February 11, 2025

Tim Asplund
Monitoring Section Manager
Bureau of Water Quality
Wisconsin Department of Natural Resources
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RE: Water Quality Management Letter for Dane County Water Quality Plan Amendment Request #2308 – MMSD ("Nine Springs WWTP Effluent Revision" for WPDES Permit WI-0024597-09-02 Outfall 005)

Mr. Asplund:

As you are aware, the Department of Natural Resources ("WDNR") conditionally approved Madison Metropolitan Sewerage District's ("MMSD") water quality plan amendment request on September 9, 2024. As part of that approval, WDNR required MMSD to engage in the following work:

- "Conduct additional trial periods of effluent flow cessation to collect more data representing a wider range of conditions" in Badger Mill Creek;
- "Using the data collected … conduct a thorough analysis using appropriate modeling or statistical techniques to predict DO and stream temperature under a full range of flow and temperature conditions without the supplemental effluent flow."

MMSD retained Ramboll Americas Engineering Solutions, Inc. ("Ramboll") to conduct this work.

The attached report documents the data collected during the additional trial period of flow cessation and a thorough modeling analysis using that data. Both the data collected and the modeling analysis demonstrate that Badger Mill Creek will continue to meet water quality standards under a full range of flow and temperature conditions without the supplemental effluent flow. The model shows, in fact, that cessation of the discharge to Badger Mill Creek will result in a net positive impact on dissolved oxygen.

With submittal of this report, MMSD believes that it has fulfilled the required conditions of the September 9, 2024 conditional approval for its water quality plan amendment request. MMSD would appreciate WDNR's confirmation in writing of fulfillment of the required conditions.

Sincerely,

Eric Dundee, Executive Director
Madison Metropolitan Sewerage District

Martye Griffin, Director of Ecosystem Services
Madison Metropolitan Sewerage District

February 11, 2025

CC: Jason Knutson, Wastewater Section Manager, WDNR
Adrian Stocks, Bureau Director, WDNR
Tim Ryan, Field Operations Director, WDNR
Michael Sorge, Water Resources Field Supervisor, WDNR
Ashley Brechlin, Wastewater Engineer, WDNR
Alixandra Burke, Staff Attorney, WDNR
Kevin Kirsch, Water Resource Engineer, WDNR
Camille Bruhn, Water Resource Management Specialist, WDNR

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WATER

MEMO

Project name	**MMSD: Nine Springs WWTP WPDES Permit Renewal**
Project no.	**1940109578**
Client	**Madison Metropolitan Sewer District (MMSD)**
To	**Rita Neff, PE**
From	**Michael L. Thompson, PE***
Copy to	**Martin Griffin, Kathy Lake**

Prepared by	**Jackie Backus**
Checked by	**Felix Kristanovich**
Approved by	**Robin L. Richards, REM**

*- Licensed PE in Louisiana

Date February 10, 2025

1 Introduction

The Madison Metropolitan Sewer District (MMSD) owns and operates the Nine Springs Wastewater Treatment Plant, which has historically discharged treated effluent to: the Badfish Creek, from Outfall 001; and to Badger Mill Creek, from Outfall 005. Authorization was granted to MMSD for these discharges by means of Wisconsin Pollutant Discharge Elimination System (WPDES) Permit No. WI-0024597-09-2, which is set to expire on March 31, 2025.

MMSD has recently received approval from the Wisconsin Department of Natural Resources (WDNR) to discontinue discharging effluent to Badger Mill Creek via Outfall 005.[1] In its September 9, 2024 conditional approval of MMSD's Areawide Water Quality Management Plan Amendment Modification (the "Amendment Request"), WDNR determined that the Amendment Request is "consistent with adopted policies and procedures of the Areawide Water Quality Management Plan under chapter NR 121, Wis. Adm. Code and Section 283.83, Wis. Stats. …" As permitted by state law, WDNR approved the Amendment Request conditioned on MMSD fulfilling supplemental data collection and modeling required conditions. WDNR is requiring MMSD to conduct additional analysis using appropriate modeling or statistical techniques to predict dissolved oxygen (DO) within Badger Mill Creek under a variety of conditions without the supplemental effluent flow. To satisfy this request, a modeling approach that focused on low flow and high temperature conditions with variable DO and stream dimensions was utilized.

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[1] *See* Madison Metropolitan Sewerage District's April 2023 Final Alternatives Assessment for Phosphorus Compliance, Badger Mill Creek, Outfall 005 ("April 2023 Final Alternatives Assessment") and the exhibits contained therein; *see also* the Madison Metropolitan Sewerage District's June 2024 Areawide Water Quality Management Plan Amendment Modification for WPDES Permit WI-0024597-09-02, Outfall 005 and the attachments contained therein and WDNR's September 9, 2024 conditional approval of MMSD's Areawide Water Quality Management Plan Amendment Modification.

This technical memorandum (TM) summarizes the methodologies, assumptions, data inputs, and conditions/scenarios, employed by Ramboll Americas Engineering Solutions, Inc. (Ramboll) in conducting a Modified Streeter-Phelps (MSP) model to predict the impact of Outfall 005 discharge on in-stream DO concentrations for Badger Mill Creek.

2 Methodology

Ramboll utilized Modified Streeter-Phelps (MSP) dissolved oxygen (DO) model[2] developed by Oregon Department of Environmental Quality (DEQ). This model is available in Microsoft Excel routine and provides a user-friendly alternative to modeling with QUAL2K. The model utilizes modified Streeter-Phelps equations that calculates DO concentrations in Badger Mill Creek downstream from the Outfall 005 discharge for steady-state conditions in the Creek (constant flow discharge and water temperature), and assuming instantaneous mixing in the Creek downstream of the 005 discharge. The MSP model describes how DO in Badger Mill Creek responds to degradation of biochemical oxygen demand (BOD) introduced by the addition of Outfall 005 discharge and the sinks and inputs of other BOD sources. The Streeter-Phelps equation describes changes in DO and BOD in time and along Badger Creek downstream of the 005 discharge. In this steady-state model, hydraulic properties in the creek do not change, including Creek discharge, Creek width and depth. Thus, the MSP model ignores all other inflows into the Creek downstream of the Outfall 005 discharge.

