-predicted and measured water quality values for Charley, Pleasant, Sucker-Vadnais, and White Bear Lake.

Lake	Total Phosphorus (mg/L)		Phosphate (mg/L)		Total Nitrogen (mg/L)		Chl <i>a</i> (ug/L)		Total Organic Carbon (mg/L)	
	Model	Measured	Model	Measured	Model	Measured	Model	Measured	Modeled	Measured
Charley	0.096	0.096	0.044	0.031	1.60	1.55	30	22	10.6	10.3
Pleasant (west) ¹	0.087	0.091	0.036	0.033	1.34	1.11	11	19	7.8	9.7
Sucker ²	0.0393	0.040	0.018	0.020	0.87	1.06	4.3	10	1.9	9.0
East Vadnais (north)	0.029	0.028	0.0205	0.004	0.757	0.787	2.6	4.6	0.5	8.6
White Bear (north) ³	0.020	0.019	0.005	0.003	0.65	0.62	4.7	4.6	3.7	4.6

1. VLAWMO data collected at monitoring point 62-0046-00-205 which is west Pleasant Lake for total phosphorus, phosphate, and chlorophyll *a*, primarily due to concerns about low bias in the SPRWS data. Nitrogen and total organic carbon data collected at location 62-0046-00-204 by Saint Paul Regional Water Services.

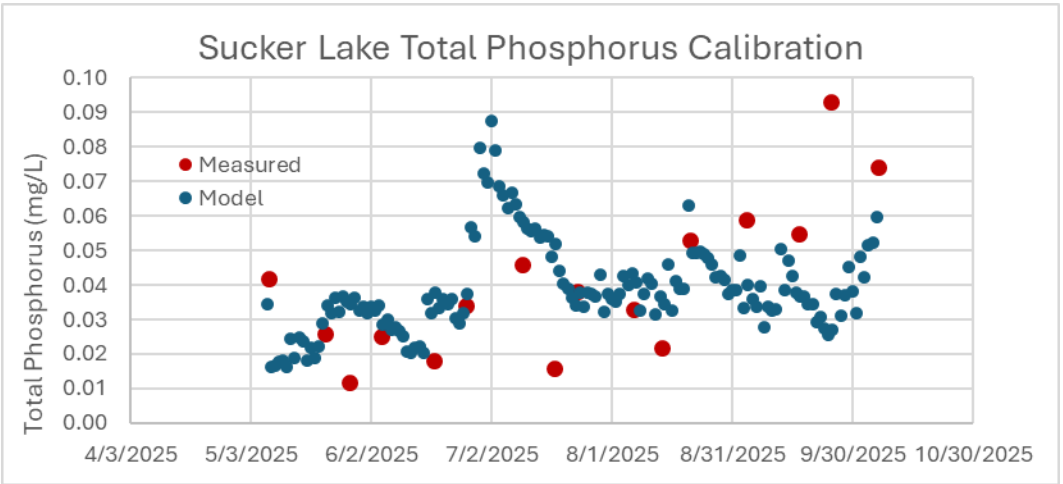
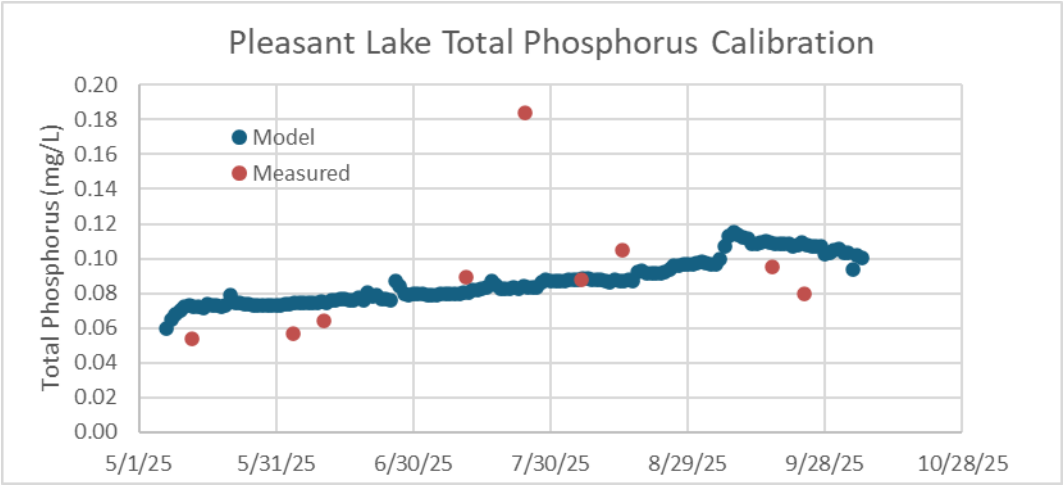
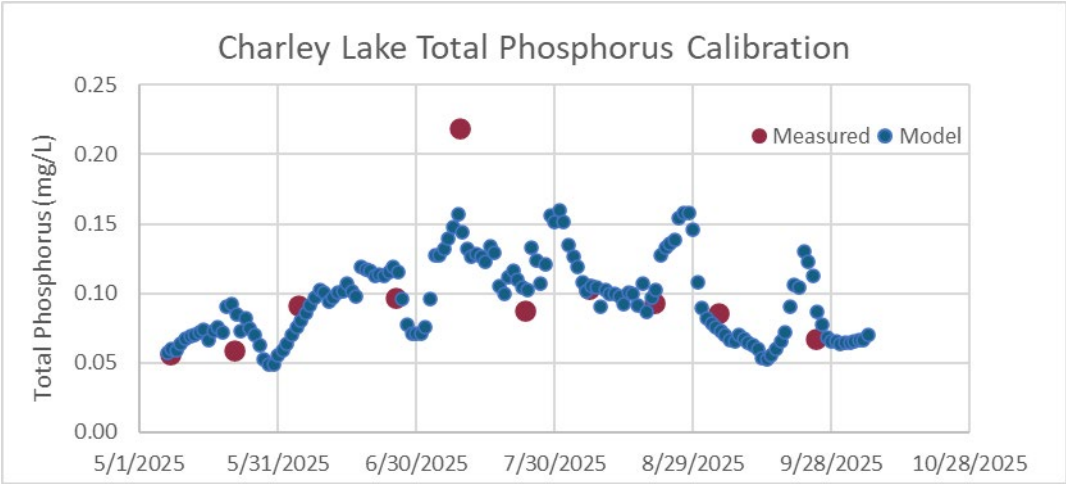
2. Monitoring data from monitoring location 62-0028-00-401 and VLAWMO deep hole location.

3. Model output at monitoring site 82-0167-00-229 / north bay of White Bear Lake.

The calibrated CE-QUAL-W2 model provided good agreement between modeled and measured total phosphorus for all of the study lakes (0 to 5 percent relative percent difference), and reasonably good agreement for total nitrogen with relative percent differences ranging from 4 to 20 percent.

On an average basis, there were notable differences between modeled and measured chlorophyll *a* values for Charley, Pleasant, and Sucker Lake. This may have been a function of the high variability of these systems and the effect of extreme individual monitoring data points on the calculation of averages (see Figure A-7). Hence, a visual inspection of Figure A-7 is warranted to better understand the models' accuracy with respect to chlorophyll *a* calibration for these lakes. There was good agreement between measured and modeled values for East Vadnais and White Bear Lake. The model for White Bear Lake was capable of accurately simulating both the magnitude and seasonal change in chlorophyll *a* in White Bear Lake.

The total organic carbon calibration for Charley Lake, Pleasant Lake and White Bear Lake resulted in relative percent differences ranging from 3 to 23 percent. The difference between modeled and measured values in White Bear Lake averaged less than 1 mg/L. Overall total organic carbon concentrations are low in White Bear Lake. There were large differences between modeled and measured TOC values in Sucker and East Vadnais Lake and this may have been a function of use of model coefficients and functionality employed to simulate the effect of iron (resulting from ferric chloride addition) in East Vadnais Lake.



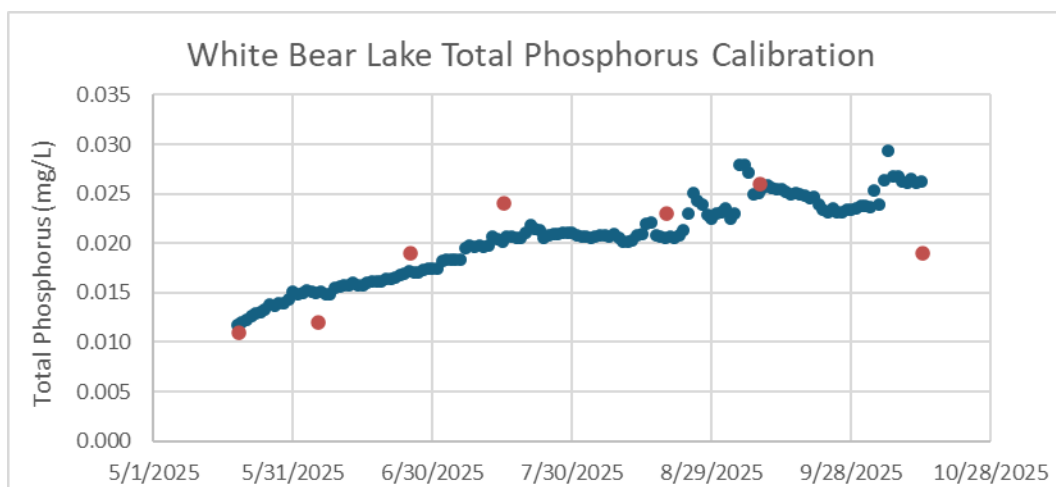
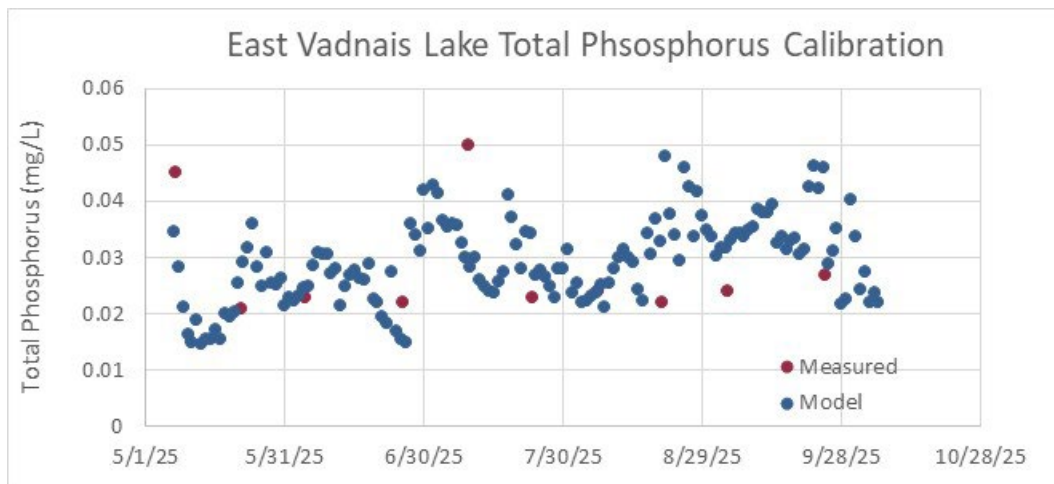
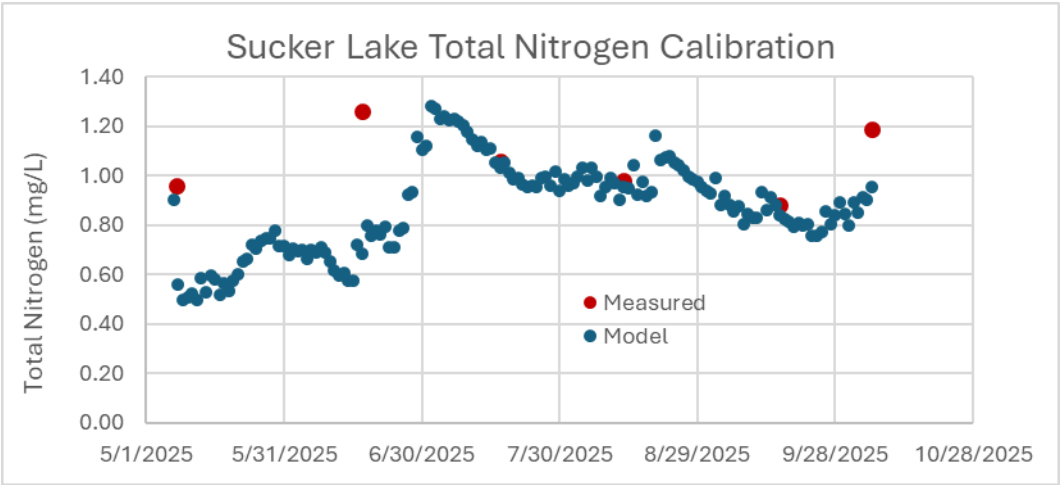
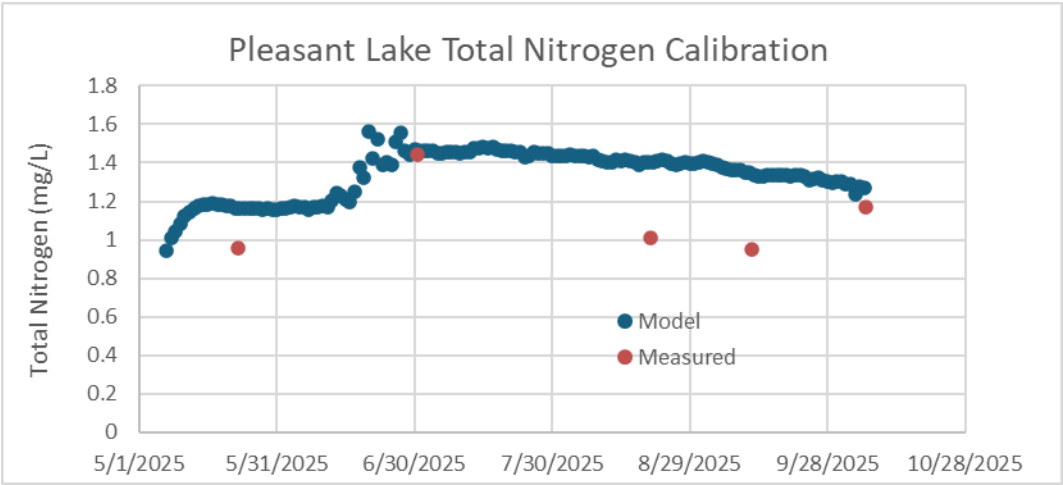
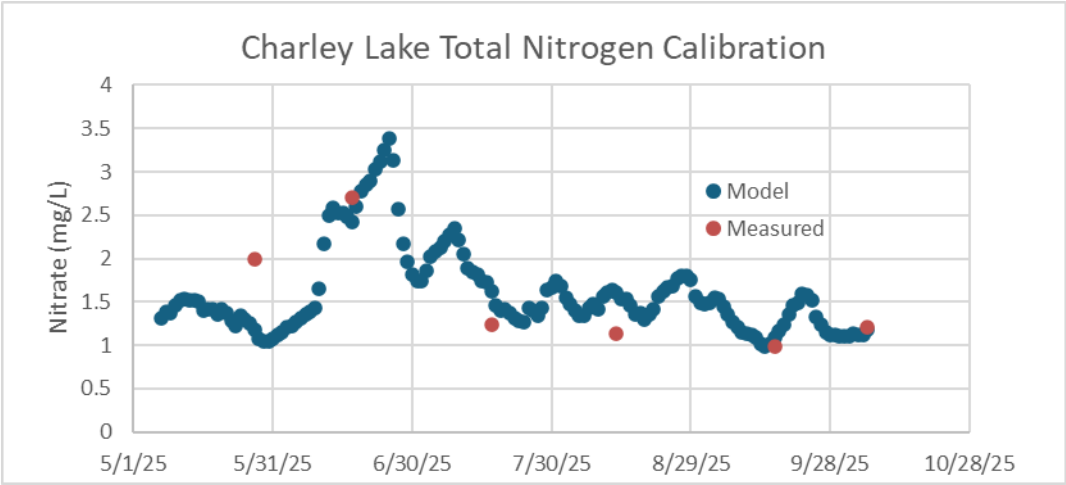


Figure A-5. Total phosphorus calibration outcome for Charley, Pleasant, Sucker, East Vadnais, and White Bear Lakes.



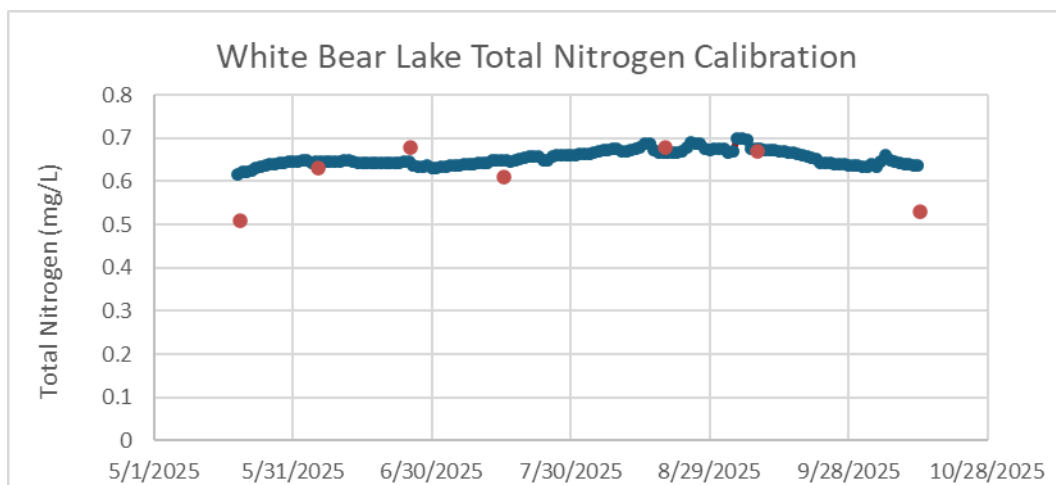
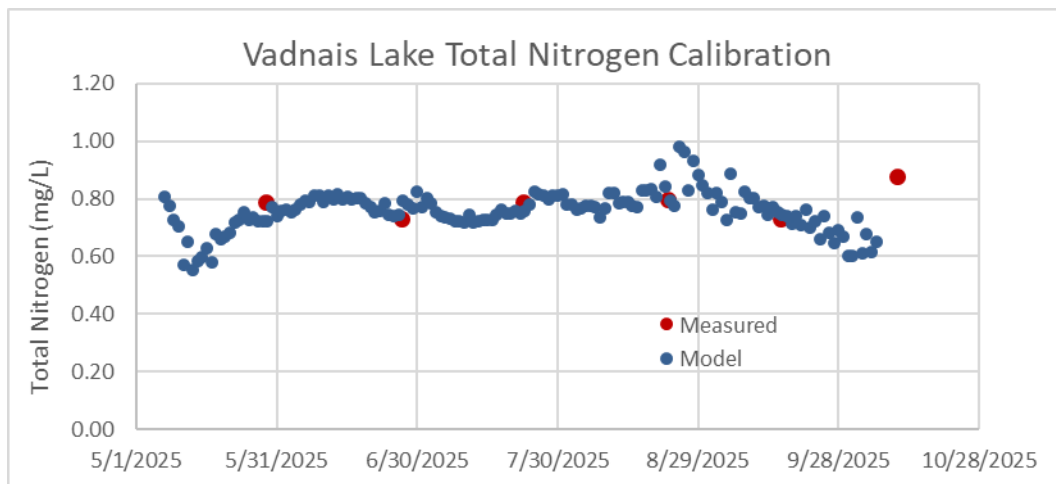
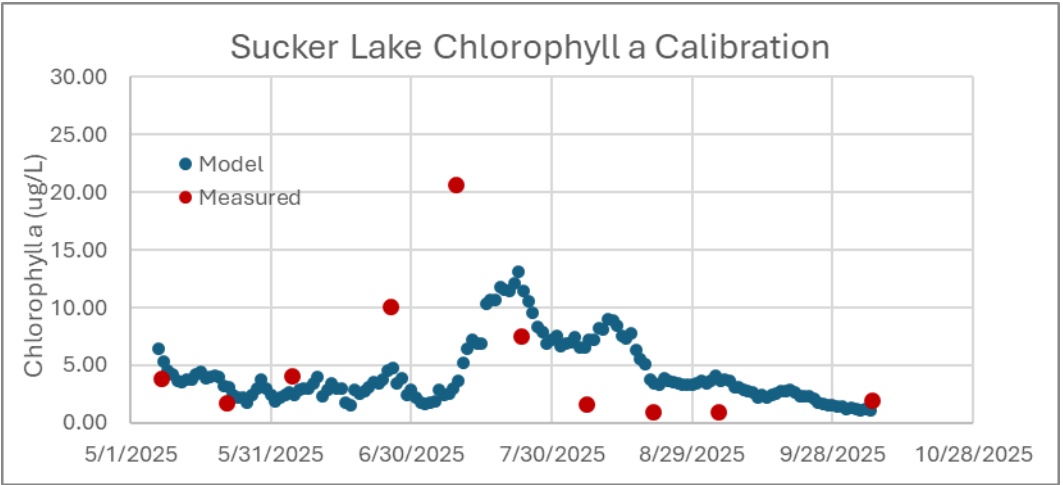
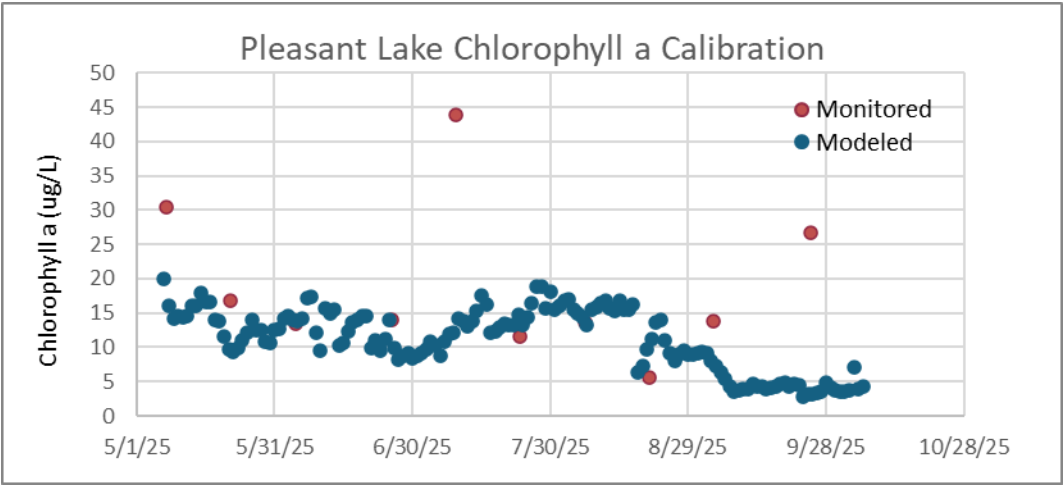
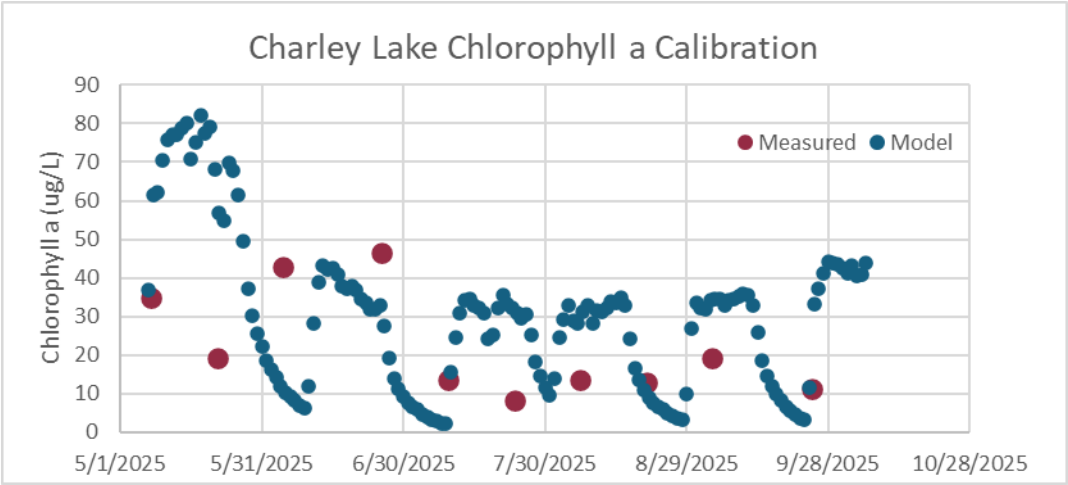


Figure A-6. Total nitrogen calibration results for Charley, Pleasant, Sucker, East Vadnais, and White Bear Lake.



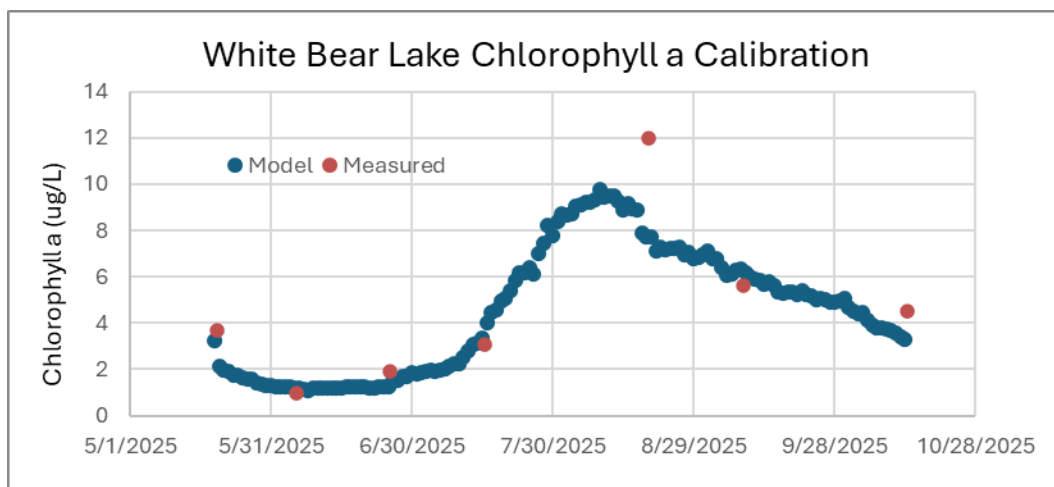
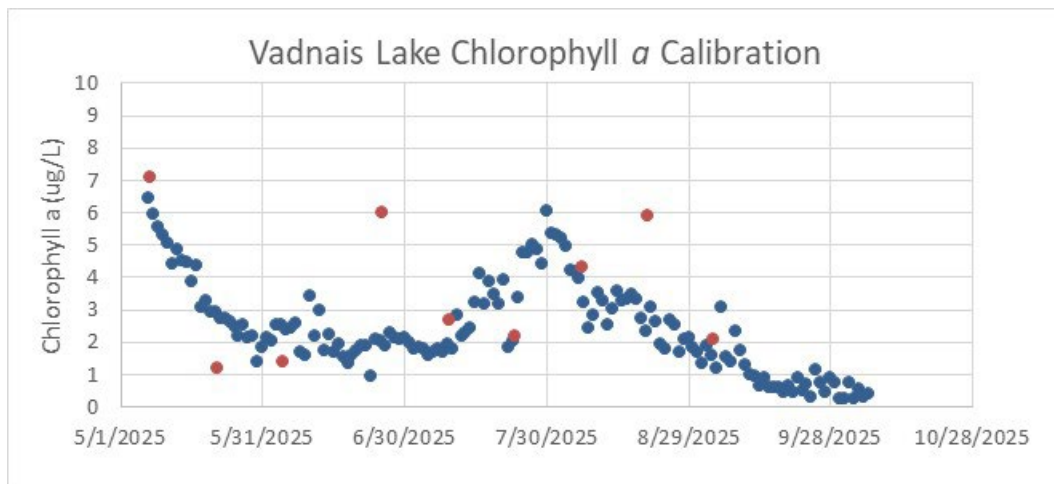
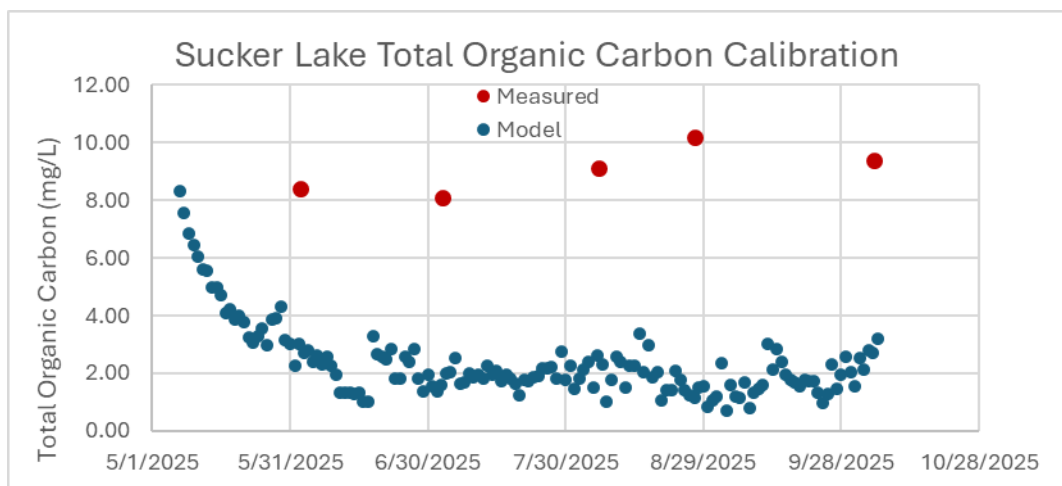
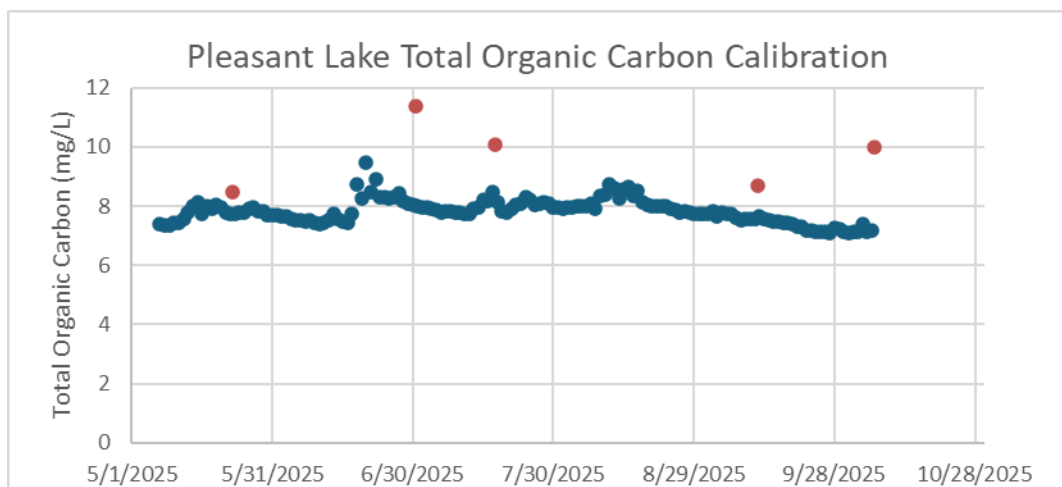
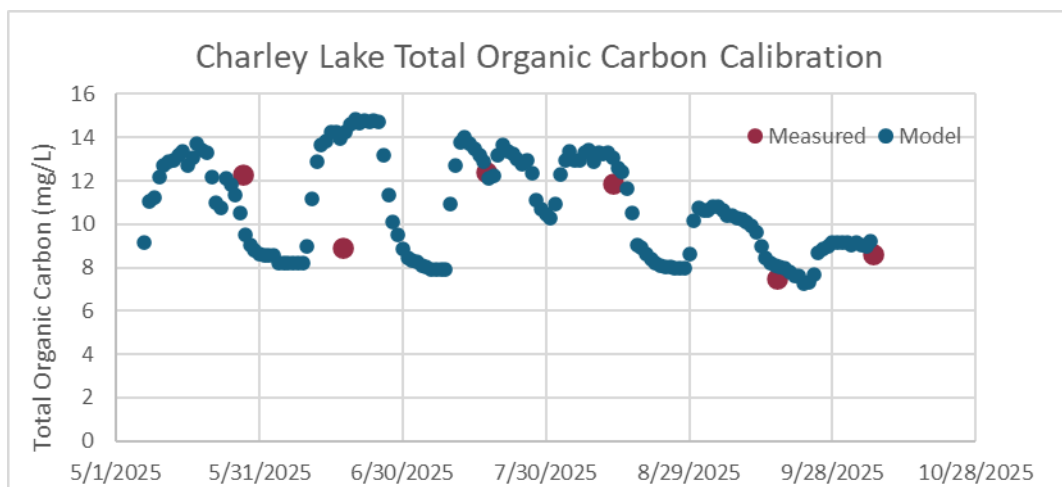


Figure A-7. Chlorophyll *a* calibration results for Charley, Pleasant, Sucker, East Vadnais, and White Bear Lake.



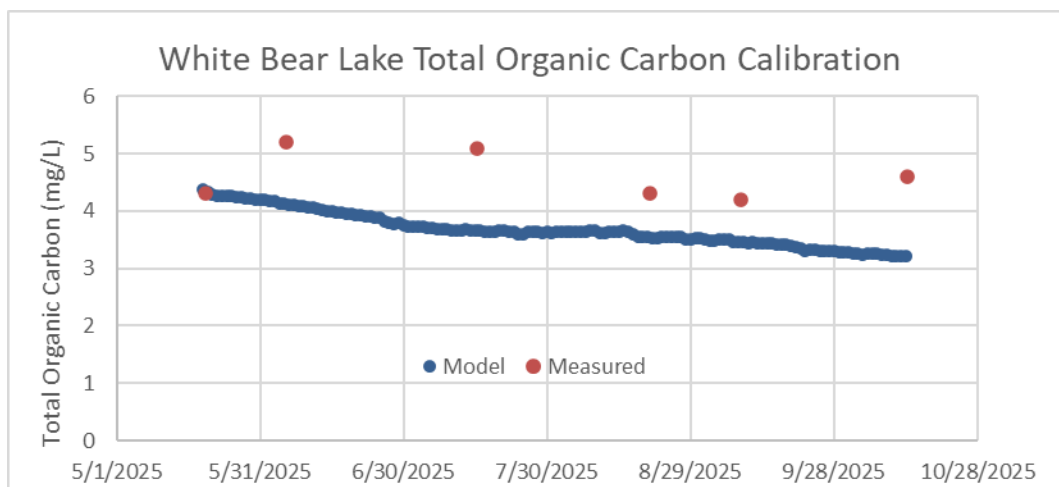
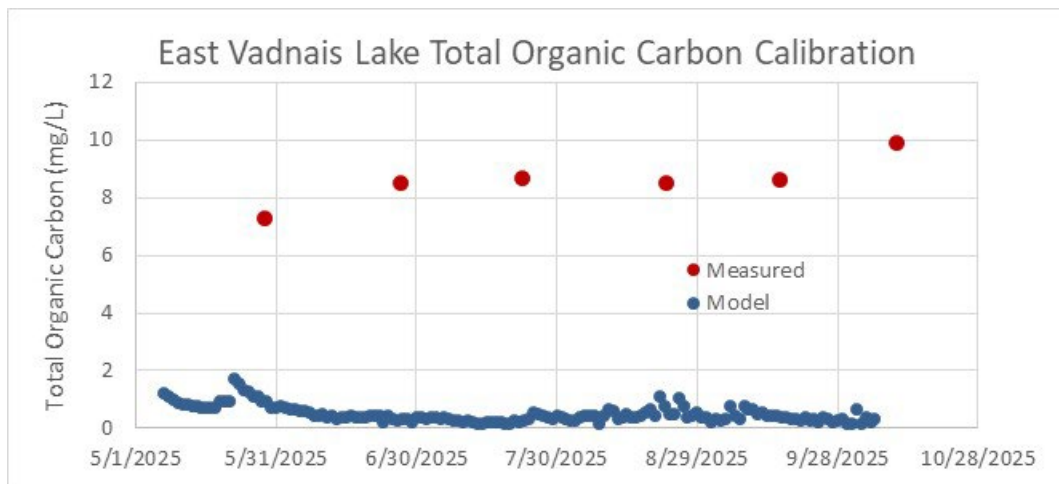


Figure A-8. Total organic carbon calibration results for Charley, Pleasant, Sucker, East Vadnais, and White Bear Lake.

Dissolved Oxygen

Dissolved oxygen is an important parameter as it can affect internal phosphorus loading and hence stimulate algal blooms if persistently low. Particular emphasis was placed on dissolved oxygen in Charley, Pleasant, and East Vadnais Lake. For Charley Lake, dissolved oxygen is important as organic inputs from the Mississippi River will have significant effect on the dissolved oxygen in that lake which will in turn could affect downstream lakes. Pleasant Lake and East Vadnais Lake have direct oxygen bubble injection systems operated by SPRWS that are designed to prevent internal loading phosphorus in those lakes.

Comparison of modeled and measured surface concentrations in Charley Lake is provided in Figure A-9. There is generally good agreement between modeled and measured values showing that the model is accurately representing processes that affect dissolved oxygen, including sediment oxygen demand, algal growth and respiration, and decay of organic matter in the water column.

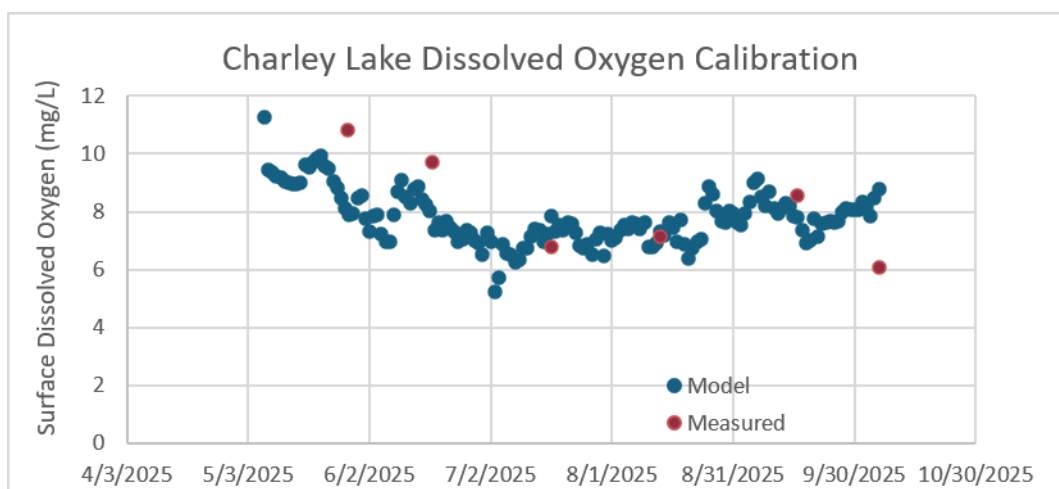


Figure A-9. Dissolved oxygen (surface) calibration results for Charley Lake.

Dissolved oxygen was calibrated in Pleasant Lake and East Vadnais Lake by comparing modeled and measured concentrations from the surface to the bottom of the lake in order to evaluate the operation of the oxygenation systems in these lakes (Figure A-10, Figure A-11).

For Pleasant Lake, initial runs included direct-oxygen mass addition to the west and east bay in accordance with the oxygen loading data provided by SPRWS and the location of the main injection sites. This resulted in model-predicted dissolved oxygen concentrations that were significantly greater than measured values. Based on the 2025 monitored oxygen profile data for Pleasant Lake (both east and west), much of the hypolimnion of the lake in both the east and west locations of the lake is anoxic for the summer months (usually below 1 mg/L or at 0 mg/L). SPRWS completed work on the system in June 2025 (including repair to a cut line near the shore and cleaning of the diffusers) so the oxygenation system was likely not operational/poorly functioning during the first part of the 2025 season. However, the monitoring data also suggests the dissolved oxygen levels in both the east and west stations in the lake remained very low/anoxic throughout the summer. For

calibration, the aeration system was either not working properly in Pleasant Lake and not delivering the oxygen as expected to the hypolimnion or the sediment oxygen demand is so high that the current DO application is not providing sufficient dosing. As a result, for the 2025 model calibration proceeded without the addition of oxygen in the Pleasant Lake model.

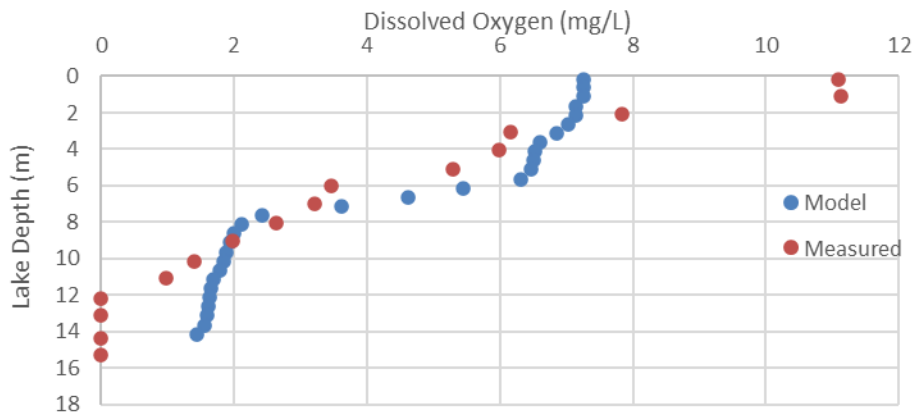
For East Vadnais Lake, direct oxygen aeration was included in the model for the north and south deep holes of East Vadnais Lake based on the location of system. The mass of oxygen added in the East Vadnais model was applied at rates informed by the dosing data provided by SPRWS (see Table A-7). Missing data in August was linearly estimated from July and September data.

Dissolved oxygen profiles for modeled and measured values for East Vadnais Lake show the effect of oxygen injection in the north and south deep holes. The model is not designed to simulate the effect of pure oxygen bubbles which are added at the lake bottom and then rise and dissolve while traveling upward in the water column. This has the effect of less oxygen addition to the bottom waters and more oxygen addition to waters mid-depth on the hypolimnion. A model work-around was implemented where oxygen was injected in the model at a range of depths in the hypolimnion to simulate the bubble plume dissolution process. Sediment oxygen demand is likely higher at the lake bottom, hence, the model is either under or over predicting dissolved oxygen on the lake bottom. Model results in August are likely most representative of the current effectiveness of the aeration system.

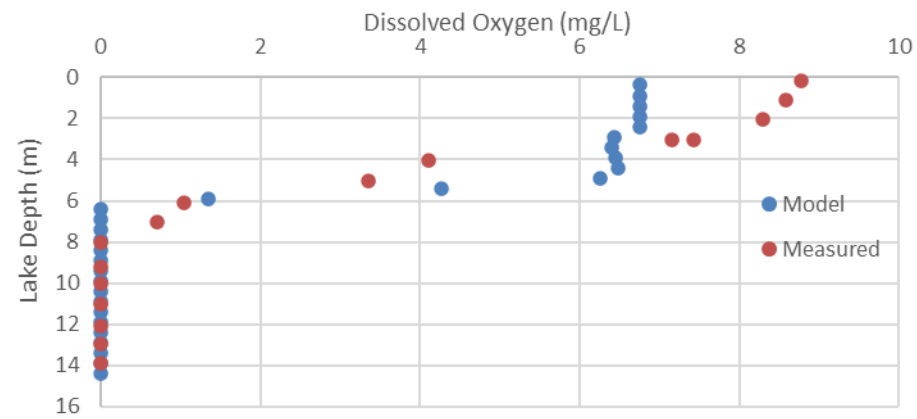
Table A-7. East Vadnais Lake 2025 oxygen usage data provided by the SPRWS and the calculated lake-wide daily oxygen injection rate used to inform the CE-QUAL-W2 model.

