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# NUTRIENT ASSESSMENT REDUCTION PLAN FOR THE UPPER DES PLAINES RIVER

*Prepared for*

**Des Plaines River Watershed Workgroup**

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Project MOW5554

December 2023

# TABLE OF CONTENTS

## LIST OF TABLES



## LIST OF FIGURES

## LIST OF APPENDICES

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| % | percent |
| µg/L | micrograms per liter |
| DO | dissolved oxygen |
| DRWW | Des Plaines River Watershed Workgroup |
| GIMS | Green Infrastructure Model and Strategy |
| Illinois EPA | Illinois Environmental Protection Agency |
| mg/L | milligrams per liter |
| mm | millimeters |
| MS4 | Municipal Separate Storm Sewer System |
| NARP | Nutrient Assessment Reduction Plan |
| NPDES | National Pollutant Discharge Elimination System |
| NPS | nonpoint source |
| POTW | publicly owned treatment works |
| SMC | Stormwater Management Commission |
| SWAT | Soil and Water Assessment Tool |
| TMDL | total maximum daily load |
| TP | total phosphorous |
| TSS | total suspended solids |
| WBP | watershed-based plan |
| WDNR | Wisconsin Department of Natural Resources |

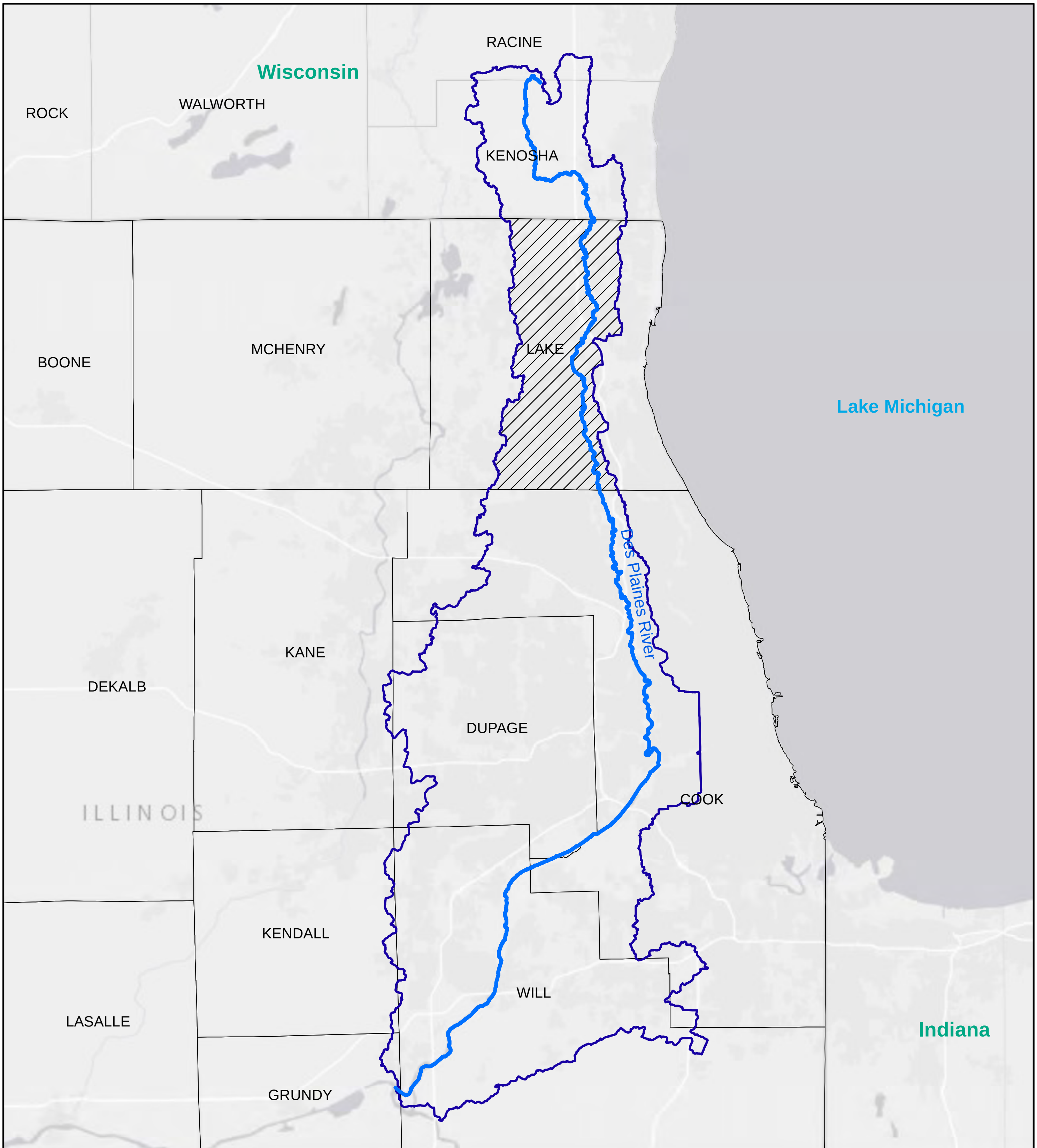
# 1. INTRODUCTION

## 1.1 Study Area

The Des Plaines River originates near Union Grove, Wisconsin and drains an area of 1,455 square miles through Racine and Kenosha counties in southeastern Wisconsin and through Lake, Cook, and Will counties in northeastern Illinois (**Figure 1**). The river joins the Chicago Sanitary and Ship Canal in Lockport, Illinois and then flows west through Joliet before converging with the Kankakee River to form the Illinois River. The Study Area for the Upper Des Plaines River Watershed Nutrient Assessment Reduction Plan (NARP) focuses on the 36.3-mile stretch of the Des Plaines River between Russell Road in Lake County (at the Wisconsin and Illinois boundary) and its confluence with Wheeling Ditch in Cook County (**Figure 1**). This section of the river drains a watershed area of 235 square miles, which is referred to as the Study Area in this report henceforth.

Land use in the Study Area is predominantly residential (31.2 percent); agriculture (18.4 percent); and transportation, utility, and waste facility (10.3 percent) with the remaining area being institutional, industrial, commercial, public and private open space based on the 2015 Chicago Metropolitan Agency data (**Figure 2**). Most of the soil in the Study Area consists of sand clay loam, which is classified as Hydrologic Soil Group C. This type of soil is poorly drained and has a high runoff potential. The NARP Study Area has a warm continental climate with warm summers and cold winters. The polar jet stream creates low-pressure systems that bring clouds, wind, and precipitation. Impervious surfaces such as buildings, roads, parking lots, and industrial activities result in increased temperatures in the urban area. Lake Michigan moderates the temperatures in winter and summer seasons.

According to the 2020 United States Census, the population in the Study Area is 281,514. The population is anticipated to increase by 20% by 2050 (Lake County Stormwater Management Commission [SMC] 2018).




- Des Plaines River Watershed
- Des Plaines River
- Study Area
- Illinois County Boundary
- Wisconsin County Boundary

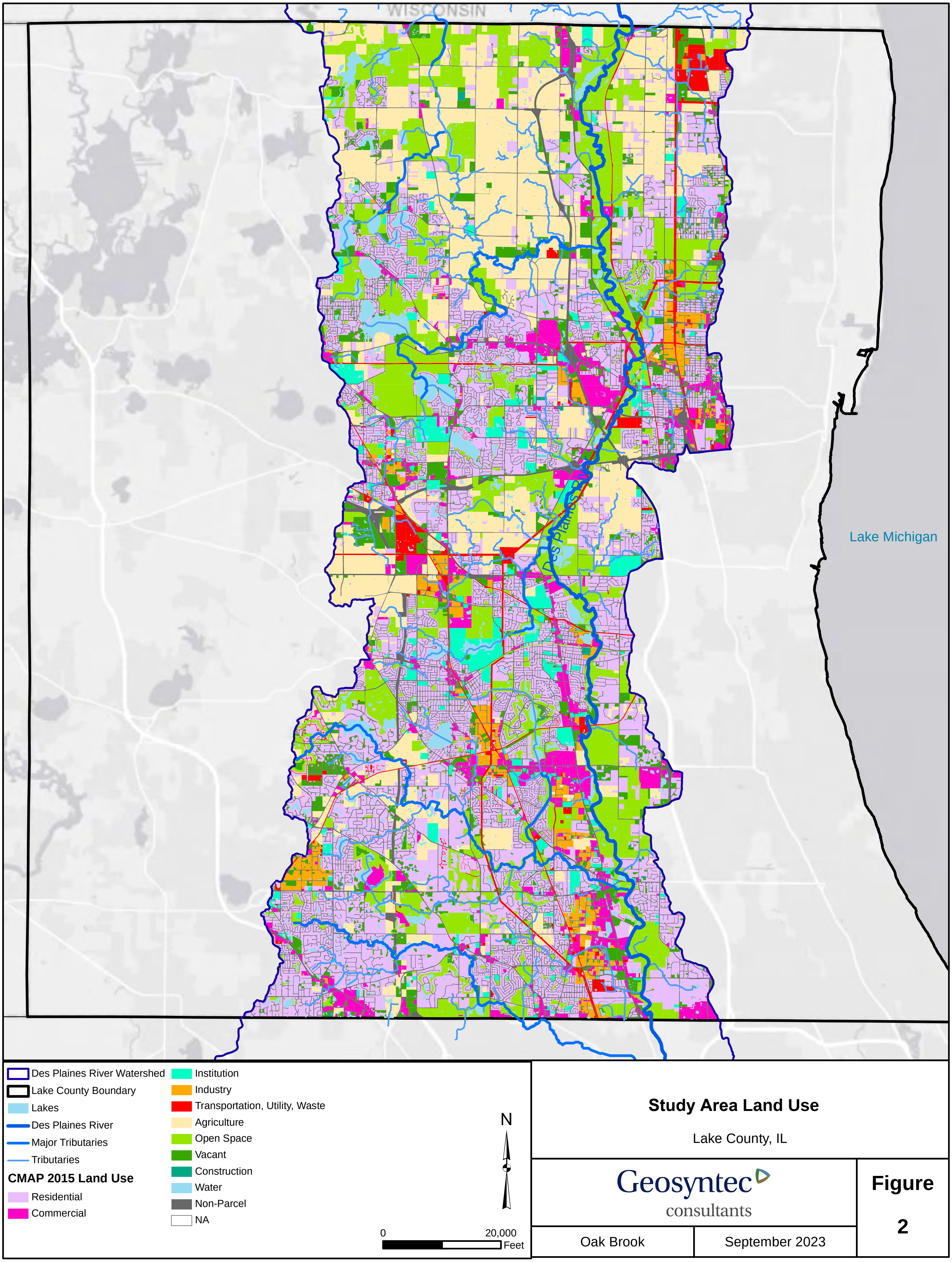
N

0 15 Miles

**Des Plaines River Watershed**

Geosyntec consultants

| Oak Brook | September 2023 | **Figure 1** |
|---|---|---|




**Study Area Land Use**

Lake County, IL

Geosyntec consultants

**Figure 2**

Oak Brook | September 2023

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## 1.2 Purpose of the NARP

The Illinois EPA has incorporated a special condition requirement to develop a NARP in many Illinois National Pollutant Discharge Elimination System (NPDES) permits for major POTWs. The NARP requirements apply to POTWs discharging upstream of water bodies that are determined to have a phosphorus-related impairment[1] or to be at "risk of eutrophication"[2]. In addition, there are conditions in the Municipal Separate Storm Sewer System (MS4) general permit that require permittees to provide a schedule for meeting waste load allocations in total maximum daily loads (TMDLs) or watershed management plans.

The purpose of the NARP is to identify phosphorus input reductions and other measures necessary to address the phosphorus-related impairment. Illinois EPA recognizes that other measures (such as dam removal, stream restoration, riparian buffers, or constructed wetlands) may be needed to eliminate impairments. Therefore, Illinois EPA has encouraged POTWs to develop NARPs on a watershed-wide basis with input from MS4s and other stakeholders

## 1.3 Watershed Group

The Des Plaines River Watershed Workgroup (DRWW) is a voluntary, dues-collecting organization whose mission is to meet Illinois EPA requirements by making cost-effective improvements to water quality in the Upper Des Plaines River and its tributaries in Lake County. The DRWW brings together a diverse coalition of stakeholders: members include communities, POTWs, and other interested parties. A complete list of participants can be found on the DRWW website (DRWW 2023).

The DRWW is developing a NARP for the Study Area. There are eight major POTWs in the Study Area (**Figure 3**) with design flows ranging from 4 to 24 million gallons per day **(Table 1**). The NPDES permits for these POTWs include the NARP special conditions because the POTWs are located upstream of a reach that Illinois EPA has identified as impaired due to phosphorus (Illinois EPA 2022). Among these eight POTWs, the Village of Mundelein Sewage Treatment Plant is not currently a member of the DRWW, and this report does not satisfy their NPDES special condition requirement.

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[1] A water body with a phosphorus-related impairment means is listed by Illinois EPA as impaired because of the presence of dissolved oxygen or "offensive conditions" (e.g., algae or aquatic plant growth).
[2] A water body is determined to be at "risk at eutrophication" if the levels of sestonic chlorophyll, pH, and dissolved oxygen are above the thresholds set by Illinois Risk of Eutrophication Committee.

**Table 2: Publicly Owned Treatment Works in the Nutrient Assessment Reduction Plan Study Area**

| Publicly Owned Treatment Works | Design Average Flow (MGD) | Receiving Water Body |
|---|---|---|
| North Shore Water Reclamation District (NSWRD) - Gurnee Water Reclamation Facility (WRF) | 23.6 | Des Plaines River |
| NSWRD - Waukegan WRF | 22.0 | Des Plaines River |
| Des Plaines River STP | 16.0 | Des Plaines River |
| New Century Town WRF | 6.0 | Des Plaines River |
| *Village of Mundelein STP** | *4.95* | *Des Plaines River* |
| Village of Libertyville STP | 4.0 | Des Plaines River |
| Mill Creek WRF | 2.1 | Mill Creek |
| Lindenhurst Sanitary District Sewage Treatment Plant (STP) | 2.0 | Hastings Creek |

* *Not part of the Des Plaines River Watershed Workgroup*
MGD: million gallons per day

DRWW hired Geosyntec Consultants, Inc. (Geosyntec) to develop a work plan to identify the scope, schedule, and budget for subsequent work required to produce the NARP (Geosyntec 2020). The work plan was submitted by DRWW to Illinois EPA to meet the special condition in the NPDES permit of POTWs. DRWW did not receive any specific feedback on the work plan from Illinois EPA.

## 1.4 Report Organization

DRWW hired a project team consisting of Geosyntec (prime consultant), Kieser & Associates, and The Conservation Fund to develop the NARP. The project team worked closely with the DRWW Monitoring Committee in the development of the NARP. This report documents the work that the project team conducted to execute the work plan for the Study Area NARP (Geosyntec 2020).

Chapter 2 of the report provides an overview of water quality impairments, nutrient sources, and other factors impacting water quality and previous water quality studies. The NARP development process, which included collecting data and analyzing, modeling, and evaluating management scenarios, is described in Chapter 3. Chapter 4 recommends an implementation plan and schedule to address phosphorus-related impairments.

# 2. WATER QUALITY STATUS

## 2.1 Phosphorus-Related Impairments

To fulfill the requirements of Section 303(d) of the federal Clean Water Act, every two years the Illinois EPA prepares a list of impaired waterbodies not meeting their intended uses (fishing, swimming, drinking water supply, etc.) and the criteria used as basis of the impairment. The criteria can be numeric or non-numeric (Section 303[d] List). The 2022 Section 303(d) List includes the following waterbodies in the Study Area for phosphorus-related impairments (Illinois EPA 2022) (**Table 2**):

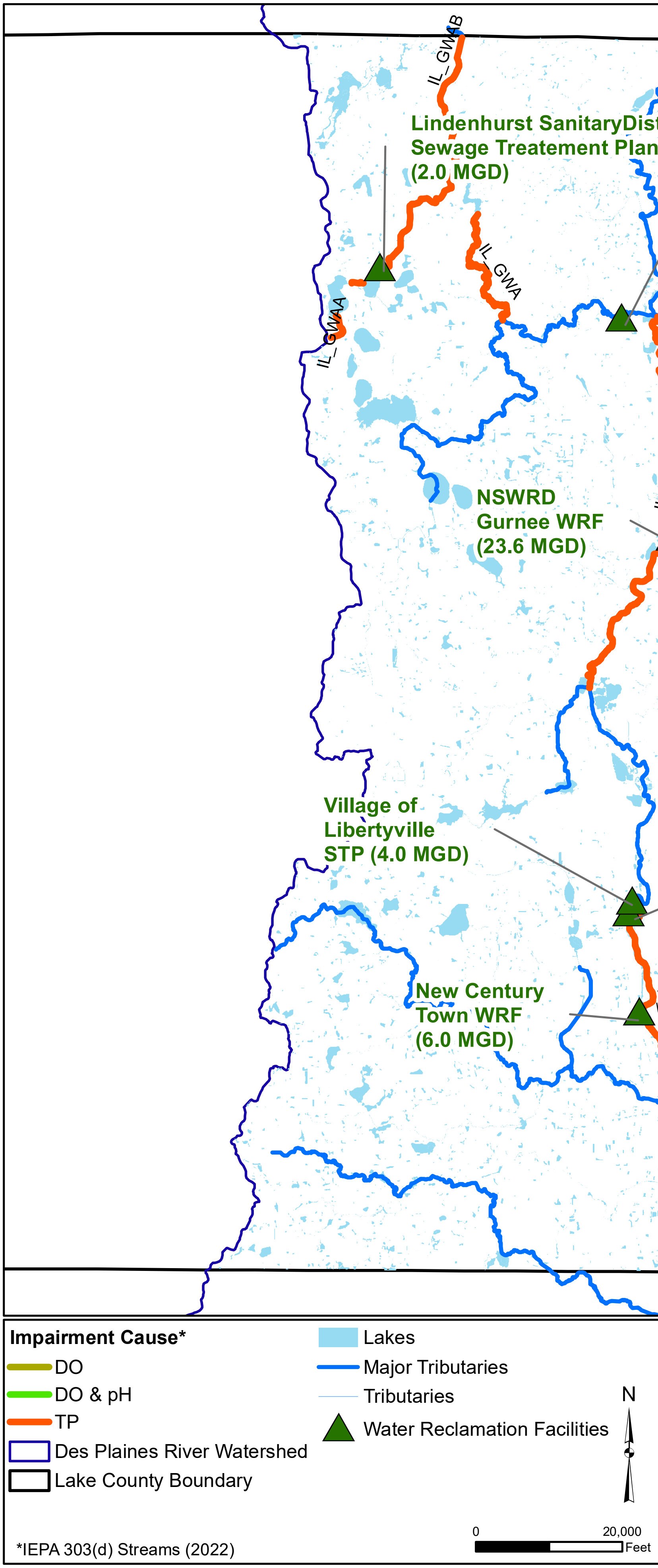
1. Des Plaines River segments IL_G-35, IL_G-36, and IL_G-07
2. North Mill Creek segment IL_GWA
3. Dutch Gap Canal segment IL_GWAB
4. Hastings Creek segment IL_GWAA

**Figure 3** shows the location of these reaches. Segments of the Des Plaines River (IL_G-25, IL_G-08), Mill Creek (IL_GW-02), and Indian Creek (IL_GU-02) were listed for phosphorus-related impairment in the 2016 Section 303(d) List (Illinois EPA 2016) but were delisted in the 2022 Section 303(d) List.

**Table 3: Phosphorus-Related Impaired Reaches (Illinois EPA 2022)**

| Water Body | Segment | Length (miles) | Cause of Impairment by Designated Use | |
|---|---|---|---|---|
| | | | Aquatic Life | Aesthetic Quality |
| Des Plaines River | IL_G-35 | 5.00 | Cause Unk, Total Phosphorus (**TP**) | F |
| Des Plaines River | IL_G-36 | 7.22 | **Algae**, CauseUnk, FlowMod, **TP** | F |
| Des Plaines River | IL_G-07 | 10.78 | As, Cause Unk, Nitrogen, Stream Alt, **TP** | F |
| North Mill Creek | IL_GWA | 5.48 | As, Cause Unk, Flow Alt, Flow Mod, Sed/Silt, **TP** | F |
| Dutch Gap Canal | IL_GWAB | 1.1 | As, Flow Alt, Flow Mod, Manganese, Sed/Silt, **TP** | X |
| Hastings Creek | IL_GWAA | 4.04 | As, Flow Mod, Sed/Silt, Stream Alt, **TP** | X |

As: arsenic
CauseUnk: Cause Unknown
F: Fully Supporting
FlowAlt: Flow Alteration – Changes in Depth and Flow Velocity
FlowMod: Flow Regime Modification
Sed/Silt: Sedimentation/Siltation
StreamAlt: Alteration in Stream-side or littoral vegetative covers
X: Not Assessed




**Study Area Impaired Reaches**

Lake County, IL

Geosyntec consultants

Oak Brook | September 2023

**Figure 3**

Z:\prj1\WATER RESOURCES - 1840\MOW5554 - DRWW NARP Development\3.0 GIS\MXDs\Report\2023(0313)_Risk of Eutrophication.mxd 9/30/2023 4:09:04 PM

## 2.2 Water Quality Goals and Load Reductions Targets

The DRWW has identified within their Bylaws the following goal:

> "The goal of the Workgroup is to improve water quality in the Des Plaines River and its tributaries through monitoring, project and best practices implementation, and education and outreach that will achieve attainment of water quality standards and designated uses for the watershed."

These Bylaws, originally established in 2018, and further revised in 2022, demonstrate a willingness by the DRWW to actively address the identified water quality impairments identified by the Illinois EPA and develop a reasonable framework as part of this NARP to accomplish the implementation necessary to achieve this goal. The segments of Des Plaines River and its tributaries impaired for phosphorus-related impairments (dissolved oxygen [DO] and nuisance algae impairment) are identified in Section 2.1. A summary of water quality standards in the Des Plaines River and its tributaries for DO and nuisance algae is provided below.

**Dissolved Oxygen:** Numeric criteria for DO are described in Illinois Administrative Code (Ill. Adm. Code or IAC) rules for water quality standards (35 Ill. Adm. Code 302). The DO criteria are dependent on the time of the year and include three components: (1) an instantaneous criterion, (2) a daily mean averaged over seven days, and (3) a daily mean averaged over 30 days. **Table 3** presents the DO standards for reaches in the Study Area.

**Table 4: Dissolved Oxygen Water Quality Standards**

| DO Standard | March through July | August through February |
|---|---|---|
| Instantaneous (mg/L) | 5.0 | 3.5 |
| Daily mean averaged over seven days (mg/L) | 6.0 | 4.0 |
| Daily mean averaged over 30 days (mg/L) | N/A | 5.5 |

**Nuisance Algae:** There are no numeric standards for nuisance algae in Illinois. The provisions of IAC Section 302.203 are a narrative description for the offensive condition in streams that is applicable to the reaches in the Study Area: "*Waters of the State shall be free from sludge or bottom deposits, floating debris, visible oil, odor, plant or algal growth, color or turbidity of other than natural origin*". The Illinois EPA uses a visual assessment by a trained biologist to determine whether a stream complies with these provisions. The biologist documents the visual results assessment in a field form along with the offensive condition such as excessive plant or algal growth.

The Illinois EPA 303(d) list identifies total phosphorus (TP) as a cause of impairment for several of the Des Plaines River and its tributaries' reaches associated with nuisance algae or plant growth. There are no numeric or narrative water quality criteria for TP in rivers and streams in Illinois.

From 2015 to 2018, a Nutrient Science Advisory Committee (NSAC) met and developed recommendations for numeric nutrient criteria for non-wadeable streams and rivers and wadeable streams for Illinois' southern and northern ecosystems. The NSAC recommended TP, total nitrogen, benthic chlorophyll *a*, and water column chlorophyll-a criteria (Illinois NSAC, 2018). The recommended TP criterion for non-wadeable streams in a northern Illinois ecosystem like the Des Plaines River was 113 micrograms per liter (µg/L). The Illinois EPA has not acted on the NSAC recommendations. Hence, this recommended criterion was not used for the NARP.

The Illinois Nutrient Loss Reduction Strategy recommends statewide TP load reduction targets of 45 % from the Year 2011 baseline loading for the period by 2045 (Illinois EPA et al., 2015). This load reduction target was used a reference for the Study Area as the NARP goal of meeting water quality standards and addressing phosphorus related impairments would need to be ongoing and adaptive in nature to verify the impact of implemented projected

## 2.3 Nutrient Sources

The nutrient sources in the NARP Study Area include point-source loading from major POTWs, loadings from the upstream area, and nonpoint-source (NPS) loading from surface runoff. NPS loading can be grouped into three major categories:

1. Agricultural
2. Urban (developed and open space in urban areas)
3. Other (forest, rural grassland, surface water, and wetlands)

The distribution of these land uses within the NARP Study Area is shown in **Figure 2.**

As part of NARP development, the project team developed a Soil and Water Assessment Tool (SWAT) model to quantify the TP loading. Annual TP loads were calculated based on the 2013 to 2020 modeling results for the NARP Study Area. **Figure 4** provides the annual average percentage contribution of TP from different sources for the NARP Study Area from 2013 to 2020. The total simulated annual average TP load for the entire Study Area from 2013 to 2020 is 441,850 pounds. Approximately 71% of this load is estimated to be from POTWs, while 37% is estimated to originate from the upstream area in Wisconsin. Urban runoff accounts for approximately 10% of the TP load, while other NPS contribute approximately 1% of total load.

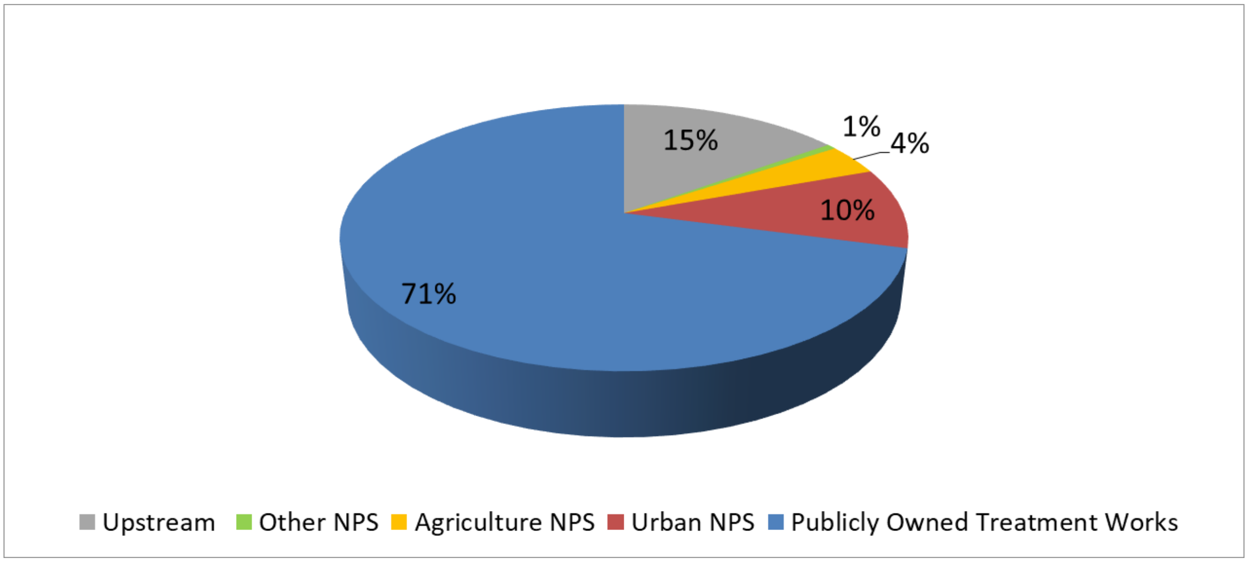



**Figure 4: Estimated Annual Average Total Phosphorus Loading, 2013 to 2020**

## 2.4 Other Factors

Streambank erosion is another factor that impacts water quality. The Lake County SMC conducted a stream inventory of the Des Plaines River and its tributaries. The results indicated that reaches of the mainstem of the Des Plaines River and the North Mill Creek are moderately eroded for 89% and 59% of miles assessed, respectively (Lake County SMC 2018).

## 2.5 Water Quality Studies

There have been extensive water quality studies and management plans for the Des Plaines River and its tributaries. Summaries of relevant studies and management plans are provided below.

### 2.5.1 Des Plaines River Watershed-Based Plan

The Lake County SMC developed a nine-element WBP for the Des Plaines River watershed planning area (Lake County SMC 2018). The plan identified nutrients, organic enrichment, and sedimentation and siltation as the major causes of impairments in the river and streams. The WBP included estimation of current and future annual average TP and total nitrogen loads from NPS based on existing and future conditions. The pollutant loading was estimated using the Spatial Watershed Assessment and Management Model. The model predicted an increase of 82% and 54% for TP and total nitrogen, respectively, for the future condition as compared to the existing condition. The WBP recommended several actions to reduce pollution entering the watershed, including investing in POTWs, upgrading stormwater management systems, and reducing the use of pesticides and fertilizers. The WBP also recommends using green infrastructure such as rain gardens and bioswales to manage stormwater runoff and reduce flooding and loading from urban sources.

### 2.5.2 Monitoring Studies

The DRWW and Illinois EPA have performed water quality monitoring in the Study Area, which is briefly described below.

#### *2.5.2.1 DRWW Monitoring*

Since September 2015, the DRWW has undertaken a comprehensive monitoring program to collect physical, chemical, and biological data in the mainstem Des Plaines River and its tributaries. The goals of the monitoring program as stated in the DRWW monitoring strategy documents are (1) to "develop and implement a comprehensive monitoring program that will include chemical, physical, and biological components that will accurately identify the quality of stream and river ecosystems as well as stressors associated with non-attainment of water quality standards and designated uses" and (2) to "assist the NPDES permittees including the POTWs and MS4 in meeting monitoring requirements" (DRWW 2015, 2017, 2018, 2020).

The comprehensive water quality monitoring undertaken by DRWW leveraged a tiered site design, which allowed for more frequent monitoring of sites with greater flow and tributary area while still providing comprehensive coverage of the watershed. The numbers of stations in each tier varied each year. Tier 1 included monitoring stations on Des Plaines River and Mill Creek. Monitoring of Tier 1 sites included biological assessment, sestonic and benthic chlorophyll a studies, and water column and sediment monitoring programs. Tier 2 consists of stations located on Des Plaines River and tributary streams, which were sampled for biological assessment and water column and sediment chemistry every 6 years. The 18 tributary stations were sampled for biological assessment and water column data every six years. The location of monitoring stations is shown in **Figure 5**

The components of monitoring included:

1. **Biological monitoring**. Biological monitoring includes sampling fish and macroinvertebrate habitat assessment. Biological monitoring was conducted for 69 sites in 2016 and then on a rotating basis for a minimum of 20 out of 70 total sites in the following years.
2. **Water column and sediment chemistry monitoring**. The water column and sediment data were collected using tiered monitoring strategy described above. The monitoring locations are shown in **Figure 5**. Water column monitoring consisted of both continuous monitoring of DO, pH, temperature, and conductivity and grab sample collection for DO, DO saturation, ammonia, nitrogen, TP, organic carbon, total suspended solids (TSS), pH, conductivity, and chlorine. Sediment samples were analyzed for metals and organics.
3. **Flow monitoring**. DRWW hired Burns & McDonnell Engineering Company, Inc. to install a network of 15 stage data loggers and measured flow data monitors to develop flow rating curves in the mainstem Des Plaines River and its tributaries.

DRWW also hired Midwest Biodiversity Institute to develop an Integrated Prioritization System tool to identify the most limiting stressors in receiving streams based on the above-described comprehensive monitoring program (MBI, 2022).

#### *2.5.2.2 Illinois EPA Monitoring*

Illinois EPA collected continuous and discrete water quality monitoring data in the watershed in 2013 and 2018 as part of its Intensive River Basin Survey program. Additional data were collected in the watershed as part of Illinois EPA's Ambient Water Quality Monitoring Network Program and Facility Stream Survey programs (Illinois EPA 2023).

### 2.5.3 Lake County Green Infrastructure Model and Strategy

The Lake County Green Infrastructure Model and Strategy (GIMS) is a framework for identifying land conservation and restoration opportunities for the county's major native landscape types: woodland/forest, prairie/grassland/savanna, wetlands, and freshwater aquatic systems (LCFD, 2016). The GIMS was developed by the Lake County Forest Preserve District. It builds on the previous efforts of the Chicago Wilderness regional Green Infrastructure Vision and on the assessment of ecosystem service valuation in Lake County and six other Illinois counties that was conducted by the Chicago Metropolitan Agency for Planning with support from the Conservation Fund.

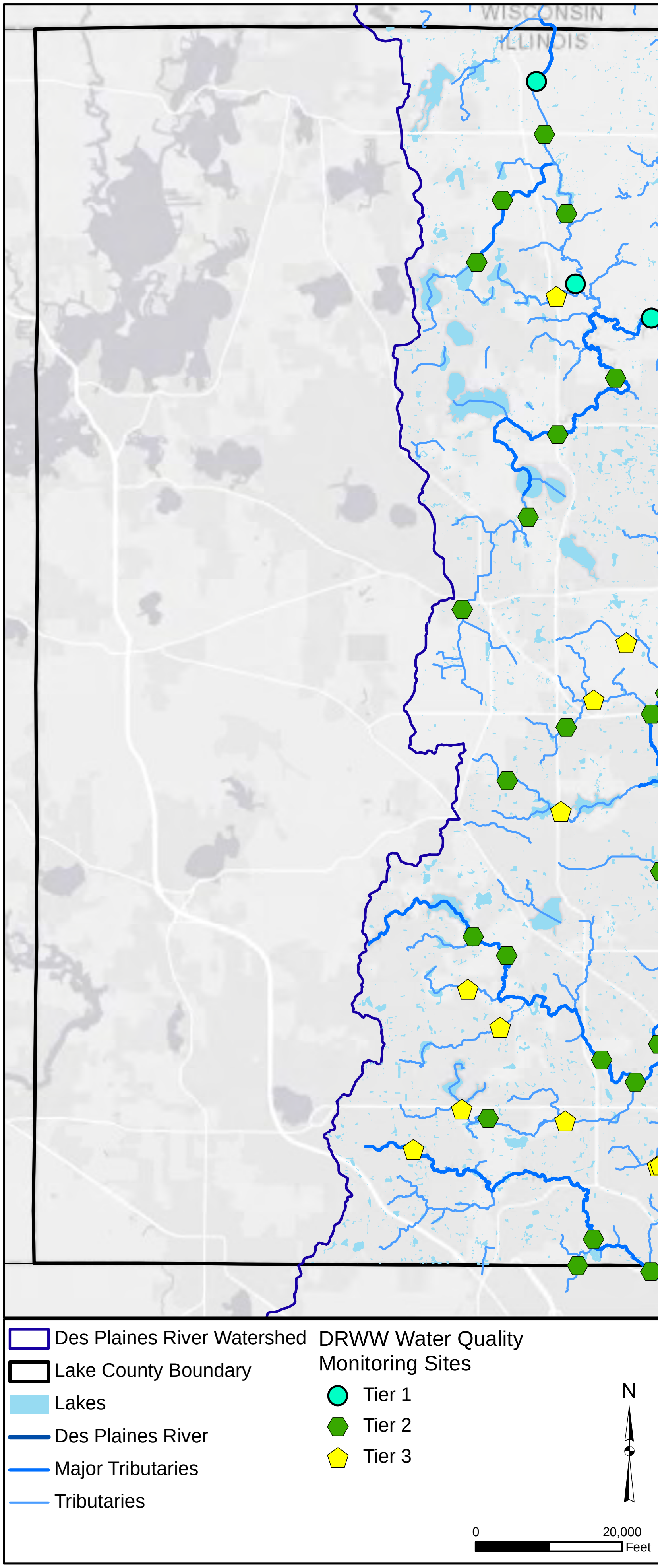
The GIMS is a valuable tool for land conservation and restoration in Lake County. It can be used to identify priority areas for conservation, develop restoration plans, and assess the advantages of green infrastructure. The GIMS is also a valuable resource for the public, providing information about the county's green infrastructure network and the benefits of conservation. Among its major recommendations, the GIMS proposes to protect and restore core areas and functional connections, increase the connectivity of the green infrastructure network, expand the use of green infrastructure to manage stormwater runoff, and educate the public about the benefits of green infrastructure.

### 2.5.4 Wisconsin Des Plaines River Studies

The upstream load to the Study Area includes loading from the Des Plaines River watershed in southeastern Wisconsin, with a drainage area of 133 square miles. Although upstream of the NARP Study Area, this area is relevant because upstream water quality (e.g., nutrients, algae, and DO) impacts the water quality in the DRWW NARP Study Area.

The Southeastern Watershed Regional Planning Commission developed a comprehensive regional plan for the Des Plaines River watershed in southeastern Wisconsin (SEWRPC, 1978). The plan identifies the major water quality, flooding, and land use issues in the watershed and outlines strategies for addressing them. The plan also includes a set of goals and objectives for the watershed, as well as a list of actions that need to be taken to achieve these goals.

The Wisconsin Department of Natural Resources (WDNR) is developing a TMDL for the Fox Illinois River Basin (WDNR 2023). The study area for this TMDL includes the Des Plaines River watershed in Wisconsin. The mainstem Des Plaines River segments in Wisconsin are listed as being impaired on Wisconsin's Section 303(d) List (WDNR, 2022). The TMDL and subsequent implementation plan will provide a framework to address the impairments in these segments.




**Location of DRWW Monitoring Stations**

Lake County, IL

Geosyntec consultants

| | | Figure 5 |
|---|---|---|
| Oak Brook | September 2023 | |

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## 3. NARP DEVELOPMENT PROCESS

### 3.1 Data Collection and Analysis

DRWW conducted NARP–focused monitoring in 2020, which consisted of the following components:

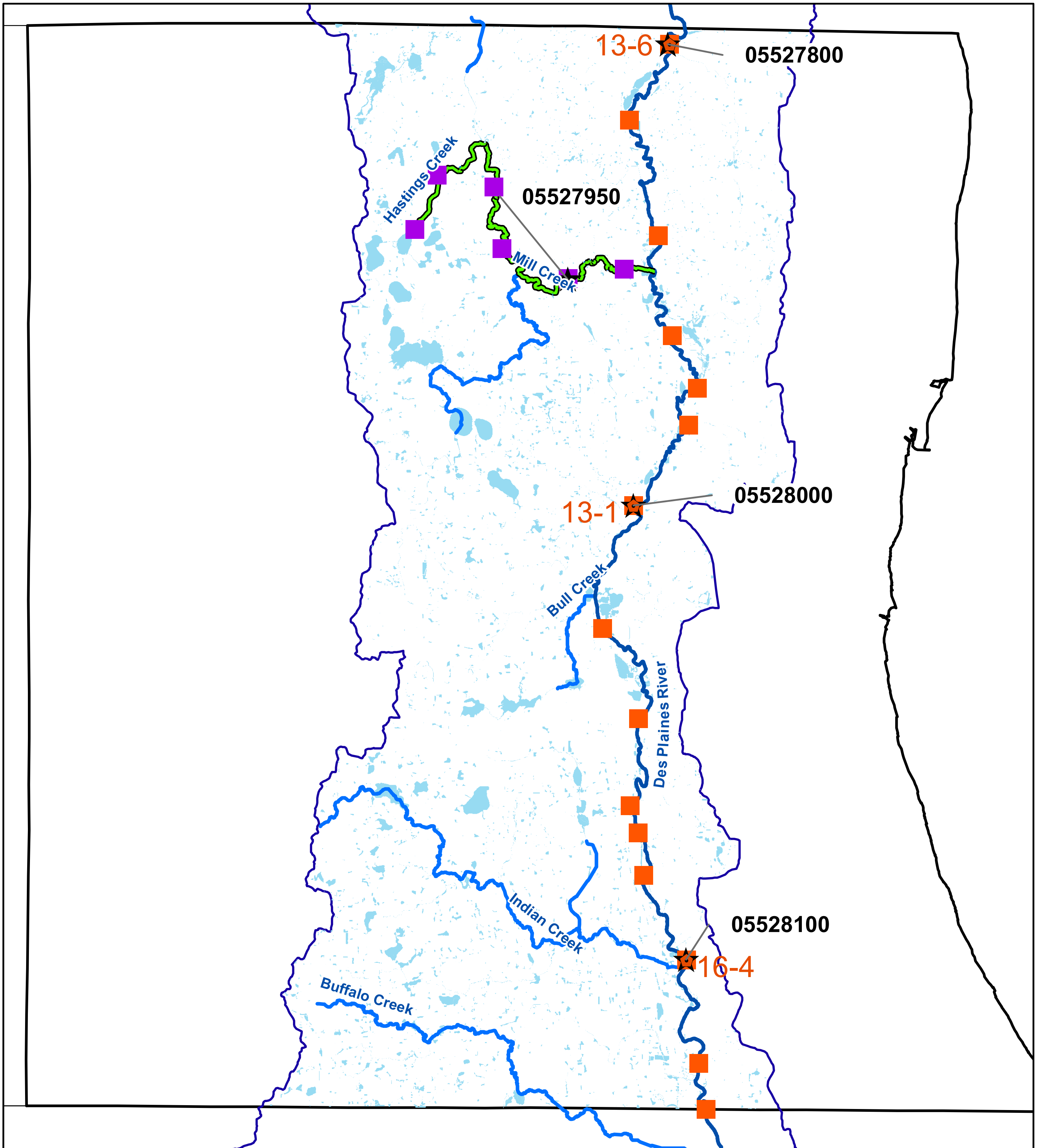
1. **Continuous monitoring**. Three sondes on the mainstem of the Des Plaines River (**Figure 6**) measured DO, temperature, TSS, pH, chlorophyll *a*, and conductivity.
2. **Discrete sampling**. Discrete measurements were taken for DO, temperature, pH, nutrients, sestonic chlorophyll *a*, and benthic algae at 15 Tier 1 sites on the mainstem of the Des Plaines River and three (3) tier sites on the Mill Creek. Samples were taken monthly during the summer period.

Data for the growing season (May to October) from 2017 to 2020 were analyzed to assess the longitudinal trends along the mainstem of the Des Plaines River. **Figure 7** shows the longitudinal box-and-whisker plots for measured instream TP.[3] The *x* axis on the graph represents miles on the Des Plaines River, decreasing from left to right in the direction of flow. The plot shows that the instream TP increased with inputs from POTWs but decreased shortly after.

**Figure 8** shows a similar plot for sestonic chlorophyll *a*. Instream chlorophyll *a* is high (greater than 15 µg/L) at the upstream boundary at the Illinois-Wisconsin border, and it decreases downstream due to dilution from discharge inputs from POTWs.

This trend is also apparent in **Figure 9**, which shows high chlorophyll *a* levels at upstream station 13-1 (Rusell Road) and decreased levels at downstream station 16-4 (Rt 120). The high chlorophyll *a* levels at the upstream boundary resulted in large variability in DO at the upstream boundary (**Figure 10** and **Figure 11**). Downstream, the variability in DO is reduced by discharge inputs from POTWs, which are high in DO, and reduced instream chlorophyll *a* levels. The data analysis shows that the chlorophyll *a* levels at the upstream boundary have a large impact on downstream water quality.

[3] Whiskers represent the minimum and maximum values, the edges of the box represent the 25th and 75th percentile values, and the central lines represents the median values. Text on top of each box shows the numbers of samples available




Des Plaines Watershed
Lake County Boundary
Lakes
Mill Creek Model Extent
Des Plaines River
Major Tributaries
Mainstem WQ Stations
Mill Creek Model WQ Stations
USGS Stations
Continuous WQ Stations

N

0 20,000 Feet

**2020 Nutrient Assement Reduction Plan**
**Monitoring Stations**

Lake County, IL

Geosyntec consultants

| Oak Brook | September 2023 |
|---|---|

**Figure**

**6**

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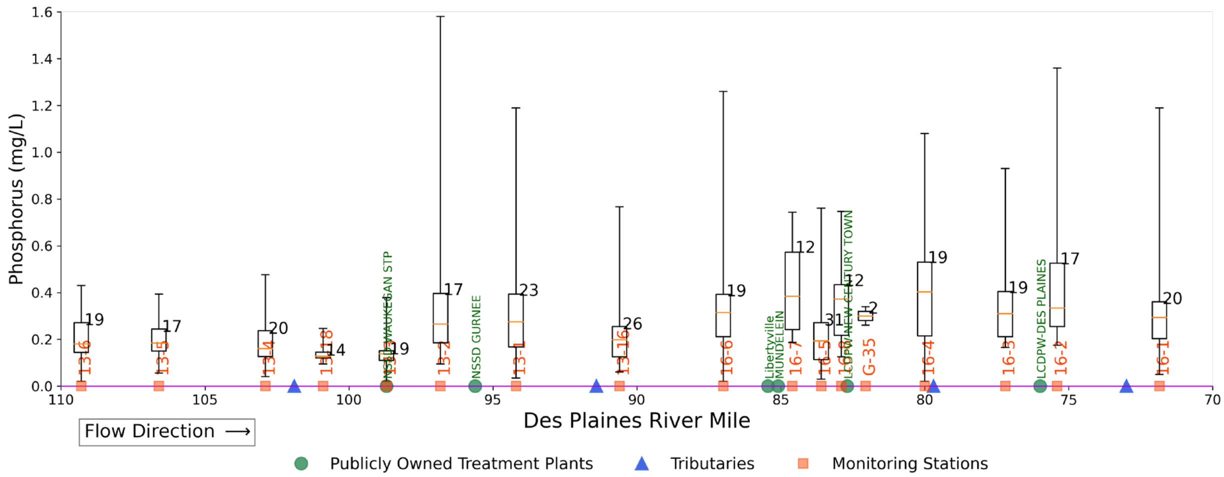


**Figure 7: Longitudinal Plot of Measured Total Phosphorus in the Des Plaines River for the Growing Season (May to October), 2017 to 2020**

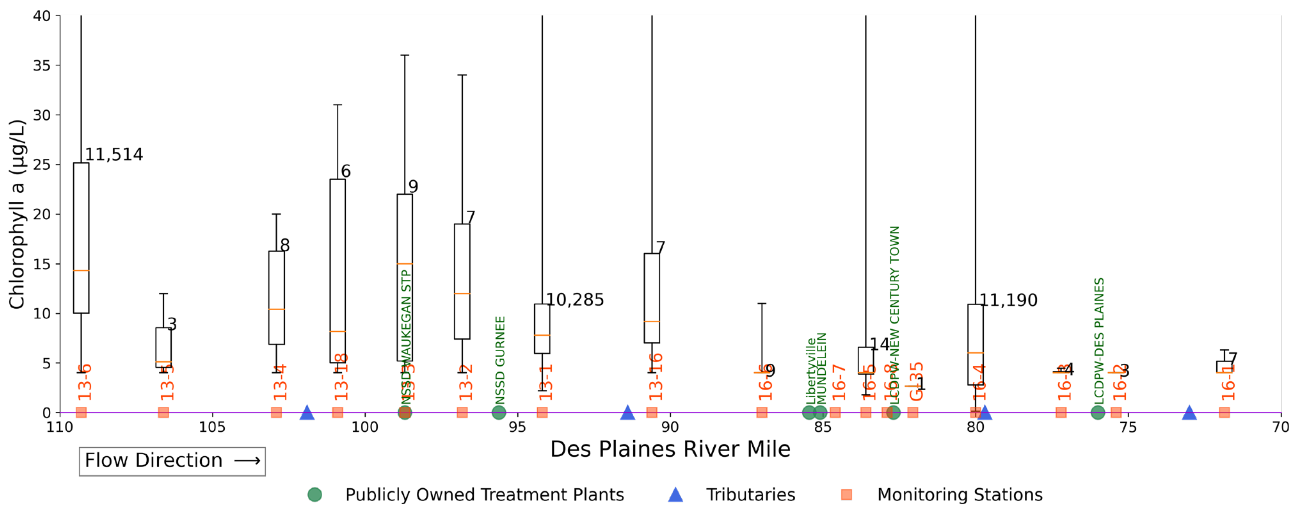


**Figure 8: Longitudinal Plot of Measured Sestonic Chlorophyll *a* in the Des Plaines River for the Growing Season (May to October), 2017 to 2020**

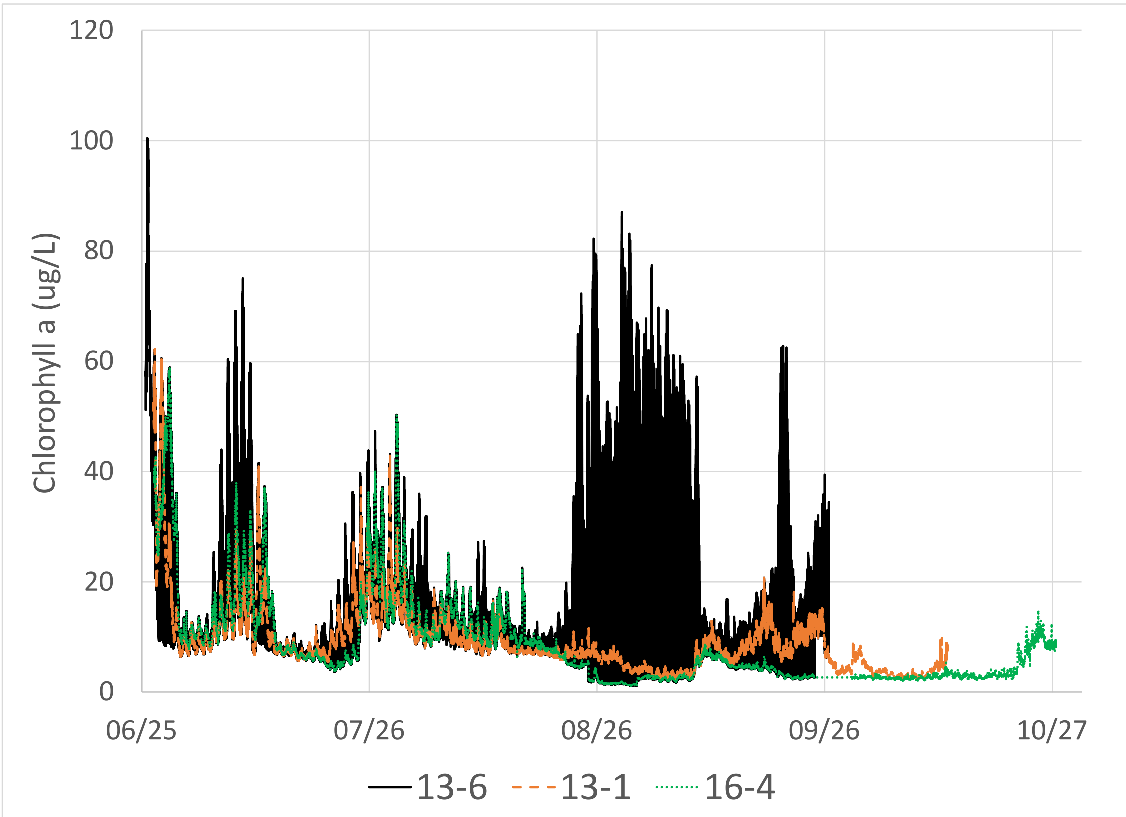


**Figure 9: Time Series of Measured Continuous Sestonic Chlorophyll *a* at Three Stations on the Des Plaines River Mainstem in 2020**

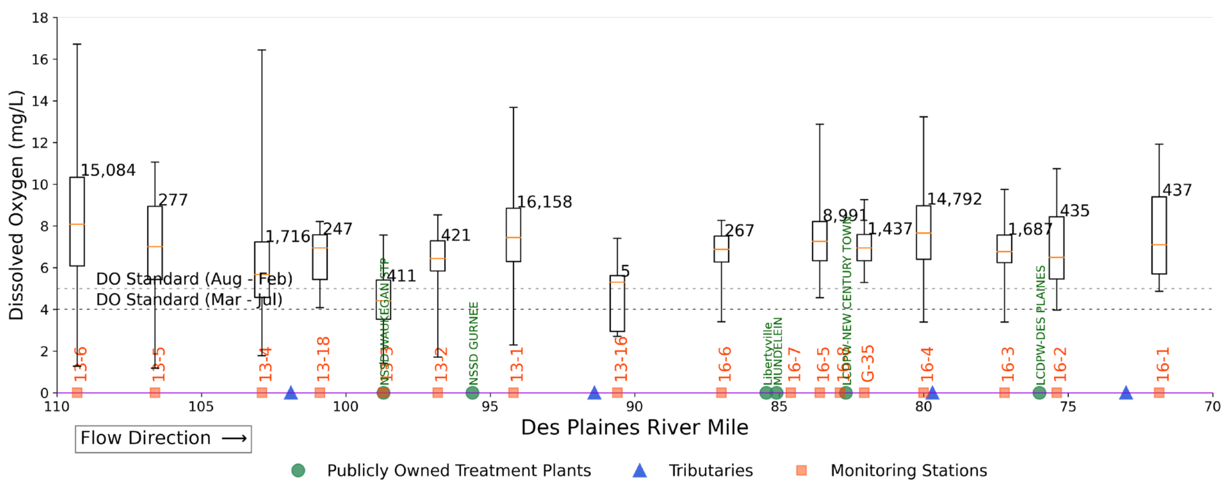


**Figure 10: Longitudinal Plot of Measured Dissolved Oxygen in the Des Plaines River for the Growing Season (May to October), 2017 to 2020**

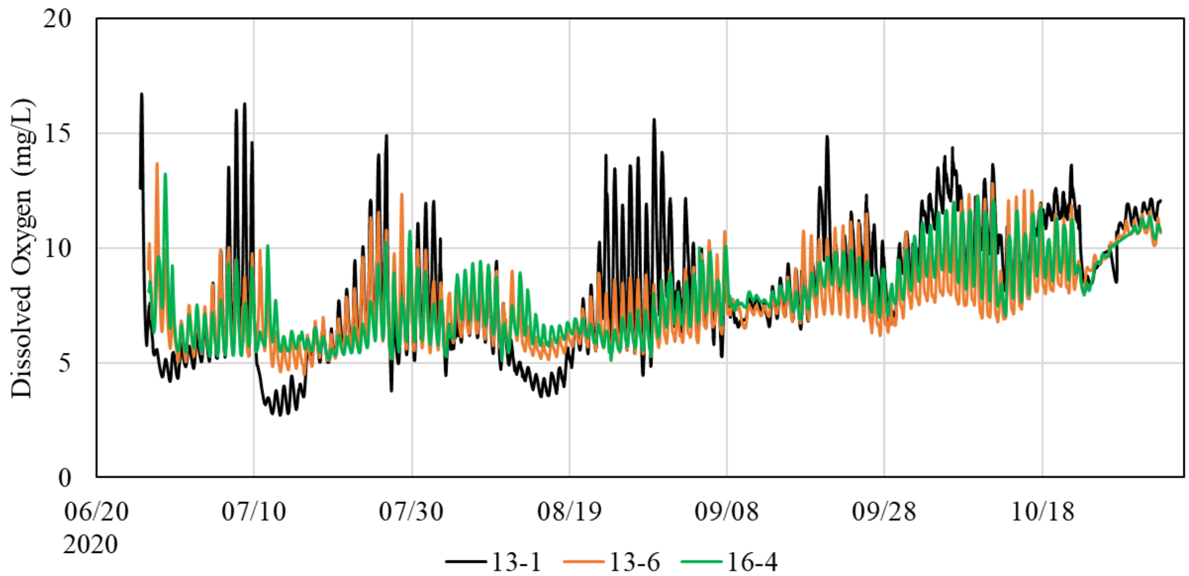


**Figure 11: Time Series of Measured Continuous Dissolved Oxygen at Three Stations on the Des Plaines River Mainstem in 2020**

## 3.2 Modeling

The NARP requires identification of phosphorus input reductions by point-source and NPS discharges, among other necessary measures to remove phosphorus-related impairments in the watershed. Models can be used to define the linkage between the phosphorus inputs and related impairments such as DO and nuisance algae, evaluate the effectiveness of different watershed management scenarios in reducing or removing impairments, and provide useful information to decision-makers as they decide which projects to prioritize in implementing NARP recommendations.

A linked numerical modeling framework was developed for the NARP, as recommended in the DRWW NARP work plan (Geosyntec 2020). The linked modeling framework consists of two components: a watershed model and two instream models with hydraulic and water-quality components (**Figure 12**). The development and calibration of the two models are briefly summarized below, and further details are included with the appendices.

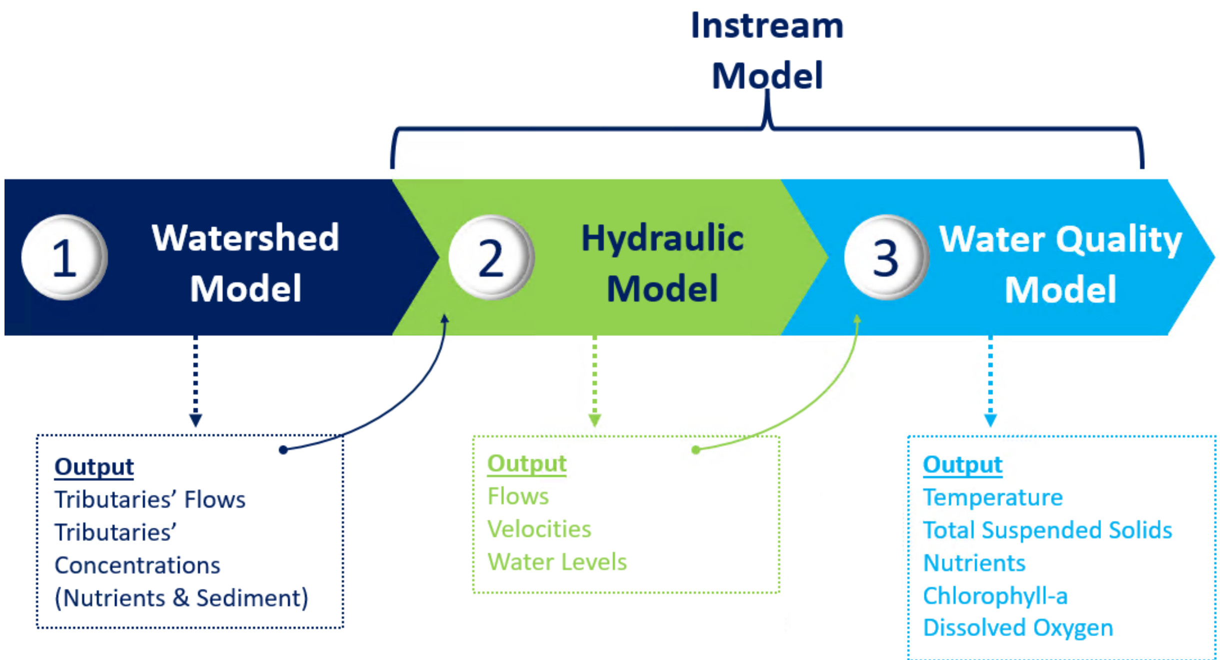


**Figure 12: Model Framework**

### 3.2.1 Watershed Model

The watershed model was developed using the Soil & Water Assessment Tool (SWAT) which is a river-basin-scale model originally developed by the United States Department of Agriculture's Agricultural Research Service (Texas A&M 2006, Neitsch et al. 2011). The extent of the SWAT model developed for the NARP includes the drainage area in Wisconsin and the NARP Study Area. The drainage area of 231,534 acres was delineated into the 89 subwatersheds based on elevation data for developing the model. The inputs into the model included data on elevation, soil, land use, stream network, and meteorology.

The SWAT model was calibrated to measured flow and available water quality data to enable the model to simulate reality reasonably well. **Figure 13** shows the daily time series comparison of simulated values and measured data at the four United States Geological Survey gages for the period of 2013 to 2018. The model simulates the daily flows reasonably well compared to the measured data except for Mill Creek. In general, the model underestimated the peaks of the biggest storms for Mill Creek, which resulted in a slight underestimation of total flow volumes from Mill Creek. For the Des Plaines River watershed, WWTP loading constitutes more than 70% of loading under the current existing conditions. Hence, the underestimation of loading from Mill Creek is unlikely to impact the water quality in the mainstem of the Des Plaines River

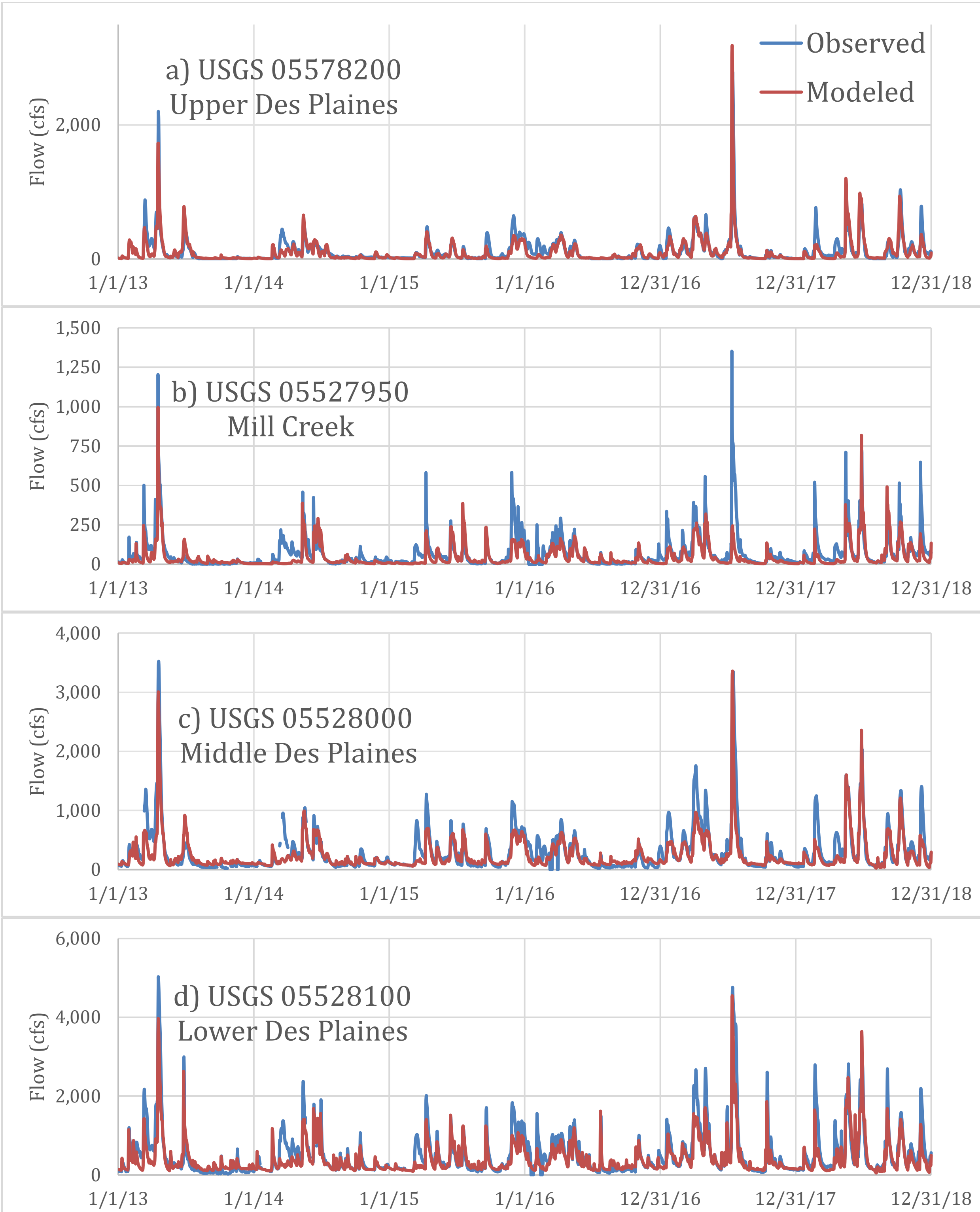


**Figure 13: Times Series Comparison of Simulated and Measured Flows in Des Plaines River**

The SWAT model was used to generate time series of flows and concentrations of TP, total nitrogen, and TSS from the land segments, including the POTW loads, to the instream models. A comparison of measured and simulated instream TP concentrations is shown in **Figure 14**. The model simulates TP concentrations in the measured data reasonably well.