3 Model Inputs

Worst-case scenario modeling is a widely used approach in environmental risk management, involving the consideration of the most severe potential outcomes or conditions that can reasonably be anticipated. In the context of Badger Mill Creek, the worst-case scenario would be a situation where the DO concentration in the creek is at its minimum. The USEPA, UGGS, and WDNR each recognize an inverse relationship between DO and water temperature (i.e., when water temperature is low, DO concentration is high; and conversely, when water temperature is high, DO concentration is low). Consequently, the MSP model was performed using available data collected during the month of August, a month when water temperatures are typically at their highest, and therefore, DO concentrations are expected to be at their lowest. In order to build on this conservative approach, an extreme low flow statistic (that is not anticipated to actually occur) was used for Badger Mill Creek, as WDNR has previously acknowledged that a low flow condition can lead to adverse impacts to DO concentrations.

The following model parameters were utilized to simulate Outfall 005 effluent:

- 5-day CBOD ($CBOD_5$): 7 mg/L, consistent with the Wisconsin Department of Natural Resources Permit (WDNR)[3] (Monthly average CBOD5 limit in effect May through October).
- DO: 6.28 (average of values measured at Outfall 005 August 1-16, 2024 when Outfall 005 was discharging). The Outfall 005 was shut off on August 16, 2024.
- Temperature: 22.75°C (72.96°F), consistent with the daily mean maximum temperature for August as cited[4] in Exhibit D of the April 2023 Final Alternatives Assessment for Phosphorus Compliance.

[2] https://www.oregon.gov/deq/FilterPermitsDocs/RPAStreeter-PhelpsDOModel.xlsx
[3] WPDES Permit No. WI-0024597-09-2
[4] April 2023 Final Alternatives Assessment Exhibit D: Additional Analysis of Effluent Impact on Badger Mill Creek, Table 8.

- Ammonia Nitrogen (NH_3-N): 0.27 mg/L, consistent with the average NH_3 for MMSD effluent[5] in August 2024.
- Total Kjeldahl Nitrogen (TKN): 1.68 mg/L, consistent with the average value for MMSD effluent in August 2024.
- Effluent flow discharge: 3.6 mgd (5.6 cfs), consistent with the design flow from the Fact Sheet of the Modified 2022 Permit[6].

The following model parameters were utilized to simulate Badger Mill Creek:

- 5-day CBOD ($CBOD_5$): 2.1 mg/L, 90% of the geomean of available Badger Mill Creek BOD_5 data[7] without Outfall 005 discharge occurring.
- DO: 5.0 mg/L – 9.0 mg/L, variety of values used to cover the period in August 2024 when Outfall 005 was not discharging; all values collected from the USGS Gage for Bader Mill Creek at Verona (Site 05435943), which is approximately 2.5 miles downstream of the Outfall 005 discharge location, as illustrated in Attachment 1. The USGS Gage is also referred to as Location BM-07 or Bruce Street in Exhibits C and D of the April 2023 Final Alternatives Assessment.
- Temperature: 21.1°C (70°F), cited weekly maximum Outfall 005 effluent temperature for August in the May 19, 2017 WDNR WQBEL Memo[8] . This weekly maximum (70 deg F = 21.1 deg C) is more conservative (higher) than the average reported by the USGS Gage for Badger Mill Creek at Verona (Site 05435943) for all Augusts over the period of 2020-2024 (18.9°C) and the individual maximum monthly average August temperature for the same period (19.9°C).
- Ammonia Nitrogen (NH_3-N): 0.27 mg/L, consistent with the average NH_3 for MMSD effluent in August 2024. No specific Badger Mill Creek data were available.
- Total Kjeldahl Nitrogen (TKN): 0.60 mg/L, rounded average of Feb-Mar 2023 measurements for Badger Mill Creek without Outfall 005 discharge. Data from Exhibit D[9] of the April 2023 Final Alternatives Assessment for Phosphorus Compliance.
- Creek flow discharge: 0.01 cfs, consistent with the State of Wisconsin Correspondence Memorandum, dated May 19, 2017, regarding WPDES Permit WI-0024597. 7Q10 value was obtained as $\leq$ 0.01 cfs for USGS Station S9, where Outfall 005 is located. It should be noted that this creek flow discharge rate is significantly than what may be currently observed when there is no contribution from Outfall 005; however, this lower flow allows for a more conservative approach in completing the MSP model.
- Average Badger Mill Creek stream depth (1.2 feet) and width (21 feet) measured at Old County Road PB[10], downstream of the Outfall 005 discharge location were used to represent hydraulics of the creek channel. Sensitivity analysis was also performed by reducing measured width and depth each by half.

[5] Data for the entire period of August is available as MMSD Outfall 001 and Outfall 005 utilize the same monitoring point and are the same treated effluent.
[6] Fact Sheet (page 1) for 2022 Modification of WPDES Permit No. WI-0024597-09-2.
[7] Three BOD_5 results from 2/8/23 (2.9 mg/L), 3/8/23 (2.2 mg/L), and 4/12/23 (<2.0 mg/L).
[8] Value from the table on page 24 of Attachment 1 to the May 19, 2017 WDNR WQBEL Memo for WPDES WI-0024597.
[9] April 2023 Final Alternatives Assessment, Exhibit D: Additional Analysis of Effluent Impact on Badger Mill Creek, Table 4.
[10] April 2023 Final Alternatives Assessment Exhibit C: Badger Creek Hydraulic Assessment (Emmons & Oliver Resources, Inc - 04/24/2023), Table 4.