Month	Oxygen Usage	
	Pounds	kg/d
May	47081	689
June	42961	650
July	87353	1279
August	77293	1132
September	67233	1017
October	480	7

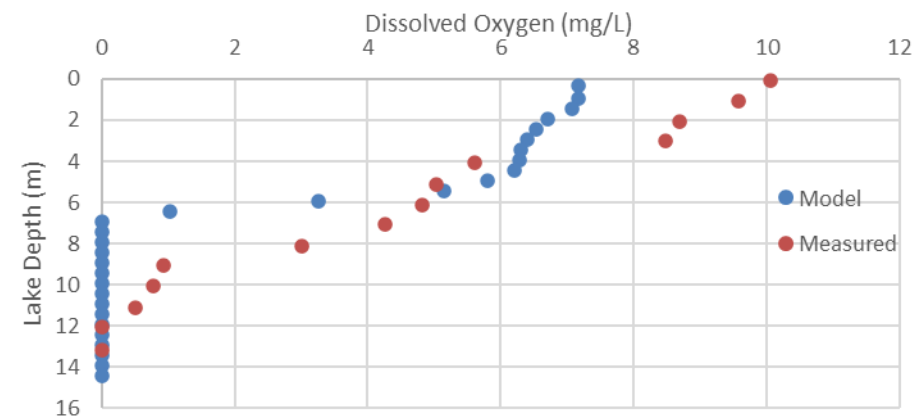
6/30/2025-West Pleasant Lake



7/18/2025-West Pleasant Lake



8/20/2025-West Pleasant Lake



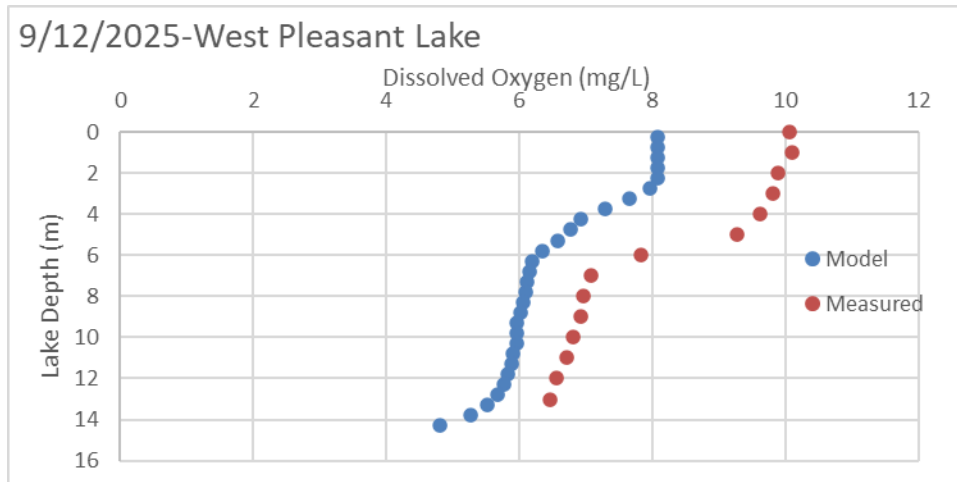
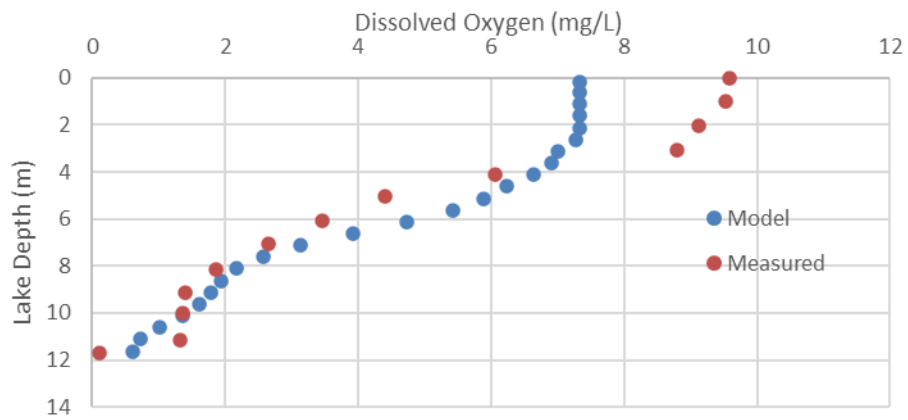
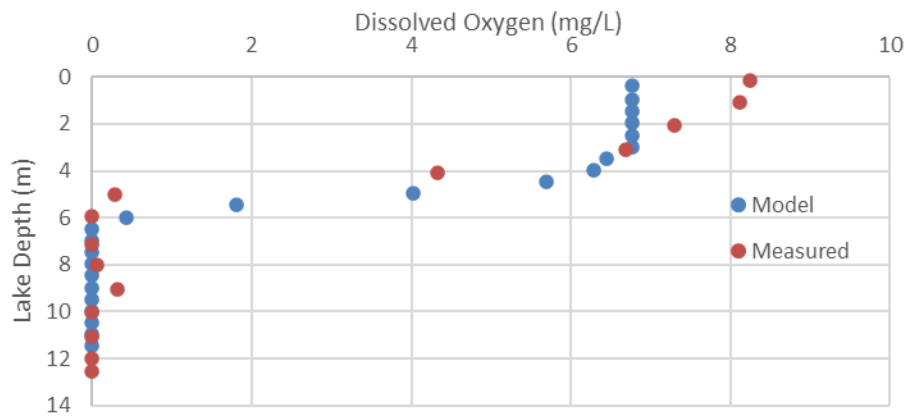


Figure A-10. Dissolved oxygen profiles for modeled and measured data for West Pleasant Lake.

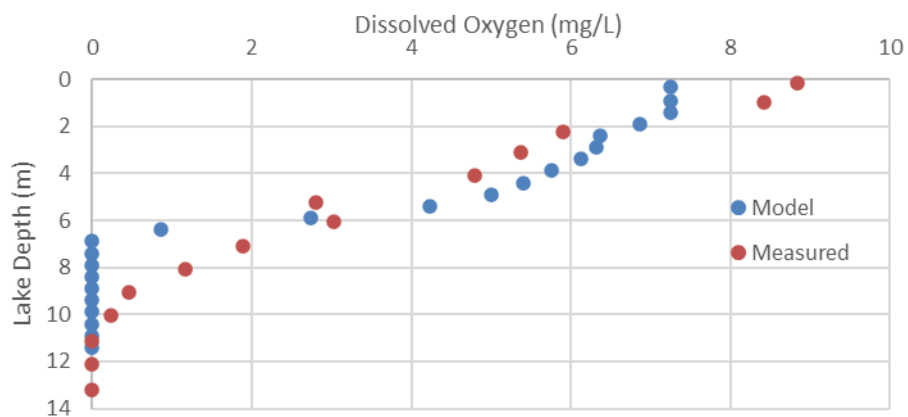
6/30/2025-East Pleasant Lake



7/18/2025-East Pleasant Lake



8/20/2025-East Pleasant Lake



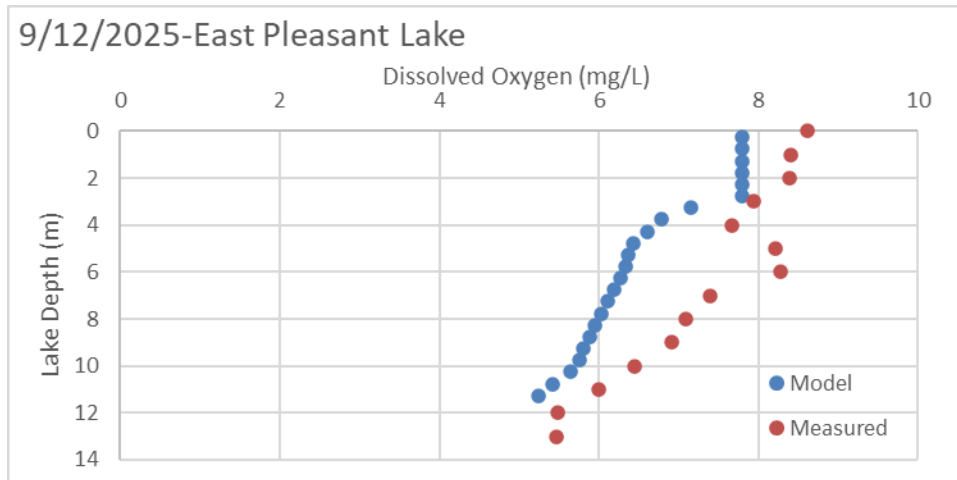
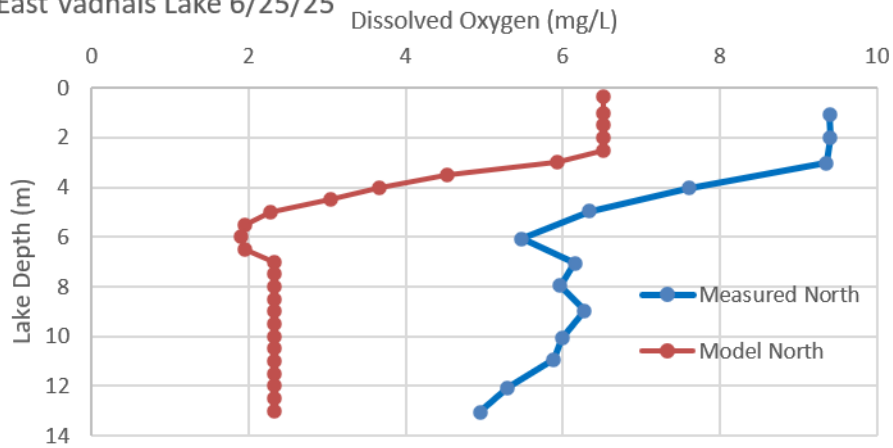
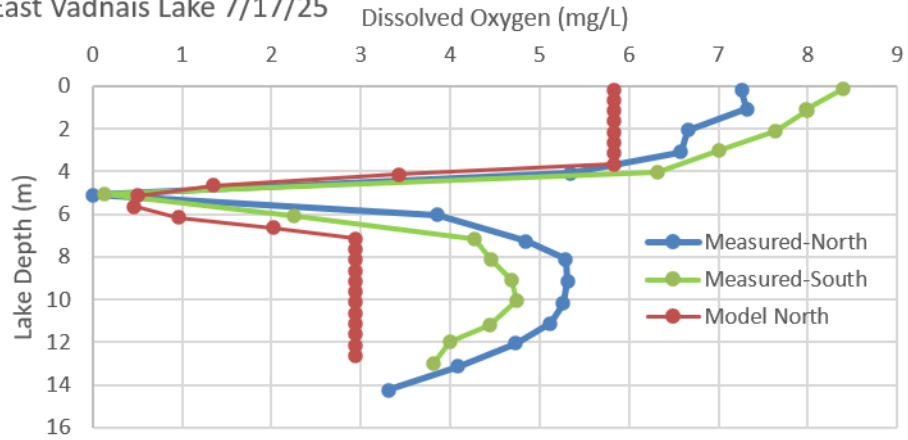


Figure A-11. Dissolved oxygen profiles for modeled and measured data for East Pleasant Lake.

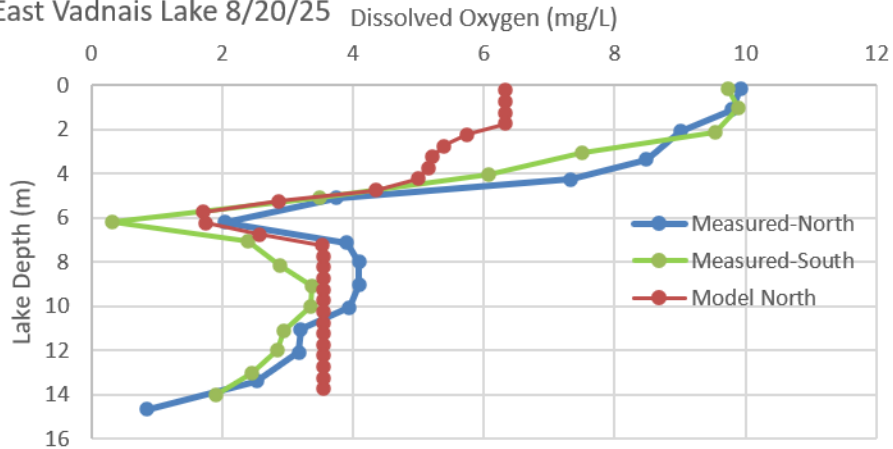
East Vadnais Lake 6/25/25



East Vadnais Lake 7/17/25



East Vadnais Lake 8/20/25



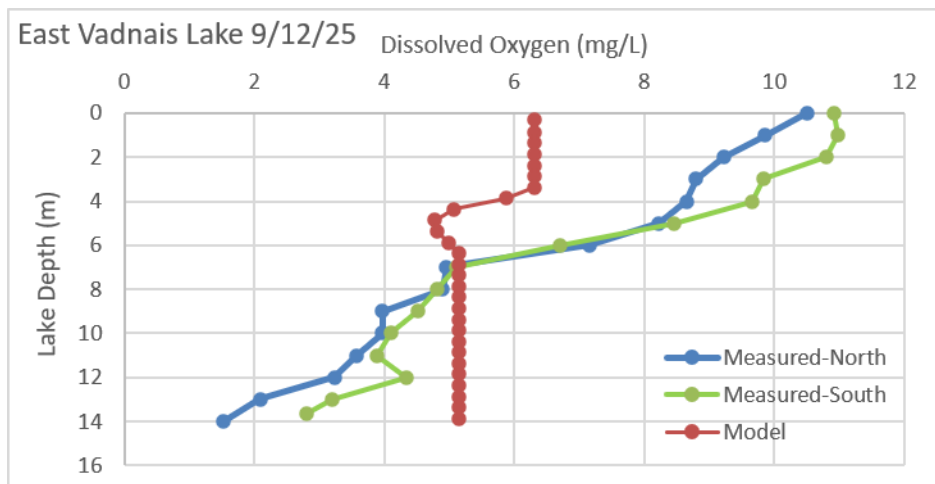


Figure A-12. Dissolved oxygen profiles for modeled and measured data for North East Vadnais Lake.

Model Calibration Summary

Based on the calibration using the best available 2025 data, the CE-QUAL-W2 model is an appropriate tool that can be used to evaluate the effect of future flow and load scenarios as part of Study 7A to understand the lake eutrophication response as a function of these flows and loads. The model can be used to accurately predict the effect of external and internal phosphorus and nitrogen loads on in-lake concentrations of phosphorus and nitrogen. The calibration for chlorophyll *a* was reasonably accurate for Charley, Pleasant, Sucker, and Vadnais, and highly accurate for White Bear. The highly manipulated lake system for the SPRWS chain of lakes, which included iron addition and oxygen injection created some challenges for the calibration of chlorophyll *a*. However, the effect of potential nutrient loads from augmentation from Sucker or East Vadnais to White Bear Lake on nutrient response and the resulting phytoplankton growth in White Bear Lake will be well represented by the calibrated CE-QUAL-W2 model for White Bear Lake.

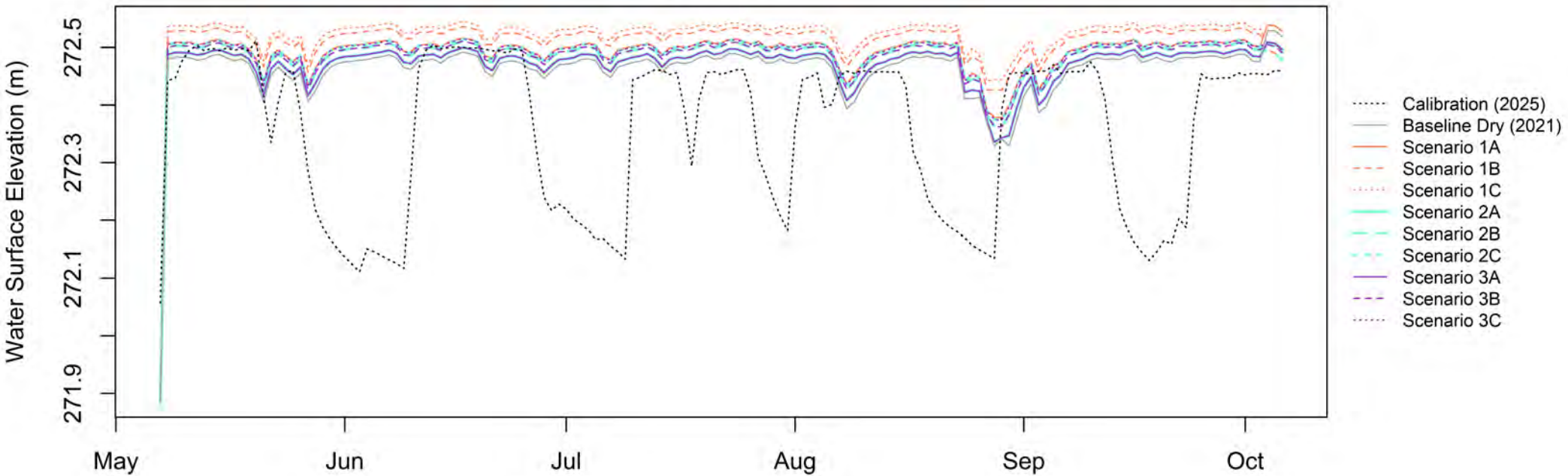


Appendix 6

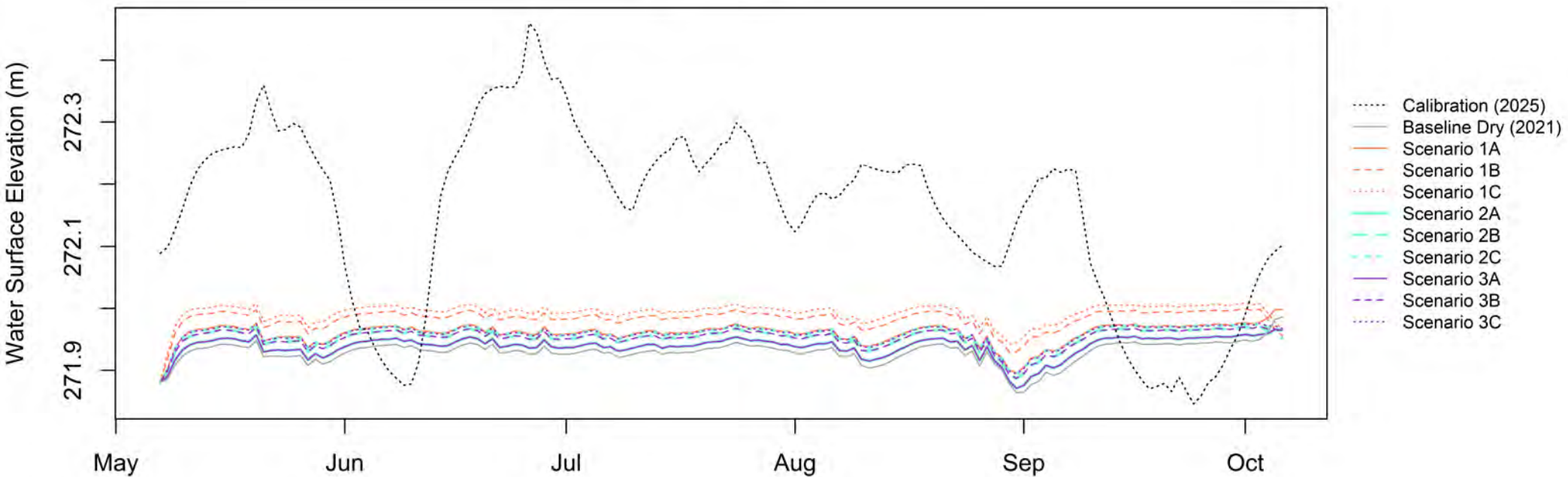
Scenario Evaluation Results (CE-QUAL-W2)



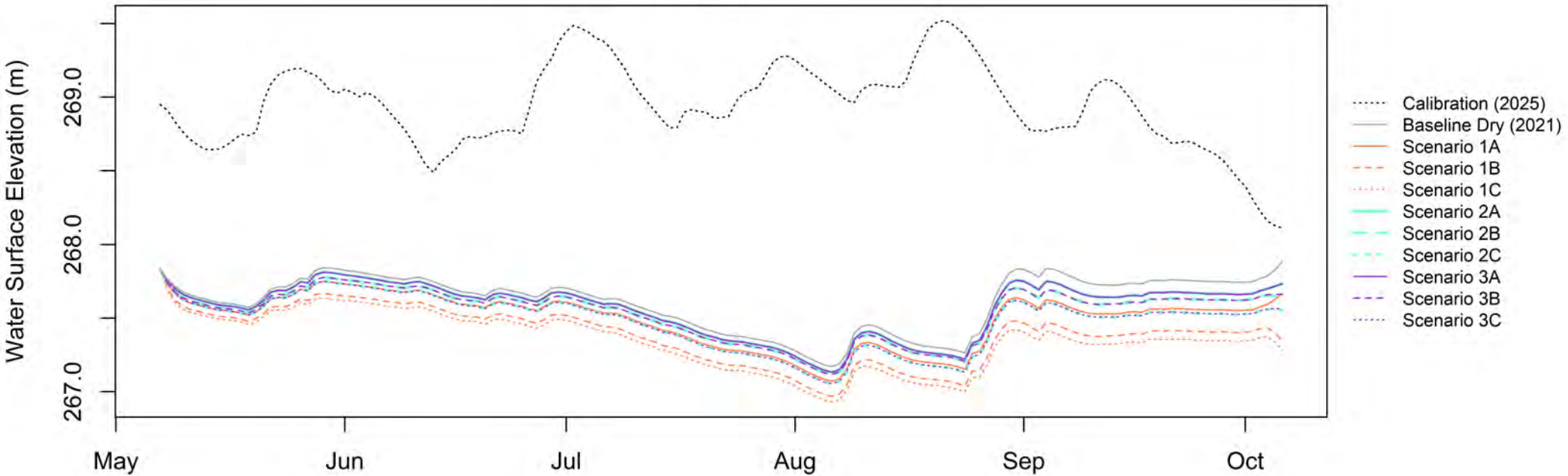
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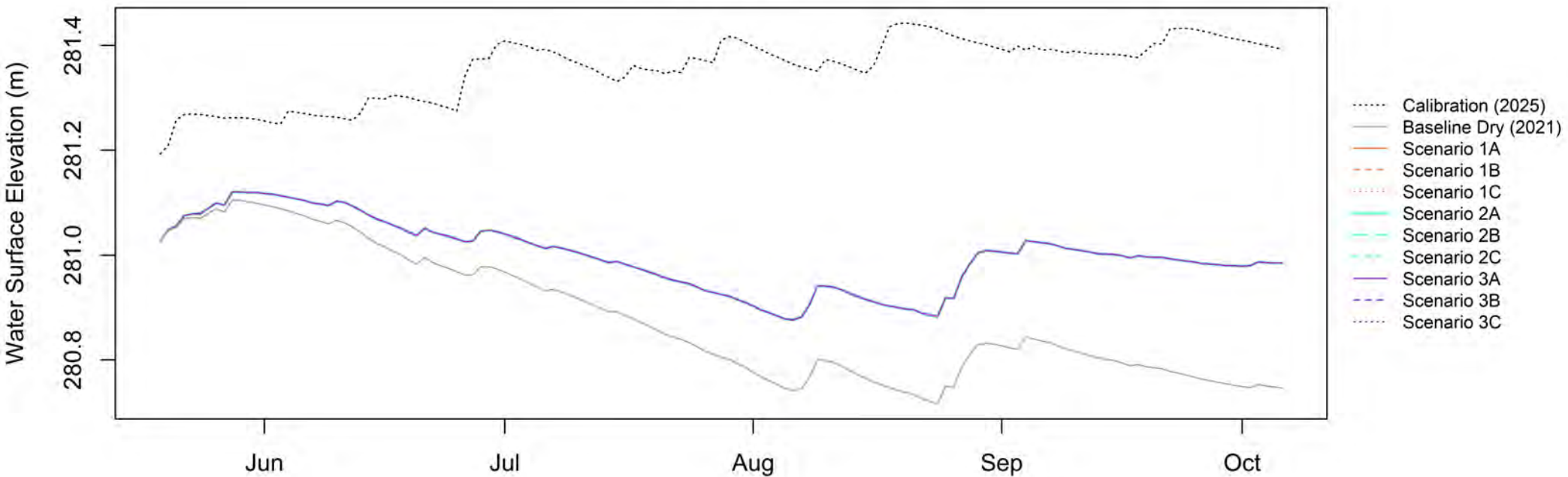
pleasant