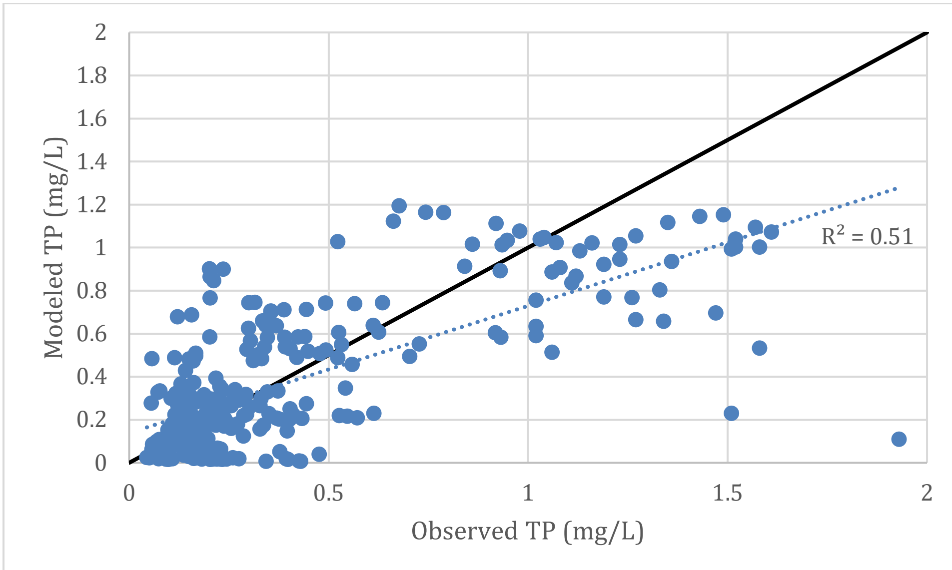


**Figure 14: Overall Modeled Stream Total Phosphorus Concentrations versus Observed Data**

**Figure 15** illustrates estimated annual TP loads from 2013 to 2020 for the NARP Study Area. POTW loads constitute the majority of TP load for all years. POTW loads show a generally declining trend from 2013 to 2020, except in 2019. Precipitation in 2019 (46.4 inches) average for the 10 utilized precipitation stations) was higher than in any year from the 2011 to 2020 period (36.2 in average, 25–46.4 mm range, *Appendix A: DRWW NARP Watershed Modeling*). If any excess inflow and infiltration was handled by POTWs, it could have contributed to the increased effluent TP load for that year. The NPS loads are largely driven by stormwater runoff and correlate strongly with precipitation totals. The annual precipitation totals from 2017 to 2020 were higher than the annual totals from 2013 to 2016, and the NPS loads for these years follow this trend as well.

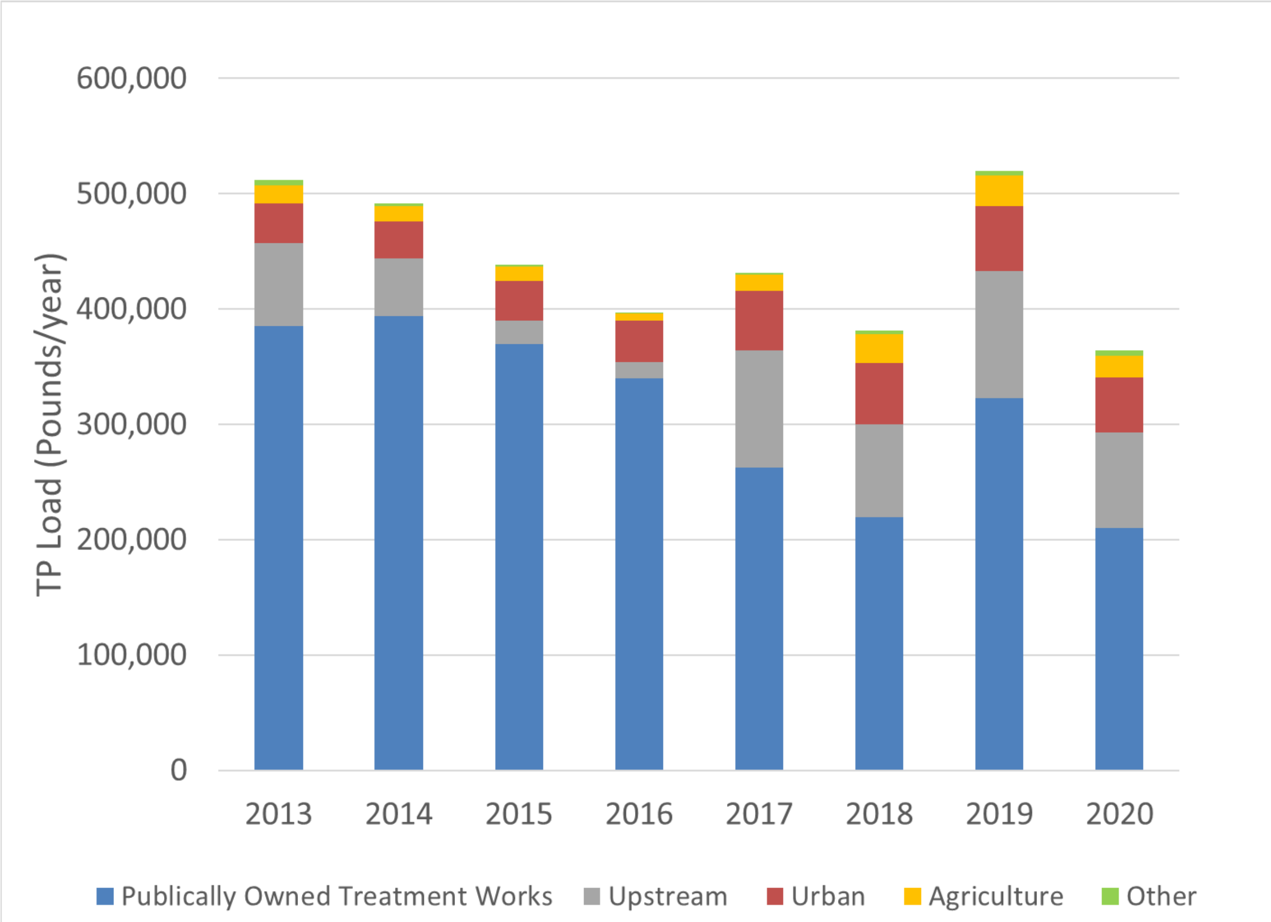


**Figure 15: Simulated Annual Total Phosphorus Loads from Different Sources from 2013 to 2020**

The SWAT model was also run for two additional theoretical management scenarios in which POTW effluent TP concentrations were capped at 1 milligram per liter (mg/L) and 0.5 mg/L. **Figure 16** compares the existing annual average loads with TP loads and two scenarios with POTW effluent TP limits of 1.0 mg/L and 0.5 mg/L, respectively. The two effluent limit scenarios predicted large load decreases as compared to the baseline scenarios that used observed data. For the baseline annual average scenario, POTWs accounted for 71% of the modeled TP. The percent contributions of POTWs to TP average annual loading would decrease to 38% and 25% under the 1.0 mg/L limit and 0.5 mg/L limit scenarios, respectively.

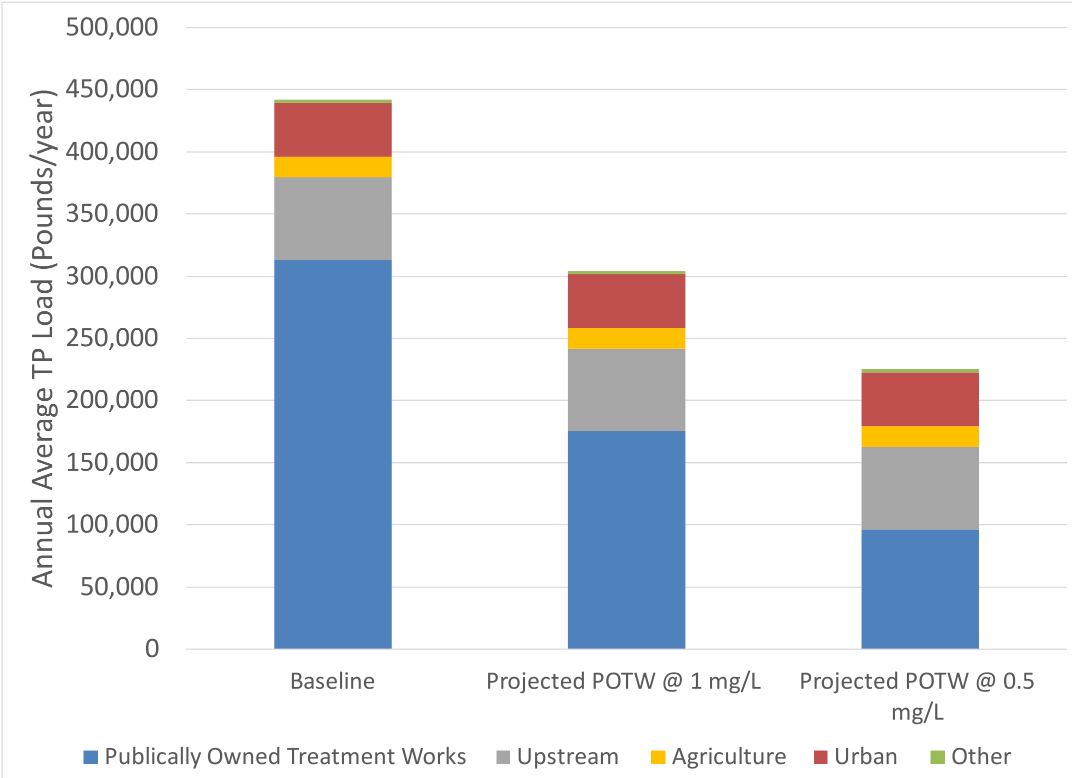


**Figure 16: Estimated Quantity of Annual Average Total Phosphorus Load, 2013 to 2020**

The watershed model development and calibration are described in detail in Appendix A (DRWW NARP Watershed Modeling).

### 3.2.2 Instream Model

The instream model was developed using the QUAL2Kw framework (Pelletier et al. 2006). QUAL2Kw can perform a continuous simulation of flow and water quality. The QUAL2Kw framework provided the DRWW with a tool to inform management decisions concerning water quality under varying flow conditions over the growing season.

The modeled reaches include the Des Plaines River mainstem and the tributaries that receive discharges from POTWs shown in **Figure 2**. The modeled tributaries are as follows:

1. Hastings Creek, downstream of Hasting Lake (receives effluent from Lindenhurst Sanitary District STP)
2. North Mill Creek, downstream of the confluence with Hastings Creek (downstream of Hastings Creek)
3. Mill Creek, downstream of the confluence with North Mill Creek (receives the effluent discharge from Mill Creek water reclamation facility or WRF)

QUAL2Kw cannot model branched tributaries. Therefore, two QUAL2kw models were developed to simulate the reaches above using the same parameterization: the Mainstem Model, which includes thirty-five miles on the mainstem of the Des Plaines River, and the Tributary Model, which includes thirteen miles on the three tributary segments listed above.

The instream model development and calibration are described in detail in Appendix B (DRWW Instream Model) and are summarized below.

#### *3.2.2.1 Development*

The inputs into the instream model included meteorology, channel characteristics, and time series of flows and water quality constituents from the upstream boundary, NPS, and point sources.

#### *3.2.2.2 Calibration*

The instream model was calibrated to available flow and water quality data for the growing season of May to October 2020. This period was chosen because it provides the most available instream water quality data (including concurrent continuous and discrete water quality). The flow in the mainstem of the Des Plaines River was high in May 2020 and very low from June to October 2020.

**Figure 17** compares simulated and measured TP at the Route 120 station in the Des Plaines River (river mile 20.8). The model does a reasonable job of representing the measurements. **Figure 18** compares simulated and measured discrete and continuous chlorophyll *a* data at the Route 120 station in the Des Plaines River (river mile 20.8). The Mainstem Model simulations captured the overall trend of measured chlorophyll *a* reasonably well. However, the model significantly underpredicts peaks for chlorophyll *a*, especially in late August and late September. The underprediction is linked to an underprediction of chlorophyll *a* from the Mill Creek tributary. **Figure 19** compares simulated and measured DO in the Des Plaines River at Route 120 (river mile 20.8) for July 1 to August 15, 2020. The model captures the DO diurnal fluctuations reasonably well during this period.

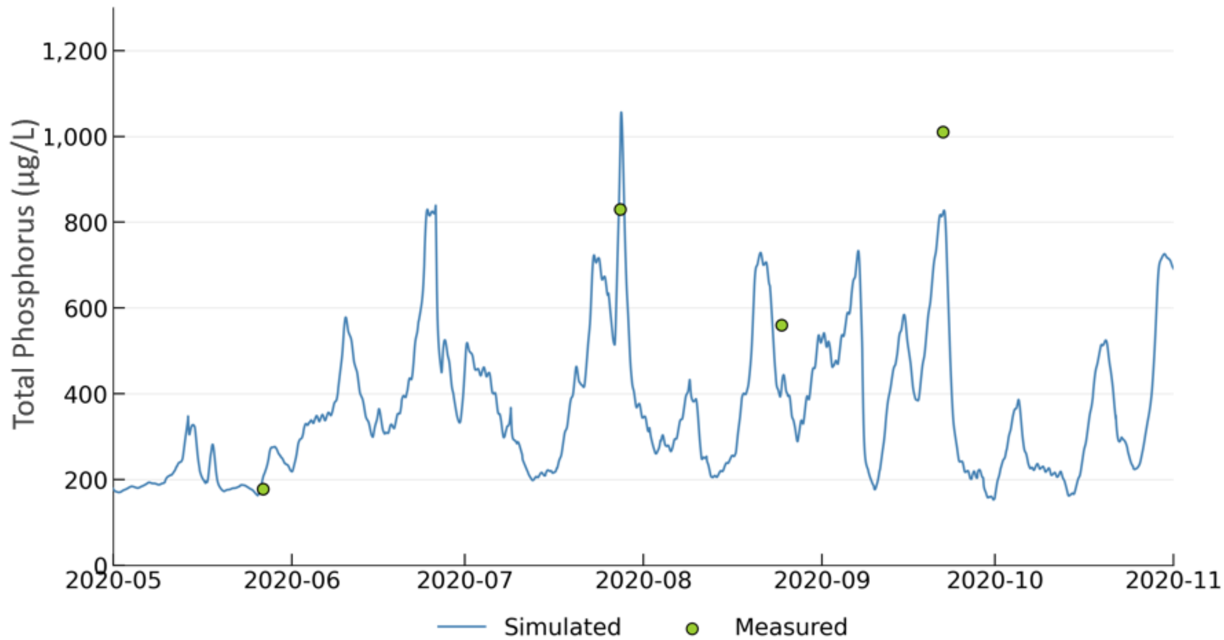


**Figure 17: Simulated and Measured Total Phosphorus on the Des Plaines River at Route 120 (River Mile 20.8)**

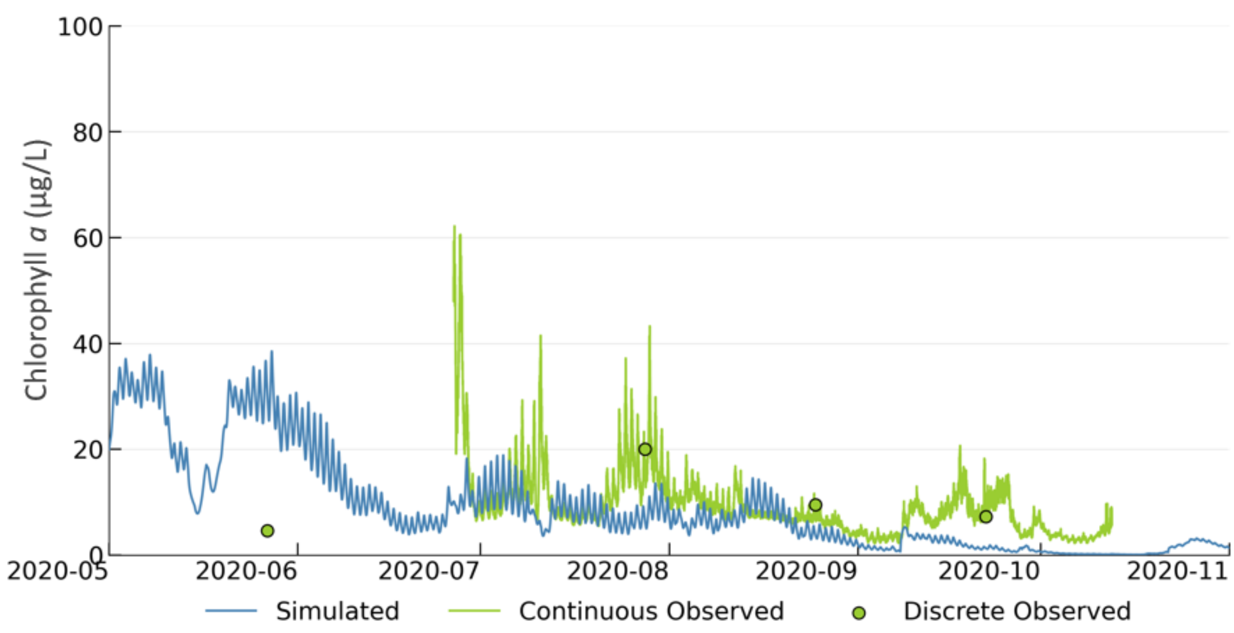


**Figure 18: Simulated and Measured Sestonic Chlorophyll *a* in the Des Plaines River at Route 120 (River Mile 20.8)**

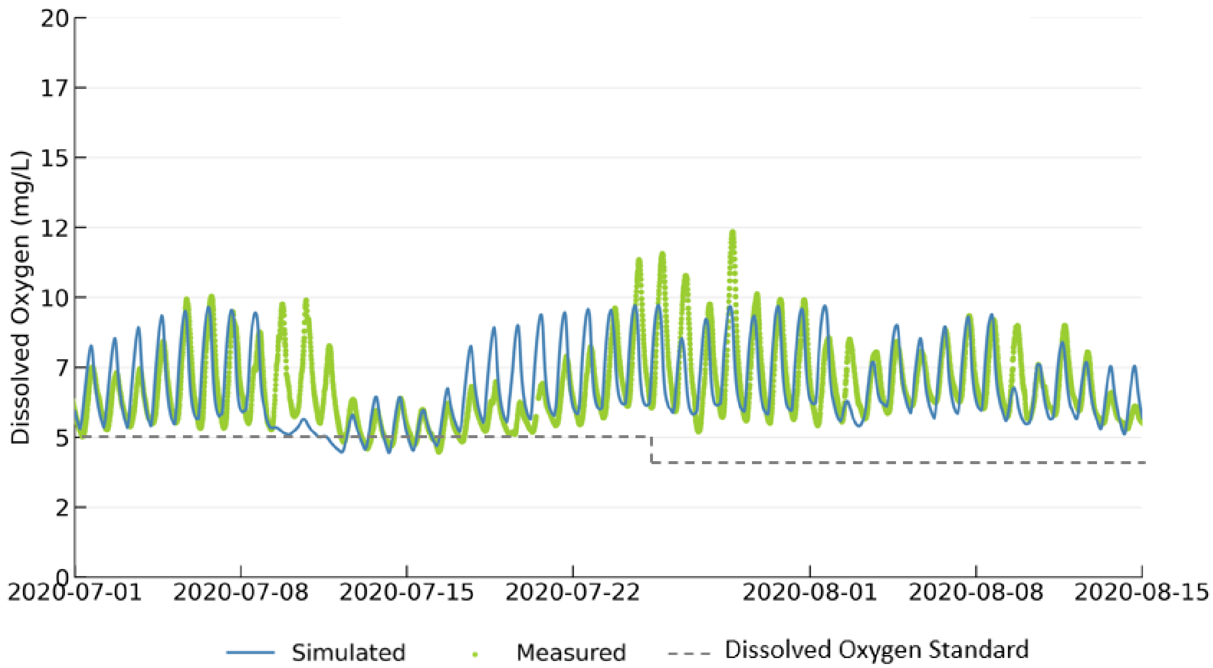


**Figure 19: Simulated and Measured Dissolved Oxygen in the Des Plaines River at Route 120 (River Mile 20.8), July to August 2020**

## 3.3 Management Scenarios

The models were used to simulate several scenarios to evaluate the effectiveness of watershed-based strategies in improving the water quality in the Upper Des Plaines River. These scenarios were compared with the baseline scenario, which represents the existing condition of the system. The instream calibrated model for the growing season of May to October 2020 was used as the baseline scenario for evaluating watershed management actions.

The watershed management scenarios are described briefly below.

### 3.3.1 Load Reduction from POTWs

The TP concentrations for POTWs in the baseline scenario range from 0.1 to 6.8 mg/L. The instream model was run to simulate the impact of POTW TP load reduction scenarios by capping the TP effluent concentrations to constant values of 0.5 mg/L and 0.1 mg/L.

### 3.3.2 Load Reduction from Upstream Sources

The upstream load constitutes approximately 20% of the total TP load into the Study Area for the period of May to October 2020. The instream model was run for a scenario with a 75% reduction in upstream TP load. The reduction was simulated by proportionally reducing the upstream concentrations of organic phosphorus, inorganic phosphorus, and internal phosphorus within sestonic algae (i.e., algae suspended in the water column). The upstream boundary sestonic chlorophyll *a* values for the baseline scenario ranged from 9 to 96 µg/L over the growing season. For the 75% reduction scenario, the upstream sestonic chlorophyll *a* boundary ranged from 2 to

24 µg/L. It is unknown at this time whether this load reduction can be realized with the TMDL for the Des Plaines River in Wisconsin, which is currently under development.

### 3.3.3 Load Reduction from Nonpoint sources

The contribution of tributary loads varies by river mile and is simulated with the SWAT model. The instream model was run for a scenario with a reduction of 75% of the tributary load.

### 3.3.4 Combined Scenario

The watershed management scenarios described above were grouped into two combined scenarios based on the Monitoring/Water Quality Improvements Committee's review of the results of the management scenarios described above. The two combined scenarios are as follows:

1. **Combined Scenario #1:** 25% upstream TP reduction, 25% tributaries TP reduction, and 0.5 mg/L POTW effluent TP
2. **Combined Scenario #2:** 50% upstream TP reduction, 25% tributaries TP reduction, and 0.5 mg/L POTW effluent TP

### 3.3.5 Other Measures

The Des Plaines River at the Illinois-Wisconsin border is very sluggish and has very low DO at times (**Figure 11**). This part of the river could benefit from a stream restoration project, which would involve creating riffles and pools to increase natural aeration. The impact of this stream restoration project was simulated in the model by increasing the velocity by 2.5 times[4] and reducing the depth of upstream reach by the same factor.

## 3.4 Evaluation of Management Scenarios

The models were used to evaluate the watershed management actions and combined scenarios by comparing the results to the baseline scenarios for the three selected periods:

1. Growing Season Period (May to October 2020)
2. High-Flow Period (May 1 to May 31, 2020)
3. Low DO Period (July 1 to July 7, 2020, when the upstream DO was below the water quality criteria)

The modeling results and key findings are summarized below and are described in detail in Appendix B (DRWW Instream Model).

### 3.4.1 Key Takeaway #1: POTW total phosphorus reductions beyond 0.5 mg/L have minimal impact on water quality.

The impact of load reductions associated with more stringent effluent TP limits for POTWs was simulated by capping the POTW effluent concentrations to 0.5 mg/ L and 0.1 mg/L in the model.

[4] The factor of 2.5 was chosen arbitrarily to assess the impact increased velocity and decreased depth on stream reaeration

Simulated results for the baseline scenario (**Figure 20**, black solid line) were compared with a scenario with POTW effluent TP capped at 0.5 mg/L and a scenario with POTW effluent TP capped at 0.1 mg/L for the growing season (May to October 2020). The results show that decreasing POTW TP effluent substantially reduces instream TP downstream of river mile 23. For the scenario with a POTW TP effluent concentration at 0.5 mg/L, the TP loading transported through the system would be reduced by approximately 29% (**Figure 20)**. Even after the POTW TP effluent load reduction of 0.1 mg/L, the reduced instream TP concentrations are still above the critical thresholds to cause nutrient limitation for algae. Therefore, the reduction in POTW TP effluent concentration beyond 0.5 mg/L has no major impact on instream sestonic chlorophyll *a* or DO.

### 3.4.2 Key Takeaway #2: Upstream total phosphorus reduction reduces sestonic chlorophyll *a* and improves dissolved oxygen during high flows.

The scenarios for the upstream TP load reduction included a modeled reduction in upstream sestonic chlorophyll *a*, because a portion of TP is also bound up as internal phosphorus in sestonic chlorophyll *a*. Simulated results for the baseline scenario (**Figure 21**, black solid line) were compared with a scenario with a 75% upstream reduction (blue dashed line) for the high-flow period (May 1 to May 31, 2020). The results show that reducing the upstream TP load reduces the instream TP and sestonic chlorophyll *a*. The reduction in instream chlorophyll *a* improves DO because of reduced DO swings and increased benthic algae activity after wet events.

### 3.4.3 Key Takeaway #3: Tributary total phosphorus reductions reduce sestonic chlorophyll *a* in the mainstem river but have minimal impact on dissolved oxygen.

The impact of reducing tributary loads on the mainstem Des Plaines River was assessed by running scenarios with 75% reductions in simulated tributary TP loadings. Simulated results for the baseline scenario (**Figure 22**, black solid line) were compared with a scenario with a 75% tributary TP load reduction (green dashed line) for the high-flow period (May 1 to May 31). The results show that reducing the tributary TP load slightly reduces the instream TP and sestonic chlorophyll *a*, mostly following wet events. Tributary phosphorus load reductions have a minimal impact on the instream DO.

### 3.4.4 Key Takeaway #4: A combined reduction in the load from POTWs, nonpoint sources, and upstream improves the water quality in the Des Plaines River.

The impact of combined management actions that reduce the load from POTWs, nonpoint sources, and upstream was assessed by running two additional modeling scenarios. Modeling results were compared during the growing season (May to October 2020) for the baseline scenarios, Combined Scenario #1 (25% upstream TP reduction, 25% tributaries TP reduction, and 0.5 mg/L POTW effluent TP), and Combined Scenario # 2 (50% upstream TP reduction, 25% tributaries TP reduction, and 0.5 mg/L POTW effluent TP) (**Figure 23**). The results show that combining the POTW load reduction with load reduction from NPS and from upstream sources results in improved DO due to the reduction in instream TP, sestonic chlorophyll *a,* and benthic algae. This combined strategy is recommended to address the phosphorus-related impairment in the Study Area.

### 3.4.5 Key Takeaway #5: Improving upstream dissolved oxygen addresses the impairment in upper reaches of the Des Plaines River.

The impact of a stream restoration project in the Des Plaines River near the Illinois-Wisconsin border was simulated in the model by increasing the velocity and decreasing the depth each by a factor of 2.5. The modeling results show that increased velocity and reduced depth would result in increased reaeration, which would address the DO impairment in upper reaches of the NARP Study Area (**Figure 24**).

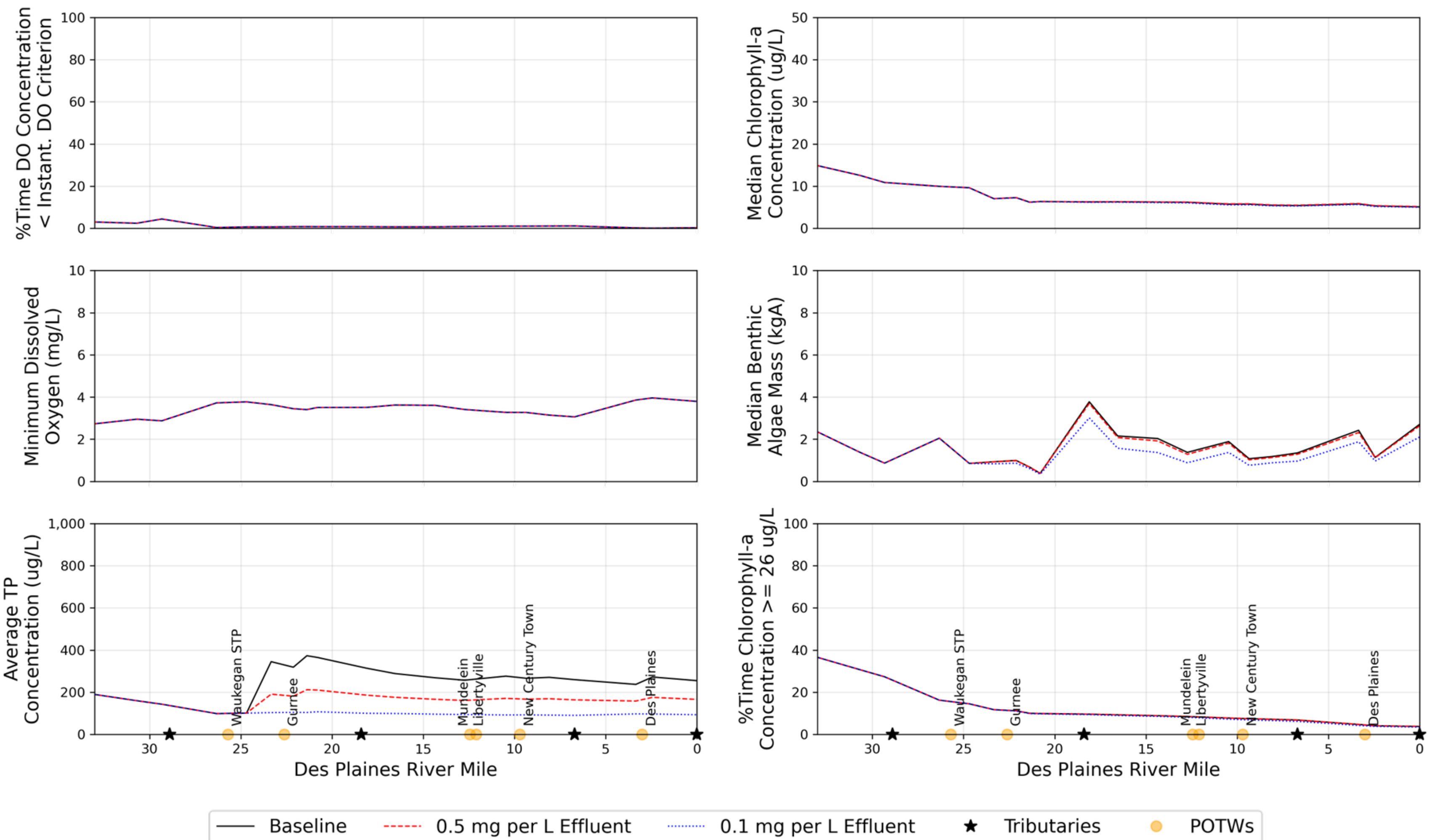


**Figure 20:Comparison of Baseline Scenario and Scenarios with POTW Effluent Discharge at 0.5 mg/L and 0.1 mg/L Total Phosphorus (May 1 to October 31, 2020)**

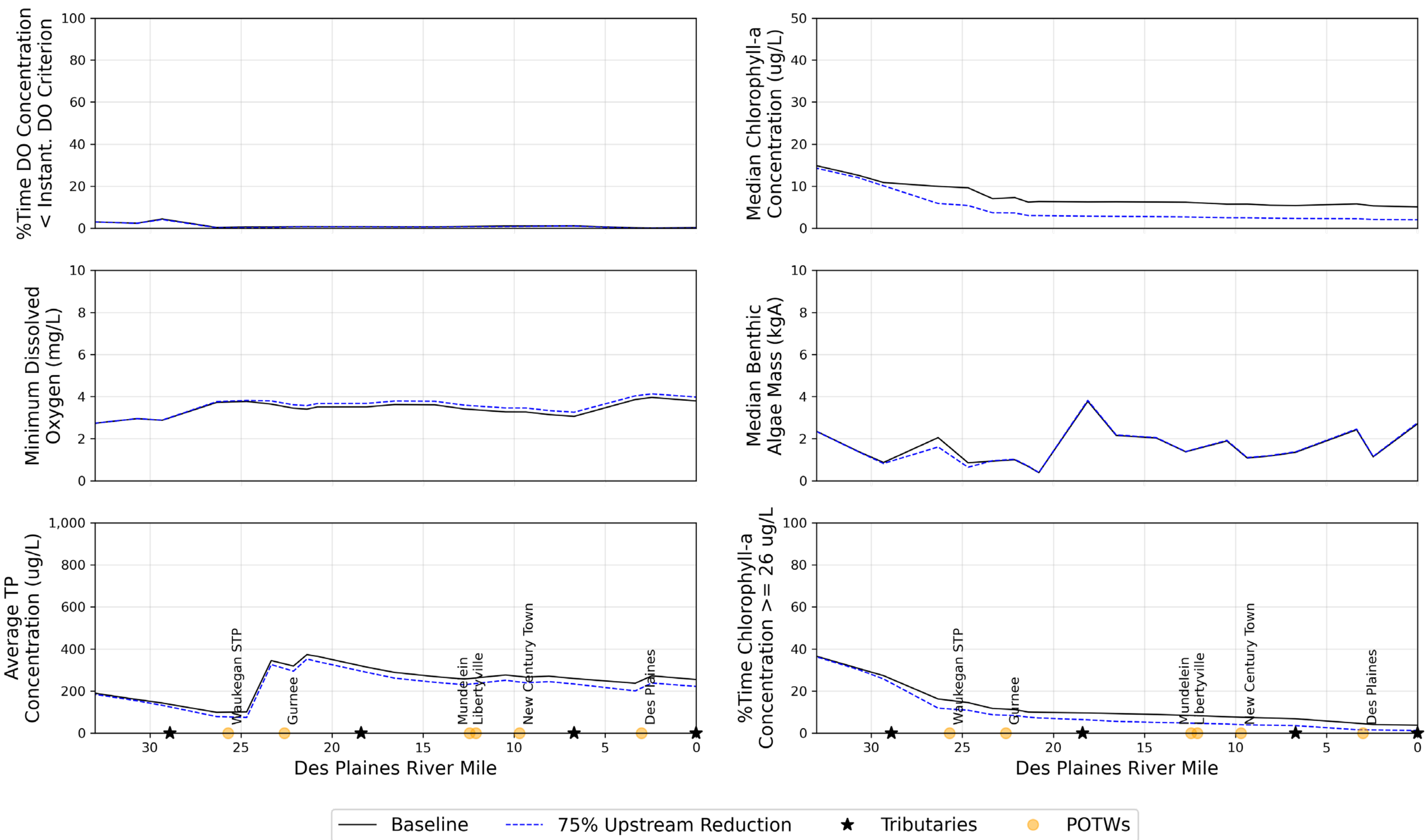


**Figure 21: Comparison of Baseline Scenario and Scenario with Upstream Total Phosphorus Reduced by 75% (May 1 to May 31, 2020)**

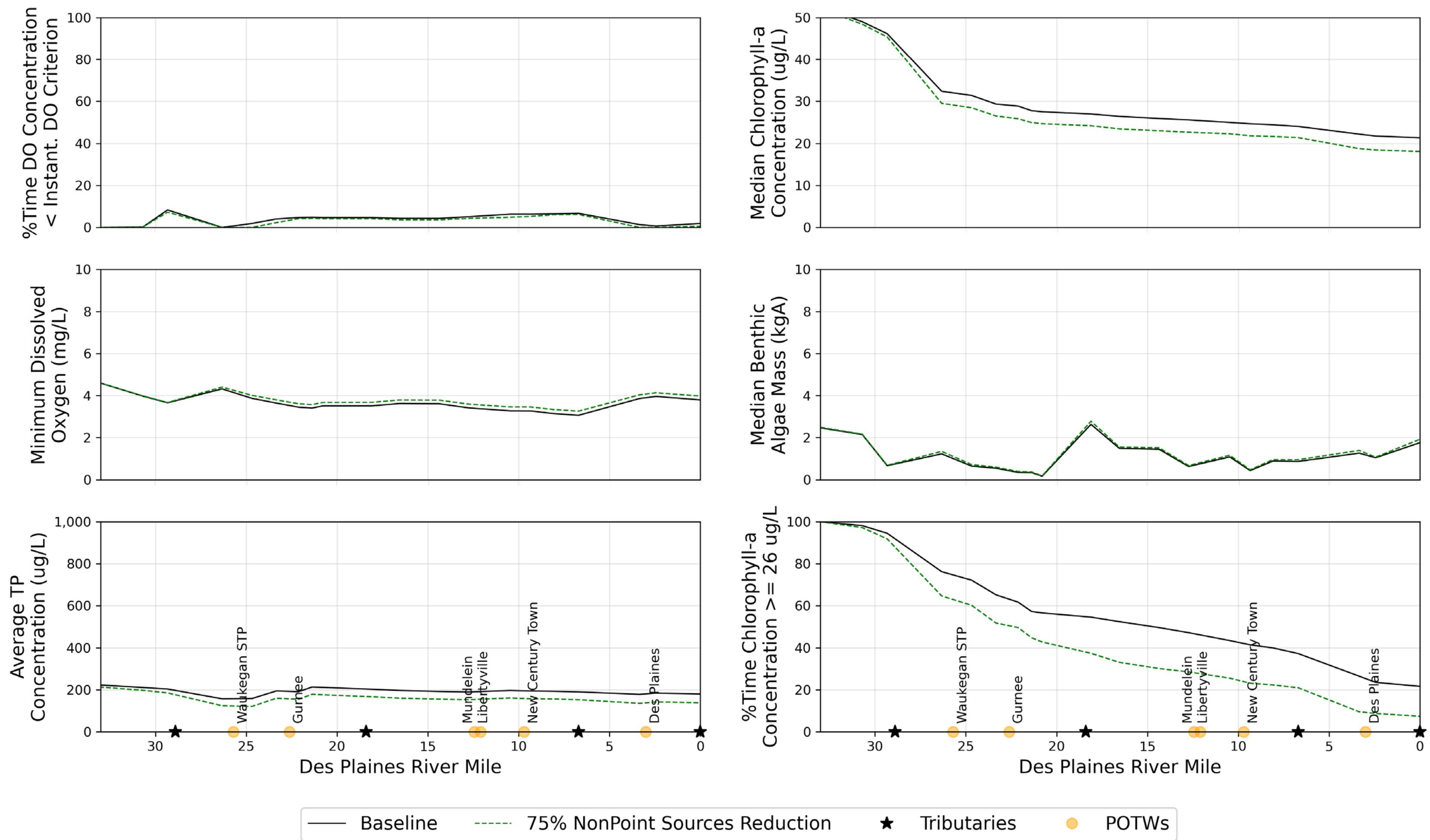


**Figure 22: Comparison of Baseline Scenario and Scenario with Nonpoint Sources Total Phosphorus Reduced by 75% (May 1 to May 31, 2020)**

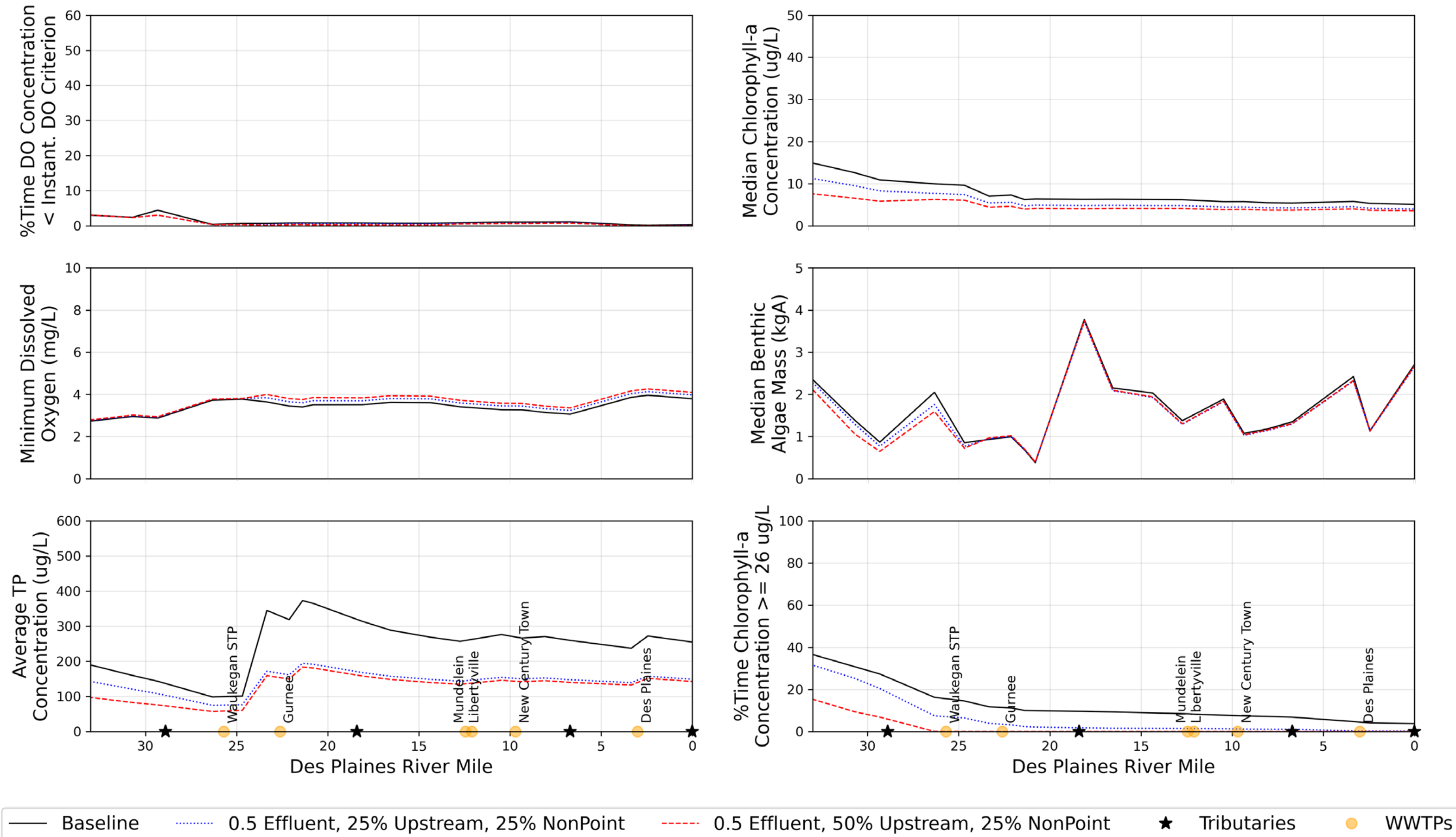


**Figure 23: Comparison of Baseline Scenario, Combined Scenario #1, and Combined Scenario #2**

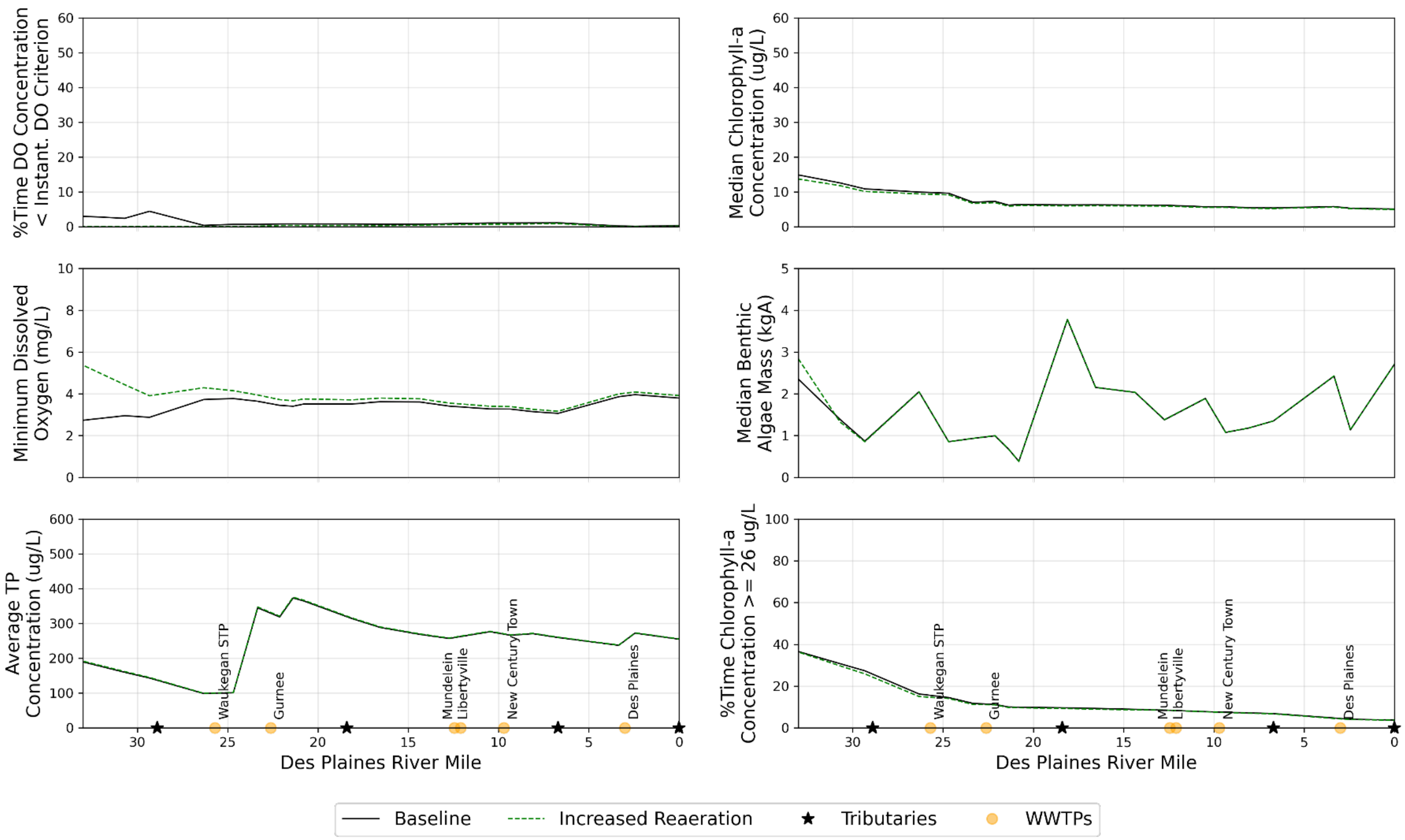


**Figure 24: Comparison of Baseline Scenario and Scenario with Increased Reaeration at the Upstream Boundary (May to October 2020)**

# 4. IMPLEMENTATION PLAN AND SCHEDULE

The work completed for the NARP focused on identifying management actions to eliminate DO and nuisance algae impairments. Future work would continue these efforts but may also expand to study other impairments or issues, such as sedimentation and hydromodification. This section presents the recommended management actions for addressing phosphorus-related impairments in the Study Area. Recommended actions fall under the following categories:

1. Administrative actions
2. Actions to address DO and nuisance algae impairments
3. Actions to provide other ancillary benefits
4. Monitoring and modeling studies

The recommended actions include shorter-term actions that can be implemented prior to 2033 and longer-term priorities for implementation after 2033. An implementation schedule with realistic milestones has been developed to allow the DRWW and other watershed stakeholders to pursue and utilize funds from public and private sources more effectively. The pre- and post-2033 recommended actions, along with key stakeholders and potential funding sources, are summarized in **Table 4** and described in detail below.

**Table 5: Nutrient Assessment Reduction Plan Recommended Actions**

| Category | Subcategory | Pre-2033 | Post-2033 | Key Stakeholders | Potential Funding Sources |
|---|---|---|---|---|---|
| Administrative | | Evaluate the role of the Des Plaines River Watershed Workgroup (DRWW) in addressing impairments related to the Nutrient Assessment Reduction Plan (NARP) | TBD based on evaluation | DRWW | DRWW, Applicable local, state and federal funding sources' |
| | | Continue DRWW monthly meetings and annual newsletters | Assess meeting frequency | DRWW | DRWW |
| Actions to address dissolved oxygen (DO) and nuisance algae impairments | Upstream Sources | Engage with the Wisconsin Department of Natural Resources (WDNR) on the development of a total maximum daily load (TMDL) for the Des Plaines River (DPR) and its tributaries in Wisconsin. | Continue to work with WDNR as a key stakeholder, including evaluating the potential for interstate program implementation such as the Regional Conservation Partnership Program (RCPP) | Illinois Environmental Protection Agency (Illinois EPA);<br>DRWW;<br>WDNR | WDNR, Applicable local, state and federal funding sources |
| | Major Publicly Owned Treatment Works (POTW) Upgrades | Meet a 0.5 milligram-per-liter (mg/L) total phosphorus effluent limit (12-month rolling geometric mean, calculated monthly) or alternate limit by January 1, 2030 | Monitor the impact of 0.5 mg/L effluent attainment of mainstem DO swings and algal growth | Major POTWs; Illinois EPA; DRWW | POTW capital budgets;<br>Illinois EPA;<br>State Revolving Fund loans;<br>User rates |

| Category | Subcategory | Pre-2033 | Post-2033 | Key Stakeholders | Potential Funding Sources |
|---|---|---|---|---|---|
| Actions to provide ancillary benefits | Urban | Consider policy recommendations on numeric total suspended solids (TSS) capture and impervious area percentage restriction per Watershed Based Plan recommendation | Support appropriate policy change in the watershed | DRWW;<br>Lake County SMC;<br>Lake County Technical Advisory Committee (TAC);<br>Local Communities | N/A |
| | | Encourage and distribute educational materials focused on the impacts of phosphorus. | Update and continue | DRWW;<br>Lake County SMC | DRWW |
| | | Encourage/support and distribute educational materials focused on the impacts of hydromodification. | | | |
| | | Explore/study the potential for nutrient credit or trading program | Update and or implement strategy if feasible and membership supports | DRWW;<br>Illinois EPA;<br>Chicago Metropolitan Agency for Planning (CMAP) | Illinois EPA 604B;<br>CMAP Local Technical Assistance;<br>DRWW |
| | | Look for ways to increase funding program expenditures within the DPR watershed. | Increase expenditures on beneficial stormwater projects as appropriate | DRWW;<br>Local Communities;<br>Lake County SMC;<br>Public Private Partnership (P3) Collaborator | DRWW;<br>Lake County Watershed Management Board (WMB);<br>Lake County SMC;<br>P3 |

| Category | Subcategory | Pre-2033 | Post-2033 | Key Stakeholders | Potential Funding Sources |
|---|---|---|---|---|---|
| Actions to provide ancillary benefits | Urban | In accordance with pending Illinois EPA guidance, review opportunities to enhance current maintenance and monitoring requirements with member communities. | Consider establishing annual maintenance and monitoring reporting from all new developments. | DRWW; Local Communities; Lake County SMC; | DRWW; Local Communities; Lake County SMC |
| | | Review communal practices in relation to seasonal street sweeping and leaf litter pickup. | Encourage a targeted leaf collection program. | | |
| | | Continue to promote the retrofitting of stormwater detention facilities consistent with the Watershed-Based Plan (WBP). | Encourage tracking of detention facility retrofits and dead pool storage maintenance. | | |
| | | Promote Lake County SMC's "Guide to Maintaining Stormwater Best Management Practices" for homeowners' associations and property owners, including ways to enhance it at the community level. | Continue to promote homeowner association engagement; consider inclusion of homeowner association guidance as part of Special Service Area (SSA) establishment. | | |

| Category | Subcategory | Pre-2033 | Post-2033 | Key Stakeholders | Potential Funding Sources |
|---|---|---|---|---|---|
| Actions to provide ancillary benefits | Agriculture | Explore relationships with the local Natural Resources Conservation Service (NRCS) office and the Lake County Farm Bureau. | Consider engagement with identified agricultural producers | DRWW;<br>NRCS;<br>Illinois Farm Bureau;<br>Lake County Farm Bureau;<br>Local Communities | DRWW<br>NRCS |
| | | Explore opportunities to engage in bi-state agricultural implementation programs like RCPP and Soil and Water Outcomes Fund. | | | |
| | Stream & Wetland Restoration | Explore stream restoration opportunities for improving stream reaeration and maintenance of baseflow. | Support stream restoration measures | DRWW;<br>Local Communities;<br>Illinois EPA;<br>Lake County SMC | Section 319 grants, Other applicable local, state and federal funding sources |
| | | Explore wetland restoration projects in consultation with Lake County Forest Preserve District | Support wetland restoration measures | DRWW;<br>Local Communities;<br>Illinois EPA;<br>Lake County SMC | Section 319 grants, Other applicable local, state and federal funding sources |
| | | Explore project opportunities to remove hydraulic impediments to flow on tributaries | Support projects to remove hydrologic impediments to flow on tributaries | | |
| Monitoring and Modeling Studies | | Establish a monitoring program for implementation post-2033 to assess the impact of POTW upgrades. | Implement monitoring program | DRWW;<br>Local communities;<br>POTWs | DRWW |

| Category | Subcategory | Pre-2033 | Post-2033 | Key Stakeholders | Potential Funding Sources |
|---|---|---|---|---|---|
| Monitoring and Modeling Studies | | Monitoring to meet the requirements of NPDES permit requirements for POTWs and municipal separate storm sewer systems (MS4s) | Assess data and continue monitoring as needed | DRWW;<br>POTWs;<br>MS4s | DRWW |
| | | Work with watershed partners to develop a watershed-wide tracking program of development and restoration projects. | Use project tracking to evaluate whether loading from site development has outpaced DRWW's ability to implement phosphorus-load-reducing projects. | DRWW;<br>Local communities;<br>Lake County SMC | Lake County SMC;<br>WMB |
| | | Work with the United States Geological Survey (USGS) and other stakeholders to consider establishing a Next Generation Water Observing Station on Des Plaines River at IL-WI border | | DRWW;<br>USGS;<br>WDNR;<br>Illinois EPA;<br>Lake County SMC | DRWW;<br>USGS;<br>WDNR;<br>Illinois EPA;<br>Lake County SMC |

## 4.1 Administrative Actions

The DRWW will continue to work on its goal to "*improve water quality in the Des Plaines River and its tributaries through monitoring, project and best practices implementation, and education and outreach that will achieve attainment of water quality standards and designated uses for the watershed*." Key to achieving this goal is the upgrades at the POTWs to achieve the 0.5 mg/L TP effluent limit and for the POTWs to continue to participate in the DRWW. Other actions need to remain voluntary for the DRWW to leverage potential resources outside of the workgroup members. The DRWW will continue to evaluate its role in its implementation of NARP recommendations in 2024 and beyond. Specific action items for the workgroup will be based on that evaluation. The workgroup will continue holding regular meetings to bring watershed stakeholders together. It will also continue to develop annual newsletter and other educational materials.

## 4.2 Actions for Addressing DO and Nuisance Algae Impairments

The recommended actions for eliminating low DO and nuisance algae impairments in the Study Area include POTW upgrades and upstream load reductions. These are described below.

### 4.2.1 POTW Upgrades

The POTW load reduction targets of 0.5 mg/L TP are believed to be achievable through a combination of biological phosphorus reduction combined with (in some instances) chemical addition. All DRWW POTWs are in the process of upgrading facilities to meet the 0.5 mg/L TP effluent limits. The technologies being utilized to meet these targets include biological phosphorus removal, chemical (ferric chloride) dosing, and alum treatments. A detailed description of these technologies is included in the phosphorus optimization feasibility reports and the annual progress reports submitted to Illinois EPA by each facility.

SWAT modeling results show that reducing POTW effluent concentrations of TP to 0.5 mg/L by 2033 will reduce annual average loading by more than 50% from the existing average baseline condition (**Figure 16)**. Due to the significance of this reduction, the potential implications of other sources should be evaluated once sufficient data have been collected after 2033. The water quality model simulations indicate that further reductions at the POTW beyond 0.5 mg/L will not provide significant benefits to the mainstem of the Des Plaines River. The stream response based on such significant nutrient reductions could require recalibration with additional data points to sufficiently diagnose the impact or benefit of POTW load reductions.

The NPDES permits for the POTWs required that the facilities meet the monthly average TP effluent limit of 1.0 mg/L by 2022. All POTWs are already meeting this requirement. These POTWs must also meet a 0.5 mg/L effluent limit (12-month rolling geometric mean, calculated monthly) by January 1, 2033. The Lindenhurst Sanitary District STP, New Century Town WRF, and Mill Creek WRF are already meeting the 0.5 mg/L TP limit. A summary of progress made by POTWs in reducing TP is provided in **Table 5.**

Special conditions within NPDES permits for POTW's in the watershed require identifying and providing adequate justification of any exception or circumstance to meeting an effluent limit of 0.5 mg/L TP 12-month rolling geometric mean by January 1, 2030. This justification is required to be submitted to the Illinois EPA at the time of renewal of the permits or by December 31, 2023, whichever date is first. North Shore Water Reclamation District indicated that they've submitted such a report to Illinois EPA on November 30, 2023, for its Waukegan (IL0035092, December 1, 2020) and Gurnee POTWs (IL0035092, December 1, 2020) identifying two exceptions which may apply to their facilities. During a virtual meeting with the DRWW on December 7, 2023, Illinois EPA staff stated that they would review NSWRD and any other submissions for permit renewals, but the NARP may supersede these conditions. Illinois EPA also stated they may be open to a TP limit that is higher than 0.5 mg/L if POTW's were to undertake watershed projects that would reduce the phosphorus loading by a differential amount between the higher limit and 0.5 mg/L TP. POTW's within the watershed may elect to engage with Illinois EPA regarding this approach after the NARP submission.

**Table 6: Publicly Owned Treatment Works Upgrade Progress**

| POTW | Meeting Monthly Average Total Phosphorus (TP) of 1.0 mg/L? | Annual Average TP (mg/L) | Meeting Annual Geometric Mean of 0.5 mg/L TP? | Current Process | Planned Upgrades |
|---|---|---|---|---|---|
| North Shore Water Reclamation District (NSWRD) -Waukegan Water Reclamation Facility (WRF) | Y | 0.68 | N | Biological phosphorus removal (BPR) with some ferric chloride is used to ensure compliance with 1.0 mg/l monthly average limit | More robust chemical system is under construction now with expectation to meet future limits of 0.5 mg/l rolling geomean in 2030. |
| NSWRD - Gurnee WRF | Y | 0.85 | N | BPR with some ferric chloride is used to ensure compliance with 1.0 mg/l monthly average limit | More robust chemical system is under construction now with expectation to meet future limits of 0.5 mg/l rolling geomean in 2030. |
| Lindenhurst Sanitary District Sewage Treatment Plant (STP) | Y | 0.479 | Y | BPR along with alum for summer months | N/A |
| New Century Town WRF | Y | 0.3 | Y | BPR with alum as a back-up treatment when needed | N/A |
| Mill Creek Water Reclamation Facility (WRF) | Y | 0.1 | Y | BPR with alum as a back-up treatment when needed | N/A |
| Des Plaines River STP | Y | 0.6 | N | BPR with alum as a back-up treatment when needed | N/A |
| Village of Libertyville STP | Y | 0.9 | N | Chemical feed system with PAC alum based | Engineering study completed and construction planned for 2028-2029 |

### 4.2.2 Upstream Load Reduction

Once the POTWs achieve compliance with the TP effluent limit of 0.5 mg/L, loading from upstream sources (i.e., Wisconsin tributaries) will be the largest contributor of phosphorus to the Study Area. The WDNR is taking the lead in developing a TMDL for the Wisconsin contribution. Upon completion of the modeling effort, the WDNR will undertake an extensive planning process with stakeholder input to help shape TMDL implementation.

DRWW should identify individuals who will remain engaged as the process unfolds. This may include attending meetings (in person or virtual) to provide input. The TMDL process is anticipated to take 2–3 years to complete. The Wisconsin state standard for TP in streams is 0.075 mg/L, but the anticipated timeline to reach compliance with the TMDL would likely take much longer. For this reason, DRWW should continue to engage with WDNR as a downstream recipient. The Des Plaines River corridor has continued to develop in Wisconsin along Interstate 43 in Racine and Kenosha Counties and is expected to continue to grow, even without the rapid growth originally anticipated with the proposed Foxconn facility.

#### *4.2.2.1 Potential Practices*

Anticipated practices will likely be a combination of agricultural and stormwater NPS practices; however, implementation will be dictated by the WDNR through the stakeholder meeting engagement process.

## 4.3 Actions for Providing Other Ancillary Benefits

Other impairments in the Study Area include sedimentation and siltation, habitat degradation, hydromodification, and impacts from other contaminants. Sedimentation, habit degradation, and hydromodification can be addressed by reducing the impact of stormwater runoff and other NPS in agricultural and urban tributary watersheds.

Recommendations for reducing phosphorus loading from agricultural and urban areas are provided below. The Project Team also evaluated the specific project recommendations for stream and wetland restoration and hydraulic impediment removal in the DPR WBP to improve water quality in the Des Plaines River. These recommendations are not meant to specifically address the NARP-related DO and nuisance related impairments but are meant to identify potential, voluntary opportunities for project implementation by stakeholders in the watershed.

### 4.3.1 Non-Point Source Load Reduction

#### *4.3.1.1 Agricultural*

Significant agricultural activity takes place in the upper portion of the Study Area (**Figure 2**). Agriculture is expected to continue to contribute a notable amount of phosphorus to the watershed after 2033. Agricultural runoff might warrant a select group of best management practices (BMPs) more conducive to capturing water in a rural field setting. Engaging agricultural communities in collaborative efforts to reduce NPS pollution is a strategy that has been widely adopted to aid instream water quality improvements. Although attribution and quantification remain challenging, field-level research documents the benefit of implementing in-field, edge-of-field, and structural practices to decrease field runoff.

Farmers make decisions to implement conservation practices based on multiple considerations, including bottom-line cost, land tenure, soil productivity, and peer norms, beliefs, and attitudes. Access to information can also affect how these decisions are made. Programs to increase conservation adoption should consider how all these factors come together to affect land management decisions and associated practices. Financial assistance has traditionally been offered to incentivize farmers to change their work practices or try something new. Recent research suggests that additional tactics that can successfully address NPS agricultural runoff include working in localized, smaller watersheds, aligning cost-share incentives to target the highest contributors, and promoting adoption of conservation systems (e.g., by adopting graduated cost-share rate that supports multi-practice adoption). A targeted and tailored outreach and engagement strategy is equally important.

***Potential Practices***

Advancements in agriculture, a better understanding of the use of cover crops, and the implementation of no-till farming techniques have been highly successful in reducing agricultural runoff. Other options for edge-of-field practices, such as field borders, saturated buffers, and agricultural runoff treatment systems, exist. However, because much of the remaining farmland in the watershed is leased, there can be resistance to placing any land in long-term easements, considering the potential for conversion to future residential, commercial, or industrial uses.

Lake County still maintains an active United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) office and county farm bureau. DRWW may look for opportunities to coordinate with active farmland owners who have concerns about easements and dedicating land to runoff controls. By working with agricultural agencies, DRWW may consider using creative language to convert “agricultural runoff controls” to “developmental stormwater management controls,” thus assuaging land conversion concerns and preempting resistance to temporary agricultural runoff controls.

#### ***4.3.1.2 Urban Sources***

Stormwater runoff from urban areas in many member communities will continue to be a source of sediment and nutrients in the watershed. As agricultural areas in the watershed are redeveloped for urban land uses, impervious surfaces become more prevalent. Approaches to urban stormwater management might be better evaluated by distinguishing between new and existing developments.

***New Development***

Improvements to the Lake County Watershed Development Ordinance (WDO) in 2013 were successful in establishing programmatic controls such as runoff volume reduction requirements and water quality volume requirements for new development. Additionally, improved efforts were made to enhance and encourage communities to better enforce maintenance of stormwater facilities through the recording of easements and maintenance agreements. It is still incumbent on those communities to follow through on inspections and enforcement. If the designed BMPs are not maintained according to the recorded agreement, they provide little value in protecting against water quality degradation.

DRWW was identified as the lead entity for two policy considerations in the DPR WBP (Lake County SMC, 2018) that could provide significant beneficial returns on stormwater water quality in the watershed:

1. Development of standards for TSS: In compliance with Illinois EPA, standards for TSS or other numeric water quality performance standards can be established for new development and redevelopment in the DPR planning area. The State of Wisconsin requires new developments to remove an annual average of 80% of TSS from stormwater. The State of Minnesota utilizes a 75% average annual total phosphorus (TP) load reduction requirement for new development. TSS and TP have a strong relationship due to phosphorus's association with sediment. The Lake County WDO has reference TSS values for 140 water bodies in Lake County, primarily lakes. Similarly, the DRWW could develop a baseline TSS value for the Des Plaines River that could be leveraged in developing a target stormwater runoff threshold.

2. Impervious surface coverage regulations: Increase education and political desire to provide funding and technical analysis for improving local and countywide regulations pertaining to impervious surface stormwater runoff and BMPs. Impervious surface coverage regulations could be considered at appropriate scales (such as parcels or catchments) to reduce runoff volumes for new development or redevelopment. The NRCS curve number method, commonly applied for stormwater design criteria throughout northeastern Illinois and the wider Midwest, assumes a threshold for the percentage of impervious surfaces for development. These percentages are rarely enforced or audited. Additionally, it is common for residential property owners to expand their impervious footprint with yard amenities; there may be a cumulative impact that is generally not tracked at the community level. Offsets for property additions or lot restrictions could help to reduce system volume, which can, in turn, reduce other system inputs and phosphorus load.

***Existing Development***

The Lake County SMC inventoried 2,303 stormwater detention basins in 2016 as part of the Des Plaines River WBP development process. The purpose of the inventory was to evaluate opportunities for stormwater detention basin retrofits, which could enhance water-quality performance. Enhancements for retrofits typically include nativizing shorelines to reduce bank erosion potential and converting turf or dry basins into wet basins to enhance the capture of particulates. The inventory did not assess the maintenance for facility dead pool storage that would be required to effectively capture the desired sediment and associated nutrients. As dead pool storage is lost and sediment volume increases, aged detention ponds, instead of providing effective capture as originally intended, can become nutrient sources. Lake County SMC recommends the depth contours for stormwater facilities be checked every two years (Lake County SMC, 2002) to ensure the function of the facility remains consistent with the original design intent. Sediment storage availability can be highly dependent on the original design, upstream tributary area, and tributary land use. Lake County SMC also suggests that dredging in an "eventual cost." A lifetime of 15-20 years is very typical.