The MSP model coefficients were inputted as:

- CBOD Bottle decay rate (K_1) of 0.07, consistent with literature average values for activated sludge facilities.
- Effective deoxygenation rate (K_d) of 0.20/day, consistent with the BOD decay rate used for partially contaminated rivers (between 0.10 for pristine rivers and 0.35 for untreated rivers).
- Ammonia to Nitrite decay rate (K_{ai}) of 0.30/day, consistent with 0.30 value used for US rivers.
- Organic Nitrogen to Ammonia decay rate (K_{oa}) of 0.69/day, literature standard value.
- Nitrite to Nitrate decay rate (K_{in}) of 0.70/day, literature standard value.
- Settling rate Ks of 0.03/day, consistent with very low value for facilities with secondary treatment (0.0 -0.03/day).
- Sediment Oxygen Demand (S_B) of 2. The valued range from 0.3 to 3 g O_2/m^2 day, with higher values associated with higher water temperature and lower DO. 2.0 is good assumption.
- Temperature Coefficient for CBOD (Theta CBOD) of 1.047, standard literature value (see Oregon MSP model), in lieu of no specific data.
- Temperature Coefficient for oxygen (Theta O_2) of 1.047, standard literature value, see Oregon MSP model, in lieu of no specific data.
- Temperature Coefficient for sediment (Theta SOD) of 1.065, standard literature value, see Oregon MSP model, in lieu of no specific data.
- Temperature Coefficient Theta for Nitrogenous Oxygen Demand (NBOD) (Theta NBOD) of 1.08, standard literature value, see Oregon MSP model, in lieu of no specific data.

4 Model Scenarios and Results

A total of eight scenarios were examined using the MSP model. Four scenarios used the Badger Mill Creek dimensions (1.2 feet deep and 21 feet wide) "Full Dimension" but varied the initial Badger Mill Creek DO value (5.0, 6.0, 8.0, and 9.0 mg/L). Four additional scenarios were modeled for sensitivity analysis using reduced (by one half) Badger Mill Creek dimensions (0.6 feet deep and 10.5 feet wide) "Half Dimensions" but varied the initial Badger Mill Creek DO value (5.0, 6.0, 8.0, and 9.0 mg/L). All other inputs remained the same for all eight scenarios. The results for these scenarios are summarized below.

4.1 Full Dimension Scenario Results

Table 1 summarizes the DO profiles for Badger Mill Creek without Outfall 005 (the "River Only") and Badger Mill Creek mixed with Outfall 005 effluent (the "River+Source") over a distance of 2.5 miles[11]. Corresponding graphs are shown in Attachment 2 (Full Dimension Scenario Graphs). For each scenario an overall average DO depression occurs when Outfall 005 is mixed with Badger Mill Creek. For the initial DO 5.0 and 6.0 mg/L cases, a short (based on miles downstream) increase in DO of the mixed river + source is noted. However, within 0.6 miles downstream or less, the mixture w/Outfall 005 shows a DO sag as compared to Badger Mill Creek without Outfall 005.

[11] The USGS Gage for Badger Mill Creek at Verona (site 05435943) is ~2.5 miles downstream of the Outfall 005 discharge location. The USGS Gage is referred to as Location BM-07 or Bruce Street in Exhibits C and D of the April 2023 Final Alternatives Assessment.

Table 1. Summary Results for Full Badger Creek Mill Dimension Scenarios				
Statistic	**Initial DO 5.0 mg/L**	**Initial DO 6.0 mg/L**	**Initial DO 8.0 mg/L**	**Initial DO 9.0mg/L**
Range of DO Delta[12] (River vs River+Source)	-1.28 to 0.87 mg/L	-0.28 to 0.89 mg/L	0.93 to 1.72 mg/L	0.95 to 2.72 mg/L
Average of DO Delta[13] (River vs River+Source)	*0.36 mg/L*	*0.62 mg/L*	*1.13 mg/L*	*1.38 mg/L*
Predicted DO Delta at 2.5 miles Downstream (at USGS Gage)	0.87 mg/L	0.89 mg/L	0.93 mg/L	0.95 mg/L
Note: "Delta" is the difference between Badger Mill Creek with and without Outfall 005. • Negative indicates that presence of Outfall 005 increased DO in the Creek. • Positive indicates presence of Outfall 005 decreased DO in the Creek.				

For all full dimension scenarios, the MSP model shows that the addition of Outfall 005 to Badger Mill Creek is expected to depress (on average) the in-stream DO.

4.2 Half Dimension Scenario Results

Table 2 summarizes the DO profiles for Badger Mill Creek without Outfall 005 (the "River Only") and Badger Mill Creek mixed with Outfall 005 effluent (the "River+Source") over a distance of 2.5 miles[12]. Corresponding graphs are shown in Attachment 3 (Half Dimension Scenario Graphs). Similar to the full dimension scenarios, an overall average DO depression occurs when Outfall 005 is mixed with Badger Mill Creek. For the initial DO 5.0 and 6.0 mg/L cases, a short (based on miles downstream) increase in DO of the mixed river + source is noted. However, within less than 0.5 miles downstream, the mixture w/Outfall 005 shows a DO sag as compared to Badger Mill Creek without Outfall 005.

Table 2. Summary Results for Half Badger Creek Mill Dimension Scenarios				
Statistic	**Initial DO 5.0 mg/L**	**Initial DO 6.0 mg/L**	**Initial DO 8.0 mg/L**	**Initial DO 9.0mg/L**
Range of DO Delta[13] (River vs River+Source)	-1.28 to 0.35 mg/L	-0.28 to 0.35 mg/L	0.35 to 1.72 mg/L	0.35 to 2.72 mg/L
Average of DO Delta[14] (River vs River+Source)	*0.13 mg/L*	*0.26 mg/L*	*0.51 mg/L*	*0.64 mg/L*
Predicted DO Delta at 2.5 miles Downstream (at USGS Gage)	0.35 mg/L	0.35 mg/L	0.35 mg/L	0.35 mg/L
Note: "Delta" is the difference between Badger Mill Creek with and without Outfall 005. • Negative indicates that presence of Outfall 005 increased DO in the Creek. • Positive indicates presence of Outfall 005 decreased DO in the Creek.				