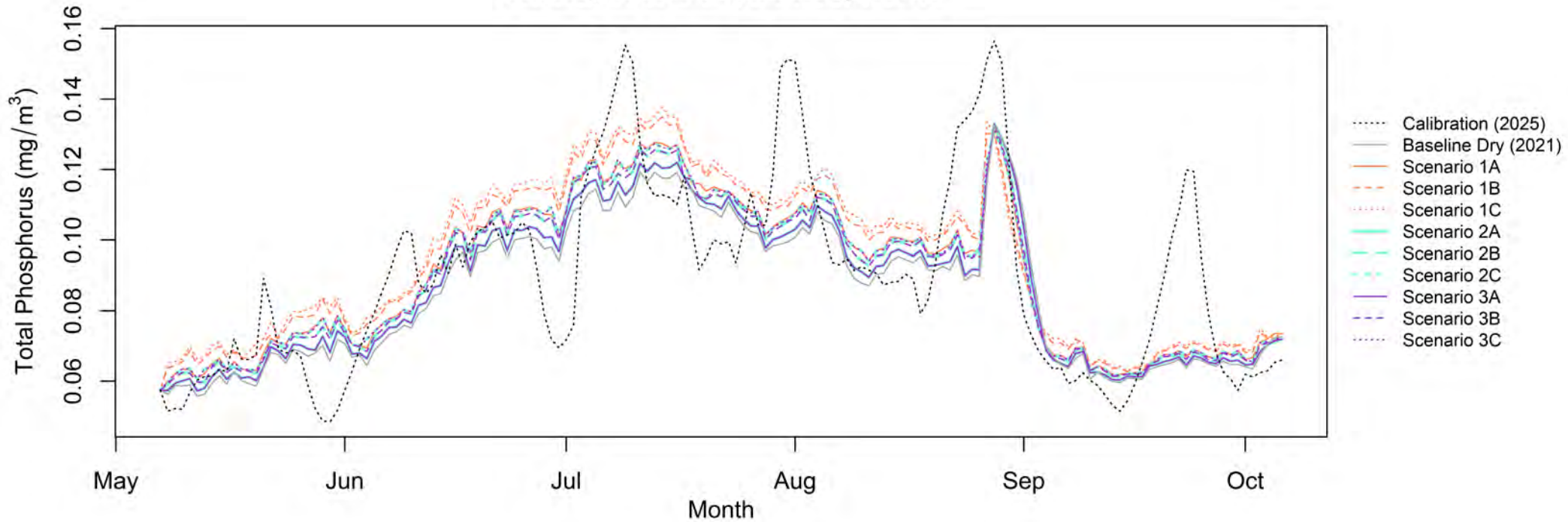
sucker_vadnais



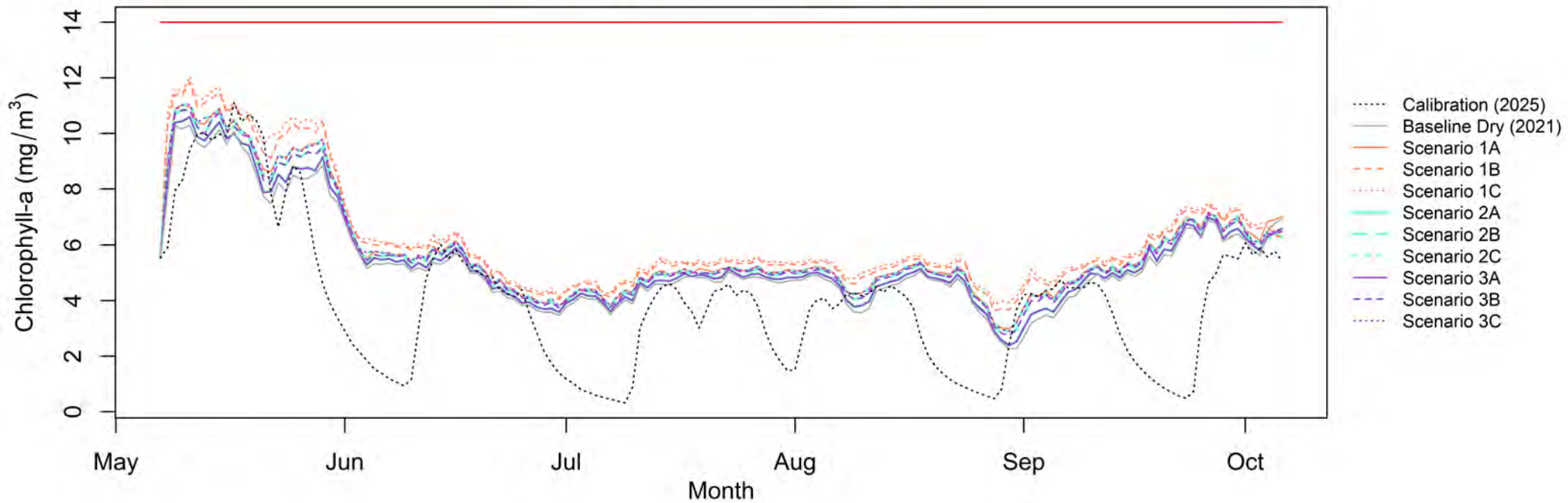
whitebear



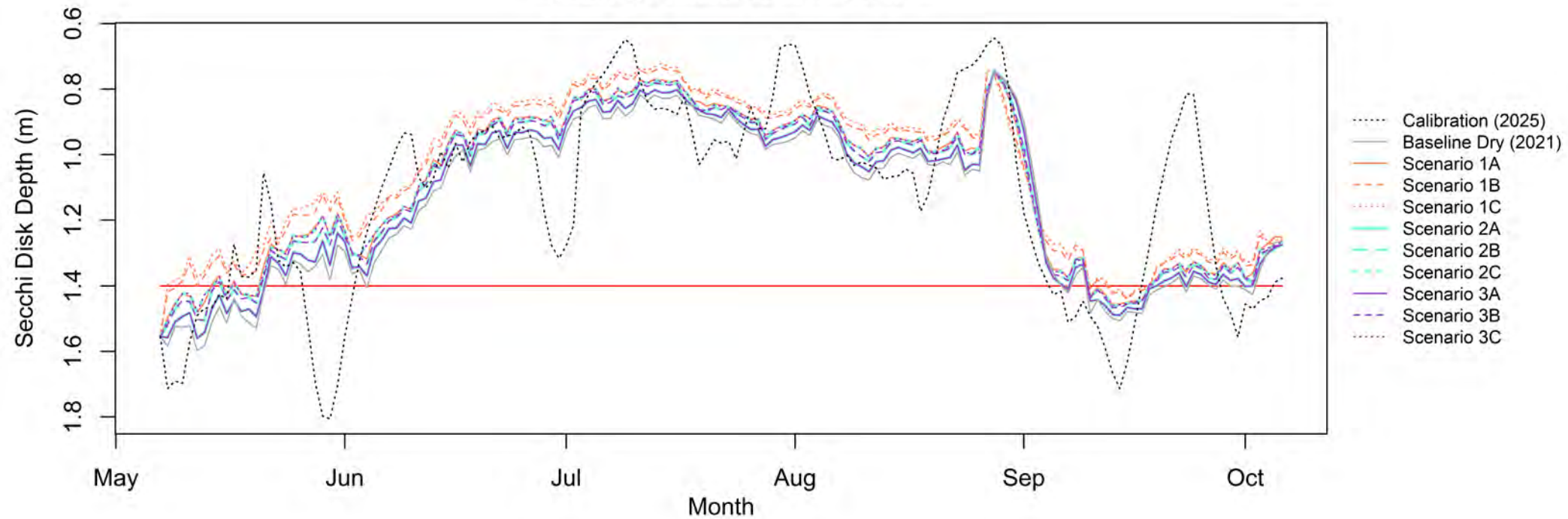
Charley Lake: Total Phosphorus



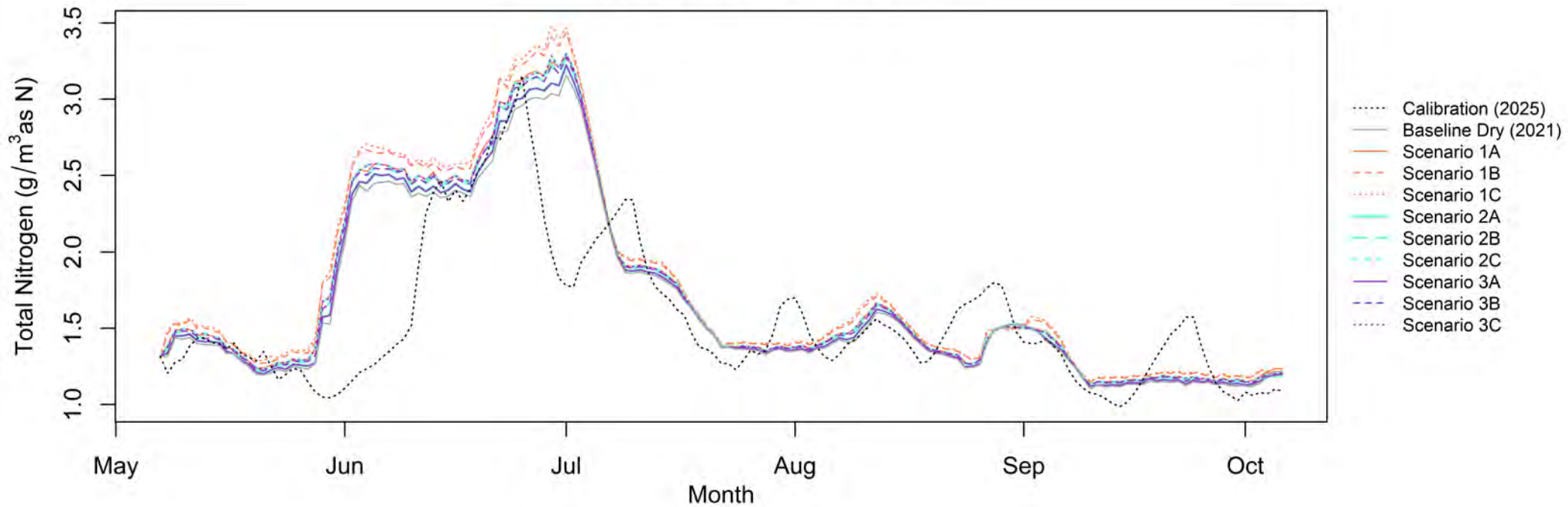
Charley Lake: Chlorophyll-a



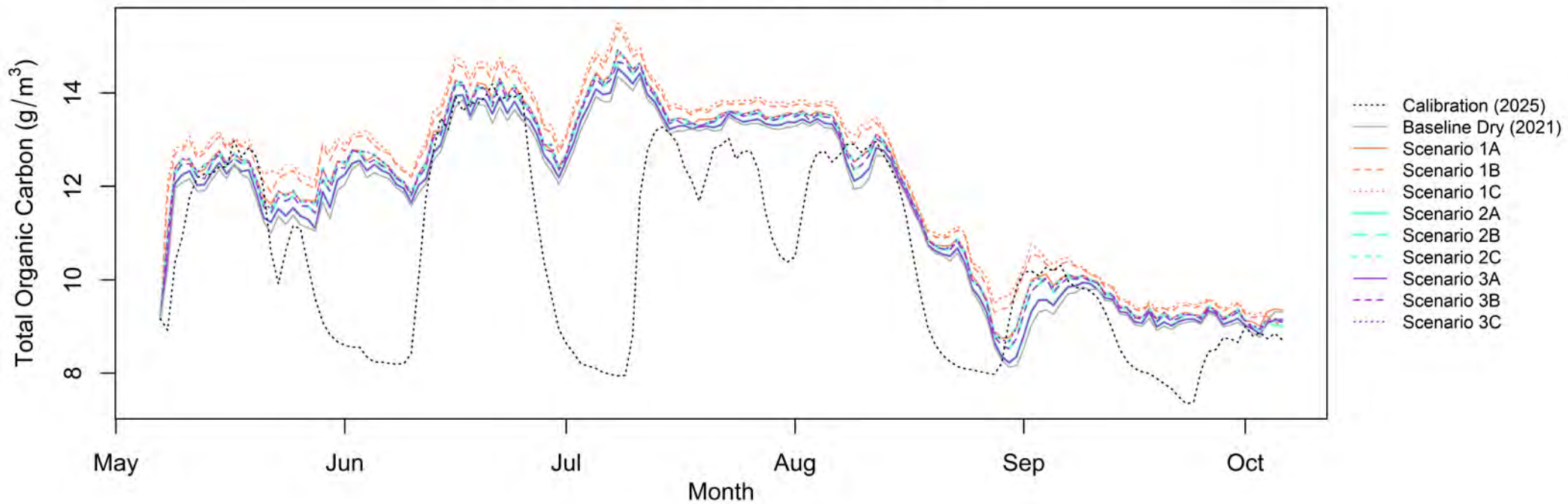
Charley Lake: Secchi Disk



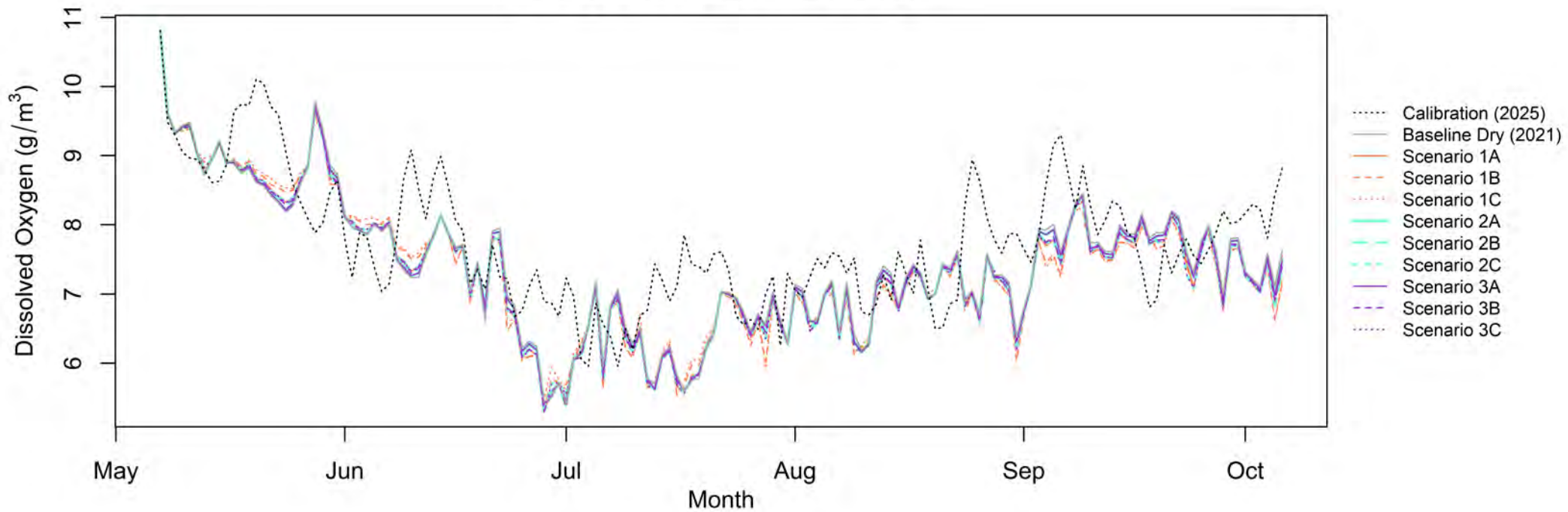
Charley Lake: Total Nitrogen



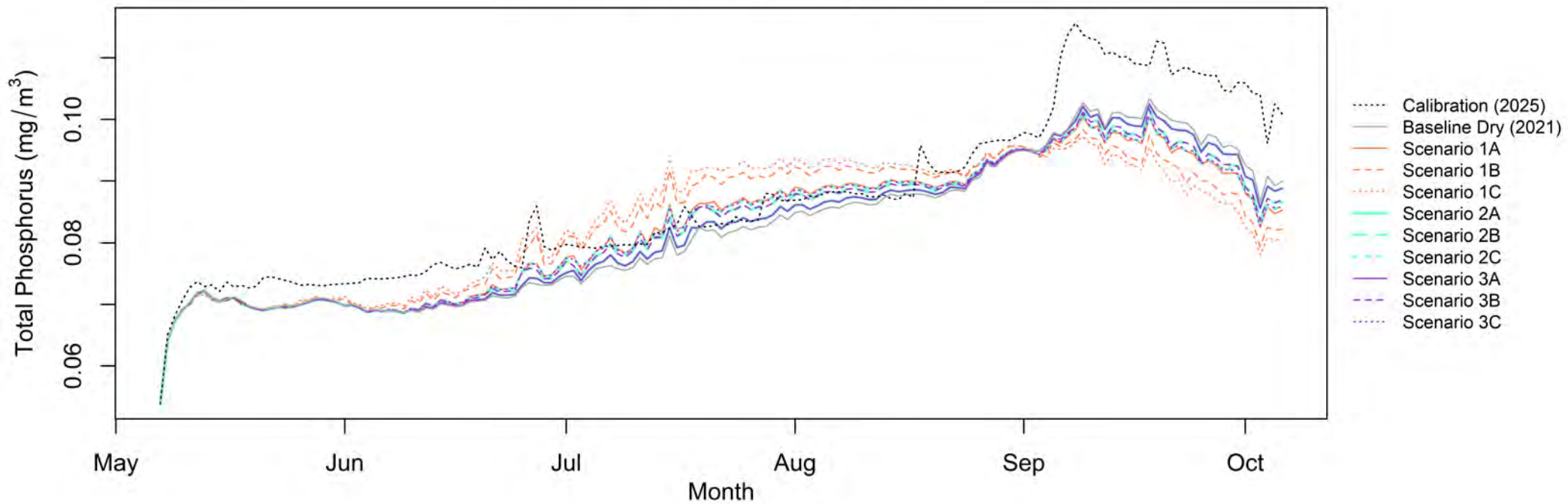
Charley Lake: Total Organic Carbon



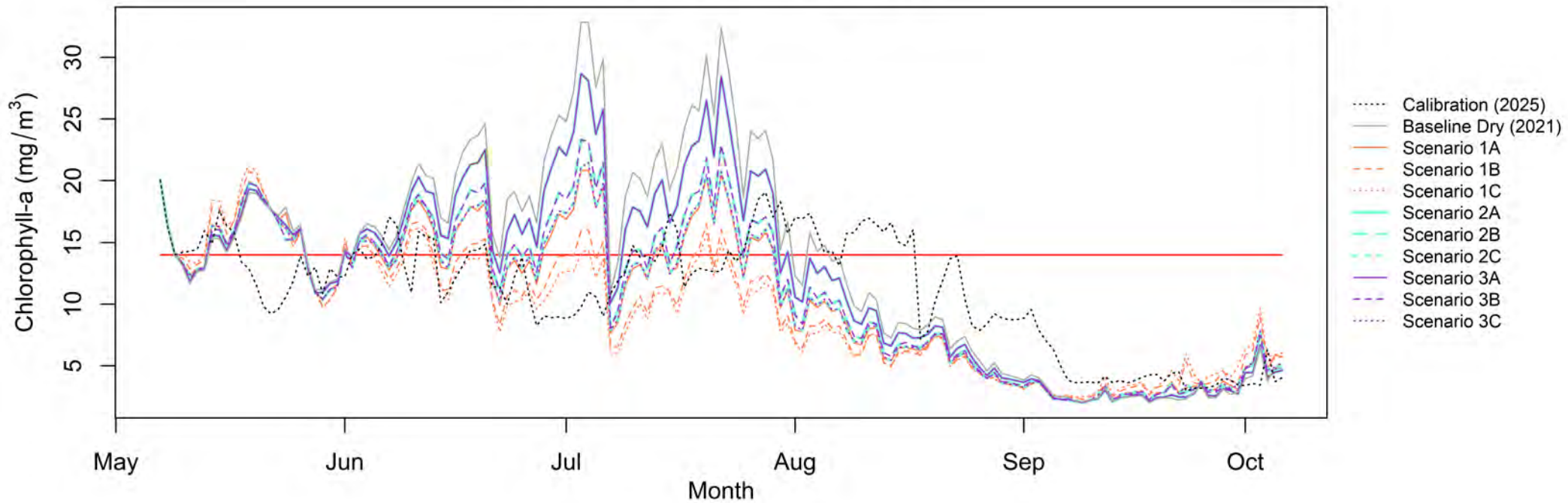
Charley Lake: Dissolved Oxygen



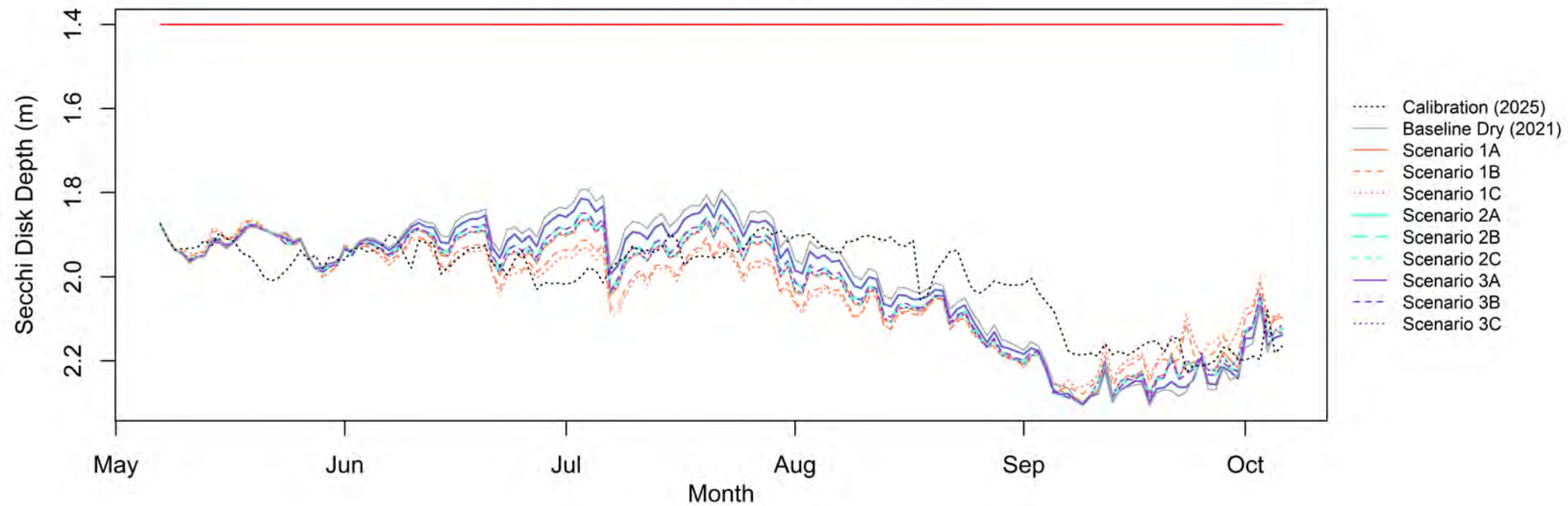
Pleasant Lake: Total Phosphorus



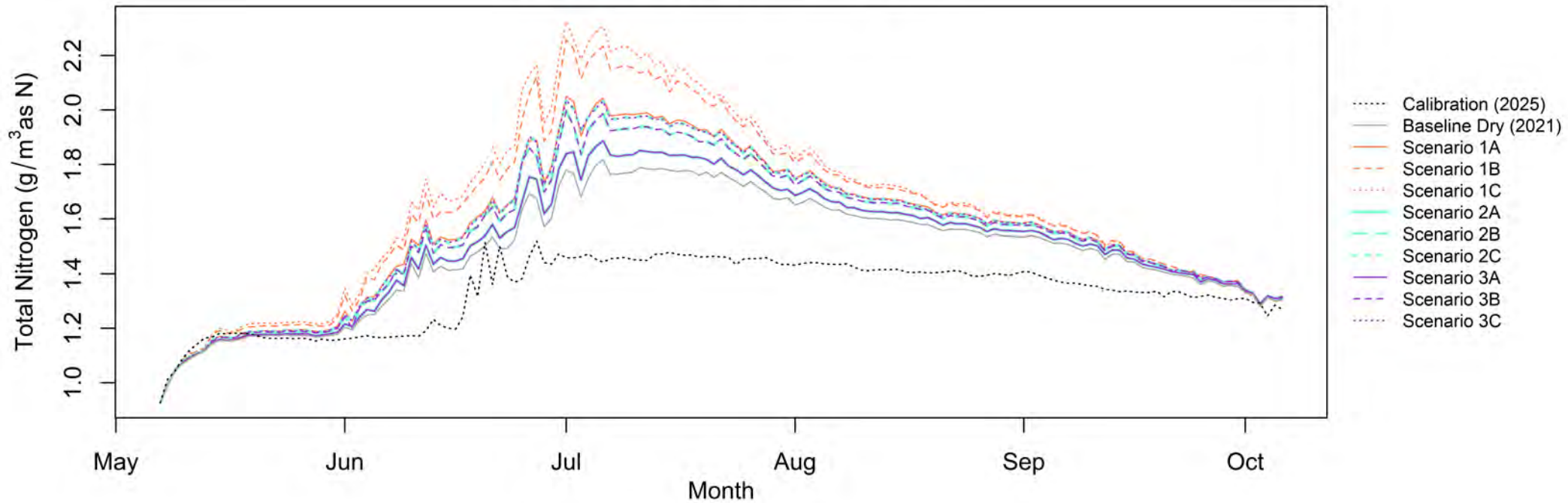
Pleasant Lake: Chlorophyll-a



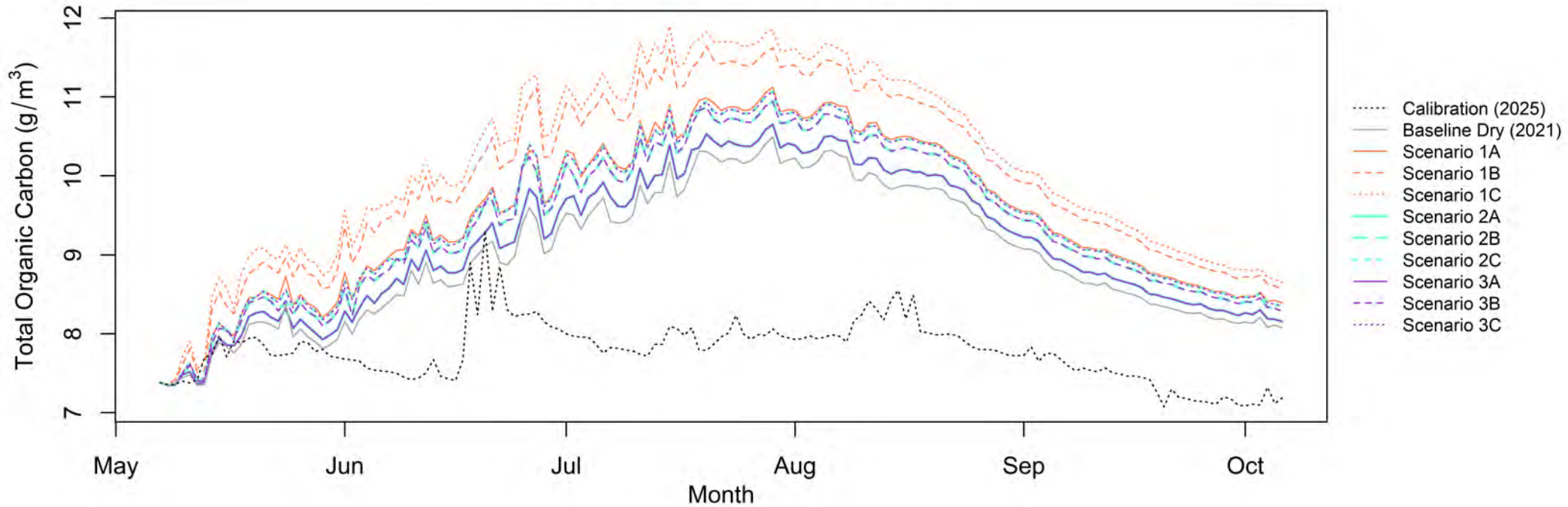
Pleasant Lake: Secchi Disk



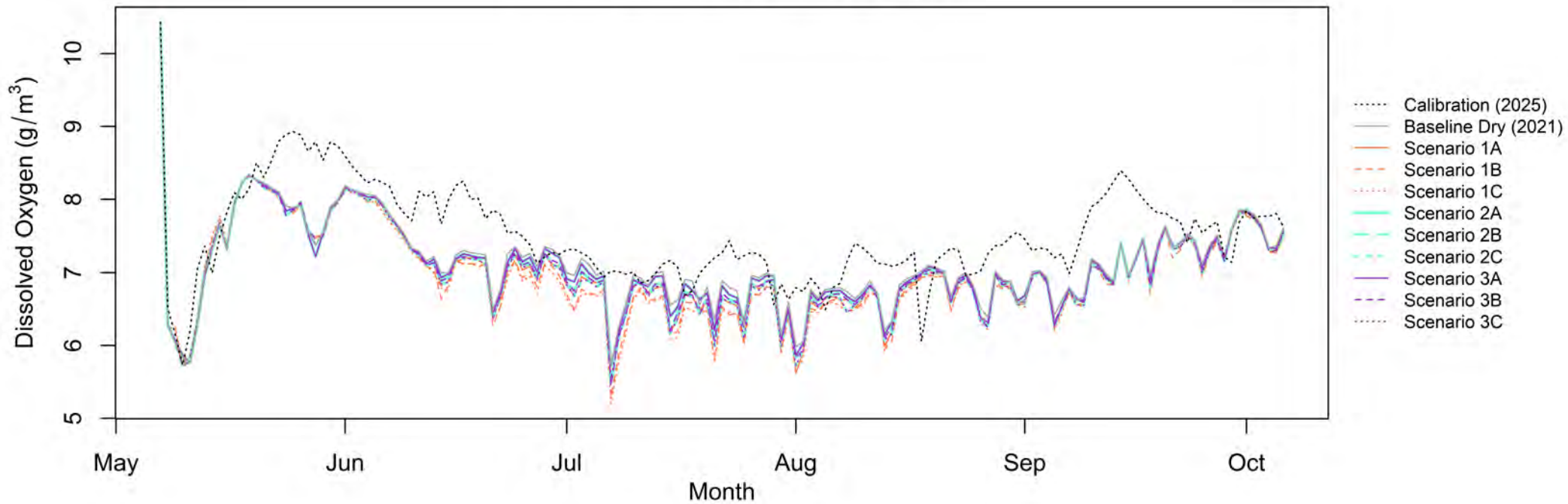
Pleasant Lake: Total Nitrogen



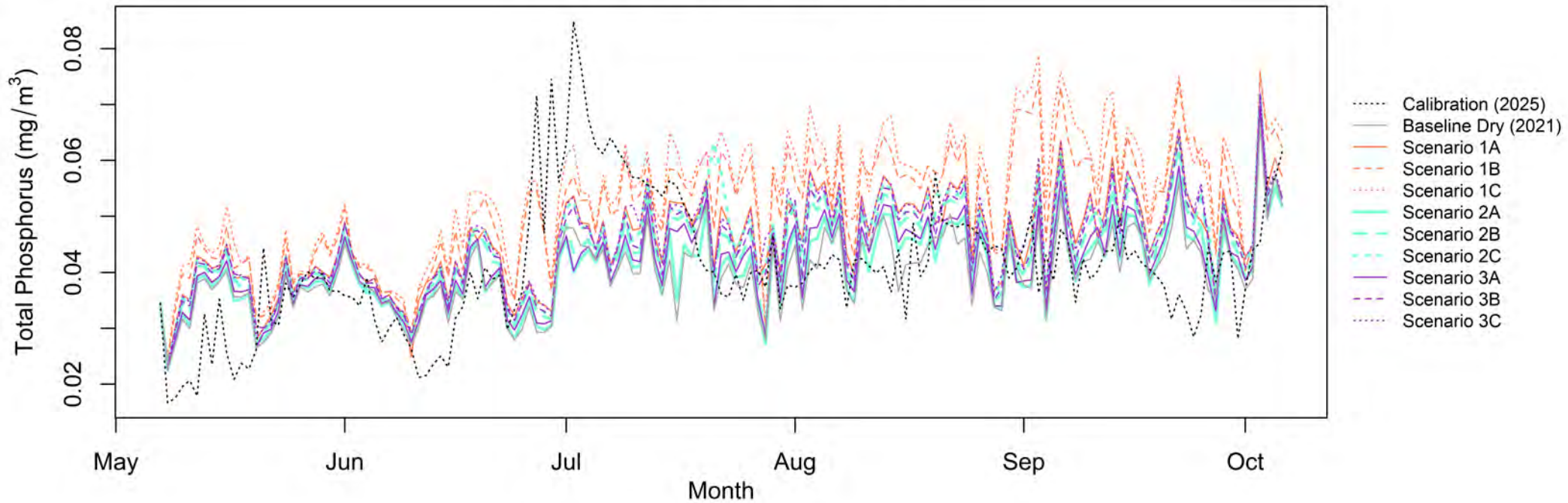
Pleasant Lake: Total Organic Carbon



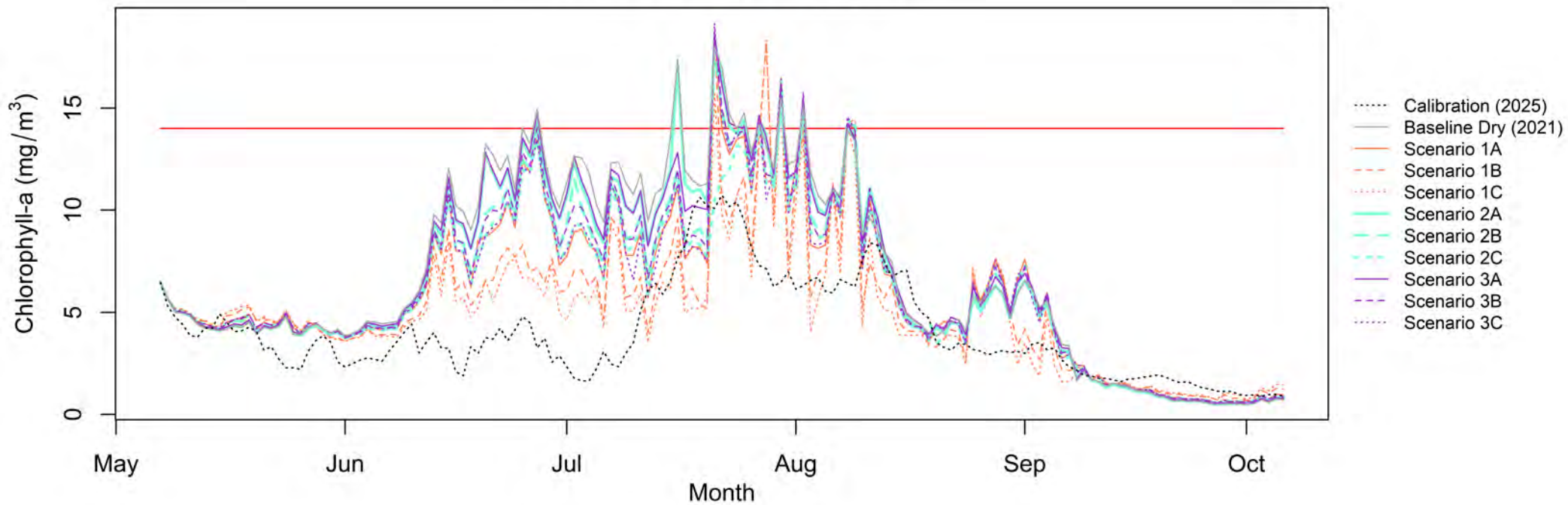
Pleasant Lake: Dissolved Oxygen



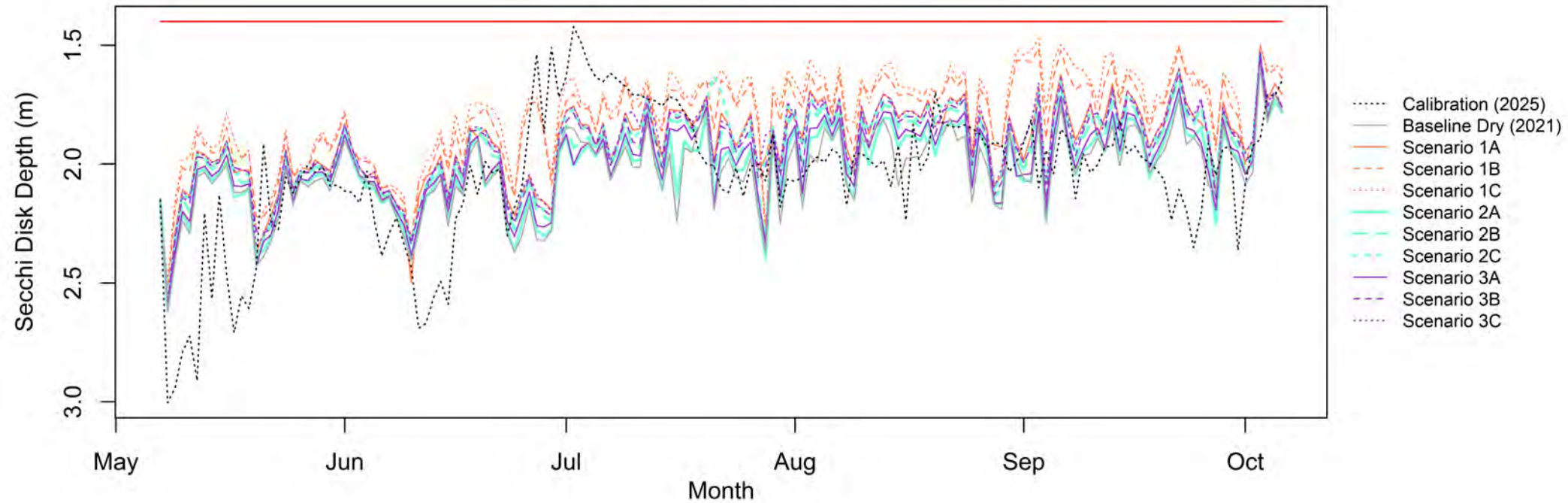
Sucker Lake: Total Phosphorus



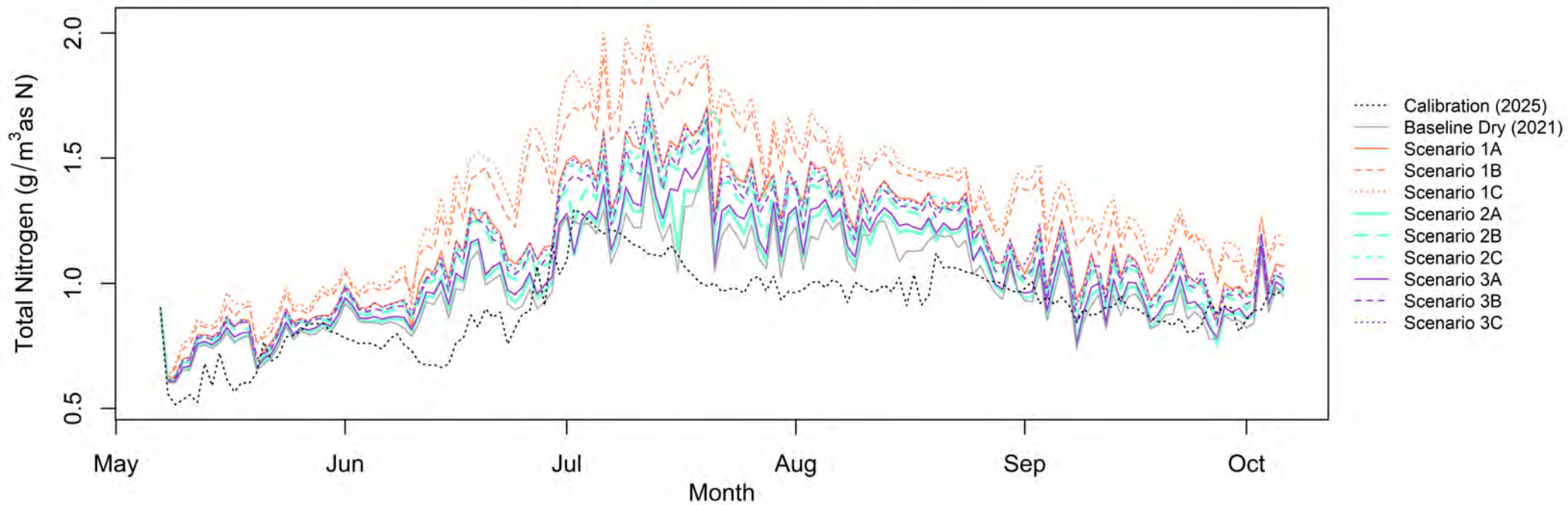
Sucker Lake: Chlorophyll-a



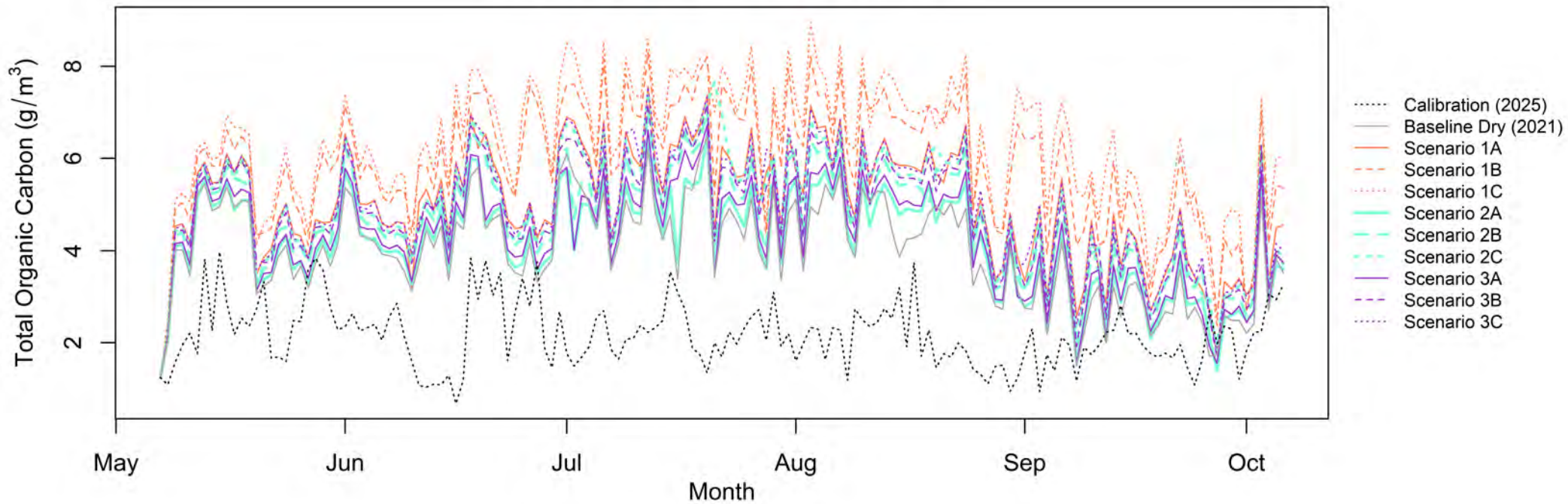
Sucker Lake: Secchi Disk



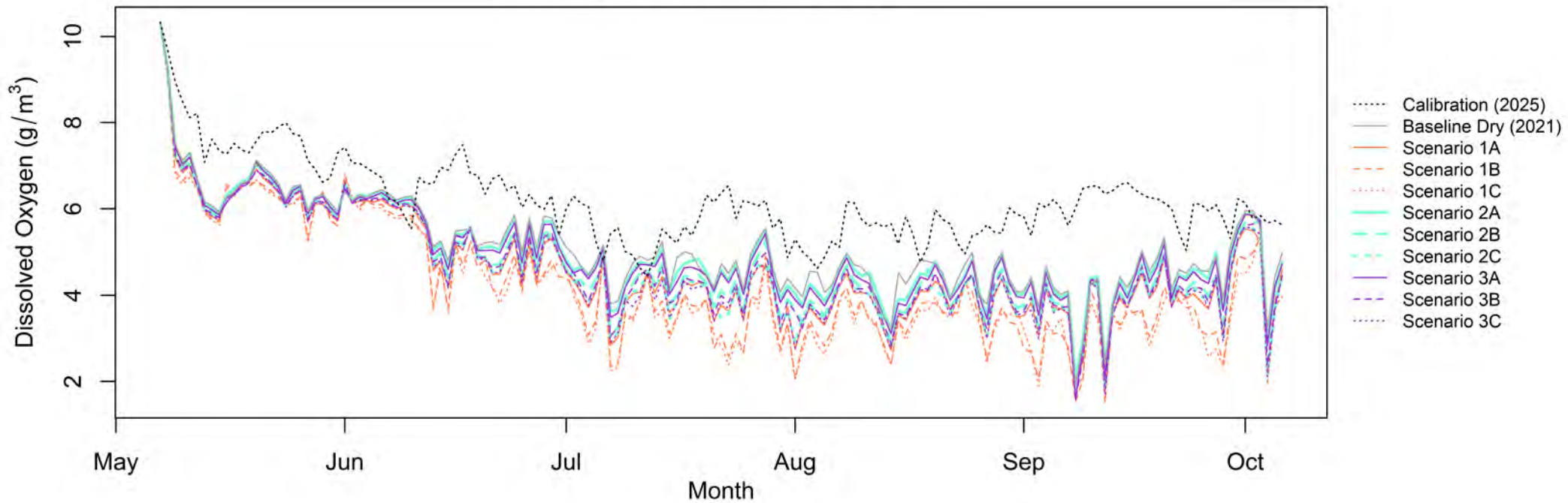
Sucker Lake: Total Nitrogen



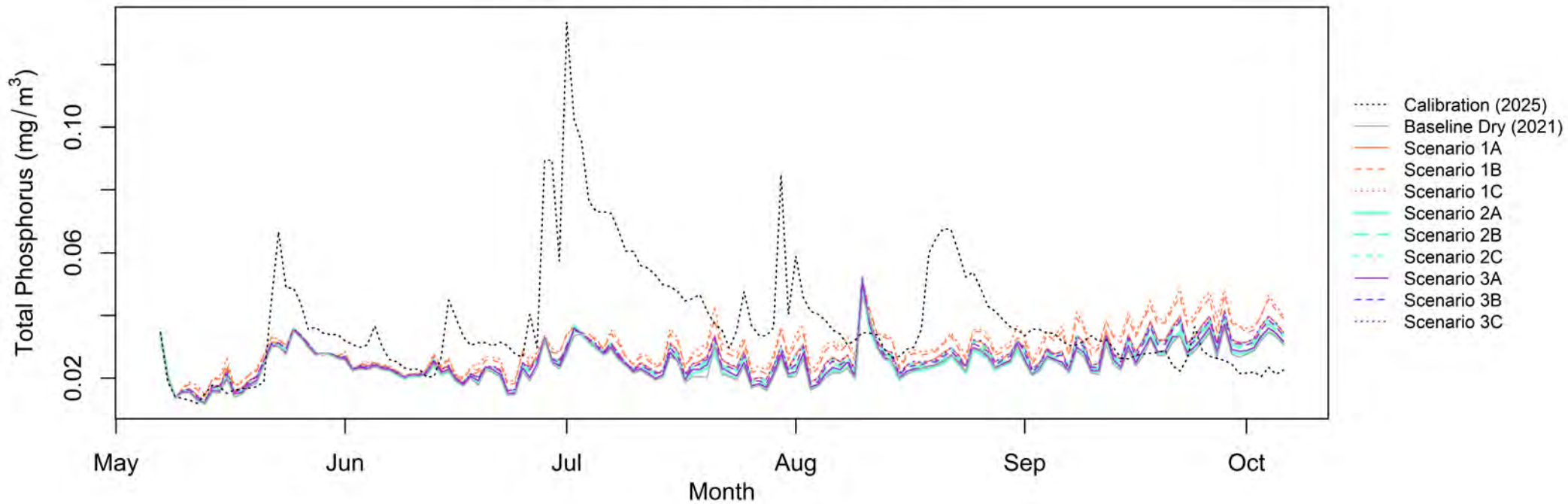
Sucker Lake: Total Organic Carbon



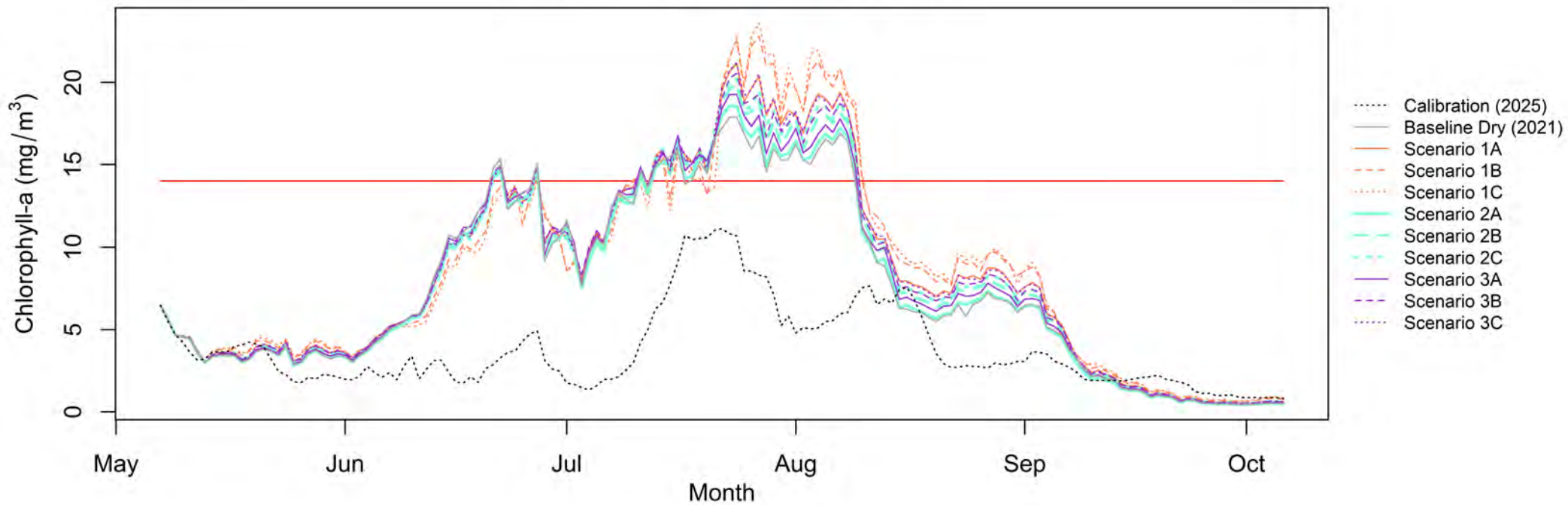
Sucker Lake: Dissolved Oxygen



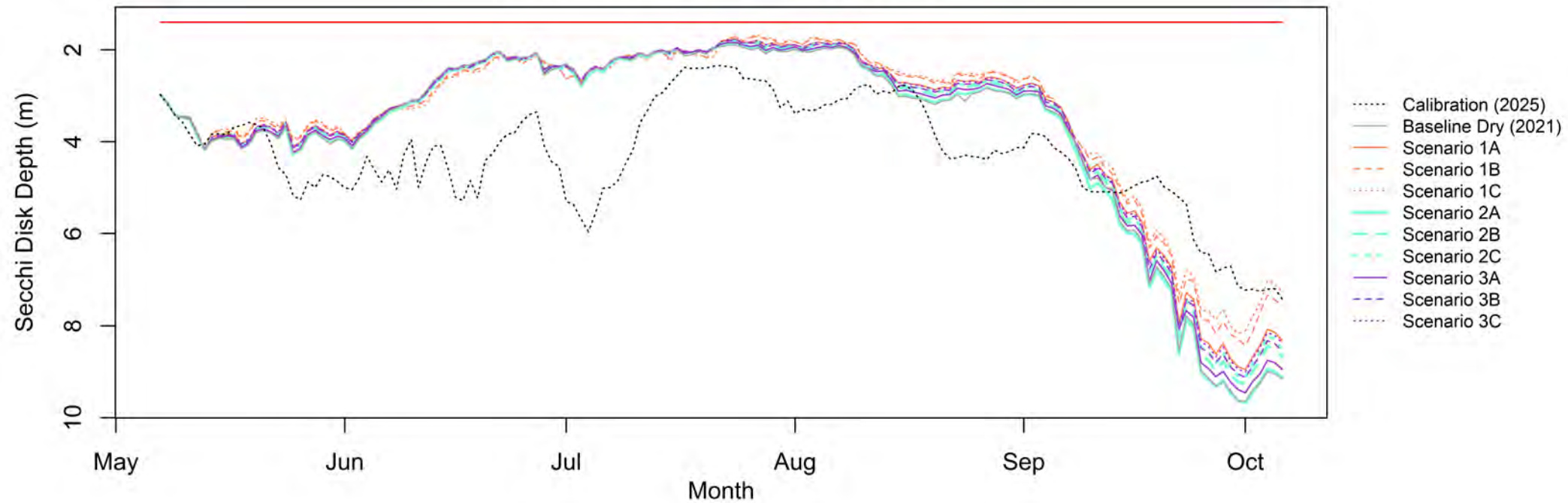
East Vadnais Lake: Total Phosphorus



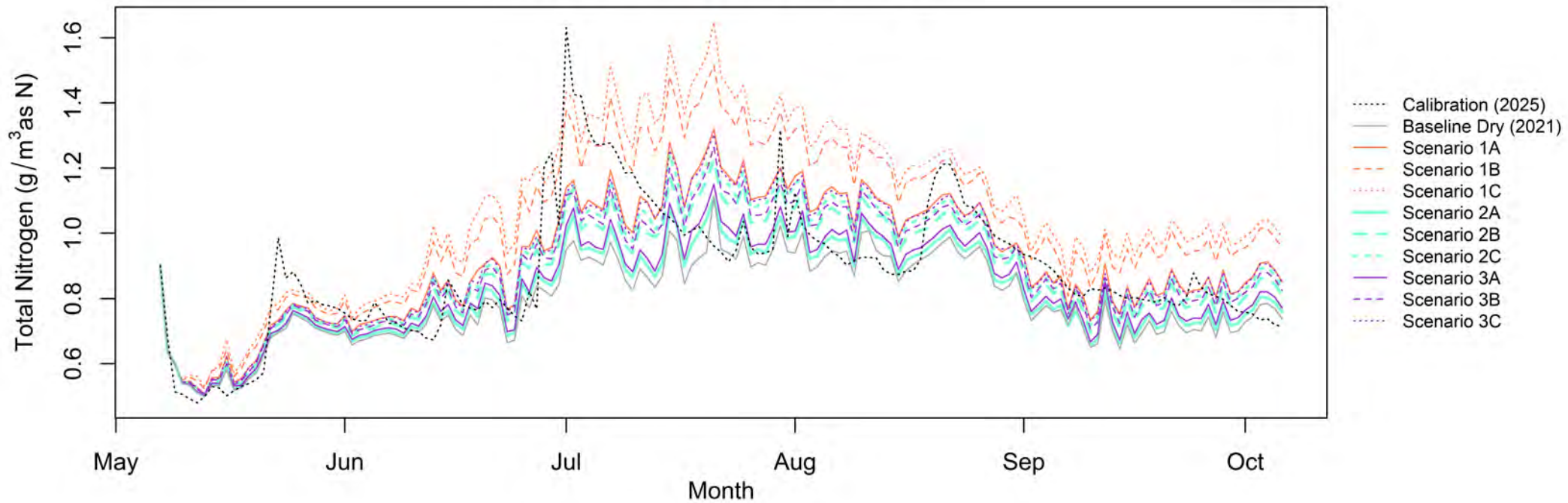
East Vadnais Lake: Chlorophyll-a



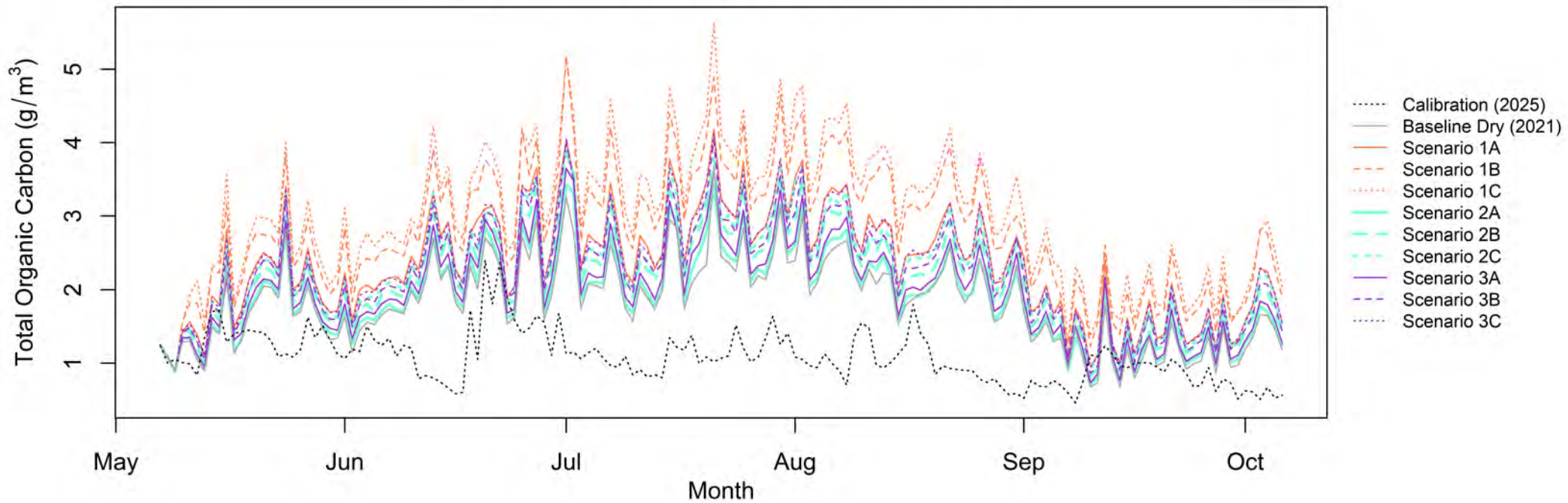