It is also necessary to maintain the function and storage associated with any on-site BMP practices, which the WDO now requires to be recorded and maintained in a stormwater easement. It is incumbent upon the communities within the watershed to regulate these areas to ensure that they performing as designed.

DRWW can facilitate a process to track the maintenance of stormwater detention basins in the Study Area. This could be an initiative among member communities and a beneficial addition to the MS4 program language. Most backup Special Service Areas and other maintenance improvement requirements are not triggered until an issue develops. Proactive language targeted to address dead pool storage will preserve the capability of sediment and nutrient storage. Suggested improvements include surveying sediment buildup within wet detention facilities on a minimum 10-year basis and maintaining a permanent set dead pool storage volume. The DRWW may wish to investigate a pilot program focused on required maintenance and monitoring to determine the financial implications on a select group of property or business owners.

### 4.3.2 Stream and Wetland Restoration

Stream restoration, hydraulic impediment removal, and wetland restoration may not necessarily impact nutrient levels in the stream but help to mitigate conditions that promote low DO and nuisance algae impairments. These are briefly described below and discussed in detail in *Appendix C: Project Recommendations*

#### *4.3.2.1 Stream Restoration*

Streams sections with low velocities result in low natural reaeration and provide conditions for algae growth due to large travel times. It is recommended to add stream riffles and pools on suitable stream sections to improve natural reaeration and reduce algae growth due to faster velocity. Example stream restoration projects based on stakeholder input and DPR WBP are provided in *Appendix C: Project Recommendations.*

#### *4.3.2.2 Hydraulic Impediment Removal*

Impediments such as beaver dams, nonfunctional dams, and blocked culverts can slow down water, which promotes algae and reduces aeration. The removal of these hydrologic impediments would improve DO and reduce algae growth. For example, the North Mill Creek dam impounded Rasmussen Lake, which was listed by Illinois EPA as being impaired for a phosphorus-related impairment due to low DO. Water quality was greatly improved in the stream when the North Mill Creek dam was removed, and the Lake County Forest Preserve District undertook a stream restoration project.

Restored North Mill Creek after Removal of North Mill Creek Dam. Photo Courtesy: Interfluve

#### *4.3.2.3 Wetland Restoration*

Wetland restoration adjoining the stream improves the stream's water quality. Wetland restoration can help to maintain stream baseflow, provide waterway shading, promote retention of sediment and other particulates, stabilize shorelines and stream banks, and support nutrient uptake. The Lake County Wetland Restoration and Preservation Plan (WRAPP) identifies and assesses the functional significance of existing and potentially restorable wetlands in Lake County, Illinois (Lake County SMC 2020). The WRAPP identifies several potentially restorable wetlands adjoining the six stream segments listed as impaired for phosphorus. The Lake County Forest Preserve District is currently working with US Armey Corps Engineers on Dutch Gap Canal wetland restoration project over a 785-acre site in the Village of Antioch, Lake County. The development of plans and specifications will begin upon receipt of funding, with the goal of awarding a construction contract in Fiscal Year 2024 (USACE, 2023)

### 4.3.3 Project Recommendations

A total of 597 projects from DPR WBP were assessed for TP load reduction potential and cost-effectiveness. Of these, 29 projects were identified with a potential phosphorus reduction greater than 50 pounds per year, while eight (8) projects were identified with a potential phosphorus reduction greater than 100 pounds per year.

Field borders, grass waterways, sediment forebays, streambank stabilization, and wetland creation/restoration were the only project categories identified with the potential to provide a potential phosphorus reduction greater than 100 pounds per year. Of these, grass waterways provide the most cost-effective benefit ($65/lb P), while wetland creation/restoration was the least cost-effective ($4,266/lb P).

When looking at projects with the potential to reduce phosphorus loads by 50 pounds per year or greater, there was a more diverse set of project types. Grass waterways, ponds, and stormwater management BMPs (Best Management Practices) are more cost-effective on a per-pound basis than practices such as streambank restoration and wetland creation but typically have smaller impacts. Grass waterways are substantially more efficient than other practices, making up the top four (5) options when analyzing the most efficient qualifying projects. Details on the project are included in *Appendix C: Recommended Projects for the NARP.*

## 4.4 Monitoring Studies

The DRWW will undertake the following actions to assess the impact of implemented projects for adaptive watershed management:

1. Update monitoring strategy based on the NARP results and recommendations. Implement updated monitoring recommendations.
2. Establish a monitoring program for implementation post-2033 to assess the impact of WWTP plant upgrades. Execute monitoring programs post 2033.
3. Work with watershed partners to develop a watershed-wide tracking program for development and restoration projects.
4. Work with the United States Geological Survey (USGS) and other stakeholders to consider establishing a Next Generation Water Observing Station on Des Plaines River at the IL-WI border.

## 4.5 Budgeting and Funding

The DRWW currently consists of 30 community, township, and agency members, along with a number of private associate members (DRWW 2023). The potential revenue needed to confront the water quality impairment and reach the goal of use attainment will be best addressed as a group, provided the challenge can be approached from an incremental and adaptable standpoint. Any approach will require an assessment of the financial resources of the group and a means to utilize them in a fiscally responsible way that demonstrates progress based on membership consensus.

Because the amount of effort needed to make measurable progress is not easily assessed, DRWW will be well suited to establish reasonable milestones that are complemented with monitoring. Projects for consideration may also be shared among members to maximize financial resources wherever possible.

Before the amount of money necessary to reach the desired nutrient reductions is determined, it is first necessary to understand whether ongoing improvement projects are providing the necessary beneficial returns needed to improve the baseline phosphorus conditions assessed as part of the NARP. If the impact of new watershed development projects negates the beneficial reduction of phosphorus or phosphorus-related impairments, additional funding will need to be provided by member communities or through the DRWW to offset the increase in loading due to new developments.

### 4.5.1 Member Fees

The revenue generated by DRWW membership fees for fiscal years 2022 and 2023 was $271,400 and $260,500, respectively. A significant amount of these dues was utilized for the data and NARP development. Once the NARP has been completed, DRWW may choose to modify membership fees based on the DRWW's desired involvement at the implementation level. These fees can be used in several ways based on the workgroup's ultimate approach to project implementation. Member fees can be used, for example, to initiate pilot projects, continue monitoring efforts, or provide matching funds for grants.

### 4.5.2 Grants

The Study Area is wholly within Lake County, which currently has programs that can assist in water quality improvement projects. The Des Plaines River WBP provides an extensive list of potential grant funding sources; however, the programs listed below in **Table 6** have a proven track record within the region of use and applicability in the watershed. The Lake County SMC grants specifically are a unique opportunity to implement small- to medium-level projects that may not qualify for Section 319 funding. The chance of grant application success is typically improved by having any project preidentified in an appropriate planning document, such as a watershed plan or similar. While Section 604B is typically associated with watershed planning activities, it could be leveraged to ascertain the viability of programmatic avenues for improvement, such as alternative project delivery, credit programs, or trading. CMAP also provides a local unique funding source to evaluate a wide source of topics and supports sustainability objectives in northeastern Illinois.

**Table 6: Recommended Grant Programs for Project Implementation**

| Entity | Program | Typical Award | Due Date |
|---|---|---|---|
| Lake County SMC | Watershed Management Board (WMB) Program Grants | $5K-$30K | October |
| Lake County SMC | Stormwater Infrastructure Repair Program (SIRF) | $100K | October |
| Illinois EPA | Section 319 Program | $200K | August (can vary) |
| Illinois EPA | Green Infrastructure Grant Opportunity (GIGO) | $50K+ | October |
| Illinois EPA | Section 604B Program | $200K+ | December |
| CMAP | Local Technical Assistance Program | $100K+ | February |

CMAP: Chicago Metropolitan Agency for Planning
Illinois EPA: Illinois Environmental Protection Agency
SMC: Stormwater Management Commission

## 4.5.3 Alternative Source Funding

### *4.5.3.1 Private-Public Partnerships (P3)*

Another innovative funding source for programmatic implementation or retrofit of green infrastructure is a public-private partnership (P3). P3s provide an opportunity to leverage private industry to capture scale efficiencies and coordinated maintenance. A P3 is an agreement between one or more public- and private-sector entities to accomplish goals more efficiently than what can be accomplished individually. This involves a private entity developing or maintaining stormwater infrastructure on behalf of public partners. The P3 shares the risk and cost so that no one organization bears the full burden. This cooperation helps to drive innovation and build strong, long-term relationships. For example, the Milwaukee Metropolitan Sewerage District is currently implementing green infrastructure to reduce overflows into Lake Michigan through a P3 program. P3s are an alternative funding option that the DRWW and its members could explore to expand green infrastructure in the Study Area.

### *4.5.3.2 Water Quality Trading*

In 2023, Wisconsin approved the Water Quality Trading Clearinghouse, designed to provide flexibility in trading and better visibility of potential trading partners. While DRWW does not need as diverse a platform to facilitate such activity, dialogue targeted at working across the watershed can help to address phosphorus-related impairments where the return on investments provides the largest benefit. At the moment, this could suggest a simple peer-to-peer system that would enable members to work as partners in implementing in-the-ground projects on available land rather than forcing unmaintainable projects at undesirable locations. To develop such a program, DRWW would likely have to develop a study to assess feasibility and interest.

#### 4.5.3.3 USDA Regional Conservation Partnership Program (RCPP)

Administered by the USDA-NRCS, the Regional Conservation Partnership Program (RCPP) is a competitive program authorized for $1.5 billion under the 2018 federal Farm Bill, plus an additional $4.95 billion through the Inflation Reduction Act. Through RCPP, a group of partners in a specific place combine their resources and capacity to collectively address a natural resource concern, such as water quality. NRCS will coinvest in the local or regional collaborative effort by awarding a federal commitment of at least $1 to $1 over the course of a 5-year agreement. The federal dollars are delivered directly to farmers to cover costs associated with implementing conservation practices or permanently protecting their farmland from development. RCPP award sizes range from $250,000 to $25 million and can be bi-state.

A good example of a successful RCPP is the Milwaukee River Watershed Conservation Partnership (MRWCP). The MRWCP consists of 13 partners, led by the Milwaukee Metropolitan Sewerage District, working in the Milwaukee River Watershed to address water quality and flood control by engaging and paying farmers to implement conservation practices. County land and water conservation department staff and NRCS staff, working with producer-led watershed groups, identify priority projects and help operators implement practices that achieve the needed pollution reduction but are also acceptable from the farm management perspective. Since the first RCPP in 2016, the group has deployed $9.3 million of federal cost-share across the watershed.

A new producer-led watershed group in Kenosha County, Kenosha County Regenerative Producers, would make an excellent partner on an RCPP proposal. This group received a 2023 grant from the Wisconsin Department of Agriculture, Trade, and Consumer Protection, which provides funding to producer-led groups that focus on NPS pollution abatement activities. The Kenosha County group provides peer support and technical assistance to encourage innovative regenerative farming techniques that keep nutrients on the farm.

With a producer-led watershed group already organizing around conservation adoption, there is an excellent opportunity for DRWW to support the effort with supplemental cost-share or additional watershed capacity (or both) through an RCPP proposal. A small group could be assembled to discuss the opportunity and potential; this group might include Mark Jenks, Kenosha County Conservationist, and Kirsten Jurcek with Glacierland Resource Conservation & Development.

#### 4.5.3.4 Wisconsin Wetland Conservation Trust In-Lieu Fee Program

Wetland mitigation funding in Wisconsin can be used to restore and enhance wetlands that provide a water quality benefit. The WDNR's Wisconsin Wetland Conservation Trust (WWCT) program provides grants for wetland restoration and enhancement projects. The WWCT account currently holds $850,000 for use in the Upper Illinois District (which includes Kenosha County) for one or more wetland projects that generate 15 or more credits. The ILF program provides one credit per acre for hydrology and vegetation restoration in effectively drained wetlands and about 0.5 credits per acre for vegetation enhancement in existing wetlands. WWCT dollars can be used for acquisition, restoration, monitoring, and stewardship. The Wetlands and Watersheds Explorer mapping tool identifies multiple areas that have strong wetland restoration potential in the Upper Des Plaines River watershed in Wisconsin.

Potential partners for a project like this would be Seno K/RLT Conservancy, a long-term holder of the land (Stacy Santiago, Executive Director), and RES, a project developer (Erin Delawalla, Project Manager).

RES develops projects focused on nature-based solutions for 404 mitigation, wastewater and stormwater permit compliance, and community resiliency. RES has worked extensively on wetland and stream restoration projects in southeast Wisconsin and northeastern Illinois. RES might have projects already identified to improve DO levels or reduce phosphorus and nitrogen conditions. RES owns and manages the Wisconsin Water Quality Trading Clearinghouse for water quality trading in Wisconsin. NPS activities in the Upper Des Plaines would not be good candidates for the water quality trading program because there is no Wisconsin discharger downstream who could use credits; however, the clearinghouse is a way to identify potential projects because farmers can register a potential project independently. The clearinghouse could be helpful in identifying projects located in the Des Plaines watershed in Wisconsin, which would provide the most cost-effective nutrient reductions for downstream Illinois communities in the Des Plaines watershed.

#### *4.5.3.5 Soil and Water Outcomes Fund*

The Soil and Water Outcomes Fund, currently active in Illinois and Wisconsin, could be a source of leverage for any investments DRWW seeks to undertake in those areas. The Outcomes Fund provides a bridge between (1) corporations, government, and utilities interested in seeing quantified environmental uplift and (2) farmers who transition to on-farm conservation practices that yield positive environmental outcomes like water quality improvement. The Outcomes Fund provides financial assistance and new revenue streams for farmers by selling environmental outcomes to public and private beneficiaries to meet regulatory and voluntary sustainability goals. Beneficiaries' resources are often stacked with USDA and other funding sources, including RCPP, to provide cost-competitive environmental outcomes.

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# APPENDIX A
## Watershed Model

# DES PLAINES RIVER NUTRIENT ASSESSMENT REDUCTION PLAN: WATERSHED MODEL

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Project Number: MOW5554

March 2023

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# TABLE OF CONTENTS



## LIST OF TABLES



## LIST OF FIGURES

## LIST OF ATTACHMENTS

## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| CMAP | Chicago Metropolitan Agency for Planning |
| DRWW | Des Plaines River Watershed Workgroup |
| GIS | geographic information system |
| HRU | hydrologic response unit |
| mg/L | milligram per liter |
| MUSLE | modified universal soil loss equation |
| NARP | Nutrient Assessment Reduction Plan |
| NLCD | National Land Cover Database |
| NSE | Nash-Sutcliffe model efficiency coefficient |
| SSURGO | Soil Survey Geographic Database |
| SWAT | Soil and Water Assessment Tool |
| TP | total phosphorus |
| TSS | total suspended solids |
| USDA | United States Department of Agriculture |
| USGS | United States Geological Survey |
| WWTP | wastewater treatment plant |

# 1. INTRODUCTION

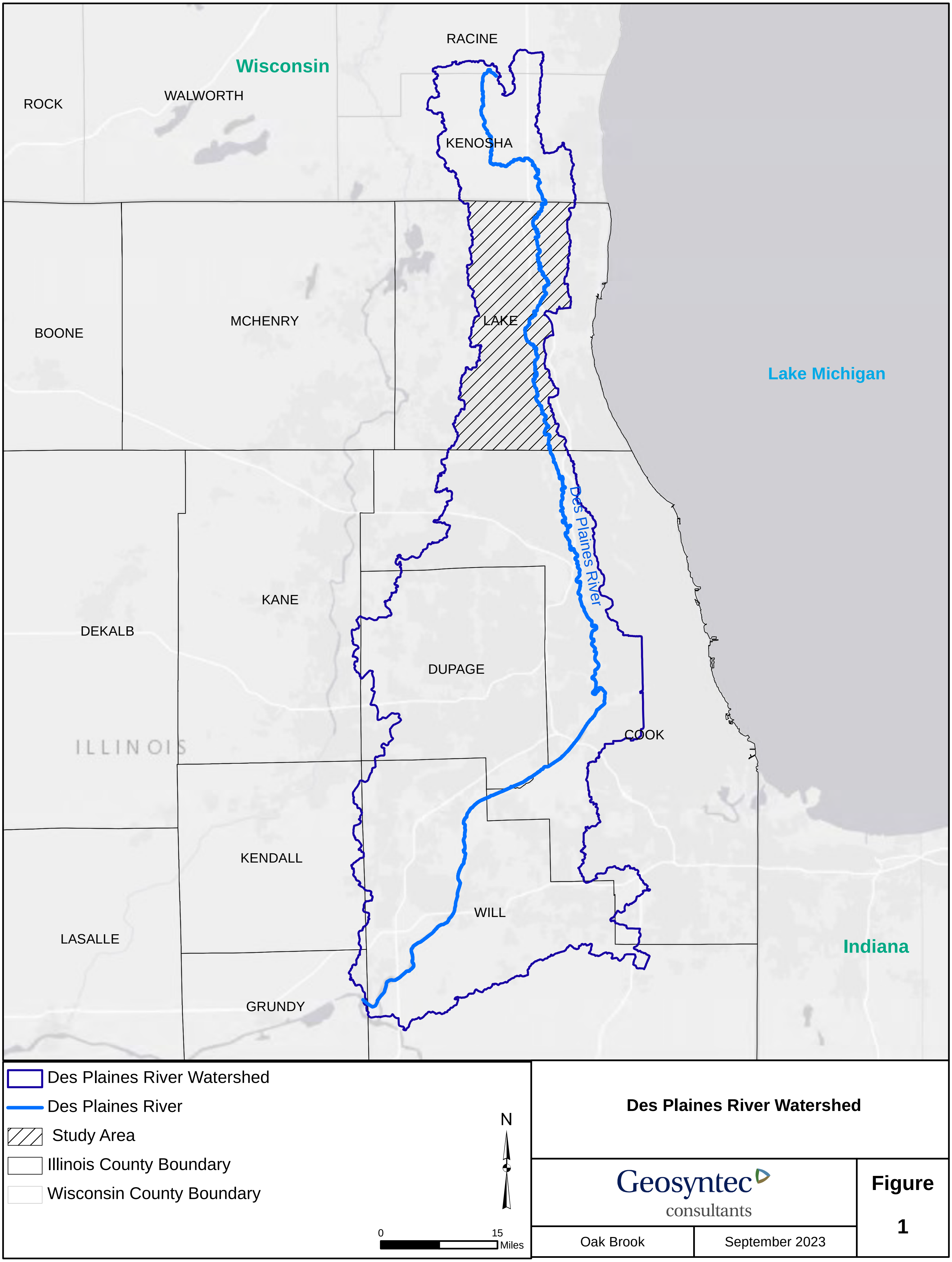
The Nutrient Assessment Reduction Plan (NARP) for the Upper Des Plaines River will address phosphorus-related impairments in the river by identifying phosphorus load reductions from point and nonpoint source discharges, among other necessary measures. Models can define the linkage between the phosphorus loading and other factors (dams, lack of shading, etc.) in the watershed and the related impairments, such as dissolved oxygen and nuisance algae in the river. Models can also be used to assess the effectiveness of different watershed management scenarios in removing or reducing impairments. This information informs project prioritization for the NARP implementation.

This report details efforts by Kieser & Associates, LLC to develop and calibrate a watershed model of the Upper Des Plaines River watershed. These efforts included data acquisition and processing, watershed delineation, calibration and validation of the model, and a sensitivity analysis of model parameters. Flow and nutrient loading output from the watershed model is used as inputs to an instream water quality model of the river to examine the impacts of different management scenarios on water quality. The development and calibration of the instream model is documented in Appendix B of the NARP report.

## 1.1 Study Area

The Des Plaines River originates near Union Grove, Wisconsin, and drains an area of 1,455 square miles through Racine and Kenosha Counties in southeastern Wisconsin and Lake, Cook, and Will counties in northeastern Illinois (**Figure 1**). The river joins the Chicago Sanitary and Ship Canal in Lockport, Illinois, and then flows west through Joliet before converging with the Kankakee River to form the Illinois River.

The study area for the NARP focuses on the 36.3-mile stretch of the Des Plaines River between Russell Road and its confluence with Wheeling Ditch in Lake County (Figure 1). This section of river drains a watershed area of 235 square miles. Land use in the study area is predominantly rural (58.9%) and urban (29.6%). The remaining area comprises surface water, wetlands, and forests (11.5%).




**Des Plaines River Watershed**

Geosyntec consultants

| | | |
|---|---|---|
| Oak Brook | September 2023 | Figure 1 |

Z:\prj1\WATER RESOURCES - 1840\MOW5554 - DRWW NARP Development\3.0 GIS\MXDs\Report\2023(0817)_Figure1_DRWW NARP Watershed_Study Area.mxd 9/20/2023 10:15:40

# 2. MODEL DEVLOPMENT

## 2.1 Modeling Framework

A linked numerical modeling framework was developed for the NARP, as recommended in the Des Plaines River Watershed Workgroup (DRWW) NARP Workplan (Geosyntec 2020). The linked modeling framework consists of two components: a watershed model and an instream model with hydraulic and water quality components (**Figure 2**).

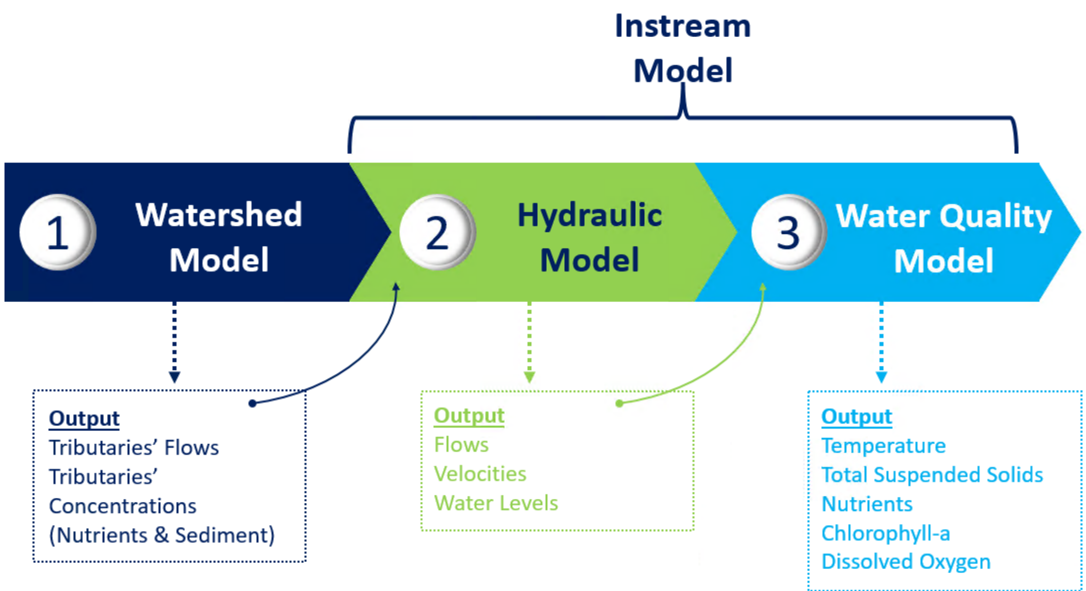



**Figure 2: Model Framework**

The Soil and Water Assessment Tool (SWAT) was used as the modeling framework for the watershed model in accordance with the NARP Workplan. The SWAT model is a river basin-scale model originally developed by the United States Department of Agriculture (USDA) Agricultural Research Service (Texas A&M, 2006, Neitsch et al. 2011). SWAT predicts the long-term impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land uses, and management conditions. Since its creation from several predecessor models in the early 1990s, SWAT has undergone regular updates and several major improvements, such as the inclusion of urban land management simulations. An ArcGIS interface called ArcSWAT was also developed to facilitate the development of SWAT model input files from geographic information system (GIS) datasets. For this study, SWAT2012 version 681 was used. This version, which was released on May 26, 2020, was the latest version when this modeling study commenced in July 2021. ArcSWAT version 2012.10.4.21 for ArcGIS 10.4 was used for GIS data processing and watershed delineation.

## 2.2 Data Acquisition and Processing

SWAT requires a range of geophysical and anthropological data to drive model simulation and model calibration. **Table 1** lists the data acquired and processed for the development of the SWAT model, including descriptions of the properties of these datasets and their applications in the model. A detailed description of the datasets used is available in the DRWW NARP Workplan (Geosyntec 2020).

## 2.3 Model Extent and Watershed Delineation

The watershed area used in the SWAT model includes the Des Plaines River watershed area in Wisconsin and the DRWW NARP study area (**Figure 3**). SWAT is a semi-distributed model meaning it considers the spatial variability of phenomena acting on a watershed as opposed to more global models such as physical-based conceptual models or empirical models. The watershed within SWAT is broken down into sub-basins. It is critical to have enough sub-basins in the model to accurately represent different types of soil and land use, precipitation conditions, flow and material travel distances, and other location-sensitive processes taking place in the watershed. Watershed delineation for the Des Plaines River watershed and its sub-basins was a key step in the SWAT model setup. A detailed description of watershed delineation process is included (Attachment 1). The modeled watershed was delineated into 89 sub-basins (Figure 3). The median sub-basin area was 0.3% of the total watershed area, below the recommended 2–5% recommended for accurately predicting flow, sediment, and nutrients in a SWAT model (Jha et. al 2004). Sub-basin area ranged from 0.1% to 5.5% of the total watershed area, with 85 of the 89 sub-basins being below 5% of the total watershed area.

**Table 1: Datasets Used for Building and Calibrating the SWAT Model**

| Type | Dataset | Origination | Version/Coverage | Purpose |
|---|---|---|---|---|
| Elevation | Light Detection and Ranging (LiDAR)-based 3m resolution digital elevation model (DEM) | IL: Illinois Height Modernization: LiDAR Data;<br>WI: Wisconsin Elevation and LiDAR Data Inventory | County-wide data for the four counties in the Des Plaines watershed; LiDAR-derived DEM data processed to 3m resolution for model watershed delineation and hydrologic response unit (HRU) slope derivation | Watershed and sub-basin delineation<br>Slope derivation for HRUs |
| Soils | Soil Survey Geographic Database (SURRGO) | United States Department of Agriculture Natural Resource Conservation Service (USDA-NRCS) | IL: Lake and Cook Counties<br>WI: Racine and Kenosha Counties | All soil related model input information |
| Land use | 30m United States Geological Survey (USGS) National Land Cover Database (NLCD) coverage for Wisconsin;<br>Parcel-based polygon land use coverage | USGS;<br>Chicago Metropolitan Agency for Planning (CMAP) | USGS 2016 NLCD<br>CMAP 2015 | Model land use mapping and definition |
| Stream network | National Hydrography Dataset High Resolution (NHDPlus) | USGS | USGS Hydrologic Unit Codes HUC8 watershed 07120004 | Stream network, flow direction, and stream channel dimensions |
| WWTP | Flow, TSS and nutrient concentrations | Point sources via Des Plaines River Watershed Workgroup (DRWW) | 2013–2020 | Model input |

| Type | Dataset | Origination | Version/Coverage | Purpose |
|---|---|---|---|---|
| Meteorological data | Daily precipitation, temperature, humidity, and wind | National Oceanic Atmospheric Administration (NOAA)<br>Lake County | 1/1/2013–12/31/2020 | Model input |
| Stream flow | Daily average stream flows | 4 USGS stations | Daily, 1/1/2013-12/31/2020 | Model hydrology calibration and validation |
| Sediment and nutrient concentrations | 3 USGS stations, 1 Illinois Environmental Protection Agency (IEPA) grab samples; DRWW grab samples | USGS<br>Illinois EPA<br>DRWW | USGS: 2013–2020;<br>Illinois IEPA: 2013–2020;<br>DRWW: 2015–2020. | Model water quality calibration |

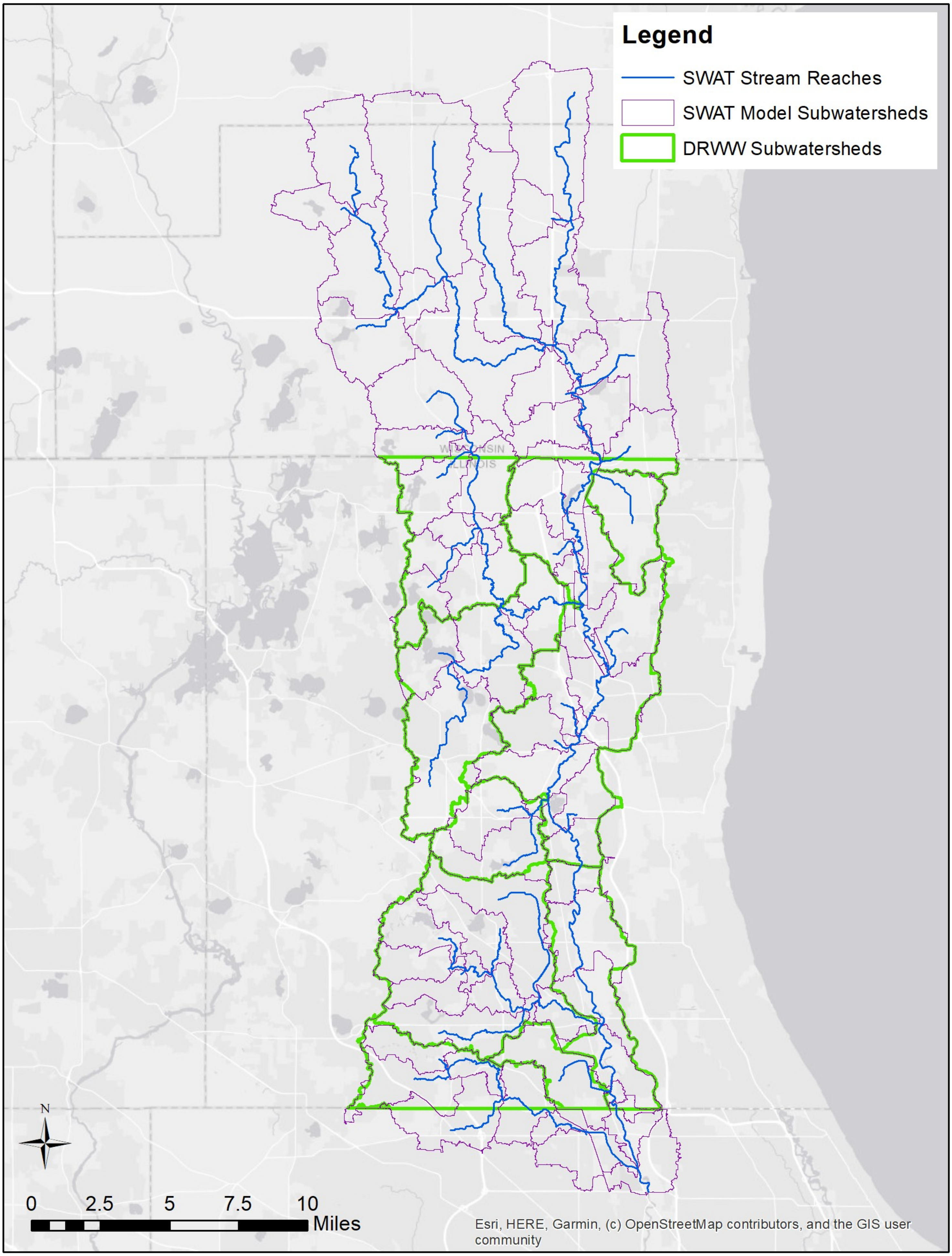



**Figure 3: SWAT Watershed Model Setup**

## 2.4 Defining Hydrologic Response Units

The basic model computational unit in SWAT is the hydrologic response unit (HRU), which is a unique combination of land use, soil, and slope in a sub-basin. Each sub-basin has many HRUs and each HRU generates its own output time series of flow, sediment, nutrients, and other pollutants and materials. The driving forces of the output are meteorological events, vegetation growth, and agricultural and other human activities. The formation of HRUs in the model thus requires land use, soil, and slope information for the entire watershed area under study.

Land use coverage for the Illinois part of the watershed was obtained from the Chicago Metropolitan Agency for Planning (CMAP). This GIS land use inventory is a parcel area-based vector dataset. The latest publicly available version was the 2015 inventory. For the Wisconsin part, the United States Geological Survey (USGS) 2016 National Land Cover Database (NLCD) was used. The NLCD datasets are grid-cell-based raster data with a resolution of about 30 meters. These two land uses were combined into one dataset so that ArcSWAT could process and generate land use input for the SWAT model. Accordingly, the CMAP dataset was first converted from the vector format to raster with a 30-meter resolution. The converted CMAP dataset was then combined with the USGS NLCD dataset to form a complete coverage of the entire watershed. Finally, each of the land use categories was assigned an equivalent SWAT land use type based on the description of the categories from CMAP and USGS data documentations.

For soil information, the Soil Survey Geographic Database (SSURGO) coverages for the four counties in the Des Plaines River watershed were downloaded from the USDA Natural Resource Conservation Service's Web Soil Survey portal. The SSURGO database contains soil map coverage for soil series in the survey area, which is usually a county. The database also contains soil physical and chemical properties in tabular format for the mapped soil series. ArcSWAT has the built-in capability to overlay soil location information with the land use data layer and extract soil properties information required by SWAT from the SSURGO database.

Slope was calculated from the digital elevation model data in ArcSWAT for the entire watershed. Due to the continuous nature of slope values, five slope groups (the maximum allowed by ArcSWAT) were defined for the HRU formation for the Des Plaines River watershed.

When defining HRUs from the three datasets (land use, soil, and slope), all available types of each landscape property can be used to generate as many HRUs as possible for a sub-basin. However, doing so would result in numerous exceedingly small HRUs with negligible contributions from the sub-basin to the overall flow and other material outputs. On the other hand, inclusion of these small HRUs requires the same computational power as large ones during model execution and increases the model runtime, which is especially inefficient for the model sensitivity and calibration processes where hundreds of model simulations are necessary. To increase model execution efficiency while maintaining sufficient model resolution, a threshold of 5% area was used during HRU generation. This threshold omitted land use, soil, or slope classes that were less than 5% of the total area of a sub-basin. ArcSWAT then automatically filled the omitted areas proportionally with the included types of land use, soil, or slope.

# 3. MODEL CALIBRATION AND VALIDATION

The SWAT model is a complex set of calculations that use both measured meteorological inputs (temperature, wind speed, precipitation, solar radiation, relative humidity) and model coefficients as variables. A model that is fully physically based would theoretically not require any coefficient calibration. However, the data and computation requirements for such a model would be enormous and infeasible. Instead, hydrologic models use empirical relationships as a compromise to generate output with commonly available resources. As empirical relationships are specific to the time, place, and the conditions of the data upon which they were formulated, the coefficients they use need to be calibrated. The general premise of model calibration is to use measured data (flow rates and nutrient concentrations) and modify model coefficients to maximize agreement between the model output and measured data. This agreement is otherwise known as "goodness-of-fit." In essence, calibration is an optimization problem, with goodness-of-fit being the optimization goal.

For model validation, the model results are compared with the measured data for a different period without changing the parameters. This helps ensure that the model can handle different model inputs than were used during the model calibration period.

## 3.1 Hydrology Calibration Process

The Nash-Sutcliffe model efficiency coefficient (NSE) is commonly used as a metric for hydrology model calibration and was used as the optimization goal (maximization) for this study (Nash and Sutcliffe 1970). Four USGS water flow measurement stations were used as calibration points within the modeled watershed because they provided robust data availability for both the calibration and validation periods. The delineated sub-basins were lumped into four subwatersheds that correspond with each of these calibration points (**Figure** 3**, Table 2**). The Mill Creek and Wisconsin subwatersheds were considered "upstream" subwatersheds because no other water bodies or subwatersheds contribute to them. The Gurnee and Outlet subwatersheds were considered "downstream" subwatersheds; the Gurnee subwatershed receives flows from the Mill Creek and Wisconsin subwatersheds, and the Outlet subwatershed receives flows from the Gurnee subwatershed (and consequently the entire modeled upstream Des Plaines River watershed). In terms of modeling processes, the entire watershed first undergoes an initial calibration, followed by a finer calibration of the upstream subwatersheds and, lastly, calibration of the downstream subwatersheds. The goal of calibration was to get the daily and monthly NSE value at each of the calibration stations to at least 0.6. A total of eight coefficients were used to calibrate model hydrology. These parameters were listed in **Table 3**. Numerous coefficients within the SWAT model were adjusted through both a manual and automated calibration process (Attachment 1).

The watershed model was calibrated for hydrology (flow) using the data for the period of January 2013 to December 2015 and validated using data for the period of January 2016 to December 2018.

**Table 2: Calibration Subwatersheds and Associated USGS Stations**

| Subwatershed | USGS Station Name | Station ID |
|---|---|---|
| Upper Des Plaines | Des Plaines River at Russell, IL | USGS 05527800 |
| Mill Creek | Mill Creek at Old Mill Creek, IL | USGS 05527950 |
| Mid Des Plaines | Des Plaines River near Gurnee, IL | USGS 05528000 |
| Lower Des Plaines | Des Plaines River near Des Plaines, IL | USGS 05529000 |

USGS: United States Geological Survey

**Table 3: SWAT Model Hydrology Coefficients and Ranges**

| Variable | Unit | Default | Minimum | Maximum |
|---|---|---|---|---|
| Curve Number | Ratio: Calibration/Default | 1 | 0.75 | 1.1 |
| Soil Water Capacity | Ratio: Calibration/Default | 1 | 0.75 | 1.1 |
| Groundwater Recharge Rate (Decay Coefficient) | Unitless | 31 | 1 | 64 |
| Groundwater Recharge Delay | Days | 0.20 | 0.05 | 0.50 |
| Soil Evaporation Compensation Factor (ESCO) | Unitless | 0.95 | 0.90 | 1.00 |
| Channel Manning's N (Roughness) | Unitless | 0.015 | 0.010 | 0.100 |
| Channel Hydraulic Conductivity | mm/day | 0 | 0 | 20 |
| Urban Land Use Impervious Fraction | Ratio: Calibration/Default | 1 | 0.75 | 1.25 |
| Maximum Snowpack Melting Rate | mm/day | 4.5 | 1.5 | 8.5 |

mm/day: millimeter per day

## 3.2 Hydrology Model Calibration and Validation Results

The final calibrated values of model parameters for the four subwatershed is listed in **Table 4**. Of note is the groundwater recharge delay coefficient, which was calibrated to 1, the minimum possible value, for all four subwatersheds. This is a good illustration of what the SWAT model must do to compensate for artificially drained land, both in tile-drained agricultural areas and urban areas with storm drains. In an undrained landscape, groundwater can take weeks or months to transit from the point it entered the ground to when it exits into a water body. Agricultural tile drains and storm sewers in developed areas can reduce this transit time to a matter of hours.

**Figure 4** shows the daily timeseries comparison of simulated values and measured data at the four USGS stations for the calibration period and the validation period (blue boxes). The simulated flow values match the measured data reasonably well. The calibration and validation NSE values for daily and monthly flows using the final calibrated model parameters are summarized in **Table**

**5.** Calibration and validation NSE values largely exceeded expectations for a mixed-use urban and agricultural SWAT model (Qiu and Wang 2014, Sisay et al. 2017). The validation NSE values are close to (and, in the case of the watershed outlet, higher than) calibration NSE values which demonstrates that the model is representative of actual conditions.

**Table 4: Final Calibrated Model Values**

| Variable | Unit | Upper Des Plaines | Mill Creek | Mid Des Plaines | Lower Des Plaines |
|---|---|---|---|---|---|
| Curve Number | Ratio: Calibration/Default | 0.78 | 0.75 | 0.82 | 0.82 |
| Soil Water Capacity | Ratio: Calibration/Default | 0.88 | 0.91 | 0.92 | 0.79 |
| Groundwater Recharge Rate | Unitless | 0.41 | 0.32 | 0.42 | 0.48 |
| Groundwater Recharge Delay | Days | 1 | 1 | 1 | 1 |
| Soil Evaporation Compensation Factor (ESCO) | Unitless | 0.93 | 0.91 | 0.93 | 0.99 |
| Channel Manning's N (Roughness) | Unitless | 0.088 | 0.096 | 0.087 | 0.062 |
| Channel Hydraulic Conductivity | mm/day | 16 | 19 | 6 | 7 |
| Urban Land Use Impervious Fraction | Ratio: Calibration/Default | 1.10 | 1.10 | 1.10 | 1.10 |
| Maximum Snowpack Melting Rate | mm/day | 2.37 | 2.37 | 2.37 | 2.37 |

mm/day: millimeter per day

**Table 5: Calibration/Validation Daily and Monthly Flow NSE Values**

| Subwatershed | Calibration NSE | | Validation NSE | |
|---|---|---|---|---|
| | Daily | Monthly | Daily | Monthly |
| Upper Des Plaines | 0.75 | 0.81 | 0.73 | 0.86 |
| Mill Creek | 0.63 | 0.69 | 0.44 | 0.37 |
| Mid Des Plaines | 0.75 | 0.80 | 0.74 | 0.74 |
| Lower Des Plaines | 0.71 | 0.74 | 0.73 | 0.76 |

NSE: Nash-Sutcliffe model efficiency coefficient

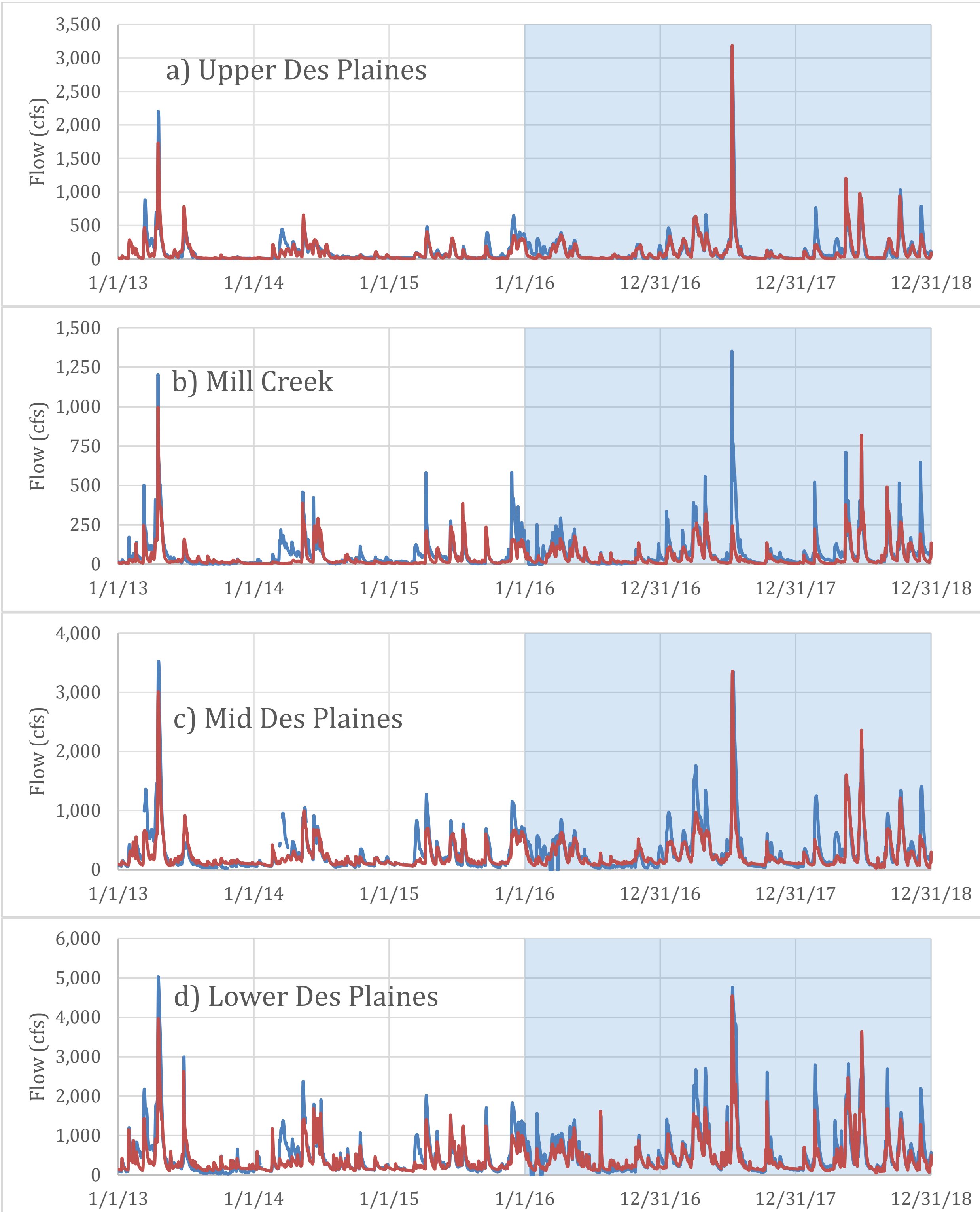



**Figure 4: Times Series Comparison of Simulated and Measured Flows in Des Plaines River.**

## 3.3 Water Quality Model Calibration Process

Watershed modeling efforts with the SWAT model focused largely on hydrology calibration and validation for the Des Plaines River watershed application, with only a limited water quality calibration. While the hydrologic calibration/validation process benefited from a large quantity of USGS continuous flow data at multiple locations, water quality data available for calibration were comparatively quite limited. Select DRWW data collected between 2015 and 2018 for total phosphorus (TP) and total suspended solids (TSS) at various stations in Mill Creek and the Des Plaines River were otherwise used for this preliminary SWAT model water quality calibration.

The water quality calibration process closely mirrored that for hydrology calibration. The range of model coefficients used for water quality model calibration are provided in **Table 6**. Due to the scarcity of measured data, the calibration goal was not purely the NSE value of model versus measured data. Best professional judgement was used where data were not available to guide model calibration. For example, if coefficient changes increased the NSE value but produced output that appeared unreasonable for other periods of time (or ungaged watershed areas in the model), that coefficient change would not be accepted.

**Table 6: Calibrated Model Water Quality Coefficients and Ranges**

| Variable | Unit | Default | Minimum | Maximum |
|---|---|---|---|---|
| USLE C Factor | Fraction of 1 | Varies | 0 | 1 |
| Sediment Re-entrainment Ratio | Unitless | .0001 | 0.0001 | 0.01 |
| P Partitioning Coefficient | 10 $m^3$/Mg | 175 | 75 | 400 |
| P Sediment Enrichment Ratio | Ratio: Calibration /Default | n/a | 0 | 1 |

$m^3$/Mg: cubic metre/milligram
USLE: universal soil loss equation

## 3.4 Water Quality Calibration Results

The SWAT model uses the modified universal soil loss equation (MUSLE) to calculate erosion, and this erosion method does not use a separate sediment delivery ratio. This can work well in small watersheds where HRUs within the model are in close proximity to the modeled stream reaches, but accuracy diminishes in larger watersheds as distance between HRUs and stream reaches increases (Bonumá et. al 2014, Pontes et al. 2021). The presence of tile drains and urban stormwater drains further complicates model ability to represent sediment delivery to the receiving streams. The SWAT model compensates for this by causing excess sediment in stream channels to drop out of the flow and become immobile deposition. As a result, sediment concentration calibration was limited, though modeled concentrations were of the same order of magnitude as compared to observed data. **Figure 5** shows a comparison of daily modeled TSS to measured data for all sites over the simulation period (the solid black line represents a theoretical 1:1 relationship). Model correlation to observed values produced a low $R^2$ value of 0.140. Modeled TSS concentrations were higher than observed concentrations at the minimum sediment re-entrainment ratio, so this coefficient was not raised any higher. The TSS concentrations predicted by the model were not sensitive to MUSLE factors because of the size of the watershed modeled and the nature of the SWAT sediment simulation approach.

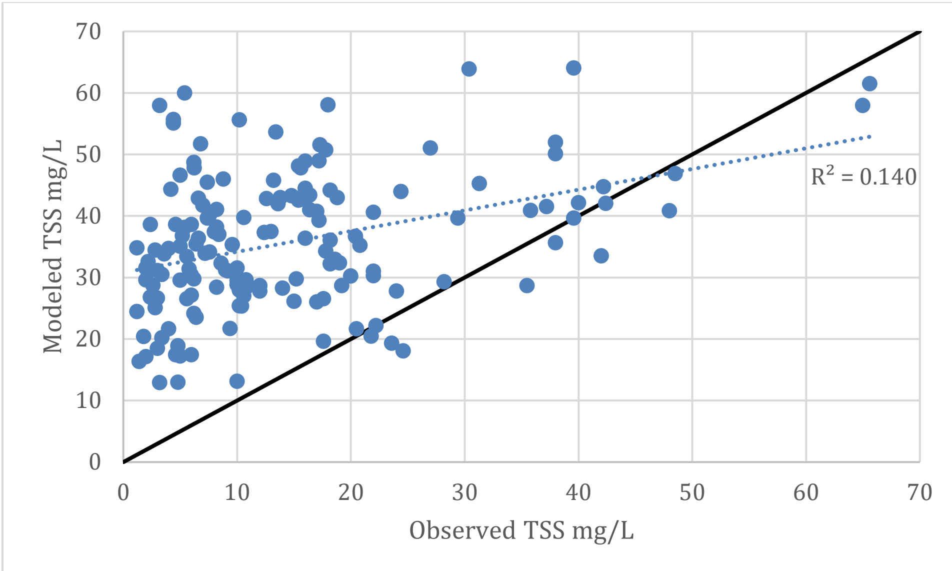



**Figure 5: Modeled Total Suspended Sediment (TSS) versus Observed Data**

Calibrating the model for instream TP concentrations yielded better results than calibrating for TSS (**Figure 6**). TP concentrations predicted by the model were insensitive to the phosphorus partitioning coefficient, but the phosphorus sediment enrichment ratio[1] was found to be sensitive in regard to altering modeled results.

[1] The phosphorus sediment enrichment ratio is the ratio of phosphorus mass entering a stream reach compared to the phosphorus mass removed from soil as erosion or in runoff. The ratio accounts for the fact that phosphorus generally attaches to finer sediments, which in turn get transported effectively to the stream.

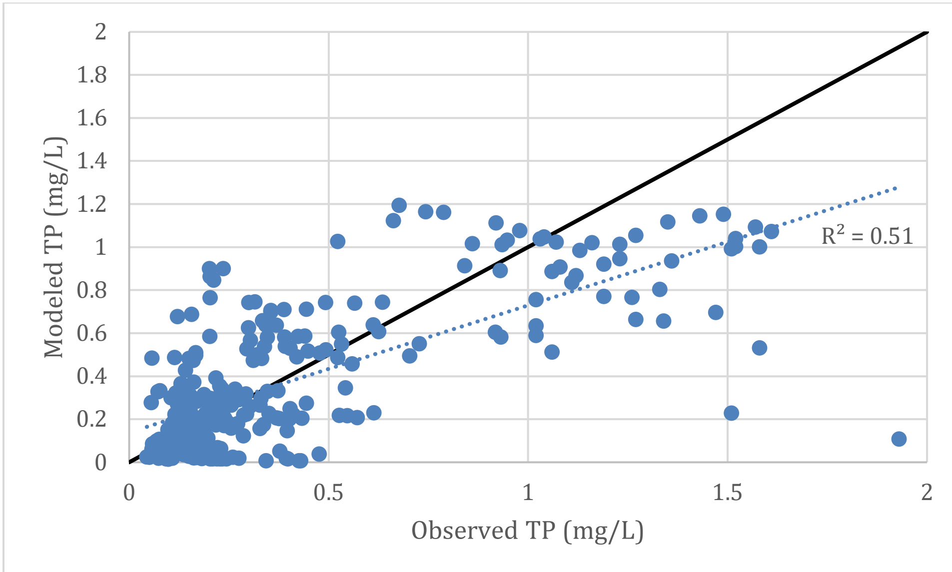



**Figure 6: Overall Modeled Stream Total Phosphorus (TP) Concentrations versus Observed Data**

# 4. SENSITIVITY ANALYSIS

A sensitivity analysis was performed on the calibrated/validated model, focusing on hydrology for the calibration period. Performing a sensitivity analysis on a model helps to determine which model coefficients have the largest impacts on model output. At the modeled watershed outlet, these analyses revealed that channel roughness was the most sensitive variable. Curve number and the soil evaporation coefficient were the least sensitive variables. A detailed description of the sensitivity analysis procedure and results is included in Attachment 1.

# 5. LOADING RESULT AND DISCUSSION

The primary focus of the SWAT model was to simulate hydrology and nutrient loadings to different segments of the river's main branch and its tributaries, particularly Mill Creek. In the absence of rigorous sampling over a long period, this kind of modeling analysis can provide insight into watershed loading and potential water quality issues. Understanding how the watershed responds to changes in precipitation patterns and wastewater treatment plant (WWTP) upgrades allows managers to better forecast how anticipated implementation projects or land use changes may affect future conditions.

Annual TP loads were calculated based on the modeling results for 2013 to 2020 at different points in the watershed, separated by source type. **Figures 7-11** illustrate estimate annual average total phosphorus (TP) loads at the model's four calibration points from WWTP and non-point sources. The non-point sources of loading include runoff from agriculture, urban and other (includes forest and wetland land) landuses. The non-point source (NPS) loads are largely driven by stormwater runoff and correlate strongly with precipitation totals. 2017-2020 yearly precipitation totals were all higher than those from 2013-2016, and the NPS loads for these years follow this trend as well. WWTP loads show a generally declining trend from 2013-2020, with the exception of 2019. Precipitation for 2019 (1179 mm average for the 10 utilized precipitation stations) was the highest for the 2011-2020 period (920 mm average, 635-1179 mm range). If excess stormwater was handled by WWTP's, this could have played a part in the increased effluent TP load for that year.

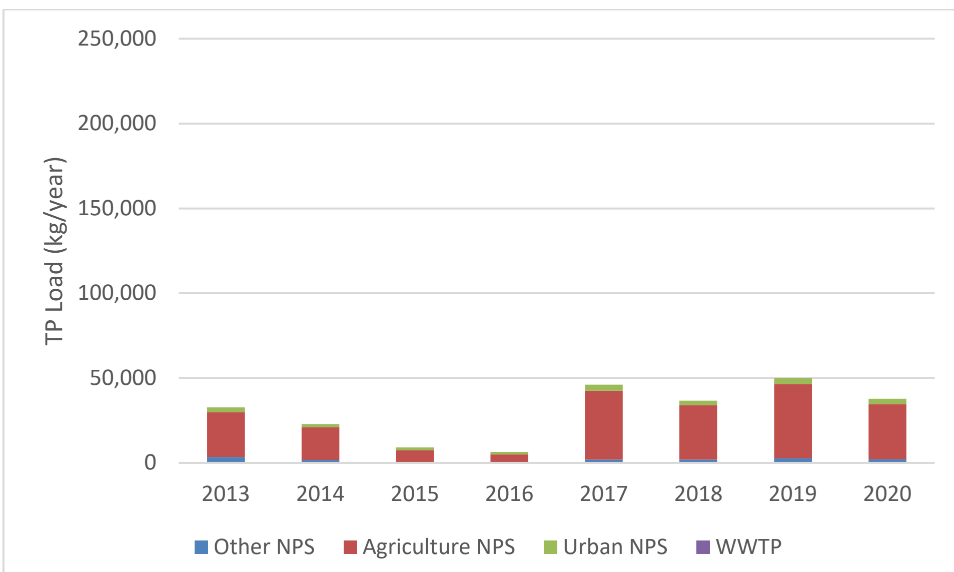



**Figure 7: Watershed Total Phosphorus (TP) Load from Wastewater Treatment Plants (WWTP), and Non-Point Sources (NPS) for the Upper Des Plaines subwatershed (USGS 05527800).**

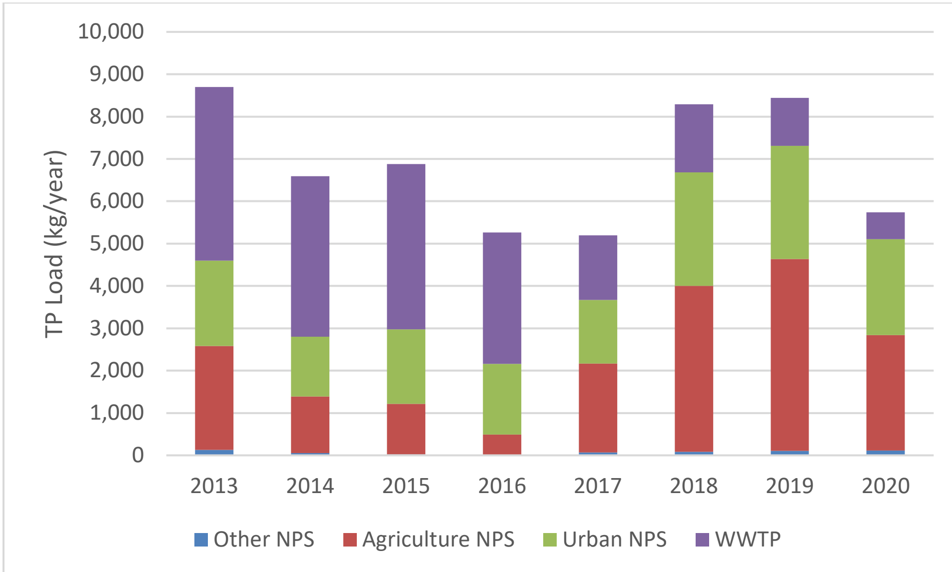



**Figure 8: Watershed Total Phosphorus (TP) Load from Wastewater Treatment Plants (WWTP), and Non-Point Sources (NPS) for the Mill Creek subwatershed (USGS 05527950).**

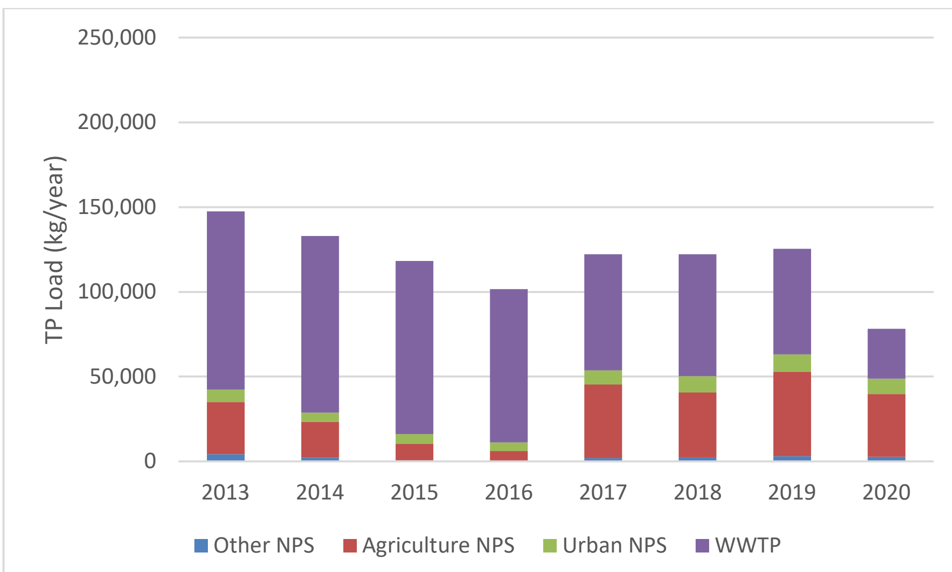



**Figure 9: Watershed Total Phosphorus (TP) Load from Wastewater Treatment Plants (WWTP), and Non-Point Sources (NPS) at the Middle Des Plaines calibration point (USGS 05528000**

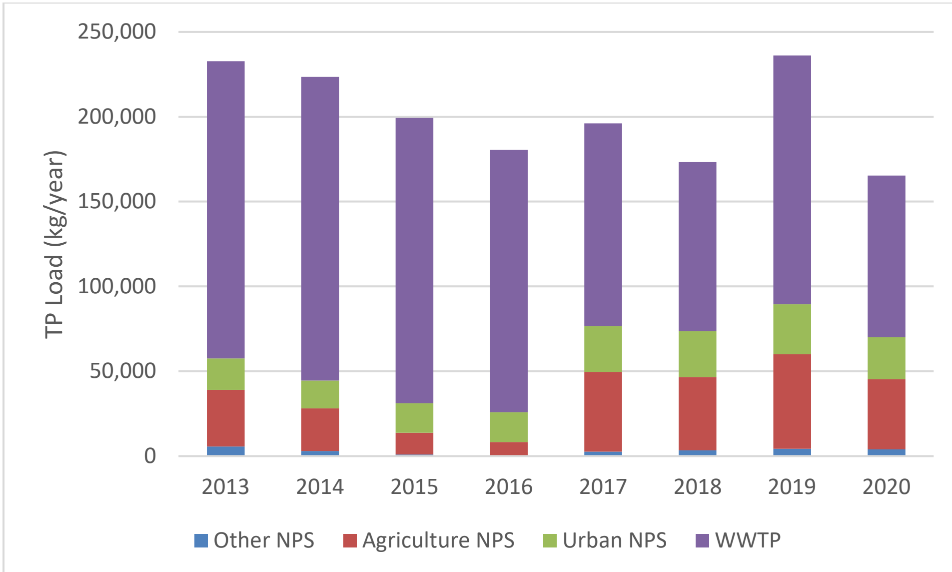



**Figure 10: Watershed Total Phosphorus (TP) Load from Wastewater Treatment Plants (WWTP), and Non-Point Sources (NPS) at the model outlet (USGS 05529000).**

The SWAT watershed model was also run for two additional theoretical management scenarios based on capping WWTP effluent TP concentrations. **Figures 12 and 13** illustrate modeled TP loads at the model outlet assuming WWTP effluent TP limits of 1.0 mg/L and 0.5 mg/L, respectively. **Figure 11** illustrates WWTP TP loads for two different time periods (2013-2016 and 2017-2020) as well as for different effluent TP limits (no limit / observed data, 1.0 mg/L limit, and 0.5 mg/L limit). Effluent limit scenarios predicted large load decreases as compared to the baseline scenarios utilizing observed data. For the 2020 year, WWTP's were responsible for 58% of the modeled TP at the model outlet. This would decrease to 36% and 25% under the 1.0 mg/L limit and 0.5 mg/L limit scenarios, respectively.