For all half dimension scenarios, the MSP model shows that the addition of Outfall 005 to Badger Mill Creek is expected to depress (on average) the in-stream DO.

[12] Range: Outfall 005 to 2.5 miles downstream.
[13] Average: average of DO delta over the 2.5 miles

5 Badger Mill Creek Gage Data

USGS gage data[14] (discharge, DO, and gage height) for Badger Mill Creek (at Bruce Street in Verona) was also evaluated for periods with ("On") and without the Outfall 005 discharge ("Off"). The calendar months of August, October, and December were chosen for the evaluation due to these months having historical lower flows than other months except February. February was excluded from the evaluation due to the potential for freezing conditions impacting gage measurements. The comparison is shown in Table 3.

Table 3. Badger Mill Creek Gage Data Comparison

Calendar Month	Discharge (cfs)	DO (mg/L)	Gage Height (feet)
August Average Values	On: 15.0 Off: 11.8	On: 8.18 Off: 8.95	On: 4.70 Off: 4.60
Average August Change (w/out Outfall 005)	*-3.2*	*0.77*	*-0.10*
October Average Values	On: 15.0 Off: 12.8	On: 8.75 Off: 9.50	On: 4.59 Off: 4.54
Average October Change (w/out Outfall 005)	*-2.2*	*0.75*	*-0.05*
December Average Values	On: 12.6 Off: 10.5	On: 9.86 Off: 10.58	On: 4.44 Off: 4.39
Average December Change (w/out Outfall 005)	*-2.2*	*0.72*	*-0.05*

Notes:

Effluent On Timeframes	Effluent Off Timeframes
August: Aug 2020, Aug 2021, Aug 2022, Aug 2023, Aug 1-15, 2024	August: Aug 17-31, 2024
October: Oct 2020, Oct 2021, Oct 2022, Oct 2023	October: Oct 2024
December: Dec 2020, Dec 2021, Dec 2022, Dec 2023	December: Dec 2024

Table 3 data show that while the average discharge volume and gage height decreased when the Outfall 005 discharge was not present, the average DO for Badger Mill Creek increased.

Attachments 4, 5, and 6 graphically show the USGS gage data (discharge, DO, and temperature) for Badger Mill Creek (at Bruce Street in Verona) over the period of August 2024 through January 2025. These graphs show the daily gage data (blue lines) and the historical median daily statistics. Review of the graphs indicates the following since the Outfall 005 discharge ceased on August 16, 2024:

- Badger Mill Creek discharge flows on average have decreased compared to the historical median daily statistics. However, the discharge has remained at ~7 cfs or higher which is well above the low flow statistic (<0.01 cfs) used in the MSP modeling.
- Badger Mill Creek DO values on average are at or above the historical median daily statistics. This data is consistent with the trend predicted by the MSP model.
- Badger Mill temperatures on average are decreased compared to the historical median daily statistics but have remained above the critical temperature threshold (i.e., 0 degrees C) for the winter season.

[14] USGS Badger Mill Creek at Verona (site 05435943). https://waterdata.usgs.gov/monitoring-location/05435943/#dataTypeId=continuous-00065-608393985&period=P7D&showMedian=false

6 Conclusions

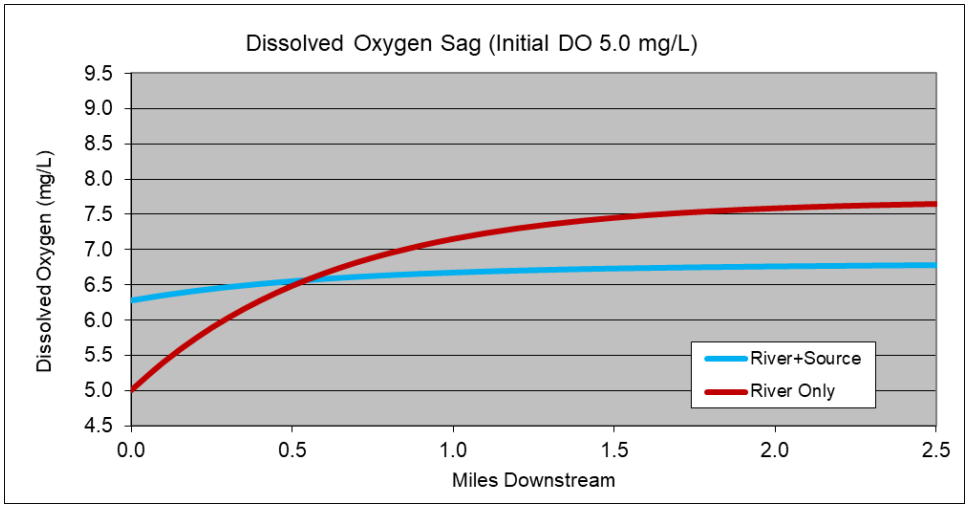
MSP modeling for the Outfall 005 effluent and Badger Mill Creek was carried out under a variety of scenarios. The scenario inputs were selected to span a range of initial in-stream DO values (5.0 to 9.0 mg/L) reported by the USGS Gage for Bader Mill Creek at Verona (Site 05435943) and examine the impact of extreme (conservative) reductions in Badger Mill Creek depth and width dimensions. The MSP model results showed that for some scenarios, a short term (as indicated downstream distance) positive impact to in-stream DO could be expected, and the in-stream DO values (on average) are expected to be depressed by the addition of the Outfall 005 to Badger Mill Creek.