East Vadnais Lake: Secchi Disk



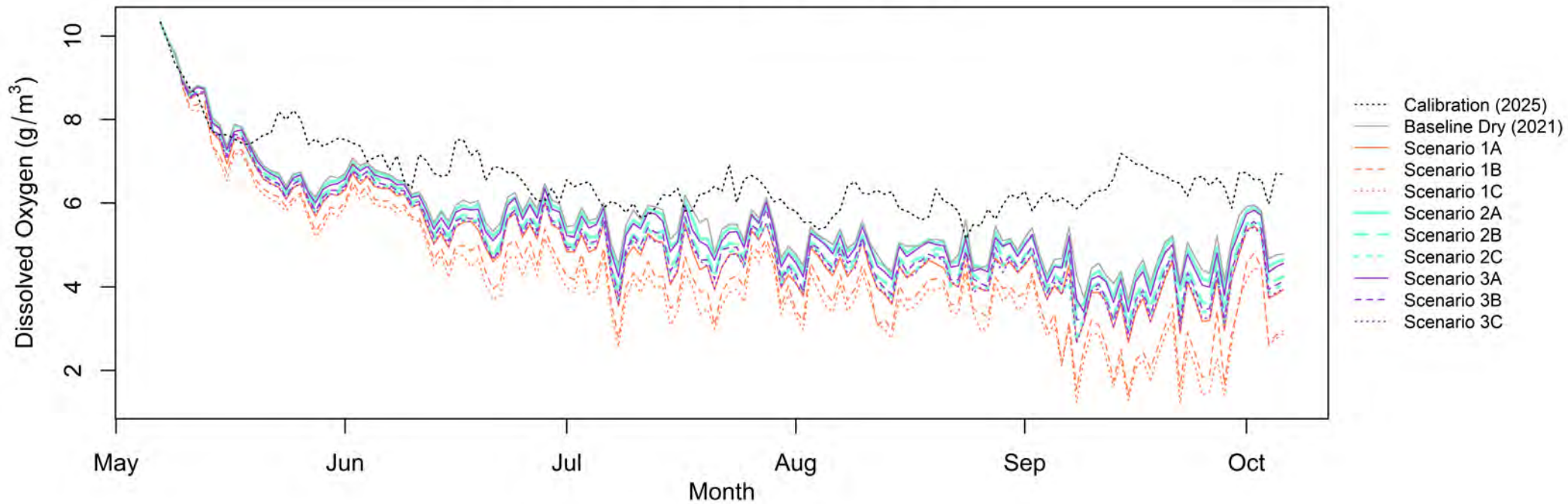
East Vadnais Lake: Total Nitrogen



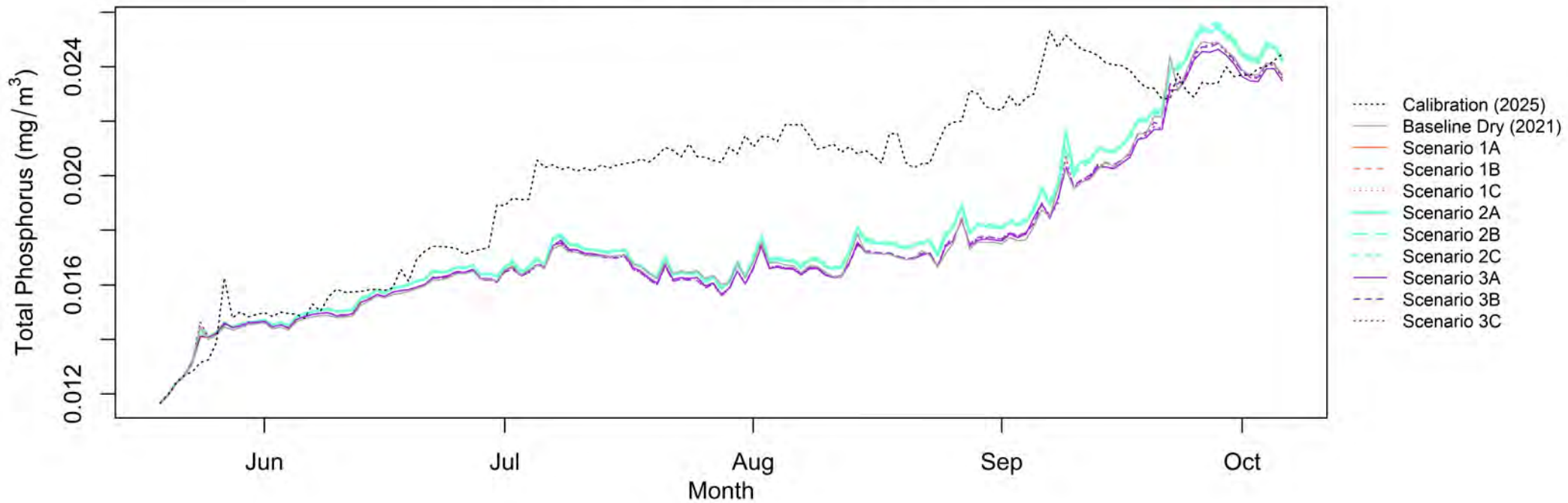
East Vadnais Lake: Total Organic Carbon



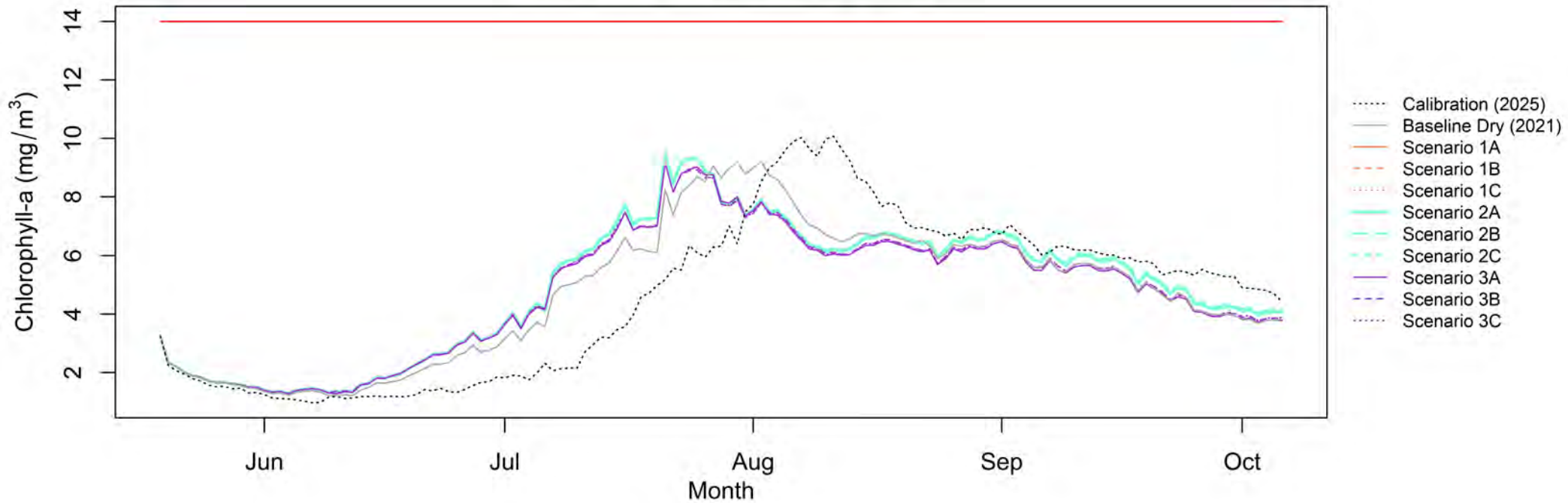
East Vadnais Lake: Dissolved Oxygen



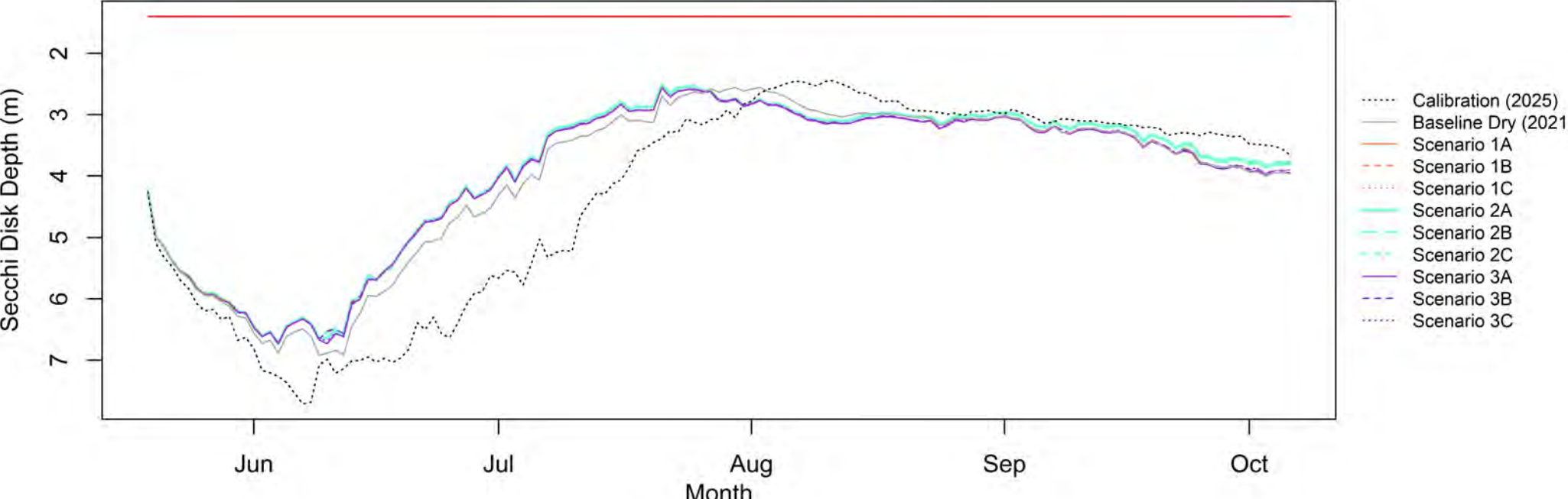
White Bear Lake: Total Phosphorus



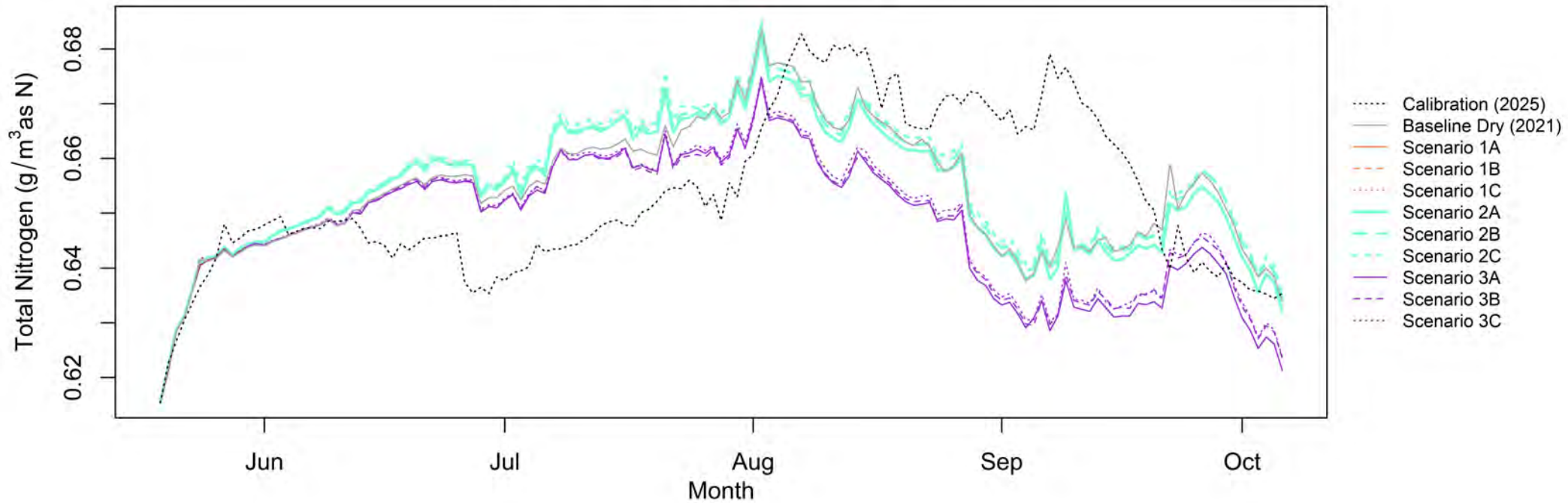
White Bear Lake: Chlorophyll-a



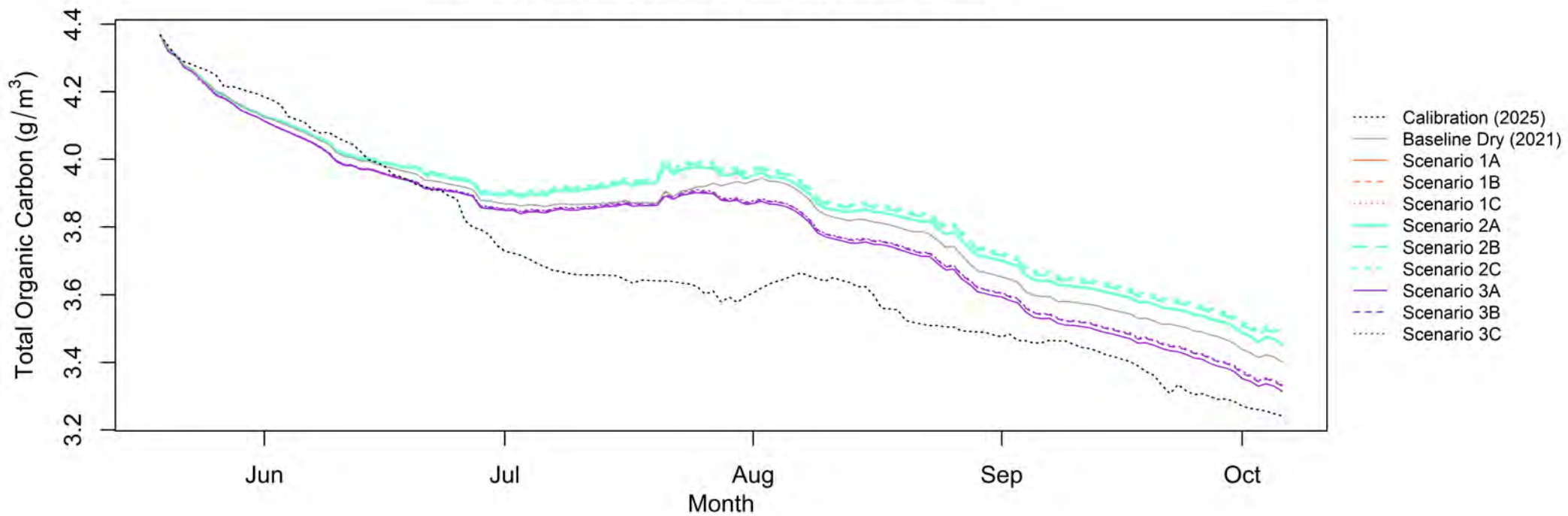
White Bear Lake: Secchi Disk



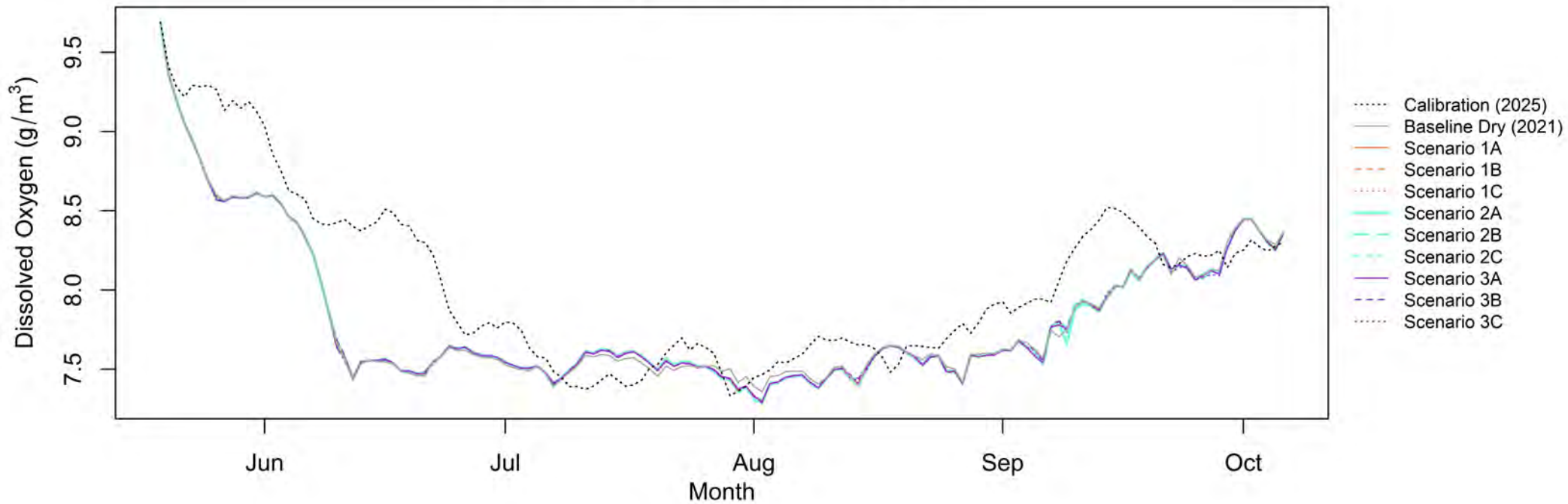
White Bear Lake: Total Nitrogen



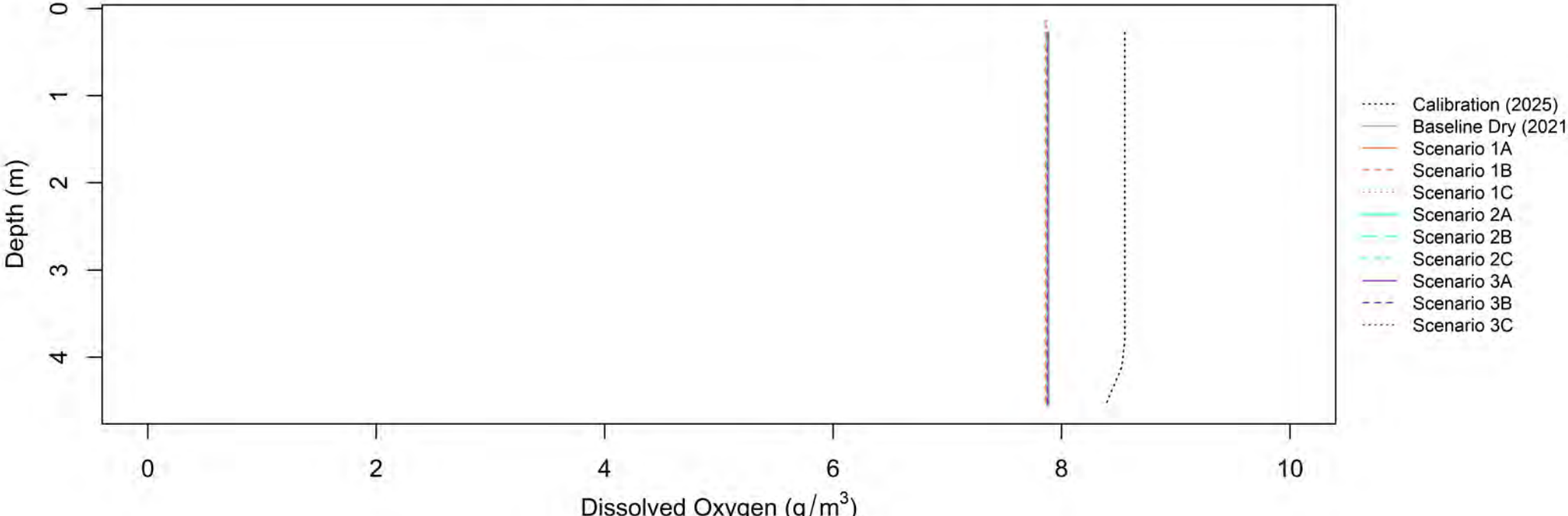
White Bear Lake: Total Organic Carbon



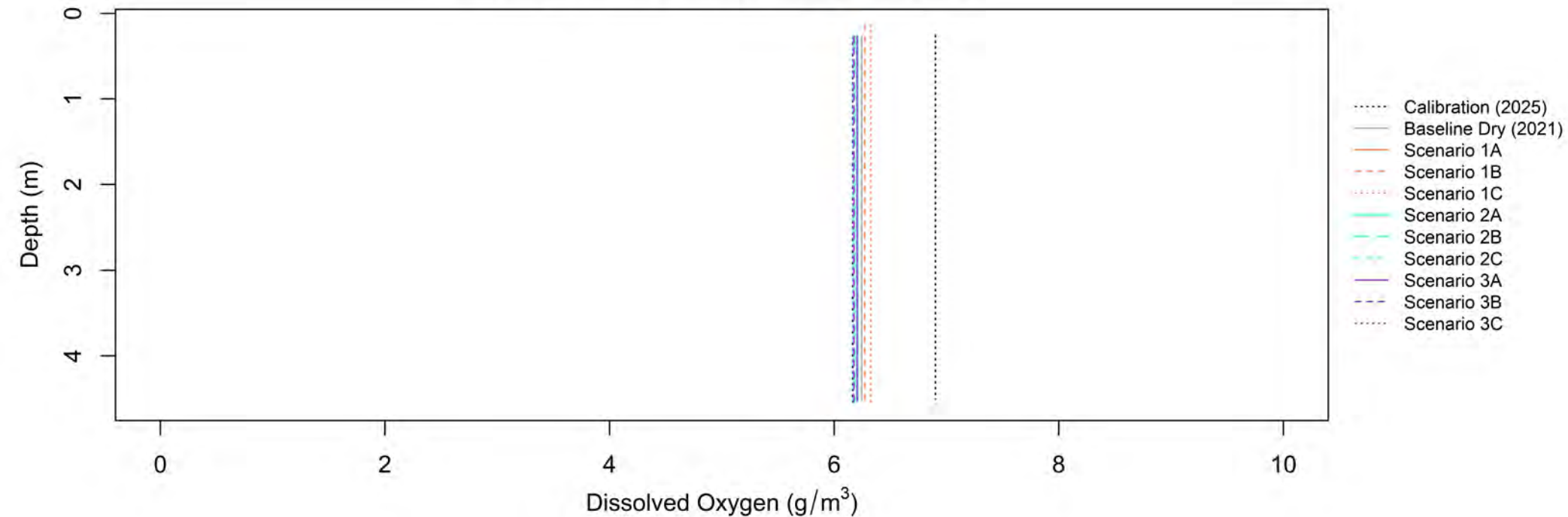
White Bear Lake: Dissolved Oxygen



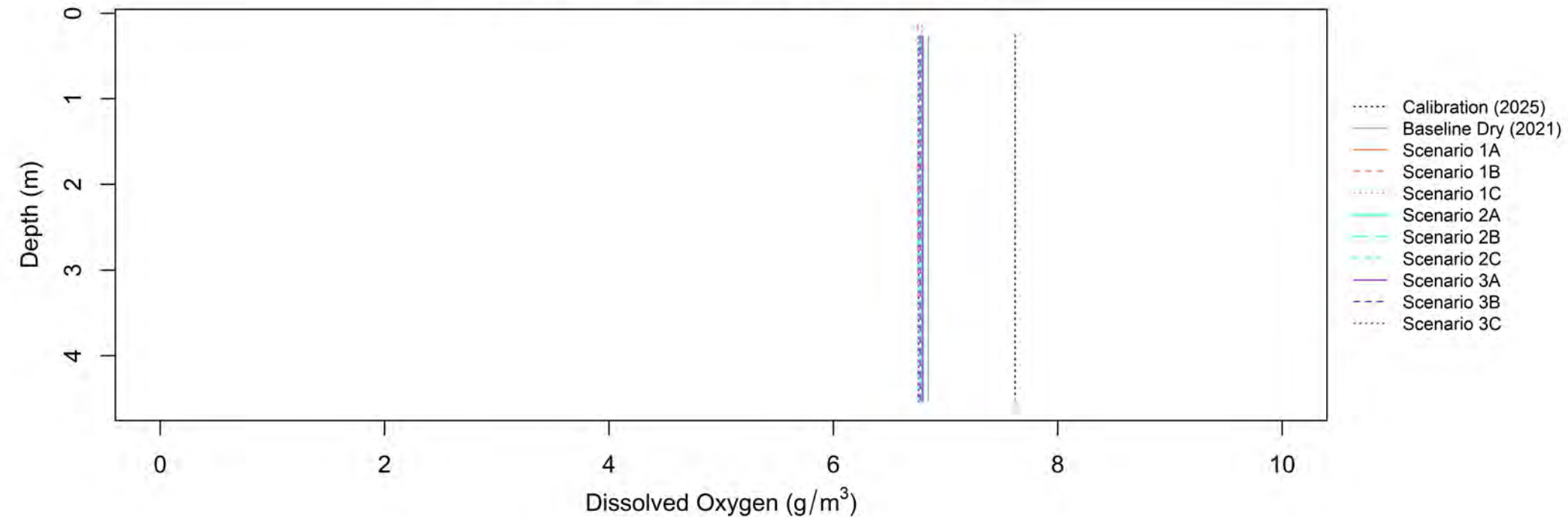
Charley Lake: Dissolved Oxygen (June)



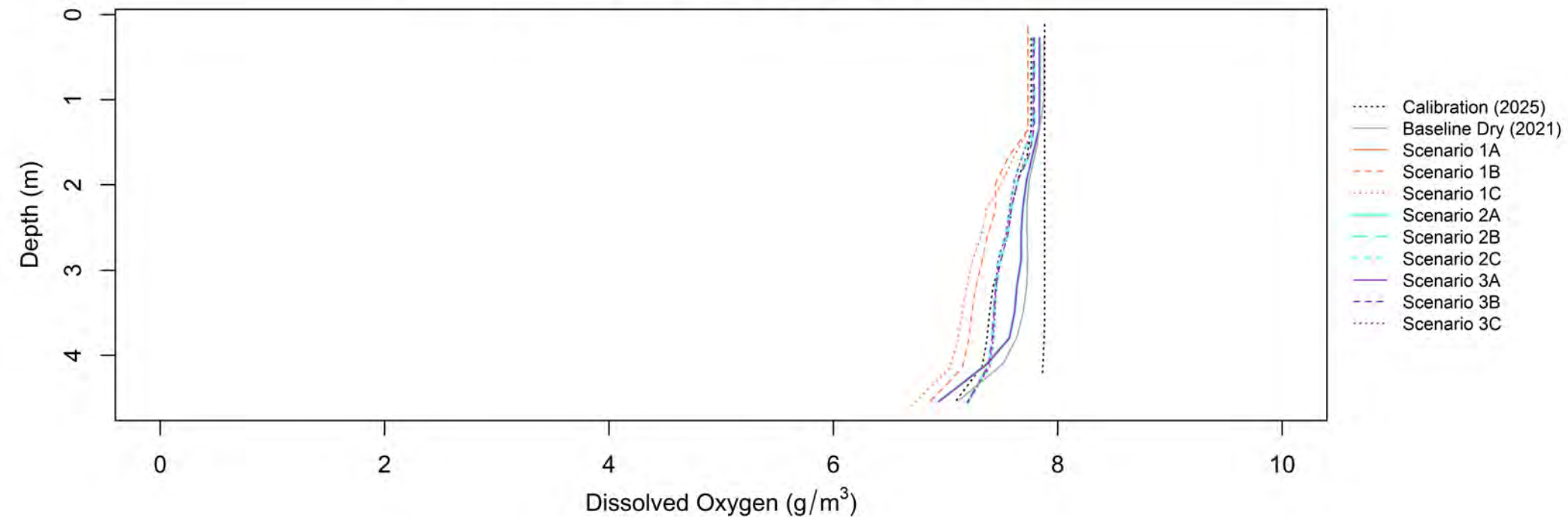
Charley Lake: Dissolved Oxygen (July)



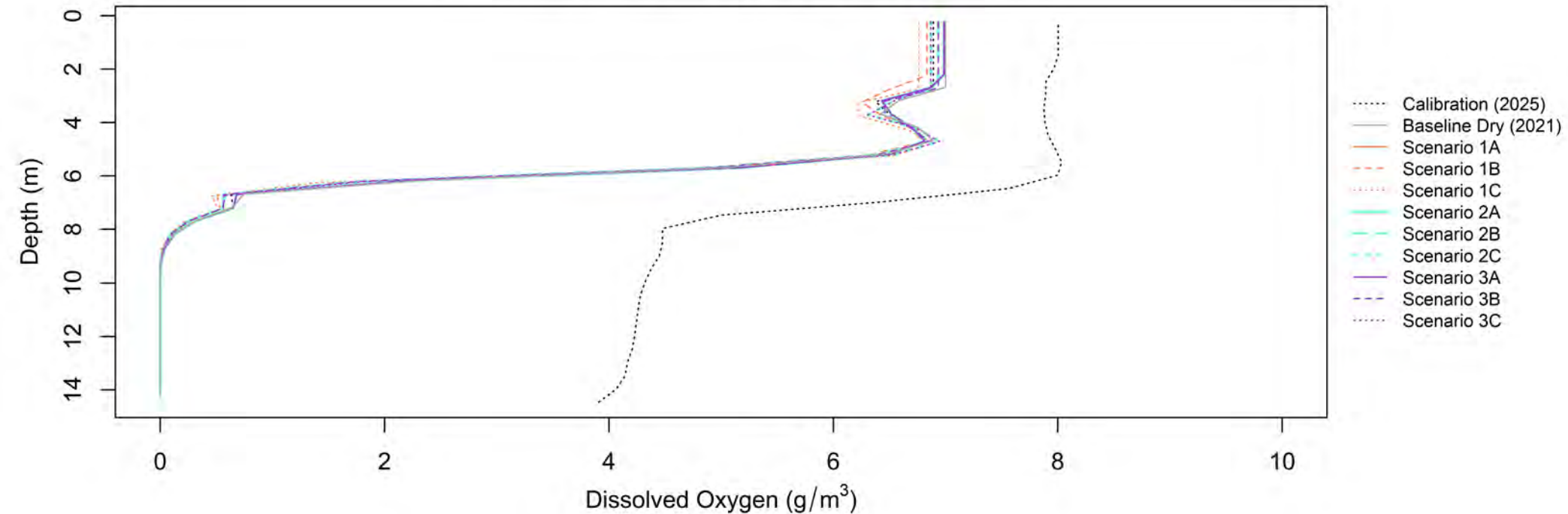
Charley Lake: Dissolved Oxygen (August)



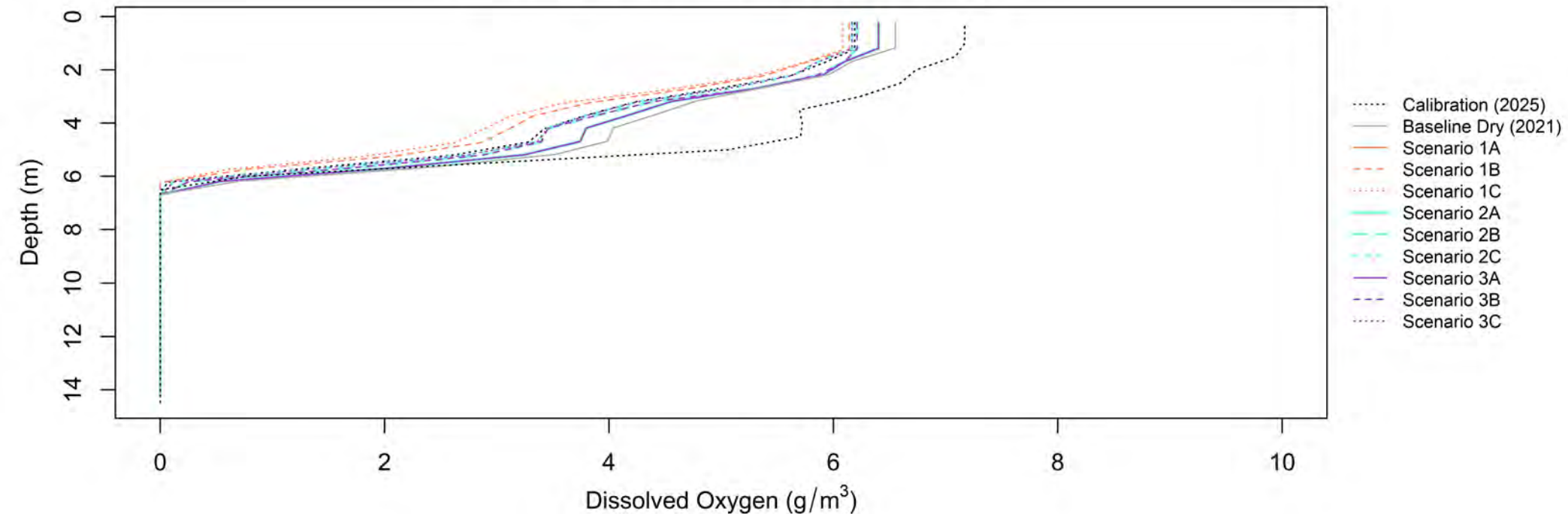
Charley Lake: Dissolved Oxygen (September)



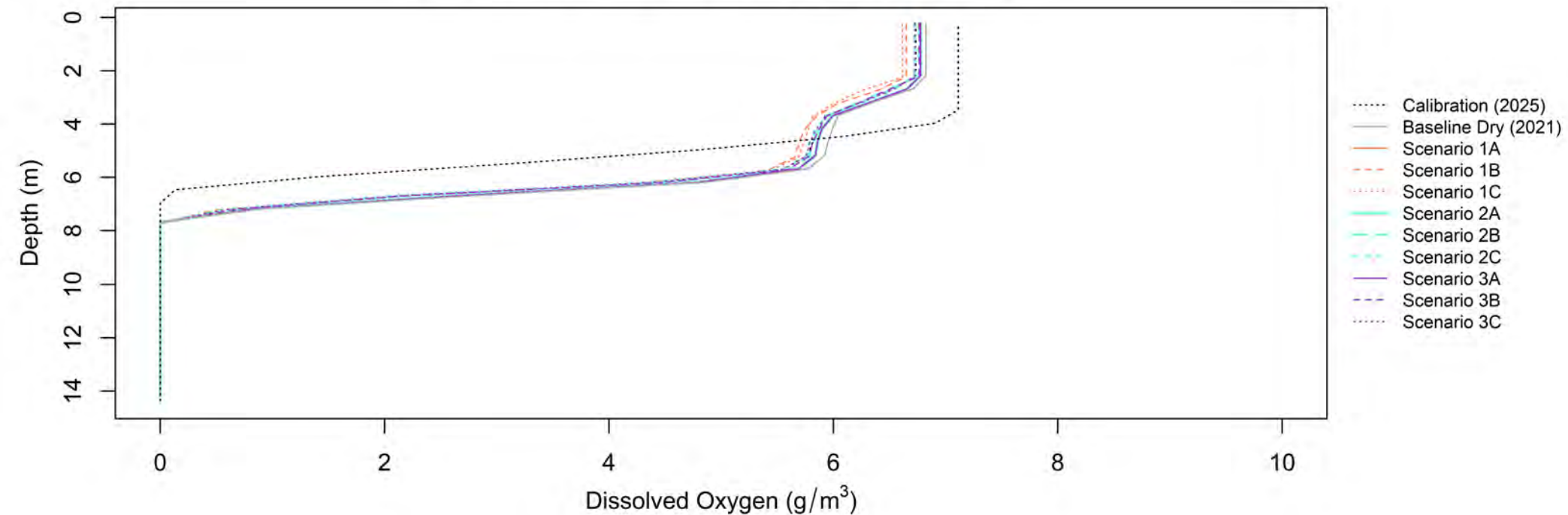
Pleasant Lake: Dissolved Oxygen (June)



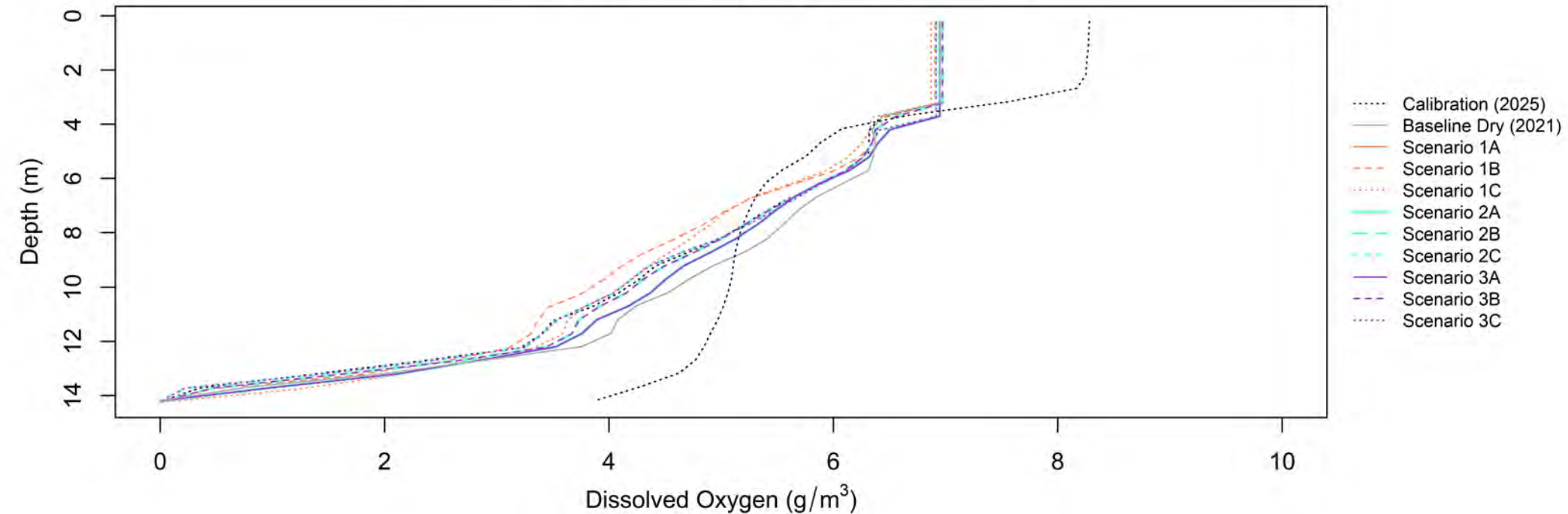
Pleasant Lake: Dissolved Oxygen (July)



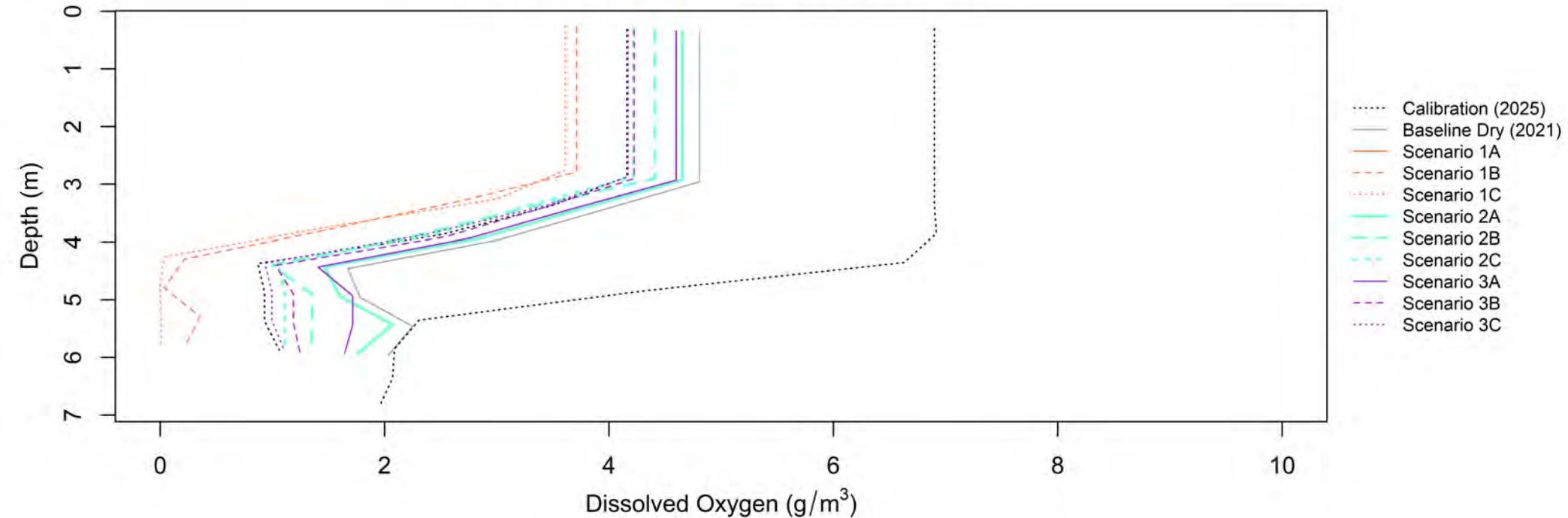
Pleasant Lake: Dissolved Oxygen (August)



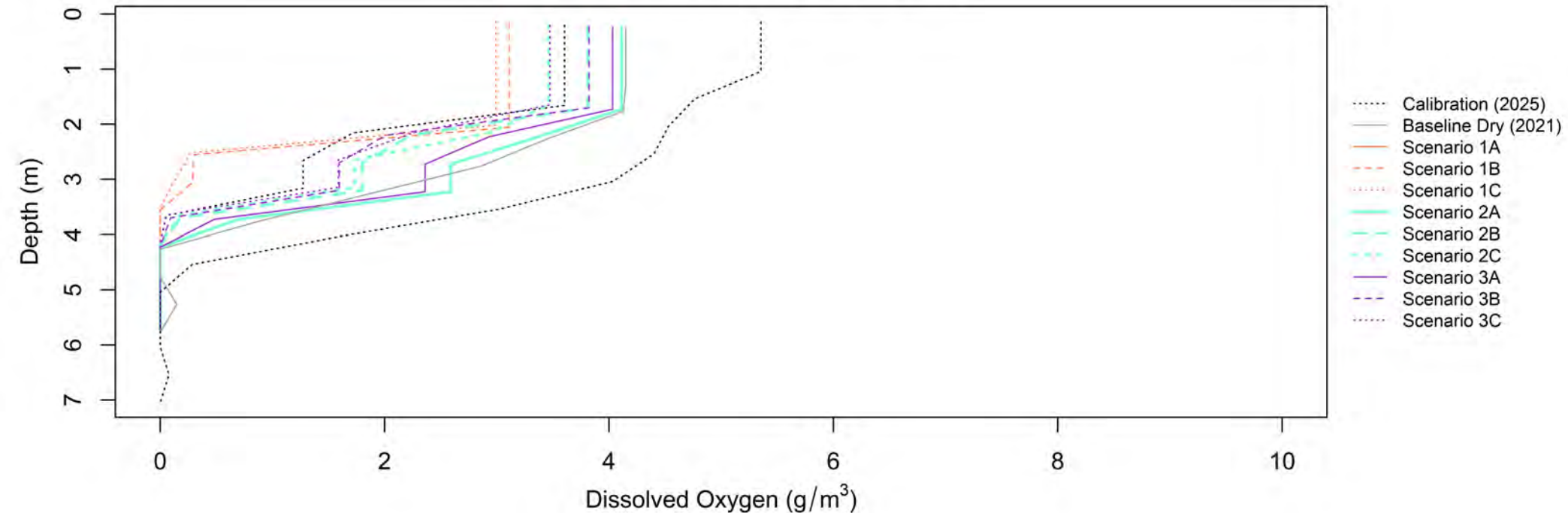
Pleasant Lake: Dissolved Oxygen (September)



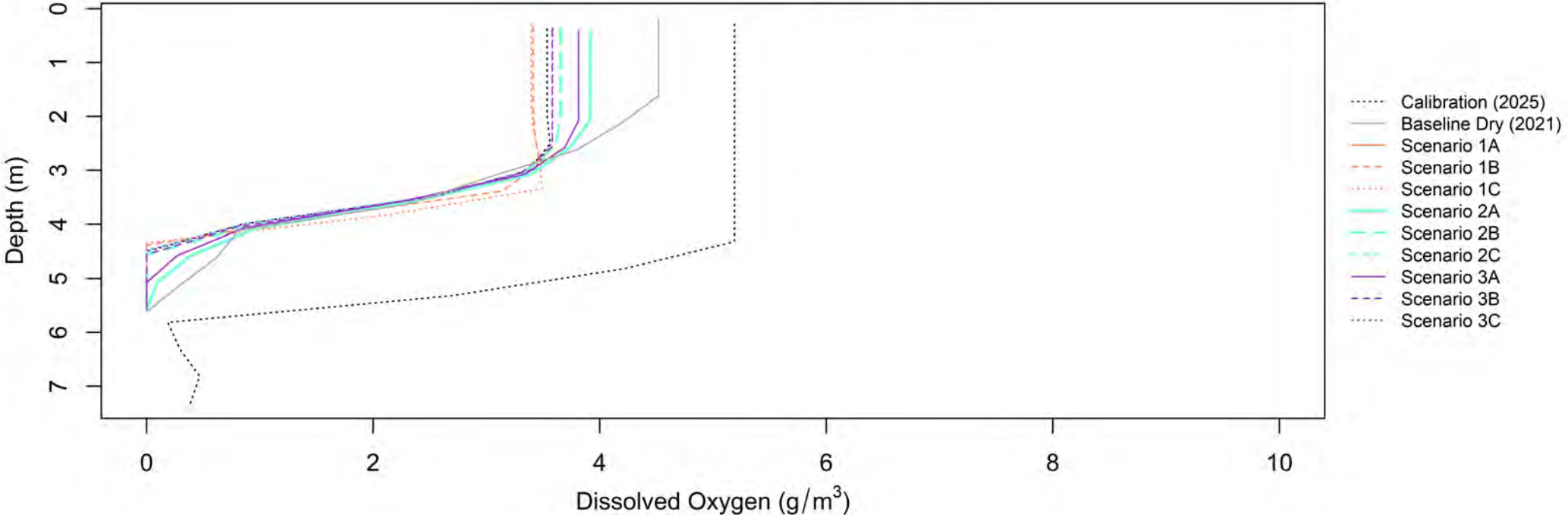
Sucker Lake: Dissolved Oxygen (June)



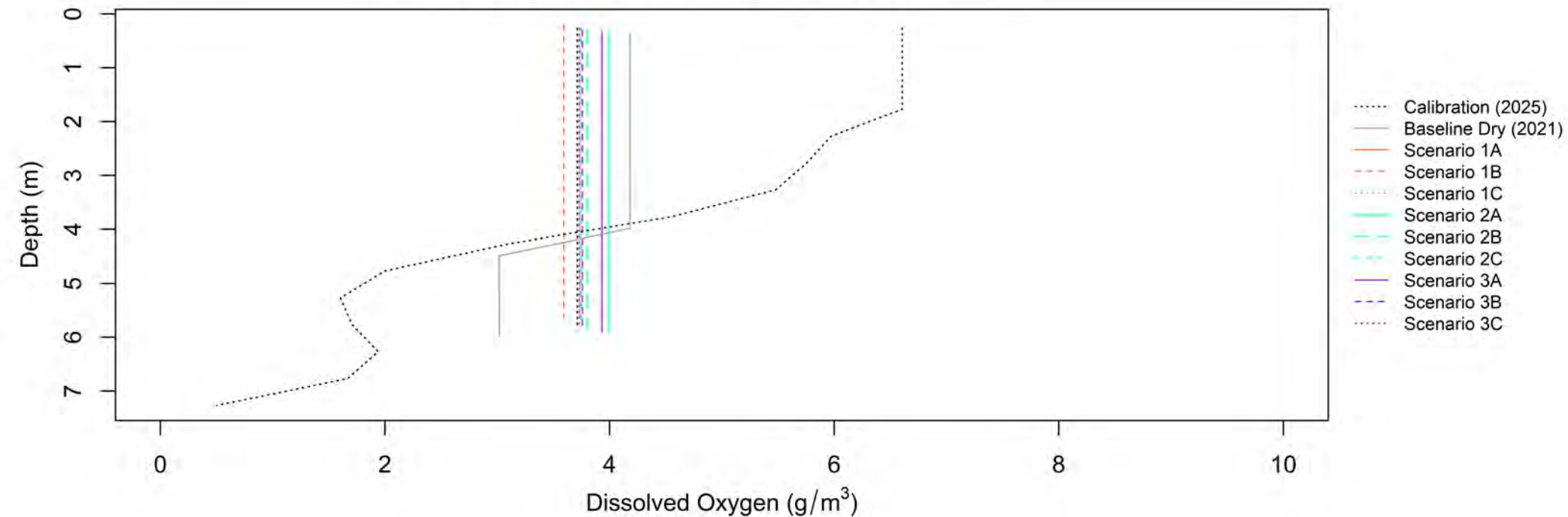
Sucker Lake: Dissolved Oxygen (July)



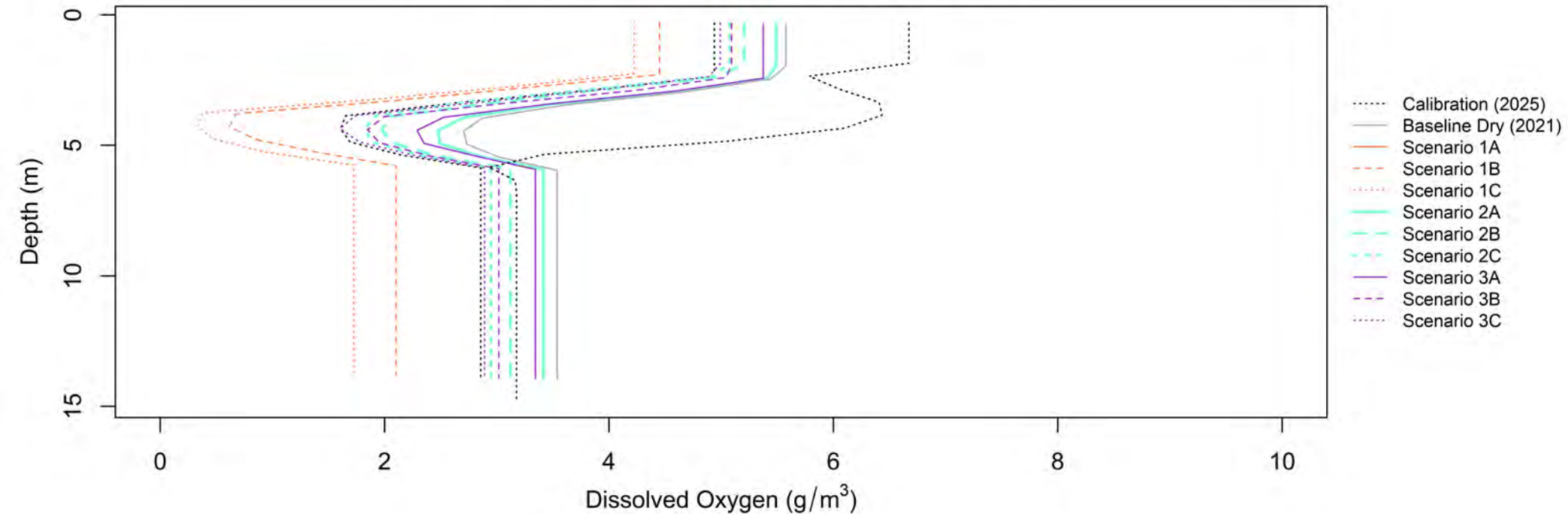
Sucker Lake: Dissolved Oxygen (August)