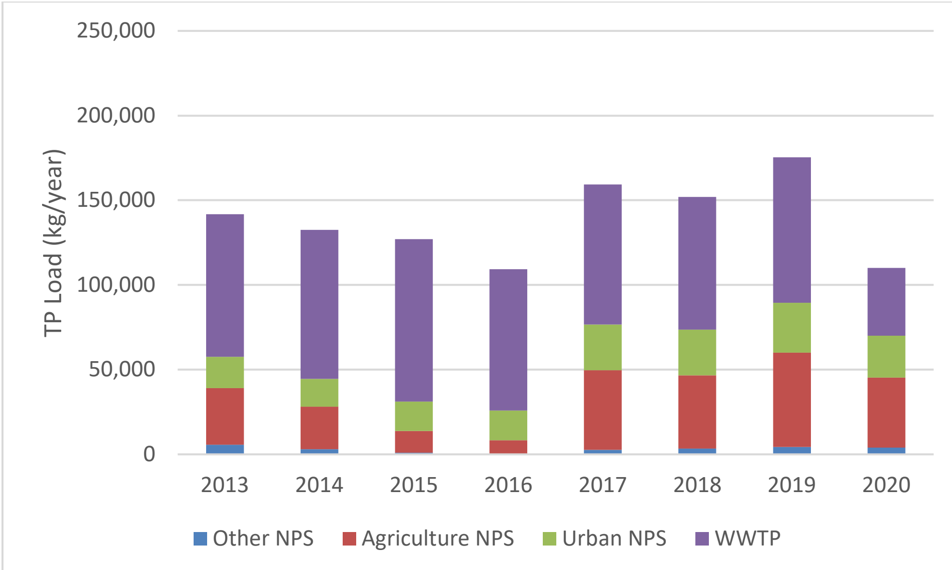



**Figure 11: Modified Total Phosphorus (TP) Load from Wastewater Treatment Plants (WWTP) assuming a 1.0 mg/L TP WWTP effluent limit, and Non-Point Sources (NPS) at the model outlet (USGS 05529000)**

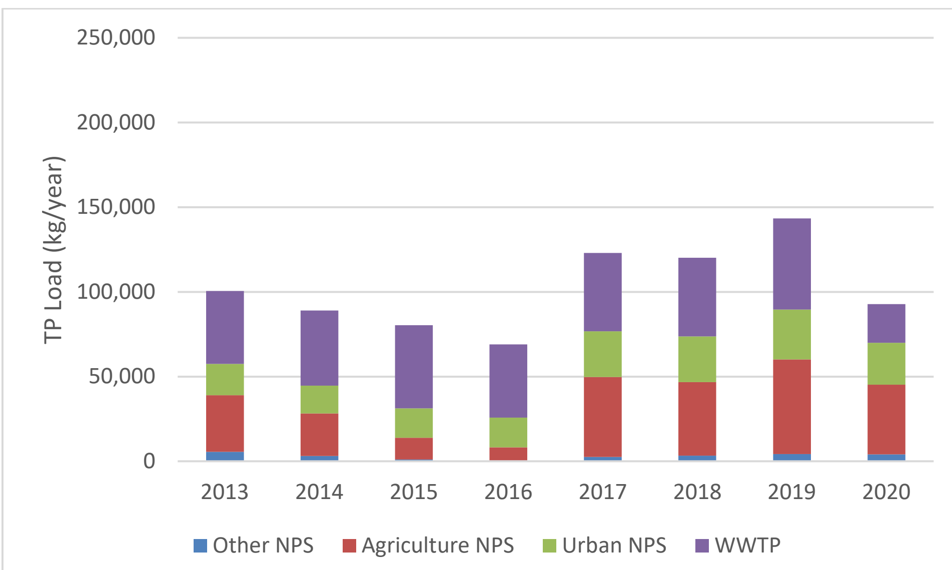



**Figure 12: Modified Total Phosphorus (TP) Load from Wastewater Treatment Plants (WWTP) assuming a 0.5 mg/L TP WWTP effluent limit, and Non-Point Sources (NPS) at the model outlet (USGS 05529000).**

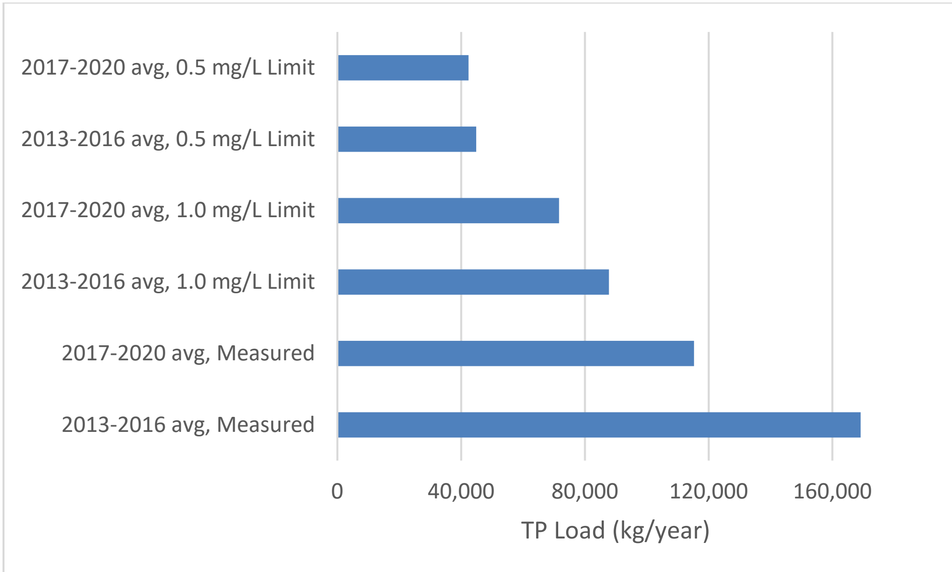



**Figure 13: Wastewater Treatment Plants (WWTP) Total Phosphorus (TP) load averages for the 2013-2016 and 2017-2020 time periods, utilizing measured data as well as theoretical WWTP TP effluent limits (0.5 mg/L and 1.0 mg/L).**

# 6. SUMMARY

This report documents the development of the SWAT watershed model for the DRWW NARP. The SWAT model was calibrated to available flow and water quality data. The SWAT model was used to estimate the nutrient and sediment loading into the Des Plaines River and Mill Creek. Model results indicate that nutrient loading into the main Des Plaines River has significantly reduced over recent years and will continue to do so with the anticipated upgrades to the WWTPs.

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# ATTACHMENT 1

# 1. WATERSHED DELINEATION

Watershed boundary delineation for the Des Plaines River watershed and its sub-basins was a key step in the Soil and Water Assessment Tool (SWAT) model setup. SWAT is a semi-distributed model. Watersheds within SWAT are broken down into sub-basins. It is critical to have enough sub-basins in the model to accurately represent different types of soil and land use, precipitation conditions, flow and material travel distances, and other location-sensitive processes taking place in the watershed.

For the Des Plaines River watershed SWAT model, watershed delineation was conducted using light detection and ranging (LiDAR)-derived digital elevation model (DEM) data for the four counties (Racine and Kenosha Counties in Wisconsin and Lake and Cook Counties in Illinois) and the United States Geological Survey (USGS) National Hydrography Dataset (NHD) high-resolution stream network for the watershed. LiDAR-derived DEM for the counties in the watershed has a resolution up to two feet, resulting in large (over 10 GB) DEM files and long geographic information system (GIS) processing time. To accelerate data processing while still preserving sufficient resolution for accurate watershed delineation and slope derivation, these raw DEM files were resampled to generate DEM files with a resolution of 9.84 feet (3 meters) for the entire watershed.

For the initial steps of watershed delineation, ArcSWAT uses a grid-cell elevation-based method to determine flow directions and stream channel positions on a landscape from the input DEM. The NHD stream network is used at the beginning of the process to direct the formation of stream channels to mapped actual stream channels. After stream segments are determined, a sub-basin can be defined that drains to one and only one stream segment. Additional outlets (e.g., dams) or monitoring points on the stream network can also be designated and the sub-basins that drain to these outlets or monitoring points can be added.

In addition to the relative geographic locations and sizes of the sub-basins, the relational database associations between sub-basins, the stream segments that they drain to, and the downstream and upstream linkages in the stream network are the key output from the watershed delineation process. SWAT uses these associations to route flows throughout the modeled watershed, enabling flows and associated materials to be traced through the stream network in the watershed. It should be noted that elevation-based watershed delineation does not take into account artificial hydrologic features like culverts that alter natural flow paths. When such features result in significant deviation of actual watershed or sub-basin boundaries from DEM elevation-based delineations, manual adjustment of DEM becomes necessary.

With the addition of dams, monitoring points, potential calibration points, and major discharging points of wastewater treatment facilities, a total of 76 sub-basins were defined initially for the Des Plaines Watershed. The sub-basin boundaries, including those defining the outer boundaries of the Des Plaines watershed, were compared to the watershed boundary map used by the Des Plaines River Watershed Workgroup (DRWW). After consulting with DRWW personnel, we manually adjusted watershed boundaries to eliminate major discrepancies. Additional sub-basin divides were also added based on the DRWW map. As a result, a total of 89 sub-basins were finalized for SWAT modeling. The number of sub-basins modeled amounted to an average of 1.1% of the total watershed area per sub-basin, well below the recommended 2-5% range for accurately predicting flow, sediment, and nutrients in a SWAT model.[1]

## 2. DEFINING HYDROLOGIC RESPONSE UNITS (HRUS)

The basic model computational unit in SWAT is the hydrologic response unit (HRU), a unique combination of land use, soil, and slope in a sub-basin. Each sub-basin has many HRUs and each HRU generates its own output time series of flow, sediment, nutrients, and other pollutants/materials. The driving forces of the output are meteorological events, vegetation growth, and agricultural and other human activities. The formation of HRUs in the model thus requires land use, soil, and slope information for the entire watershed area under study.

For the Des Plaines Watershed SWAT model, land use coverage for the Illinois part of the watershed was obtained from the Chicago Metropolitan Agency for Planning (CMAP). This GIS land use inventory is a parcel area-based vector dataset. The latest public available version was the 2015 inventory. For the Wisconsin part, the USGS 2016 National Land Cover Database (NLCD) was used. The NLCD datasets are grid-cell-based raster data with a resolution of about 30 meters. These two land use datasets have different formats, resolutions, and definitions for land use types.

The two datasets had to be combined into one dataset so that ArcSWAT could process and generate land use input for the SWAT model. Accordingly, the CMAP dataset was first converted from the vector format to raster with a 30-meter resolution. The converted CMAP dataset was then combined with the USGS NLCD dataset to form a complete coverage of the entire watershed. Finally, each of the land use categories in the CMAP dataset and the NLCD dataset was assigned an equivalent SWAT land use type based on the description of the categories from CMAP and USGS data documentations.

For soil information, the Soil Survey Geographic Database (SSURGO) coverages for the four counties in the Des Plaines River watershed were downloaded from the United States Department of Agriculture Natural Resource Conservation Service's Web Soil Survey portal. The SSURGO database contains soil map coverage for soil series in the survey area, which is usually a county. The database also contains soil physical and chemical properties in tabular format for the mapped soil series. ArcSWAT has the built-in capability to overlay soil location information with the land use data layer and extract soil properties information required by SWAT from the SSURGO database.

Slope was calculated from the DEM data in ArcSWAT for the entire watershed. Due to the continuous nature of slope values, five slope groups (the maximum allowed by ArcSWAT) were defined for the HRU formation for the Des Plaines River watershed.

When defining HRUs from the three datasets (land use, soil, and slope), one can make use of all available types of each landscape property and generate as many HRUs as possible for a sub-basin. However, doing so would result in numerous exceedingly small HRUs with negligible contributions from the sub-basin to the overall flow and other material outputs. On the other hand, inclusion of these small HRUs requires the same computational power as large ones during model execution and increases the model runtime, which is especially inefficient for the model sensitivity

[1] Jha, M., P.W. Gassman, S. Secchi, R. Gu, and J. Arnold. 2004. "Effect of Watershed Subdivision on SWAT Flow, Sediment, and Nutrient Predictions." *Journal of the American Water Resources Association* 40:811–825.

and calibration processes where hundreds of model simulations are necessary. To increase model execution efficiency while maintaining sufficient model resolution, a threshold of 5% area was used during HRU generation. This threshold omitted land use, soil, or slope classes that were less than 5% of the total area of a sub-basin. ArcSWAT then automatically filled the omitted areas proportionally with the included types of land use, soil, or slope.

# 3. CALIBRATION AND VALIDATION

The SWAT model is a complex set of calculations that use both measured meteorological inputs (temperature, wind speed, precipitation, solar radiation, relative humidity) and model coefficients as variables. A model that is fully physically based would theoretically not require any coefficient calibration. However, the data and computation requirements for such a model would be enormous and infeasible. Instead, hydrologic models use empirical relationships as a compromise in order to generate output with commonly available resources. As empirical relationships are specific to the time, place, and the conditions of the data upon which they were formulated, the coefficients they use need to be calibrated. The general premise of model calibration is to use measured data (flow rates and nutrient concentrations) and modify model coefficients in order to maximize agreement between the model output and measured data. This agreement is otherwise known as "goodness-of-fit." In essence, calibration is an optimization problem, with goodness-of-fit being the optimization goal.

The Nash-Sutcliffe model efficiency coefficient (NSE) is commonly used as a metric for hydrologic model calibrations[2] and was used as the optimization goal (maximization) for this case. Four USGS water flow measurement stations were used as calibration points within the modeled watershed because they provided robust data availability for both the calibration and validation periods. The model was divided into four subwatersheds that correspond with each of these calibration points. The Mill Creek and Wisconsin subwatersheds were considered"upstream" subwatersheds because no other water bodies or subwatersheds contribute to them. The Gurnee and Outlet subwatersheds were considered "downstream" subwatersheds; the Gurnee subwatershed receives flows from the Mill Creek and Wisconsin subwatersheds, and the Outlet subwatershed receives flows from the Gurnee subwatershed (and consequently the entire modeled upstream Des Plaines River watershed). In terms of modeling processes, the entire watershed first undergoes an initial calibration, followed by a finer calibration of the upstream subwatersheds, and lastly, calibration of the downstream subwatersheds.

## 3.1 Manual Calibration

When calibrating SWAT model hydrology, it is recommended to first focus on surface runoff, which is typically one of the more sensitive aspects of the model and has a substantial impact on all other aspects, including baseflow and water quality.[3] Because instream flows contain both surface flows and baseflow (from groundwater), separating the two is technically difficult. The Baseflow Filter Program available on the SWAT model website[4] was used to facilitate calibration

[2] Nash, J. E., and J. V. Sutcliffe. 1970. "River flow forecasting through conceptual models part I—A discussion of principles." *Journal of Hydrology*, 10(3):282–290.
[3] Arnold, J. G., D. N. Moriasi, P. W. Gassman, K. C. Abbaspour, M. J. White, R. Srinivasan, C. Santhi, R. D. Harmel, A. Van Griensven, M. W. Van Liew, and N. Kannan. 2012. "SWAT: Model use, calibration, and validation." *Transactions of the American Society of Agricultural and Biological Engineers* 55(4):1491–1508.
[4] Texas A&M University. 2006. *SWAT: Soil & Water Assessment Tool*. Software. https://swat.tamu.edu/software.

and overcome this challenge. To calibrate surface flows, baseflow was separated from measured total flow and the resulting surface flows were compared with modeled output. The SWAT model computes surface runoff using the curve number method, and each HRU within the model has a curve number associated with it.[5] These curve numbers were modified within a range of reasonable values for each land use category in order to calibrate surface runoff within the model. After the curve number values were modified, the model was run and the output compared against measured values to compute an NSE value. The goal for this step was to get the monthly NSE value at the model outlet to at least 0.6.

After a satisfactory initial calibration of surface flows, total flow was then calibrated. This step focused on two coefficients that impact evapotranspiration and percolation to groundwater: available soil water capacity (HRU-specific) and the soil evaporation compensation factor (ESCO), which controls model limits on how much soil water is made available for evapotranspiration. In the SWAT model, any precipitation that does not become surface runoff enters the soil, and these two coefficients control whether that water then becomes either evapotranspiration or groundwater. Groundwater eventually flows to streams, adding to total flow. These two coefficients were modified repeatedly with model output compared against measured flows, similar to the calibration of surface flows; this case, however, involved a total flow comparison. Once the monthly NSE for total flow at the model outlet exceeded 0.6, the calibration proceeded to the next step.

Including the three coefficients already mentioned, a total of eight coefficients were used to calibrate model hydrology. A list of these coefficients, as well as their description and ranges, is provided in Table 1-1. Numerous coefficients within the SWAT model are somewhat interdependent. Modifying multiple coefficients at once and then manually attempting to interpret their impacts on goodness-of-fit is therefore impractical.[6] With this in mind, coefficients were adjusted one at a time and the model output was analyzed for how it improved, if at all. When each coefficient adjustment began producing diminishing or negative NSE values, calibration then proceeded to the next coefficient. After all coefficients had been calibrated for the entire model in this fashion, the calibration process proceeded to subwatershed-level calibration. The process of subwatershed calibration was almost identical to the process used for the entire watershed, except that urban land use impervious fraction and snowpack melt rate were not used. As previously mentioned, these two coefficients can only be adjusted for the entire model.

**Table 1-1: Calibrated Model Hydrology Coefficients and Ranges**

| Variable | Unit | Default | Minimum | Maximum |
|---|---|---|---|---|
| Curve Number | Ratio: Calibration/Default | 1 | 0.75 | 1.1 |
| Soil Water Capacity | Ratio: Calibration/Default | 1 | 0.75 | 1.1 |
| Groundwater Recharge Rate (Decay Coefficient) | Unitless | 31 | 1 | 64 |
| Groundwater Recharge Delay | Days | 0.20 | 0.05 | 0.50 |

[5] Neitsch, S. L., J. G. Arnold, J. R. Kiniry, and J. R. Williams. 2011. *Soil and Water Assessment Tool Theoretical Documentation—Version 2009*. TWRI Report TR-406. Texas Water Resources Institute, College Station, Texas.
[6] Arnold et al.

| Variable | Unit | Default | Minimum | Maximum |
|---|---|---|---|---|
| Soil evaporation Compensation Factor (ESCO) | Unitless | 0.95 | 0.90 | 1.00 |
| Channel Manning's N (roughness) | Unitless | 0.015 | 0.010 | 0.100 |
| Channel Hydraulic Conductivity | Millimeter per day (mm/day) | 0 | 0 | 20 |
| Urban land use impervious fraction | Ratio: Calibration/Default | 1 | 0.75 | 1.25 |
| Maximum snowpack melting rate | mm/day | 4.5 | 1.5 | 8.5 |

## 3.2 Automatic Calibration

Manually calibrating a model is useful in determining which model coefficients are important and which potential calibration ranges are appropriate for each of those coefficients. However, manual calibration presents two challenges: time requirements for computational decision-making and model runs, and non-convex optimization. Time is a challenge because a successful calibration may require hundreds of model runs. Manual decision-making and input changes between each run can become time-consuming to the point of infeasibility. Non-convex optimization is an even greater challenge because human biases (as well as some algorithmic optimization methods) can make optimizing such a problem infeasible if the interdependencies of the variables being manipulated are not sufficiently understood. A non-convex function has multiple potential optimization solution points, so it is possible to focus on the "wrong" point. Optimizing a problem involves finding the minimum or maximum of a function or equation. In the case of a SWAT model calibration, the optimization function is represented by the NSE equation, and the function variables being manipulated are model coefficients. An evolutionary algorithm was used to address the challenges of computation time and non-convex optimization.

In order to solve the problem of multiple optimization convergence points, an evolutionary optimization algorithm was developed to analyze the output of the Des Plaines SWAT model in a noncontinuous fashion. Evolutionary algorithms do this by mimicking biological processes.[7] Each model coefficient being calibrated is represented by a "gene" that consists of bits (which can be either 0 or 1), and an "individual" (the model) is represented by an array of genes, one for each calibrating model coefficient. Each gene has $2^n$ possible values, where n is the number of bits in the gene. Model coefficients with larger potential calibration ranges and coefficients that require values with more significant digits are assigned genes with more bits than coefficients that do not require as much precision. A collection of individuals is a "population," which changes over time ("generations" of populations) as the algorithm converges on a maximum NSE value. Just as with an actual biological population, the algorithm's population must be large enough to provide enough genetic variation to successfully produce subsequent generations and reach a stable state (i.e., converge on a solution). In this case, each generation consisted of 50 individuals.

[7] Van Veldhuizen, D. A., and G. B. Lamont. 1998. *Multiobjective Evolutionary Algorithm Research: A History and Analysis*. Technical Report TR-98-03. Department of Electrical and Computer Engineering, Graduate School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio.

Populating the first generation properly is crucial for a successful calibration, because it is this generation that encompasses the range of possible calibration solutions. The first generation is assigned genes composed of randomly generated bits. Each successive generation will be less genetically diverse, as poorly performing individuals are excluded. If the coefficient range constraints imposed on the first generation exclude any values required to find the optimum solution, the algorithm will not reach it. Conversely, if the range constraints are applied too conservatively, the algorithm may not be able to properly converge on a solution. Manual calibration is therefore still important: It helps inform adequate range constraints for the evolutionary algorithm.

For this application, after the individuals for a generation were computed, each individual was evaluated for its "fitness" by inputting it into the SWAT model and calculating a resulting NSE score. After all individuals for a given generation were evaluated, the top 50% (in terms of NSE performance) were selected to generate the next generation. Selected individuals were "bred" together to create new individuals by randomly assigning bits to the offspring individual from its parents. If both parents had the same value for a given bit, the offspring automatically received that value. Certain bit values led to higher NSE scores, so there was less genetic variation as the algorithm converged. Because even a large initial population of genes cannot contain every possible combination, there was a random mutation chance inserted into the algorithm to improve the region of the function that was analyzed for a solution. As offspring individuals were created, each bit had a random chance of reversing (from 0 to 1 or from 1 to 0). Through successive generations, coefficient values that produced lower NSE scores were removed from the population, and the combination of coefficient values that produced the best possible NSE score emerged.

As such, final calibrated values selected (**Table A-2**) were based on both manual and automatic calibration efforts. Of particular note is the groundwater recharge delay coefficient, which was calibrated to 1, the minimum possible value, for all four subwatersheds. This is a good illustration of what the SWAT model must do to compensate for artificially drained land, both in tile-drained agricultural areas and urban areas with storm drains.

**Table 1-2: Final Calibrated Model Values**

| Variable | Unit | Upper Des Plaines | Mill Creek | Mid Des Plaines | Lower Des Plaines |
|---|---|---|---|---|---|
| Curve Number | Ratio: Calibration/Default | 0.78 | 0.75 | 0.82 | 0.82 |
| Soil Water Capacity | Ratio: Calibration/Default | 0.88 | 0.91 | 0.92 | 0.79 |
| Groundwater Recharge Rate (Decay Coefficient) | Unitless | 0.41 | 0.32 | 0.42 | 0.48 |
| Groundwater Recharge Delay | Days | 1 | 1 | 1 | 1 |
| Soil Evaporation Compensation Factor (ESCO) | Unitless | 0.93 | 0.91 | 0.93 | 0.99 |
| Channel Manning's N (roughness) | Unitless | 0.088 | 0.096 | 0.087 | 0.062 |

| Variable | Unit | Upper Des Plaines | Mill Creek | Mid Des Plaines | Lower Des Plaines |
|---|---|---|---|---|---|
| Channel Hydraulic Conductivity | Millimeter per day (mm/day) | 16 | 19 | 6 | 7 |
| Urban land-use impervious fraction | Ratio: Calibration/Default | 1.10 | 1.10 | 1.10 | 1.10 |
| Maximum Snowpack Melting Rate | mm/day | 2.37 | 2.37 | 2.37 | 2.37 |

## 3.3 Validation

For watershed model use and application, calibration and validation should be done at separate times, because certain model coefficient values may work well for one period but not for another. Analyzing calibrated values during a validation period ensures that the calibration is truly representative of the natural aspect being modeled. The only values adjusted between running a calibration and running a validation is the time of the model run. All calibrated model coefficients are otherwise kept the same. For the SWAT model, if NSE values are significantly worse during the validation period, the calibration will have to be reworked so that it can satisfy both time periods.

## 3.4 Calibration and Validation Results

NSE values largely exceeded expectations for a mixed-use urban and agricultural SWAT model, which often struggle to exceed daily NSE values of 0.7. NSE values at the Gurnee calibration point exceeded those of a previous Des Plaines SWAT study, while NSE values at the model outlet were comparable.[8] The only calibration point that failed to exceed a daily NSE value of 0.7 was Mill Creek. A variety of factors made this subwatershed challenging to model within SWAT, including low flows during dry periods, a diverse set of land uses, and the presence of multiple lakes within the subwatershed.

# 4. WATER QUALITY MODEL CALIBRATION

Watershed modeling efforts with the SWAT model focused largely on hydrologic calibration and validation for the Des Plaines River watershed application, with only a limited water quality calibration. While the hydrologic calibration/validation process benefited from a large quantity of USGS continuous flow data at multiple locations, water quality data available for calibration were comparatively quite limited. Select DRWW data collected between 2015 and 2018 for total phosphorus and total suspended solids at various stations in Mill Creek and the Des Plaines River were otherwise used for this preliminary SWAT model water quality calibration.

The water quality calibration process closely mirrored that for hydrology calibration. Calibrated coefficients and their ranges are provided in Table 1-3. Due to the scarcity of measured data, the

[8] Wilson, C. O., and Q. Weng. 2011. "Simulating the impacts of future land use and climate changes on surface water quality in the Des Plaines River watershed, Chicago Metropolitan Statistical Area, Illinois." *Science of the Total Environment* 409(20):4387–4405.

calibration goal was not purely the NSE value of model versus measured data. Best professional judgement was used where data were not available to guide model calibration. For example, if coefficient changes increased the NSE value but produced output that appeared unreasonable for other periods of time or ungaged watershed areas in the model), that coefficient change would not be accepted.

**Table 1-3: Calibrated Model Water Quality Coefficients and Ranges**

| Variable | Unit | Default | Minimum | Maximum |
|---|---|---|---|---|
| USLE C Factor | Fraction of 1 | Varies | 0 | 1 |
| Sediment Re-entrainment Ratio | Unitless | .0001 | 0.0001 | 0.01 |
| P Partitioning Coefficient | 10 $m^3$/Mg | 175 | 75 | 400 |
| P Sediment Enrichment Ratio | Ratio: Calibration /Default | n/a | 0 | 1 |

$m^3$/Mg:cubic metre/miligram
USLE: universal soil loss equation

## 4.1 Water Quality Results

The SWAT model uses the modified universal soil loss equation to calculate erosion, and this erosion method does not use a separate sediment delivery ratio.[9] This can work well in small watersheds where HRUs within the model are in close proximity to the modeled stream reaches, but accuracy diminishes in larger watersheds as distance between HRUs and stream reaches increases.[10,11] The presence of tile drains and urban stormwater drains, further complicates model ability to represent actual sediment delivery to the receiving streams. The SWAT model compensates for this by causing excess sediment in stream channels to drop out of the flow and become immobile deposition. As a result, sediment concentration calibration was limited, though modeled concentrations were of an appropriate magnitude as compared to observed data (see Figure 1-1, where the solid black line represents a theoretical 1:1 relationship). Model correlation to observed values produced a low $R^2$ value of 0.140. Modeled stream suspended sediment concentrations were higher than observed concentrations at the minimum sediment re-entrainment ratio, so this coefficient was not raised any higher. Stream sediment concentrations predicted by the model were not sensitive to universal soil loss equation factors, because of the size of the watershed modeled and the nature of the SWAT sediment simulation approach.

[9] Neitsch et al.
[10] Bonumá, N. B., C. G. Rossi, J. G. Arnold, J. M. Reichert, J. P. Minella, P. M. Allen, and M. Volk. 2014. "Simulating landscape sediment transport capacity by using a modified SWAT model." *Journal of Environmental Quality* 43(1): 55–66.
[11] Pontes, L. M., P. V. G. Batista, B. P. C. Silva, M. R. Viola, H. R. D. Rocha, and M. L. N. Silva. 2021. "Assessing sediment yield and streamflow with SWAT model in a small sub-basin of the Cantareira System." *Revista Brasileira de Ciência do Solo* 45.

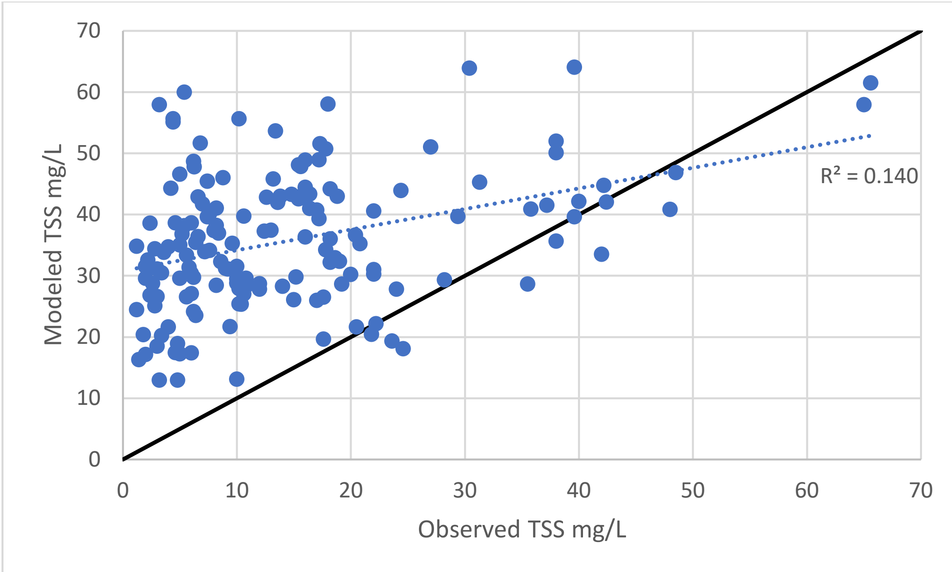


**Figure 1-1: Modeled Stream Sediment Concentrations (TSS) versus Observed Data**

Calibrating the model for instream phosphorus concentrations yielded better results than calibrating for suspended sediment concentrations did. Stream phosphorus concentrations predicted by the model were fairly insensitive to the partitioning coefficient, but the sediment enrichment ratio was found to be sensitive to altering modeled results. The sediment enrichment ratio is the ratio of phosphorus mass entering a stream reach compared to the phosphorus mass removed from soil as erosion or in runoff. The ratio accounts for the fact that phosphorus generally attaches to finer sediments, which in turn get transported effectively to the stream.

The SWAT model can calculate this value on a per-event basis via an empirical equation. However, because results showed poor correlation using this method, the decision was made to manually calibrate the coefficient. Other studies that have manually calibrated the phosphorus enrichment ratio have found that a value between 0.1 and 0.6 produces the best correlation with observed values.[12,13] For the Des Plaines River model, a value of 0.2 was found to be the optimum value for calibration for most subwatersheds, except for the Upper Des Plaines subwatershed, where a value of 0.4 produced the best results. Results for some of the individual data collection points are illustrated in **Figure 1-2**, where a solid black line represents a theoretical 1:1 relationship. The calibrated phosphorus concentrations $R^2$ value of 0.51 (see **Figure 1-3**, where a solid black line represents a theoretical 1:1 relationship) for all data is on the low side for statistical correlation, but this is to be expected for comparing a limited set of observed data on a daily time step. Nutrient loading in SWAT output is often considered in terms of monthly or annual loading.[14]

[12] Malagó, A., F. Bouraoui, O. Vigiak, B. Grizzetti, and M. Pastori. 2017. "Modelling water and nutrient fluxes in the Danube River Basin with SWAT." *Science of the Total Environment* 603:196–218.
[13] Dakhlalla, A. O., and P. B. Parajuli. 2019. "Assessing model parameters sensitivity and uncertainty of streamflow, sediment, and nutrient transport using SWAT." *Information Processing in Agriculture* 6(1):61–72.
[14] Arnold et al.

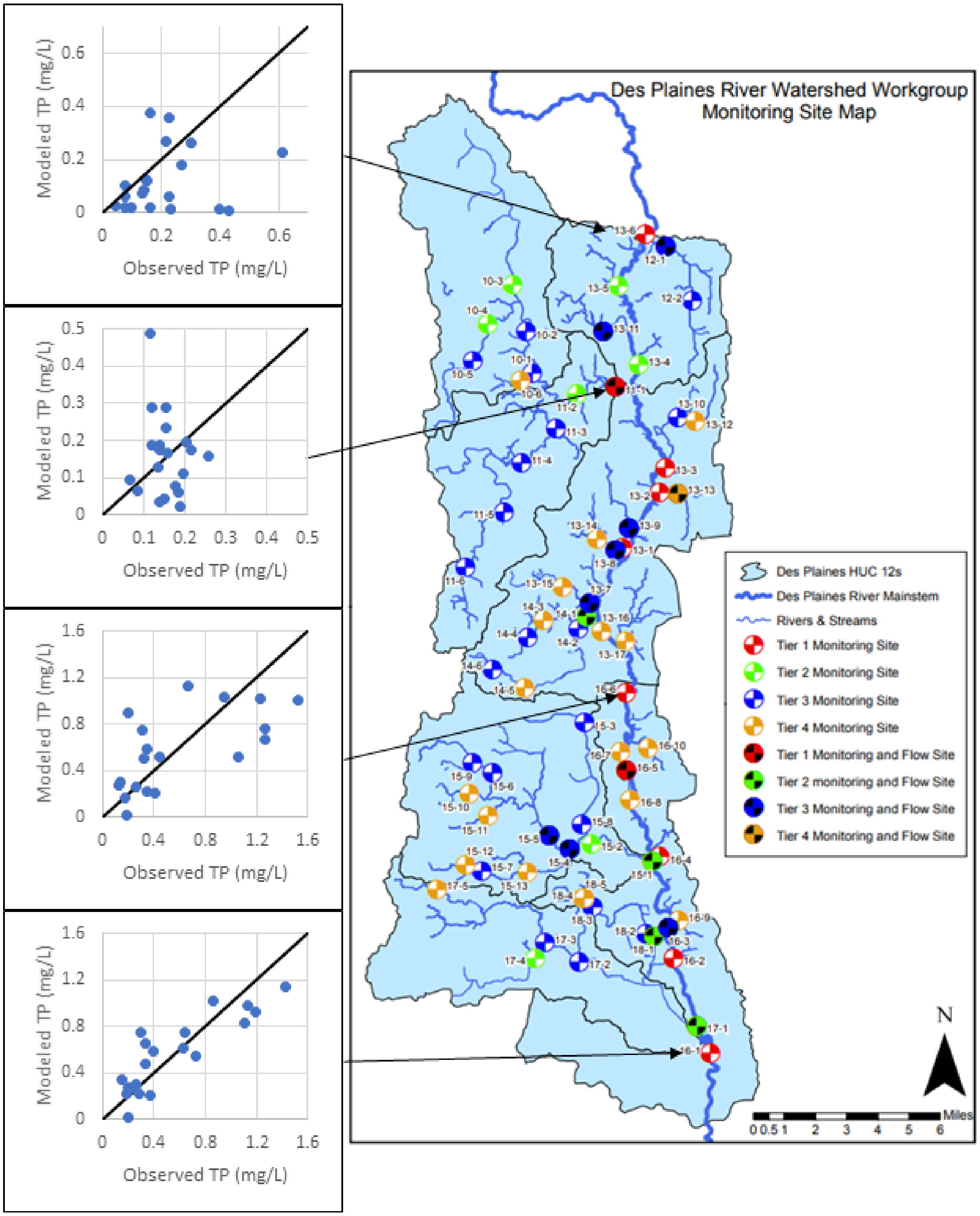


**Figure 1-2: Modeled Stream Phosphorus Concentrations versus Observed Data at Specific Data Collection Sites**

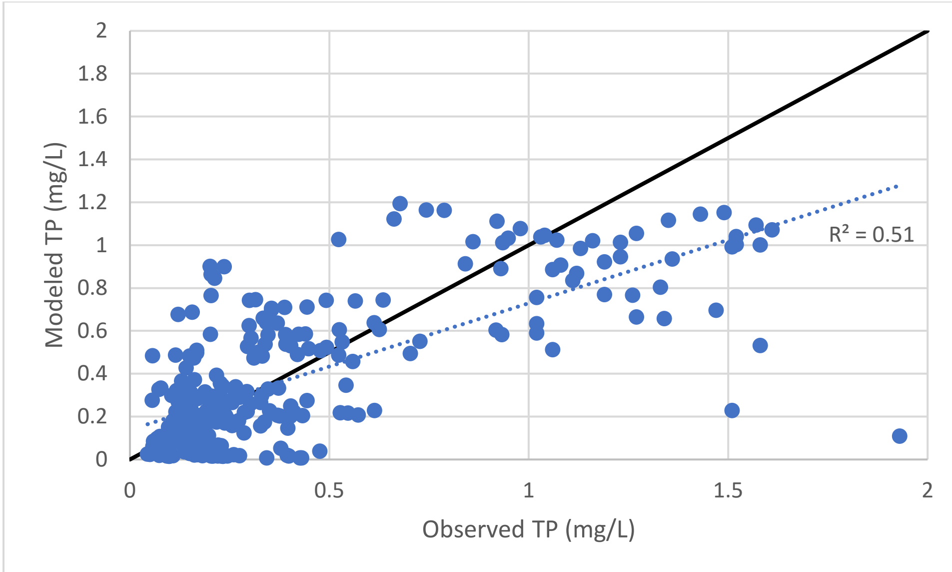


**Figure 1-3: Overall Modeled Stream Total Phosphorus (TP) Concentrations versus Observed Data**

## 5. SENSITIVITY ANALYSIS

A sensitivity analysis was performed on the calibrated/validated model, focusing on hydrology for the calibration period. Performing a sensitivity analysis on a model helps to determine which model coefficients have the largest impacts on model output. For simpler empirical models this can be a straight forward exercise, but a complex hydrological model poses a number of challenges. The SWAT model quantifies output as pollutant mass and hydrologic volume, but it performs this quantification both temporally and spatially.

Temporal variation must be considered for any SWAT model sensitivity analysis because the timing of flow and pollutant mass are at least equally important to annual loads. Spatial variation must be taken into account because variables may have a small impact on some parts of the watershed but a large impact on others. For example, the curve number was far more sensitive in mixed-land-use subwatersheds than in heavily developed areas where runoff is more dependent on the impervious cover fraction. On top of these matters, the fact that many SWAT coefficients are somewhat interdependent means that running a more traditional sensitivity analysis (where one variable at a time is manipulated) may not provide the full picture of model sensitivity.

In order to meet the challenges of analyzing both spatial and temporal variation, goodness-of-fit (the NSE value in this case) was used as the analysis metric in the sensitivity analysis.[15] Two separate analyses were run to account for interdependent model variables: a single-variable analysis, where one model coefficient is manipulated at a time and all other coefficients are kept constant, and a global sensitivity analysis, where multiple model coefficients are manipulated simultaneously

For the single-variable analysis, each of the model coefficients targeted for calibration were manipulated sequentially within a possible range determined by the initial manual calibration, and

[15] Gupta, H. V., and H. Kling. 2011. "On typical range, sensitivity, and normalization of Mean Squared Error and Nash-Sutcliffe Efficiency type metrics." *Water Resources Research* 47(10).

the model was run multiple times throughout that range. During any given model run, all coefficients that were not being analyzed were kept at constant values. The T-statistic for NSE scores was then calculated for each analyzed coefficient and at each of the four model calibration points. The T-statistic is the ratio of the difference of a parameter value from the parameter's mean compared against the parameter's standard deviation. For this analysis, sensitive coefficients will exhibit a T-statistic further (positive or negative) from 0.[16]

For the global sensitivity analysis, all of the model coefficients targeted for calibration were manipulated simultaneously. For each run, all targeted coefficients were assigned a random value within the possible range determined by the initial manual calibration (Table A-1), and then the model was run. This was repeated several hundred times in order to generate a larger population of possibilities. A generalized additive model was used to calculate the correlation between individual model coefficients and NSE scores, as well as the associated variability for each coefficient at each of the four model calibration points. From this analysis comes a ranking of coefficient sensitivity. More sensitive coefficients exhibit a stronger correlation with NSE scores and a larger variance.[17]

## 5.1 Sensitivity Results

At the model outlet, channel roughness was the most sensitive variable for both the single variable and global sensitivity analyses. Curve number was the least sensitive variable under the single variable analyses, and soil evaporation coefficient was the least sensitive variable under the global analysis. Sensitivity results at the model outlet for both single variable and global analyses are shown in **Table 1-4**. Using the single variable T-statistic analysis, most variables showed a similar sensitivity, with the exception of the aforementioned curve number (low sensitivity) and channel roughness (high sensitivity).

**Table 1-4: Sensitivity Analysis Variable Statistics and Ranks**

| | Single Variable | | Global Analysis | |
|---|---|---|---|---|
| **Model Coefficient** | **T Stat** | **Rank** | **Variance** | **Rank** |
| Curve Number | 1.31 | 8 | 0.016 | 7 |
| Soil Water Capacity | 2.61 | 4 | 0.066 | 6 |
| Groundwater Recharge Rate | 2.44 | 5 | 0.150 | 2 |
| Groundwater Recharge Delay | 2.64 | 3 | 0.147 | 3 |
| Soil Evaporation Coefficient | 2.27 | 6 | 0.004 | 8 |
| Channel Roughness 'n' | -5.86 | 1 | 0.400 | 1 |
| Channel Hydraulic Conductivity | 1.94 | 7 | 0.085 | 4 |
| Snowpack Melting Rate | 2.66 | 2 | 0.076 | 5 |

In addition to the model outlet, global sensitivity was analyzed at each of the other three calibration points (**Table 1-5**). Most variables maintained similar sensitivity ranks at each of the four points,

[16] Arnold et al.
[17] Ryan, E., O. Wild, A. Voulgarakis, and L. Lee. 2018. "Fast sensitivity analysis methods for computationally expensive models with multi-dimensional output." *Geoscientific Model Development* 11(8):3131–3146.

with the exception of curve number. Curve number is extremely sensitive (rank 1 or 2 of 8) in the two upstream subwatersheds, while it is insensitive (rank 7 of 8) at the model outlet. This is likely because a hydrologic model is as much a model of flow timing as it is of flow volume, and the curve number method simulates agricultural land more accurately than urban land. Curve number affects estimated surface runoff, which in upstream reaches enters streams within a few hours. At the lower reaches of a watershed, flow timing is more a result of how the river has conveyed the flow to that point. Stream velocity is most impacted by the channel roughness variable, so it is reasonable that this variable was the most sensitive at the outlet.

**Table 1-5: Global Sensitivity Analysis Variable Ranks for Each Model Calibration Point**

| Model Coefficient | Sensitivity Rank | | | |
|---|---|---|---|---|
| | Upper Des Plaines | Mill Creek | Mid Des Plaines | Lower Des Plaines |
| Curve Number | 2 | 1 | 4 | 7 |
| Soil Water Capacity | 6 | 8 | 6 | 6 |
| Groundwater Recharge Rate | 4 | 4 | 3 | 2 |
| Groundwater Recharge Delay | 3 | 3 | 2 | 3 |
| Soil Evaporation Coefficient | 8 | 6 | 8 | 8 |
| Channel Roughness 'n' | 1 | 2 | 1 | 1 |
| Channel Hydraulic Conductivity | 7 | 5 | 7 | 4 |
| Snowpack Melting Rate | 5 | 7 | 5 | 5 |

Results for the global analysis are also illustrated visually in **Figure 1-4**. (The Y-axis represents the change to NSE values as a function of the variable value; the X-axis represents the variable value, normalized from its analysis range to 0–1; and the blue line represents the best-fit line while the red dotted lines bound the 95% confidence interval.) Sensitivity can be visualized in this fashion as function lines with steep slopes or greater variability between their minimum and maximum values. The charts within this figure show the variability at the model outlet, corresponding with the "Lower Des Plaines" column in **Table 1-5**. The NSE value for the most sensitive variable, channel roughness, can be observed to change significantly throughout the variable's range. In contrast, the two least sensitive variables (curve number and soil evaporation coefficient) show up as relatively straight horizontal lines.

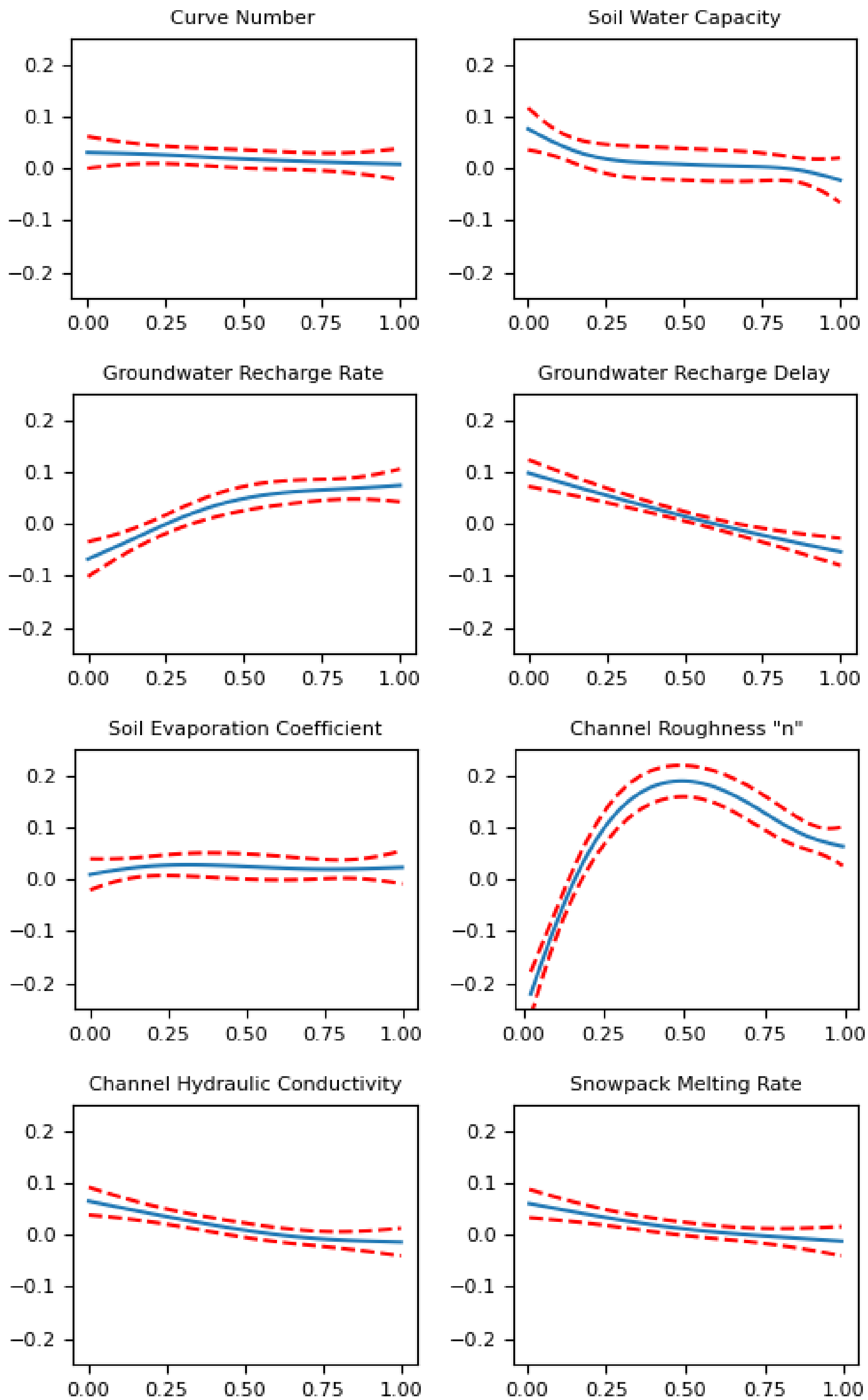


**Figure 1-4: Generalized Additive Model (GAM) Sensitivity Analysis Results at the Model Outlet**

# APPENDIX B
Instream Model

engineers | scientists | innovators

# DES PLAINES RIVER NUTRIENT ASSESSMENT REDUCTION PLAN

## Instream Model Development and Application

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Project MOW5554

May 2023

## TABLE OF CONTENTS

## LIST OF TABLES



## LIST OF FIGURES

# LIST OF ATTACHMENTS

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| BOD5 | 5-day biochemical oxygen demand |
| CBOD | carbonaceous biochemical oxygen demand |
| cfs | cubic feet per second |
| DO | dissolved oxygen |
| DRWW | Des Plaines River Watershed Workgroup |
| kg | kilograms |
| mg/L | milligrams per liter |
| µg/L | micrograms per liter |
| NARP | Nutrient Assessment Reduction Plan |
| NOAA | National Oceanic and Atmospheric Administration |
| NSWRD | North Shore Water Reclamation District |
| POTW | Publicly Owned Treatment Works |
| STP | sewage treatment plant |
| SWAT | Soil & Water Assessment Tool |
| TP | total phosphorous |
| USGS | United States Geological Survey |
| WRF | water reclamation facility |
| WTF | wastewater treatment facility |

# 1. INTRODUCTION

The Des Plaines River Watershed Workgroup (DRWW) is developing a Nutrient Assessment Reduction Plan (NARP) on behalf of major publicly owned treatment works (POTWs) in the Upper Des Plaines River watershed. The NARP for the Upper Des Plaines River watershed aims to address phosphorus-related impairments in the river by identifying phosphorus load reductions from point and nonpoint source discharges, among other necessary measures.

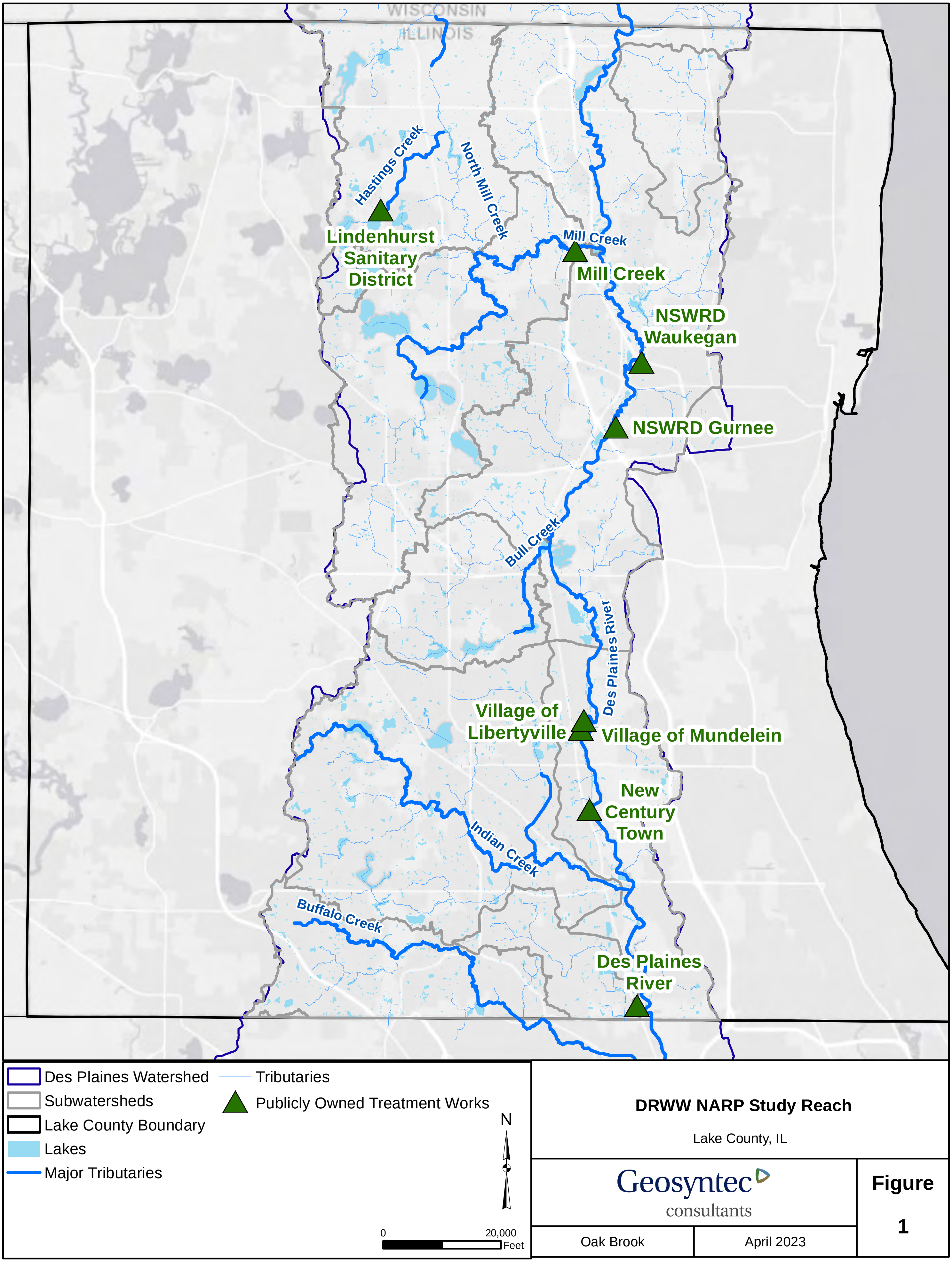
The linkage between phosphorus loading in the watershed and related impairments, such as dissolved oxygen (DO) and nuisance algae, can be defined using models. Models can also be used to assess the effectiveness of different watershed management scenarios in removing or reducing impairments. This information will inform project priorities in the NARP implementation.

This report details how an instream water quality model was developed, calibrated, and applied to evaluate the effectiveness of watershed management strategies for the Upper Des Plaines River watershed.

## 1.1 Study Area

The Des Plaines River originates near Union Grove, Wisconsin, and drains an area of 1,455 square miles through Racine and Kenosha Counties in southeastern Wisconsin and Lake, Cook, and Will counties in northeastern Illinois. The river joins the Chicago Sanitary and Ship Canal in Lockport, Illinois, and then flows west through Joliet before converging with the Kankakee River to form the Illinois River.

The study area for the NARP focuses on the 36.3-mile stretch of the Des Plaines River between Russell Road and its confluence with Wheeling Ditch in Lake County (**Figure 1**). This section of the river drains a watershed area of 235 square miles.




**DRWW NARP Study Reach**

Lake County, IL

Geosyntec consultants

Oak Brook | April 2023

**Figure 1**

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## 1.2 Modeling Process Overview

Developing an instream water quality model involves several steps, including data review and analysis, model development, model calibration, sensitivity analysis, and model application to evaluate management scenarios (**Figure 2**). These steps are briefly described below.

### 1.2.1 Data Review and Analysis

The first step in developing the water quality model is to review and analyze data. The data review helps to determine the model's spatial and temporal constraints, the availability of model input and calibration data, and the results (e.g., flows, concentrations) needed to meet the modeling objectives.

### 1.2.2 Model Development

Model development involves river reach segmentation, input data preprocessing, and initial model parameterization. In river reach segmentation, the river is divided into smaller segments based on available bathymetric, cross-sectional, and other geometric data. Input data preprocessing involves preparing timeseries of meteorological data, flow, and water quality constituents of interest from the different sources (i.e., upstream, nonpoint sources, and POTWs). The last step in model development is specifying model parameters based on site-specific conditions and ranges typical in the literature.

### 1.2.3 Model Calibration

In the model calibration step, model parameters are adjusted so that the simulated results match the measured data for each constituent. Parameters are adjusted based on site-specific information, previous literature values, and best professional judgment while maintaining the typical range for each parameter. Model calibration is crucial in ensuring that the model reproduces reality as accurately as possible.

### 1.2.4 Sensitivity Analysis

The sensitivity analysis identifies the most sensitive model parameters to improve model calibration, if necessary. During the sensitivity analysis, input data and model parameters are adjusted by a fixed amount, and the model response is monitored to identify the most sensitive parameters.

### 1.2.5 Management Scenarios

The calibrated model is applied to evaluate the effectiveness of different watershed management strategies on the instream water quality.

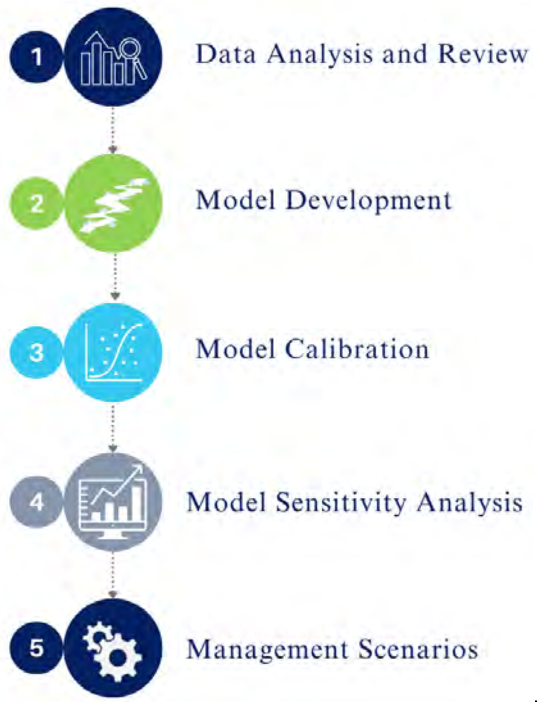



**Figure 2: Modeling Process**

## 2. DATA REVIEW AND ANALYSIS

Geosyntec reviewed historical instream water quality data through 2018 for the Des Plaines River and tributaries as part of the NARP work plan development (Geosyntec 2020). DRWW conducted an NARP-focused monitoring in 2020, which consisted of the following components:

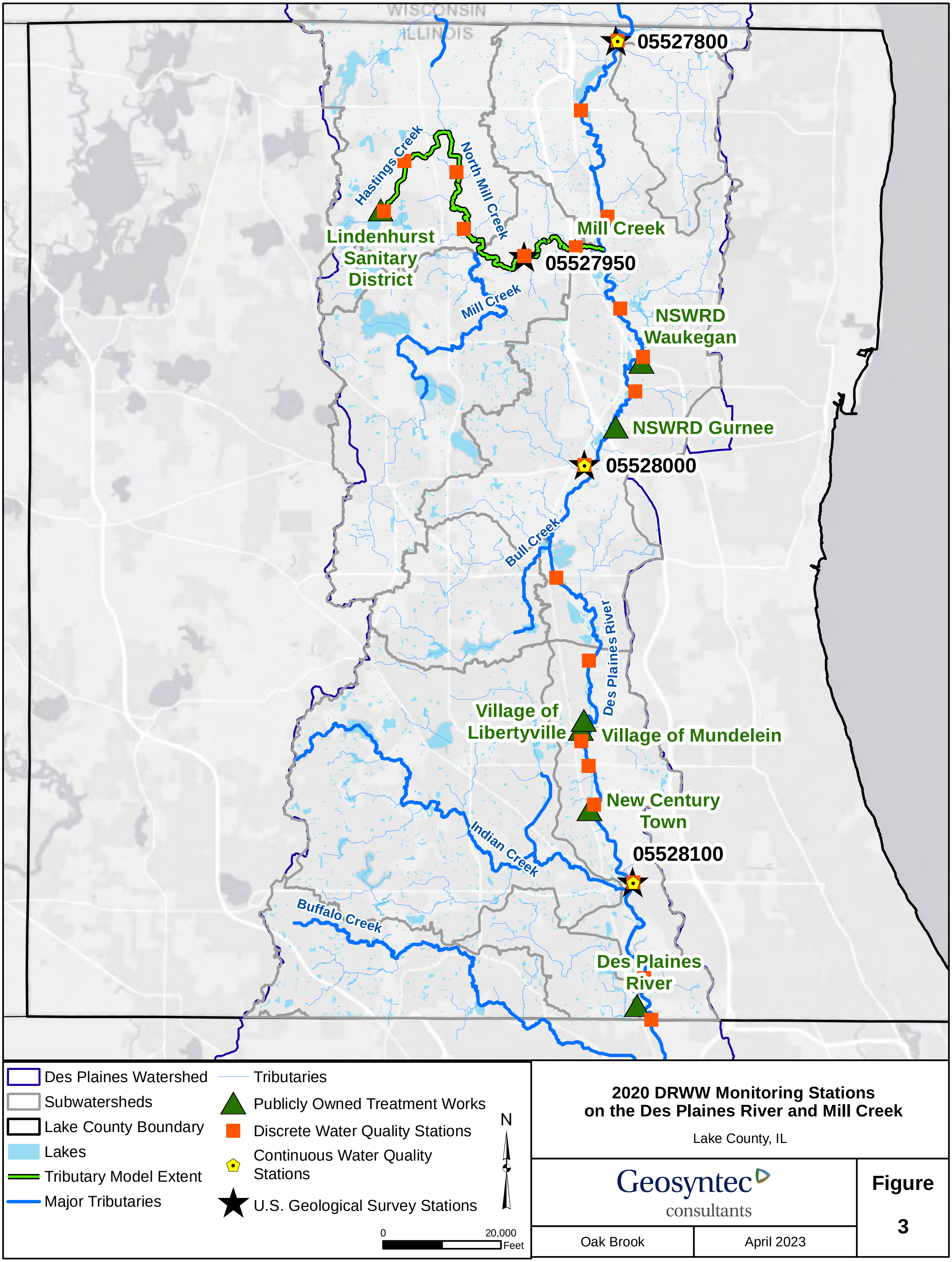
- Continuous Monitoring: Three sondes on the mainstem of the Des Plaines River (**Figure 3**) measured DO, temperature, total suspended solids, pH, chlorophyll *a*, and conductivity.
- Discrete Sampling: Discrete measurements were taken for nutrients, sestonic chlorophyll *a*, and benthic algae at 15 sites on the mainstem of the Des Plaines River and three sites on the Mill Creek (**Figure 3**). Samples were taken monthly during the summer period.

Data for the growing season (May to October) from 2017 to 2020 were analyzed to assess the longitudinal trends along the mainstem of the Des Plaines River.

**Figure 4** shows the longitudinal box-and-whisker plots[1] for measured instream total phosphorus (TP). The *x* axis on the graph represents miles on the Des Plaines River, decreasing from left to right. The plot shows that the instream TP increased with inputs from POTWs but decreased shortly after. **Figure 5** shows a similar plot for sestonic chlorophyll *a*. Instream chlorophyll *a* is high (greater than 15 micrograms per liter or µg/L) at the upstream boundary at the Illinois-Wisconsin border, and it decreases downstream due to dilution from discharge inputs from POTWs. This trend is also apparent in **Figure 6**, which shows high chlorophyll *a* levels at the upstream station 13-6 and decreased levels at the downstream station 16-4. The high chlorophyll *a* levels at the upstream boundary resulted in large variability in DO at the upstream boundary (**Figure 7** and **Figure 8**). Downstream, the variability in DO is reduced by discharge inputs from POTWs, which are high in DO, and reduced instream chlorophyll *a* levels.

The data analysis shows that the chlorophyll *a* levels at the upstream boundary have a large impact on the downstream water quality. The growing season of May–October 2020 provides the most available instream water quality data (including concurrent continuous and discrete water quality). The flow in the mainstem of the Des Plaines River was high in May 2020 and very low from June to October 2020 **(Figure 9**). Therefore, the period of May–October 2020 was chosen to develop and calibrate the model and evaluate watershed management scenarios.

[1] Whiskers represent the minimum and maximum values, the edges of the box represent the 25th and 75th percentile values, and the central lines represents the median values.