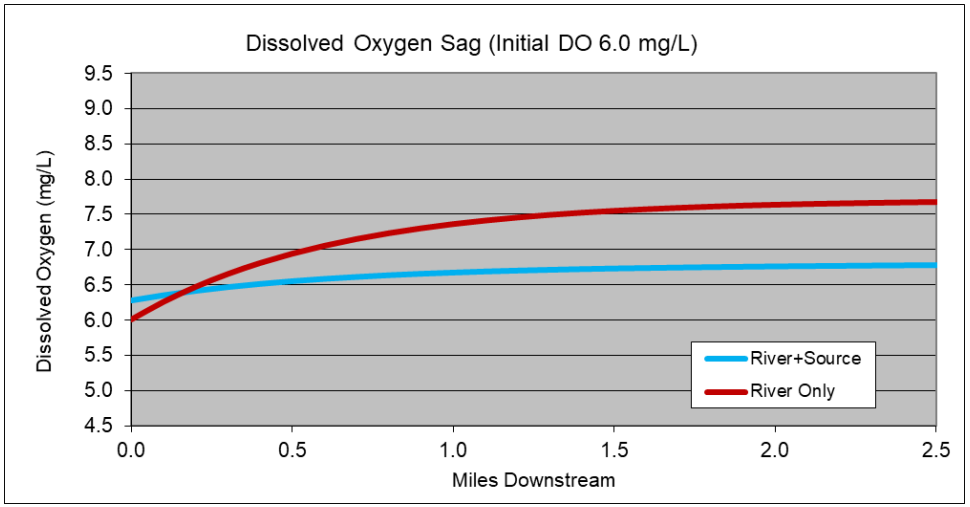
The impact of Outfall 005 on Badger Mill Creek was also evaluated using USGS gage data for Badger Mill Creek at Verona (Site 05435943). The real-world gage data show that average DO during periods without the Outfall 005 effluent was higher than with the effluent present.

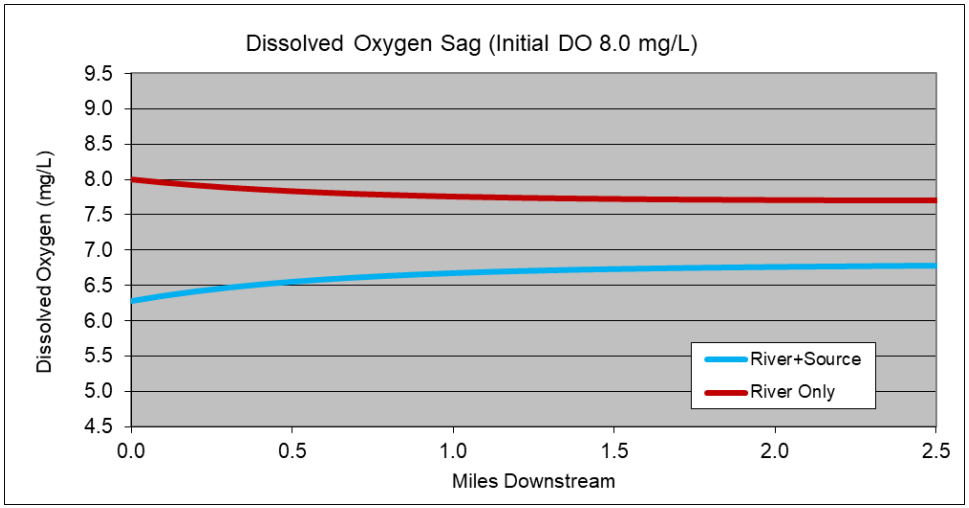
In summary, the MSP modeling indicates that the Outfall 005 discharge is expected to have a net negative impact (DO sag) on in-stream DO for the modeled scenarios. A net positive impact (i.e., either no or limited DO sag) is expected to the DO of Badger Mill Creek without Outfall 005 effluent. Specifically, the model over the range of initial Creek DO inputs, predicted a DO increase, without Outfall 005, at the gage of ~0.9 mg/L for August conditions and the gage data average was an increase of 0.8 mg/L. The MSP model results are supported by the real-world USGS gage data for Badger Mill Creek that show increased DO averages for periods of no Outfall 005 discharge.

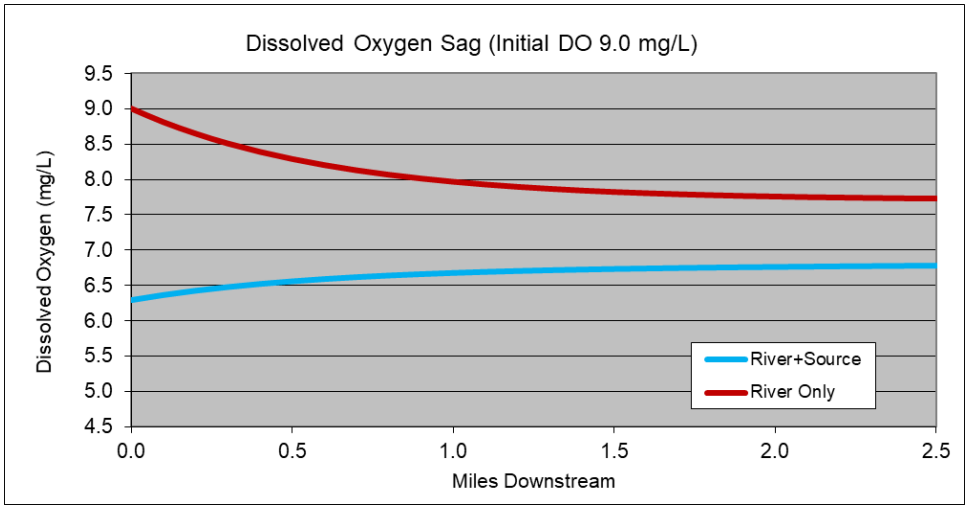
Attachment 1: Badger Mill Creek Locations