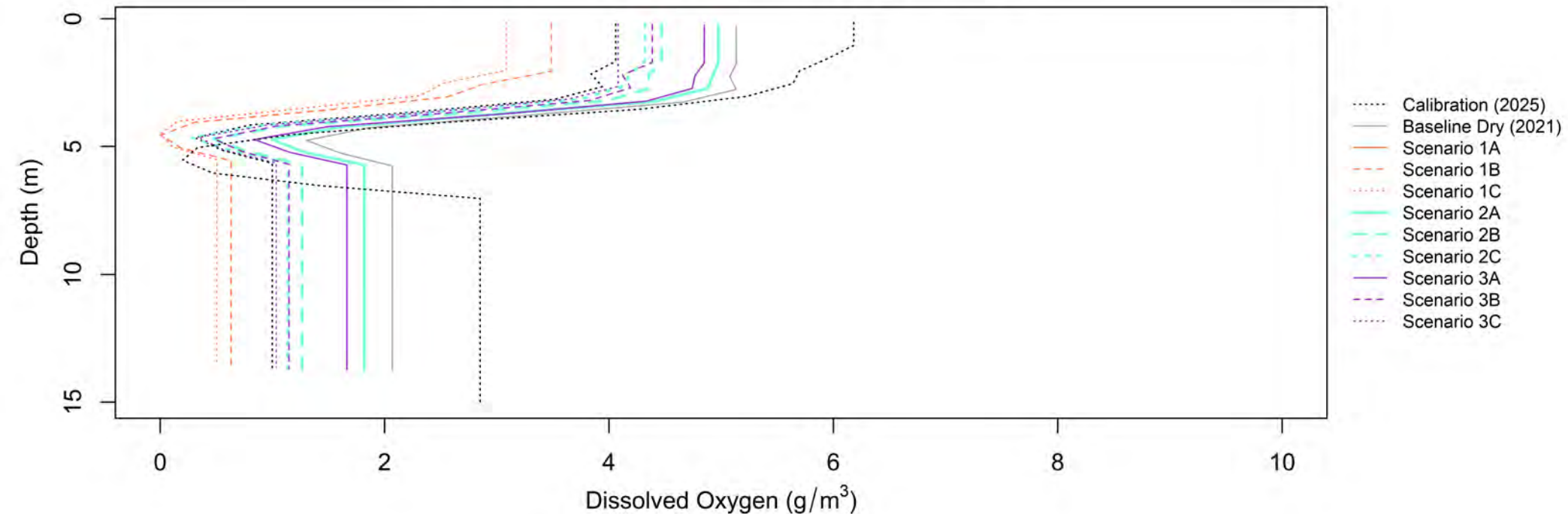
Sucker Lake: Dissolved Oxygen (September)



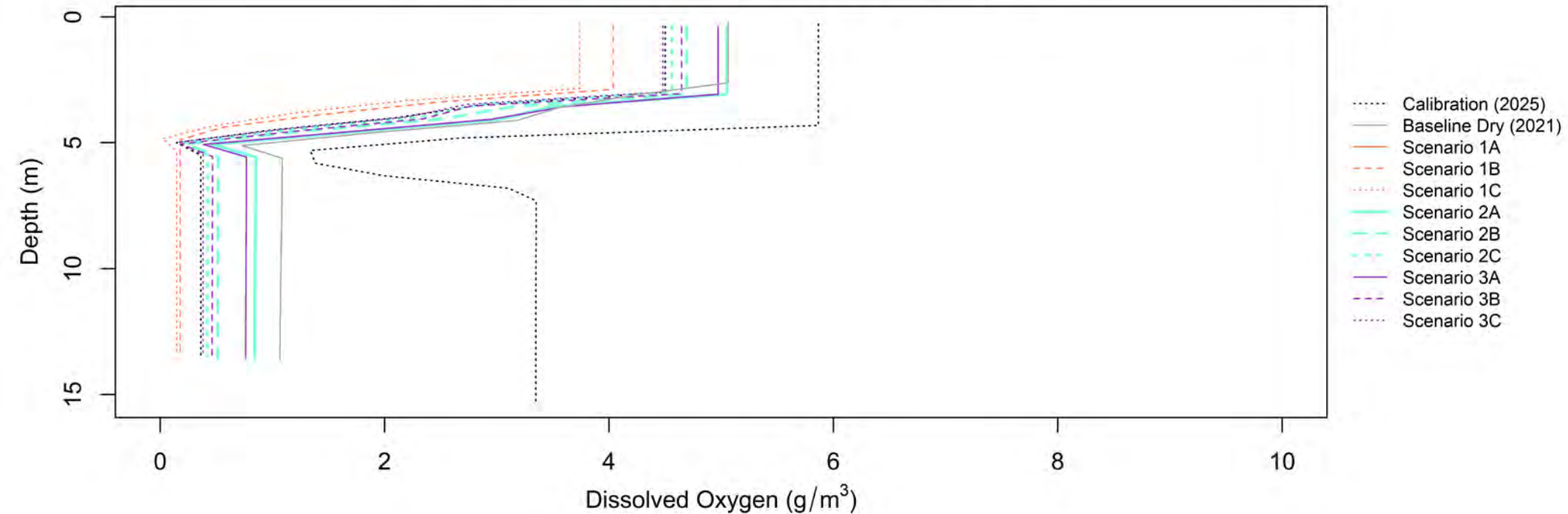
East Vadnais Lake: Dissolved Oxygen (June)



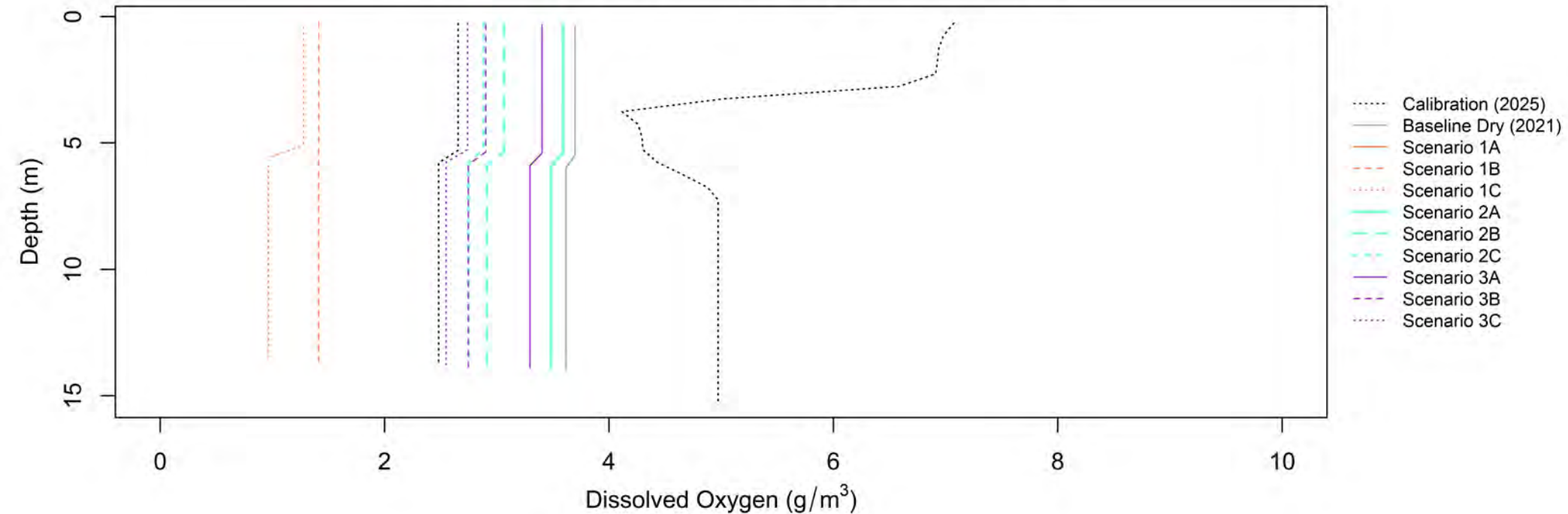
East Vadnais Lake: Dissolved Oxygen (July)



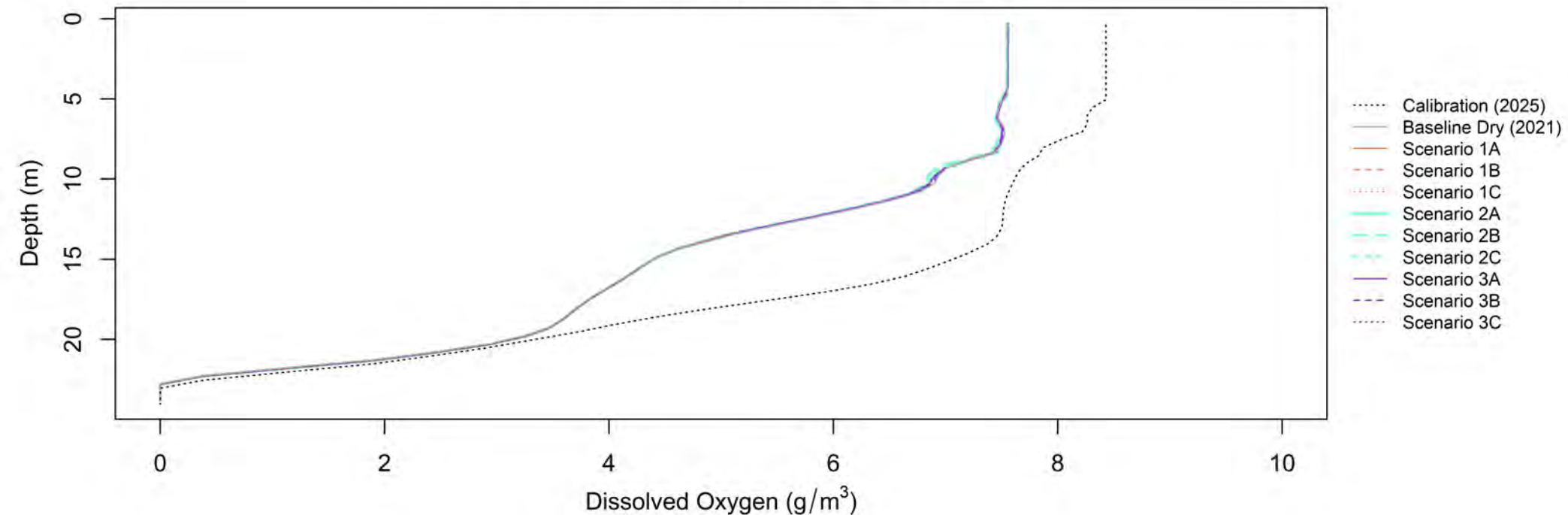
East Vadnais Lake: Dissolved Oxygen (August)



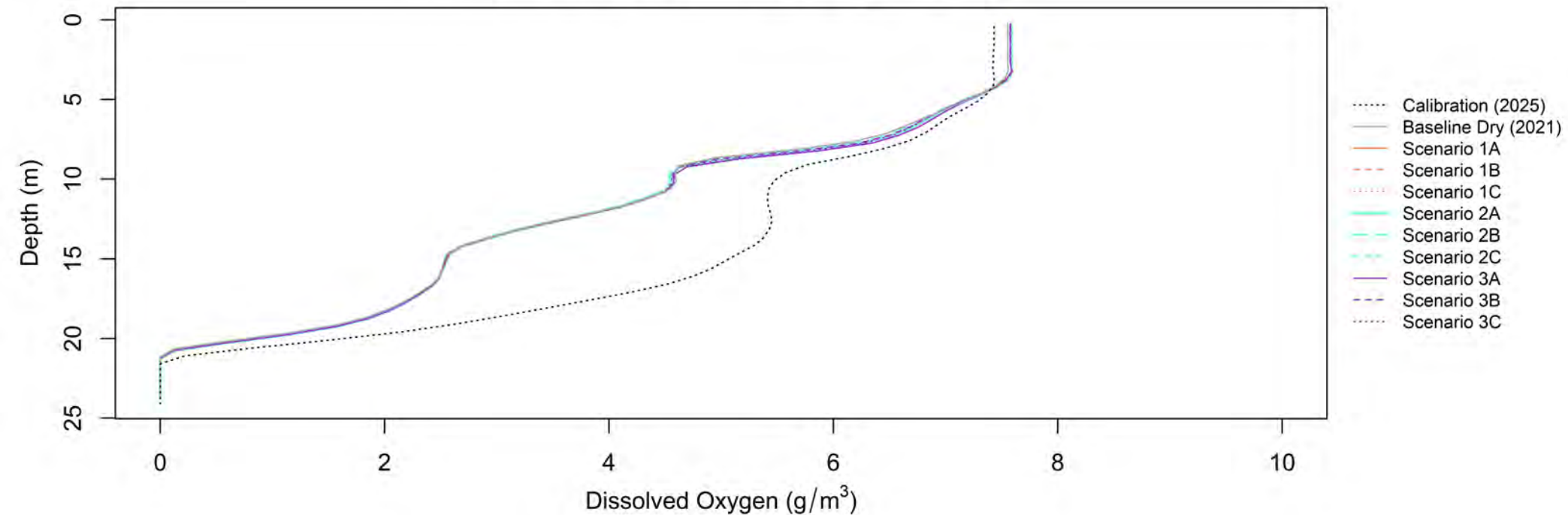
East Vadnais Lake: Dissolved Oxygen (September)



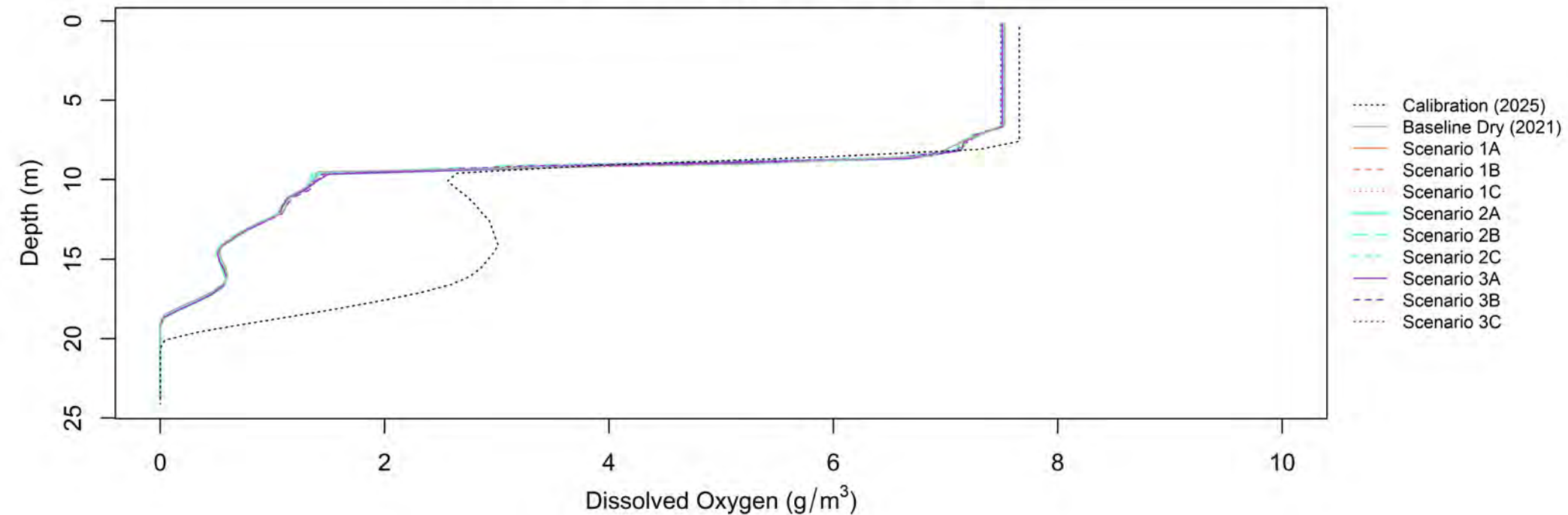
White Bear Lake: Dissolved Oxygen (June)



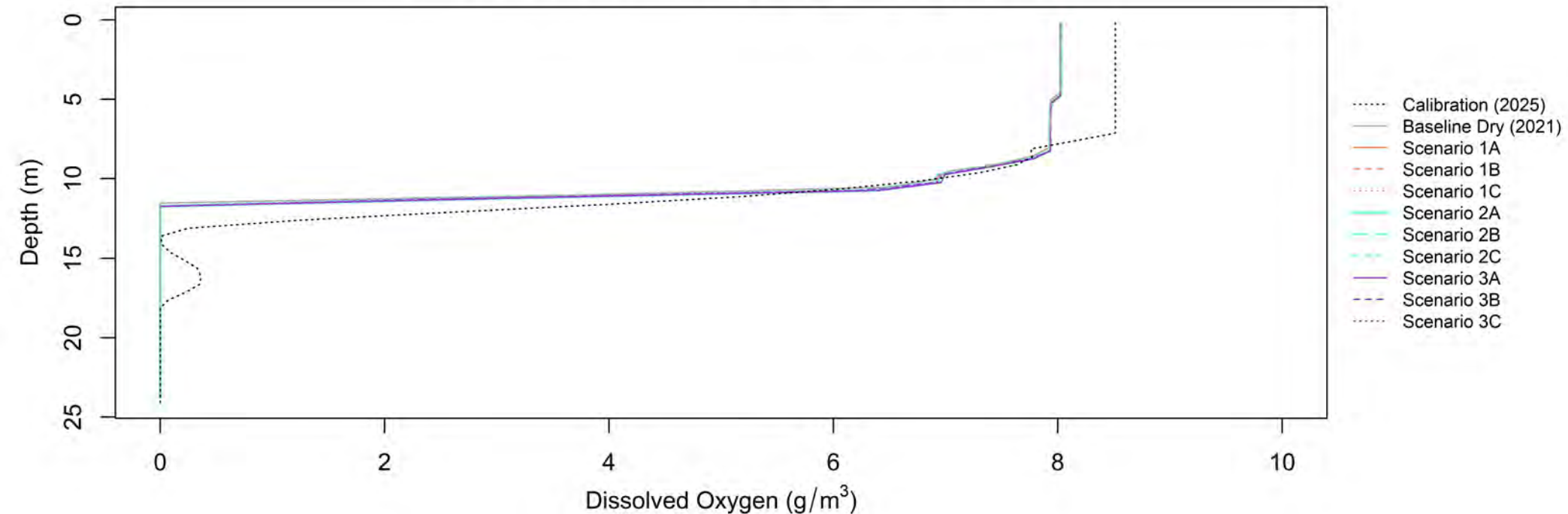
White Bear Lake: Dissolved Oxygen (July)



White Bear Lake: Dissolved Oxygen (August)



White Bear Lake: Dissolved Oxygen (September)





Appendix 7

Scenario Evalution Results (Mass Balance)



Solids, Total Suspended

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	10.64	3.94	3.37	2.16	1.56	3.60
Dry Baseline (2021) Mass Balance Concentrations	mg/L	10.64	3.85	2.89	1.60	1.01	1.58
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	10.64	3.85	2.81	1.54	0.90	1.58
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	10.64	3.84	2.77	1.50	0.84	1.58
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	10.64	3.84	2.75	1.49	0.81	1.58
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	10.64	3.85	2.86	1.58	1.00	1.72
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	10.64	3.85	2.83	1.55	0.95	1.71
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	10.64	3.85	2.81	1.54	0.93	1.71
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	10.64	3.85	2.86	1.58	0.97	1.56
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	10.64	3.85	2.83	1.55	0.93	1.56
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	10.64	3.85	2.81	1.54	0.91	1.56

Solids, Total Dissolved

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	264	262	224	236	204	188
Dry Baseline (2021) Mass Balance Concentrations	mg/L	264	263	248	242	230	180
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	264	263	251	245	234	180
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	264	263	252	247	237	180
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	264	263	253	248	239	180
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	264	263	249	243	230	189
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	264	263	250	245	233	189
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	264	263	251	245	233	190
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	264	263	249	243	231	180
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	264	263	250	245	234	180
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	264	263	251	245	234	180

Chloride

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	22.33	22.77	24.57	27.19	31.93	53.00
Dry Baseline (2021) Mass Balance Concentrations	mg/L	22.33	22.43	21.55	21.79	24.63	52.11
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	22.33	22.41	21.36	21.53	23.69	52.11
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	22.33	22.39	21.25	21.38	23.15	52.11
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	22.33	22.39	21.21	21.33	22.95	52.11
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	22.33	22.42	21.48	21.70	24.49	52.91
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	22.33	22.41	21.40	21.59	24.08	52.91
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	22.33	22.41	21.37	21.54	23.85	52.90
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	22.33	22.42	21.48	21.70	24.28	52.11
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	22.33	22.41	21.40	21.59	23.91	52.11
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	22.33	22.41	21.37	21.54	23.70	52.11

Hardness, as CaCO₃

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	207	197	150	161	136	96
Dry Baseline (2021) Mass Balance Concentrations	mg/L	207	198	169	168	146	93
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	207	198	170	170	148	93
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	207	198	171	171	149	93
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	207	198	172	171	150	93
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	207	198	169	168	146	100
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	207	198	170	169	147	100
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	207	198	170	170	147	100
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	207	198	169	168	147	93
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	207	198	170	169	148	93
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	207	198	170	170	148	93

Alkalinity, Total, as CaCO₃

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	181	179	137	148	137	87
Dry Baseline (2021) Mass Balance Concentrations	mg/L	181	180	153	153	148	84
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	181	180	155	154	150	84
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	181	180	156	155	151	84
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	181	180	156	156	151	84
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	181	180	154	153	148	90
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	181	180	154	154	149	90
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	181	180	155	154	149	90
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	181	180	154	153	149	84
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	181	180	154	154	150	84
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	181	180	155	154	149	84

Arsenic, Total

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	0.0017	0.0016	0.0011	0.0012	0.0012	0.0020
Dry Baseline (2021) Mass Balance Concentrations	mg/L	0.0017	0.0017	0.0013	0.0013	0.0012	0.0020
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	0.0017	0.0017	0.0013	0.0013	0.0012	0.0020
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	0.0017	0.0017	0.0013	0.0013	0.0013	0.0020
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	0.0017	0.0017	0.0013	0.0013	0.0013	0.0020
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	0.0017	0.0017	0.0013	0.0013	0.0012	0.0021
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	0.0017	0.0017	0.0013	0.0013	0.0012	0.0021
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	0.0017	0.0017	0.0013	0.0013	0.0012	0.0021
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	0.0017	0.0017	0.0013	0.0013	0.0012	0.0020
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	0.0017	0.0017	0.0013	0.0013	0.0012	0.0020
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	0.0017	0.0017	0.0013	0.0013	0.0012	0.0020

Aluminum, Total

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	0.0715	0.0163	0.0023	0.0025	0.0025	0.0117
Dry Baseline (2021) Mass Balance Concentrations	mg/L	0.0715	0.0162	0.0018	0.0013	0.0012	0.0051
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	0.0715	0.0162	0.0017	0.0011	0.0010	0.0051
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	0.0715	0.0162	0.0016	0.0010	0.0008	0.0051
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	0.0715	0.0162	0.0016	0.0010	0.0008	0.0051
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	0.0715	0.0162	0.0017	0.0012	0.0012	0.0052
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	0.0715	0.0162	0.0017	0.0012	0.0011	0.0052
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	0.0715	0.0162	0.0017	0.0011	0.0010	0.0052
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	0.0715	0.0162	0.0017	0.0012	0.0011	0.0051
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	0.0715	0.0162	0.0017	0.0012	0.0010	0.0051
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	0.0715	0.0162	0.0017	0.0011	0.0010	0.0051

Barium, Total

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	0.063	0.056	0.044	0.050	0.037	0.040
Dry Baseline (2021) Mass Balance Concentrations	mg/L	0.063	0.057	0.053	0.052	0.047	0.040
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	0.063	0.057	0.054	0.053	0.049	0.040
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	0.063	0.057	0.055	0.054	0.050	0.040
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	0.063	0.057	0.055	0.054	0.051	0.040
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	0.063	0.057	0.053	0.053	0.047	0.042
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	0.063	0.057	0.054	0.053	0.048	0.042
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	0.063	0.057	0.054	0.053	0.048	0.042
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	0.063	0.057	0.053	0.053	0.047	0.040
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	0.063	0.057	0.054	0.053	0.048	0.040
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	0.063	0.057	0.054	0.053	0.049	0.040

Calcium, Total

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	46.45	46.24	35.73	38.64	33.19	21.94
Dry Baseline (2021) Mass Balance Concentrations	mg/L	46.45	46.35	38.58	38.49	34.21	21.15
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	46.45	46.37	38.92	38.82	34.37	21.15
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	46.45	46.39	39.12	39.03	34.52	21.15
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	46.45	46.39	39.19	39.11	34.59	21.15
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	46.45	46.35	38.70	38.60	34.19	22.57
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	46.45	46.37	38.85	38.76	34.34	22.57
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	46.45	46.37	38.90	38.80	34.28	22.58
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	46.45	46.35	38.70	38.60	34.21	21.15
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	46.45	46.37	38.85	38.76	34.36	21.15
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	46.45	46.37	38.90	38.80	34.31	21.15

Copper, Total

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	0.0040	0.0035	0.0017	0.0015	0.0041	0.0014
Dry Baseline (2021) Mass Balance Concentrations	mg/L	0.0040	0.0033	0.0013	0.0009	0.0022	0.0006
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	0.0040	0.0033	0.0012	0.0009	0.0018	0.0006
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	0.0040	0.0032	0.0012	0.0008	0.0016	0.0006
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	0.0040	0.0032	0.0012	0.0008	0.0015	0.0006
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	0.0040	0.0033	0.0012	0.0009	0.0022	0.0007
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	0.0040	0.0033	0.0012	0.0009	0.0020	0.0007
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	0.0040	0.0033	0.0012	0.0009	0.0019	0.0007
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	0.0040	0.0033	0.0012	0.0009	0.0020	0.0006
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	0.0040	0.0033	0.0012	0.0009	0.0019	0.0006
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	0.0040	0.0033	0.0012	0.0009	0.0018	0.0006

Fluoride

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	0.120	0.111	0.102	0.097	0.091	0.091
Dry Baseline (2021) Mass Balance Concentrations	mg/L	0.120	0.110	0.101	0.088	0.078	0.087
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	0.120	0.110	0.101	0.087	0.075	0.087
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	0.120	0.110	0.100	0.087	0.073	0.087
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	0.120	0.110	0.100	0.087	0.072	0.087
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	0.120	0.110	0.101	0.088	0.077	0.090
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	0.120	0.110	0.101	0.087	0.076	0.090
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	0.120	0.110	0.101	0.087	0.075	0.090
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	0.120	0.110	0.101	0.088	0.076	0.087
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	0.120	0.110	0.101	0.087	0.075	0.087
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	0.120	0.110	0.101	0.087	0.075	0.087

Magnesium, Total

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	24.88	18.87	14.68	15.92	13.92	10.07
Dry Baseline (2021) Mass Balance Concentrations	mg/L	24.88	18.96	16.18	16.16	14.02	9.72
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	24.88	18.97	16.31	16.28	14.05	9.72
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	24.88	18.98	16.38	16.35	14.09	9.72
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	24.88	18.98	16.41	16.38	14.11	9.72
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	24.88	18.96	16.22	16.19	14.01	10.32
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	24.88	18.97	16.28	16.25	14.05	10.32
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	24.88	18.97	16.30	16.27	14.02	10.32
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	24.88	18.96	16.22	16.19	14.01	9.72
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	24.88	18.97	16.28	16.25	14.05	9.72
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	24.88	18.97	16.30	16.27	14.03	9.72

Manganese, Total

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	0.127	0.083	0.212	0.067	0.033	0.040
Dry Baseline (2021) Mass Balance Concentrations	mg/L	0.127	0.080	0.167	0.048	0.020	0.018
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	0.127	0.080	0.160	0.046	0.018	0.018
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	0.127	0.080	0.156	0.045	0.016	0.018
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	0.127	0.080	0.154	0.044	0.015	0.018
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	0.127	0.080	0.164	0.047	0.020	0.021
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	0.127	0.080	0.161	0.046	0.019	0.021
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	0.127	0.080	0.160	0.046	0.018	0.021
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	0.127	0.080	0.164	0.047	0.019	0.017
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	0.127	0.080	0.161	0.046	0.018	0.017
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	0.127	0.080	0.160	0.046	0.018	0.017

Sulfate, as SO4

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	13.50	14.11	8.98	10.92	7.98	3.93
Dry Baseline (2021) Mass Balance Concentrations	mg/L	13.50	13.66	7.65	8.10	4.93	1.72
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	13.50	13.62	7.46	7.79	4.41	1.72
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	13.50	13.60	7.34	7.62	4.11	1.72
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	13.50	13.59	7.30	7.56	3.99	1.72
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	13.50	13.64	7.58	7.99	4.88	2.24
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	13.50	13.63	7.49	7.86	4.64	2.23
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	13.50	13.62	7.46	7.81	4.53	2.22
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	13.50	13.64	7.58	7.99	4.74	1.71
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	13.50	13.63	7.49	7.86	4.53	1.71
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	13.50	13.62	7.46	7.81	4.43	1.71

Chlorine Dioxide

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	0.450	0.439	0.320	0.293	0.097	0.372
Dry Baseline (2021) Mass Balance Concentrations	mg/L	0.450	0.447	0.407	0.287	0.125	0.372
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	0.450	0.447	0.416	0.295	0.133	0.372
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	0.450	0.448	0.422	0.300	0.138	0.372
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	0.450	0.448	0.425	0.302	0.140	0.372
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	0.450	0.447	0.410	0.290	0.126	0.383
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	0.450	0.447	0.414	0.294	0.130	0.383
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	0.450	0.447	0.416	0.295	0.131	0.383
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	0.450	0.447	0.410	0.290	0.128	0.372
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	0.450	0.447	0.414	0.294	0.132	0.372
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	0.450	0.447	0.416	0.295	0.133	0.372

Gross Alpha (Radiation)

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	pCi/L	2.61	2.38	1.45	1.52	1.51	1.38
Dry Baseline (2021) Mass Balance Concentrations	pCi/L	2.61	2.42	1.80	1.78	1.55	1.37
Scenario 1a (Expanded Communities, Existing, No Augmentation)	pCi/L	2.61	2.42	1.84	1.82	1.63	1.37
Scenario 1b (Expanded Communities, 2050, No Augmentation)	pCi/L	2.61	2.42	1.86	1.85	1.68	1.37
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	pCi/L	2.61	2.43	1.87	1.85	1.70	1.37
Scenario 2a (SPRWS, Existing, Sucker to WBL)	pCi/L	2.61	2.42	1.81	1.79	1.56	1.44
Scenario 2b (SPRWS, 2050, Sucker to WBL)	pCi/L	2.61	2.42	1.83	1.81	1.60	1.44
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	pCi/L	2.61	2.42	1.84	1.82	1.61	1.44
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	pCi/L	2.61	2.42	1.81	1.79	1.58	1.37
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	pCi/L	2.61	2.42	1.83	1.81	1.62	1.37
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	pCi/L	2.61	2.42	1.84	1.82	1.63	1.37

Gross Beta (Radiation)

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	pCi/L	3.96	3.87	2.90	3.52	2.71	4.00
Dry Baseline (2021) Mass Balance Concentrations	pCi/L	3.96	3.92	3.60	3.55	3.08	3.99
Scenario 1a (Expanded Communities, Existing, No Augmentation)	pCi/L	3.96	3.93	3.68	3.64	3.25	3.99
Scenario 1b (Expanded Communities, 2050, No Augmentation)	pCi/L	3.96	3.93	3.73	3.69	3.35	3.99
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	pCi/L	3.96	3.93	3.75	3.71	3.39	3.99
Scenario 2a (SPRWS, Existing, Sucker to WBL)	pCi/L	3.96	3.93	3.63	3.58	3.10	4.12
Scenario 2b (SPRWS, 2050, Sucker to WBL)	pCi/L	3.96	3.93	3.67	3.62	3.18	4.12
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	pCi/L	3.96	3.93	3.68	3.64	3.20	4.12
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	pCi/L	3.96	3.93	3.63	3.58	3.13	3.99
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	pCi/L	3.96	3.93	3.67	3.62	3.21	3.99
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	pCi/L	3.96	3.93	3.68	3.64	3.23	3.99

Radium 226

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	pCi/L	0.267	0.256	0.227	0.363	0.233	0.050
Dry Baseline (2021) Mass Balance Concentrations	pCi/L	0.267	0.244	0.180	0.197	0.051	0.022
Scenario 1a (Expanded Communities, Existing, No Augmentation)	pCi/L	0.267	0.243	0.172	0.186	0.045	0.022
Scenario 1b (Expanded Communities, 2050, No Augmentation)	pCi/L	0.267	0.243	0.168	0.179	0.042	0.022
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	pCi/L	0.267	0.242	0.167	0.176	0.040	0.022
Scenario 2a (SPRWS, Existing, Sucker to WBL)	pCi/L	0.267	0.244	0.177	0.193	0.051	0.028
Scenario 2b (SPRWS, 2050, Sucker to WBL)	pCi/L	0.267	0.243	0.174	0.188	0.048	0.028
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	pCi/L	0.267	0.243	0.173	0.186	0.047	0.028
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	pCi/L	0.267	0.244	0.177	0.193	0.049	0.022
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	pCi/L	0.267	0.243	0.174	0.188	0.047	0.022
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	pCi/L	0.267	0.243	0.173	0.186	0.046	0.022

Radium 228

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	pCi/L	0.816	0.813	0.734	0.092	0.314	0.658
Dry Baseline (2021) Mass Balance Concentrations	pCi/L	0.816	0.812	0.793	0.088	0.196	0.641
Scenario 1a (Expanded Communities, Existing, No Augmentation)	pCi/L	0.816	0.812	0.798	0.088	0.173	0.641
Scenario 1b (Expanded Communities, 2050, No Augmentation)	pCi/L	0.816	0.813	0.800	0.089	0.158	0.641
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	pCi/L	0.816	0.813	0.801	0.089	0.153	0.641
Scenario 2a (SPRWS, Existing, Sucker to WBL)	pCi/L	0.816	0.812	0.795	0.088	0.196	0.644
Scenario 2b (SPRWS, 2050, Sucker to WBL)	pCi/L	0.816	0.812	0.797	0.088	0.184	0.644
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	pCi/L	0.816	0.812	0.797	0.088	0.179	0.644
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	pCi/L	0.816	0.812	0.795	0.088	0.188	0.641
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	pCi/L	0.816	0.812	0.797	0.088	0.178	0.641
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	pCi/L	0.816	0.812	0.797	0.088	0.173	0.641

Micro Plastic Particles, Total

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mpp/L	5989	4854	519	520	843	1174
Dry Baseline (2021) Mass Balance Concentrations	mpp/L	5989	4930	657	613	98	1169
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mpp/L	5989	4939	673	638	104	1169
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mpp/L	5989	4944	682	653	108	1169
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mpp/L	5989	4946	685	658	109	1169
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mpp/L	5989	4933	662	621	99	1192
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mpp/L	5989	4937	669	632	102	1193
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mpp/L	5989	4939	672	637	103	1193
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mpp/L	5989	4933	662	621	100	1170
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mpp/L	5989	4937	669	632	103	1170
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mpp/L	5989	4939	672	637	104	1170

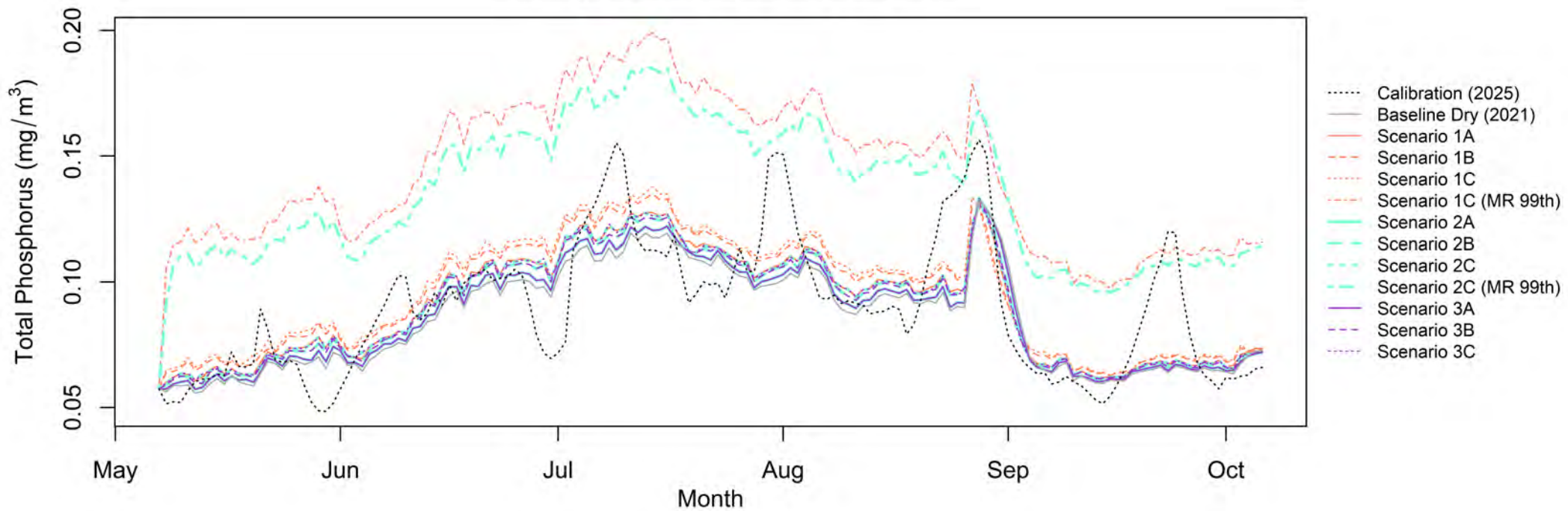


Appendix 8

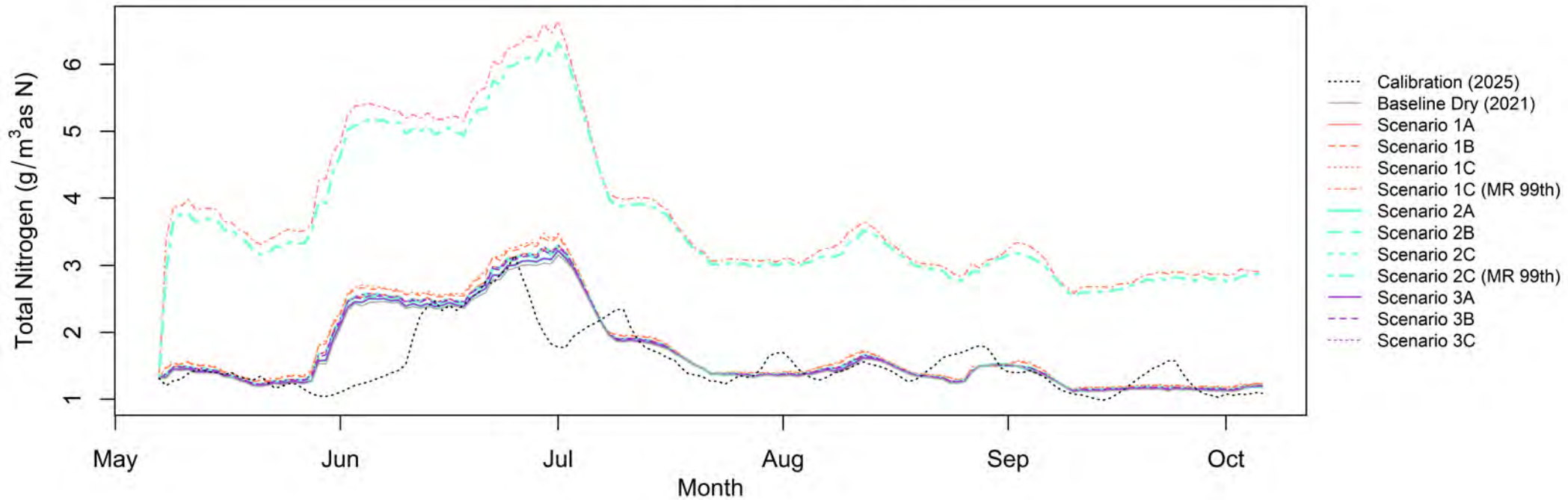
Sensitivity Evaluation Results
(CE-QUAL-W2)