**2020 DRWW Monitoring Stations on the Des Plaines River and Mill Creek**

Lake County, IL

Geosyntec consultants

**Figure 3**

| Oak Brook | April 2023 |
|---|---|

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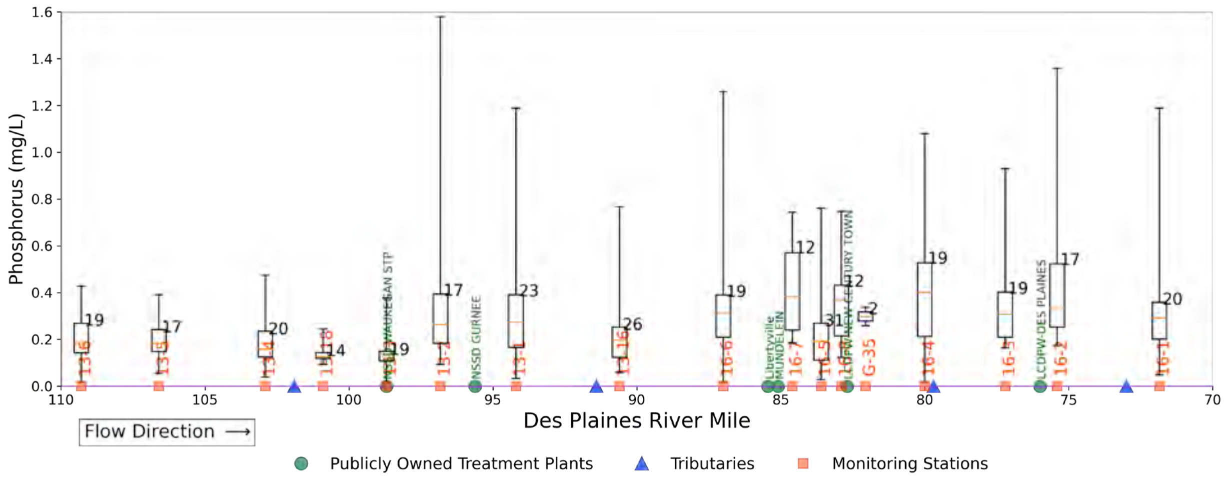



**Figure 4: Longitudinal Plot of Measured Total Phosphorus in the Des Plaines River for the Growing Season (May to October), 2017–2020**

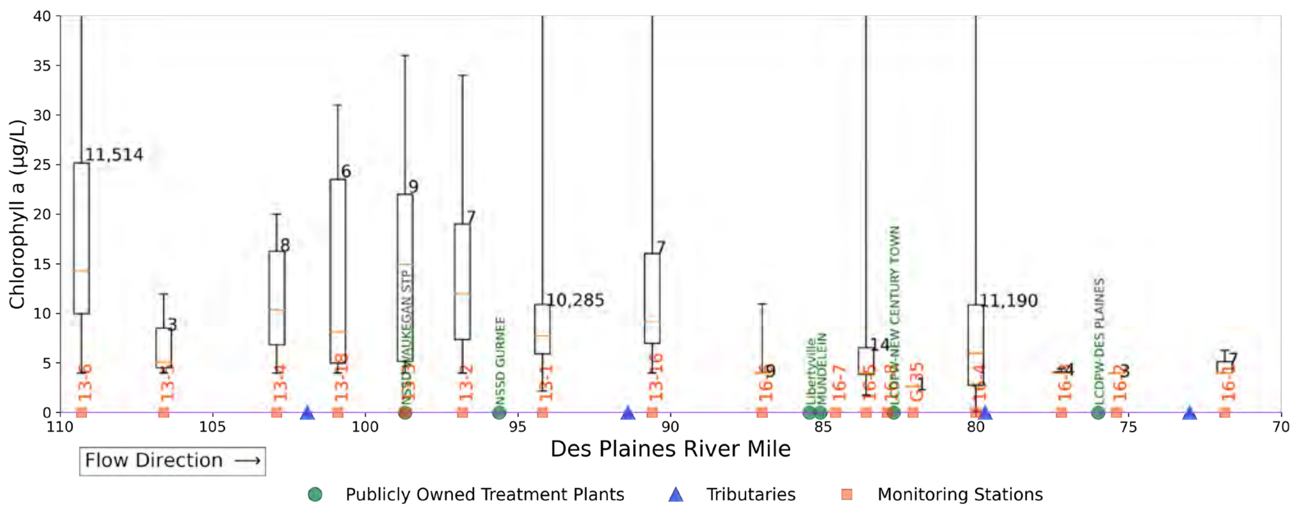



**Figure 5: Longitudinal Plot of Measured Sestonic Chlorophyll *a* in the Des Plaines River for the Growing Season (May to October), 2017–2020**

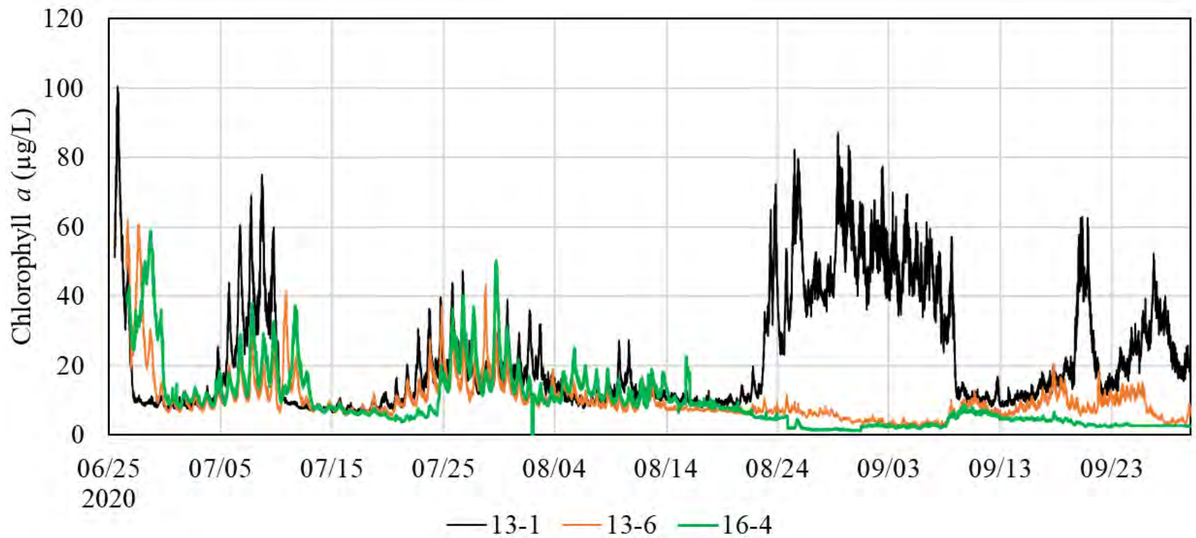



**Figure 6: Timeseries of Measured Continuous Sestonic Chlorophyll *a* at Three Stations on the Des Plaines River Mainstem**

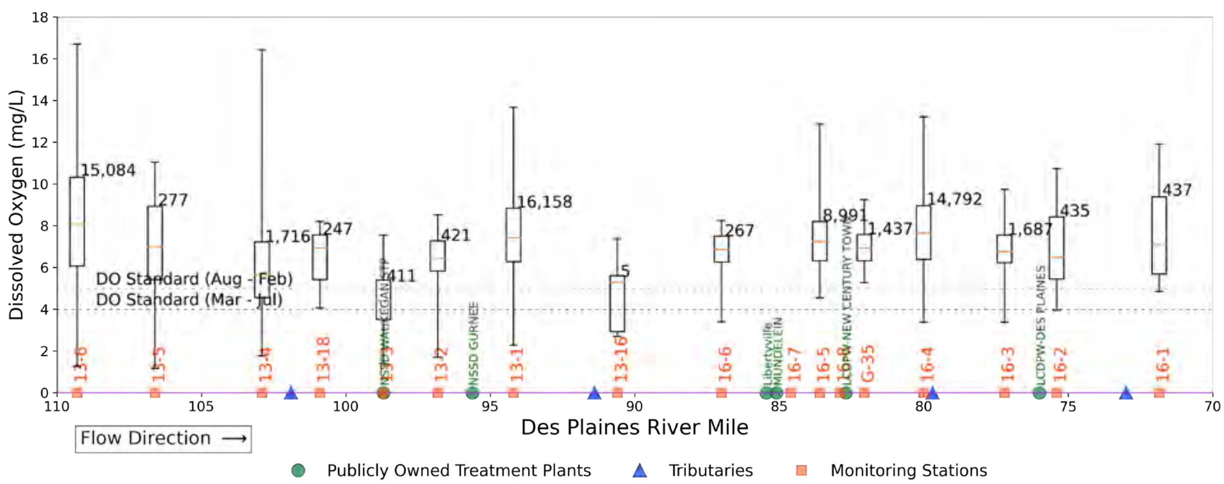


**Figure 7: Longitudinal Plot of Measured Dissolved Oxygen in the Des Plaines River for the Growing Season (May to October), 2017–2020**

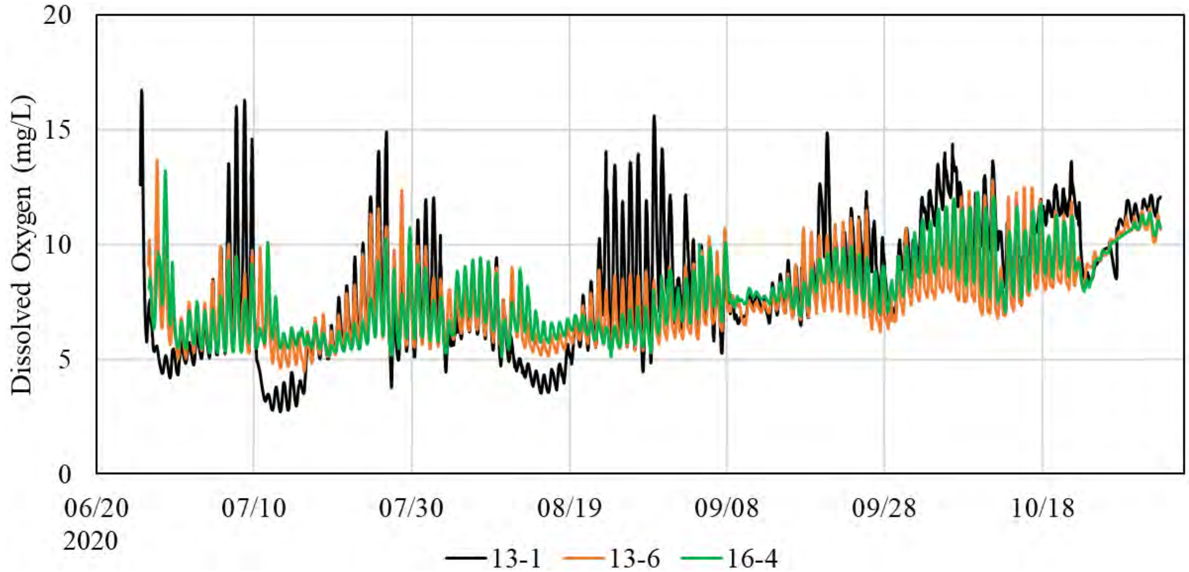



**Figure 8: Timeseries of Measured Continuous Sestonic Chlorophyll *a* at Three Stations on the Des Plaines River Mainstem**

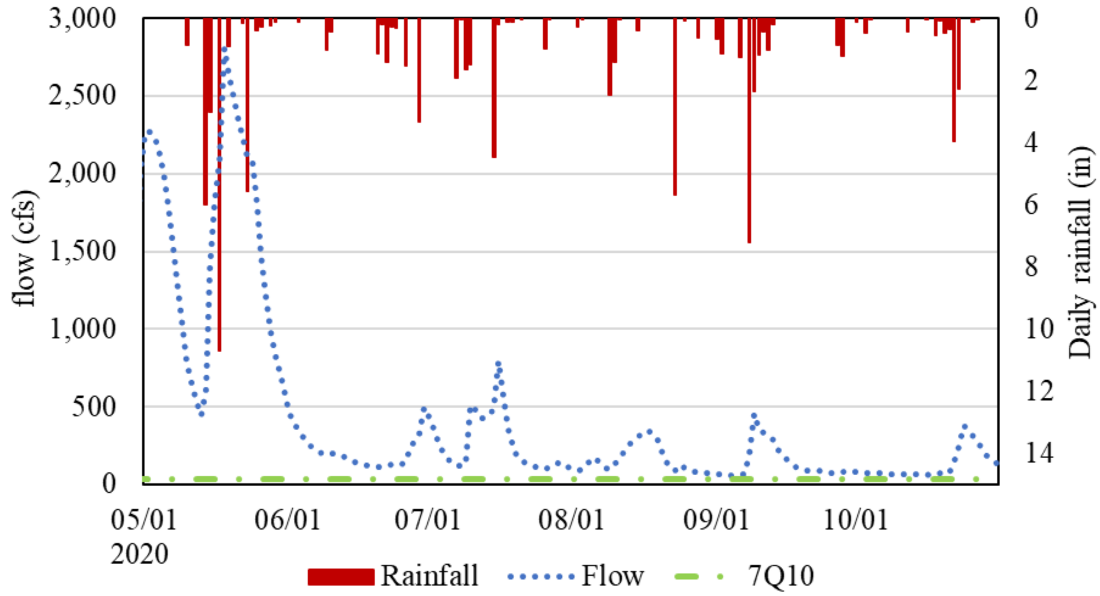



**Figure 9: Timeseries of Measured Daily Flow at USGS Gage 05528100 (Des Plaines River at Lincolnshire) and Rainfall at Riverwoods, May–October 2020**

# 3. MODEL DEVELOPMENT

## 3.1 Modeling Framework

A linked numerical modeling framework was developed for the NARP, as recommended in the DRWW NARP work plan (Geosyntec 2020). The linked modeling framework consists of two components: a watershed model and two instream models with hydraulic and water quality components (**Figure 10**).

The watershed model for the DRWW NARP was developed using the Soil & Water Assessment Tool (SWAT). The watershed model development and calibration are described in Appendix A of the DRWW NARP report.: DRWW NARP Watershed Modeling. The watershed model generates timeseries of flows and concentrations of TP, total nitrogen, and total suspended solids from the land segments to the instream models.

The instream models simulate the impact of flow and nutrient loading on instream hydraulics and water quality. The hydraulic components of the instream models use flow inputs to calculate flows, velocities, and water levels in a stream. The water quality components of the instream models simulate the fate and transport of constituents of interest (e.g., nutrients, DO, and algae). The instream models were developed using the QUAL2Kw framework (Pelletier et al. 2006). QUAL2Kw can perform a continuous simulation of flow and water quality. The QUAL2Kw framework provided the DRWW with a tool to inform management decisions concerning water quality under varying flow conditions over the growing season.

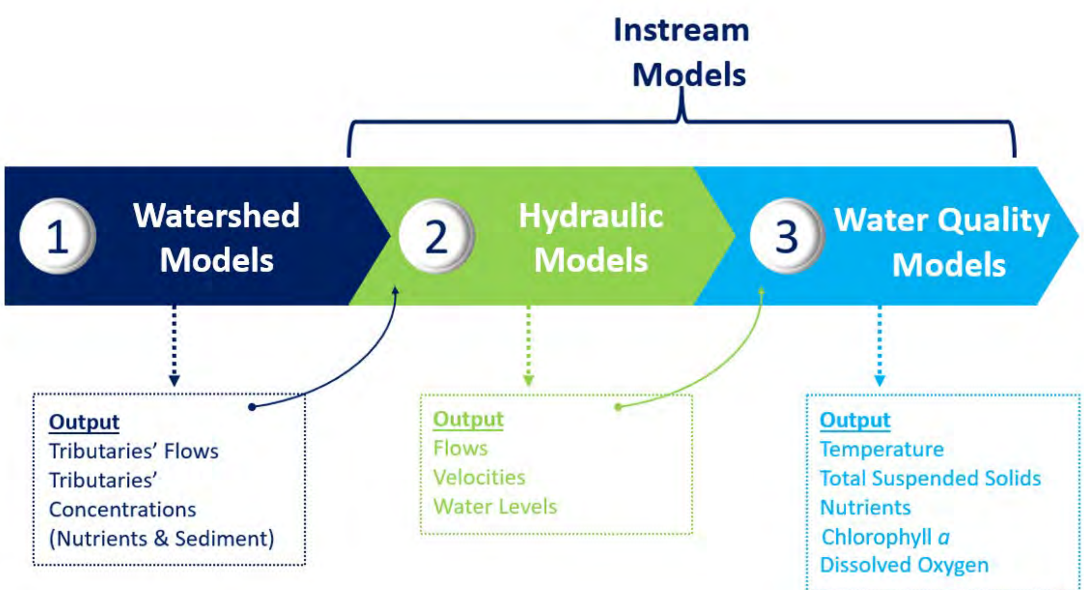



**Figure 10: Model Development Process**

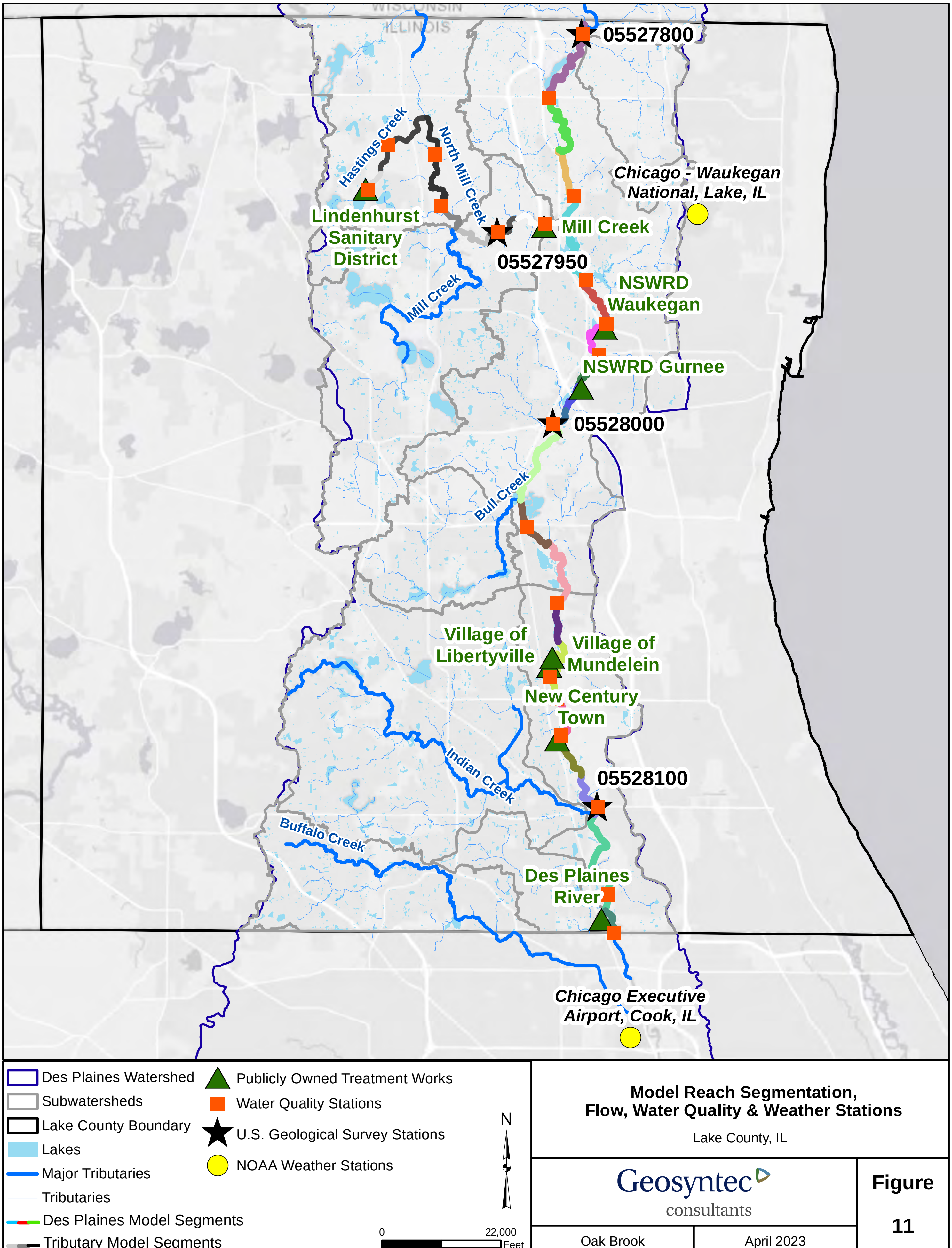
## 3.2 Modeling Domain and Reach Characterization

The modeled reaches include the Des Plaines River mainstem and the tributaries that receive discharges from wastewater treatment plants (i.e., POTWs) shown in **Figure 11**. The modeled tributaries are as follows:

- Hastings Creek, downstream of Hasting Lake (receives effluent from Lindenhurst Sanitary District POTW)
- North Mill Creek, downstream of the confluence with Hastings Creek (downstream of Lindenhurst Sanitary District POTW)
- Mill Creek, downstream of the confluence with North Mill Creek (receives the effluent discharge from Mill Creek POTW)

QUAL2Kw cannot model branched tributaries. Therefore, two QUAL2kw models were developed to simulate the reaches above using the same parameterization: the Mainstem Model, which includes thirty-five miles on the mainstem of the Des Plaines River, and the Tributary Model, which includes thirteen miles on the three tributary segments listed above (**Figure 11**).

The Mainstem Model extends from Russell Road (RM 109.3) to the confluence of the Des Plaines River with Wheeling Drainage Ditch (RM 73.0). The Tributary Model extends from Hastings Lake to the confluence of Mill Creek and Des Plaines River. The Mainstem Model was divided into 19 reaches with lengths ranging from 0.9 to 3.4 miles. The Tributary Model was divided into 14 reaches with lengths ranging from 0.4 to 3.3 miles **(Figure 11**).




**Model Reach Segmentation, Flow, Water Quality & Weather Stations**

Lake County, IL

Geosyntec consultants

Oak Brook | April 2023

Figure 11

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## 3.3 Input Data Processing

QUAL2Kw requires inputs of meteorology, channel characteristics, and flows and water quality constituents timeseries from the upstream boundary, nonpoint sources, and point sources. The following section summarizes model input preparation. A detailed summary of model inputs from the different sources is provided in the Model Input Statistics Spreadsheet (Attachment 1).

### 3.3.1 Meteorological Data

QUAL2Kw requires hourly metrological data input for air temperature, dew point temperature, cloud cover, wind speed, solar radiation, and shade. Air temperature, dew point temperature, cloud cover, and wind speed were obtained from the two closest National Oceanic and Atmospheric Administration (NOAA) weather stations (**Figure 11**). Solar radiation was obtained from the National Solar Radiation Database for the same two stations.

A diurnal shade timeseries was developed for each modeled reach using the channel shade information associated with the Lake County Stream Inventory. Lake County stream inventory data include a constant shade value for each cross section. The constant value was assigned for the hours 9 a.m. and 3 pm. A shade value of zero was assigned to the noon hour. Linear interpolation was conducted to determine the shade values between 6 am to noon and noon to 6 pm (Figure 12).

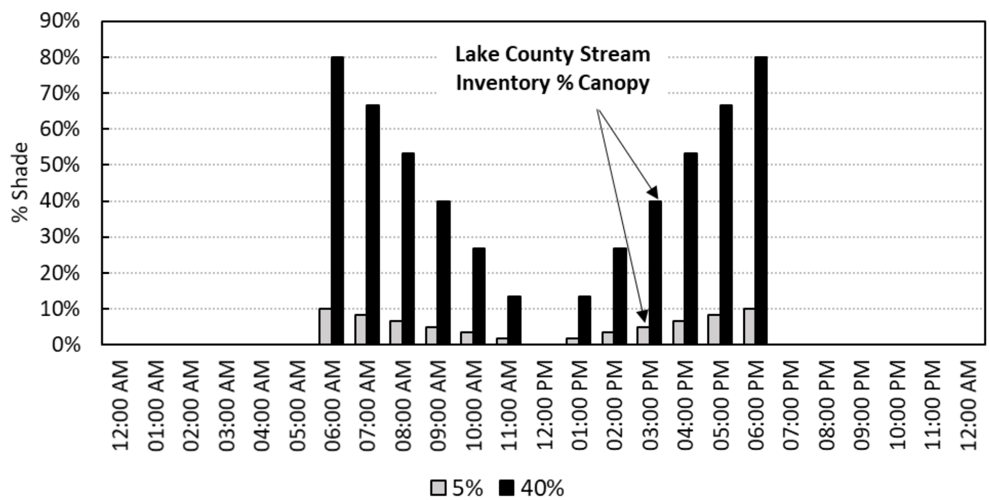



**Figure 12: Example Hourly Shade for Reaches with 5% and 40% Canopy Channel Shade**

### 3.3.2 Channel Characteristics

The river channel characteristics such as cross-section information, bottom algae coverage, and specified SOD rates for river reaches were also input into the model. The measured cross-section data from Lake County Stream Inventory Data were used to calculate the velocity-discharge and depth-discharge rating curves for the modeled reaches. These curves define the velocity and depth as a function of flow. The observations noted in the field sheets of the monitoring program were used to assign the bottom algae coverage for the river reaches. The measured SOD rates by ISWS (Butts and Evans, 1978) were used to specify the SOD rates for the river reaches. Both the bottom algae coverage and SOD rates were modified during the calibration within a reasonable range to match the measured data.

### 3.3.3 Upstream Boundary

QUAL2Kw requires hourly timeseries input for the upstream boundary for both flows and water quality constituents. Flow data was obtained from the United States Geological Survey (USGS) Gage 0552780 (Des Plaines River at Russell, Illinois). Hourly timeseries water quality data was developed using linear interpolation between measured discrete (nutrients) and continuous data (sestonic chlorophyll *a*, temperature, and DO) collected by DRWW at Russell Road. Upstream biochemical oxygen demand (BOD) was set to 2.4 milligrams per liter (mg/L) based on the average historical 5-day biochemical oxygen demand ($BOD_5$) collected by the Wisconsin Department of Natural Resources (WDNR) at station #303054 (~1.5 miles upstream of Russell Rd) using the equation.

$$BOD = \frac{BOD_5}{1 - \exp(-5k)}$$

where *k* is the DO deoxygenation rate which was set to 2/day based on the model calibration.

Hourly total suspended sediment inputs were obtained from the SWAT model output at Russel Road.

### 3.3.4 Nonpoint Sources

The daily simulated SWAT watershed model output was used to obtain hourly timeseries for nonpoint source flows and water quality constituents. The SWAT model was not calibrated for DO, temperature, or chlorophyll *a*. Therefore, tributary inputs for these constituents were based on monthly averages of historical data. Because no historical data was available for BOD in the tributaries, all tributary inputs were assigned a 2.4 mg/L BOD value (i.e., the upstream boundary value).

### 3.3.5 POTWs

The Mainstem Model includes discharges from six POTWs: the North Shore Water Reclamation District (NSWRD) Waukegan Water Reclamation Facility (WRF), the NSWRD Gurnee WRF, the Village of Libertyville Wastewater Treatment Plant (WTP), the Village of Mundelein WRF, the New Century Town WRF, and the Des Plaines River WRF. The Tributary Model receives point-source discharges from two POTWs: Lindenhurst Sanitary District Wastewater Treatment Facility (WTF) and Mill Creek WRF **(Figure 1**). Hourly point-source flows and water quality constituent inputs were calculated using linear interpolation based on data provided by DRWW.

# 4. MODEL CALIBRATION

The QUAL2Kw model was calibrated to the available flow and water quality data from May 1 to October 31, 2020. **Table 1** summarizes water quality data used for model calibration, including flow data from the USGS and continuous and discrete water quality data collected by DRWW in 2020 at stations shown in **Figure 5**.

**Table 1: Summary of Data Used for Model Calibration**

| Dataset | Data Type | Number of Sites | Samples/Days per Site |
|---|---|---|---|
| USGS Flow Data | Continuous | 4 | 183 days per site |
| DRWW Continuous Water Quality | Continuous | 2 | 128–130 days per site |
| DRWW Discrete Water Quality | Discrete | 18 | 4 samples per site |

DRWW: Des Plains River Watershed Workgroup
USGS: United States Geological Survey

The model was calibrated for the various constituents in the following order: stream flow, temperature, nutrients, chlorophyll *a*, and DO. Model parameters were adjusted to better match simulated and measured data. Model calibration results were presented to the DRWW monitoring subcommittee through several meetings and are described briefly below.

## 4.1 Hydraulic Calibration Process

The Mainstem Model was calibrated to available flow data at the three USGS gages. The measured flow during the simulation period of May to October 2020 ranges from 3.8 to 1,650 cubic feet per second (cfs) at USGS Gage 05527800 (Des Plaines River at Russell Road) and from 51.8 to 2,900 cfs at USGS Gage 05528100 (Des Plaines River at Lincolnshire). Hydraulic calibration was achieved by slightly adjusting the velocity and depth rating curve coefficients for the reaches. The calibration was assessed by calculating error statistics (coefficient of determination[2], root-mean-square error,[3] and index of agreement[4]) and performing a visual comparison between simulated and measured data at each USGS gage. Detailed information on the hydraulic calibration is provided in Attachment 2.

## 4.2 Hydraulic Calibration Results

**Table 2** compares statistics between simulated and measured data at three USGS gages—two in the mainstem and one in a tributary. An index of agreement of greater than 0.95 indicates good agreement between the simulated and measured flow values. **Figure 13** shows a timeseries comparison of simulated and measured flow data at USGS Gage 05528000, at the Des Plaines River near Gurnee, Illinois (river mile 20.8). Overall, the Mainstem Model simulations capture the measured data well for both peak and low flows.

[2] The coefficient of determination is a number between zero and one that measures how well a statistical model predicts an outcome.
[3] Root-mean-square error is the standard deviation of the residuals (i.e., prediction errors).
[4] The index of agreement represents the ratio of the mean squared error to the potential error. The agreement value of one indicates a perfect match, and zero indicates no agreement between simulated and measured values.

**Figure 14** shows a timeseries comparison of simulated and measured flow data at USGS Gage 05527950 at Mill Creek near Old Mill Creek, Illinois (River mile 2.7). Overall, the Tributary Model simulations capture the measured data well for both peak and low flows.

**Table 2: Comparison of Measured and Simulated Flows, May–October 2020**

| Station | Count | Measured (cfs) | | Simulated (cfs) | | $R^2$ | RMSE (cfs) | Index of Agreement | Calibration Assessment |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std Dev | Mean | Std Dev | | | | |
| USGS Des Plaines River near Gurnee (05528000) | 17,640 | 355 | 542 | 354 | 578 | 0.91 | 156 | 0.98 | Good |
| USGS Des Plaines River near Lincolnshire (05528100) | 17,640 | 417 | 612 | 427 | 689 | 0.85 | 238 | 0.97 | Good |
| USGS Mill Creek at Old Mill Creek (05527950) | 17,219 | 66 | 129 | 78 | 151 | 0.84 | 52 | 0.96 | Good |

cfs: cubic feet per second
$R^2$: coefficient of determination
RMSE: root mean square error
std dev: standard deviation
USGS: United States Geological Survey

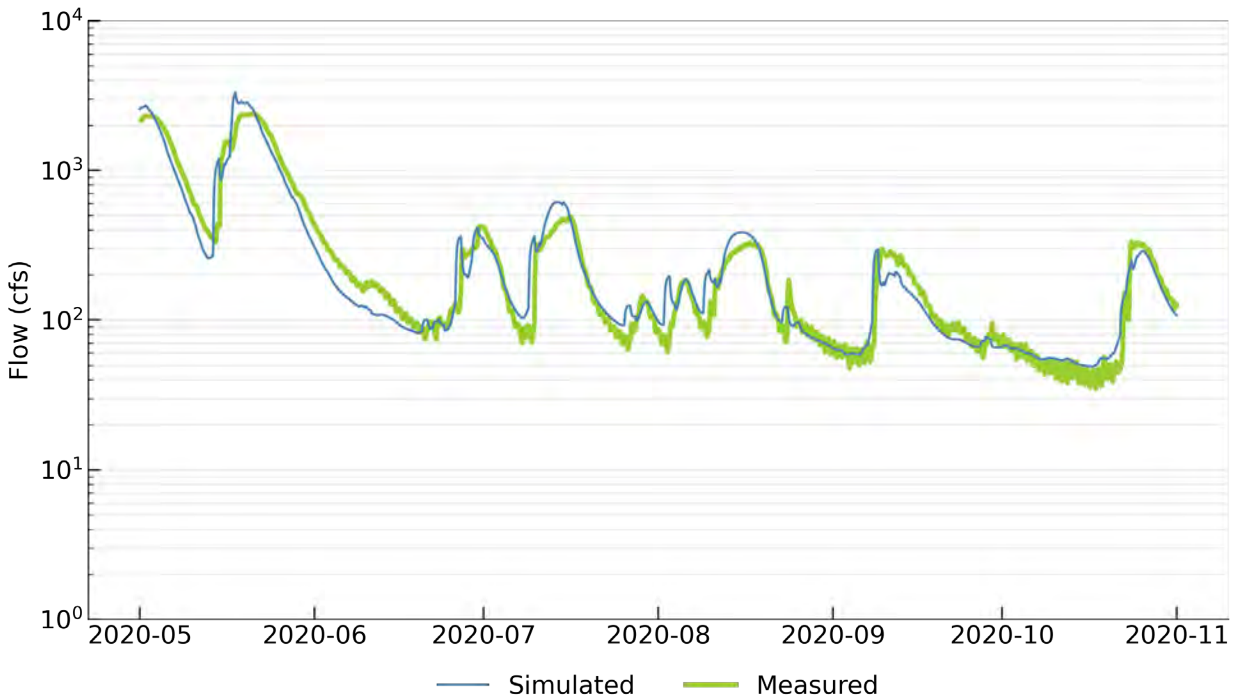



**Figure 13: Simulated and Measured Flows at USGS Gage 05528000 (Des Plaines River near Gurnee, IL)**

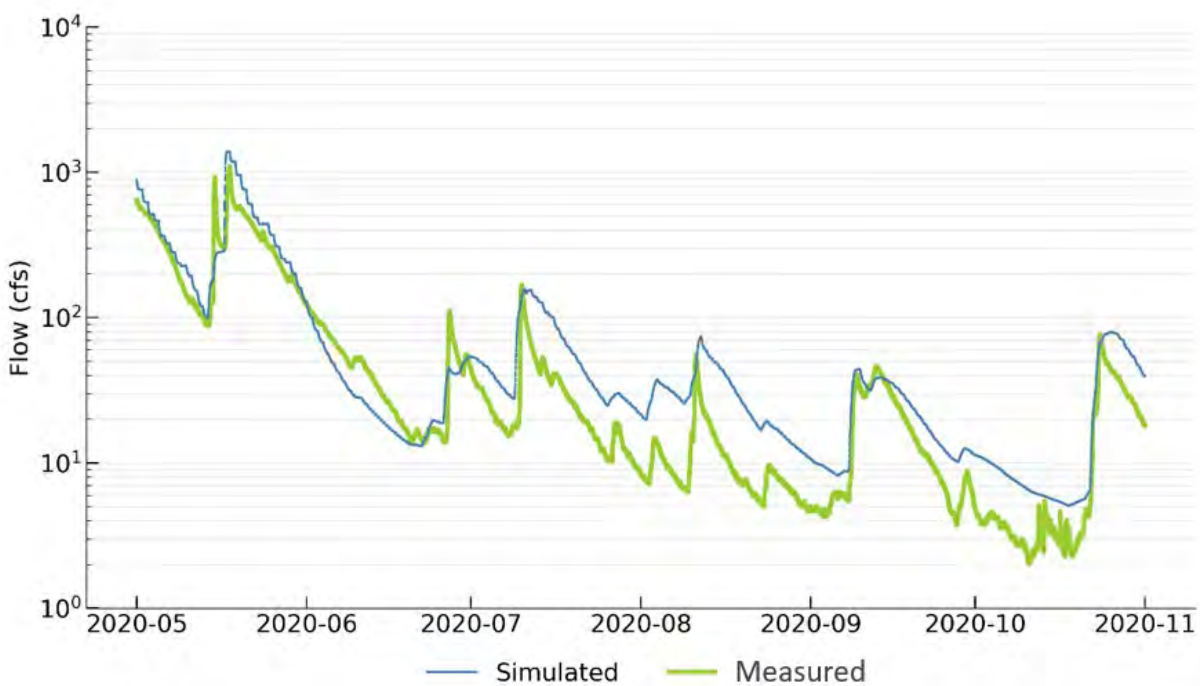



**Figure 14: Simulated and Measured Flows at USGS Gage 05527950 (Mill Creek near Old Mill Creek, IL)**

## 4.3 Water Quality Calibration Process

The model input parameters (Attachment 1) were adjusted to better match the model predictions to the measured data. The performance of the water quality model calibration was assessed by calculating model error statistics for continuous data and visually comparing simulated and measured water quality data (discrete and continuous). The model calibration results were presented to the Monitoring/Water Quality Improvements Committee through a series of meetings. The water quality model calibration was further refined based on the feedback from the monitoring committee.

The following sections summarize model performance in capturing measured temperature, TP, total nitrogen, sestonic chlorophyll *a*, benthic chlorophyll *a*, and DO for one location in the Mainstem Model (Des Plaines River at Route 120, river mile 20.8) and another location in the Tributary Model (Mill Creek at Dilley's Road, river mile 2.7). Detailed model calibration for the remaining stations, including timeseries plots and statistics comparing model simulations with measured data, are included in Attachment 3.

## 4.4 Water Quality Calibration Results

### 4.4.1 Temperature

**Table 3** shows a statistical comparison between measured and simulated continuous temperature data at two locations on the mainstem of the Des Plaines River, along with calculated statistical errors. The simulated values match the measured data well, with an index of agreement close to 1. **Figure 15** shows a plot of simulated and measured water temperature data at the Route 120 station on the Des Plaines River (river mile 20.8). **Figure 16** shows a plot of simulated and measured water temperature data at the Dilley's Road station on Mill Creek (river mile 2.7). The model captures the daily and seasonal variations in water temperature, which is an important constituent for simulating diurnal DO variations.

**Table 3: Comparison of Measured and Simulated Temperature at Two Locations in the Mainstem Des Plaines River, May–October 2020**

| Station | Measured (C°) | | | | Simulated (C°) | | | | $R^2$ | RMSE (°C) | Index of Agree-ment | Calibration Assessment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | Mean | Std Dev | Min | Max | Mean | Std Dev | | | | |
| Rte. 120 | 6.4 | 28.8 | 20.9 | 5.0 | 5.4 | 29.1 | 19.8 | 5.1 | 0.94 | 1.2 | 0.99 | Very Good |
| Rte. 22 | 6.0 | 30.0 | 20.1 | 5.6 | 3.2 | 32.7 | 20.5 | 6.3 | 0.91 | 1.6 | 0.98 | Very Good |

°C: degrees Celsius
$R^2$: coefficient of determination
RMSE: root mean square error
Rte.: Route
std dev: standard deviation

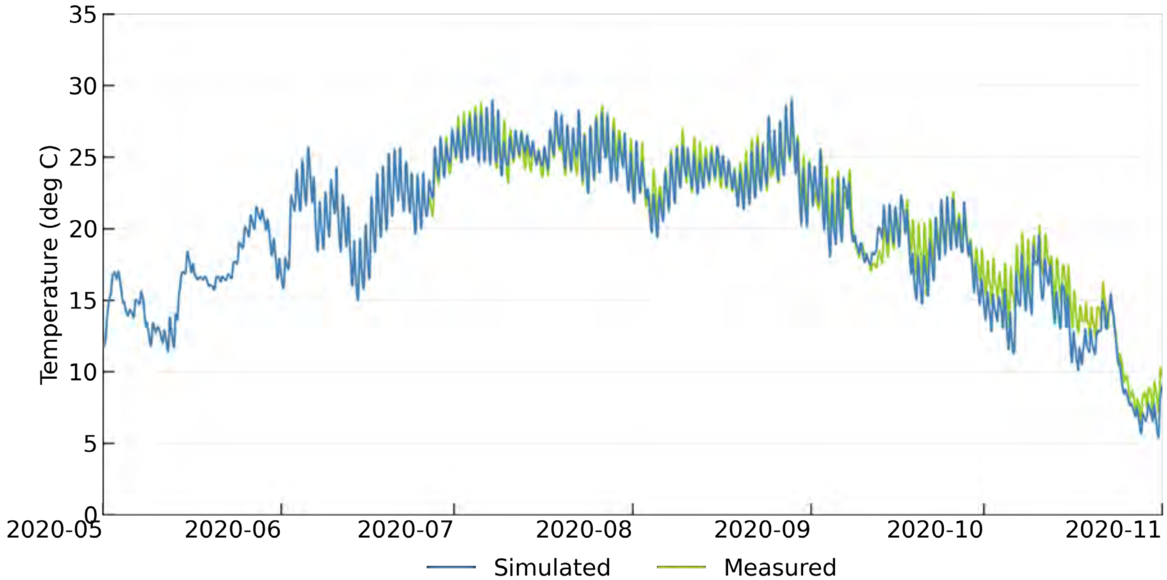



**Figure 15: Simulated and Measured Temperature in the Des Plaines River at Route 120 (River Mile 20.8)**

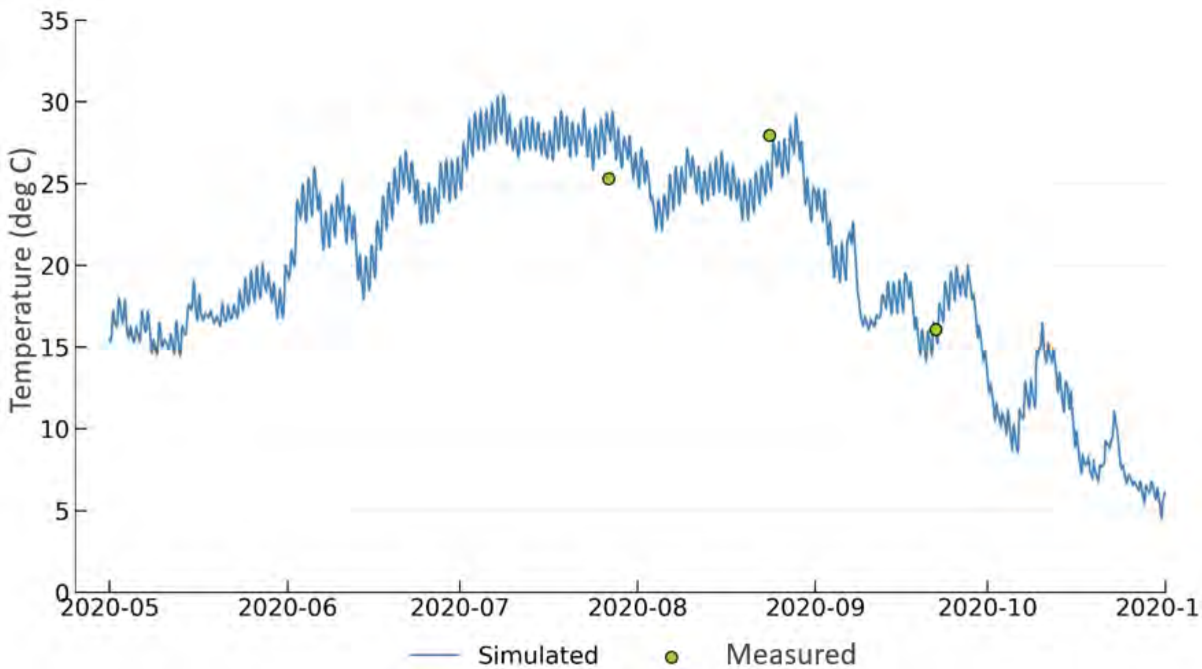



**Figure 16: Simulated and Measured Temperature in Mill Creek at Dilley's Road (River Mile 2.7)**

### 4.4.2 Total Phosphorus

**Figure 17** compares simulated and measured TP at the Route 120 station in the Des Plaines River (river mile 20.8). The model does a reasonable job of representing the measurements. **Figure 18** compares the simulated and measured TP data for Mill Creek at Dilleys Road (river mile 2.7). The model generally underpredicts the measured data for this location. This underprediction is likely associated with uncertainties in SWAT model outputs.

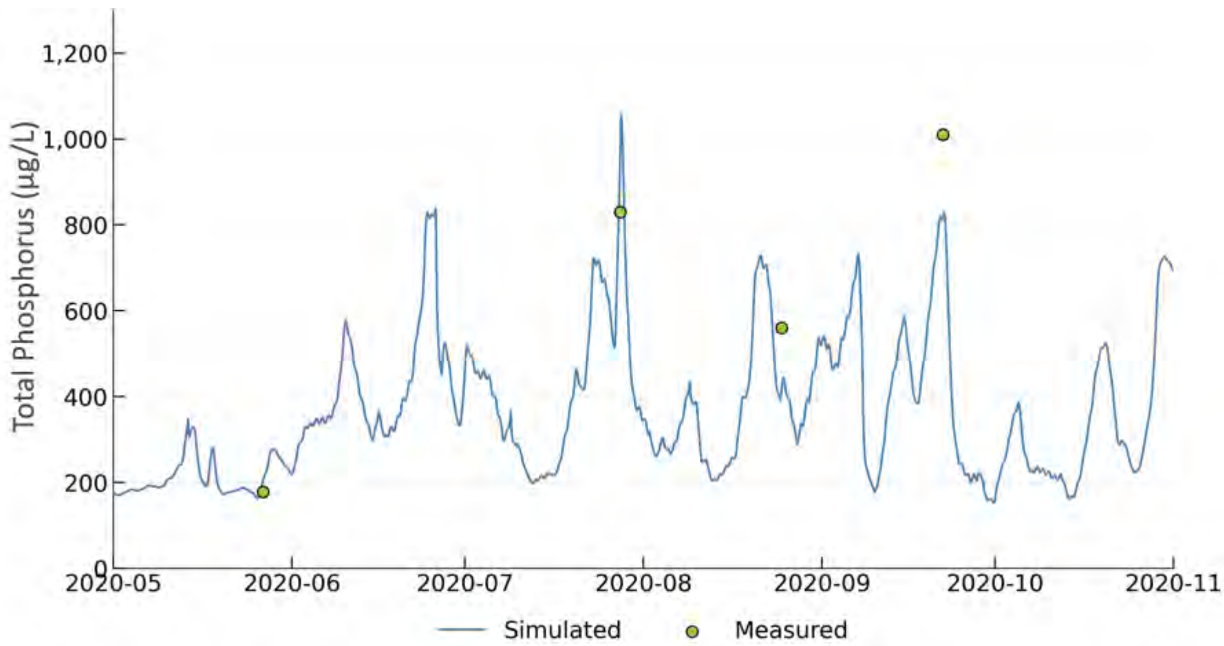



**Figure 17: Simulated and Measured Total Phosphorus on the Des Plaines River at Route 120 (River Mile 20.8)**

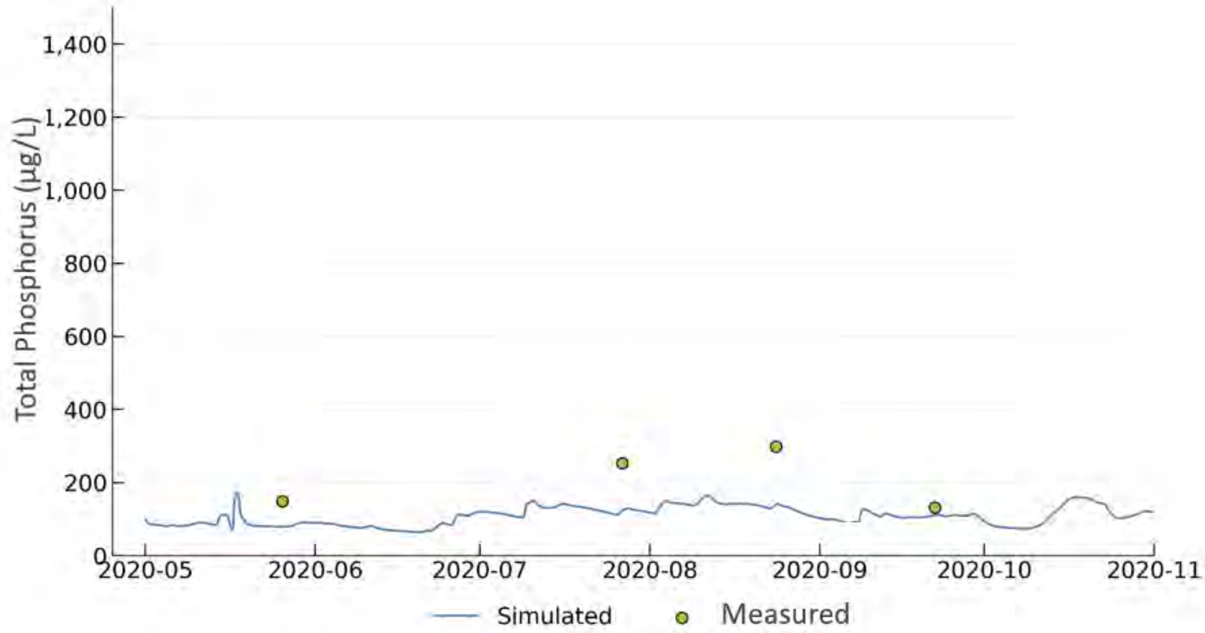



**Figure 18: Simulated and Measured Total Phosphorus on Mill Creek at Dilleys Road (River Mile 2.7)**

### 4.4.3 Total Nitrogen

**Figure 19** compares simulated and measured total nitrogen at the Route 120 station in the Des Plaines River (river mile 20.8). The simulated values match the measured data reasonably well. **Figure 20** compares simulated and measured total nitrogen data at Dilley's Road station on Mill Creek (river mile 2.7). The model underpredicts the total nitrogen at this location. This level of calibration for total nitrogen is acceptable because the NARP focuses on addressing the phosphorus-related impairments and nitrogen is not the limiting nutrient in this river.

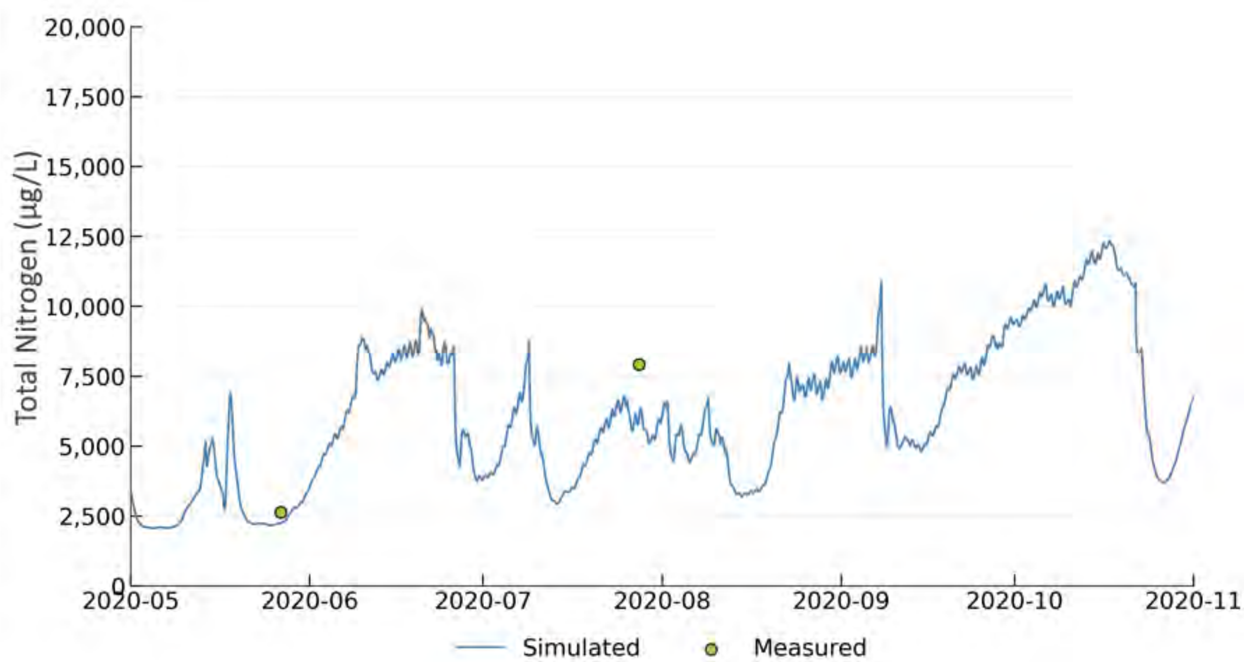



**Figure 19: Simulated and Measured Total Nitrogen in the Des Plaines River at Route 120 (River Mile 20.8)**

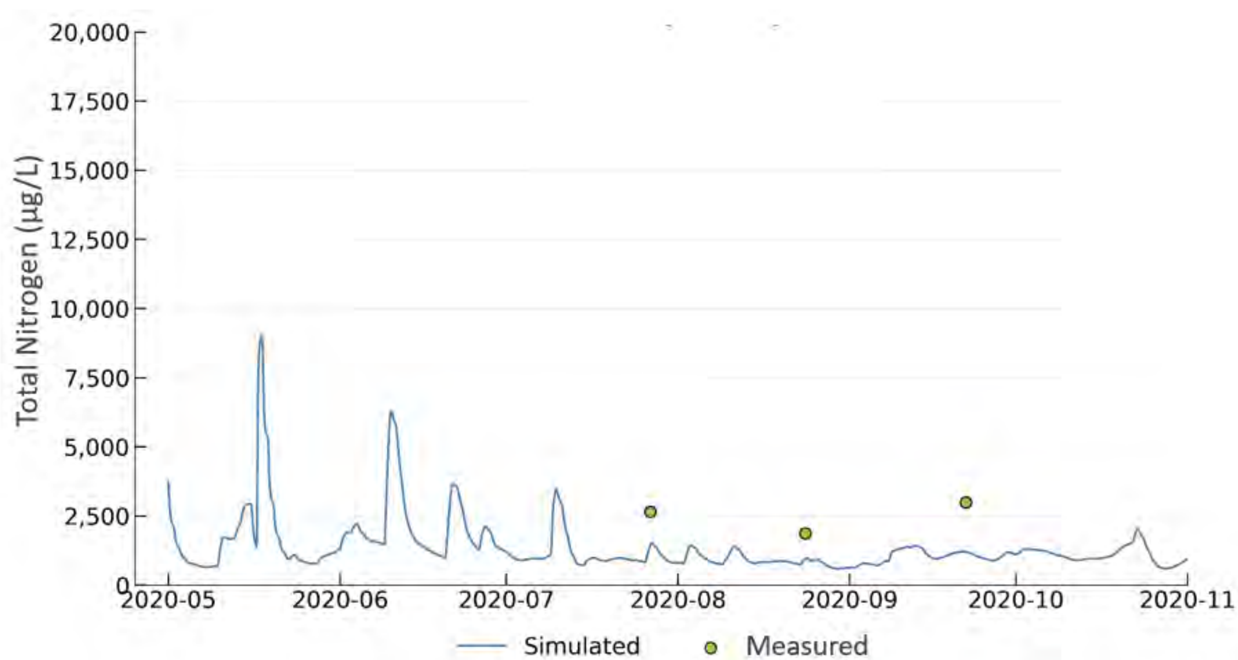



**Figure 20: Simulated and Measured Total Nitrogen in Mill Creek at Dilley's Road (River Mile 2.7)**

### 4.4.4 Sestonic Chlorophyll *a*

For the sestonic chlorophyll *a* calibration, the simulated values were compared to discrete and continuous measured chlorophyll *a* data. **Figure 21** compares simulated and measured discrete and continuous chlorophyll *a* data at the Route 120 station in the Des Plaines River (river mile 20.8). The Mainstem Model simulations captured the overall trend of measured chlorophyll *a* reasonably well. However, the model significantly underpredicts chlorophyll *a* peaks, especially in late August and late September. The underprediction is linked to underprediction of chlorophyll *a* from the Mill Creek tributary. **Figure 22** compares simulated and measured sestonic chlorophyll *a* at the Dilley's Road station in Mill Creek (river mile 2.7). The simulated values are underpredicted as compared to measured values in August and September. These results were discussed with the Monitoring/Water Quality Improvements Committee and the calibration was assessed to be fair based on the discussion.

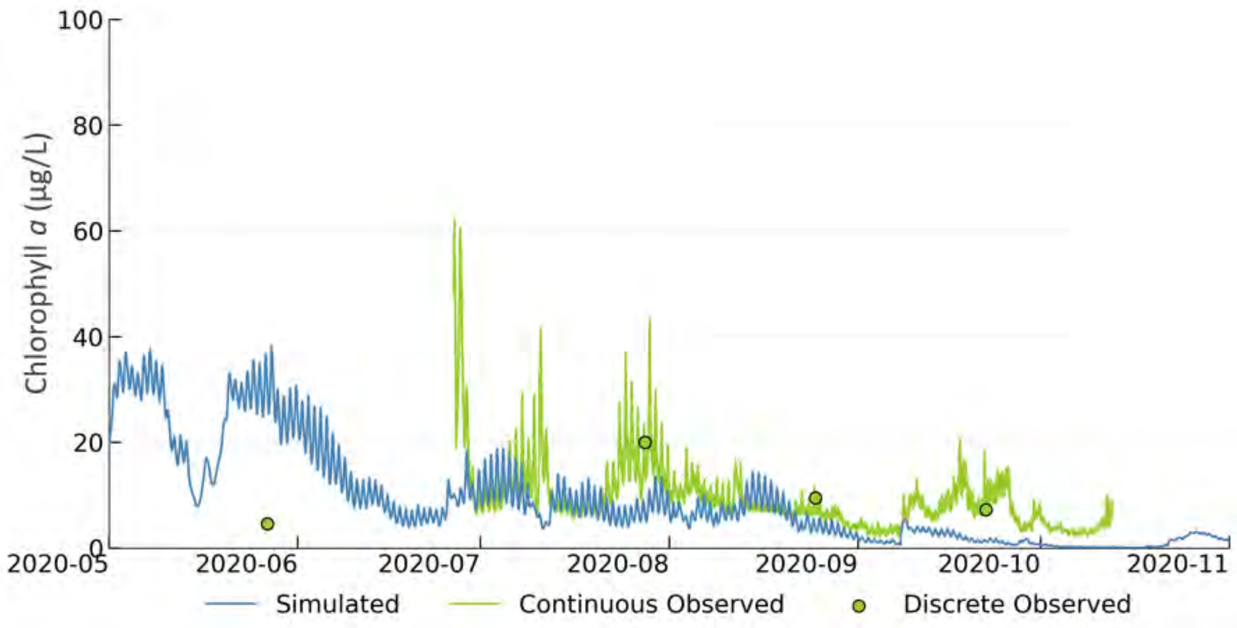



**Figure 21: Simulated and Measured Sestonic Chlorophyll *a* in the Des Plaines River at Route 120 (River Mile 20.8)**

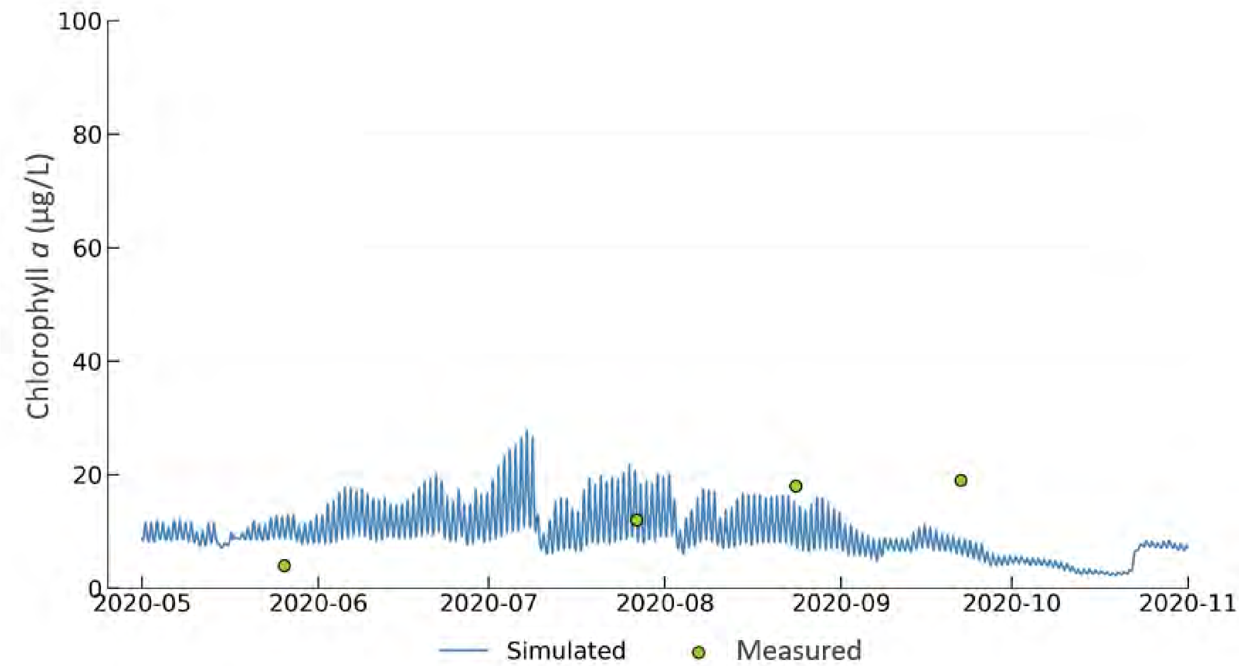



**Figure 22: Simulated and Measured Sestonic Chlorophyll *a* in Mill Creek at Dilley's Road (River Mile 2.7)**

### 4.4.5 Benthic Chlorophyll *a*

Simulated benthic chlorophyll *a* were compared to discrete samples collected at various locations along the Des Plaines River. **Figure 23** compares simulated and measured benthic algae in the Des Plaines River at Route 120 (river mile 20.8). The model captures measured benthic chlorophyll data reasonably well.

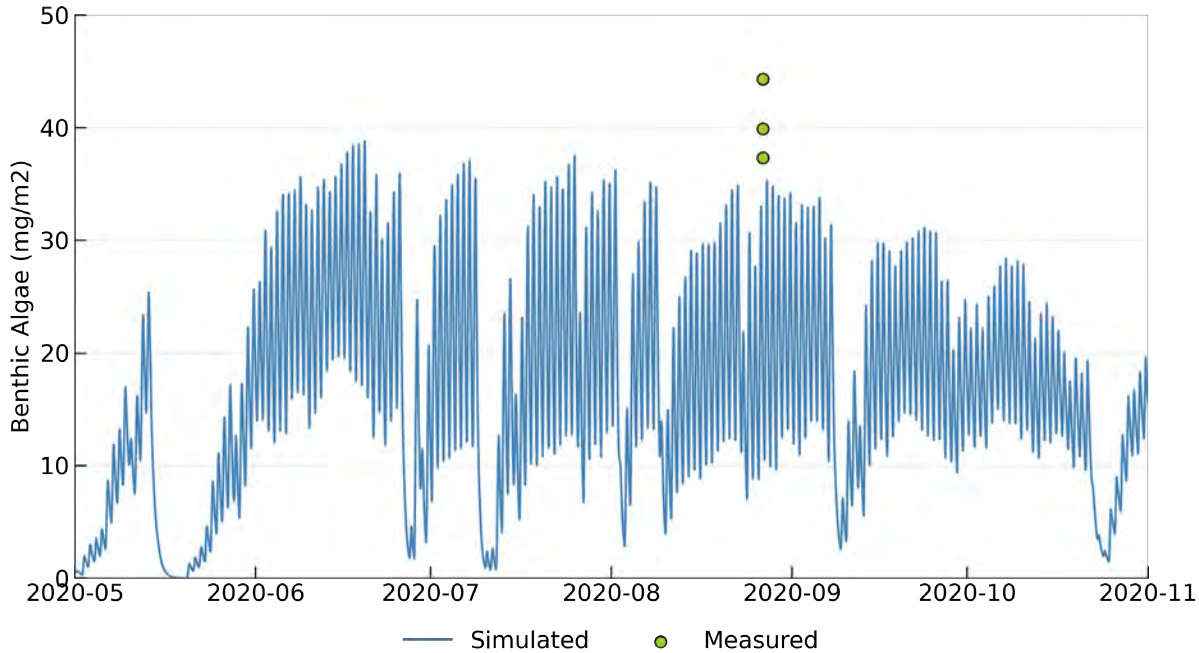



**Figure 23: Simulated and Measured Benthic Algae in the Des Plaines River at Route 120 (River Mile 20.8)**

### 4.4.6 Dissolved Oxygen

Table 4 shows a statistical comparison between simulated and measured continuous data for temperature at two locations in the mainstem of the Des Plaines River, along with calculated statistical error. The simulated values are in acceptable agreement with measured DO with a root mean square error of less than two (2) mg/L. **Figure 24** compares simulated and measured DO in the Des Plaines River at Route 120 (river mile 20.8) for the simulation period (i.e., the 2020 growing season, May to October). The model overpredicts DO in late September, but the model calibration is acceptable because measured DO does not violate the DO criterion. The model simulation underpredicts maximum DO in late October which is also acceptable since there is limited algae growth during this period. **Figure 25** provides a zoomed period from July 1 to August 15. In general, the model captures the diurnal variations in dissolved oxygen during this period.

**Table 4: Comparison of Simulated and Measured Dissolved Oxygen, May–October 2020**

| Station | Measured (mg/L) | | | | Simulated (mg/L) | | | | $R^2$ | RMSE (mg/L) | Index of Agree-ment | Calibration Assessment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | Mean | Std Dev | Min | Max | Mean | Std Dev | | | | |
| Rte. 120 | 4.5 | 13.7 | 7.6 | 1.7 | 3.5 | 9.9 | 6.9 | 1.4 | 0.00 | 1.7 | 0.70 | Good |
| Rte. 22 | 5.1 | 13.2 | 7.8 | 1.7 | 3.1 | 10.1 | 7.2 | 1.4 | 0.05 | 1.7 | 0.60 | Good |

mg/L: milligram per liter
$R^2$: coefficient of Determination
RMSE: root mean square error
Rte.: Route
std dev: standard deviation

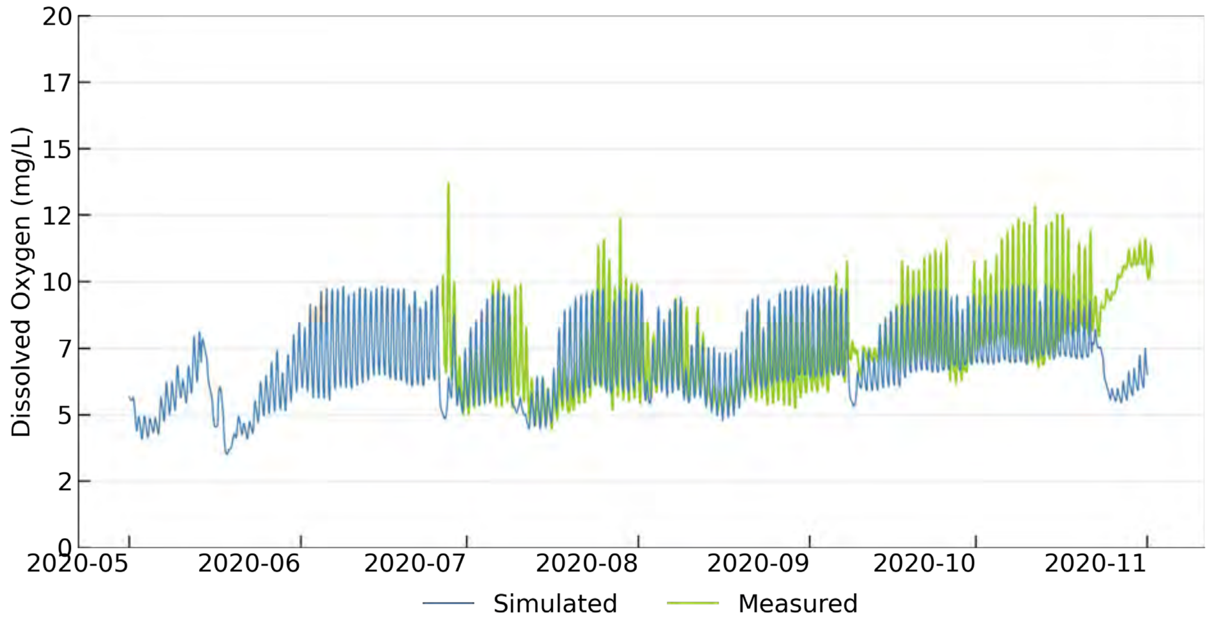



**Figure 24: Simulated and Measured Dissolved Oxygen in the Des Plaines River at Route 120 (River Mile 20.8)**

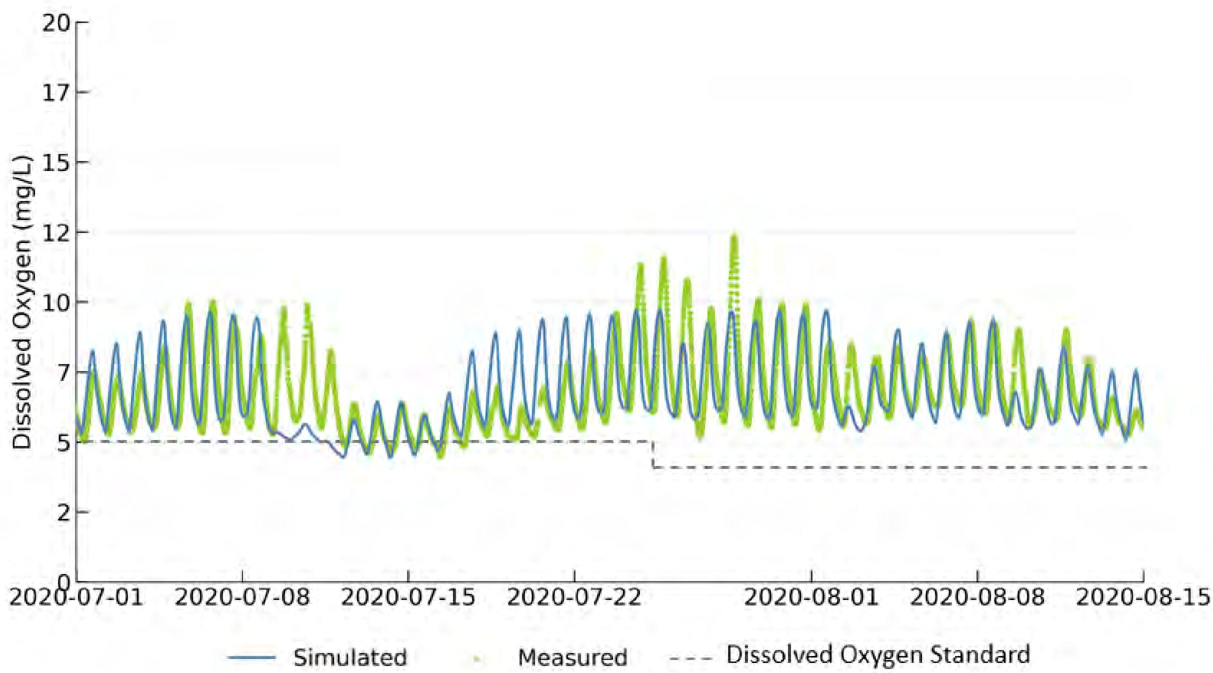



**Figure 25: Simulated and Measured Dissolved Oxygen in the Des Plaines River at Route 120 (River Mile 20.8), July–August**

## 4.5 Model Calibration Summary

**Figure 26** summarizes model calibration results at the Route 120 and Route 22 stations on the Des Plaines River. The model calibration performance for different water quality constituents was classified as Very Good, Good, or Fair based on the level of agreement between simulated and measured data for each constituent and best professional judgement. According to the model simulations results, the model performance was classified as Very Good for flow, temperature, and TP. The model calibration performance was classified as Good or Fair for DO and Fair for total nitrogen and benthic and sestonic chlorophyll *a*.