Attachment 2: Full Dimension Scenario Graphs

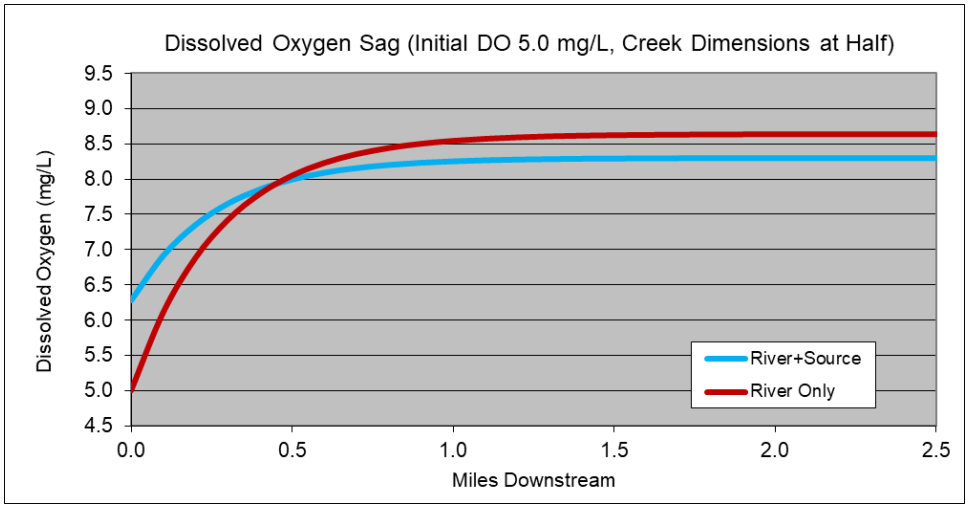


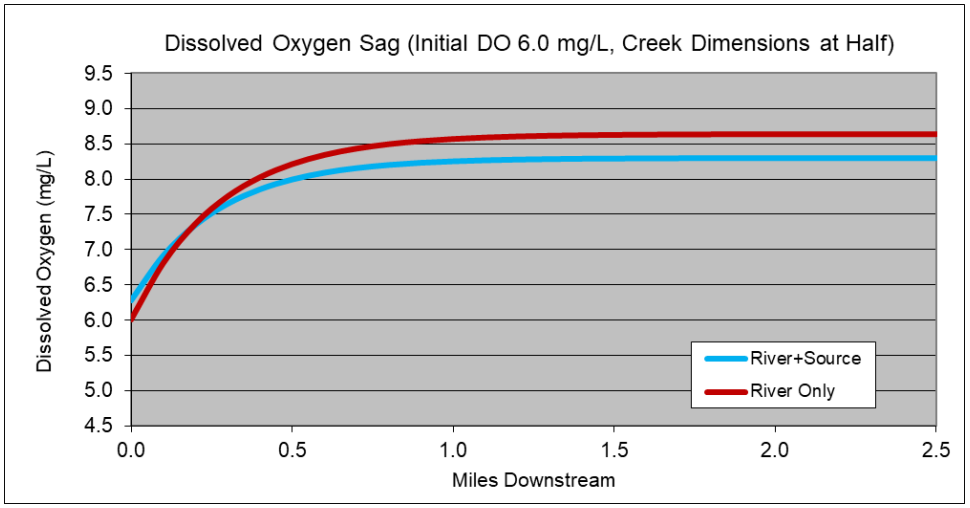


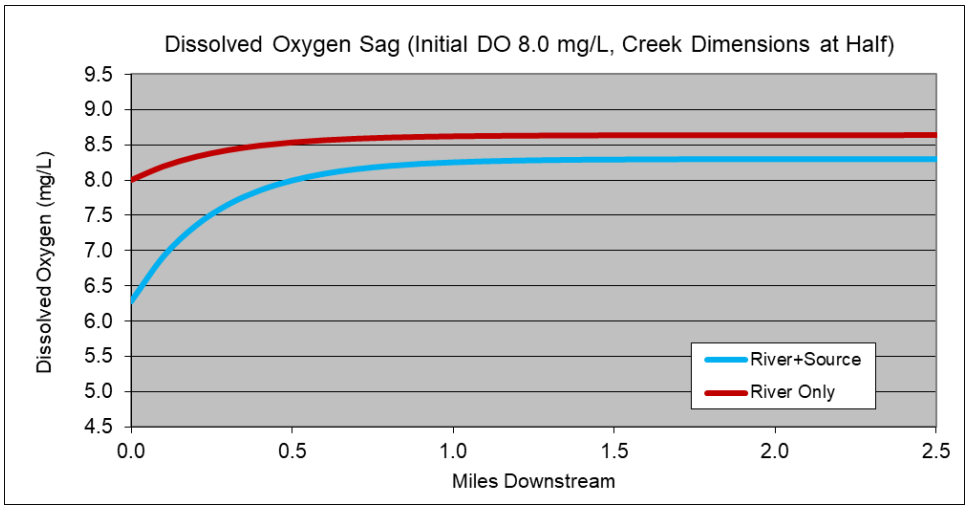


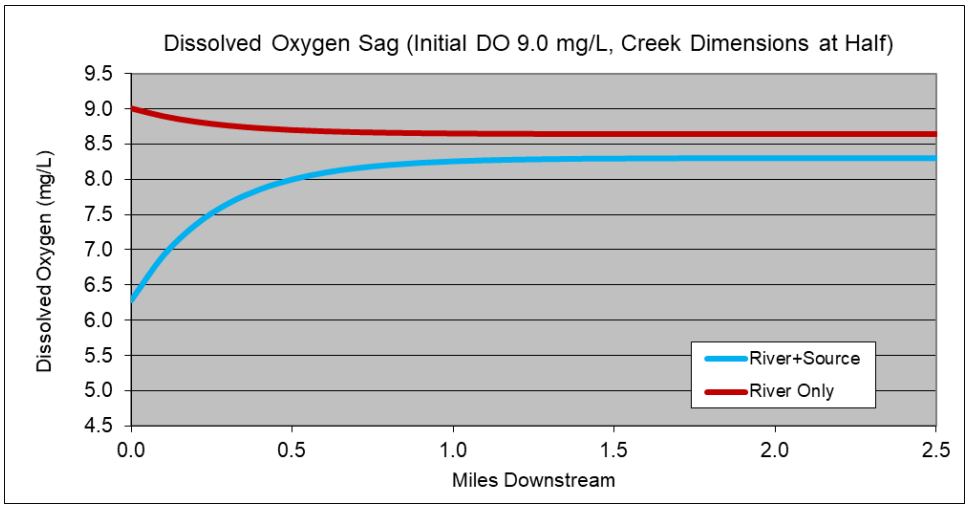


Attachment 3: Half Dimension Scenario Graphs