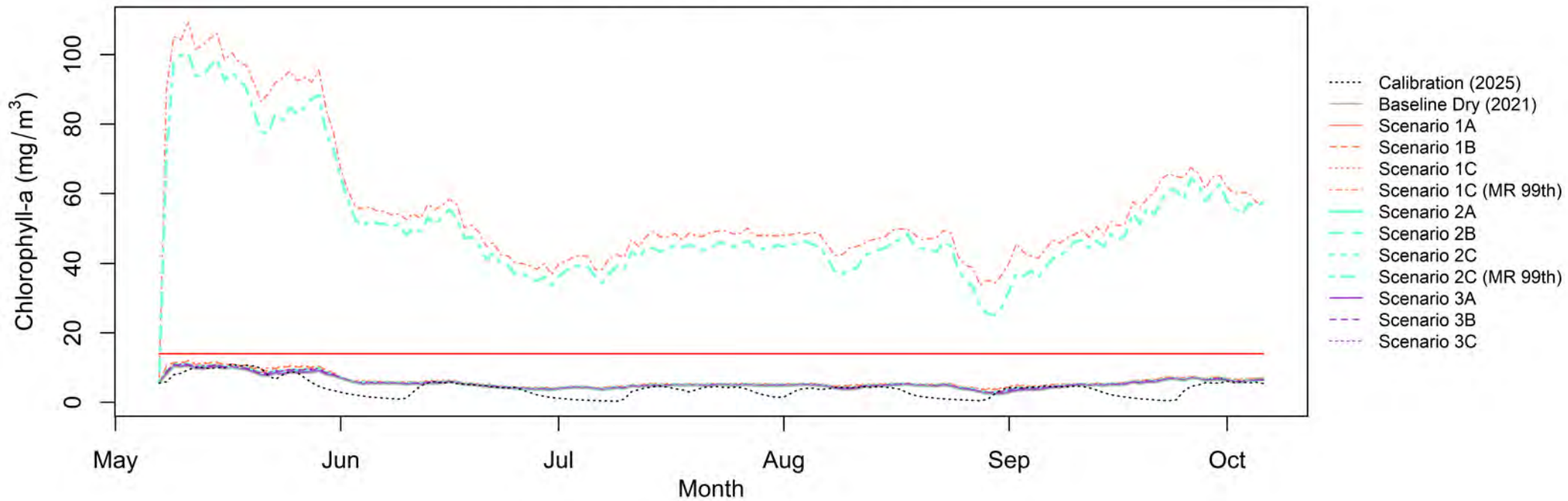
Charley Lake: Total Phosphorus



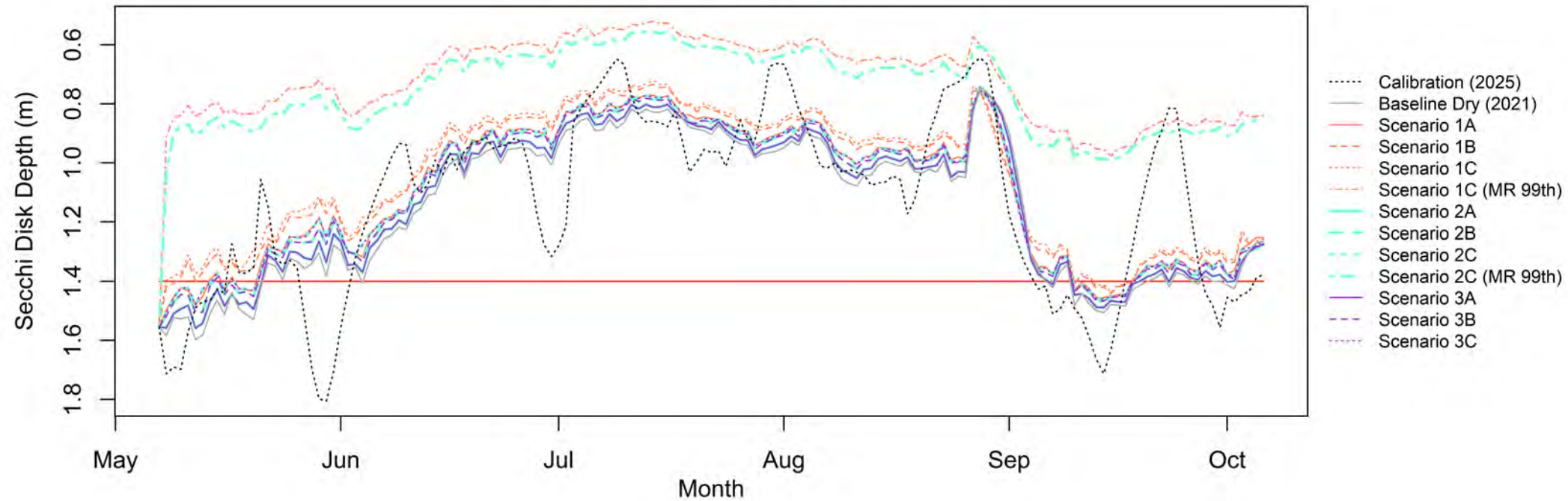
Charley Lake: Total Nitrogen



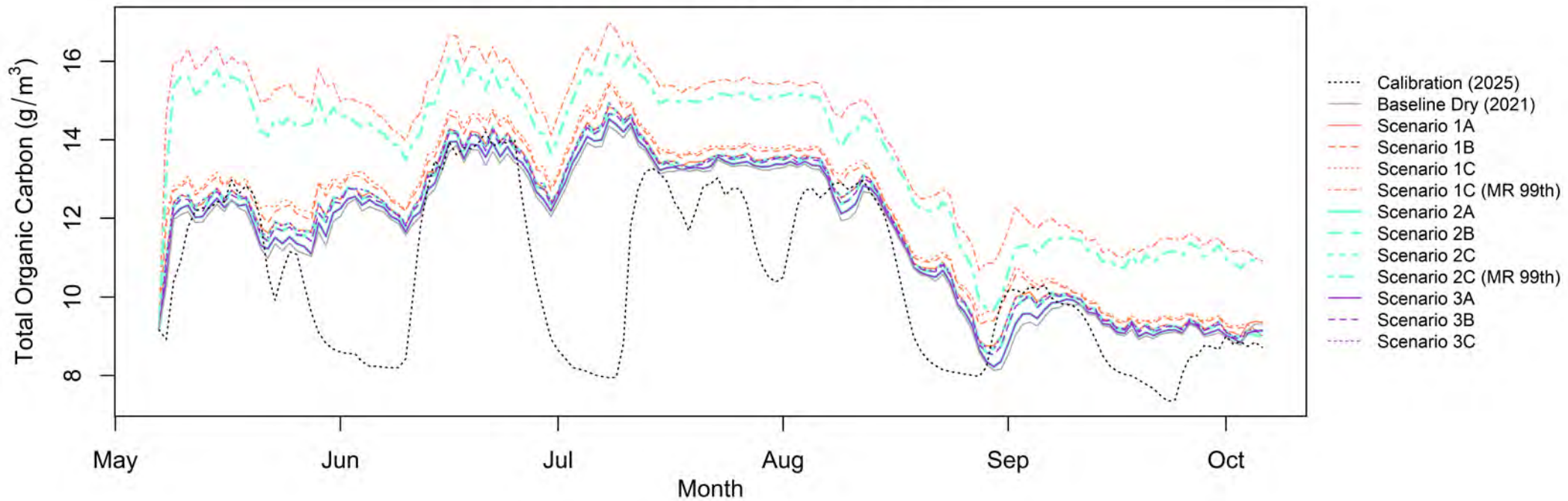
Charley Lake: Chlorophyll-a



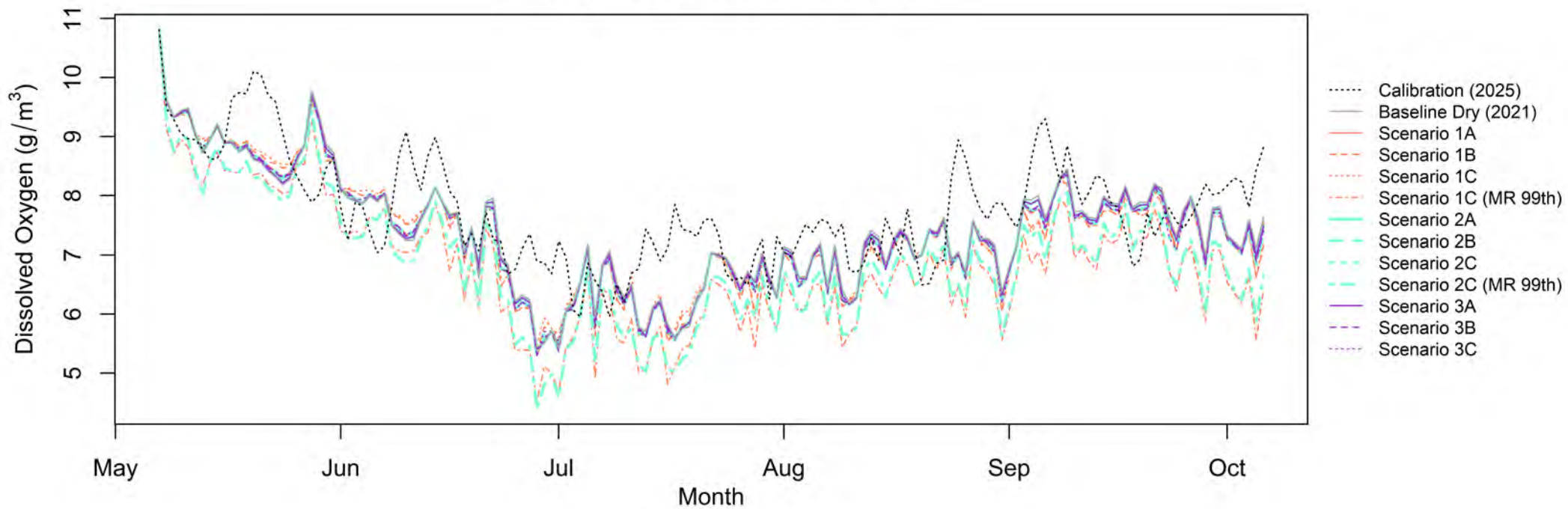
Charley Lake: Secchi Disk



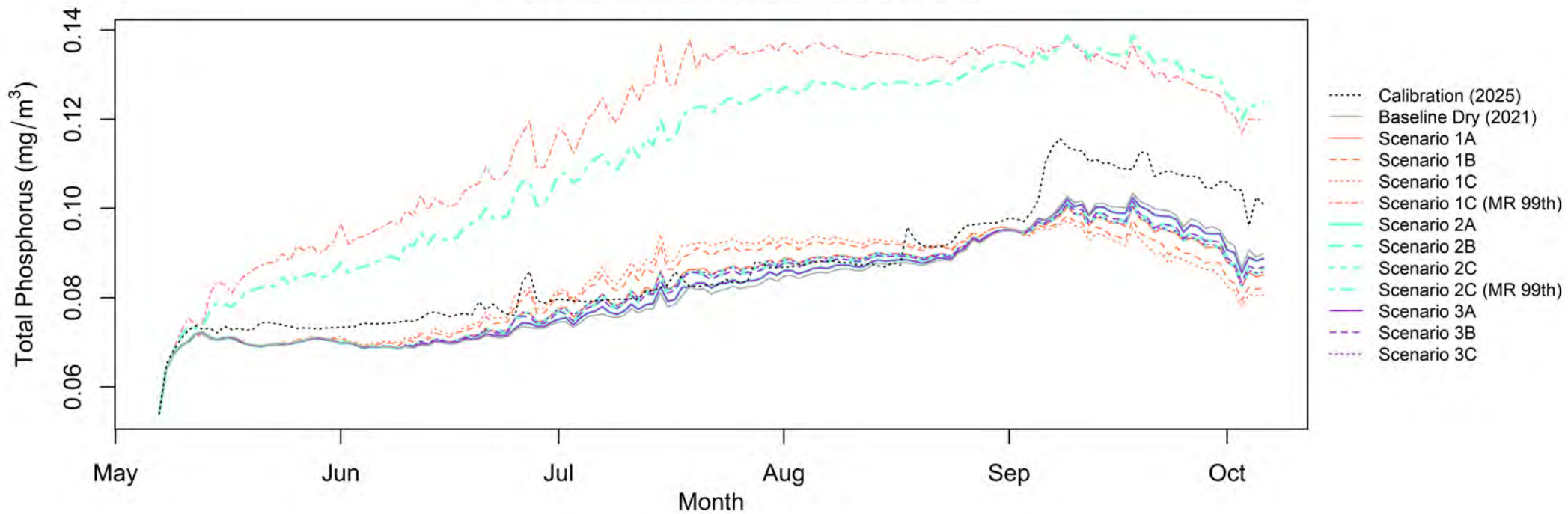
Charley Lake: Total Organic Carbon



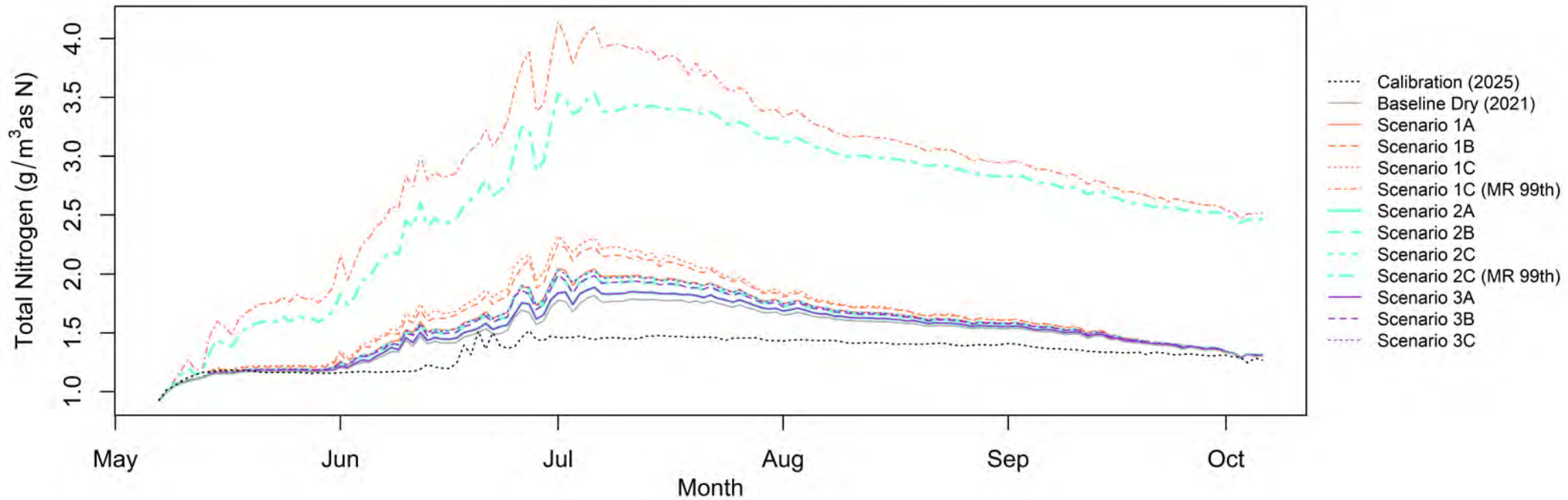
Charley Lake: Dissolved Oxygen



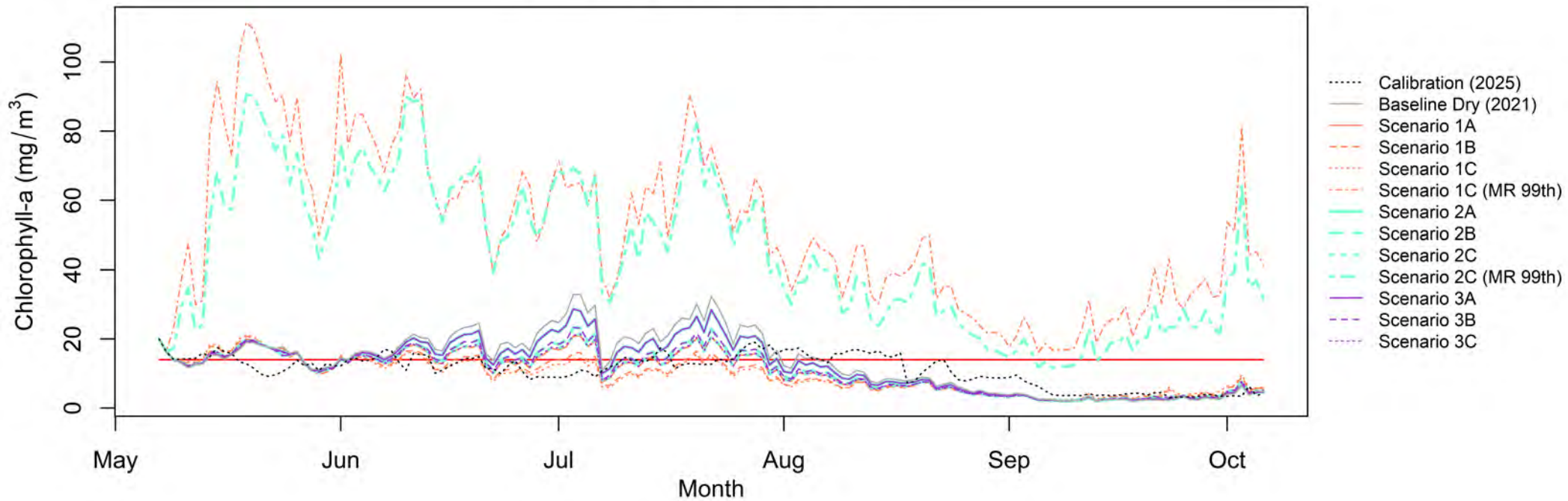
Pleasant Lake: Total Phosphorus



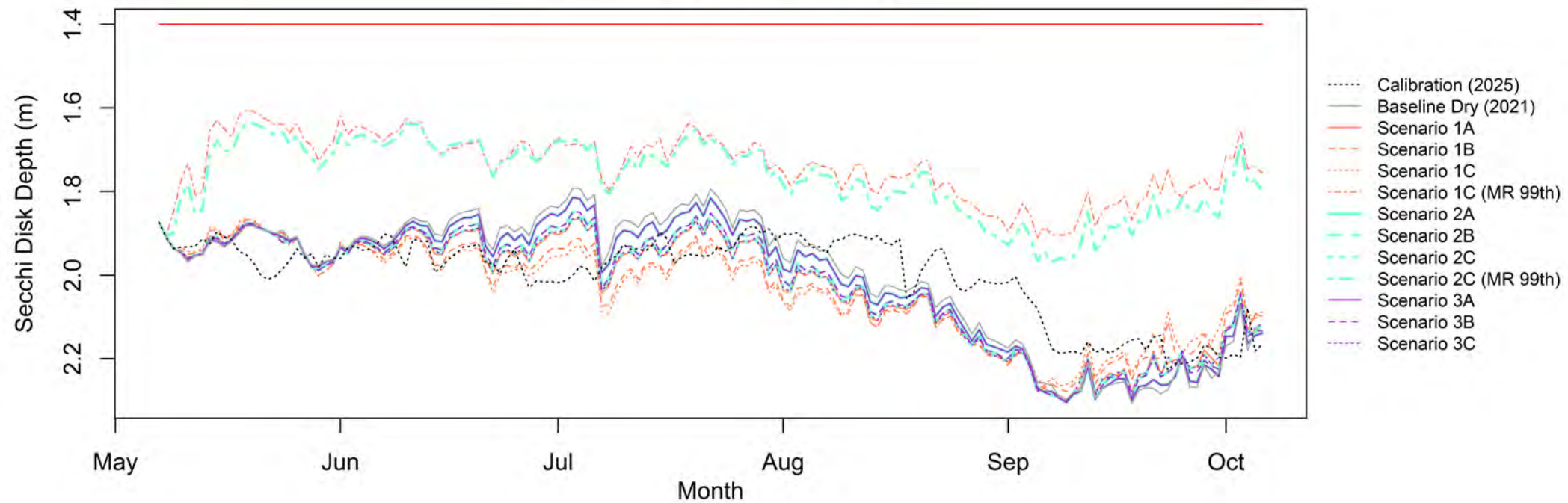
Pleasant Lake: Total Nitrogen



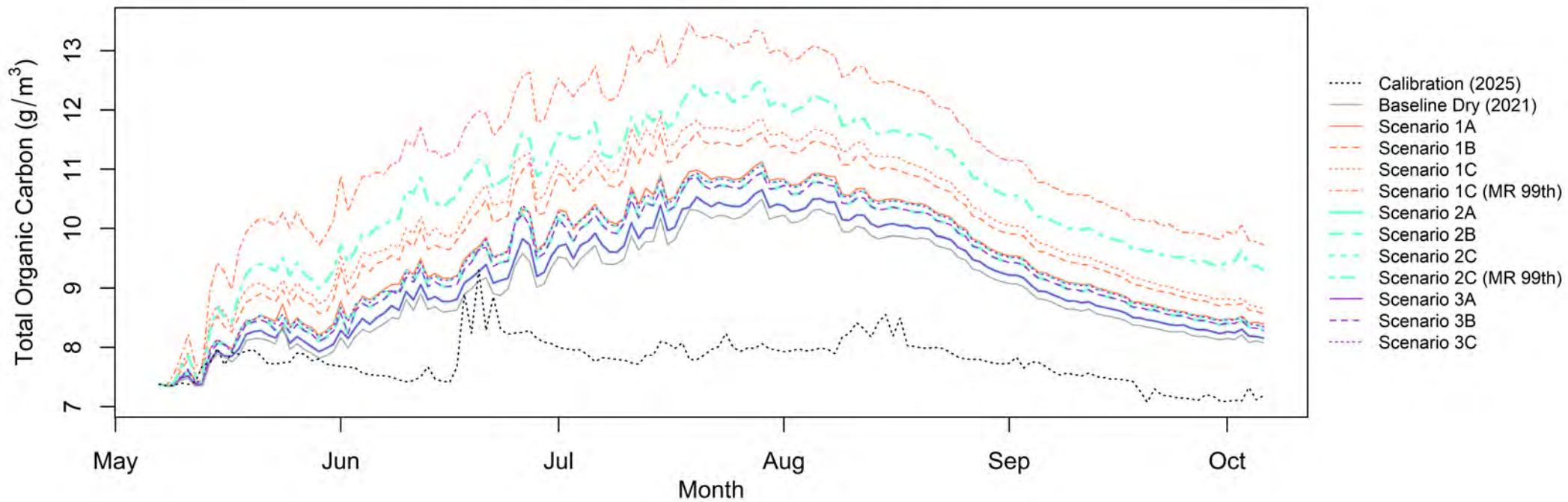
Pleasant Lake: Chlorophyll-a



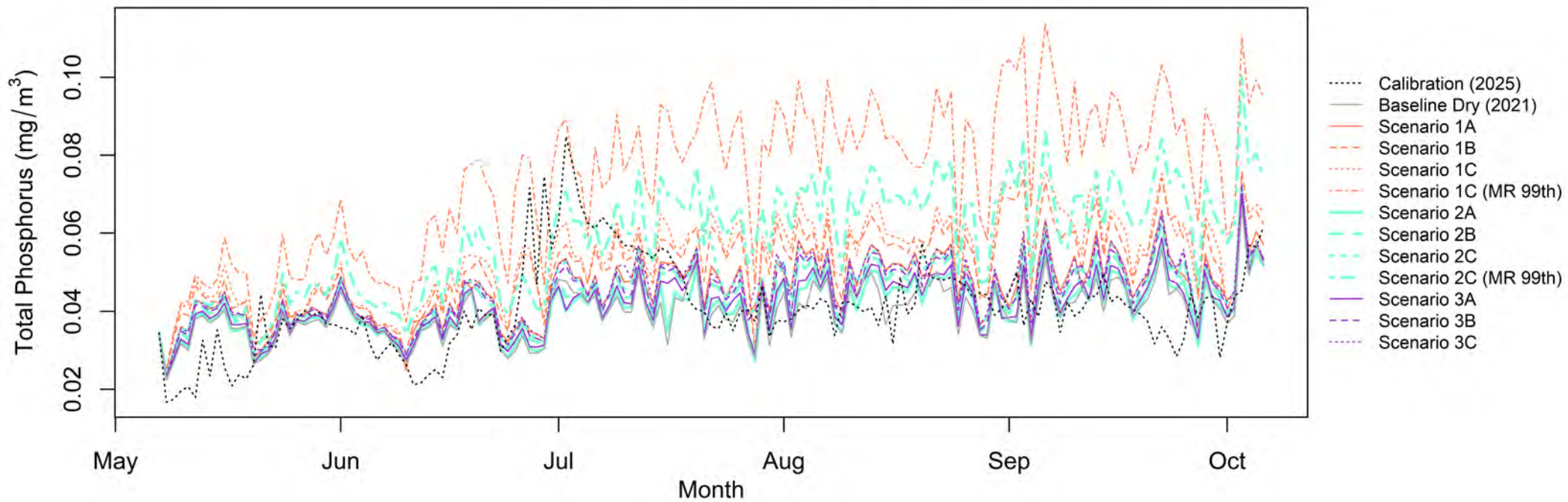
Pleasant Lake: Secchi Disk



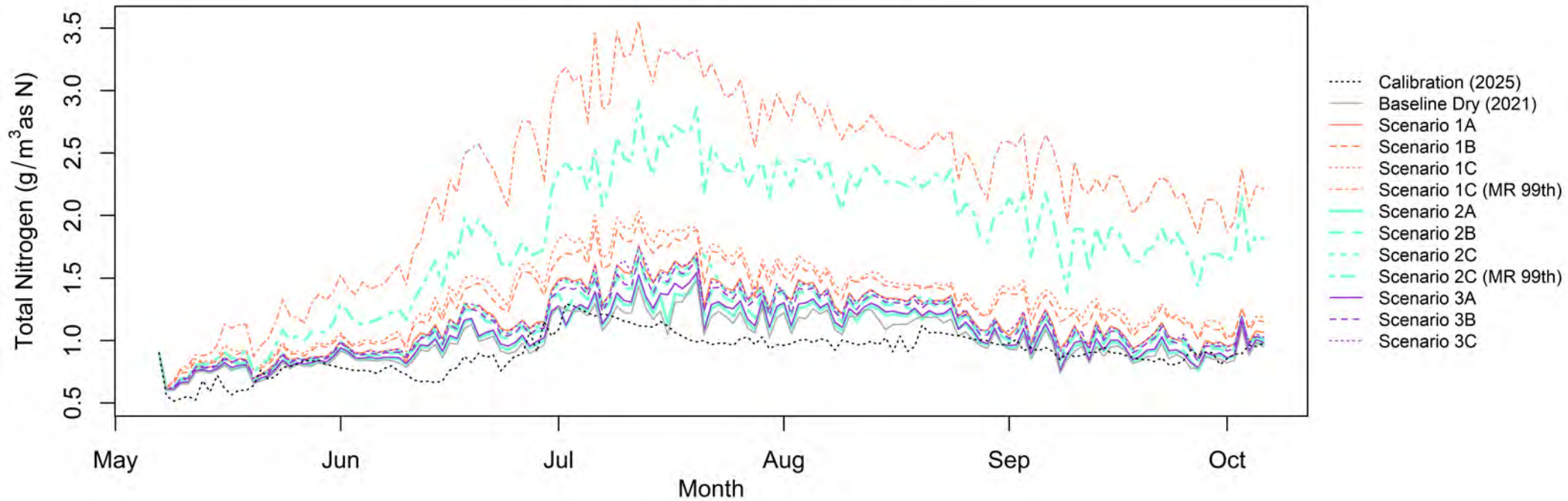
Pleasant Lake: Total Organic Carbon



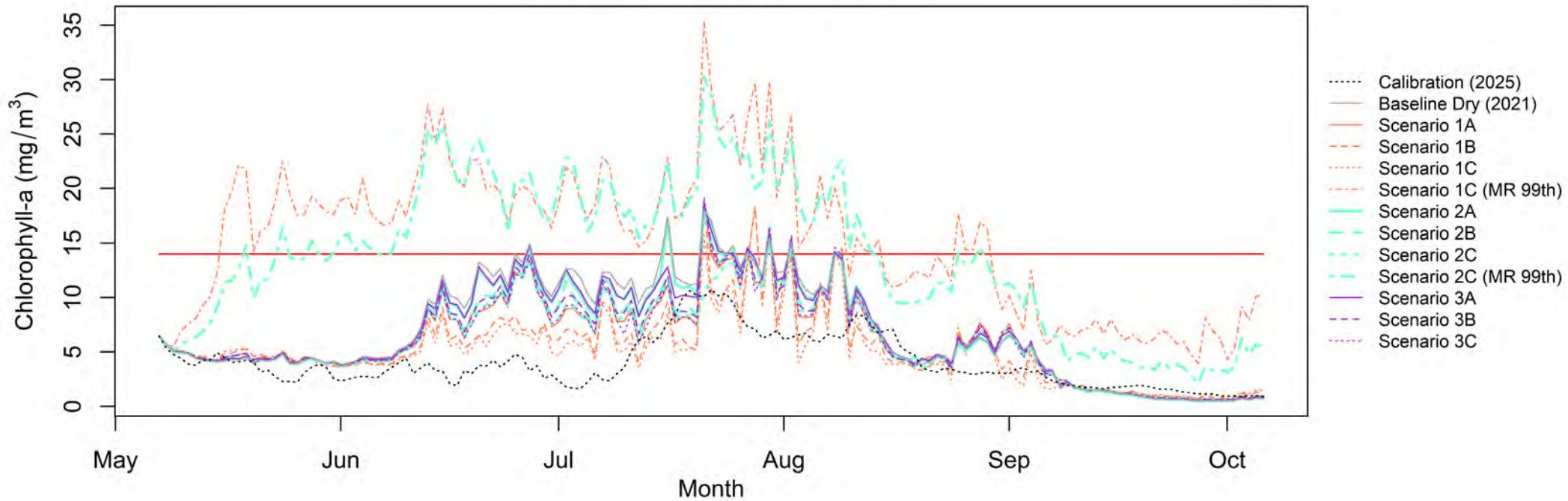
Sucker Lake: Total Phosphorus



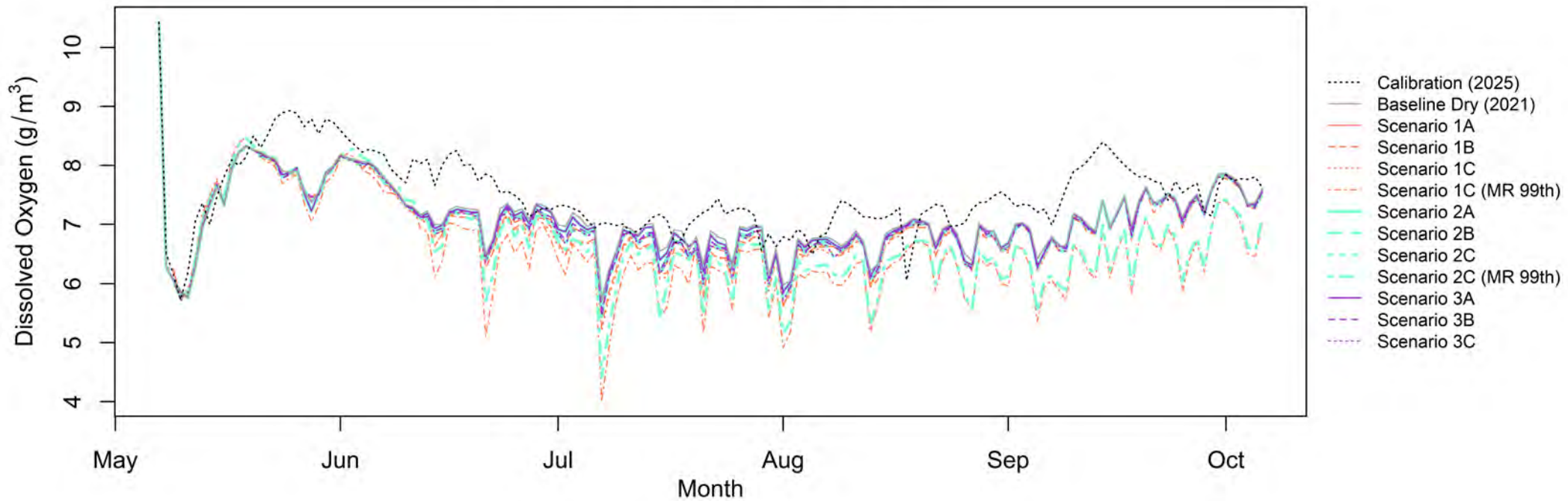
Sucker Lake: Total Nitrogen



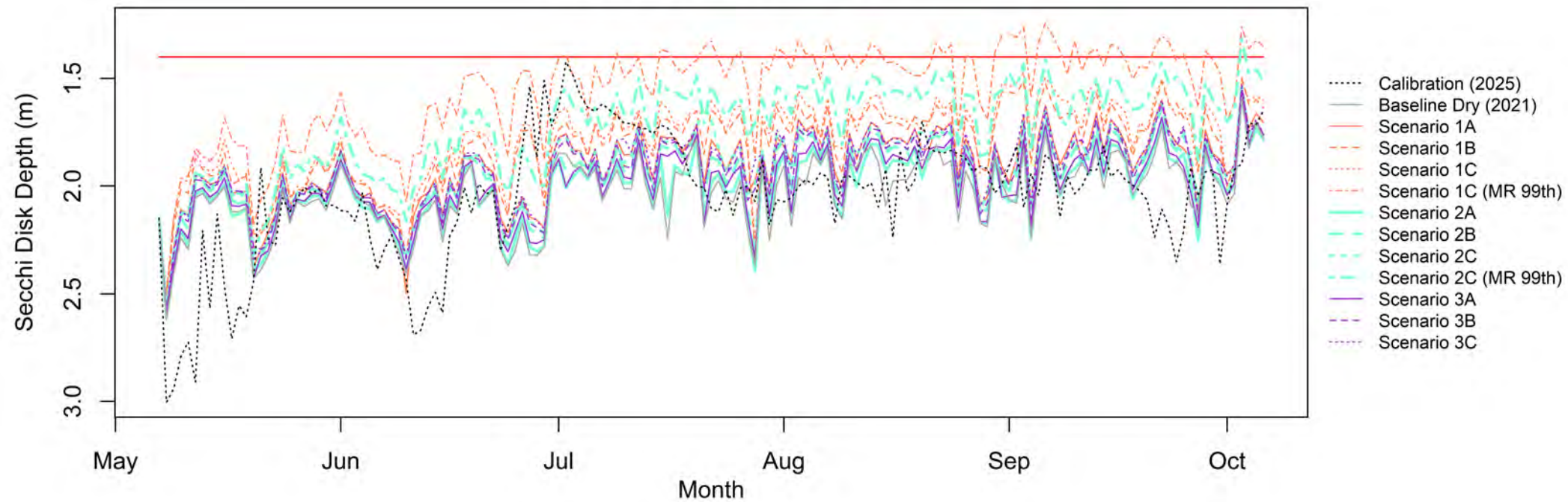
Sucker Lake: Chlorophyll-a



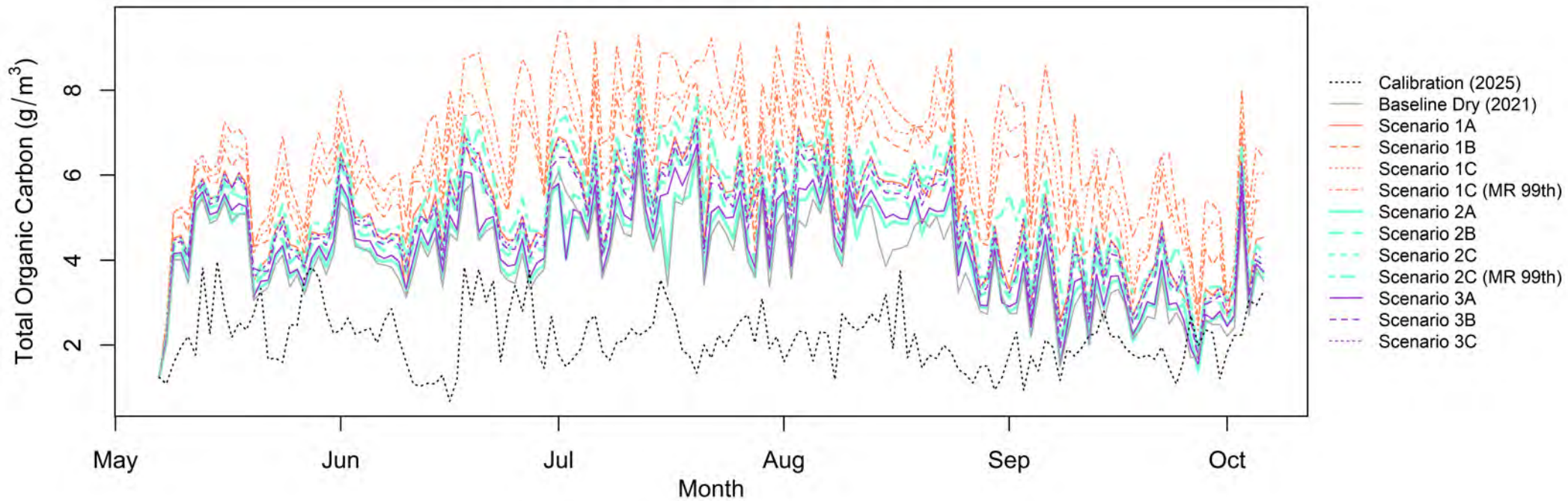
Pleasant Lake: Dissolved Oxygen



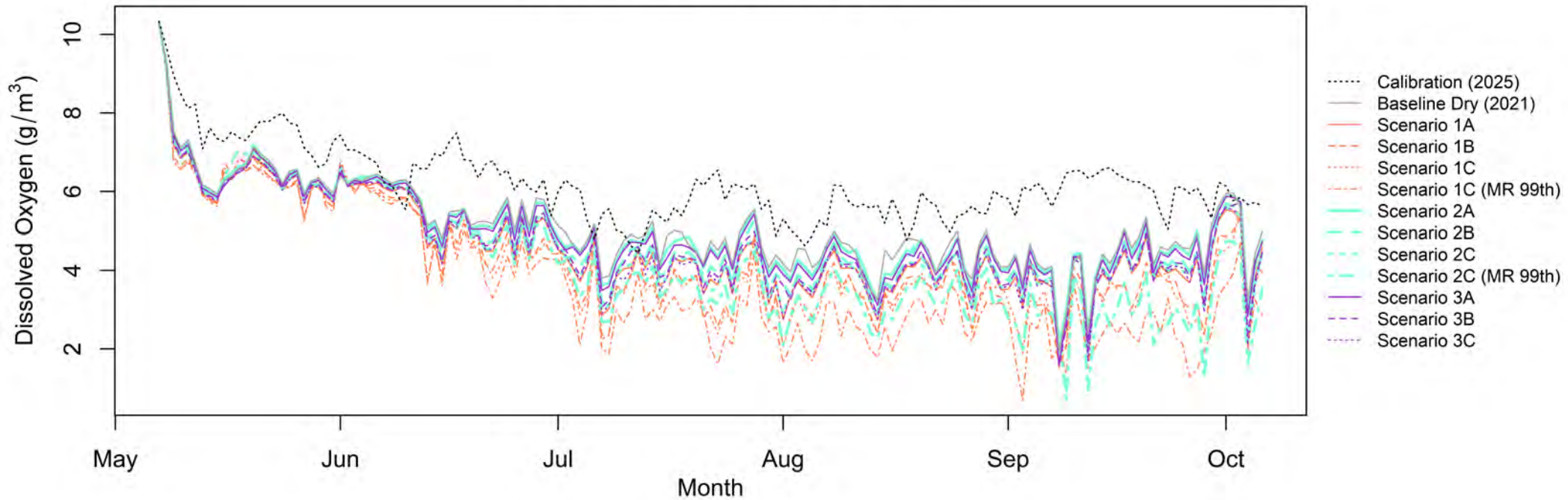
Sucker Lake: Secchi Disk



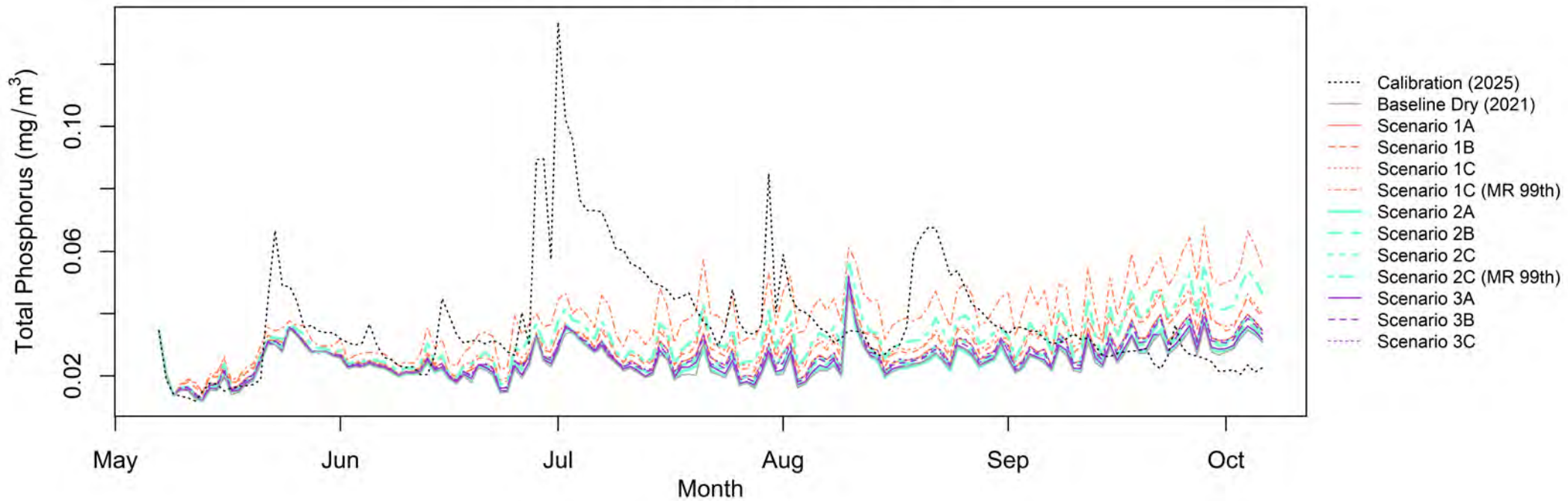
Sucker Lake: Total Organic Carbon



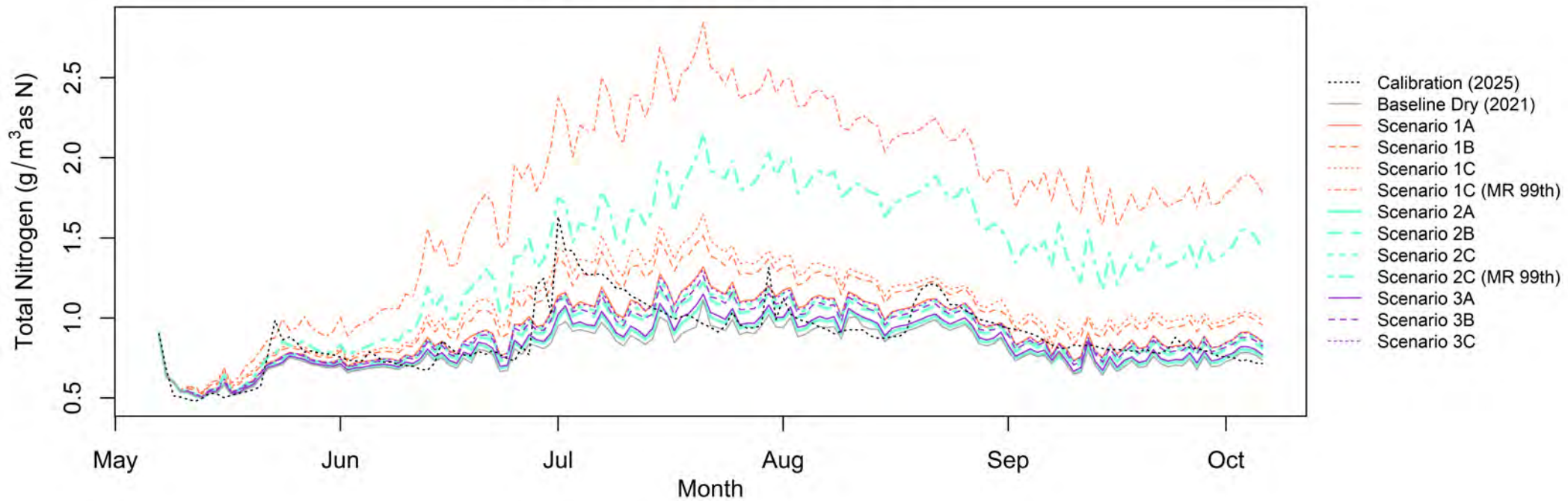
Sucker Lake: Dissolved Oxygen



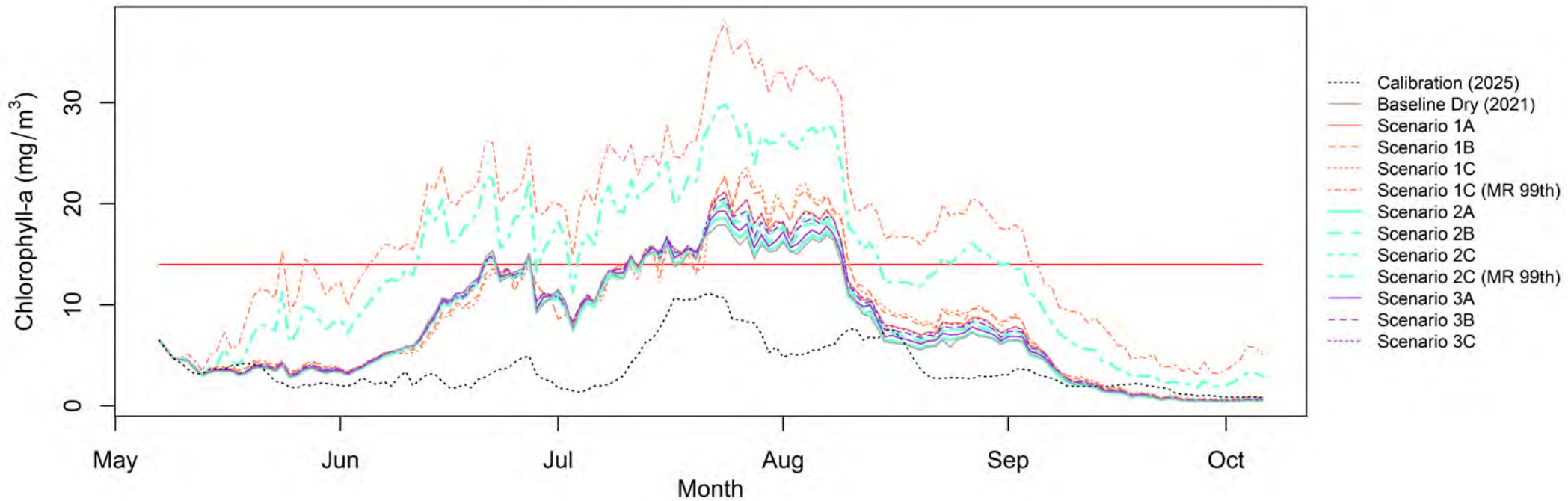
East Vadnais Lake: Total Phosphorus



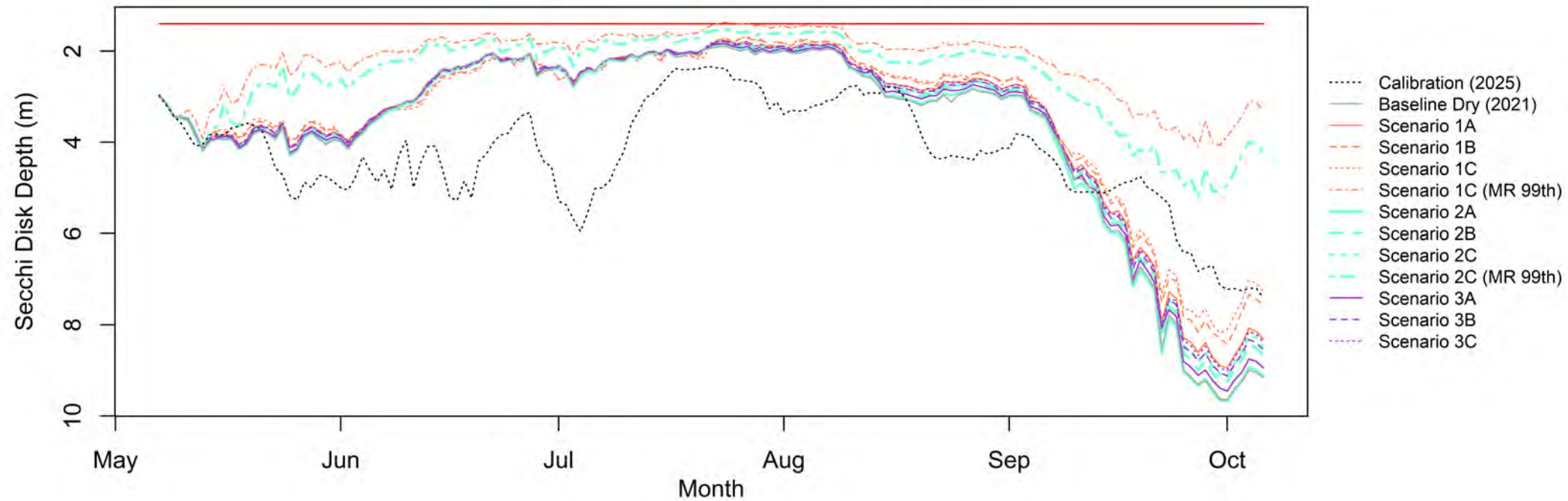