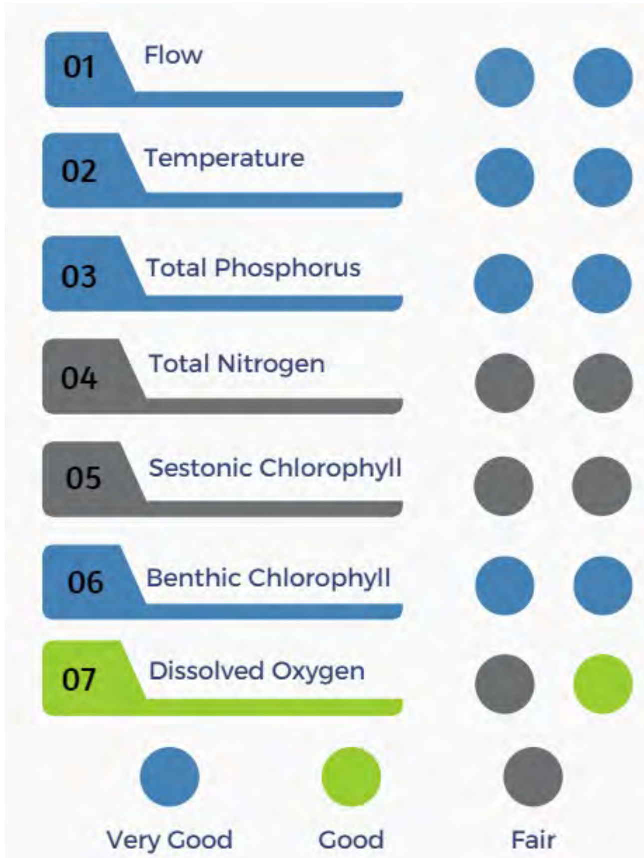



**Figure 26: Model Calibration Performance Summary**

# 5. SENSITIVITY ANALYSIS

A model sensitivity analysis was conducted to determine how changes in model inputs affect the model results.

## 5.1 Approach

For the current study, the Mainstem Model was used to assess the impact of TP inputs from upstream, POTWs, and nonpoint sources by running the following scenarios for the growing season (May 1 to October 31) for 2020:

- **Baseline Scenario** represents the existing conditions in the Des Plaines River, simulated by the calibrated model.
- For the **No Upstream Scenario**, the upstream boundary TP and chlorophyll *a* concentrations were set to zero.
- For the **No Point Sources Scenario**, the TP concentrations associated with the POTWs were set to zero.
- For the **No Nonpoint Source Scenario**, the TP and chlorophyll *a* concentratiosn associated with nonpoint sources were set to zero.

The results of the above scenarios were compared for the following parameters for the growing season for 2020:

- **Percent of Time DO Concentration is Less Than the Instantaneous Criteria (%):** Calculated percentage of time in a month when the simulated DO values are less than the instantaneous criteria.
- **Monthly Minimum DO (mg/L):** Calculated monthly minimum for each reach based on the timeseries of simulated DO values.
- **Monthly Average TP (mg/L):** Calculated average for each reach based on the timeseries of simulated TP values.
- **Monthly Median Chlorophyll *a* (micrograms per liter [µg/L]):** Calculated median for each reach based on the timeseries of simulated sestonic chlorophyll *a* values.
- **Monthly Median Benthic Algae Mass (kilograms [kgA]):** Calculated median mass for each reach based on the timeseries of simulated benthic algae chlorophyll *a* values (in milligrams per square meter [$mg/m^2$]) and area of reach (in square meters [$m^2$]). The mass of benthic algae (kg) is calculated by multiplying the model-reported benthic algae density ($mg/m^2$) by the length, the wetted width of the reach, and the percentage of benthic algae coverage.
- **Upstream Load Reduction Monthly Percent of Time Chlorophyll *a* is Greater Than or Equal to 26 µg/L (%):** Calculated percentage of time when the simulated sestonic chlorophyll *a* is greater than a threshold value of 26 µg/L. The 26 µg/L represents the Illinois Environmental Protection Agency median chlorophyll *a* value for the risk of eutrophication.

## 5.2 Results

The contribution of upstream sources, POTWs, and nonpoint sources (tributaries) to TP loading inputs for the baseline condition along the Des Plaines River is shown in **Figure 26**. This figure serves as reference for understanding the results of sensitivity analysis scenarios.

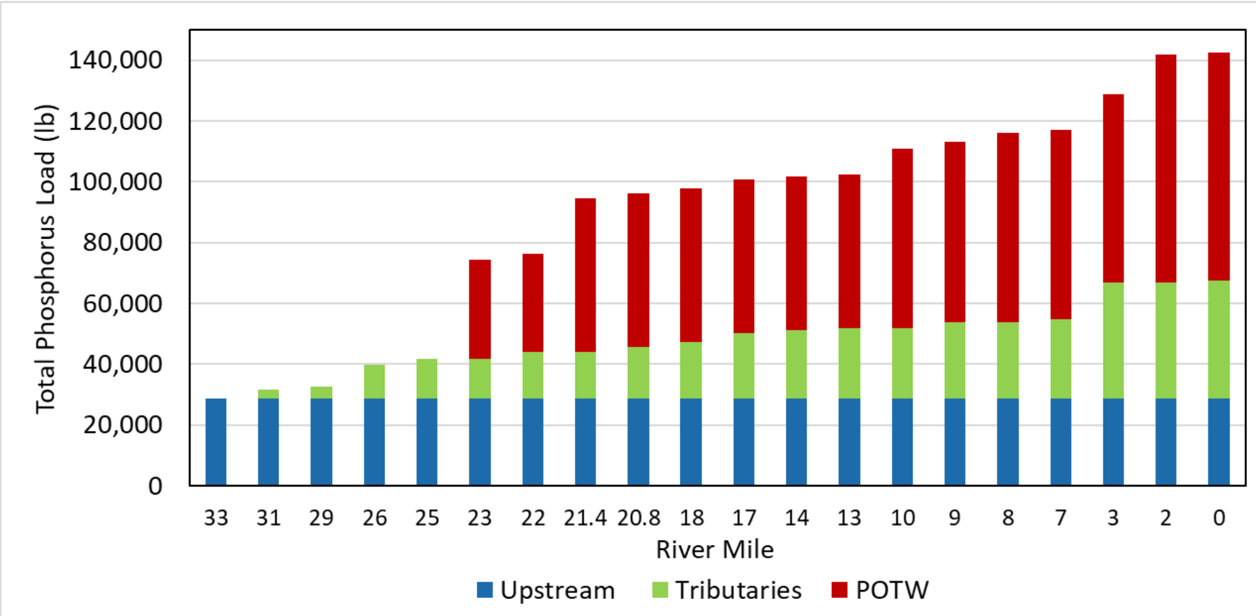



**Figure 27: Contribution of TP Loading along the Mainstem of the Des Plaines River, Growing Season (May–October) 2020**

**Figure 27** shows a comparison of growing season model results for the Baseline Scenario (black solid line), No Upstream Scenario (blue dashed line), No Point Source Scenario input (red dashed line), and No Nonpoint Source Scenario (green dashed line).

The model results show that eliminating the upstream boundary TP and chlorophyll *a* input results in reduction of TP, sestonic chlorophyll *a*, and benthic algae in the upper reaches of Des Plaines River before river mile 23. The lower sestonic chlorophyll *a* and benthic algae levels reduce photosynthetic activity, thereby decreasing the minimum DO and increasing the percentage of time when DO is less than the instantaneous criterion for the upstream reaches. For the downstream reaches after river mile 23, eliminating upstream boundary TP has a minimal impact on instream TP because of the increased loading of tributaries and POTWs. However, the chlorophyll *a* levels are significantly reduced, compared to the baseline scenario, because of dilution from POTW discharges. As a result, the DO swings are reduced in these downstream reaches which results in elevated minimum DO levels.

On the other hand, removing the point source phosphorus input reduced instream phosphorus downstream at river mile 25 but had no significant effect on growing season chlorophyll *a* or DO.

Finally, eliminating the nonpoint source phosphorus reduced chlorophyll *a* throughout the system but did not cause a significant change in DO or total phosphorus over the growing season. The relative impact of eliminating phosphorus input from the different sources can be different when investigating model results during a dry period versus after a wet event (Attachment 4).

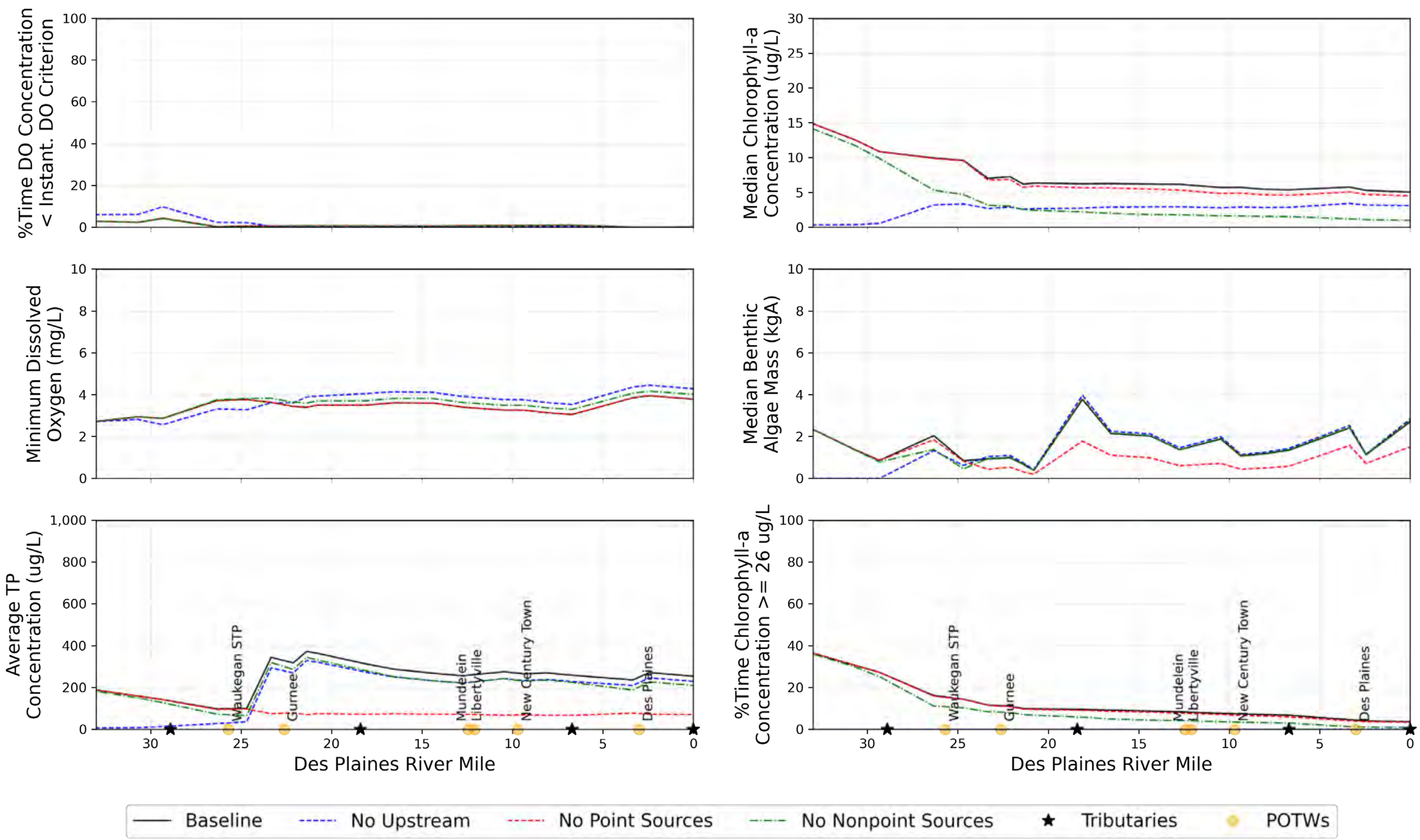



**Figure 28: Sensitivity Analysis Results, Growing Season (May to October) 2020**

# 6. WATERSHED MANAGEMENT SCENARIOS

Numerous scenarios were simulated to evaluate the effectiveness of watershed-based strategies in improving the water quality in the Upper Des Plaines River. These scenarios focused on TP load reductions from the upstream boundary, tributaries, and POTWs.

## 6.1 Approach

Geosyntec evaluated the following management actions to improve water quality in the mainstem of the Des Plaines River.

### 6.1.1 Upstream Load Reduction

The upstream load constitutes 20 percent of the total TP load into the Des Plaines River mainstem for the period of May to October 2020. The instream model was run for a scenario with a 75% reduction in upstream TP load. The reduction was simulated by proportionally reducing the upstream concentrations of organic phosphorus, inorganic phosphorus, and internal phosphorus within sestonic algae (i.e., algae suspended in the water column). The upstream TP and sestonic chlorophyll *a* boundary condition for the baseline and upstream TP load reduction scenario are shown in the left and right panels, respectively, of **Figure 28**. The upstream boundary sestonic chlorophyll *a* values for the baseline scenario ranged from 9 to 96 µg/L over the growing season. For the 75% reduction scenario, the upstream sestonic chlorophyll *a* boundary ranged from 2 to 24 µg/L.

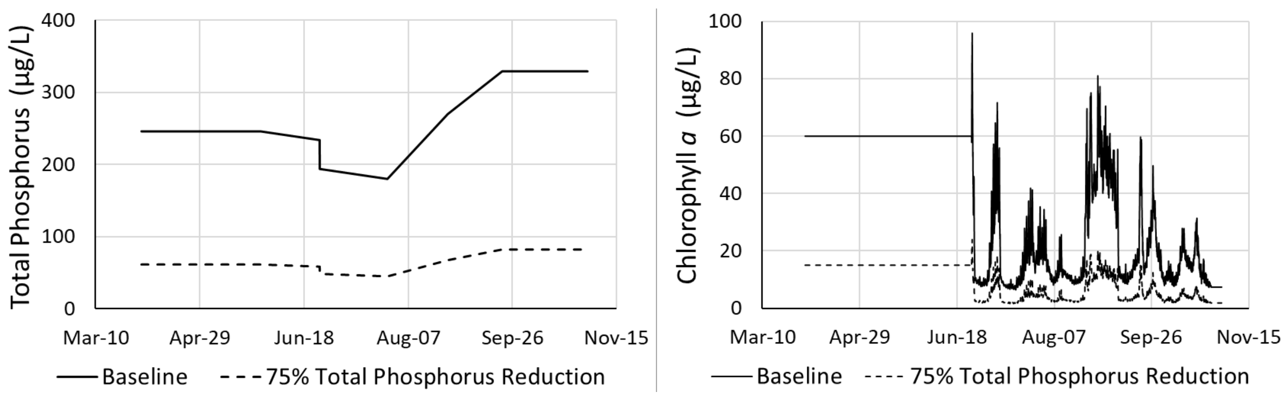



**Figure 29: Upstream Total Phosphorus Boundary Condition in Upstream Load Reduction Scenario (2020)**

### 6.1.2 Tributary Load Reduction

The contribution of tributary loads varies by river mile (**Figure 26**). The instream model was run for a scenario with a reduction of 75% of the tributary load.

### 6.1.3 POTW Load Reduction

The TP concentrations for POTWs in the baseline scenario range from 0.1 to 6.8 mg/L. The instream model was run to simulate the impact of POTW TP load reduction scenarios by capping the TP effluent concentrations to constant values of 0.5 mg/L and 0.1 mg/L for POTWs in the Mainstem and the Tributary Models. **Figure 29** shows the TP input for the baseline and the two POTW TP reduction scenarios for the NSWRD Waukegan POTW.

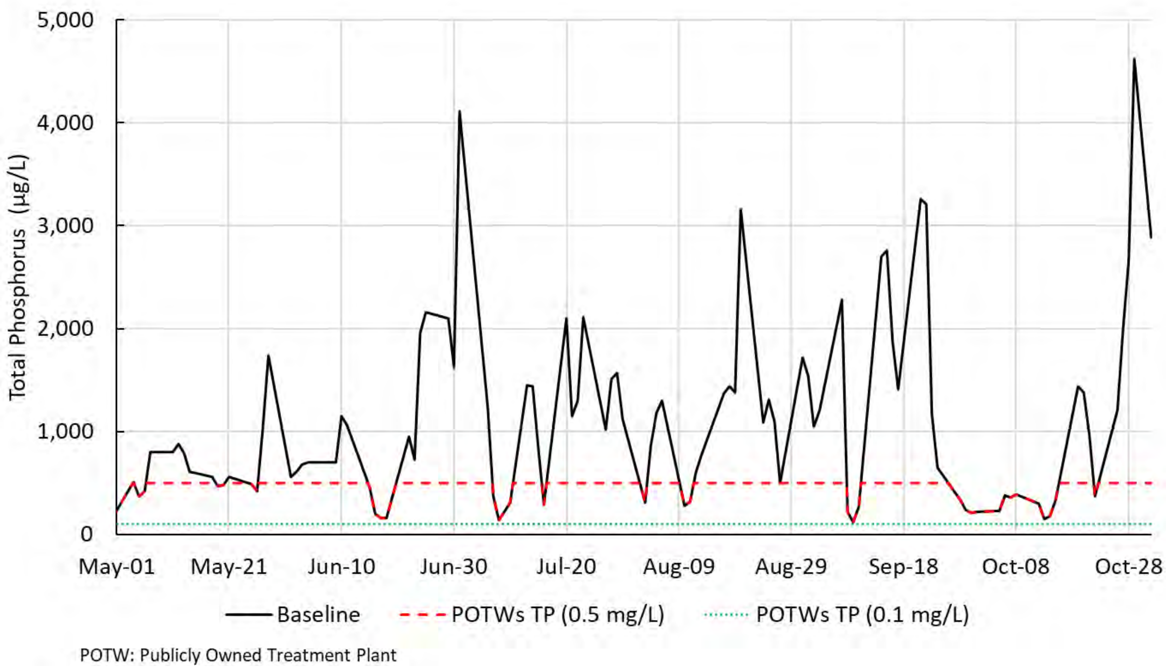



**Figure 30: NSWRD Waukegan Total Phosphorus for POTW Load Reduction Scenarios (2020)**

### 6.1.4 Combined Scenario

The watershed management scenarios described above were grouped into two combined scenarios based on the Monitoring/Water Quality Improvements Committee's review of the results of the management scenarios described above:

- Combined Scenario #1: 25% upstream TP reduction, 25% tributaries TP reduction, and 0.5 mg/L POTW effluent TP
- Combined Scenario#2: 50% upstream TP reduction, 25% tributaries TP reduction, and 0.5 mg/L POTW effluent TP

## 6.2 Results

The results of the watershed management scenarios were compared to the baseline scenario to assess the impact of watershed-based strategies on DO and algae (sestonic and benthic) in the Upper Des Plaines River mainstem. A summary of the watershed management scenarios is presented below. Details of the watershed management scenarios are included in Attachment E.

### 6.2.1 Upstream Load Reduction

The scenarios for the upstream TP load reduction included a modeled reduction in upstream sestonic chlorophyll *a* because a portion of TP is also bound up as internal phosphorus in sestonic chlorophyll *a*.

**Figure 30** and **Figure 31** compare simulated results for the baseline scenario (black solid line) with a scenario with a 75% upstream reduction (blue dashed line) for the growing season (May 1–October 30) 2020 and for a high-flow period (May 1–May 31, 2020), respectively. The results show that reducing the upstream TP load reduces the instream TP and sestonic chlorophyll *a*. This impact is pronounced during the high-flow period (**Figure 31)**. The reduction in instream chlorophyll *a* improves DO because of reduced DO swings and increased benthic algae activity after wet events.

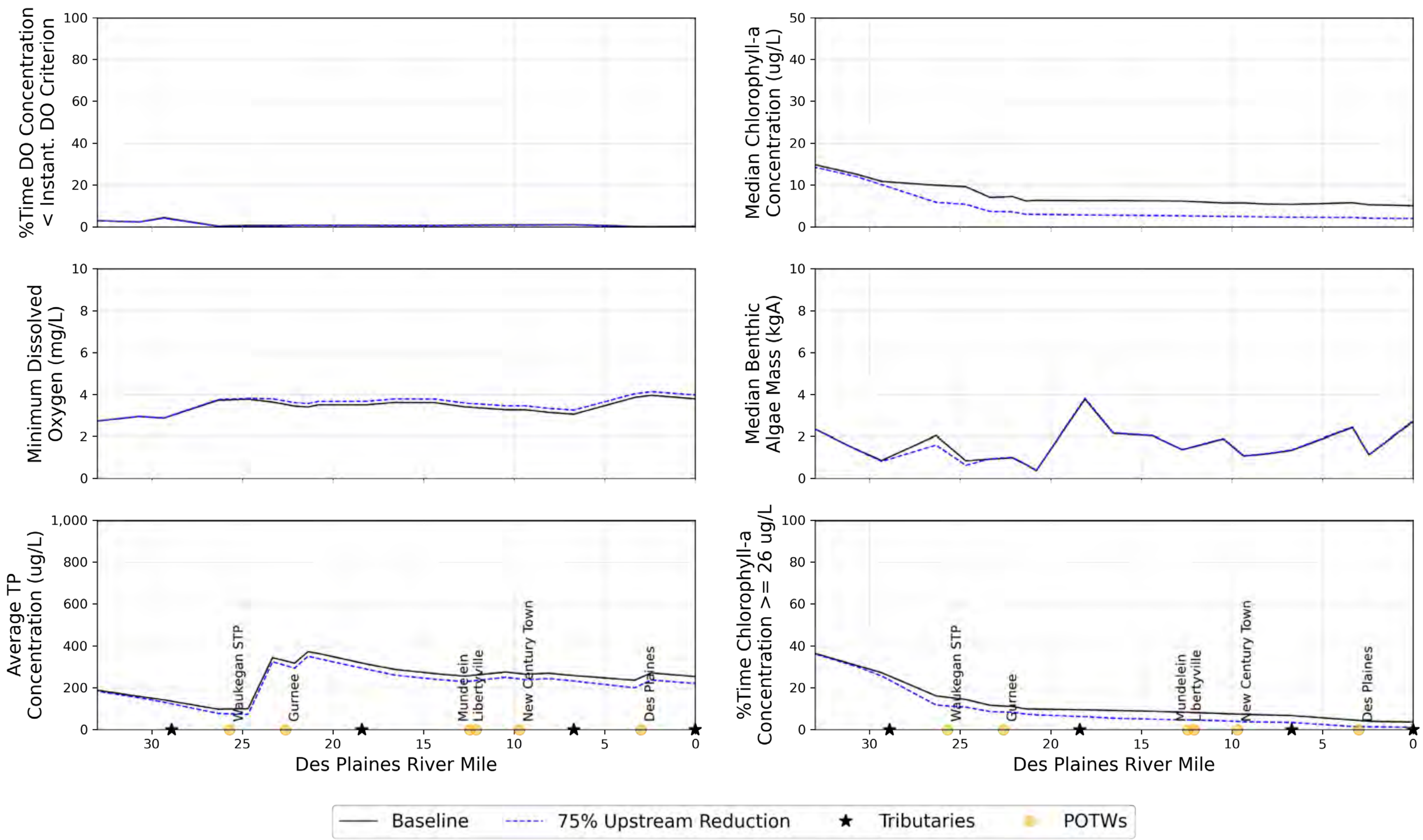



**Figure 31: Upstream Load Reduction Model Results, Growing Season (May 1–October 31, 2020)**

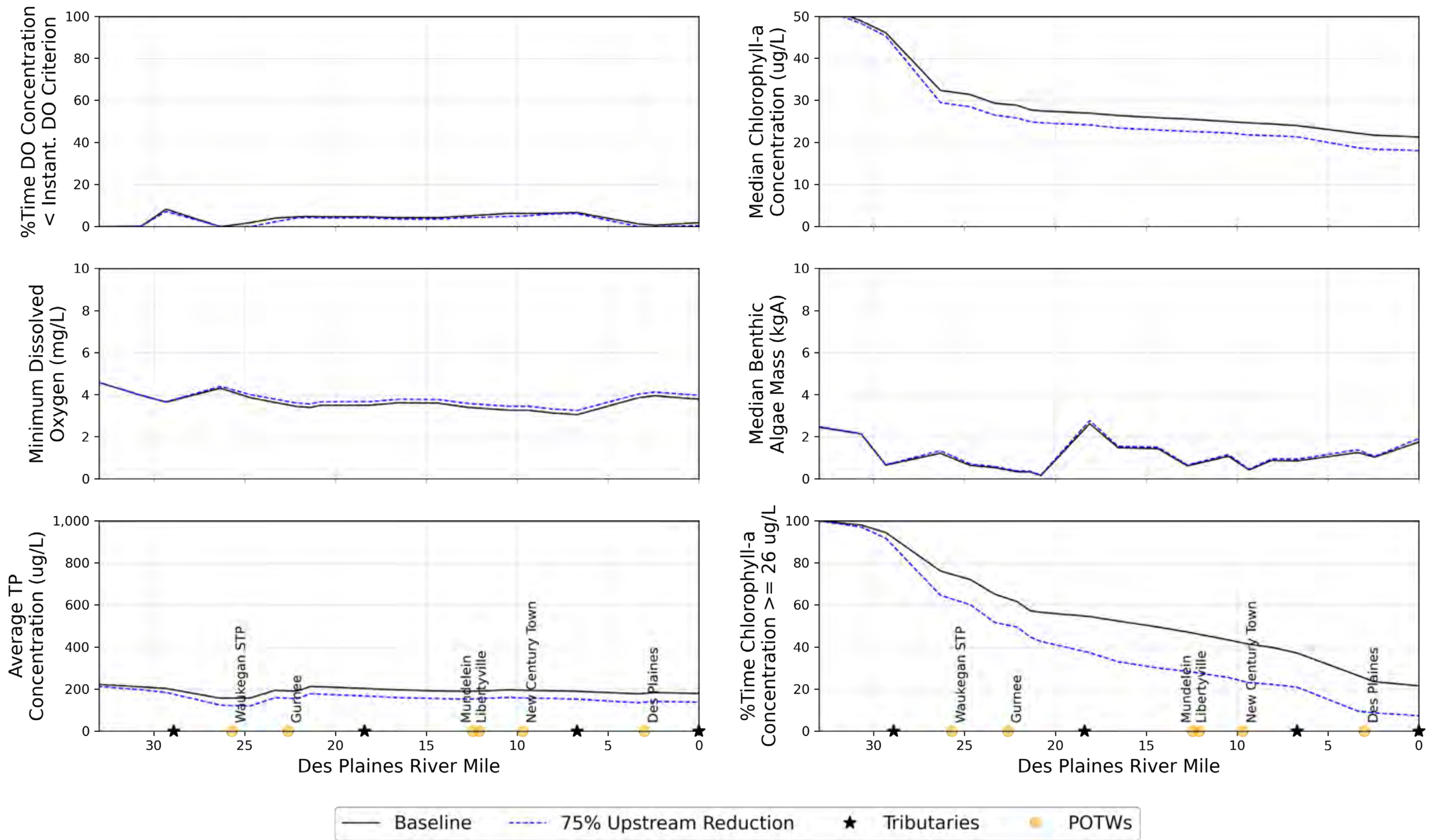



**Figure 31: Upstream Load Reduction Model Results, High Flow Period (May 1–May 31, 2020)**

### 6.2.2 Tributary Load Reduction

The impact of reducing tributary loads on the mainstem of the Fox River was assessed by running scenarios with 75% reductions in simulated tributary TP loadings.

**Figure 32** and **Figure 33** compare simulated results for the baseline scenario (black solid line) and a scenario with a 75% tributary TP load reduction (green dashed line) for the 2020 growing season (May 1–October 31) and a high-flow period (May 1–May 31), respectively. The results show that reducing the tributary TP load slightly reduces the instream TP and sestonic chlorophyll *a*, mostly following wet events. Tributary phosphorus load reductions have a minimal impact on the instream DO.

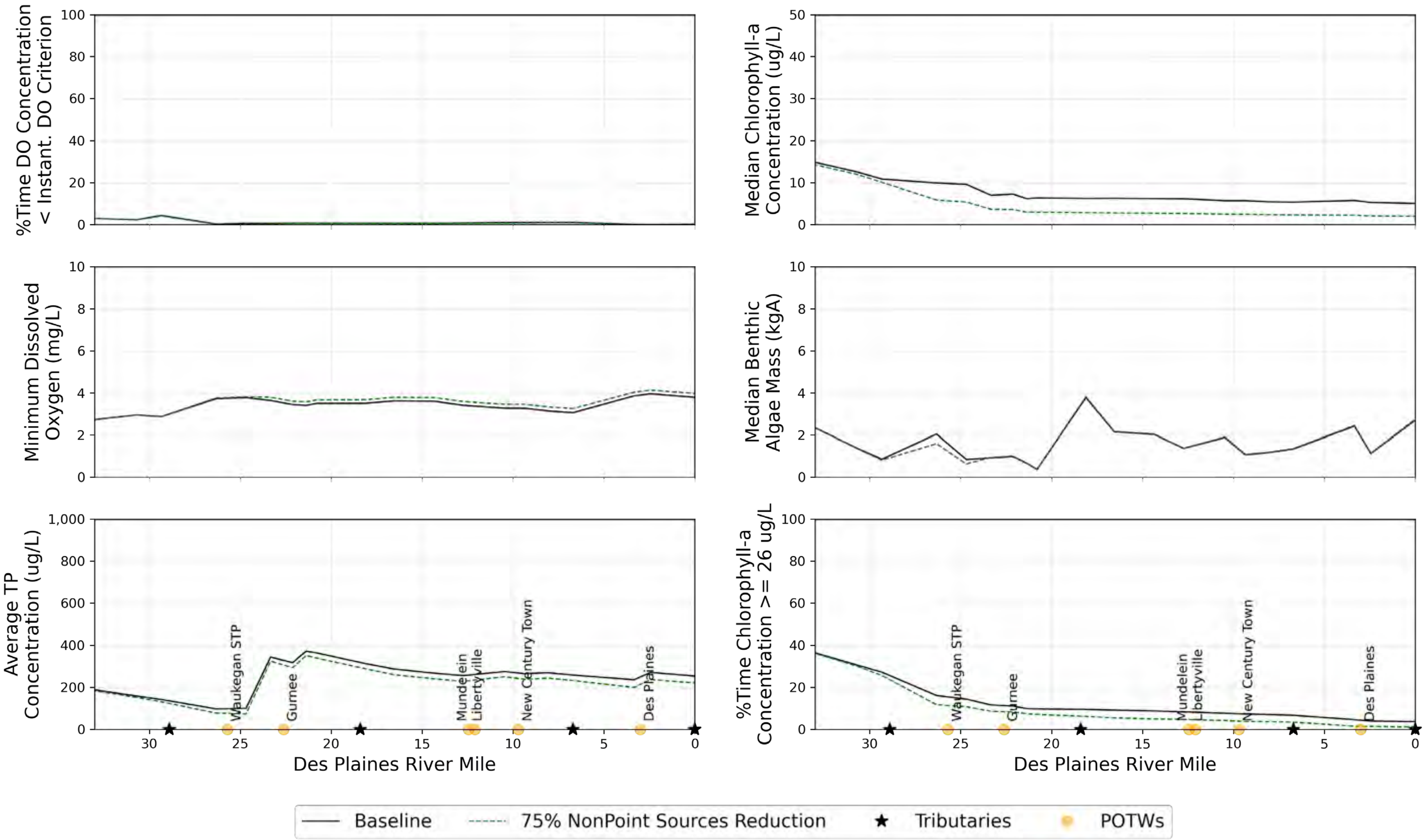



**Figure 32: Tributary Load Reduction Model Results, Growing Season (May 1–October 31, 2020)**

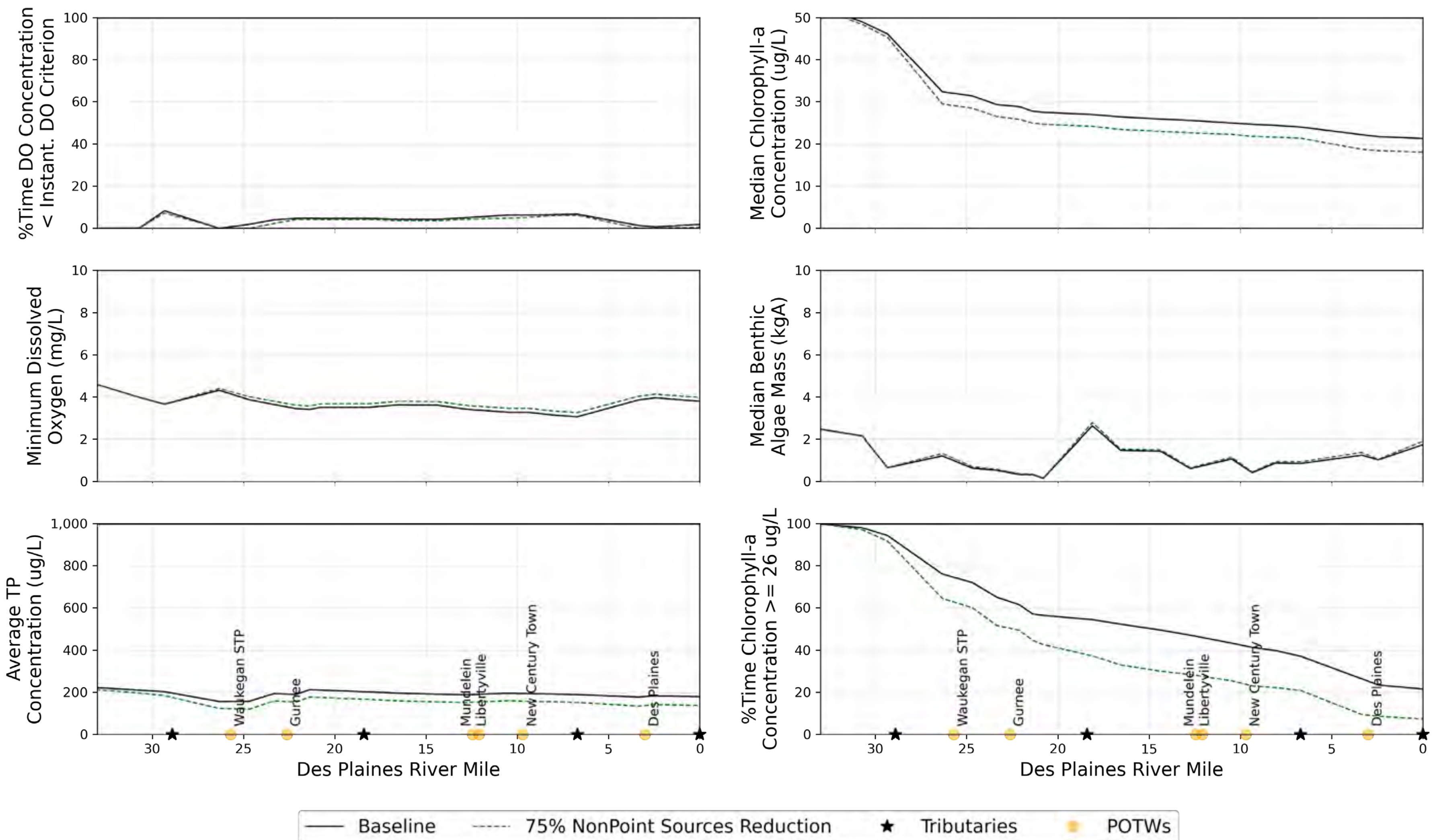



**Figure 33: Tributary Load Reduction Model Results, High Flow Period (May 1–May 31, 2020)**

### 6.2.3 POTW Load Reduction

The impact of load reductions associated with more stringent effluent TP limits for POTWs was simulated by capping the POTW effluent concentrations to 0.5 mg/ L and 0.1 mg/L in the model.

Figure 34 and Figure 35 compare simulated results for the baseline scenario (black solid line), a scenario with POTW effluent TP capped at 0.5 mg/L, and a scenario with POTW effluent TP capped at 0.1 mg/L for the growing season (May–October 2020) and for a high-flow period (May 1–May 31, 2020), respectively. The results show that decreasing POTW TP effluent substantially reduces instream TP downstream of river mile 23. For the scenario with a POTW TP effluent concentration at 0.5 mg/L, the TP loading transported through the system would be reduced by approximately 29%. After the POTW load reduction even at TP effluent of 0.1 mg/L, the reduced instream TP concentrations are still above the critical thresholds to cause nutrient limitation for algae. Hence, the reduction in POTW TP effluent concentration beyond 0.5 mg/L has no major impact on the instream sestonic chlorophyll *a* or DO.

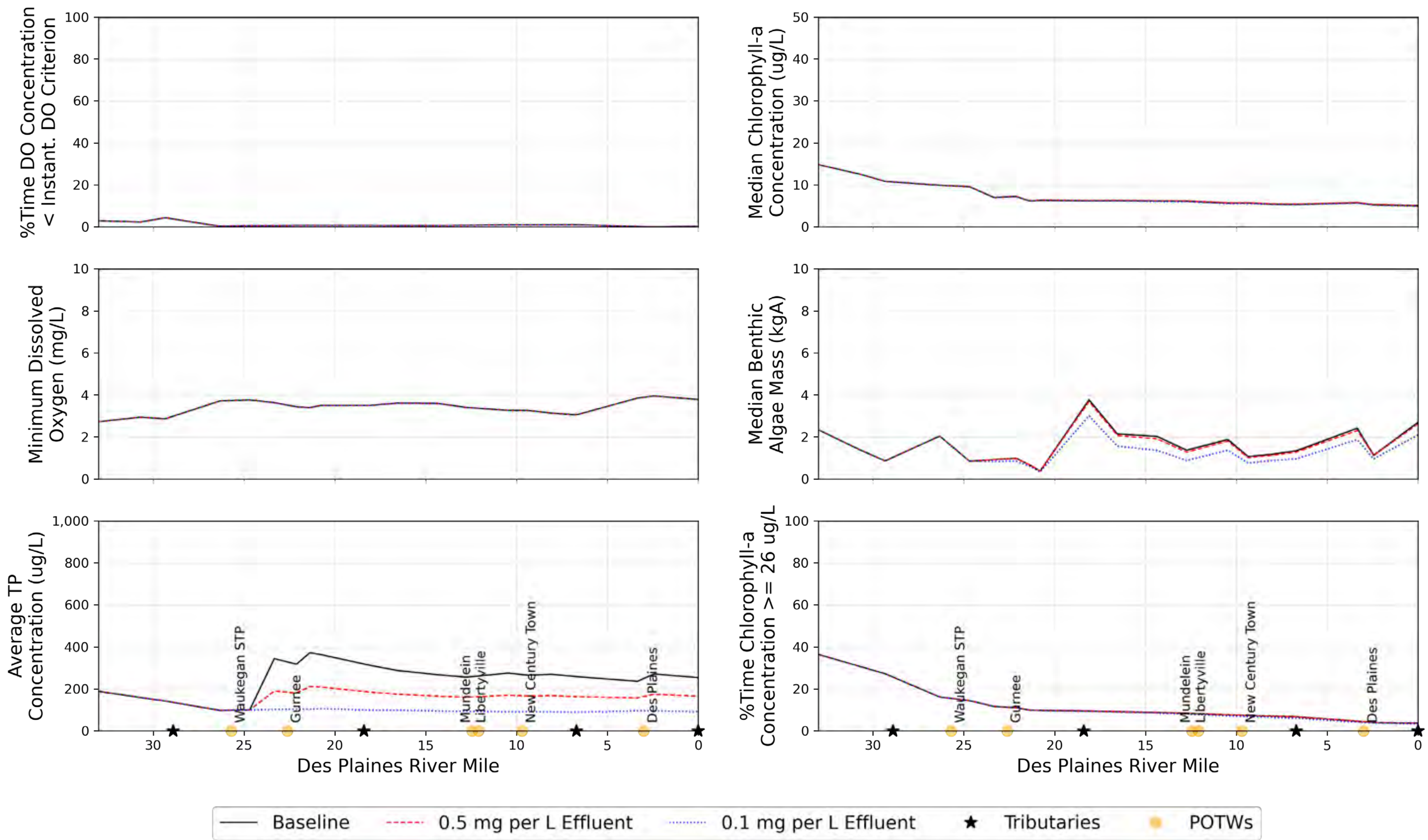



**Figure 34: POTW Load Reduction Model Results, Growing Season (May 1–October 31, 2020)**

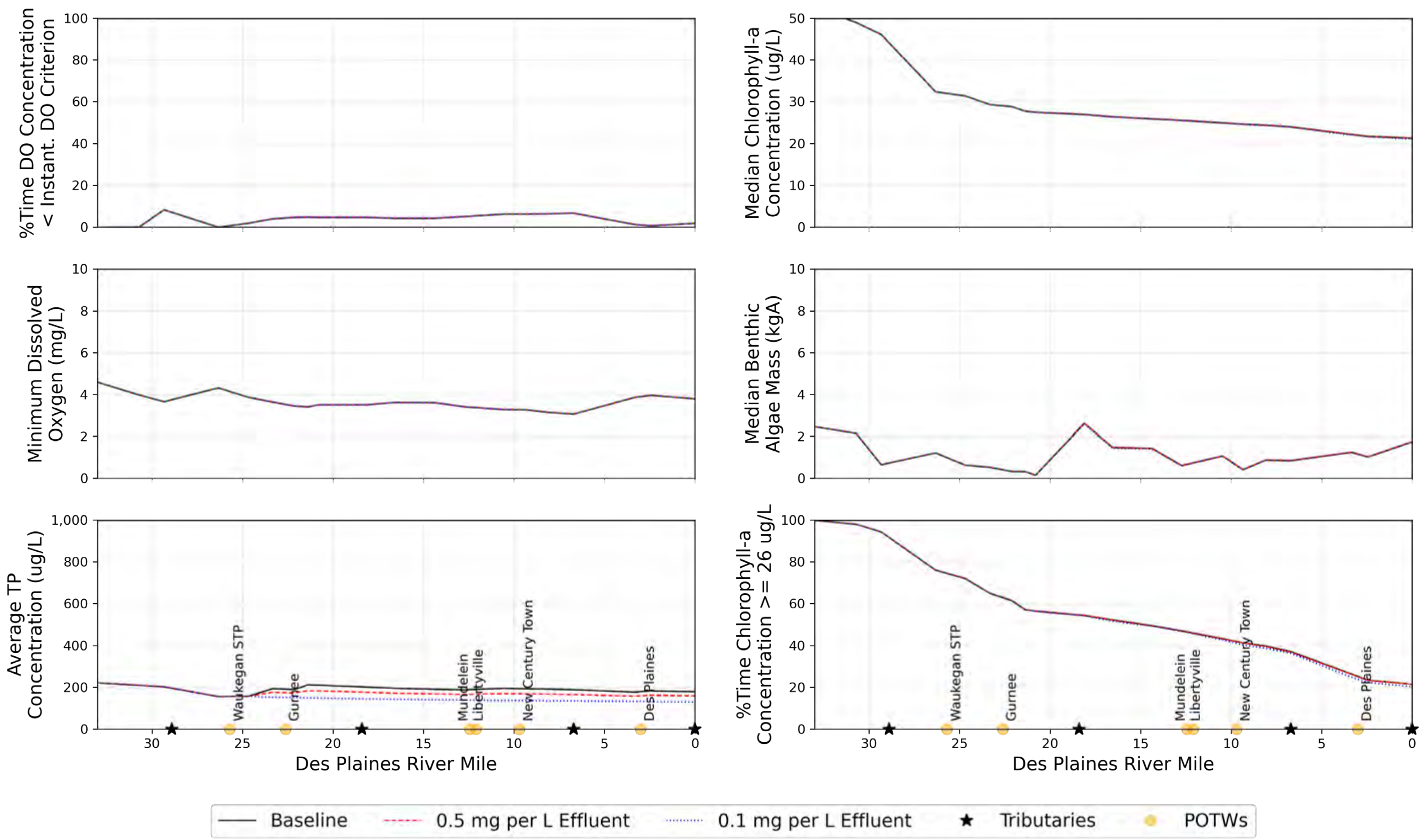



**Figure 35: POTW Load Reduction Model Results, High Flow Period (May 1–May 31, 2020)**

## 6.3 Combined Scenarios Results

A summary of the combined management scenarios is presented below, and details are included in Attachment F. The results of combined scenario for the growing season and high flow period of May 1 to May 31 are shown in **Figure 36** and **Figure 37** respectively. show that combining upstream and nonpoint-source reductions with a 0.5 mg/L POTW effluent limit improves DO by reducing instream TP and sestonic chlorophyll *a*. In addition, further reducing upstream TP and sestonic chlorophyll *a* improves instream DO during high-flow events.

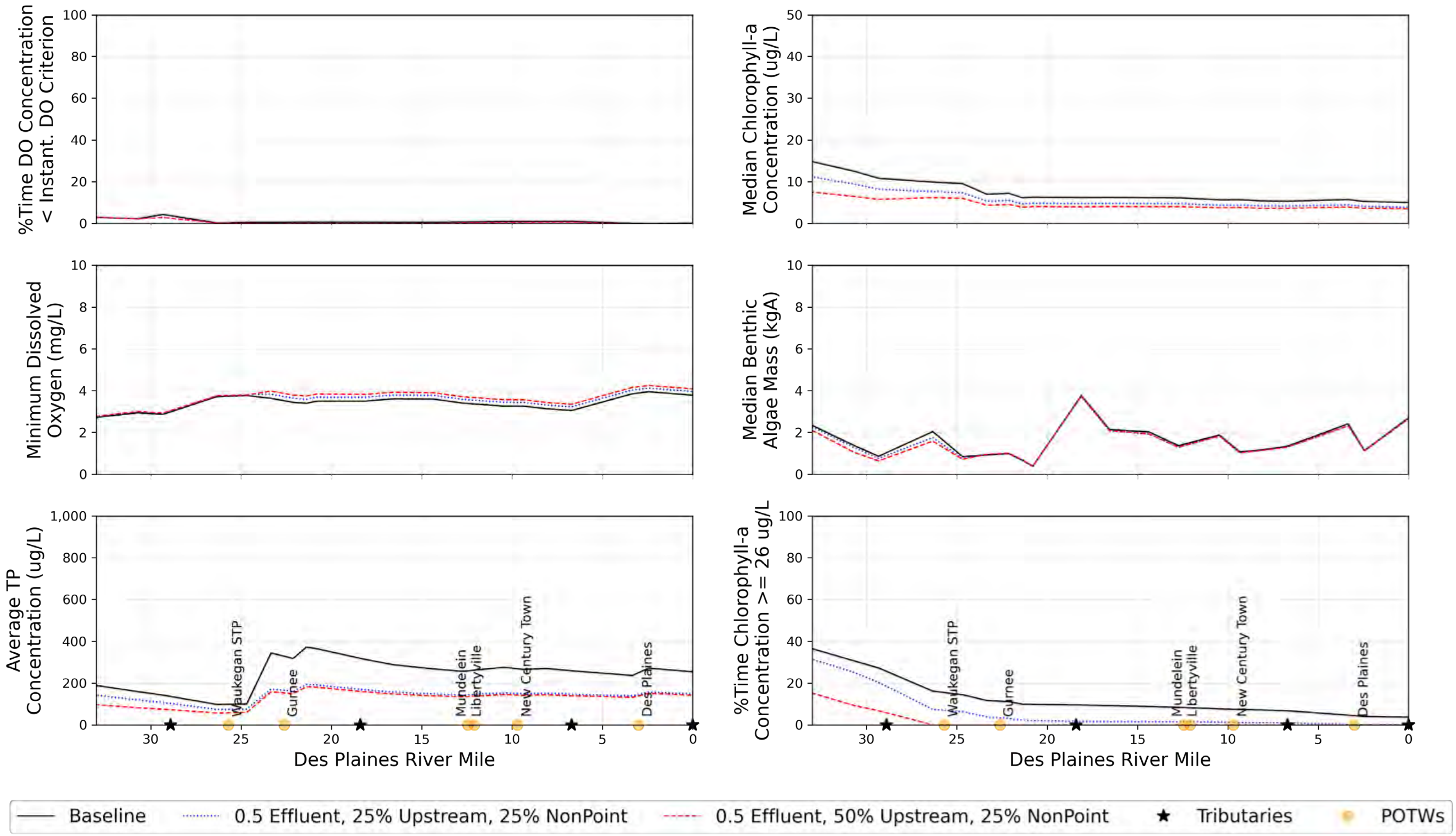



**Figure 32: Combined Scenario Model Results, Growing Season (May 1–October 31) 2020**

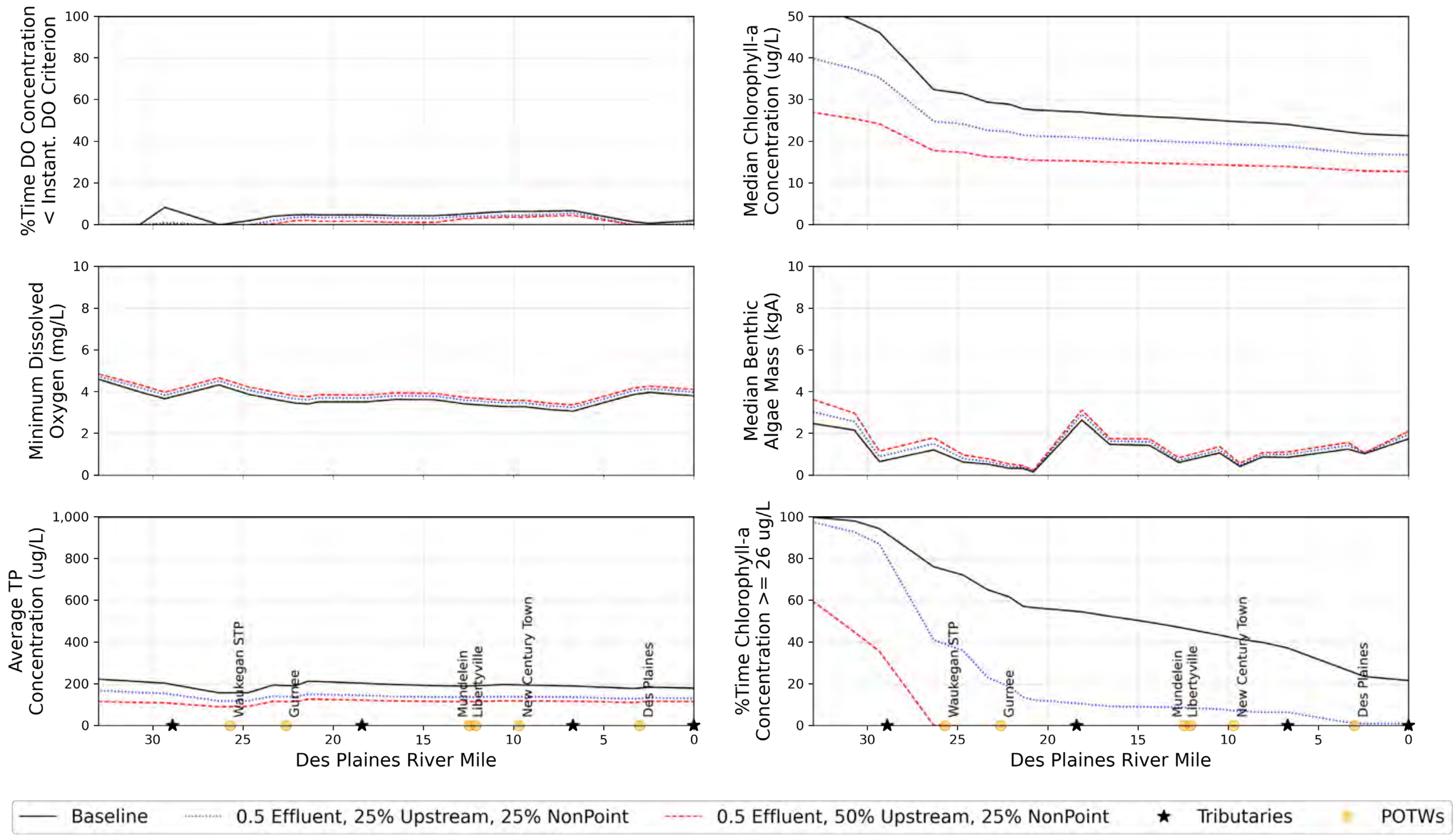



**Figure 33: Combined Scenario Model Results, High Flow Period (May 1–May 31, 2020)**

# 7. SUMMARY AND CONCLUSION

This report documents the development of the instream model for the DRWW NARP. The instream model was calibrated to available flow and water quality data. It was then applied to evaluate the effectiveness of various watershed management actions to improve water quality in the Upper Des Plaines River.

Upstream boundary phosphorus load reductions clearly offer the greatest benefits to water quality in the Des Plaines River. The results of the watershed management scenarios showed that further reducing the TP from the POTWs to below 0.5 mg/L would not substantially improve the water quality in the Des Plaines River. Therefore, a combination of watershed-based strategies, including load reductions from point and nonpoint sources and upstream boundary reductions, is recommended to address the phosphorus-related impairments in the Des Plaines River.

# 8. REFERENCES

Butts, T.A. and Evans, R.L. 1978. Sediment Oxygen Demand Studies for Selected Northeastern Illinois Streams. Illinois State Water Survey

Geosyntec. 2020. Preliminary Nutrient Assessment Reduction Plan Workplan for the Des Plaines, Illinois. Prepared by Geosyntec Consultants for the Des Plaines River Watershed Workgroup. April.

Pelletier, G.J., S.C. Chapra, and H. Tao. 2005. "QUAL2Kw - A framework for modeling water quality in streams and rivers using a genetic algorithm for calibration." *Environmental Modelling & Software* 21(3): 419–425. March.