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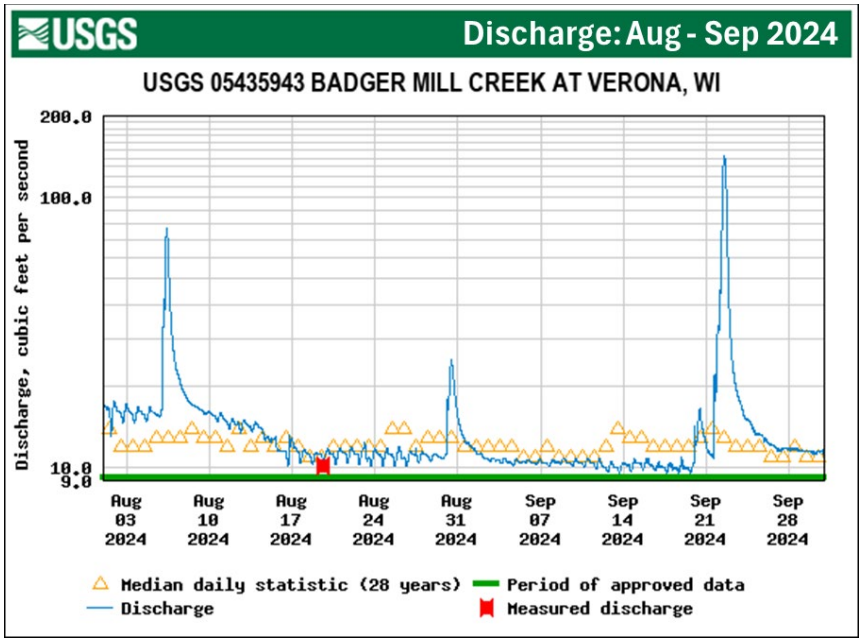
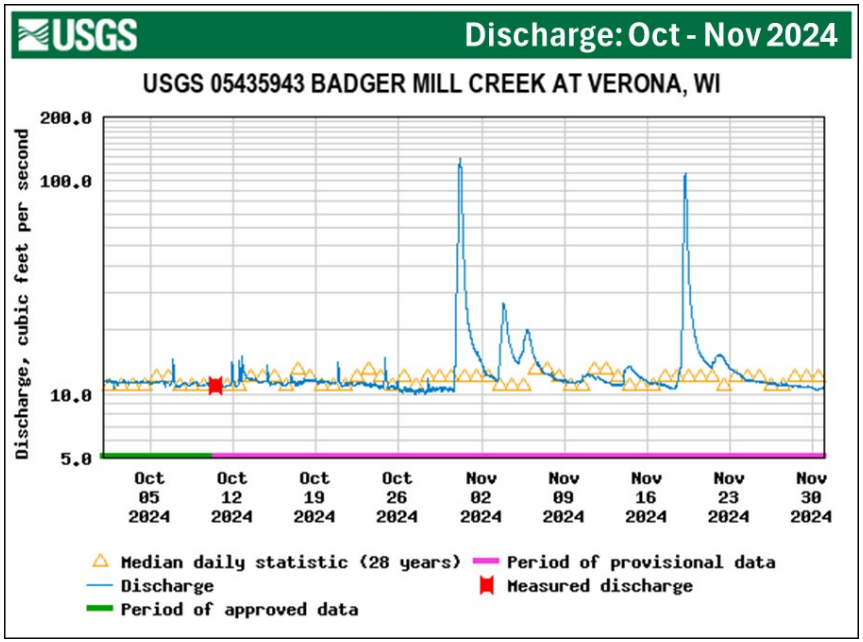
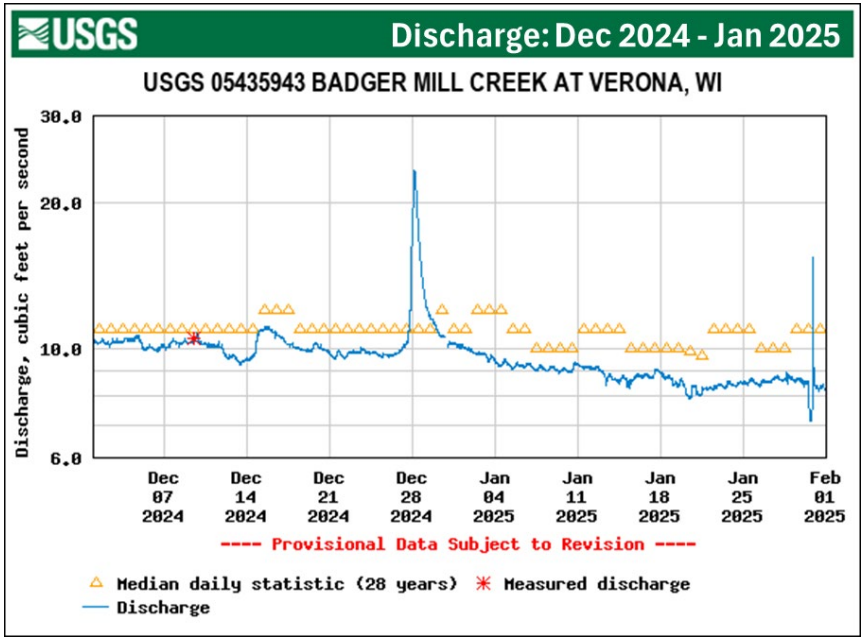
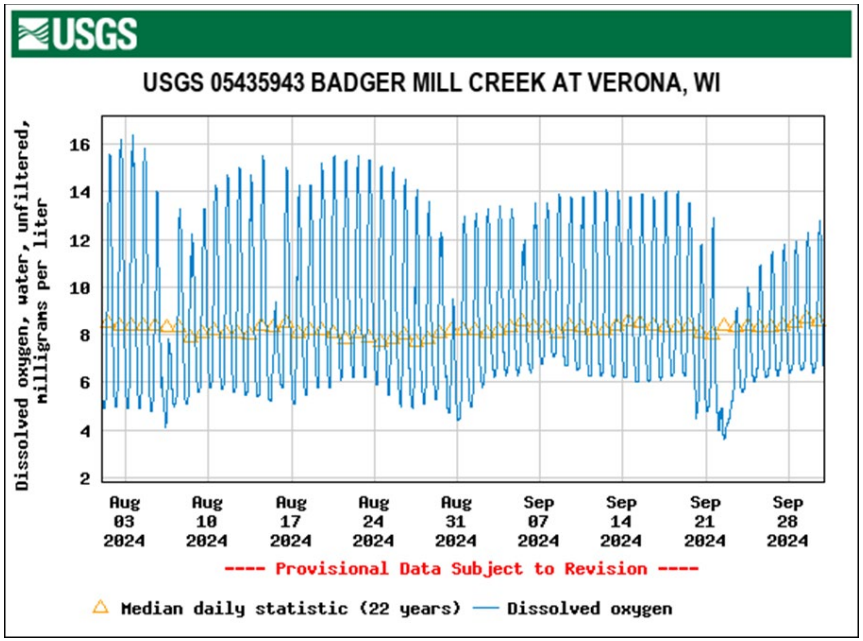
Attachment 4: USGS Gage Discharge Charts for Aug 2024 – Jan 2025