East Vadnais Lake: Total Nitrogen



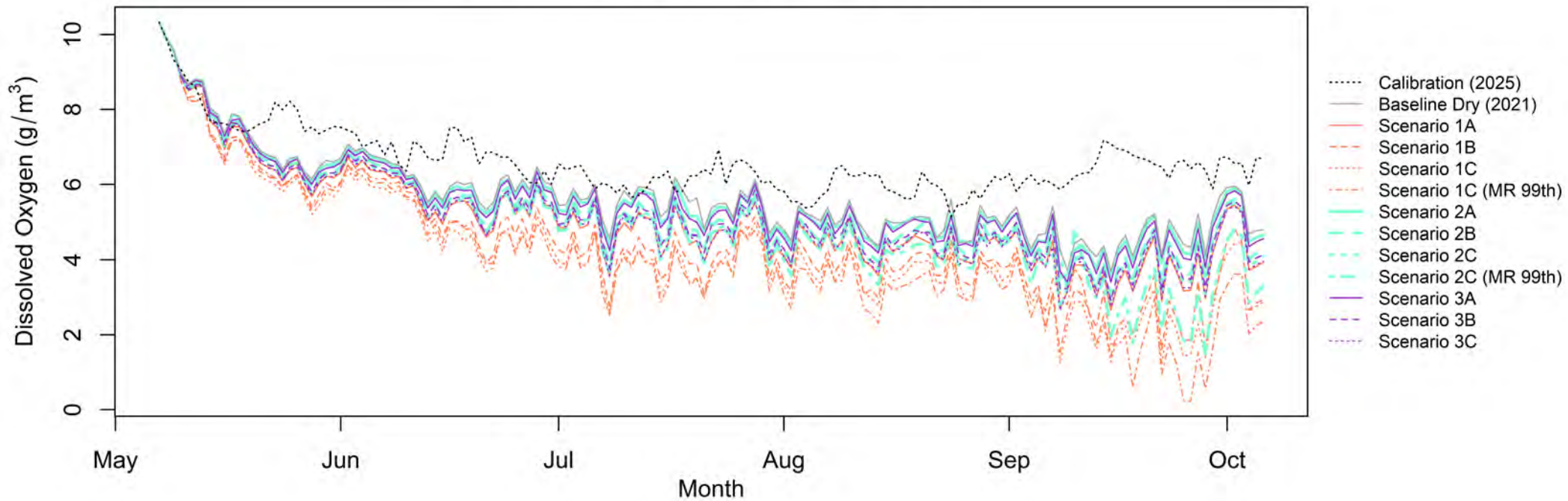
East Vadnais Lake: Chlorophyll-a



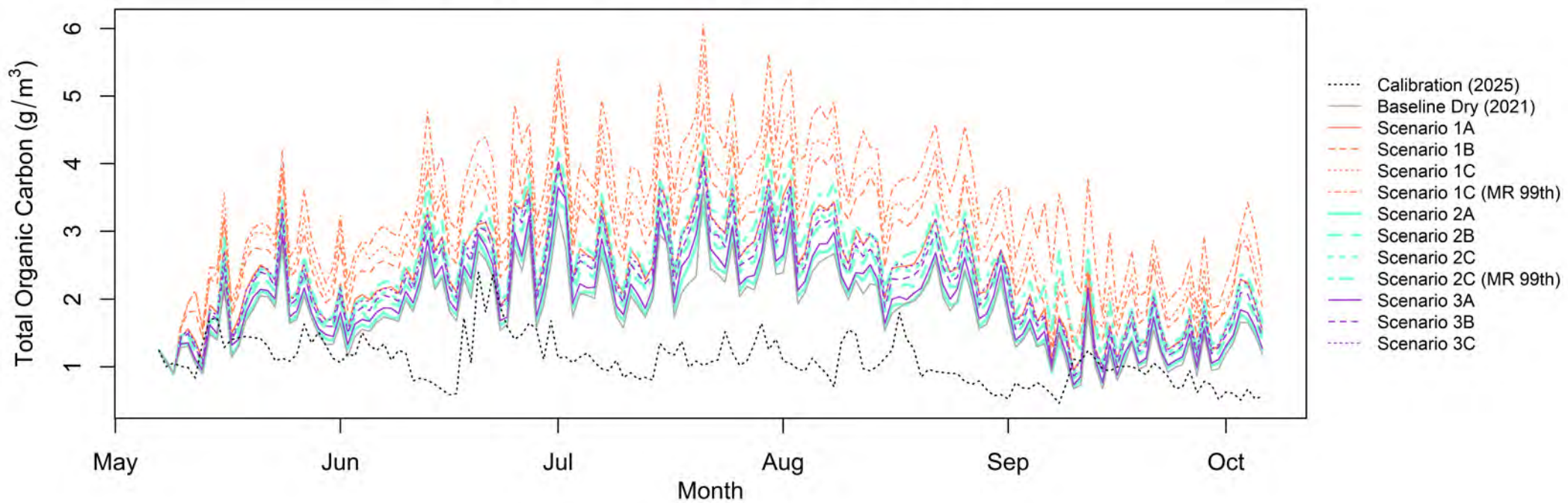
East Vadnais Lake: Secchi Disk



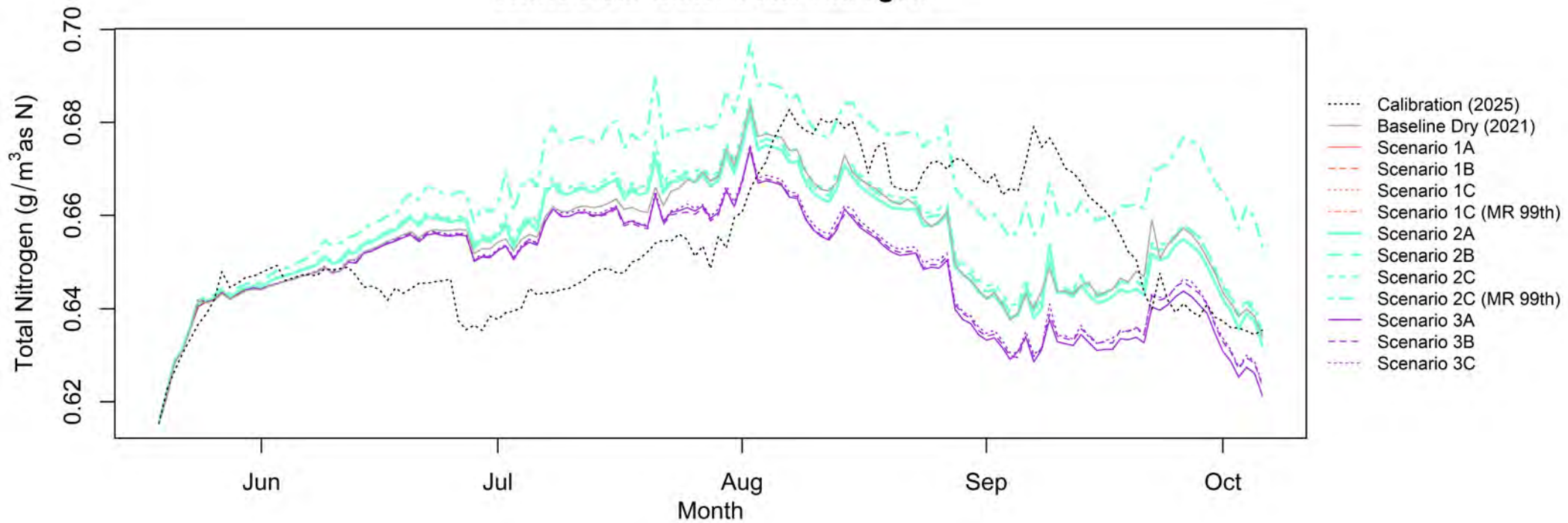
East Vadnais Lake: Dissolved Oxygen



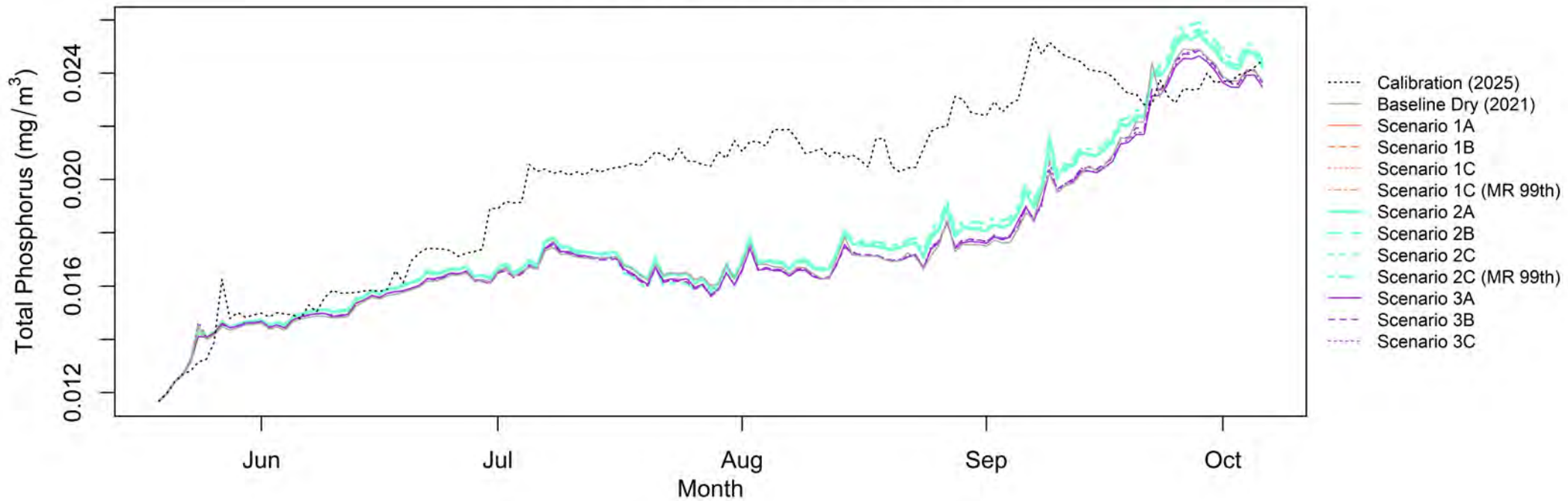
East Vadnais Lake: Total Organic Carbon



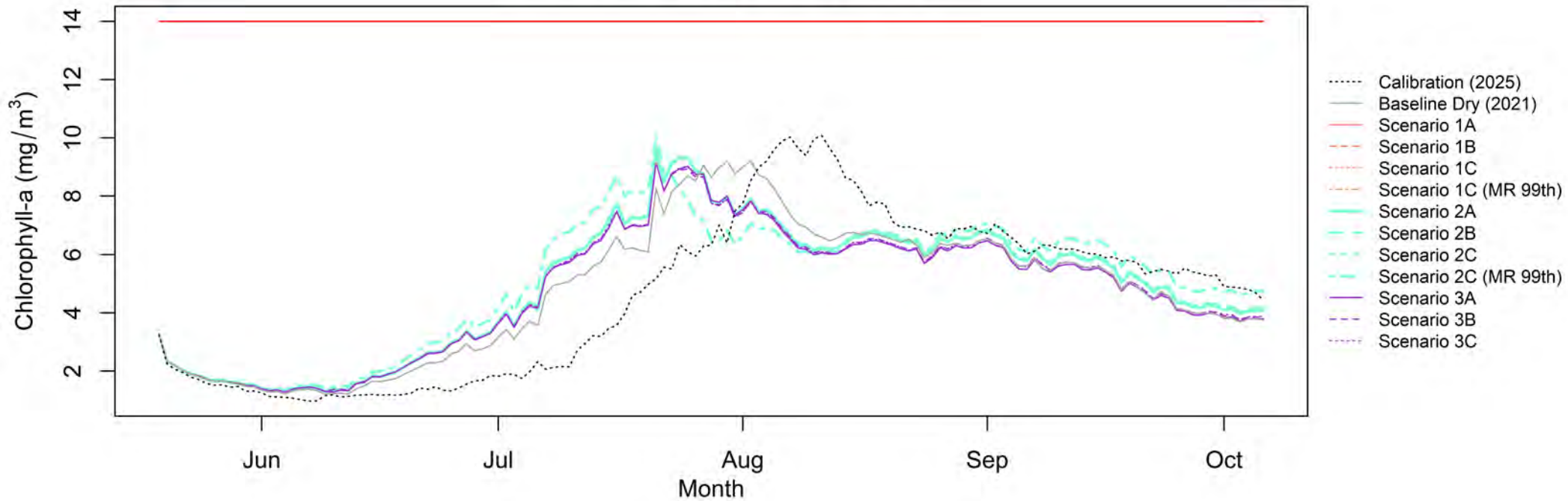
White Bear Lake: Total Nitrogen



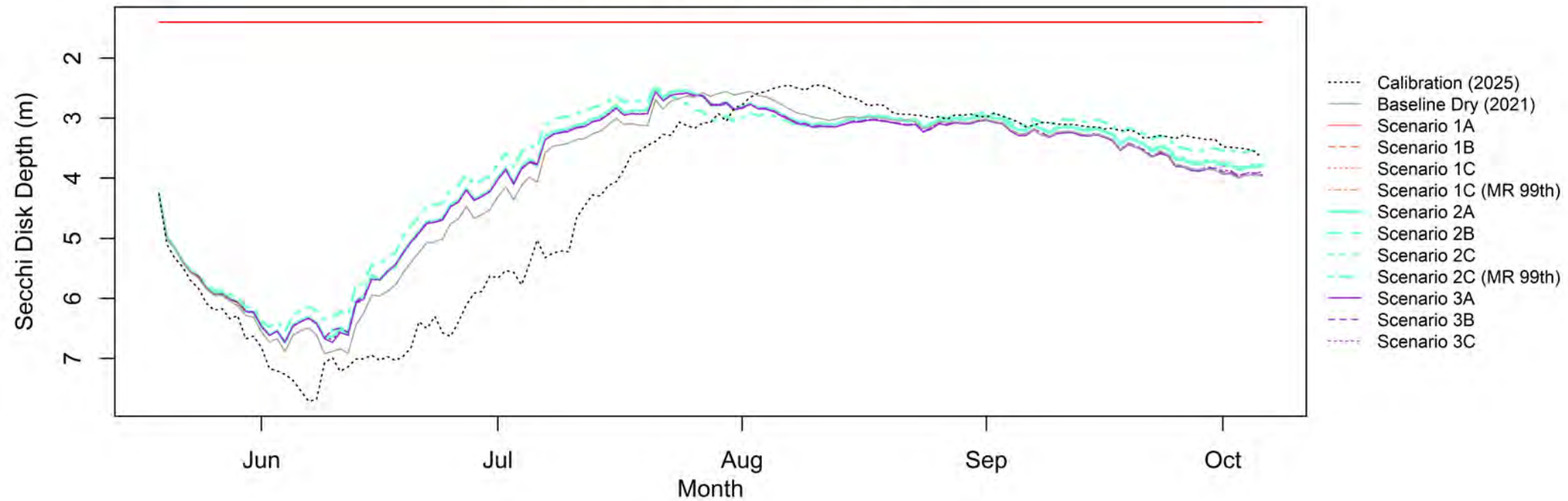
White Bear Lake: Total Phosphorus



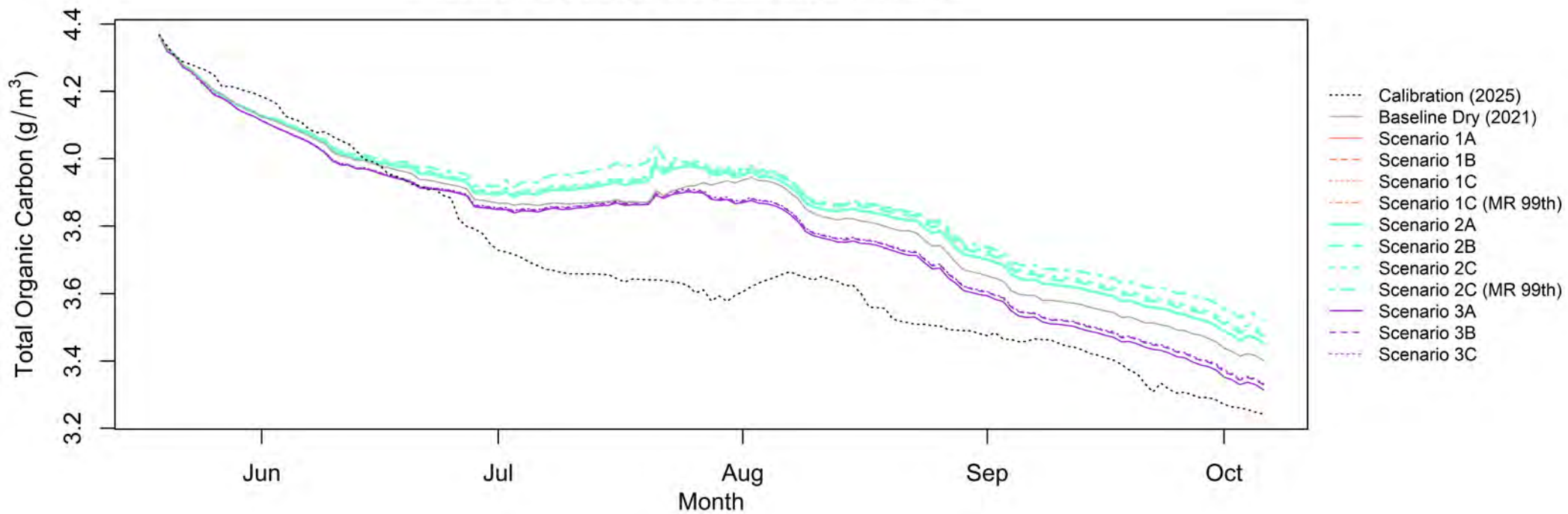
White Bear Lake: Chlorophyll-a



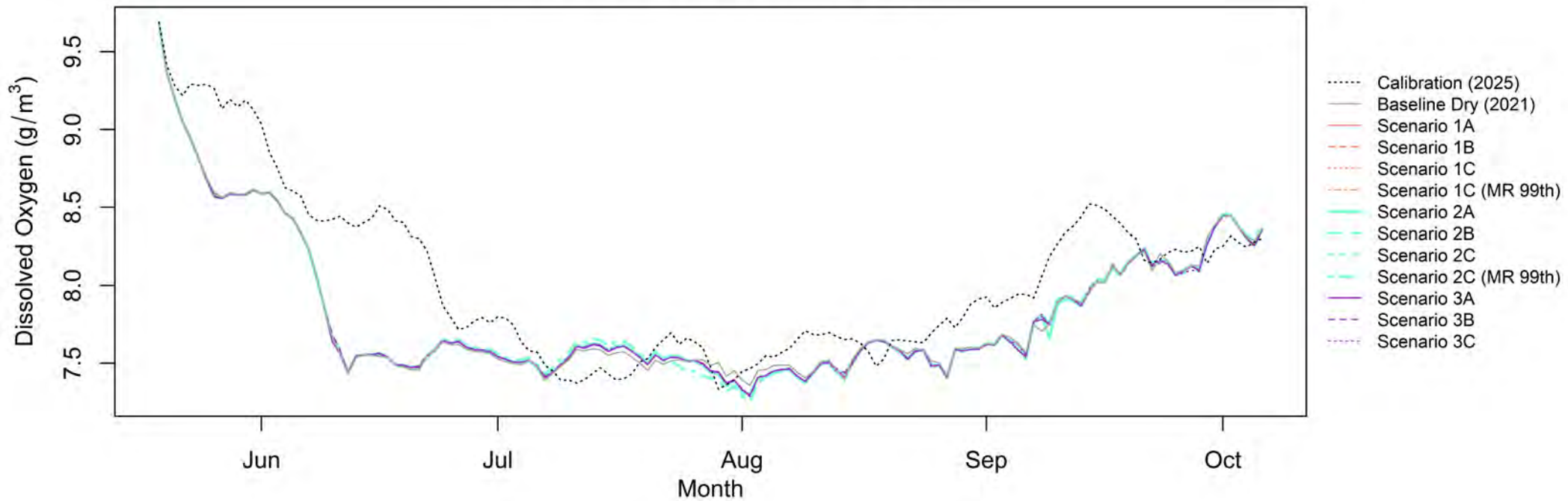
White Bear Lake: Secchi Disk



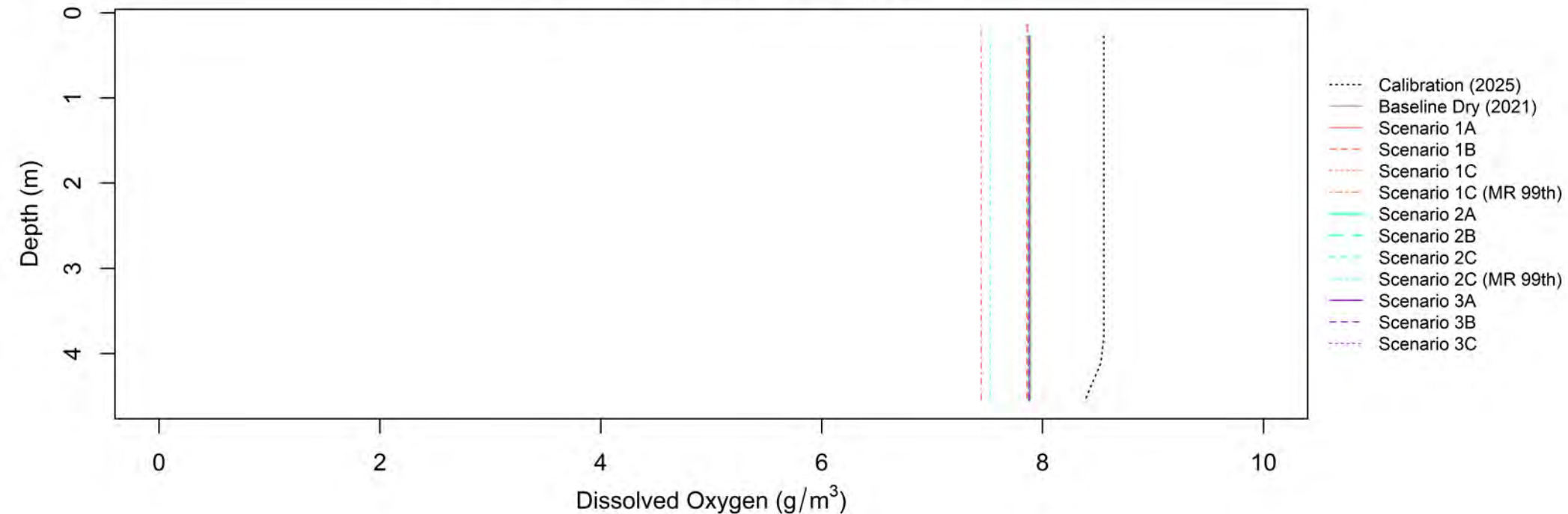
White Bear Lake: Total Organic Carbon



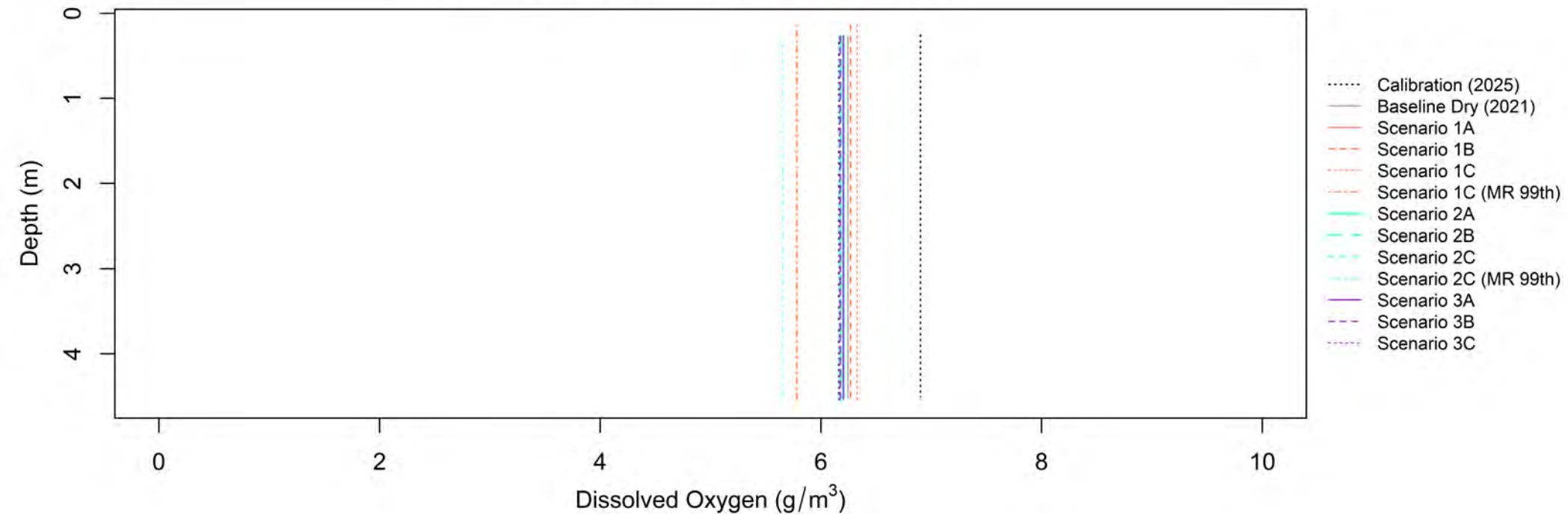
White Bear Lake: Dissolved Oxygen



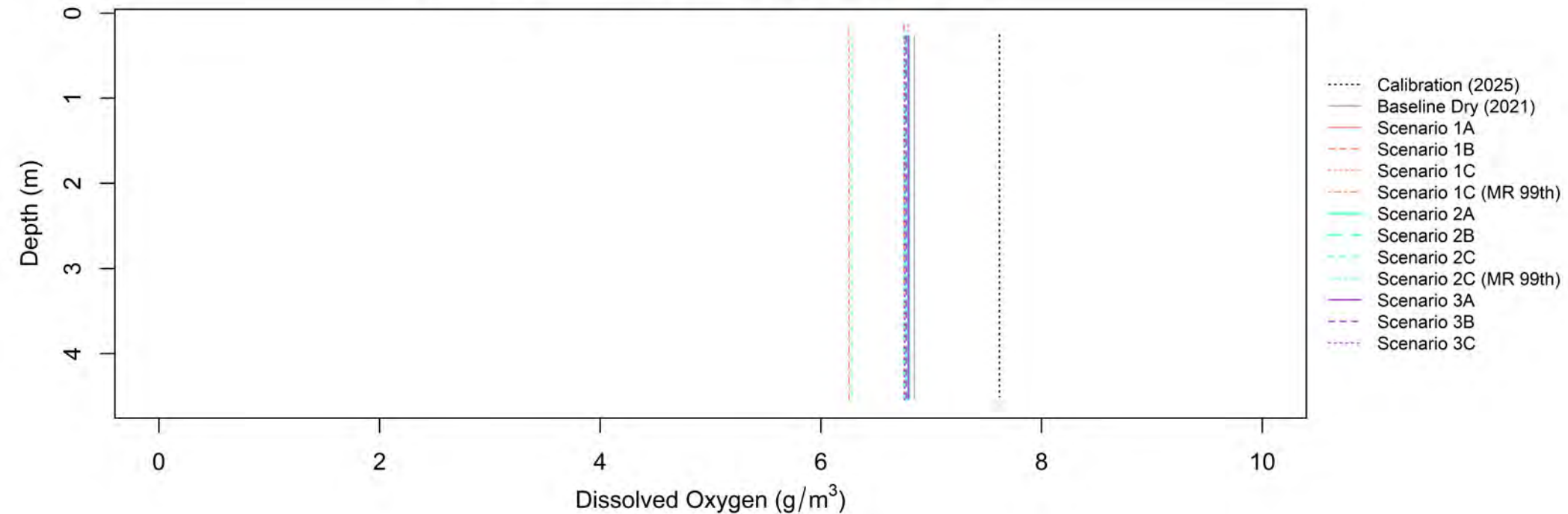
Charley Lake: Dissolved Oxygen (June)



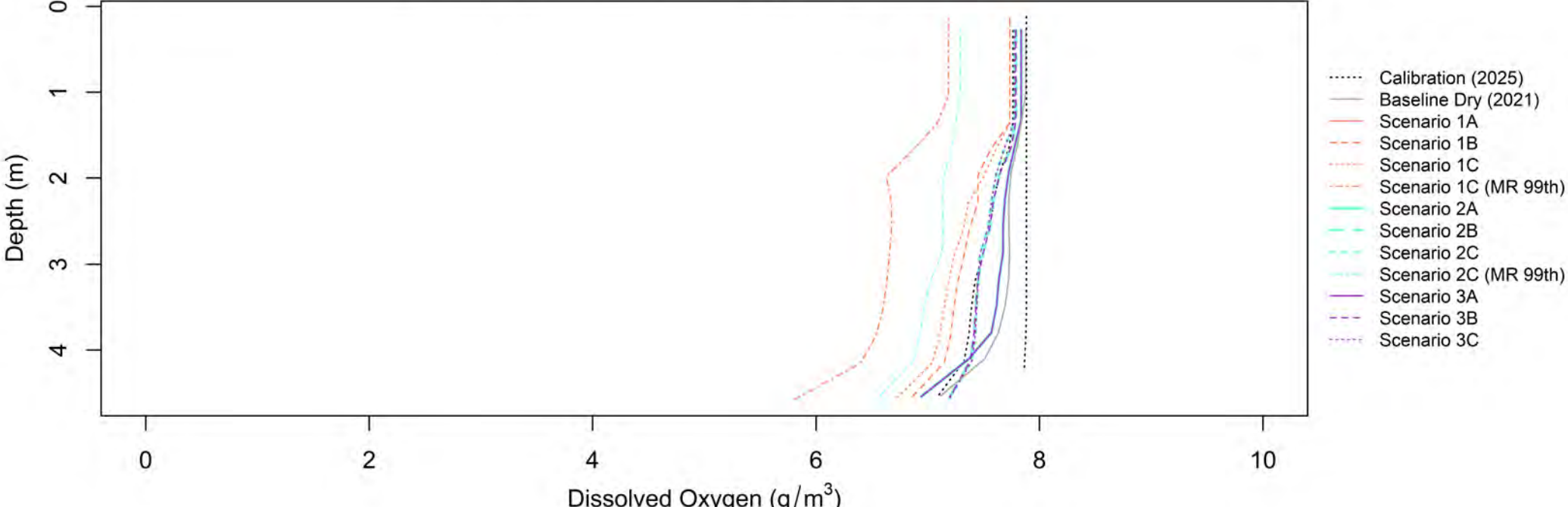
Charley Lake: Dissolved Oxygen (July)



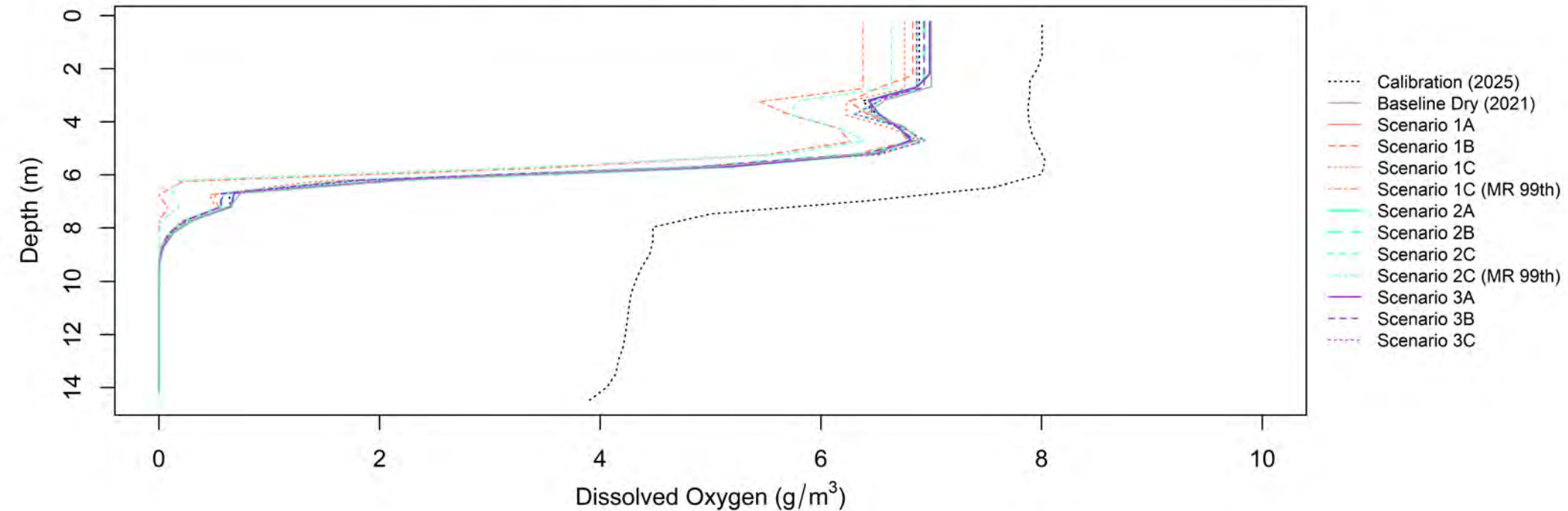
Charley Lake: Dissolved Oxygen (August)



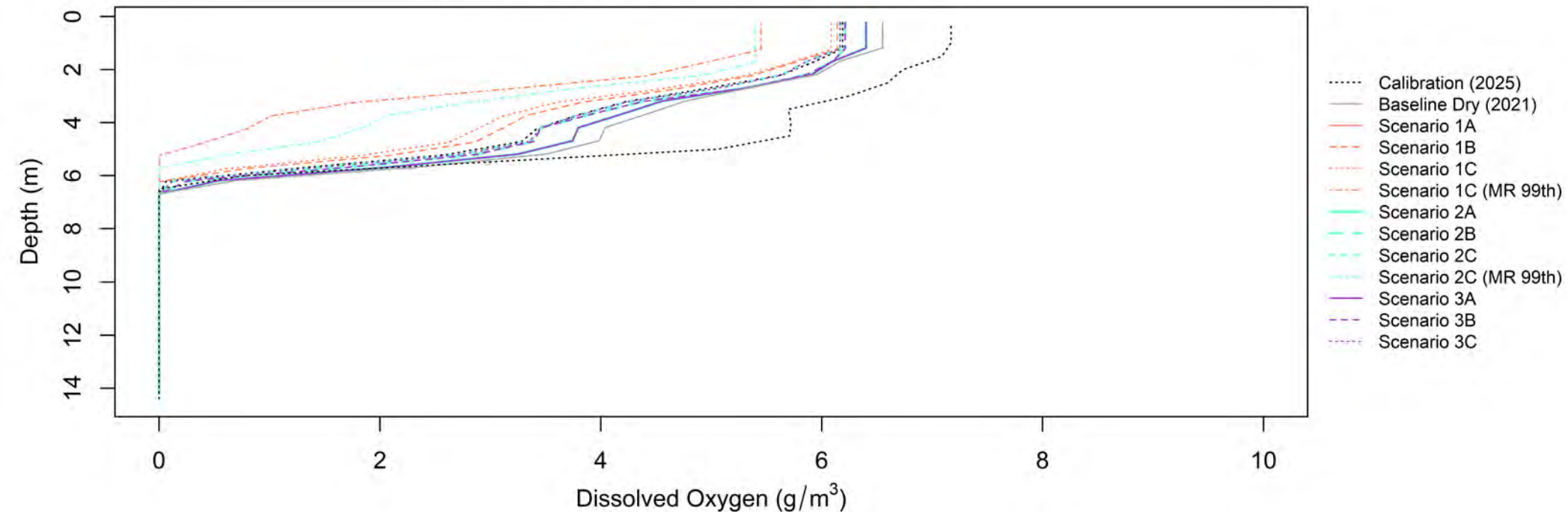
Charley Lake: Dissolved Oxygen (September)



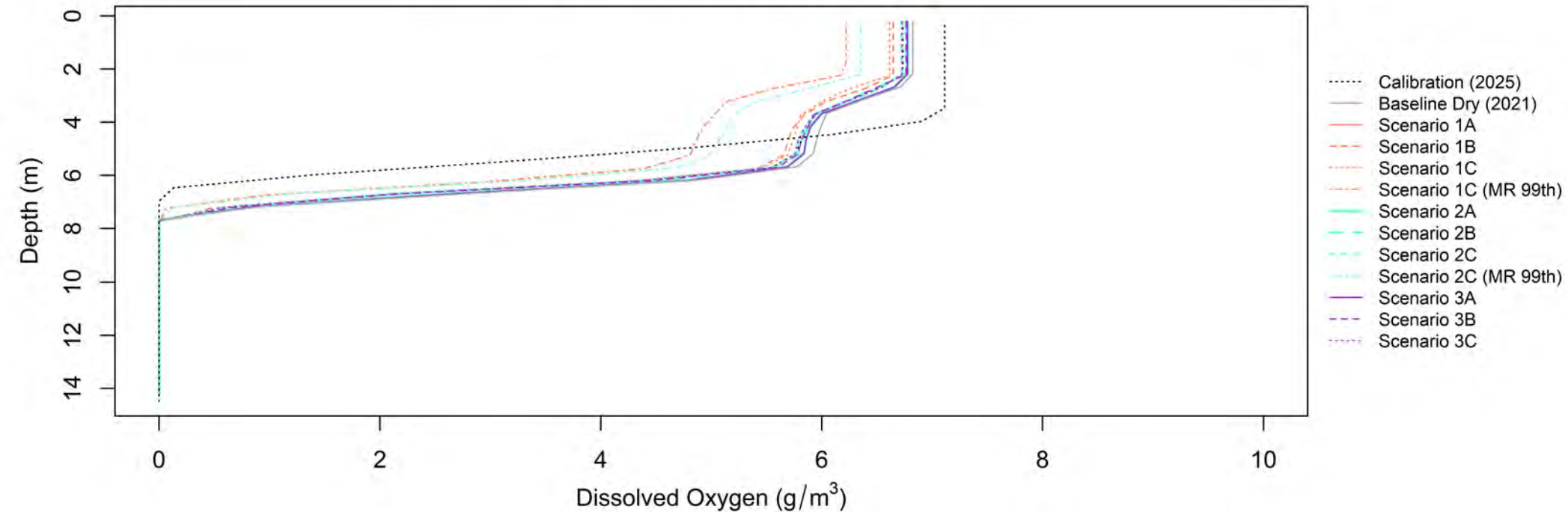
Pleasant Lake: Dissolved Oxygen (June)



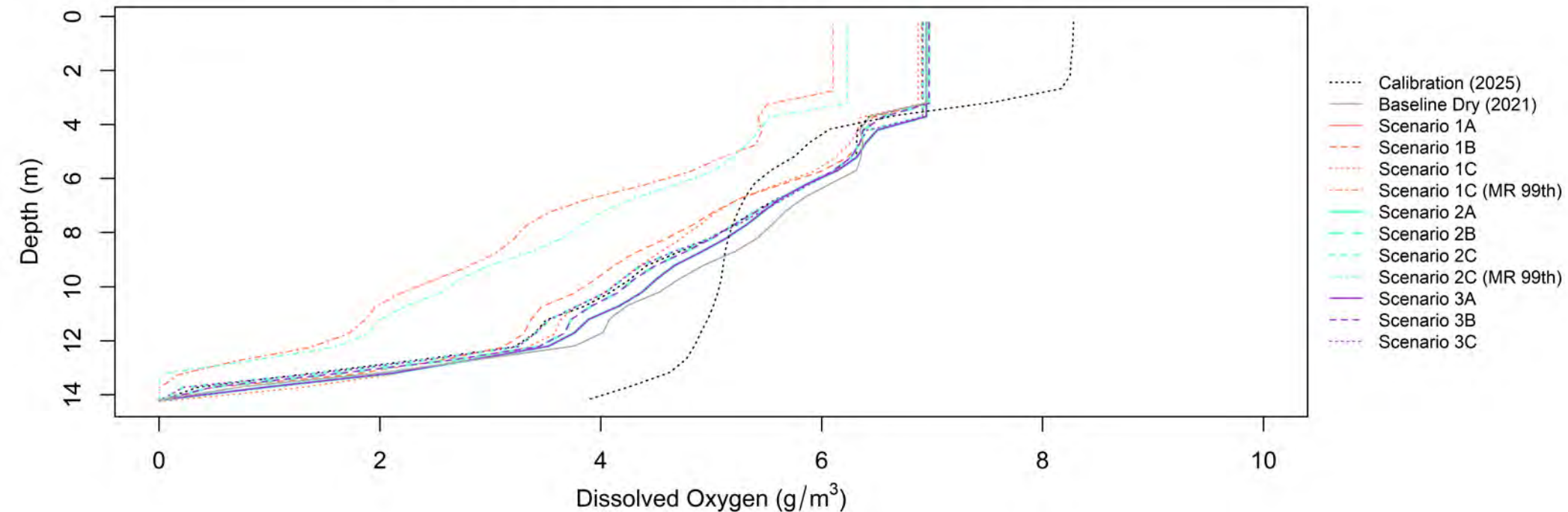
Pleasant Lake: Dissolved Oxygen (July)



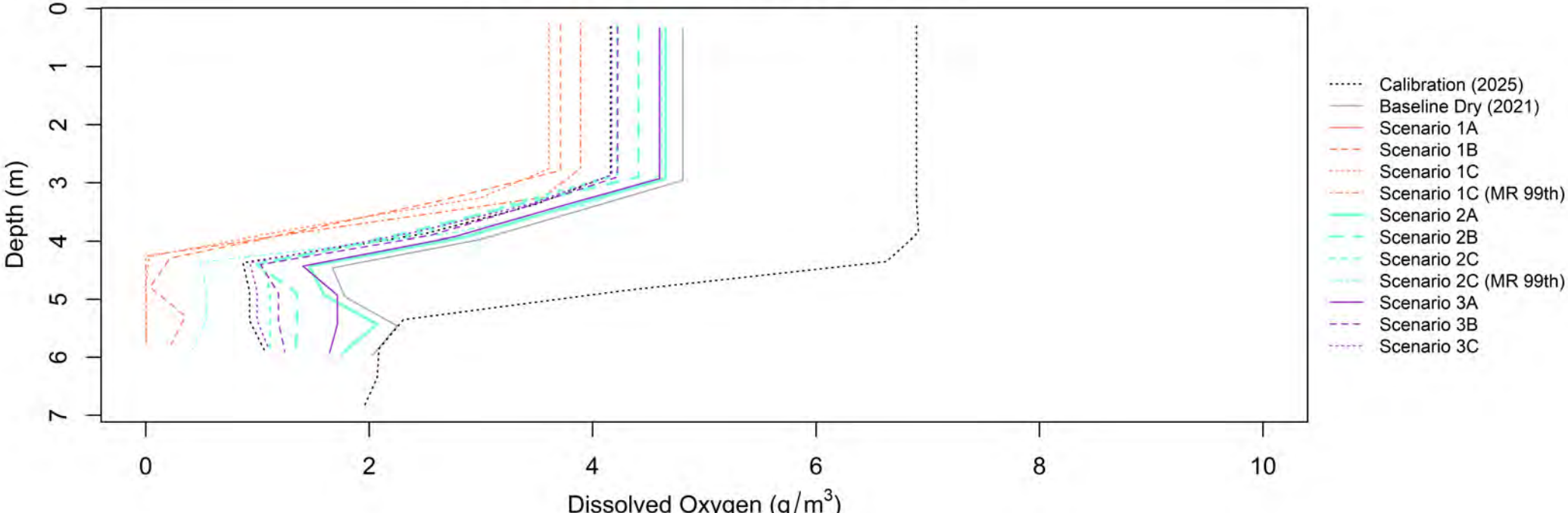
Pleasant Lake: Dissolved Oxygen (August)



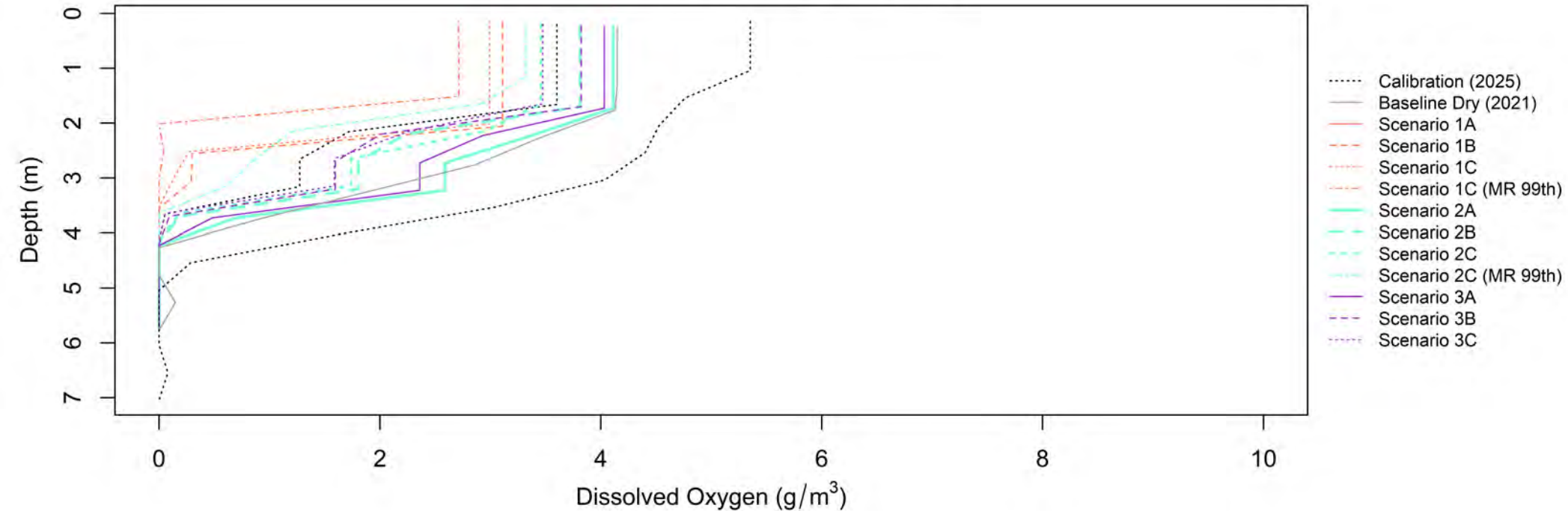
Pleasant Lake: Dissolved Oxygen (September)