# Attachment 1
## Model Input Statistics Spreadsheet

**Table A-1: Mainstem Qual2kw Model Flow and Concentrations Input for May to October 2020**

| Reach | Inflow | Flow (cfs) | | | | | | | | Temperature (C ) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Mean | Max | Percentiles | | | | | Min | Mean | Max | Percentiles | | | | |
| | | | | | 5 | 25 | 50 | 75 | 95 | | | | 5 | 25 | 50 | 75 | 95 |
| 0 | HEADWATER | 3.8 | 158.3 | 1637.5 | 7.5 | 15.2 | 35.9 | 124.0 | 801.4 | 3.4 | 18.4 | 33.8 | 8.9 | 13.8 | 18.9 | 23.4 | 27.9 |
| 1 | | 0.4 | 13.2 | 301.9 | 0.6 | 1.2 | 2.0 | 6.5 | 75.1 | 11.4 | 18.4 | 23.8 | 11.4 | 11.8 | 19.5 | 23.0 | 23.8 |
| 2 | | 0.2 | 5.7 | 127.5 | 0.3 | 0.5 | 0.9 | 2.5 | 32.8 | 11.4 | 18.4 | 23.8 | 11.4 | 11.8 | 19.5 | 23.0 | 23.8 |
| 3 | | 0.3 | 9.2 | 210.2 | 0.4 | 0.8 | 1.3 | 5.5 | 51.7 | 11.4 | 18.4 | 23.8 | 11.4 | 11.8 | 19.5 | 23.0 | 23.8 |
| 4 | MILL CREEK | 5.4 | 91.9 | 1299.0 | 6.7 | 17.2 | 32.2 | 71.7 | 401.2 | 4.0 | 19.2 | 31.0 | 8.4 | 13.8 | 19.3 | 25.3 | 28.4 |
| 5 | | 0.3 | 12.2 | 310.7 | 0.4 | 0.9 | 2.2 | 8.3 | 61.6 | 11.4 | 18.4 | 23.8 | 11.4 | 11.8 | 19.5 | 23.0 | 23.8 |
| 6 | NSSD WAUKEGAN STP | 19.8 | 33.2 | 72.4 | 21.9 | 24.1 | 29.6 | 37.1 | 63.0 | 10.8 | 16.9 | 21.6 | 10.8 | 14.1 | 18.0 | 20.0 | 20.8 |
| 7 | | 0.1 | 12.5 | 373.3 | 0.2 | 0.4 | 1.1 | 5.5 | 62.9 | 11.4 | 18.4 | 23.8 | 11.4 | 11.8 | 19.5 | 23.0 | 23.8 |
| 8 | NSSD GURNEE | 14.9 | 21.8 | 69.1 | 15.5 | 16.9 | 18.6 | 22.6 | 39.4 | 12.1 | 18.7 | 23.8 | 12.1 | 15.6 | 19.9 | 21.7 | 23.0 |
| 9 | | 0.2 | 7.7 | 187.5 | 0.2 | 0.6 | 1.1 | 5.3 | 37.4 | 11.4 | 18.4 | 23.8 | 11.4 | 11.8 | 19.5 | 23.0 | 23.8 |
| 10 | | 0.3 | 12.4 | 310.8 | 0.5 | 0.9 | 2.0 | 8.5 | 61.8 | 11.4 | 18.4 | 23.8 | 11.4 | 11.8 | 19.5 | 23.0 | 23.8 |
| 11 | | 0.4 | 19.4 | 548.1 | 0.5 | 1.2 | 2.5 | 10.6 | 94.7 | 11.4 | 18.4 | 23.8 | 11.4 | 11.8 | 19.5 | 23.0 | 23.8 |
| 12 | | 0.3 | 9.0 | 222.1 | 0.3 | 0.6 | 1.3 | 5.6 | 42.7 | 11.4 | 18.4 | 23.8 | 11.4 | 11.8 | 19.5 | 23.0 | 23.8 |
| 13 | | 0.0 | 2.9 | 83.9 | 0.0 | 0.1 | 0.3 | 1.4 | 13.3 | 11.4 | 18.4 | 23.8 | 11.4 | 11.8 | 19.5 | 23.0 | 23.8 |
| 14 | LIBERTYVILLE & MUNDELEIN | 5.9 | 10.7 | 59.2 | 6.2 | 7.0 | 8.6 | 10.8 | 23.9 | 11.0 | 18.1 | 24.3 | 11.5 | 14.6 | 19.1 | 21.6 | 22.9 |
| 15 | | 0.3 | 10.6 | 336.5 | 0.4 | 0.7 | 1.4 | 7.9 | 42.0 | 11.4 | 18.4 | 23.8 | 11.4 | 11.8 | 19.5 | 23.0 | 23.8 |
| 16 | LCDPW-NEW CENTURY TOWN | 3.3 | 4.9 | 19.4 | 3.6 | 4.1 | 4.5 | 4.9 | 7.0 | 11.1 | 18.5 | 26.1 | 11.1 | 13.9 | 19.4 | 22.7 | 24.4 |
| 17 | | 0.2 | 5.6 | 174.8 | 0.2 | 0.4 | 0.7 | 3.2 | 27.5 | 11.4 | 18.4 | 23.8 | 11.4 | 11.8 | 19.5 | 23.0 | 23.8 |
| 18 | | 2.3 | 78.2 | 1318.7 | 3.1 | 6.5 | 16.5 | 52.3 | 351.8 | 11.4 | 18.4 | 23.8 | 11.4 | 11.8 | 19.5 | 23.0 | 23.8 |
| 19 | LCDPW-DES PLAINES | 9.3 | 15.3 | 50.8 | 10.7 | 11.9 | 13.3 | 15.1 | 30.5 | 11.1 | 18.5 | 26.1 | 11.1 | 13.9 | 19.4 | 22.7 | 24.4 |
| 20 | | 0.0 | 4.1 | 123.9 | 0.1 | 0.2 | 0.4 | 2.1 | 20.9 | 11.4 | 18.4 | 23.8 | 11.4 | 11.8 | 19.5 | 23.0 | 23.8 |

**Table A-1: Mainstem Qual2kw Model Flow and Concentrations Input for May to October 2020**

| Reach | Inflow | Total Suspended Solids (mg/L) | | | | | | | | Dissolved Oxygen (mg/L) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Mean | Max | Percentiles | | | | | Min | Mean | Max | Percentiles | | | | |
| | | | | | 5 | 25 | 50 | 75 | 95 | | | | 5 | 25 | 50 | 75 | 95 |
| 0 | HEADWATER | 3.2 | 16.9 | 502.2 | 3.7 | 6.1 | 8.2 | 11.7 | 19.8 | 2.7 | 7.7 | 16.7 | 4.4 | 5.8 | 7.2 | 9.2 | 12.0 |
| 1 | | 0.0 | 78.5 | 3786.5 | 0.0 | 0.0 | 0.0 | 2.5 | 252.1 | 5.0 | 7.2 | 10.0 | 5.0 | 5.0 | 5.0 | 10.0 | 10.0 |
| 2 | | 0.0 | 144.6 | 7947.1 | 0.0 | 0.0 | 0.0 | 4.4 | 366.4 | 5.0 | 7.2 | 10.0 | 5.0 | 5.0 | 5.0 | 10.0 | 10.0 |
| 3 | | 0.0 | 115.9 | 5582.9 | 0.0 | 0.0 | 0.0 | 7.7 | 465.8 | 5.0 | 7.2 | 10.0 | 5.0 | 5.0 | 5.0 | 10.0 | 10.0 |
| 4 | MILL CREEK | 0.5 | 25.9 | 1061.9 | 1.3 | 4.7 | 8.0 | 15.1 | 101.2 | 5.8 | 8.2 | 10.6 | 7.0 | 7.7 | 8.2 | 8.7 | 9.6 |
| 5 | | 0.0 | 70.4 | 1947.9 | 0.0 | 0.0 | 0.0 | 0.0 | 412.2 | 5.0 | 7.2 | 10.0 | 5.0 | 5.0 | 5.0 | 10.0 | 10.0 |
| 6 | NSSD WAUKEGAN STP | 0.5 | 1.0 | 4.0 | 0.5 | 0.6 | 0.8 | 1.1 | 1.9 | 8.7 | 10.1 | 11.7 | 8.7 | 9.2 | 9.9 | 10.7 | 11.7 |
| 7 | | 0.0 | 37.0 | 458.8 | 0.0 | 0.0 | 0.0 | 0.0 | 223.9 | 5.0 | 7.2 | 10.0 | 5.0 | 5.0 | 5.0 | 10.0 | 10.0 |
| 8 | NSSD GURNEE | 0.5 | 1.2 | 5.0 | 0.5 | 0.6 | 1.0 | 1.5 | 3.0 | 6.6 | 8.2 | 11.7 | 6.6 | 7.3 | 8.1 | 9.3 | 9.9 |
| 9 | | 0.0 | 82.1 | 1261.9 | 0.0 | 0.0 | 0.0 | 26.3 | 450.4 | 5.0 | 7.2 | 10.0 | 5.0 | 5.0 | 5.0 | 10.0 | 10.0 |
| 10 | | 0.0 | 56.9 | 1366.0 | 0.0 | 0.0 | 0.0 | 8.1 | 294.5 | 5.0 | 7.2 | 10.0 | 5.0 | 5.0 | 5.0 | 10.0 | 10.0 |
| 11 | | 4.5 | 20.3 | 99.5 | 5.4 | 8.5 | 12.0 | 30.4 | 52.8 | 5.0 | 7.2 | 10.0 | 5.0 | 5.0 | 5.0 | 10.0 | 10.0 |
| 12 | | 0.0 | 47.1 | 1072.8 | 0.0 | 0.0 | 0.0 | 21.6 | 223.6 | 5.0 | 7.2 | 10.0 | 5.0 | 5.0 | 5.0 | 10.0 | 10.0 |
| 13 | | 0.0 | 64.3 | 824.0 | 0.0 | 0.0 | 0.0 | 0.0 | 381.2 | 5.0 | 7.2 | 10.0 | 5.0 | 5.0 | 5.0 | 10.0 | 10.0 |
| 14 | LIBERTYVILLE & MUNDELEIN | 0.5 | 2.7 | 21.4 | 0.7 | 1.1 | 1.3 | 3.1 | 9.2 | 5.2 | 7.0 | 8.8 | 5.5 | 6.1 | 6.8 | 7.8 | 8.8 |
| 15 | | 0.0 | 73.1 | 3413.2 | 0.0 | 0.0 | 0.0 | 0.5 | 283.1 | 5.0 | 7.2 | 10.0 | 5.0 | 5.0 | 5.0 | 10.0 | 10.0 |
| 16 | LCDPW-NEW CENTURY TOWN | 0.7 | 1.9 | 15.8 | 0.7 | 1.1 | 1.4 | 2.1 | 4.3 | 5.8 | 7.4 | 9.3 | 5.8 | 6.6 | 7.3 | 8.1 | 9.0 |
| 17 | | 0.0 | 67.2 | 2267.8 | 0.0 | 0.0 | 0.0 | 0.0 | 327.1 | 5.0 | 7.2 | 10.0 | 5.0 | 5.0 | 5.0 | 10.0 | 10.0 |
| 18 | | 4.3 | 33.2 | 234.3 | 5.7 | 8.9 | 14.3 | 29.0 | 165.4 | 5.0 | 7.2 | 10.0 | 5.0 | 5.0 | 5.0 | 10.0 | 10.0 |
| 19 | LCDPW-DES PLAINES | 0.7 | 1.2 | 3.4 | 0.7 | 0.7 | 1.0 | 1.5 | 2.3 | 7.7 | 9.2 | 10.7 | 7.7 | 8.5 | 9.2 | 10.0 | 10.7 |
| 20 | | 0.0 | 82.0 | 1184.1 | 0.0 | 0.0 | 0.0 | 2.4 | 541.6 | 5.0 | 7.2 | 10.0 | 5.0 | 5.0 | 5.0 | 10.0 | 10.0 |

**Table A-1: Mainstem Qual2kw Model Flow and Concentrations Input for May to October 2020**

| Reach | Inflow | CBOD (mg/L) | | | | | | | | Organic Nitrogen (ug/L) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Mean | Max | Percentiles | | | | | Min | Mean | Max | Percentiles | | | | |
| | | | | | 5 | 25 | 50 | 75 | 95 | | | | 5 | 25 | 50 | 75 | 95 |
| 0 | HEADWATER | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 1,050 | 1,360 | 2,060 | 1,050 | 1,050 | 1,320 | 1,512 | 1,950 |
| 1 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 425 | 11,068 | 0 | 0 | 20 | 419 | 2,546 |
| 2 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 427 | 13,273 | 0 | 0 | 27 | 226 | 2,888 |
| 3 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 350 | 8,844 | 0 | 0 | 6 | 297 | 1,355 |
| 4 | MILL CREEK | 0.0 | 0.3 | 2.4 | 0.0 | 0.1 | 0.1 | 0.3 | 0.9 | 155 | 792 | 7,266 | 219 | 446 | 580 | 911 | 1,806 |
| 5 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 491 | 5,471 | 0 | 0 | 84 | 818 | 1,846 |
| 6 | NSSD WAUKEGAN STP | 0.5 | 0.6 | 3.2 | 0.5 | 0.5 | 0.5 | 0.5 | 1.2 | 450 | 1,087 | 2,070 | 576 | 980 | 1,047 | 1,217 | 1,658 |
| 7 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 526 | 3,347 | 0 | 0 | 153 | 918 | 2,051 |
| 8 | NSSD GURNEE | 0.5 | 0.6 | 4.0 | 0.5 | 0.5 | 0.5 | 0.5 | 1.3 | 750 | 1,277 | 2,250 | 818 | 1,020 | 1,310 | 1,361 | 2,051 |
| 9 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 693 | 3,989 | 0 | 0 | 261 | 1,213 | 2,419 |
| 10 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 381 | 4,209 | 0 | 0 | 18 | 615 | 1,494 |
| 11 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 450 | 2,640 | 25 | 74 | 134 | 764 | 1,566 |
| 12 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 348 | 4,074 | 0 | 29 | 89 | 554 | 1,226 |
| 13 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 457 | 3,212 | 0 | 0 | 39 | 810 | 1,906 |
| 14 | LIBERTYVILLE & MUNDELEIN | 0.8 | 2.1 | 4.3 | 1.0 | 1.7 | 2.1 | 2.4 | 2.9 | 14,299 | 18,739 | 22,144 | 15,287 | 16,712 | 19,638 | 20,290 | 20,984 |
| 15 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 496 | 6,971 | 0 | 0 | 83 | 794 | 2,088 |
| 16 | LCDPW-NEW CENTURY TOWN | 1.0 | 1.7 | 4.8 | 1.0 | 1.0 | 1.3 | 2.3 | 3.4 | 1,225 | 4,615 | 6,575 | 2,171 | 4,115 | 4,932 | 5,309 | 5,695 |
| 17 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 349 | 7,763 | 0 | 0 | 5 | 372 | 1,393 |
| 18 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 503 | 2,011 | 11 | 40 | 390 | 868 | 1,388 |
| 19 | LCDPW-DES PLAINES | 1.0 | 1.3 | 6.2 | 1.0 | 1.0 | 1.0 | 1.6 | 2.5 | 450 | 1,087 | 2,070 | 576 | 980 | 1,047 | 1,217 | 1,658 |
| 20 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 530 | 4,655 | 0 | 0 | 86 | 911 | 2,186 |

**Table A-1: Mainstem Qual2kw Model Flow and Concentrations Input for May to October 2020**

| Reach | Inflow | Ammonia (ug/L) | | | | | | | | Nitrate-Nitrite (ug/L) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Mean | Max | Percentiles | | | | | Min | Mean | Max | Percentiles | | | | |
| | | | | | 5 | 25 | 50 | 75 | 95 | | | | 5 | 25 | 50 | 75 | 95 |
| 0 | HEADWATER | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 127 | 614 | 865 | 193 | 354 | 758 | 865 | 865 |
| 1 | | 0 | 24 | 273 | 0 | 3 | 7 | 26 | 111 | 58 | 1,276 | 58,214 | 112 | 260 | 535 | 983 | 3,090 |
| 2 | | 0 | 4 | 100 | 0 | 0 | 0 | 3 | 24 | 0 | 847 | 18,029 | 88 | 219 | 455 | 1,029 | 2,157 |
| 3 | | 0 | 4 | 57 | 0 | 0 | 1 | 4 | 18 | 5 | 1,046 | 49,421 | 42 | 172 | 386 | 833 | 2,501 |
| 4 | MILL CREEK | 14 | 73 | 678 | 26 | 41 | 59 | 88 | 133 | 36 | 912 | 2,538 | 446 | 582 | 779 | 1,149 | 1,818 |
| 5 | | 0 | 48 | 381 | 0 | 3 | 8 | 76 | 204 | 69 | 1,500 | 55,857 | 111 | 261 | 520 | 1,147 | 4,777 |
| 6 | NSSD WAUKEGAN STP | 50 | 56 | 190 | 50 | 50 | 50 | 50 | 105 | 3,570 | 14,294 | 20,500 | 6,455 | 11,827 | 15,484 | 16,683 | 19,243 |
| 7 | | 0 | 2 | 101 | 0 | 0 | 0 | 0 | 8 | 0 | 1,620 | 42,142 | 91 | 265 | 502 | 1,336 | 5,263 |
| 8 | NSSD GURNEE | 50 | 53 | 160 | 50 | 50 | 50 | 50 | 66 | 5,310 | 18,466 | 24,400 | 9,061 | 15,028 | 19,963 | 22,150 | 23,756 |
| 9 | | 0 | 25 | 262 | 0 | 0 | 9 | 20 | 135 | 0 | 1,607 | 35,287 | 129 | 323 | 606 | 1,692 | 5,208 |
| 10 | | 0 | 3 | 41 | 0 | 0 | 0 | 3 | 17 | 0 | 1,836 | 95,579 | 124 | 287 | 569 | 1,216 | 4,919 |
| 11 | | 0 | 32 | 135 | 0 | 14 | 26 | 42 | 99 | 104 | 1,249 | 31,925 | 196 | 273 | 579 | 1,135 | 4,209 |
| 12 | | 0 | 3 | 39 | 0 | 0 | 0 | 3 | 12 | 128 | 1,944 | 51,020 | 232 | 641 | 1,070 | 1,647 | 4,712 |
| 13 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,434 | 34,574 | 0 | 77 | 434 | 1,235 | 5,787 |
| 14 | LIBERTYVILLE & MUNDELEIN | 14 | 816 | 6,927 | 28 | 129 | 322 | 800 | 4,245 | 14,438 | 20,669 | 32,135 | 15,463 | 17,286 | 19,259 | 23,285 | 30,325 |
| 15 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 37 | 1,283 | 32,339 | 158 | 456 | 772 | 1,157 | 3,472 |
| 16 | LCDPW-NEW CENTURY TOWN | 75 | 142 | 4,650 | 75 | 75 | 75 | 75 | 170 | 3,300 | 5,420 | 7,230 | 4,121 | 5,190 | 5,509 | 5,773 | 6,301 |
| 17 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,254 | 94,866 | 0 | 105 | 372 | 772 | 2,514 |
| 18 | | 0 | 70 | 290 | 3 | 21 | 45 | 109 | 212 | 153 | 1,912 | 48,591 | 290 | 409 | 685 | 1,336 | 4,746 |
| 19 | LCDPW-DES PLAINES | 75 | 76 | 150 | 75 | 75 | 75 | 75 | 75 | 4,910 | 7,337 | 9,860 | 5,596 | 6,733 | 7,399 | 7,890 | 8,939 |
| 20 | | 0 | 4 | 116 | 0 | 0 | 0 | 2 | 15 | 0 | 1,078 | 54,219 | 0 | 142 | 376 | 843 | 3,346 |

**Table A-1: Mainstem Qual2kw Model Flow and Concentrations Input for May to October 2020**

| Reach | Inflow | Organic Phosphorus (ug/L) | | | | | | | | Inorganic Phosphorus (ug/L) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Mean | Max | Percentiles | | | | | Min | Mean | Max | Percentiles | | | | |
| | | | | | 5 | 25 | 50 | 75 | 95 | | | | 5 | 25 | 50 | 75 | 95 |
| 0 | HEADWATER | 21 | 152 | 279 | 97 | 97 | 107 | 221 | 276 | 43 | 68 | 89 | 43 | 48 | 69 | 89 | 89 |
| 1 | | 0 | 32 | 509 | 0 | 0 | 2 | 38 | 126 | 0 | 29 | 143 | 0 | 0 | 2 | 52 | 121 |
| 2 | | 0 | 37 | 786 | 0 | 0 | 1 | 26 | 167 | 0 | 16 | 113 | 0 | 0 | 1 | 17 | 87 |
| 3 | | 0 | 46 | 468 | 0 | 0 | 2 | 59 | 231 | 0 | 28 | 170 | 0 | 0 | 1 | 38 | 137 |
| 4 | MILL CREEK | 15 | 35 | 186 | 19 | 26 | 33 | 41 | 57 | 3 | 25 | 61 | 10 | 16 | 25 | 32 | 45 |
| 5 | | 0 | 68 | 450 | 0 | 0 | 9 | 119 | 305 | 0 | 60 | 354 | 0 | 0 | 13 | 118 | 209 |
| 6 | NSSD WAUKEGAN STP | 60 | 519 | 2,310 | 110 | 241 | 400 | 690 | 1,370 | 60 | 519 | 2,310 | 110 | 241 | 400 | 690 | 1,370 |
| 7 | | 0 | 76 | 572 | 0 | 0 | 20 | 125 | 320 | 0 | 46 | 234 | 0 | 0 | 15 | 91 | 164 |
| 8 | NSSD GURNEE | 85 | 452 | 2,275 | 152 | 250 | 411 | 587 | 866 | 85 | 452 | 2,275 | 152 | 250 | 411 | 587 | 866 |
| 9 | | 0 | 140 | 877 | 0 | 1 | 43 | 241 | 520 | 0 | 76 | 420 | 0 | 0 | 31 | 135 | 252 |
| 10 | | 0 | 54 | 364 | 0 | 0 | 3 | 87 | 218 | 0 | 40 | 190 | 0 | 0 | 5 | 75 | 157 |
| 11 | | 0 | 59 | 354 | 2 | 3 | 11 | 99 | 233 | 0 | 55 | 235 | 1 | 7 | 20 | 104 | 184 |
| 12 | | 0 | 48 | 317 | 0 | 2 | 7 | 89 | 193 | 0 | 40 | 180 | 0 | 1 | 10 | 78 | 142 |
| 13 | | 0 | 99 | 844 | 0 | 0 | 10 | 154 | 429 | 0 | 54 | 341 | 0 | 0 | 0 | 108 | 218 |
| 14 | LIBERTYVILLE & MUNDELEIN | 300 | 456 | 533 | 342 | 439 | 473 | 484 | 503 | 300 | 456 | 533 | 342 | 439 | 473 | 484 | 503 |
| 15 | | 0 | 82 | 659 | 0 | 0 | 12 | 133 | 384 | 0 | 38 | 261 | 0 | 0 | 7 | 69 | 166 |
| 16 | LCDPW-NEW CENTURY TOWN | 50 | 334 | 3,380 | 66 | 138 | 276 | 441 | 720 | 50 | 334 | 3,380 | 66 | 138 | 276 | 441 | 720 |
| 17 | | 0 | 59 | 496 | 0 | 0 | 2 | 78 | 281 | 0 | 40 | 224 | 0 | 0 | 0 | 61 | 186 |
| 18 | | 0 | 70 | 370 | 0 | 3 | 48 | 109 | 256 | 0 | 82 | 303 | 4 | 9 | 73 | 139 | 199 |
| 19 | LCDPW-DES PLAINES | 100 | 431 | 1,715 | 144 | 244 | 360 | 541 | 984 | 100 | 431 | 1,715 | 144 | 244 | 360 | 541 | 984 |
| 20 | | 0 | 114 | 923 | 0 | 0 | 19 | 194 | 448 | 0 | 63 | 365 | 0 | 0 | 16 | 110 | 207 |

**Table A-1: Mainstem Qual2kw Model Flow and Concentrations Input for May to October 2020**

| Reach | Inflow | Chlorophyll-a (ug/L) | | | | | | | | pH | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Mean | Max | Percentiles | | | | | Min | Mean | Max | Percentiles | | | | |
| | | | | | 5 | 25 | 50 | 75 | 95 | | | | 5 | 25 | 50 | 75 | 95 |
| 0 | HEADWATER | 6.5 | 36.0 | 95.8 | 7.8 | 11.8 | 34.9 | 60.0 | 60.0 | 7.4 | 7.9 | 9.0 | 7.5 | 7.5 | 7.8 | 8.2 | 8.5 |
| 1 | | 4.0 | 10.9 | 12.6 | 4.0 | 9.3 | 12.6 | 12.6 | 12.6 | 7.7 | 7.8 | 7.9 | 7.7 | 7.8 | 7.8 | 7.9 | 7.9 |
| 2 | | 4.0 | 10.9 | 12.6 | 4.0 | 9.3 | 12.6 | 12.6 | 12.6 | 7.7 | 7.8 | 7.9 | 7.7 | 7.8 | 7.8 | 7.9 | 7.9 |
| 3 | | 4.0 | 10.9 | 12.6 | 4.0 | 9.3 | 12.6 | 12.6 | 12.6 | 7.7 | 7.8 | 7.9 | 7.7 | 7.8 | 7.8 | 7.9 | 7.9 |
| 4 | MILL CREEK | 0.5 | 9.1 | 39.1 | 1.0 | 4.9 | 8.0 | 12.2 | 20.3 | 7.8 | 8.5 | 9.5 | 8.0 | 8.2 | 8.6 | 8.8 | 9.3 |
| 5 | | 4.0 | 10.9 | 12.6 | 4.0 | 9.3 | 12.6 | 12.6 | 12.6 | 7.7 | 7.8 | 7.9 | 7.7 | 7.8 | 7.8 | 7.9 | 7.9 |
| 6 | NSSD WAUKEGAN STP | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.6 | 7.0 | 7.5 | 6.7 | 6.9 | 6.9 | 7.1 | 7.3 |
| 7 | | 4.0 | 10.9 | 12.6 | 4.0 | 9.3 | 12.6 | 12.6 | 12.6 | 7.7 | 7.8 | 7.9 | 7.7 | 7.8 | 7.8 | 7.9 | 7.9 |
| 8 | NSSD GURNEE | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.7 | 7.0 | 7.5 | 6.9 | 7.0 | 7.1 | 7.1 | 7.2 |
| 9 | | 4.0 | 10.9 | 12.6 | 4.0 | 9.3 | 12.6 | 12.6 | 12.6 | 7.7 | 7.8 | 7.9 | 7.7 | 7.8 | 7.8 | 7.9 | 7.9 |
| 10 | | 4.0 | 10.9 | 12.6 | 4.0 | 9.3 | 12.6 | 12.6 | 12.6 | 7.7 | 7.8 | 7.9 | 7.7 | 7.8 | 7.8 | 7.9 | 7.9 |
| 11 | | 4.0 | 10.9 | 12.6 | 4.0 | 9.3 | 12.6 | 12.6 | 12.6 | 7.7 | 7.8 | 7.9 | 7.7 | 7.8 | 7.8 | 7.9 | 7.9 |
| 12 | | 4.0 | 10.9 | 12.6 | 4.0 | 9.3 | 12.6 | 12.6 | 12.6 | 7.7 | 7.8 | 7.9 | 7.7 | 7.8 | 7.8 | 7.9 | 7.9 |
| 13 | | 4.0 | 10.9 | 12.6 | 4.0 | 9.3 | 12.6 | 12.6 | 12.6 | 7.7 | 7.8 | 7.9 | 7.7 | 7.8 | 7.8 | 7.9 | 7.9 |
| 14 | LIBERTYVILLE & MUNDELEIN | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.0 | 7.3 | 7.6 | 7.1 | 7.3 | 7.3 | 7.4 | 7.5 |
| 15 | | 4.0 | 10.9 | 12.6 | 4.0 | 9.3 | 12.6 | 12.6 | 12.6 | 7.7 | 7.8 | 7.9 | 7.7 | 7.8 | 7.8 | 7.9 | 7.9 |
| 16 | LCDPW-NEW CENTURY TOWN | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.8 | 7.4 | 8.3 | 7.1 | 7.3 | 7.4 | 7.6 | 7.7 |
| 17 | | 4.0 | 10.9 | 12.6 | 4.0 | 9.3 | 12.6 | 12.6 | 12.6 | 7.7 | 7.8 | 7.9 | 7.7 | 7.8 | 7.8 | 7.9 | 7.9 |
| 18 | | 4.0 | 10.9 | 12.6 | 4.0 | 9.3 | 12.6 | 12.6 | 12.6 | 7.7 | 7.8 | 7.9 | 7.7 | 7.8 | 7.8 | 7.9 | 7.9 |
| 19 | LCDPW-DES PLAINES | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.9 | 7.8 | 8.4 | 7.5 | 7.8 | 7.8 | 7.9 | 8.0 |
| 20 | | 4.0 | 10.9 | 12.6 | 4.0 | 9.3 | 12.6 | 12.6 | 12.6 | 7.7 | 7.8 | 7.9 | 7.7 | 7.8 | 7.8 | 7.9 | 7.9 |

**Table A-2: Mill Creek Qual2kw Model Flow and Concentrations Input for May to October 2020**

| Reach | Inflow | Flow (cfs) | | | | | | | | Temperature (C ) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Mean | Max | Percentiles | | | | | Min | Mean | Max | Percentiles | | | | |
| | | | | | 5 | 25 | 50 | 75 | 95 | | | | 5 | 25 | 50 | 75 | 95 |
| 0 | HEADWATER | 0.1 | 5.5 | 103.8 | 0.2 | 0.5 | 2.6 | 5.4 | 23.3 | 6.0 | 17.1 | 26.3 | 6.0 | 9.8 | 17.7 | 22.5 | 26.3 |
| 1 | LINDENHURST STP | 1.0 | 1.9 | 7.9 | 1.3 | 1.5 | 1.7 | 2.0 | 3.1 | 12.2 | 17.5 | 21.7 | 12.2 | 15.0 | 18.3 | 21.1 | 21.7 |
| 2 | | 0.1 | 2.5 | 55.1 | 0.1 | 0.2 | 0.3 | 1.3 | 14.2 | 8.6 | 18.9 | 24.3 | 8.6 | 17.0 | 20.4 | 23.0 | 24.3 |
| 3 | | 0.1 | 2.0 | 40.5 | 0.1 | 0.2 | 0.3 | 0.7 | 12.1 | 8.6 | 18.9 | 24.3 | 8.6 | 17.0 | 20.4 | 23.0 | 24.3 |
| 4 | | 1.1 | 28.1 | 335.8 | 1.4 | 3.5 | 7.4 | 21.9 | 129.8 | 3.5 | 17.5 | 29.6 | 7.4 | 10.9 | 15.9 | 22.4 | 29.6 |
| 5 | | 0.1 | 3.9 | 87.5 | 0.2 | 0.3 | 0.5 | 2.1 | 20.8 | 8.6 | 18.9 | 24.3 | 8.6 | 17.0 | 20.4 | 23.0 | 24.3 |
| 6 | | 0.1 | 2.6 | 58.3 | 0.1 | 0.2 | 0.3 | 1.4 | 13.9 | 8.6 | 18.9 | 24.3 | 8.6 | 17.0 | 20.4 | 23.0 | 24.3 |
| 7 | | 1.0 | 36.9 | 463.3 | 1.6 | 6.0 | 14.3 | 30.4 | 168.4 | 3.1 | 18.5 | 27.1 | 7.5 | 12.2 | 17.8 | 26.1 | 27.1 |
| 8 | FIRST IMPOUNDMENT | 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 |
| 9 | | 0.0 | 0.1 | 1.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 8.6 | 18.9 | 24.3 | 8.6 | 17.0 | 20.4 | 23.0 | 24.3 |
| 10 | | 0.1 | 3.9 | 96.9 | 0.1 | 0.3 | 0.5 | 1.8 | 22.5 | 8.6 | 18.9 | 24.3 | 8.6 | 17.0 | 20.4 | 23.0 | 24.3 |
| 11 | SECOND IMPOUNDMENT | 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 |
| 12 | | 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 |
| 13 | | 0.0 | 1.0 | 24.2 | 0.0 | 0.1 | 0.1 | 0.5 | 5.6 | 8.6 | 18.9 | 24.3 | 8.6 | 17.0 | 20.4 | 23.0 | 24.3 |
| 14 | MILL CREEK WRF | 0.8 | 1.4 | 5.1 | 0.9 | 1.0 | 1.2 | 1.5 | 2.4 | 12.2 | 17.5 | 21.7 | 12.2 | 15.0 | 18.3 | 21.1 | 21.7 |
| 15 | | 0.0 | 1.0 | 26.1 | 0.0 | 0.1 | 0.1 | 0.5 | 4.9 | 8.6 | 18.9 | 24.3 | 8.6 | 17.0 | 20.4 | 23.0 | 24.3 |

**Table A-2: Mill Creek Qual2kw Model Flow and Concentrations Input for May to October 2020**

| Reach | Inflow | Total Suspended Solids (mg/L) | | | | | | | | Dissolved Oxygen (mg/L) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Mean | Max | Percentiles | | | | | Min | Mean | Max | Percentiles | | | | |
| | | | | | 5 | 25 | 50 | 75 | 95 | | | | 5 | 25 | 50 | 75 | 95 |
| 0 | HEADWATER | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.9 | 7.1 | 10.6 | 5.9 | 6.5 | 6.6 | 7.1 | 10.6 |
| 1 | LINDENHURST STP | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 7.2 | 8.8 | 16.1 | 7.7 | 7.9 | 8.5 | 9.4 | 11.9 |
| 2 | | 0.0 | 71.4 | 2891.9 | 0.0 | 0.0 | 0.0 | 3.9 | 346.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| 3 | | 0.0 | 53.4 | 3226.8 | 0.0 | 0.0 | 0.0 | 0.3 | 146.7 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| 4 | | 4.4 | 14.3 | 88.3 | 5.3 | 8.3 | 10.9 | 17.4 | 28.4 | 2.4 | 6.8 | 10.5 | 2.7 | 6.8 | 7.2 | 8.0 | 8.9 |
| 5 | | 0.0 | 59.9 | 2834.8 | 0.0 | 0.0 | 0.0 | 3.4 | 241.8 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| 6 | | 0.0 | 59.9 | 2834.8 | 0.0 | 0.0 | 0.0 | 3.4 | 241.8 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| 7 | | 4.1 | 14.3 | 102.1 | 5.2 | 8.4 | 12.6 | 19.1 | 25.5 | 5.3 | 8.0 | 11.0 | 5.4 | 7.5 | 8.4 | 9.1 | 9.1 |
| 8 | FIRST IMPOUNDMENT | 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 |
| 9 | | 0.0 | 36.5 | 2244.0 | 0.0 | 0.0 | 0.0 | 0.2 | 15.3 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| 10 | | 0.0 | 84.6 | 3207.1 | 0.0 | 0.0 | 0.0 | 1.0 | 326.3 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| 11 | SECOND IMPOUNDMENT | 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 |
| 12 | | 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 |
| 13 | | 0.0 | 84.6 | 3207.1 | 0.0 | 0.0 | 0.0 | 1.0 | 326.3 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| 14 | MILL CREEK WRF | 0.7 | 1.9 | 10.0 | 0.7 | 1.3 | 1.7 | 2.2 | 3.0 | 7.3 | 8.4 | 10.4 | 7.7 | 7.9 | 8.2 | 8.9 | 9.7 |
| 15 | | 0.0 | 122.6 | 4737.0 | 0.0 | 0.0 | 0.0 | 0.0 | 660.4 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |

**Table A-2: Mill Creek Qual2kw Model Flow and Concentrations Input for May to October 2020**

| Reach | Inflow | CBOD (mg/L) | | | | | | | | Organic Nitrogen (ug/L) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Mean | Max | Percentiles | | | | | Min | Mean | Max | Percentiles | | | | |
| | | | | | 5 | 25 | 50 | 75 | 95 | | | | 5 | 25 | 50 | 75 | 95 |
| 0 | HEADWATER | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 545 | 1,213 | 1,890 | 545 | 545 | 1,269 | 1,890 | 1,890 |
| 1 | LINDENHURST STP | 4.0 | 4.3 | 6.5 | 4.0 | 4.0 | 4.0 | 4.0 | 5.8 | 750 | 948 | 1,750 | 750 | 781 | 838 | 1,005 | 1,569 |
| 2 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 309 | 8,544 | 0 | 0 | 5 | 214 | 1,219 |
| 3 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 265 | 11,776 | 0 | 0 | 0 | 25 | 1,151 |
| 4 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 54 | 715 | 14,872 | 82 | 200 | 337 | 436 | 3,065 |
| 5 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 371 | 10,733 | 0 | 0 | 10 | 300 | 1,214 |
| 6 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 371 | 10,733 | 0 | 0 | 10 | 300 | 1,214 |
| 7 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 51 | 670 | 3,227 | 102 | 472 | 615 | 819 | 1,316 |
| 8 | FIRST IMPOUNDMENT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 170 | 9,676 | 0 | 0 | 0 | 7 | 666 |
| 10 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 392 | 10,697 | 0 | 0 | 5 | 262 | 1,633 |
| 11 | SECOND IMPOUNDMENT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 392 | 10,697 | 0 | 0 | 5 | 262 | 1,633 |
| 14 | MILL CREEK WRF | 1.0 | 1.2 | 3.5 | 1.0 | 1.0 | 1.0 | 1.0 | 2.0 | 4,000 | 9,270 | 14,000 | 5,380 | 7,867 | 9,367 | 10,875 | 12,546 |
| 15 | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 408 | 20,543 | 0 | 0 | 0 | 116 | 1,217 |

**Table A-2: Mill Creek Qual2kw Model Flow and Concentrations Input for May to October 2020**

| Reach | Inflow | Ammonia (ug/L) | | | | | | | | Nitrate-Nitrite (ug/L) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Mean | Max | Percentiles | | | | | Min | Mean | Max | Percentiles | | | | |
| | | | | | 5 | 25 | 50 | 75 | 95 | | | | 5 | 25 | 50 | 75 | 95 |
| 0 | HEADWATER | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 25 | 47 | 191 | 25 | 25 | 25 | 32 | 159 |
| 1 | LINDENHURST STP | 250 | 512 | 7,600 | 250 | 250 | 250 | 250 | 2,367 | 610 | 6,802 | 9,863 | 1,748 | 6,298 | 7,213 | 8,433 | 9,496 |
| 2 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 75 | 1,351 | 62,995 | 109 | 242 | 567 | 1,148 | 2,917 |
| 3 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 99 | 1,208 | 20,338 | 202 | 315 | 809 | 1,526 | 2,832 |
| 4 | | 5 | 190 | 2,754 | 10 | 57 | 119 | 162 | 591 | 100 | 741 | 6,829 | 187 | 404 | 603 | 935 | 1,517 |
| 5 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 63 | 1,252 | 61,538 | 109 | 301 | 557 | 1,013 | 2,463 |
| 6 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 63 | 1,252 | 61,538 | 109 | 301 | 557 | 1,013 | 2,463 |
| 7 | | 12 | 219 | 538 | 25 | 167 | 232 | 275 | 381 | 168 | 1,168 | 32,328 | 217 | 322 | 513 | 822 | 2,653 |
| 8 | FIRST IMPOUNDMENT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | | 0 | 2 | 31 | 0 | 0 | 0 | 1 | 17 | 0 | 255 | 926 | 28 | 72 | 212 | 411 | 595 |
| 10 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 29 | 1,179 | 31,205 | 71 | 231 | 496 | 1,055 | 3,328 |
| 11 | SECOND IMPOUNDMENT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 29 | 1,179 | 31,205 | 71 | 231 | 496 | 1,055 | 3,328 |
| 14 | MILL CREEK WRF | 100 | 136 | 1,100 | 100 | 100 | 100 | 136 | 200 | 500 | 10,358 | 16,000 | 5,652 | 8,976 | 10,454 | 12,167 | 14,553 |
| 15 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 909 | 50,560 | 0 | 77 | 216 | 579 | 2,894 |

**Table A-2: Mill Creek Qual2kw Model Flow and Concentrations Input for May to October 2020**

| Reach | Inflow | Organic Phosphorus (ug/L) | | | | | | | | Inorganic Phosphorus (ug/L) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Mean | Max | Percentiles | | | | | Min | Mean | Max | Percentiles | | | | |
| | | | | | 5 | 25 | 50 | 75 | 95 | | | | 5 | 25 | 50 | 75 | 95 |
| 0 | HEADWATER | 36 | 50 | 105 | 36 | 42 | 43 | 46 | 93 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 1 | LINDENHURST STP | 20 | 171 | 900 | 23 | 29 | 87 | 213 | 616 | 20 | 171 | 900 | 23 | 29 | 87 | 213 | 616 |
| 2 | | 0 | 43 | 327 | 0 | 0 | 1 | 37 | 200 | 0 | 32 | 175 | 0 | 0 | 1 | 36 | 158 |
| 3 | | 0 | 12 | 390 | 0 | 0 | 0 | 2 | 54 | 0 | 10 | 124 | 0 | 0 | 0 | 5 | 66 |
| 4 | | 77 | 101 | 133 | 81 | 83 | 106 | 112 | 128 | 26 | 47 | 63 | 27 | 31 | 53 | 61 | 62 |
| 5 | | 0 | 38 | 361 | 0 | 0 | 1 | 36 | 170 | 0 | 27 | 142 | 0 | 0 | 1 | 32 | 129 |
| 6 | | 0 | 38 | 361 | 0 | 0 | 1 | 36 | 170 | 0 | 27 | 142 | 0 | 0 | 1 | 32 | 129 |
| 7 | | 16 | 81 | 175 | 17 | 19 | 61 | 131 | 172 | 10 | 23 | 36 | 10 | 10 | 26 | 35 | 36 |
| 8 | FIRST IMPOUNDMENT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | | 0 | 5 | 280 | 0 | 0 | 0 | 0 | 16 | 0 | 2 | 42 | 0 | 0 | 0 | 1 | 13 |
| 10 | | 0 | 42 | 386 | 0 | 0 | 1 | 37 | 191 | 0 | 28 | 161 | 0 | 0 | 1 | 31 | 141 |
| 11 | SECOND IMPOUNDMENT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | | 0 | 42 | 386 | 0 | 0 | 1 | 37 | 191 | 0 | 28 | 161 | 0 | 0 | 1 | 31 | 141 |
| 14 | MILL CREEK WRF | 0 | 50 | 100 | 50 | 50 | 50 | 50 | 50 | 0 | 50 | 100 | 50 | 50 | 50 | 50 | 50 |
| 15 | | 0 | 56 | 729 | 0 | 0 | 0 | 31 | 321 | 0 | 29 | 220 | 0 | 0 | 0 | 20 | 182 |

**Table A-2: Mill Creek Qual2kw Model Flow and Concentrations Input for May to October 2020**

| Reach | Inflow | Chlorophyll-a (ug/L) | | | | | | | | pH | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Mean | Max | Percentiles | | | | | Min | Mean | Max | Percentiles | | | | |
| | | | | | 5 | 25 | 50 | 75 | 95 | | | | 5 | 25 | 50 | 75 | 95 |
| 0 | HEADWATER | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 7.9 | 8.1 | 8.3 | 7.9 | 8.0 | 8.2 | 8.2 | 8.3 |
| 1 | LINDENHURST STP | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.8 | 7.4 | 8.0 | 6.9 | 7.2 | 7.4 | 7.6 | 7.8 |
| 2 | | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 7.7 | 7.9 | 8.1 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 |
| 3 | | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 7.7 | 7.9 | 8.1 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 |
| 4 | | 7.0 | 7.1 | 7.5 | 7.0 | 7.1 | 7.1 | 7.1 | 7.3 | 7.7 | 7.9 | 8.1 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 |
| 5 | | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 7.7 | 7.9 | 8.1 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 |
| 6 | | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 7.7 | 7.9 | 8.1 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 |
| 7 | | 13.5 | 13.7 | 13.7 | 13.6 | 13.6 | 13.7 | 13.7 | 13.7 | 7.7 | 7.9 | 8.1 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 |
| 8 | FIRST IMPOUNDMENT | 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 |
| 9 | | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 7.7 | 7.9 | 8.1 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 |
| 10 | | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 7.7 | 7.9 | 8.1 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 |
| 11 | SECOND IMPOUNDMENT | 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 |
| 12 | | 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 |
| 13 | | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 7.7 | 7.9 | 8.1 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 |
| 14 | MILL CREEK WRF | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.9 | 7.5 | 7.9 | 7.2 | 7.3 | 7.5 | 7.7 | 7.9 |
| 15 | | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 7.7 | 7.9 | 8.1 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 |

# Attachment 2

## Hydraulic Calibration Results PowerPoint Presentation (July 21, 2022)

Geosyntec consultants

# DRWW Modeling Update

July 21, 2022 (Revised December 13, 2022)

# Agenda

- Summary of previous modeling update
- Mainstem WQ Model
  - Hydraulic model
    - calibration results
  - Water quality model
    - Inputs
- Chlorophyll-a Issue

# Previous Update

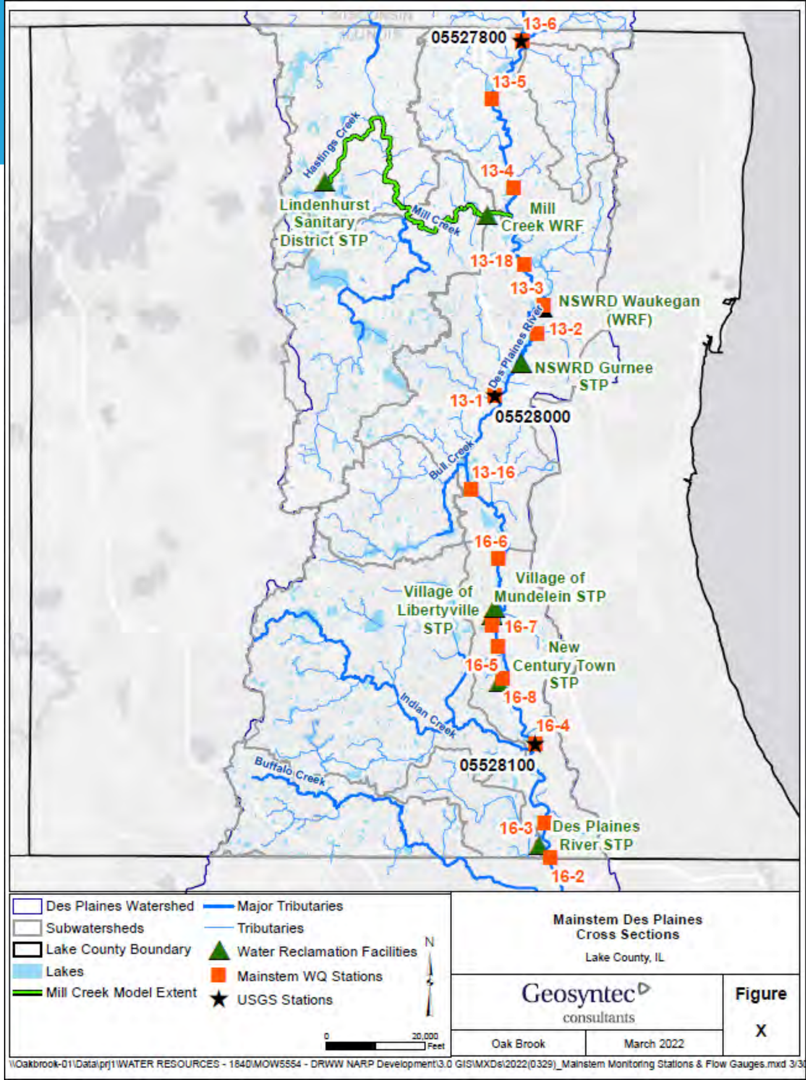
- Model segmentation
  - Modeling period
  - River characterization
- Hydraulic model input
  - Meteorological data
  - Upstream
  - WWTPs
  - Tributaries

# Mainstem Hydraulic Model Calibration Results

Geosyntec consultants

# Hydraulic Model Calibration

- Two USGS flow gages
  - 05528000 → Reach 8
  - 05528100 → Reach 16



# Hydraulic Model Calibration

- Calibration performance
  - Visual comparison
  - The Nash-Sutcliffe coefficient of efficiency

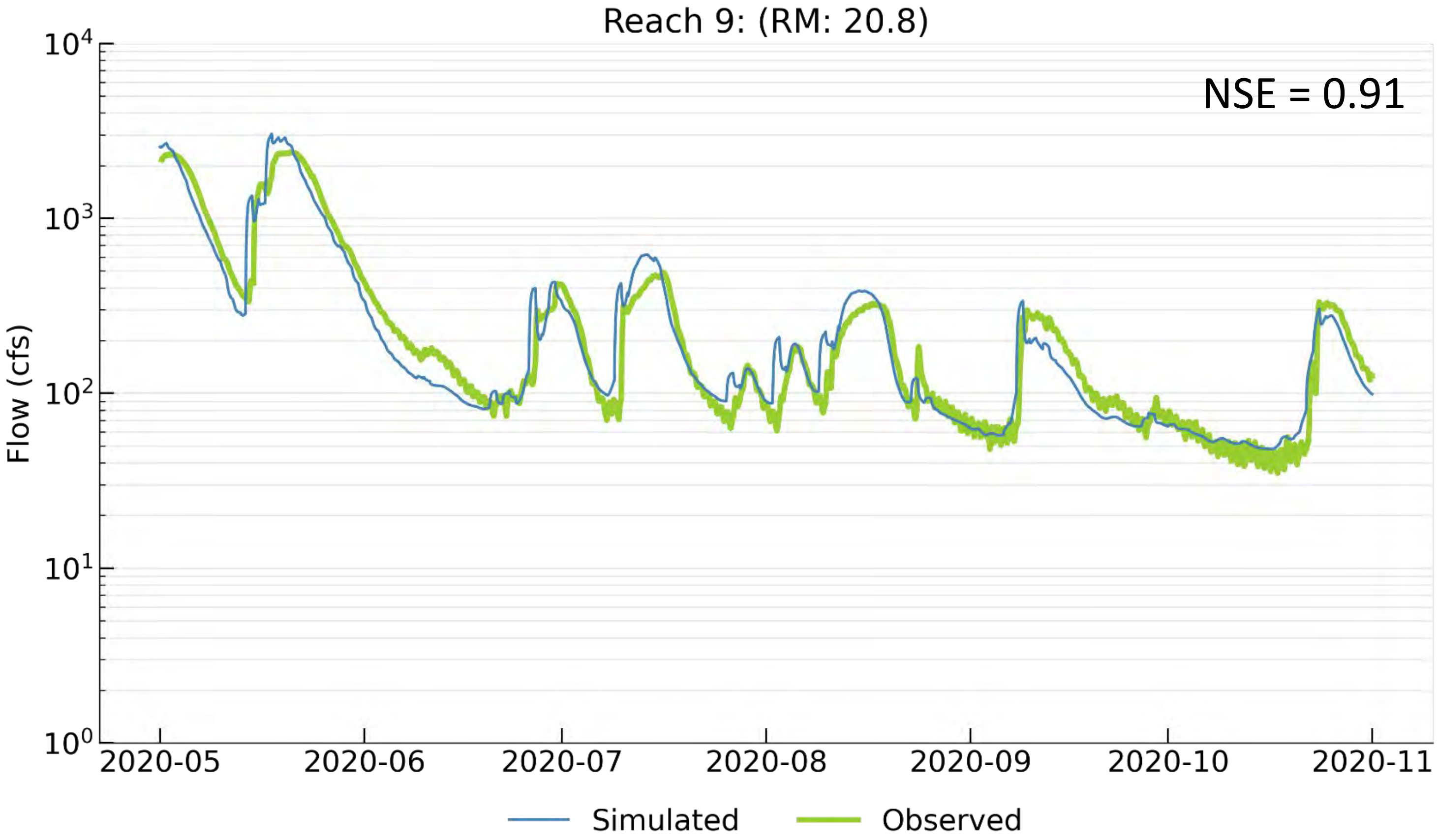
$$NSE = 1 - \frac{\sum_{t=1}^{T} \left(Q_o^t - Q_m^t\right)^2}{\sum_{t=1}^{T} \left(Q_o^t - \overline{Q}_o\right)^2}$$

where $\overline{Q}_o$ is the mean of observed discharges, and $Q_m$ is modeled discharge. $Q_o^t$ is observed discharge at time $t$.

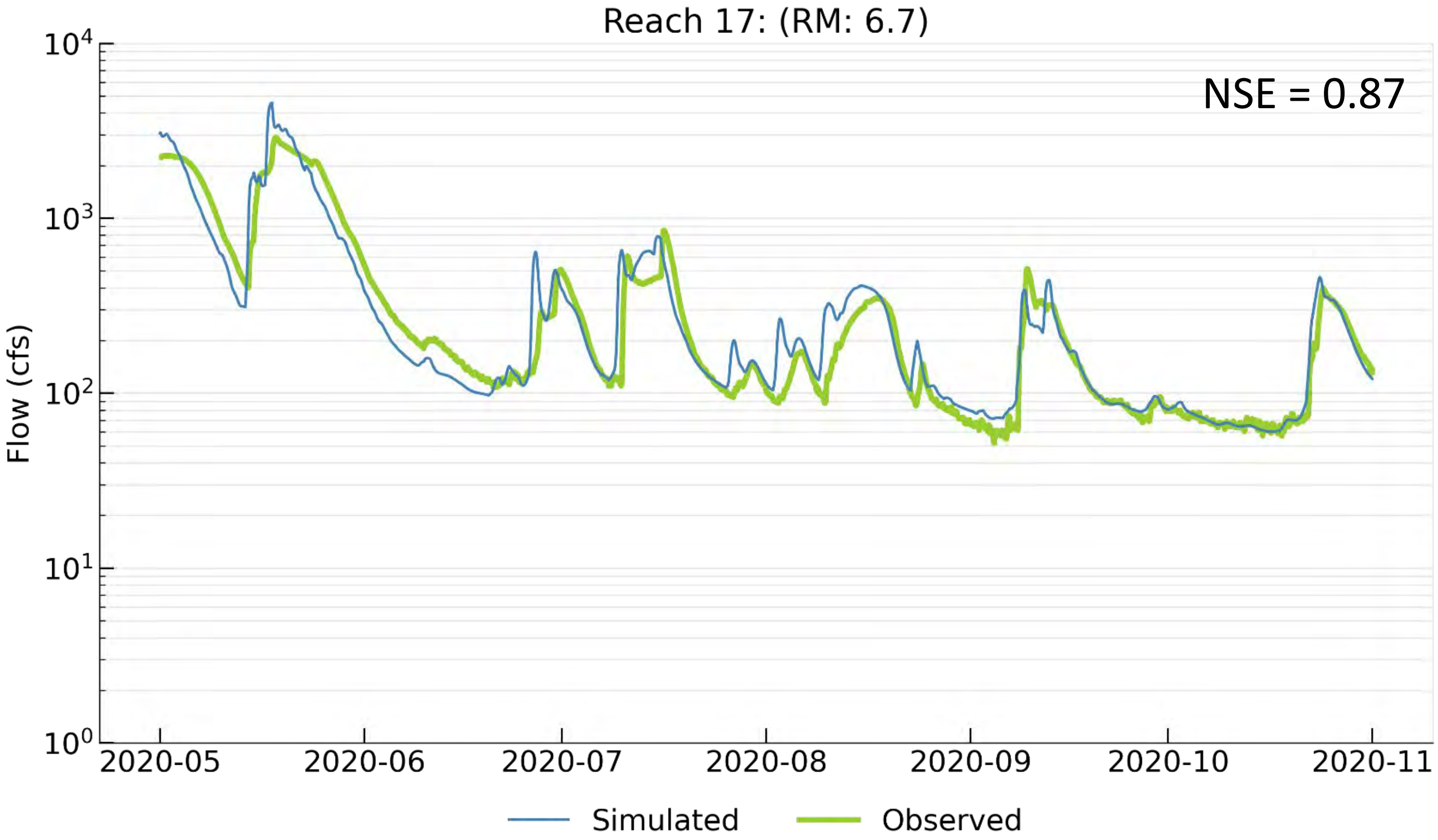
| CLASSIFICATION | COEFFICIENT OF EFFICIENCY (CALIBRATION) |
|---|---|
| Excellent | $E \geq 0.93$ |
| Good | $0.8 \leq E < 0.93$ |
| Satisfactory | $0.7 \leq E < 0.8$ |
| Passable | $0.6 \leq E < 0.7$ |
| Poor | $E < 0.6$ |

Chiew and McMahon (1993) an (Ladson, 2008).

# Hydraulic Model Calibration – Reach 8



# Hydraulic Model Calibration – Reach 16

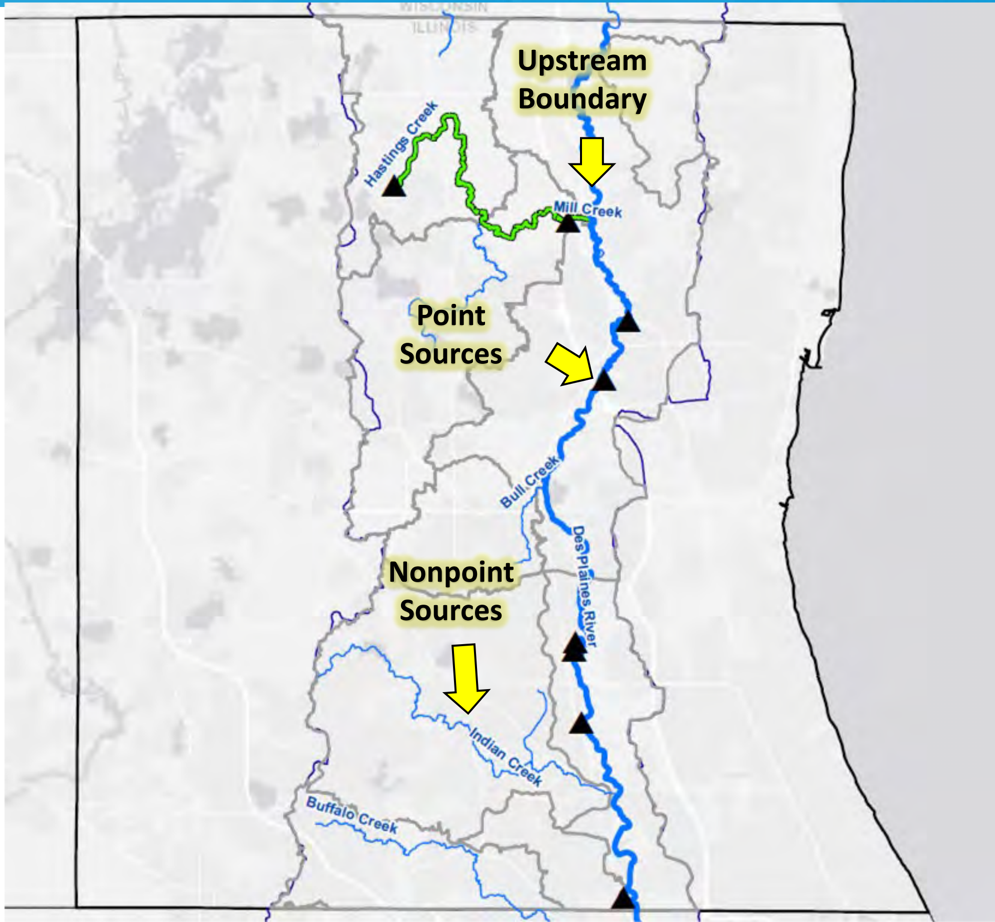


# Mainstem Water Quality Model

Geosyntec consultants

# Mainstem Water Quality Model

- Model input
  - Upstream boundary
  - Tributaries
  - Wastewater Treatment Plants (WWTPs)



# Upstream Boundary

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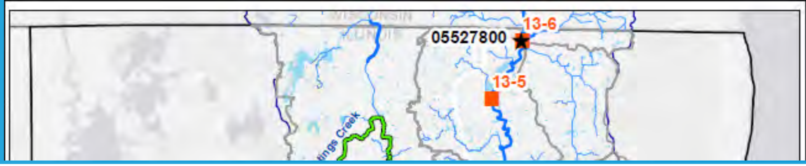
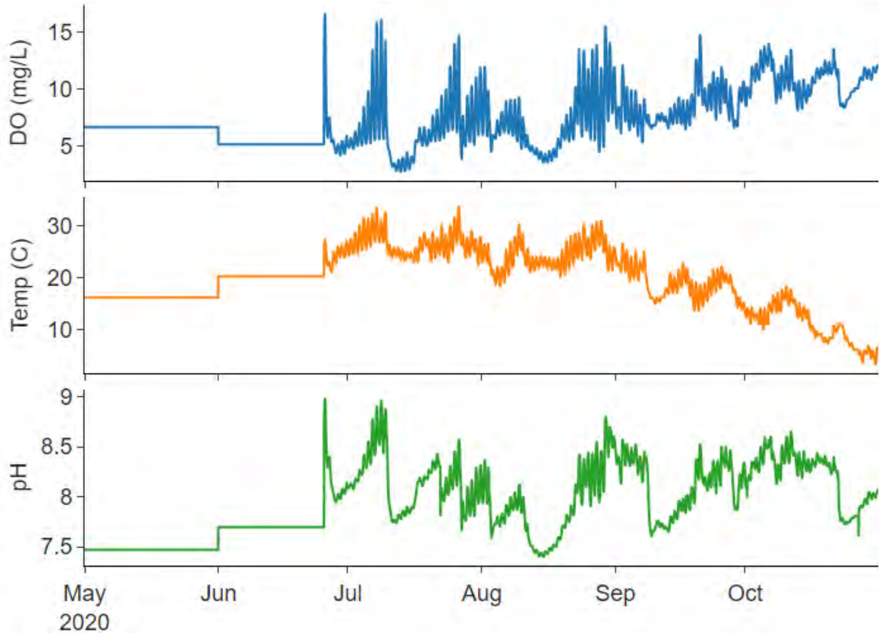
# Upstream Boundary

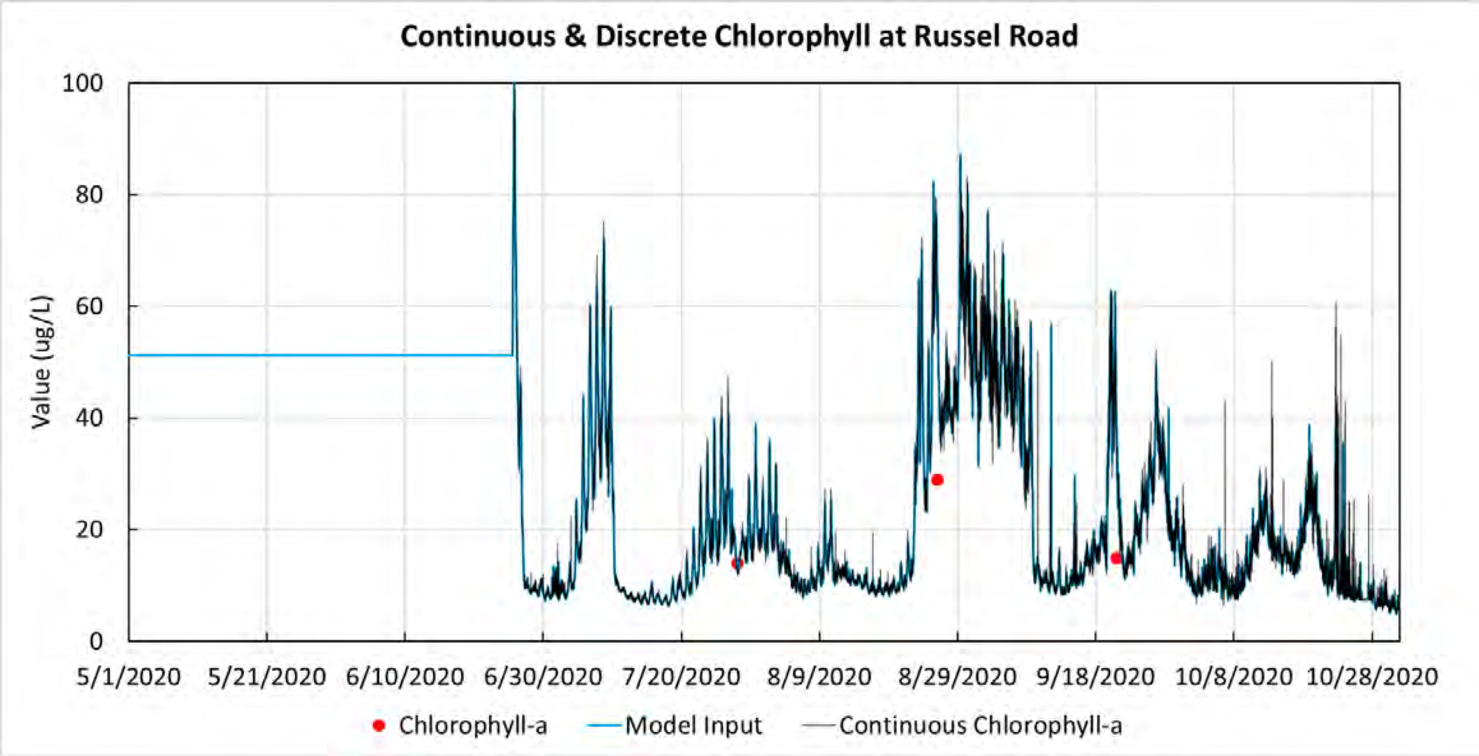



- Station 13-5 (Russel Rd)
  - Continuous data starts 6/25/2020
  - For the missing period (5/1/2020- 6/24/2020) used average monthly values from all discrete data (2008-2020)

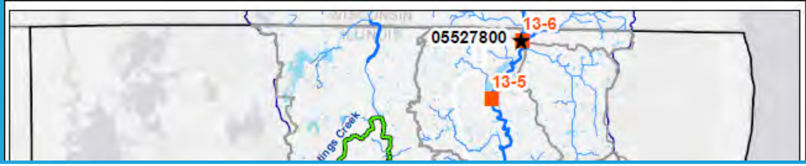


# Upstream Boundary

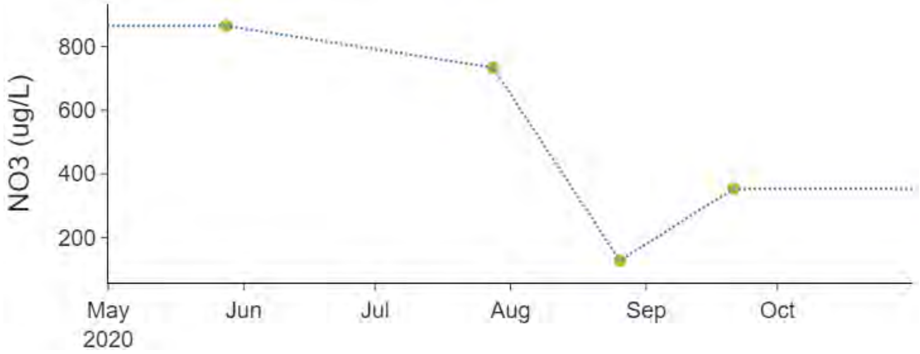

- Station 13-5 (Russel Rd)

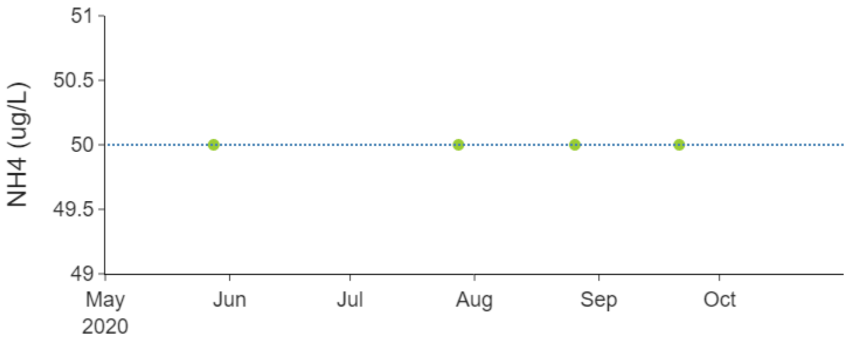


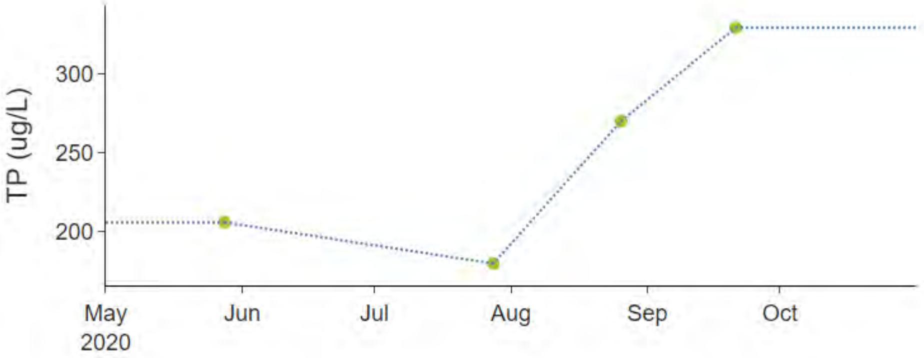
# Upstream Boundary

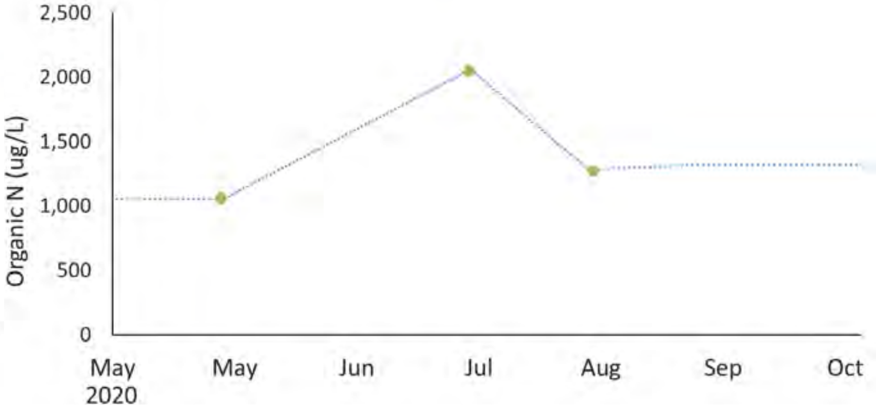



- Station 13-6
  - Discrete: interpolated between measured data



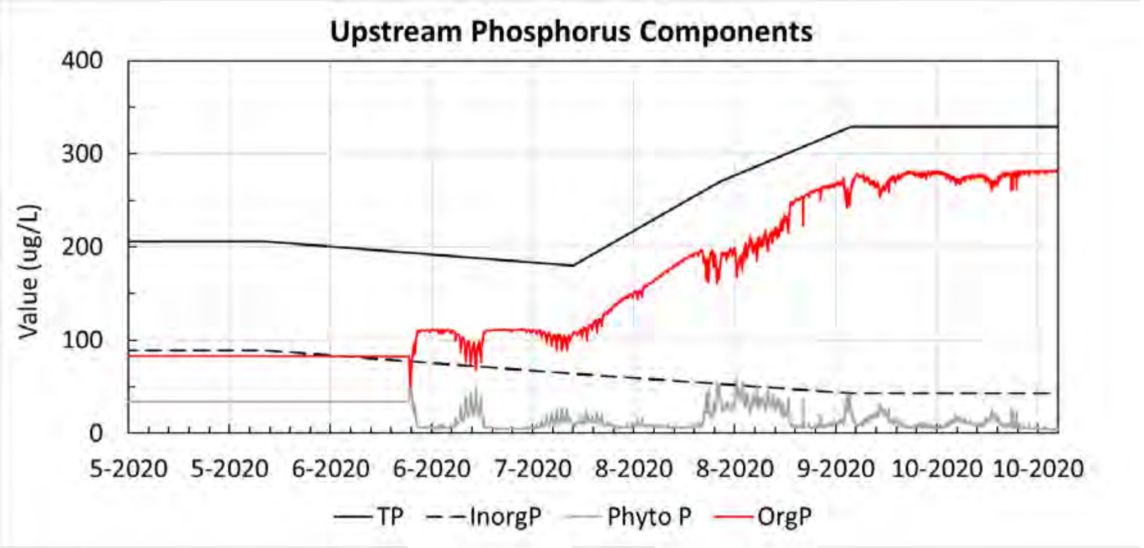
# Upstream Boundary


- Phosphorus separation
  - Total P
  - Inorganic P

$$Org_P = TP - Inorg_P - Phyto_P$$

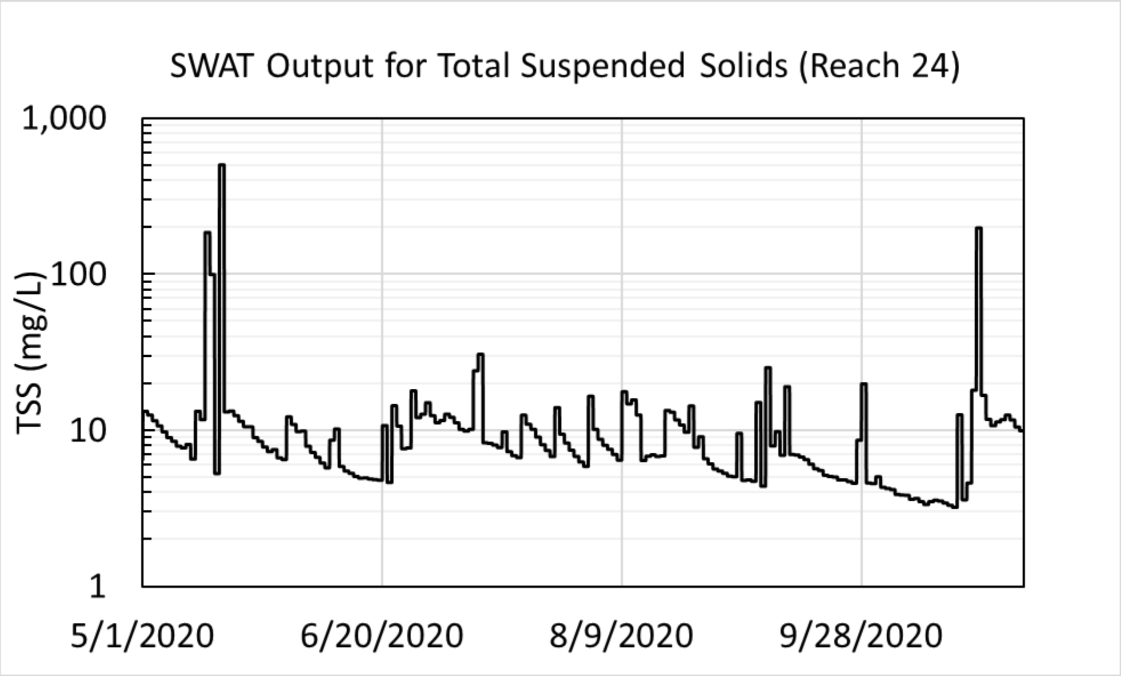
$$Phyto_P = \frac{Phyto}{1.5}$$

| Stoichiometry: | | |
|---|---|---|
| Carbon | 40 | gC |
| Nitrogen | 7.2 | gN |
| Phosphorus | 1 | gP |
| Dry weight | 100 | gD |
| Chlorophyll | 1.5 | gA |