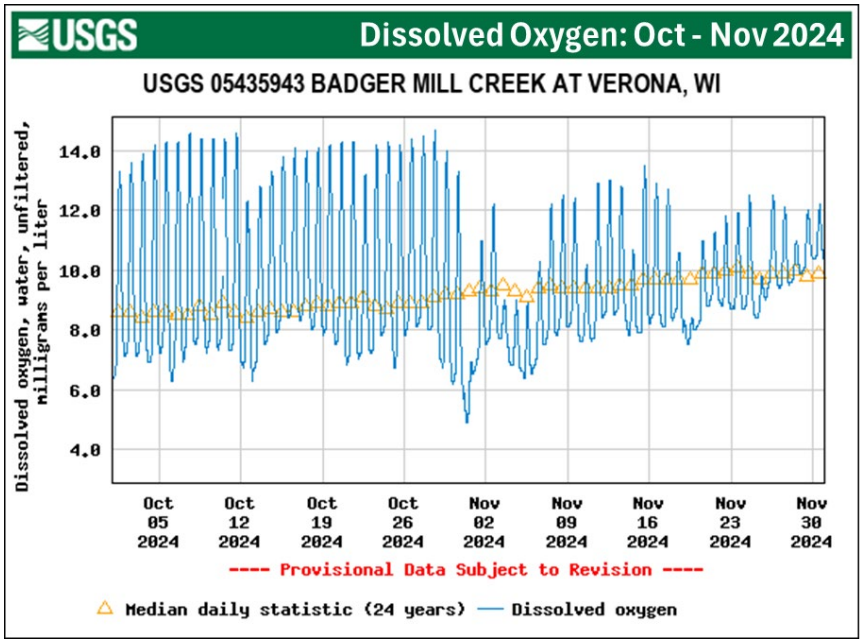


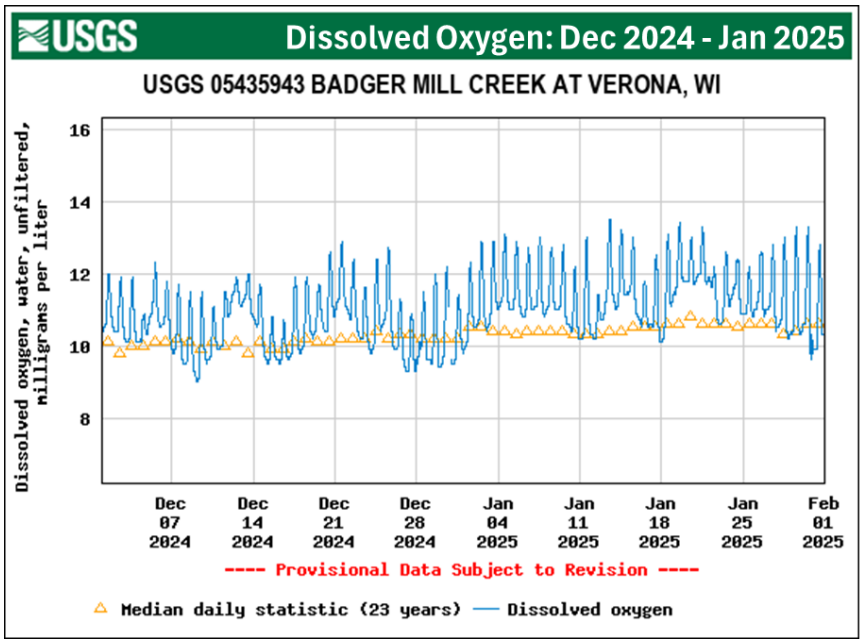




Attachment 5: USGS Gage Dissolved Oxygen Charts for Aug 2024 – Jan 2025







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Attachment 6: USGS Gage Temperature Charts for Aug 2024 – Jan 2025