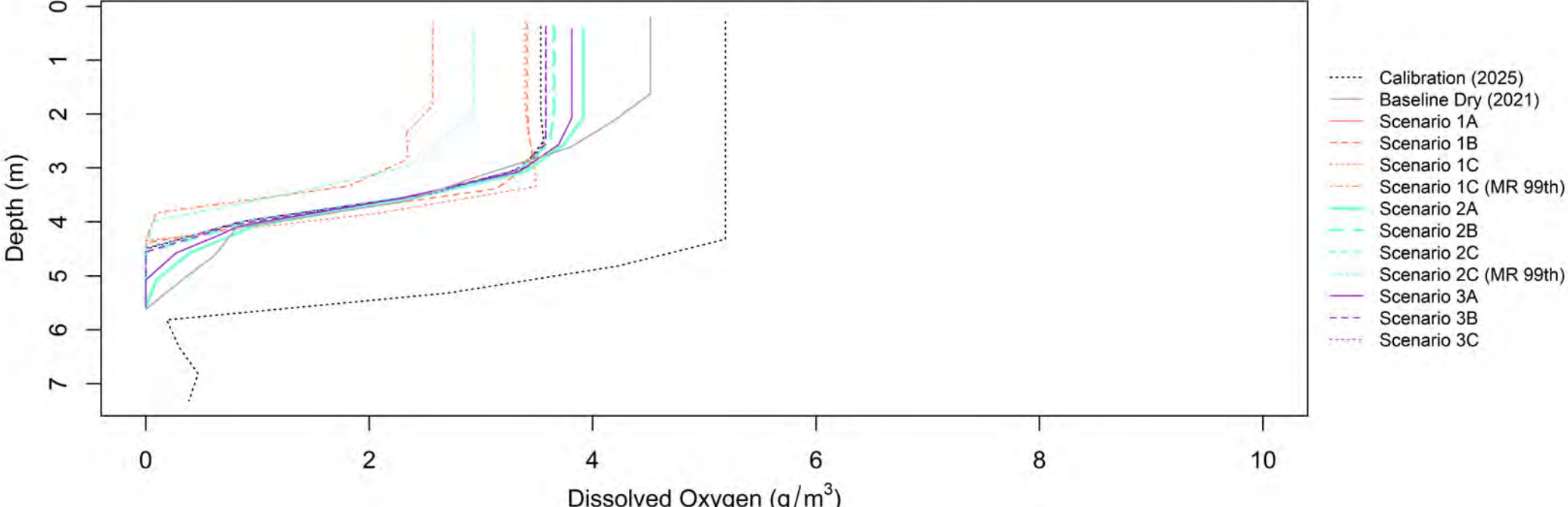
Sucker Lake: Dissolved Oxygen (June)



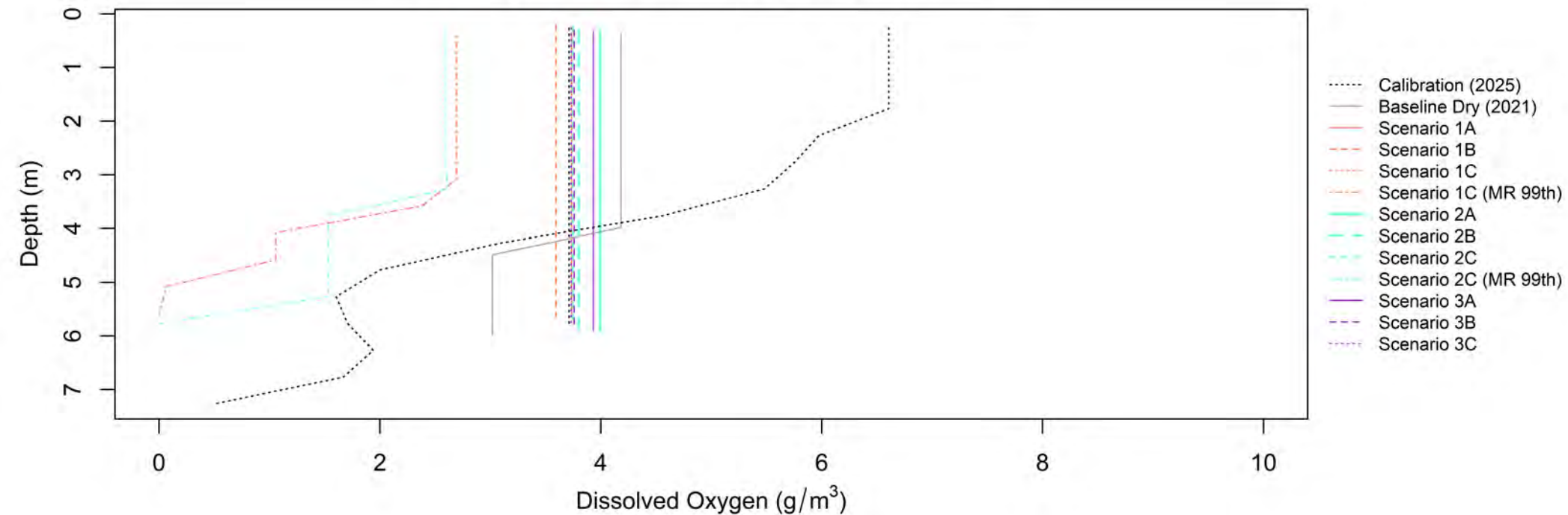
Sucker Lake: Dissolved Oxygen (July)



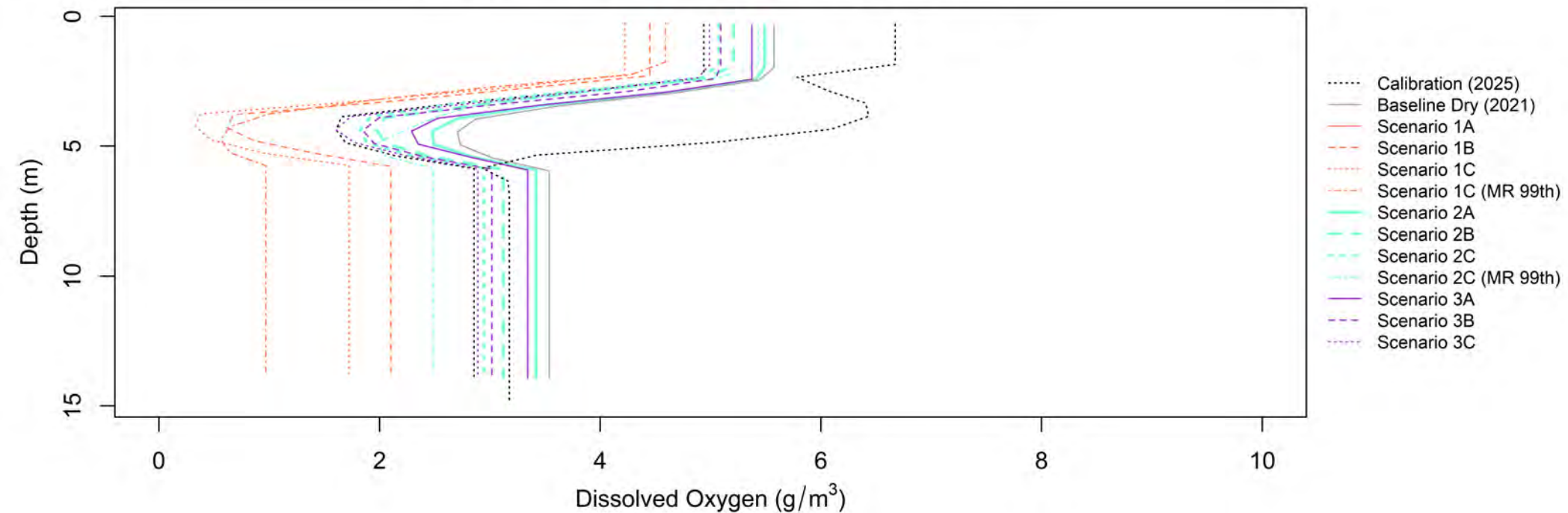
Sucker Lake: Dissolved Oxygen (August)



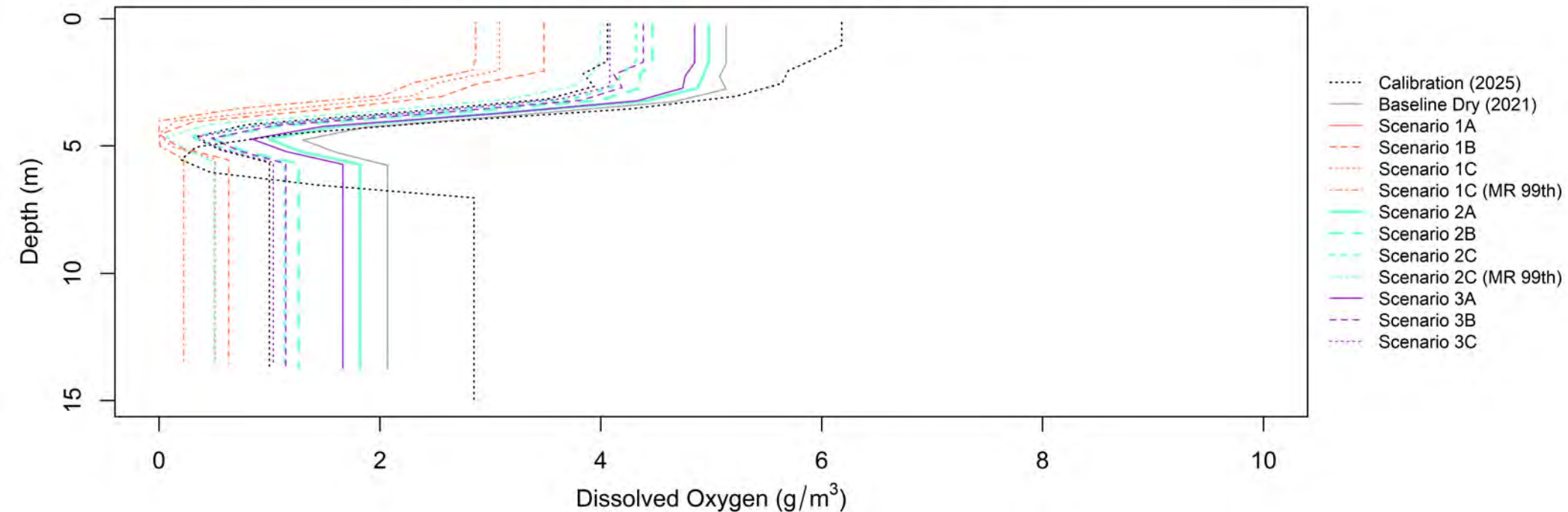
Sucker Lake: Dissolved Oxygen (September)



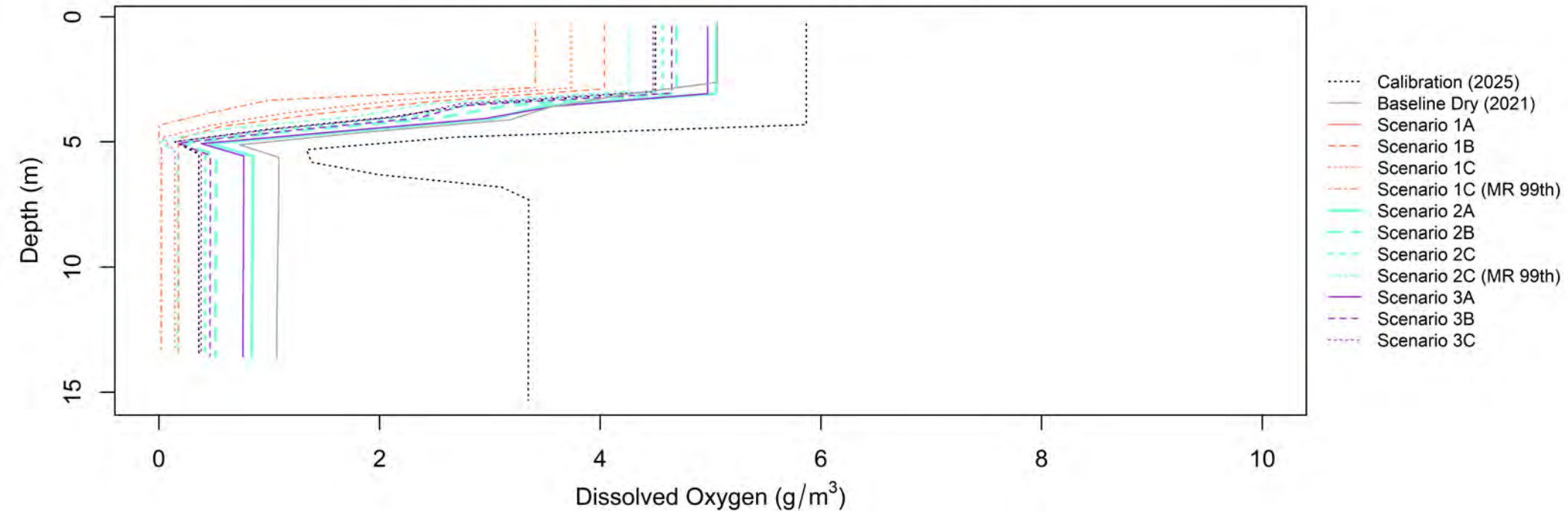
East Vadnais Lake: Dissolved Oxygen (June)



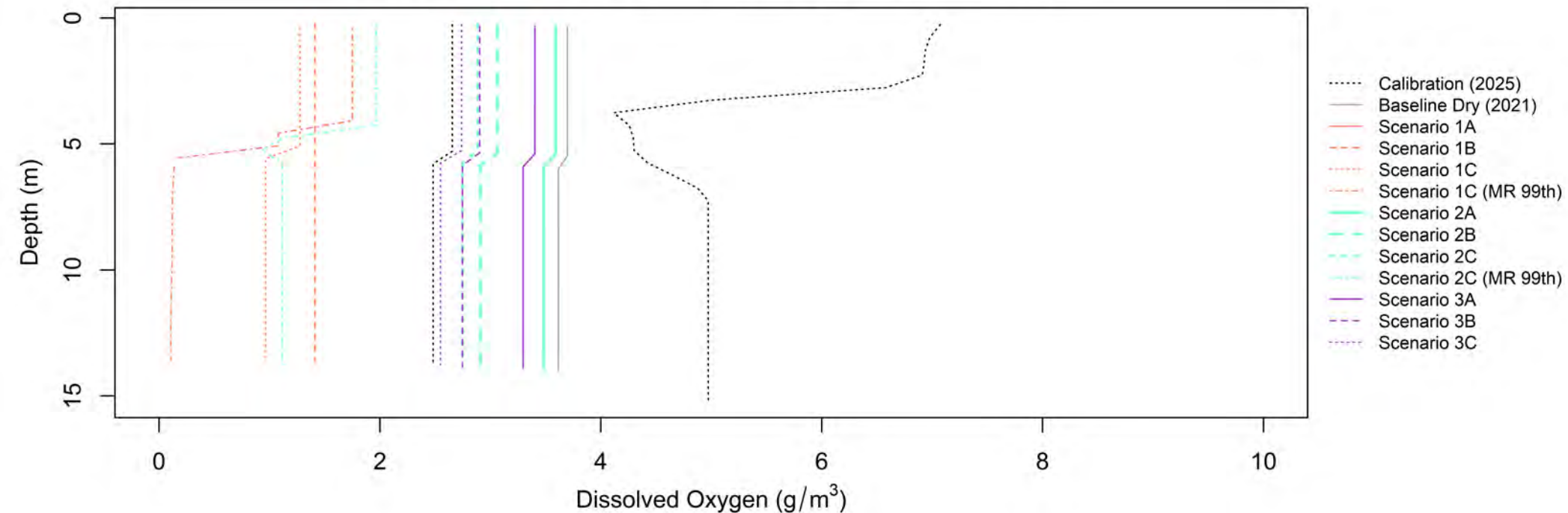
East Vadnais Lake: Dissolved Oxygen (July)



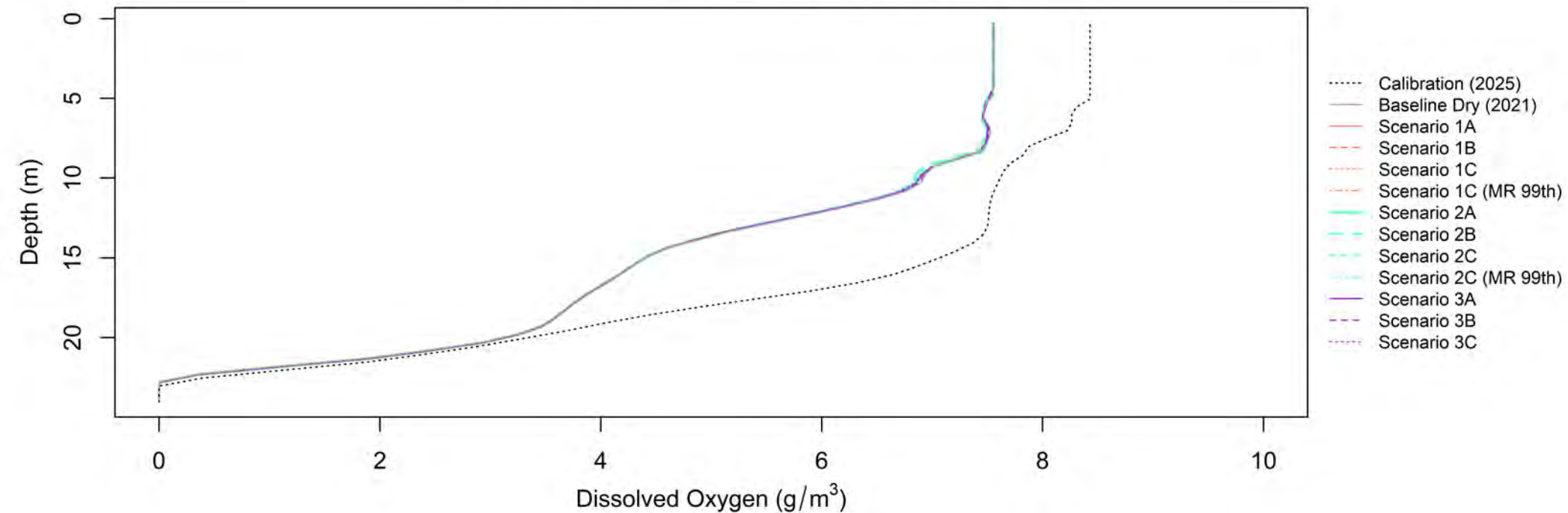
East Vadnais Lake: Dissolved Oxygen (August)



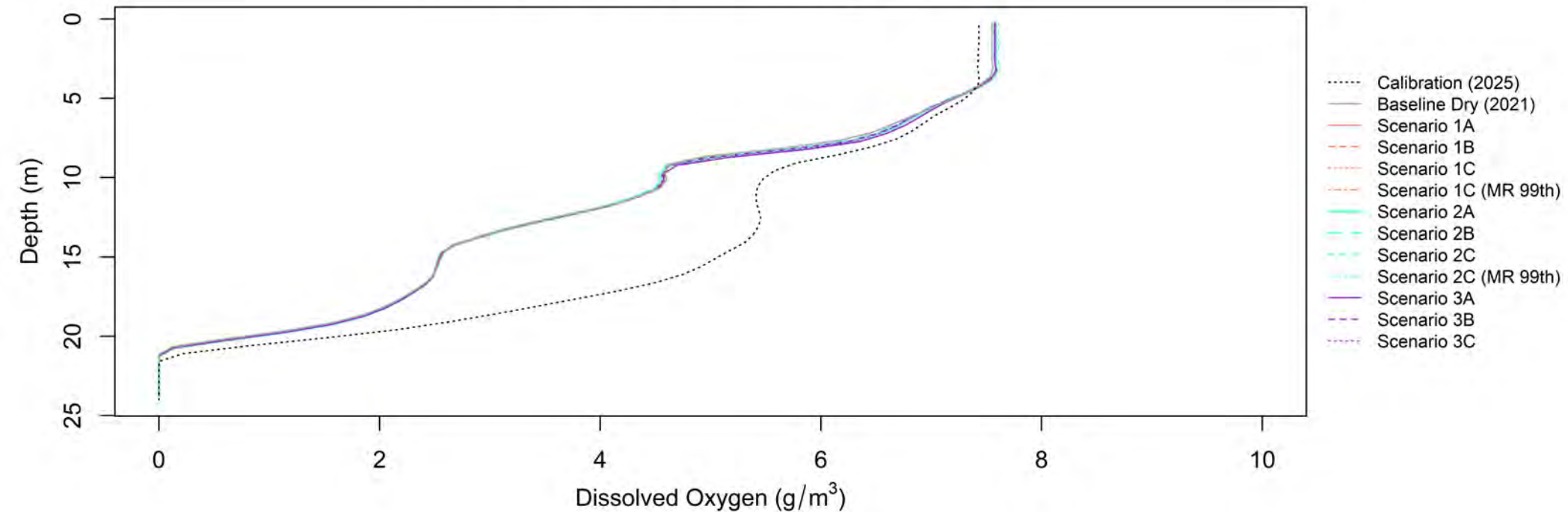
East Vadnais Lake: Dissolved Oxygen (September)



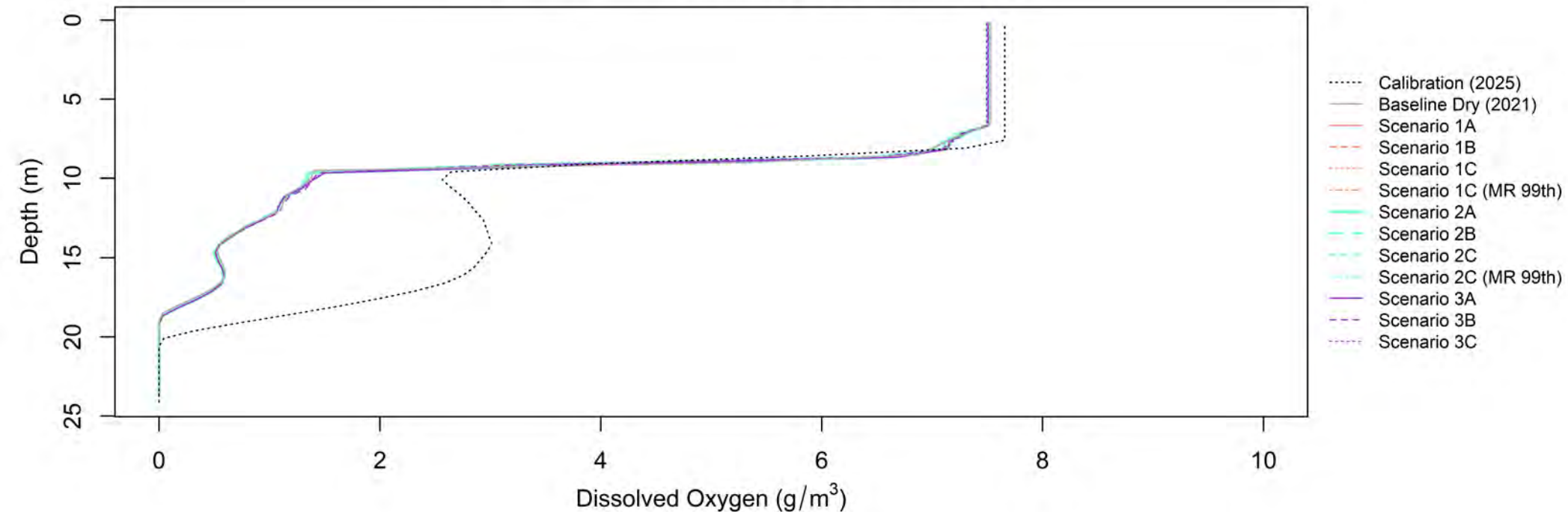
White Bear Lake: Dissolved Oxygen (June)



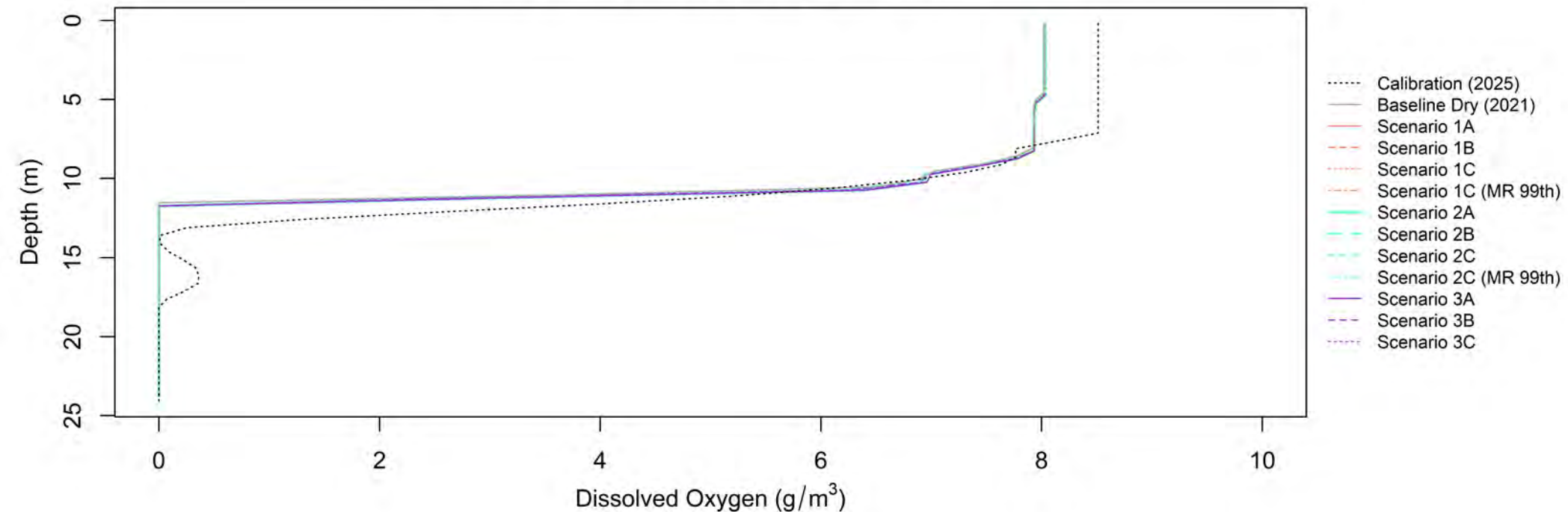
White Bear Lake: Dissolved Oxygen (July)



White Bear Lake: Dissolved Oxygen (August)



White Bear Lake: Dissolved Oxygen (September)





Appendix 9

Sensitivity Evaluation Results (Mass Balance)



Solids, Total Suspended

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	10.64	3.94	3.37	2.16	1.56	3.60
Dry Baseline (2021) Mass Balance Concentrations	mg/L	10.64	3.85	2.89	1.60	1.01	1.58
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	26.73	9.60	6.39	3.37	1.53	1.58
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	26.73	9.60	6.40	3.37	1.49	1.58
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	26.73	9.60	6.40	3.36	1.47	1.58
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	26.73	9.60	6.39	3.38	1.59	1.89
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	26.73	9.60	6.39	3.38	1.56	1.89
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	26.73	9.60	6.39	3.38	1.54	1.89
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	26.73	9.60	6.39	3.38	1.57	1.56
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	26.73	9.60	6.39	3.38	1.54	1.56
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	26.73	9.60	6.39	3.38	1.53	1.56

Solids, Total Dissolved

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	264	262	224	236	204	188
Dry Baseline (2021) Mass Balance Concentrations	mg/L	264	263	248	242	230	180
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	356	354	334	326	306	180
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	356	355	337	330	311	180
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	356	355	338	331	313	180
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	356	354	331	323	298	192
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	356	354	333	325	302	192
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	356	354	334	326	303	192
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	356	354	331	323	300	180
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	356	354	333	325	304	180
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	356	354	334	326	305	180

Chloride

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	22.33	22.77	24.57	27.19	31.93	53.00
Dry Baseline (2021) Mass Balance Concentrations	mg/L	22.33	22.43	21.55	21.79	24.63	52.11
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	48.72	48.64	44.07	43.95	43.32	52.11
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	48.72	48.66	44.29	44.17	43.53	52.11
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	48.72	48.66	44.36	44.25	43.62	52.11
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	48.72	48.63	43.85	43.72	43.06	53.72
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	48.72	48.64	44.00	43.88	43.26	53.73
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	48.72	48.64	44.06	43.93	43.20	53.73
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	48.72	48.63	43.85	43.72	43.11	52.11
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	48.72	48.64	44.00	43.88	43.31	52.11
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	48.72	48.64	44.06	43.93	43.24	52.11

Hardness, as CaCO₃

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	207	197	150	161	136	96
Dry Baseline (2021) Mass Balance Concentrations	mg/L	207	198	169	168	146	93
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	231	221	189	189	163	93
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	231	221	191	190	165	93
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	231	221	191	191	165	93
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	231	221	188	187	160	100
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	231	221	189	188	162	100
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	231	221	189	188	162	100
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	231	221	188	187	161	93
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	231	221	189	188	162	93
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	231	221	189	188	162	93

Alkalinity, Total, as CaCO3

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	181	179	137	148	137	87
Dry Baseline (2021) Mass Balance Concentrations	mg/L	181	180	153	153	148	84
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	202	201	172	171	164	84
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	202	201	173	172	166	84
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	202	201	173	173	167	84
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	202	201	171	170	162	91
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	202	201	172	171	164	91
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	202	201	172	171	164	91
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	202	201	171	170	163	84
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	202	201	172	171	164	84
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	202	201	172	171	164	84

Arsenic, Total

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	0.0017	0.0016	0.0011	0.0012	0.0012	0.0020
Dry Baseline (2021) Mass Balance Concentrations	mg/L	0.0017	0.0017	0.0013	0.0013	0.0012	0.0020
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	0.0024	0.0023	0.0018	0.0018	0.0017	0.0020
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	0.0024	0.0023	0.0018	0.0018	0.0017	0.0020
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	0.0024	0.0023	0.0018	0.0018	0.0017	0.0020
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	0.0024	0.0023	0.0018	0.0018	0.0016	0.0021
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	0.0024	0.0023	0.0018	0.0018	0.0017	0.0021
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	0.0024	0.0023	0.0018	0.0018	0.0017	0.0021
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	0.0024	0.0023	0.0018	0.0018	0.0017	0.0020
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	0.0024	0.0023	0.0018	0.0018	0.0017	0.0020
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	0.0024	0.0023	0.0018	0.0018	0.0017	0.0020

Aluminum, Total

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	0.0715	0.0163	0.0023	0.0025	0.0025	0.0117
Dry Baseline (2021) Mass Balance Concentrations	mg/L	0.0715	0.0162	0.0018	0.0013	0.0012	0.0051
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	0.2602	0.0588	0.0052	0.0027	0.0011	0.0051
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	0.2602	0.0588	0.0052	0.0026	0.0010	0.0051
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	0.2602	0.0589	0.0052	0.0026	0.0009	0.0051
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	0.2602	0.0587	0.0052	0.0028	0.0013	0.0053
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	0.2602	0.0588	0.0052	0.0027	0.0012	0.0053
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	0.2602	0.0588	0.0052	0.0027	0.0012	0.0053
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	0.2602	0.0587	0.0052	0.0028	0.0013	0.0051
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	0.2602	0.0588	0.0052	0.0027	0.0012	0.0051
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	0.2602	0.0588	0.0052	0.0027	0.0011	0.0051

Barium, Total

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	0.063	0.056	0.044	0.050	0.037	0.040
Dry Baseline (2021) Mass Balance Concentrations	mg/L	0.063	0.057	0.053	0.052	0.047	0.040
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	0.068	0.062	0.059	0.058	0.053	0.040
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	0.068	0.062	0.059	0.059	0.054	0.040
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	0.068	0.062	0.059	0.059	0.055	0.040
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	0.068	0.062	0.058	0.057	0.051	0.042
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	0.068	0.062	0.058	0.058	0.052	0.042
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	0.068	0.062	0.058	0.058	0.052	0.042
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	0.068	0.062	0.058	0.057	0.051	0.040
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	0.068	0.062	0.058	0.058	0.052	0.040
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	0.068	0.062	0.058	0.058	0.052	0.040

Calcium, Total

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	46.45	46.24	35.73	38.64	33.19	21.94
Dry Baseline (2021) Mass Balance Concentrations	mg/L	46.45	46.35	38.58	38.49	34.21	21.15
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	51.81	51.70	43.20	43.05	37.68	21.15
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	51.81	51.72	43.46	43.33	37.96	21.15
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	51.81	51.73	43.56	43.43	38.07	21.15
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	51.81	51.68	42.92	42.75	37.32	22.72
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	51.81	51.70	43.11	42.96	37.57	22.73
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	51.81	51.70	43.18	43.02	37.54	22.73
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	51.81	51.68	42.92	42.75	37.39	21.15
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	51.81	51.70	43.11	42.96	37.63	21.15
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	51.81	51.70	43.18	43.02	37.61	21.15

Copper, Total

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	0.0040	0.0035	0.0017	0.0015	0.0041	0.0014
Dry Baseline (2021) Mass Balance Concentrations	mg/L	0.0040	0.0033	0.0013	0.0009	0.0022	0.0006
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	0.0208	0.0168	0.0052	0.0033	0.0034	0.0006
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	0.0208	0.0168	0.0052	0.0033	0.0032	0.0006
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	0.0208	0.0168	0.0052	0.0033	0.0031	0.0006
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	0.0208	0.0168	0.0051	0.0033	0.0036	0.0008
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	0.0208	0.0168	0.0051	0.0033	0.0035	0.0008
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	0.0208	0.0168	0.0052	0.0033	0.0034	0.0008
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	0.0208	0.0168	0.0051	0.0033	0.0035	0.0006
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	0.0208	0.0168	0.0051	0.0033	0.0034	0.0006
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	0.0208	0.0168	0.0052	0.0033	0.0034	0.0006

Fluoride

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	0.120	0.111	0.102	0.097	0.091	0.091
Dry Baseline (2021) Mass Balance Concentrations	mg/L	0.120	0.110	0.101	0.088	0.078	0.087
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	0.130	0.119	0.108	0.094	0.079	0.087
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	0.130	0.119	0.108	0.094	0.077	0.087
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	0.130	0.119	0.108	0.093	0.077	0.087
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	0.130	0.119	0.108	0.094	0.081	0.090
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	0.130	0.119	0.108	0.094	0.080	0.090
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	0.130	0.119	0.108	0.094	0.079	0.090
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	0.130	0.119	0.108	0.094	0.081	0.087
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	0.130	0.119	0.108	0.094	0.080	0.087
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	0.130	0.119	0.108	0.094	0.079	0.087

Magnesium, Total

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	24.88	18.87	14.68	15.92	13.92	10.07
Dry Baseline (2021) Mass Balance Concentrations	mg/L	24.88	18.96	16.18	16.16	14.02	9.72
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	28.40	21.65	18.51	18.45	15.70	9.72
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	28.40	21.66	18.61	18.56	15.80	9.72
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	28.40	21.67	18.65	18.60	15.85	9.72
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	28.40	21.64	18.39	18.33	15.57	10.40
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	28.40	21.65	18.47	18.41	15.66	10.40
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	28.40	21.65	18.50	18.43	15.65	10.40
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	28.40	21.64	18.39	18.33	15.59	9.72
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	28.40	21.65	18.47	18.41	15.68	9.72
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	28.40	21.65	18.50	18.43	15.67	9.72

Manganese, Total

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	0.127	0.083	0.212	0.067	0.033	0.040
Dry Baseline (2021) Mass Balance Concentrations	mg/L	0.127	0.080	0.167	0.048	0.020	0.018
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	1.693	1.057	1.732	0.487	0.101	0.018
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	1.693	1.058	1.750	0.493	0.103	0.018
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	1.693	1.058	1.757	0.495	0.103	0.018
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	1.693	1.056	1.712	0.481	0.099	0.054
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	1.693	1.057	1.726	0.485	0.100	0.055
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	1.693	1.057	1.731	0.487	0.100	0.055
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	1.693	1.056	1.712	0.481	0.099	0.017
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	1.693	1.057	1.726	0.485	0.100	0.017
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	1.693	1.057	1.731	0.487	0.101	0.017

Sulfate, as SO4

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	13.50	14.11	8.98	10.92	7.98	3.93
Dry Baseline (2021) Mass Balance Concentrations	mg/L	13.50	13.66	7.65	8.10	4.93	1.72
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	47.00	46.93	23.17	23.31	9.63	1.72
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	47.00	46.94	23.28	23.38	9.52	1.72
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	47.00	46.95	23.32	23.41	9.48	1.72
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	47.00	46.91	23.05	23.22	9.81	3.25
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	47.00	46.92	23.13	23.28	9.73	3.25
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	47.00	46.93	23.16	23.30	9.67	3.25
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	47.00	46.91	23.05	23.22	9.74	1.71
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	47.00	46.92	23.13	23.28	9.68	1.71
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	47.00	46.93	23.16	23.30	9.62	1.71

Chlorine Dioxide

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mg/L	0.450	0.439	0.320	0.293	0.097	0.372
Dry Baseline (2021) Mass Balance Concentrations	mg/L	0.450	0.447	0.407	0.287	0.125	0.372
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mg/L	0.660	0.656	0.611	0.433	0.196	0.372
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mg/L	0.660	0.657	0.620	0.440	0.203	0.372
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mg/L	0.660	0.657	0.623	0.443	0.206	0.372
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mg/L	0.660	0.655	0.601	0.425	0.185	0.388
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mg/L	0.660	0.656	0.608	0.431	0.191	0.388
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mg/L	0.660	0.656	0.610	0.433	0.193	0.388
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mg/L	0.660	0.655	0.601	0.425	0.188	0.372
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mg/L	0.660	0.656	0.608	0.431	0.193	0.372
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mg/L	0.660	0.656	0.610	0.433	0.195	0.372

Gross Alpha (Radiation)

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	pCi/L	2.61	2.38	1.45	1.52	1.51	1.38
Dry Baseline (2021) Mass Balance Concentrations	pCi/L	2.61	2.42	1.80	1.78	1.55	1.37
Scenario 1a (Expanded Communities, Existing, No Augmentation)	pCi/L	4.69	4.34	3.29	3.25	2.88	1.37
Scenario 1b (Expanded Communities, 2050, No Augmentation)	pCi/L	4.69	4.35	3.33	3.30	2.98	1.37
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	pCi/L	4.69	4.35	3.35	3.32	3.02	1.37
Scenario 2a (SPRWS, Existing, Sucker to WBL)	pCi/L	4.69	4.34	3.24	3.20	2.75	1.49
Scenario 2b (SPRWS, 2050, Sucker to WBL)	pCi/L	4.69	4.34	3.27	3.23	2.83	1.49
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	pCi/L	4.69	4.34	3.28	3.24	2.85	1.49
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	pCi/L	4.69	4.34	3.24	3.20	2.78	1.37
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	pCi/L	4.69	4.34	3.27	3.23	2.85	1.37
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	pCi/L	4.69	4.34	3.28	3.24	2.87	1.37

Gross Beta (Radiation)

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	pCi/L	3.96	3.87	2.90	3.52	2.71	4.00
Dry Baseline (2021) Mass Balance Concentrations	pCi/L	3.96	3.92	3.60	3.55	3.08	3.99
Scenario 1a (Expanded Communities, Existing, No Augmentation)	pCi/L	6.37	6.32	5.90	5.83	5.17	3.99
Scenario 1b (Expanded Communities, 2050, No Augmentation)	pCi/L	6.37	6.32	5.98	5.92	5.35	3.99
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	pCi/L	6.37	6.33	6.01	5.96	5.41	3.99
Scenario 2a (SPRWS, Existing, Sucker to WBL)	pCi/L	6.37	6.31	5.82	5.74	4.91	4.20
Scenario 2b (SPRWS, 2050, Sucker to WBL)	pCi/L	6.37	6.31	5.88	5.80	5.06	4.20
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	pCi/L	6.37	6.32	5.90	5.83	5.10	4.20
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	pCi/L	6.37	6.31	5.82	5.74	4.97	3.99
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	pCi/L	6.37	6.31	5.88	5.80	5.11	3.99
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	pCi/L	6.37	6.32	5.90	5.83	5.14	3.99

Radium 226

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	pCi/L	0.267	0.256	0.227	0.363	0.233	0.050
Dry Baseline (2021) Mass Balance Concentrations	pCi/L	0.267	0.244	0.180	0.197	0.051	0.022
Scenario 1a (Expanded Communities, Existing, No Augmentation)	pCi/L	0.532	0.480	0.309	0.324	0.065	0.022
Scenario 1b (Expanded Communities, 2050, No Augmentation)	pCi/L	0.532	0.480	0.307	0.319	0.062	0.022
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	pCi/L	0.532	0.480	0.306	0.317	0.061	0.022
Scenario 2a (SPRWS, Existing, Sucker to WBL)	pCi/L	0.532	0.480	0.312	0.329	0.069	0.033
Scenario 2b (SPRWS, 2050, Sucker to WBL)	pCi/L	0.532	0.480	0.310	0.326	0.067	0.033
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	pCi/L	0.532	0.480	0.309	0.324	0.066	0.032
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	pCi/L	0.532	0.480	0.312	0.329	0.068	0.022
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	pCi/L	0.532	0.480	0.310	0.326	0.066	0.022
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	pCi/L	0.532	0.480	0.309	0.324	0.065	0.022

Radium 228

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	pCi/L	0.816	0.813	0.734	0.092	0.314	0.658
Dry Baseline (2021) Mass Balance Concentrations	pCi/L	0.816	0.812	0.793	0.088	0.196	0.641
Scenario 1a (Expanded Communities, Existing, No Augmentation)	pCi/L	1.490	1.480	1.419	0.157	0.232	0.641
Scenario 1b (Expanded Communities, 2050, No Augmentation)	pCi/L	1.490	1.481	1.431	0.158	0.220	0.641
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	pCi/L	1.490	1.481	1.435	0.158	0.216	0.641
Scenario 2a (SPRWS, Existing, Sucker to WBL)	pCi/L	1.490	1.479	1.407	0.155	0.252	0.647
Scenario 2b (SPRWS, 2050, Sucker to WBL)	pCi/L	1.490	1.480	1.415	0.156	0.243	0.647
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	pCi/L	1.490	1.480	1.418	0.156	0.238	0.647
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	pCi/L	1.490	1.479	1.407	0.155	0.245	0.641
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	pCi/L	1.490	1.480	1.415	0.156	0.237	0.641
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	pCi/L	1.490	1.480	1.418	0.156	0.233	0.641

Micro Plastic Particles, Total

Scenario	Units	Mississippi River	Lake				
			Charley	Pleasant	Sucker	East Vadnais	White Bear
2025 Mass Balance Concentrations	mpp/L	5989	4854	519	520	843	1174
Dry Baseline (2021) Mass Balance Concentrations	mpp/L	5989	4930	657	613	98	1169
Scenario 1a (Expanded Communities, Existing, No Augmentation)	mpp/L	15330	12642	1720	1628	260	1169
Scenario 1b (Expanded Communities, 2050, No Augmentation)	mpp/L	15330	12655	1744	1668	271	1169
Scenario 1c (Expanded Communities, Ultimate, No Augmentation)	mpp/L	15330	12660	1752	1681	275	1169
Scenario 2a (SPRWS, Existing, Sucker to WBL)	mpp/L	15330	12627	1693	1584	245	1228
Scenario 2b (SPRWS, 2050, Sucker to WBL)	mpp/L	15330	12637	1711	1614	254	1229
Scenario 2c (SPRWS, Ultimate, Sucker to WBL)	mpp/L	15330	12641	1718	1625	256	1229
Scenario 3a (SPRWS, Existing, East Vadnais to WBL)	mpp/L	15330	12627	1693	1584	248	1170
Scenario 3b (SPRWS, 2050, East Vadnais to WBL)	mpp/L	15330	12637	1711	1614	256	1170
Scenario 3c (SPRWS, Ultimate, East Vadnais to WBL)	mpp/L	15330	12641	1718	1625	259	1170



Appendix 10

Risk Assessment

Data available upon request