# Upstream Boundary

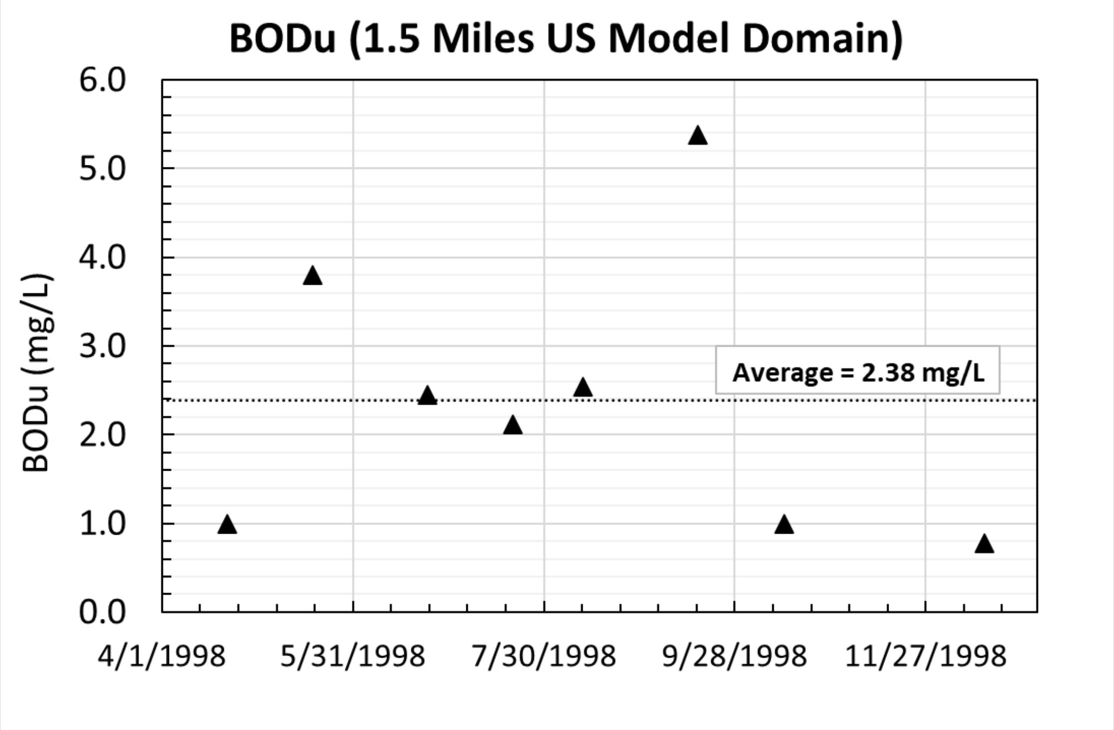
- SWAT model output for TSS



# Upstream Boundary

- Wisconsin DNR for CBOD*
  - Collect BOD 5
  - Assumed BODu is all CBOD
  - Converted BOD5 to BODu

$$CBOD_u = \frac{CBOD_5}{(1 - exp(-5k))}$$

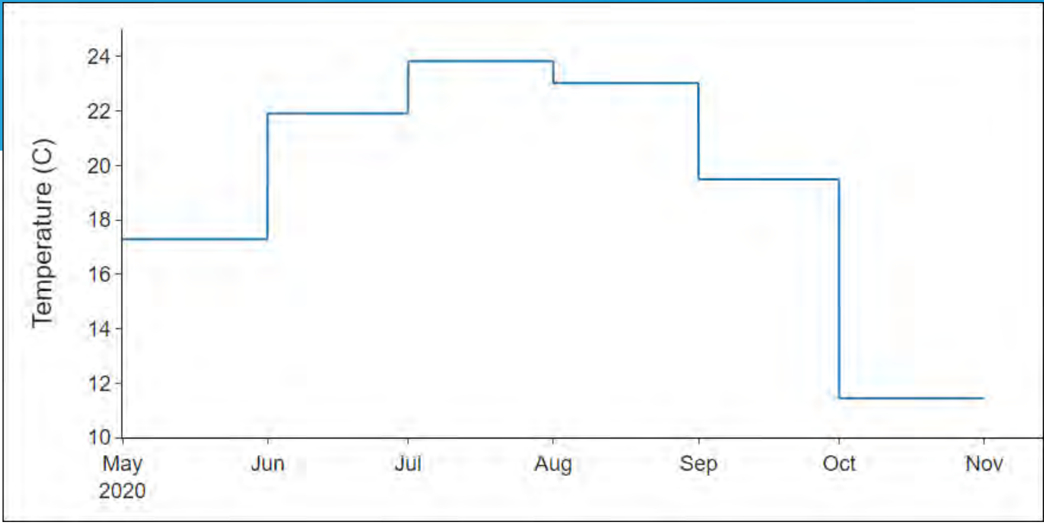


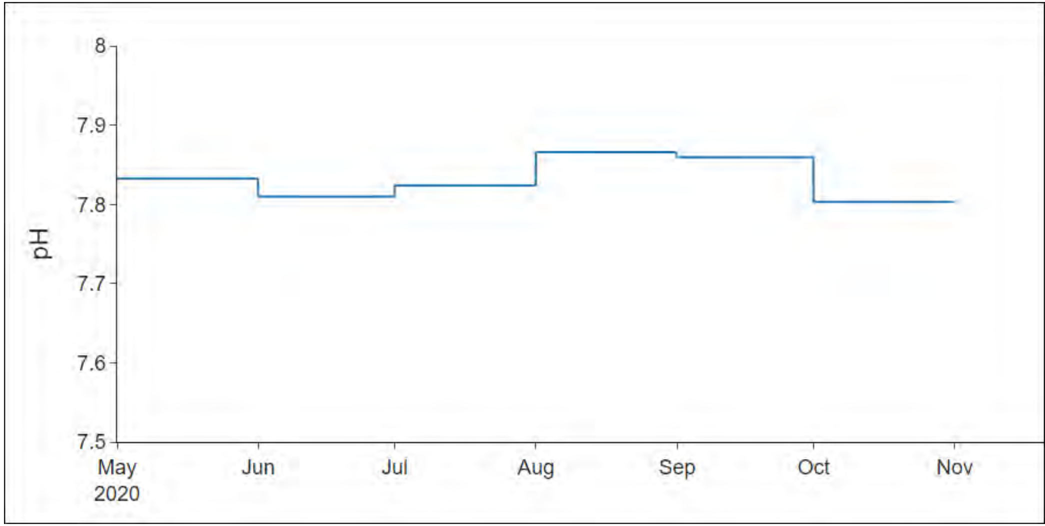

*Station 303054: ~1.5 miles upstream station 13-6

# Tributaries

# Tributaries

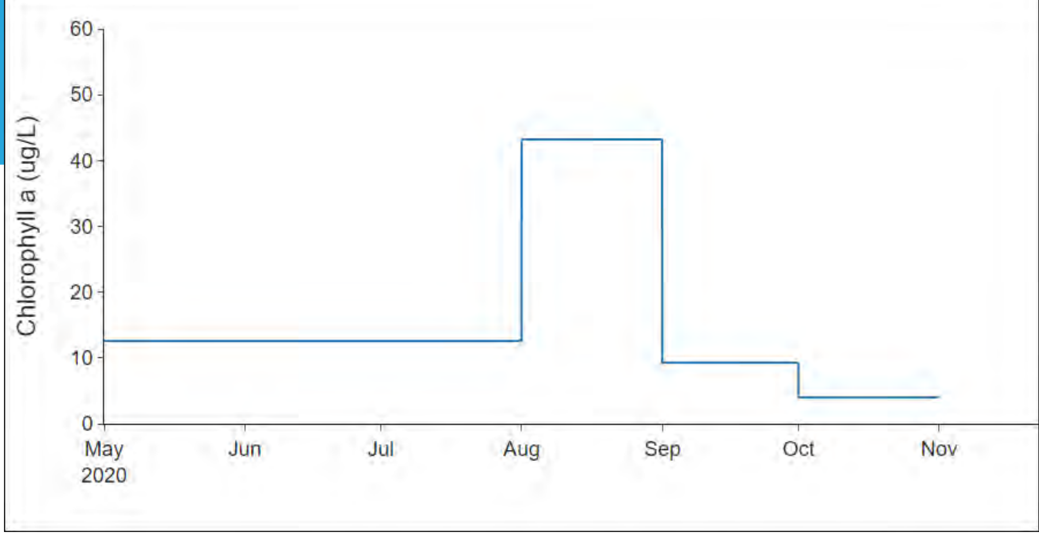
- Daily SWAT output for flow, TP, TN, and TSS
- Temperature & pH
  - Average monthly observed tributaries data (2008-2020)

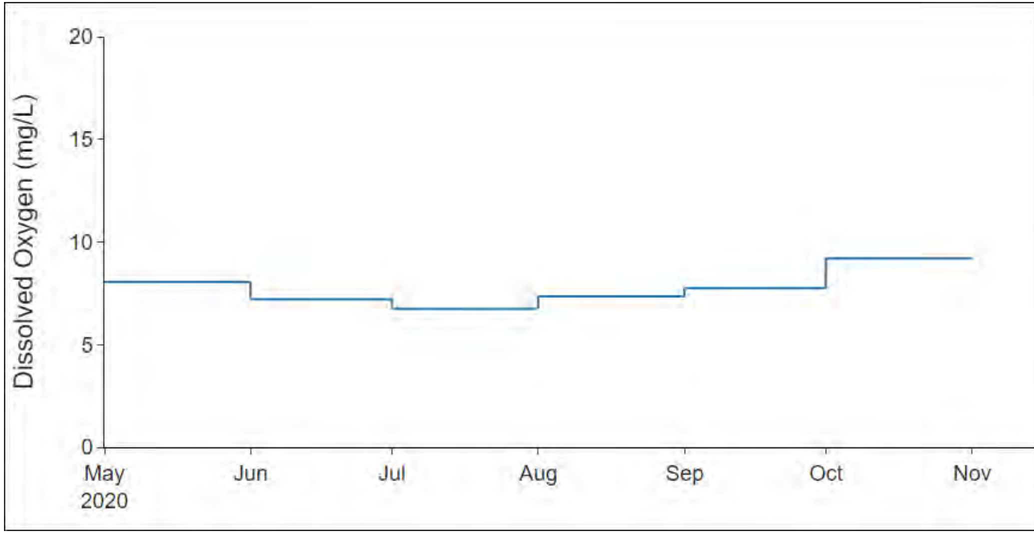


# Tributaries

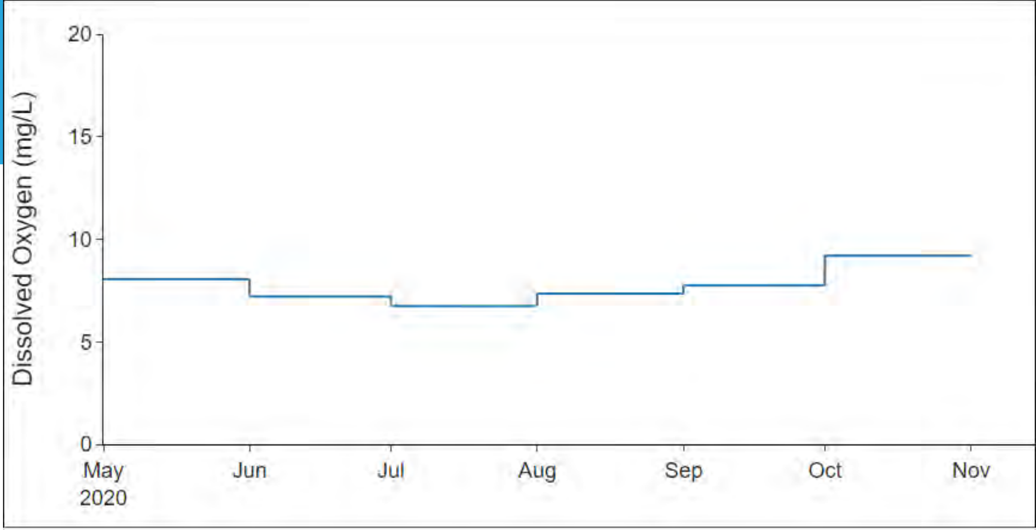
- Chlorophyll-a
  - Average monthly observed tributaries data
- CBOD
  - Upstream 2.38 mg/L

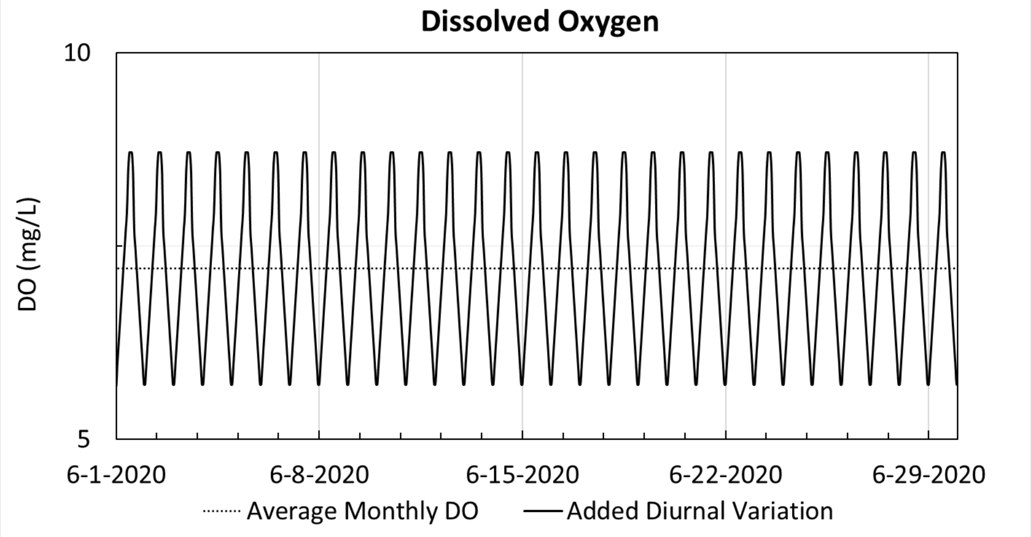


# Tributaries

- Dissolved Oxygen
  - Average monthly observed tributaries data
    - Added diurnal variation based on historical tributaries continuous Illinois EPA data



# WWTPs

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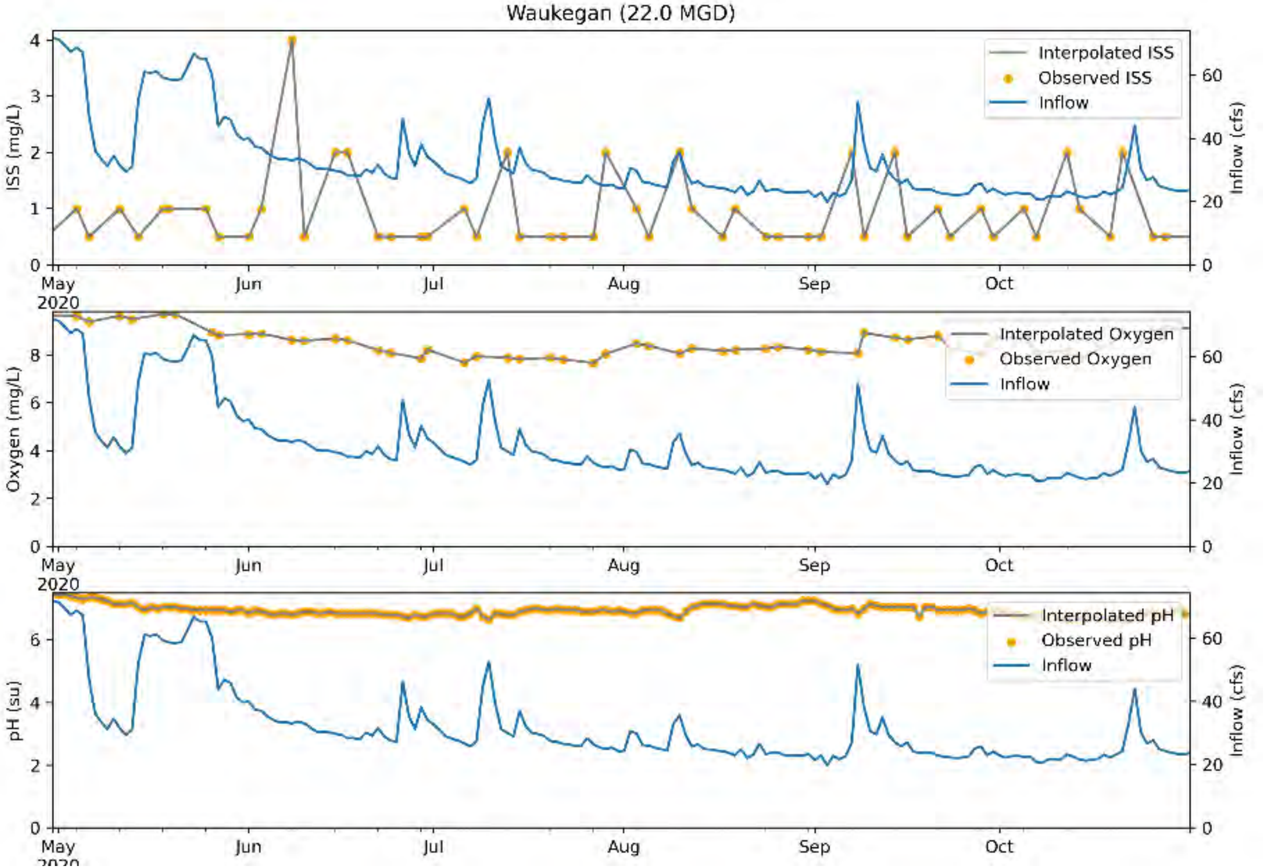
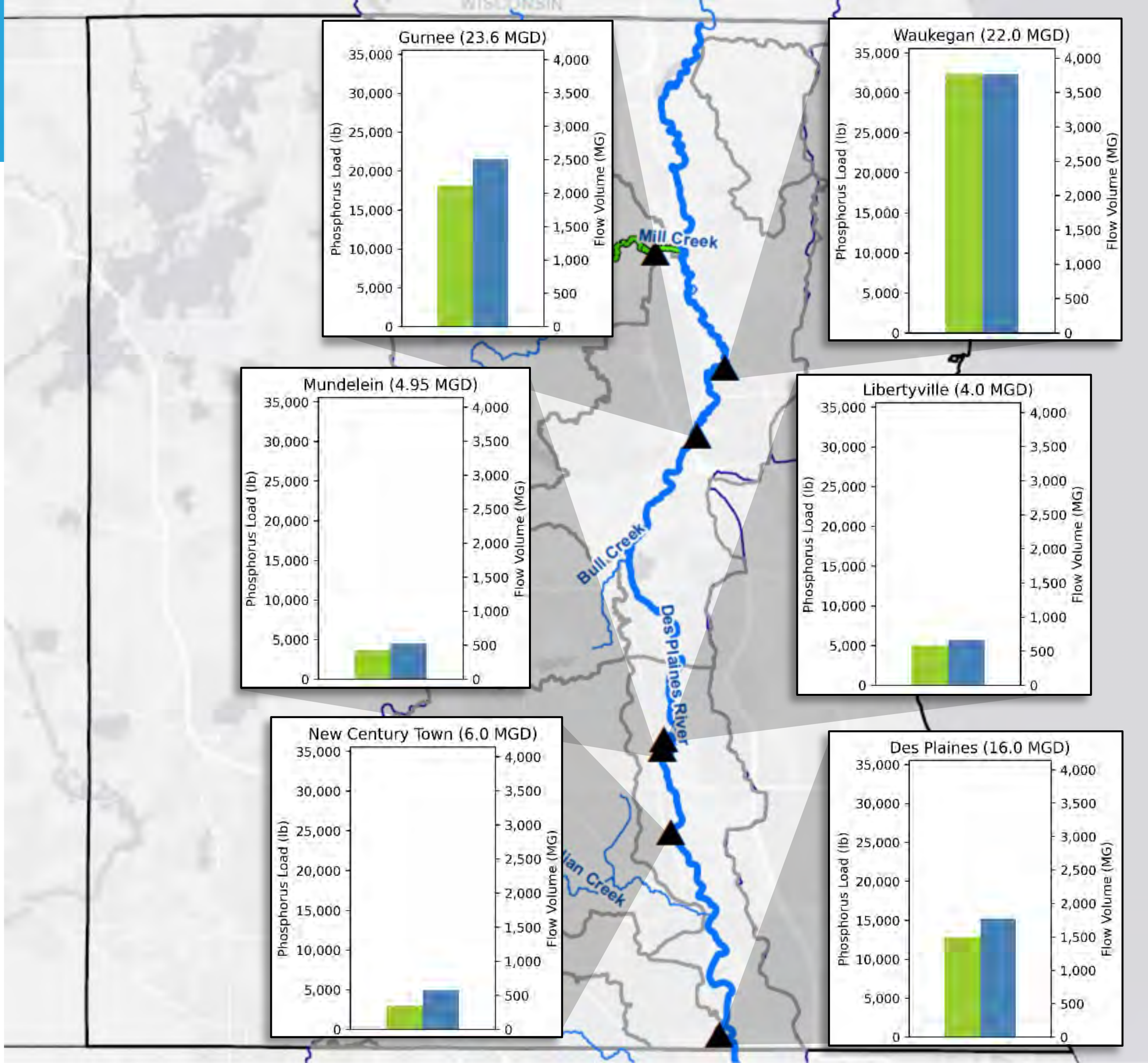
# WWTPs

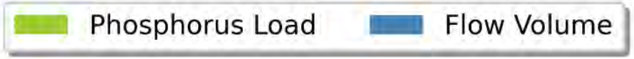
- Interpolated between measured data
  - NSWRD Waukegan



# TP Conceptual Model

- May to October 2020 WWTPs Flow volumes and phosphorus loads.



- Questions?

# Attachment 3

## Water Quality Calibration Results PowerPoint Presentation (November 17, 2022)

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# DRWW Qual2kw Water Quality Calibration

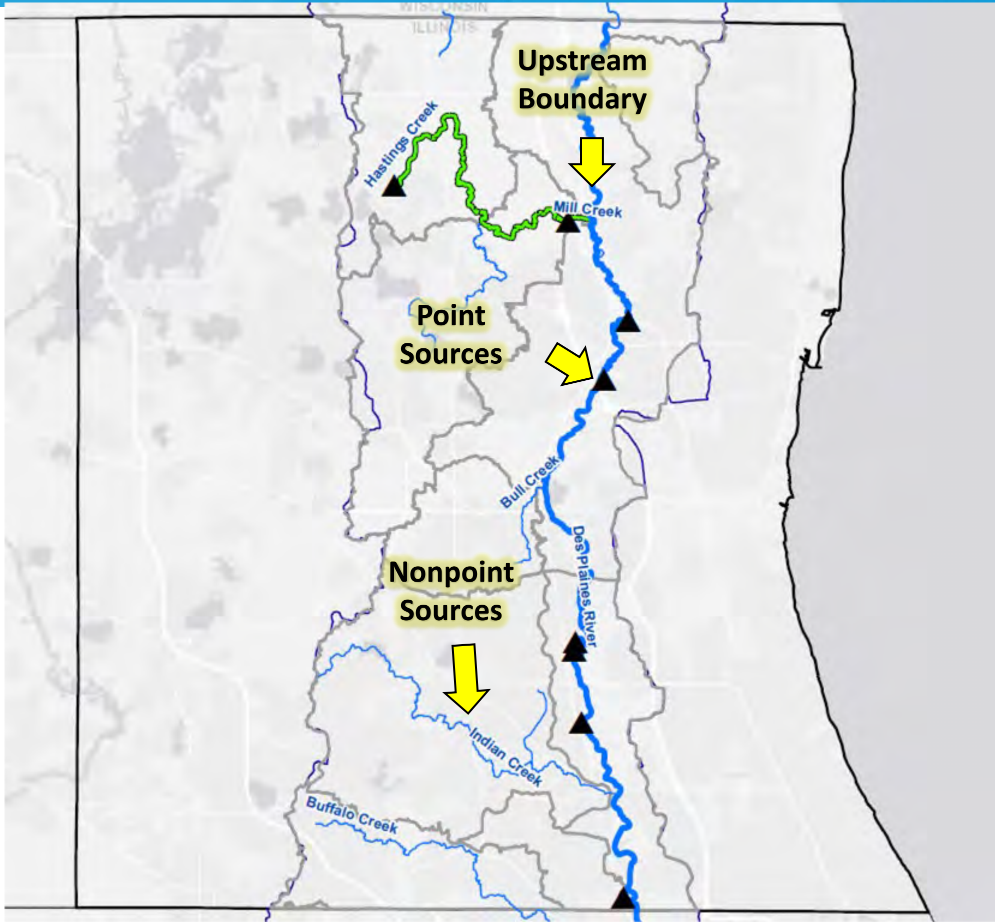
November 17, 2022

# Agenda

- Water quality model
  - Model inputs
    - Upstream
    - Tributaries
    - Point sources
  - Calibration results

# Mainstem Water Quality Model

- Model input
  - Upstream boundary
  - Tributaries
  - Wastewater Treatment Plants (WWTPs)



# Upstream Boundary

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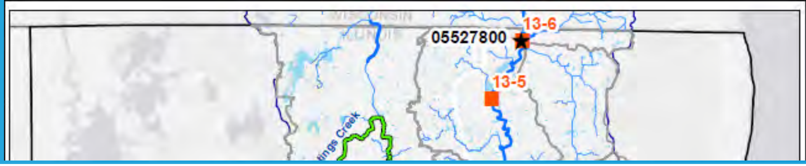
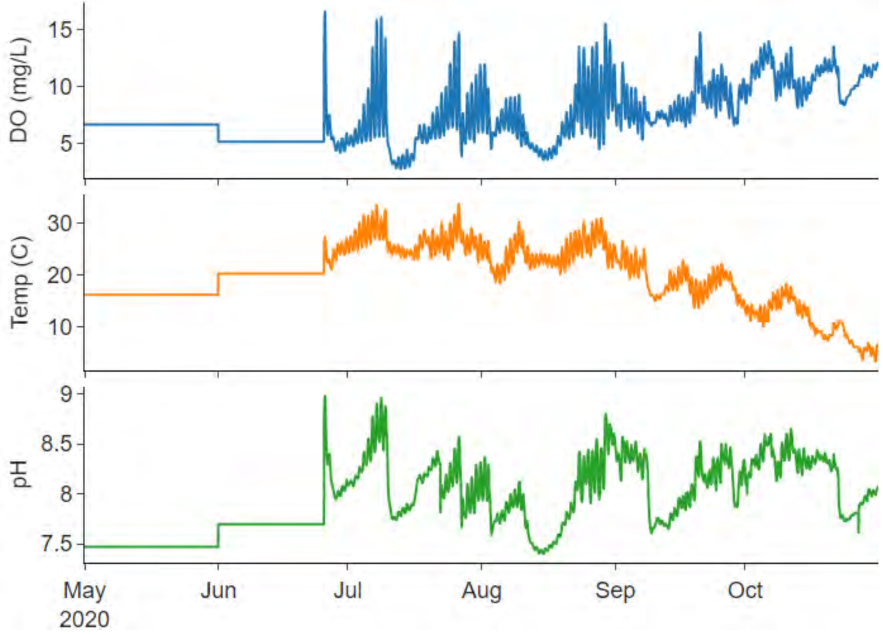
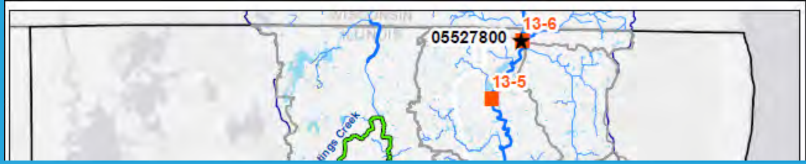
# Upstream Boundary



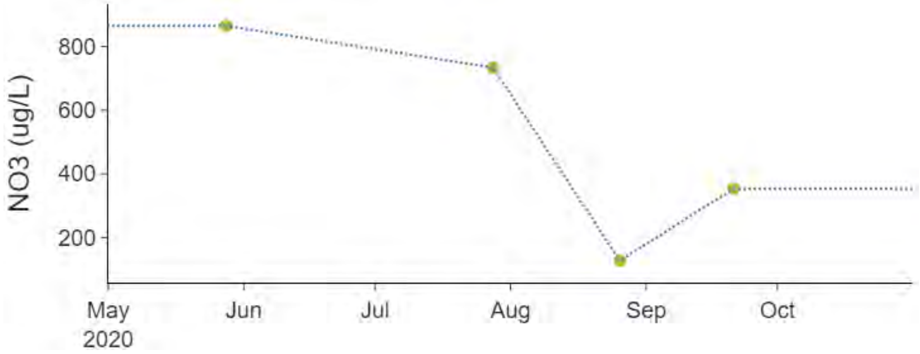

- Station 13-6 (Russel Rd)
  - Continuous data starts 6/25/2020
  - For the missing period (5/1/2020- 6/24/2020) used average monthly values from all discrete data (2008-2020)

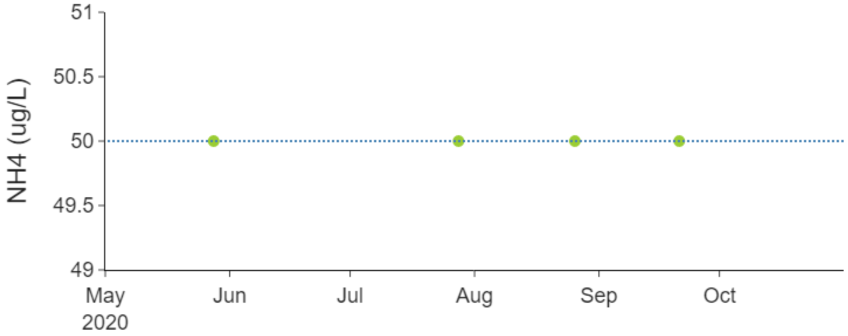


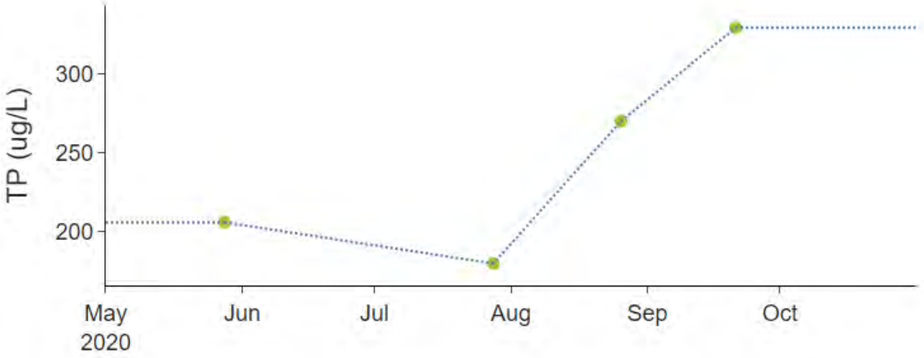
# Upstream Boundary

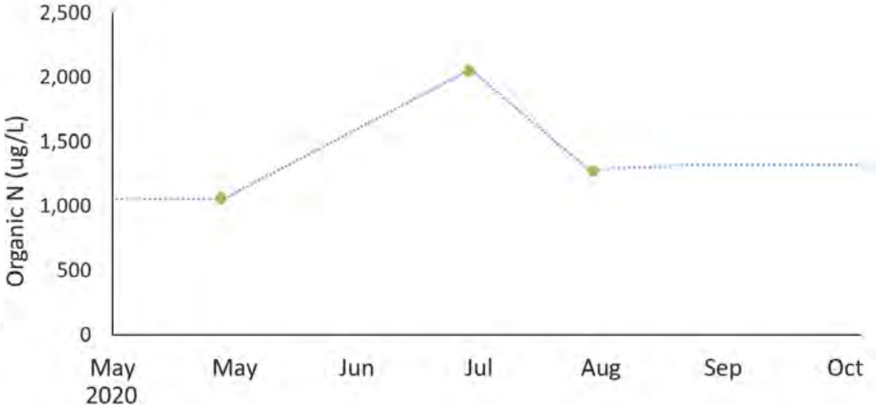



- Station 13-6
  - Discrete: interpolated between measured data



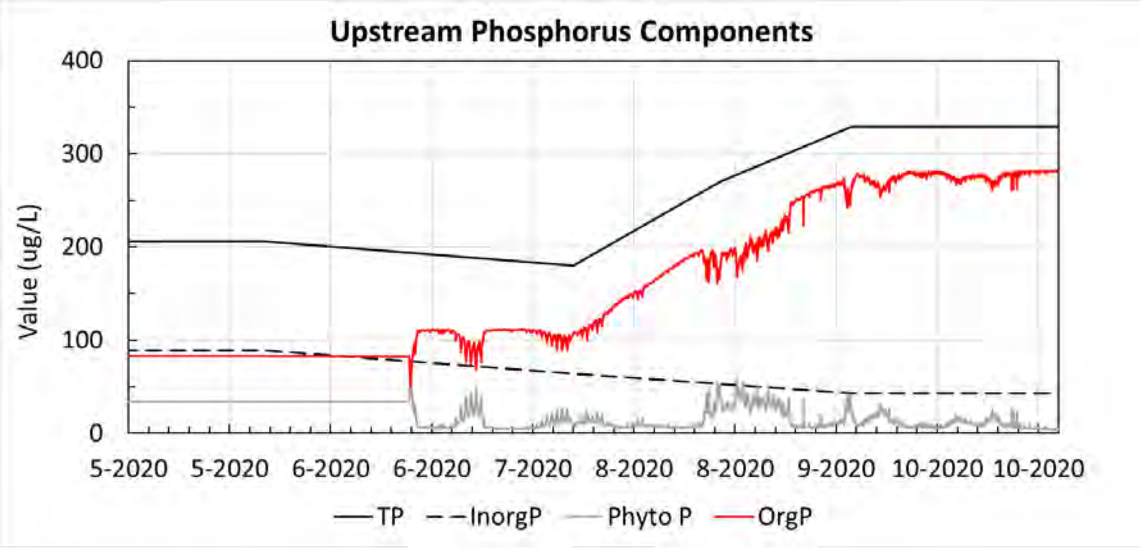
# Upstream Boundary


- Phosphorus separation
  - Total P
  - Inorganic P

$$Org_P = TP - Inorg_P - Phyto_P$$

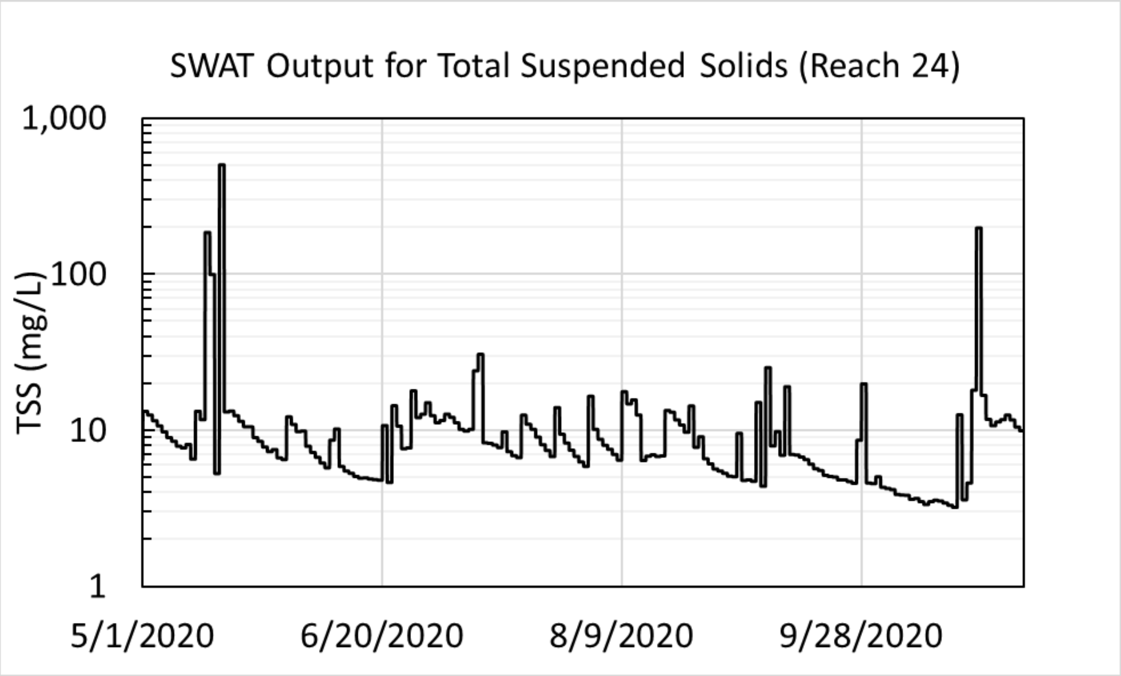
$$Phyto_P = \frac{Phyto}{1.5}$$

| Stoichiometry: | | |
|---|---|---|
| Carbon | 40 | gC |
| Nitrogen | 7.2 | gN |
| Phosphorus | 1 | gP |
| Dry weight | 100 | gD |
| Chlorophyll | 1.5 | gA |



# Upstream Boundary

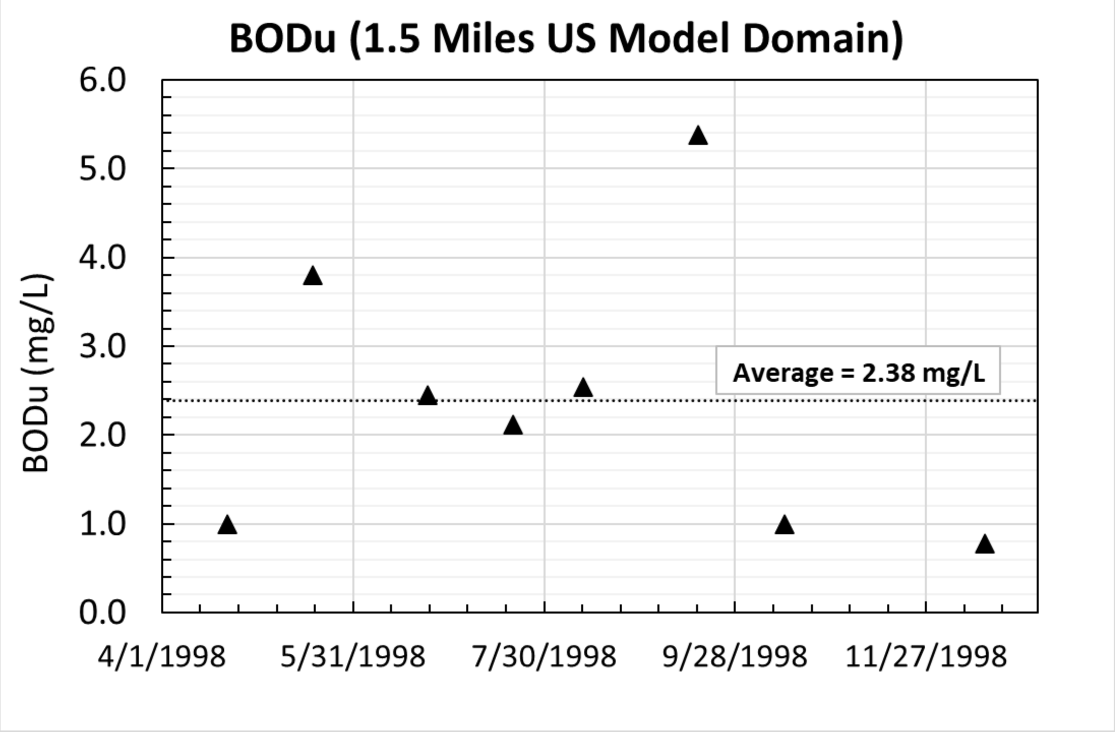
- SWAT model output for TSS



# Upstream Boundary

- Wisconsin DNR for CBOD*
  - Collect BOD 5
  - Assumed BODu is all CBOD
  - Converted BOD5 to BODu

$$CBOD_u = \frac{CBOD_5}{(1 - exp(-5k))}$$




*Station 303054: ~1.5 miles upstream station 13-6

# Observed Chlorophyll-a

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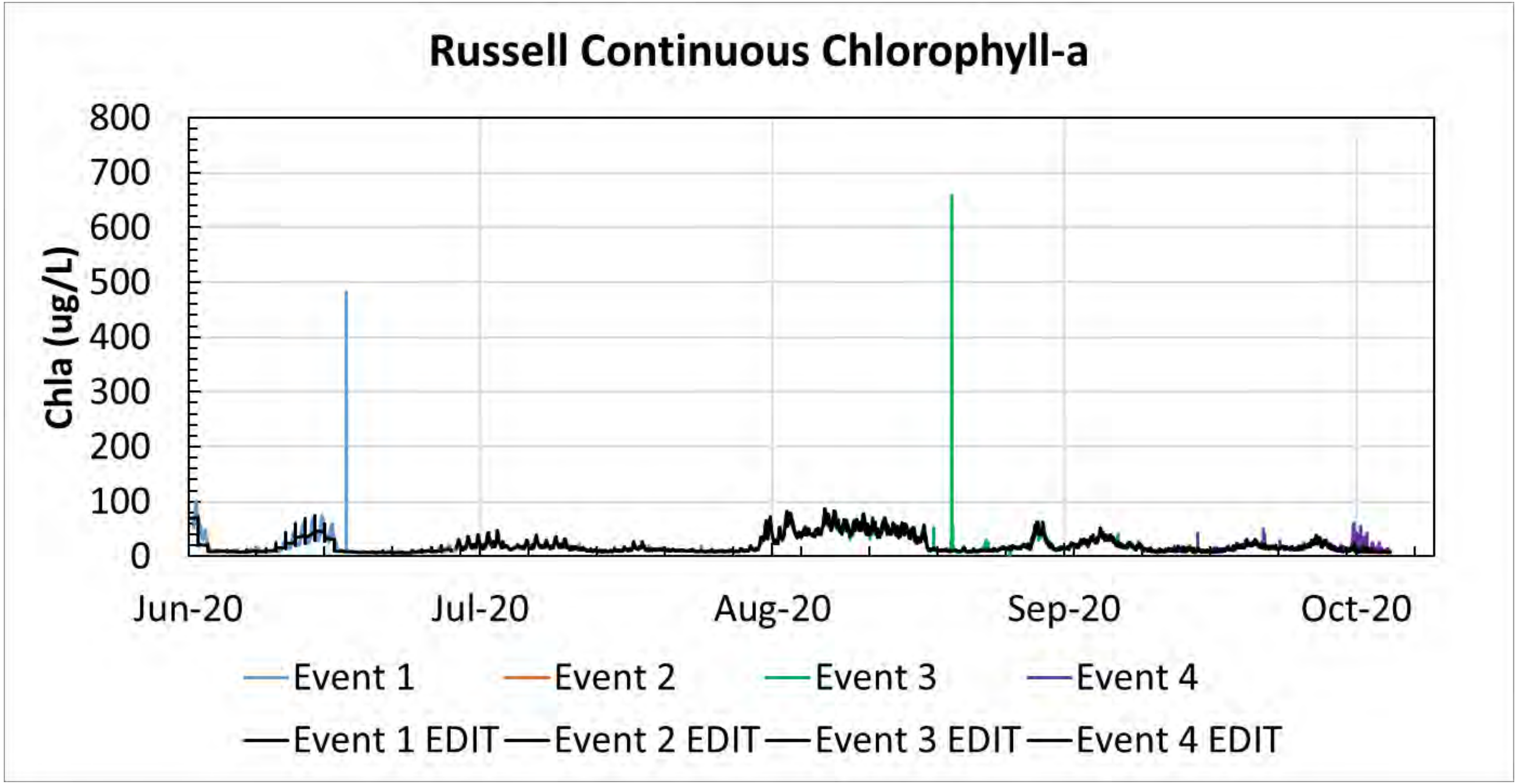
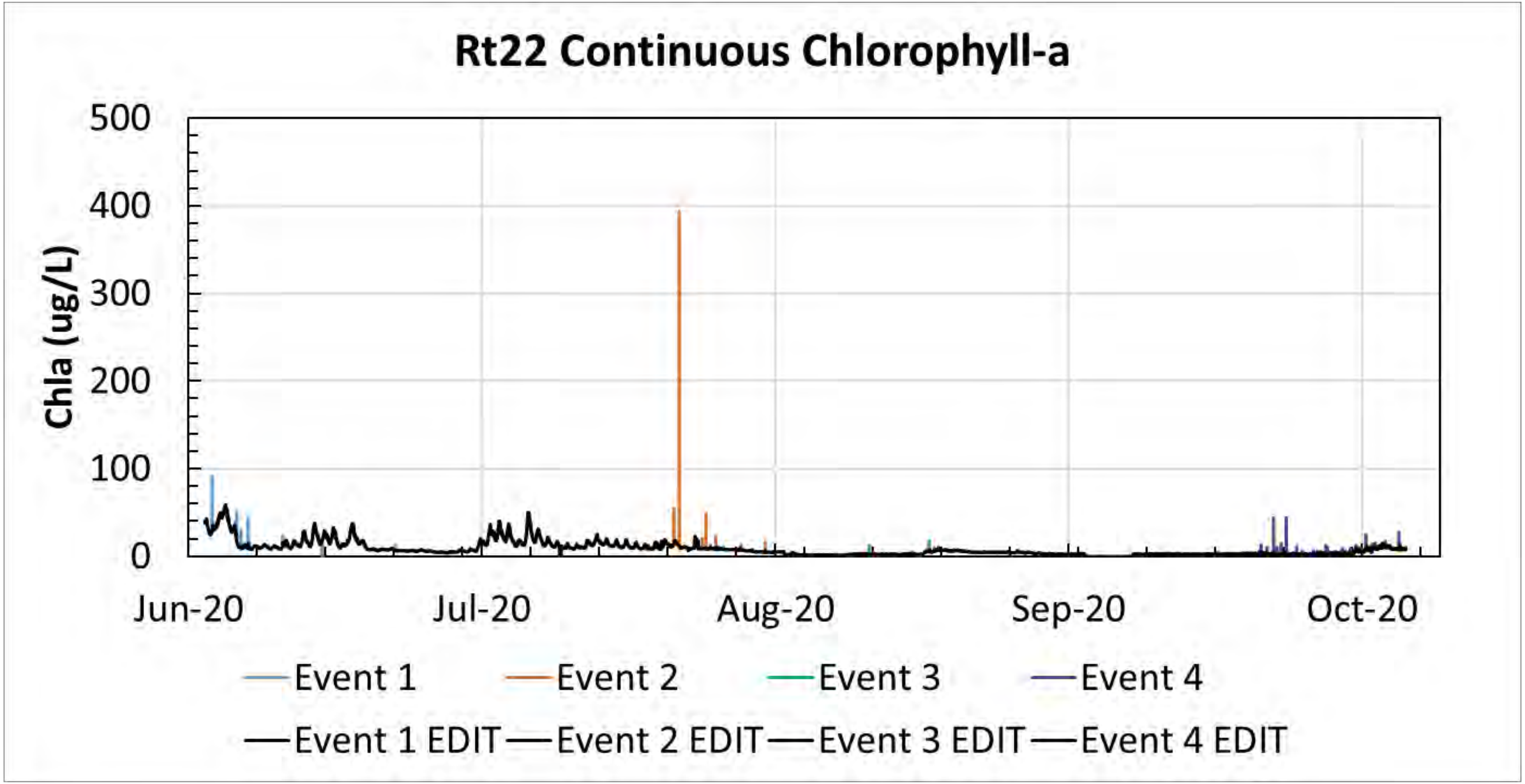
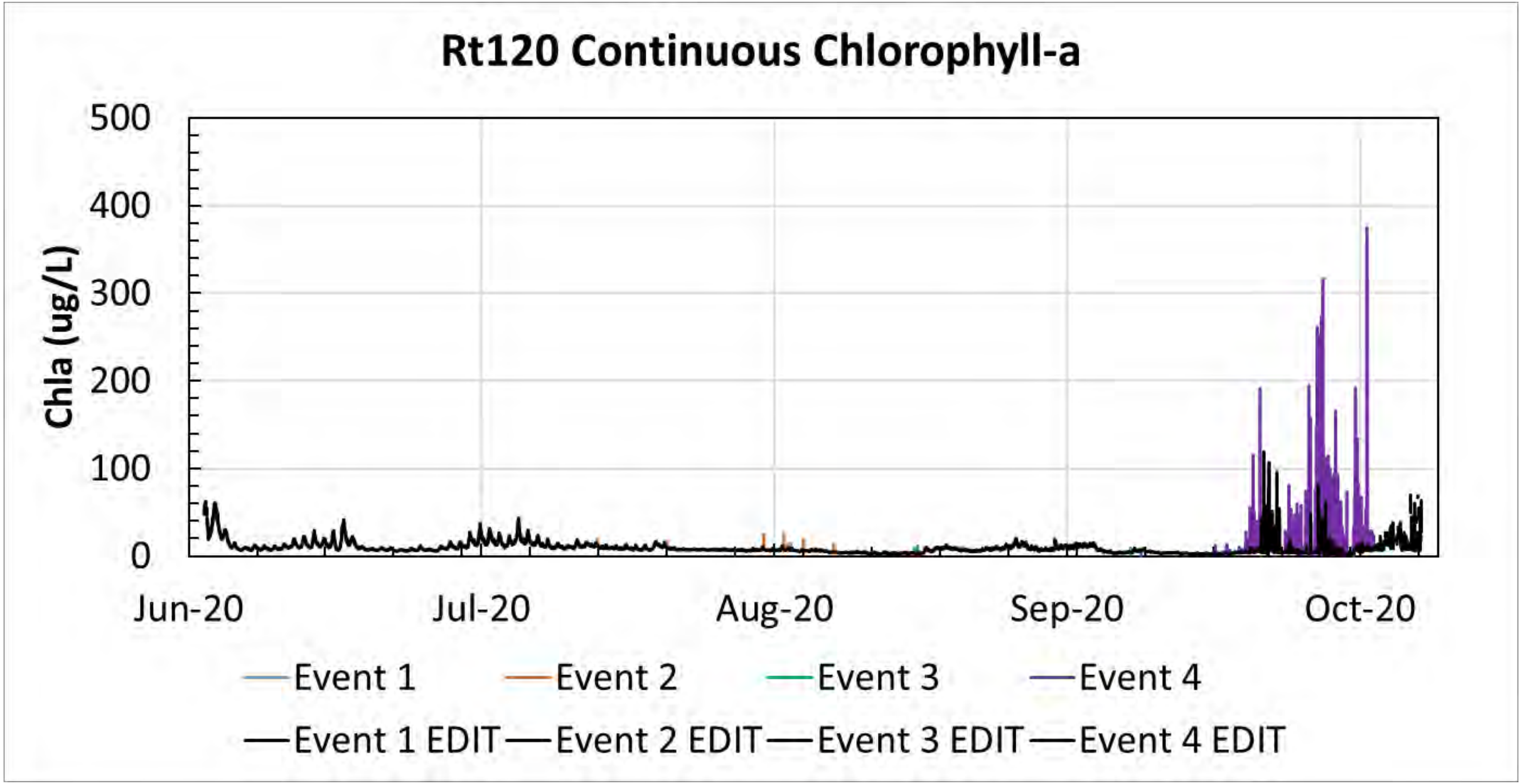
# Observed Chlorophyll-a



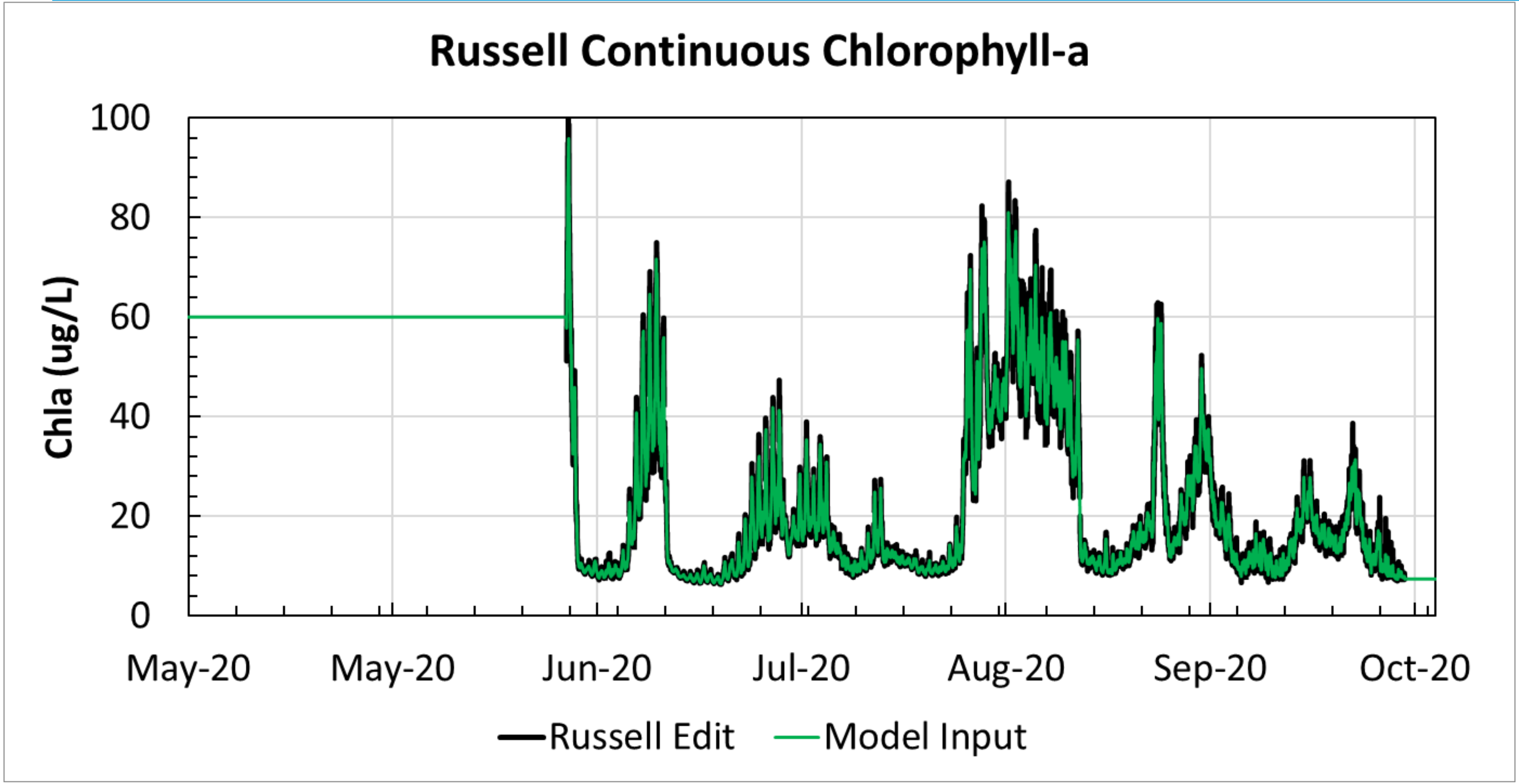
# Observed Chlorophyll-a



# Observed Chlorophyll-a



# Upstream Boundary



# Tributaries

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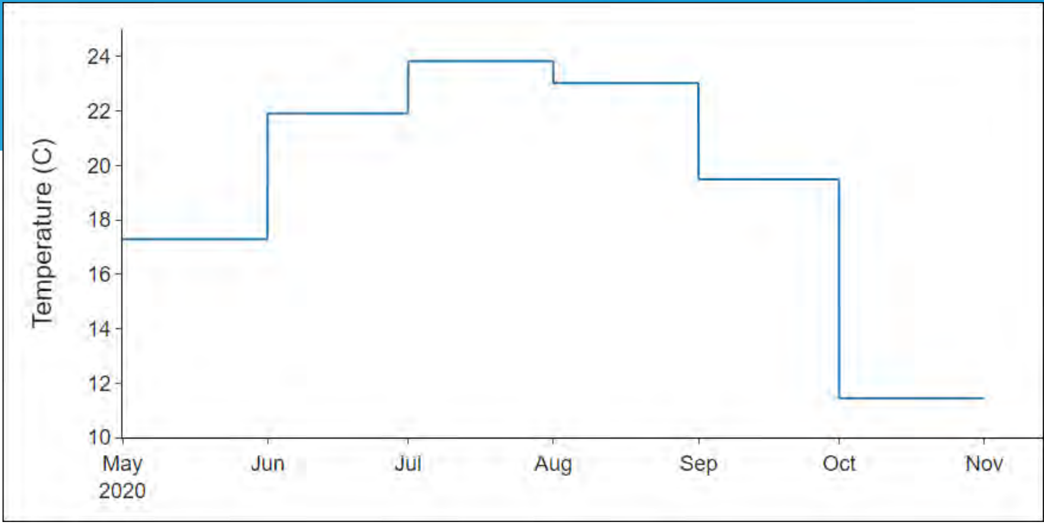
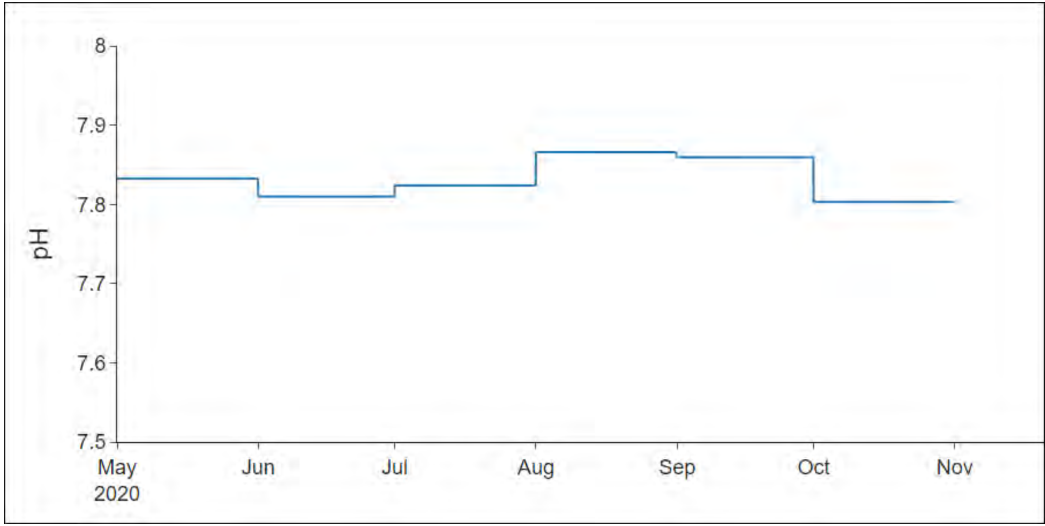
# Tributaries

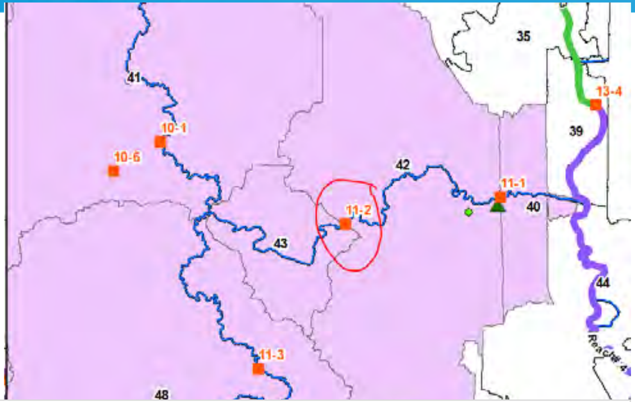
- Temperature & pH
  - Average monthly observed tributaries data
- SWAT output
  - Daily

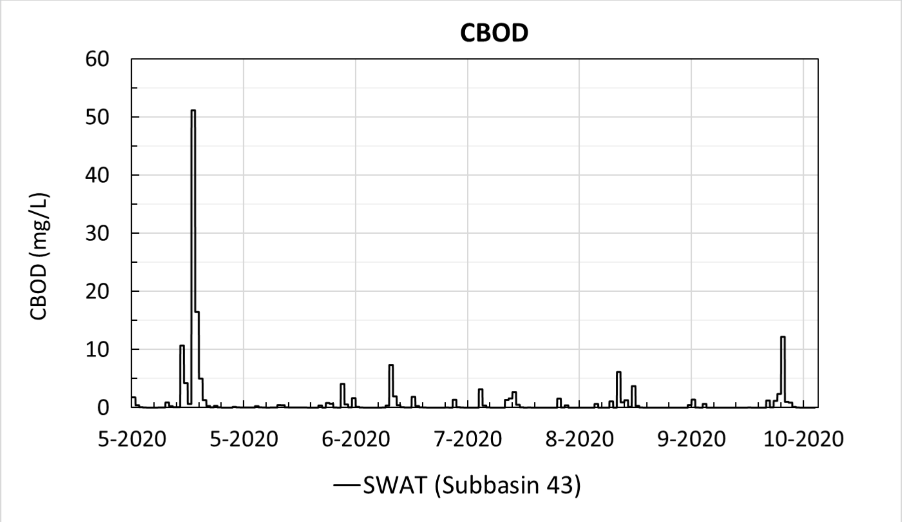


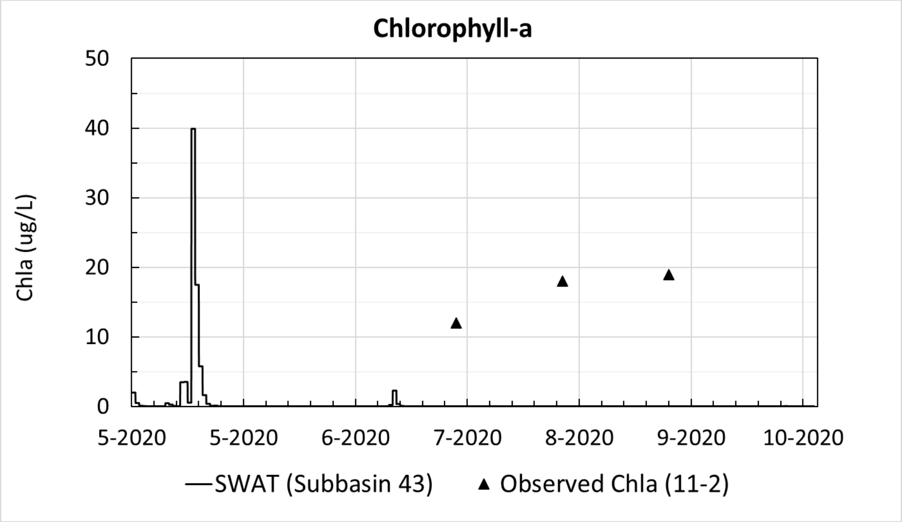



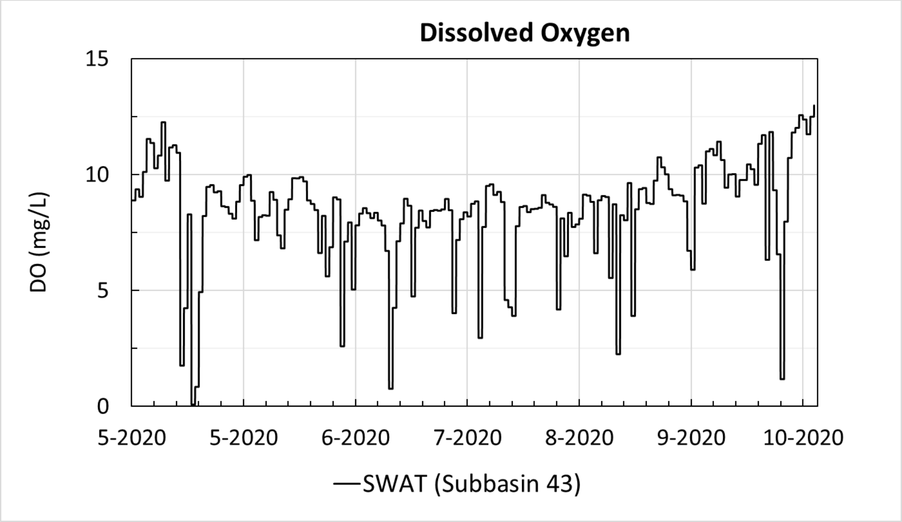
# Tributaries

## SWAT



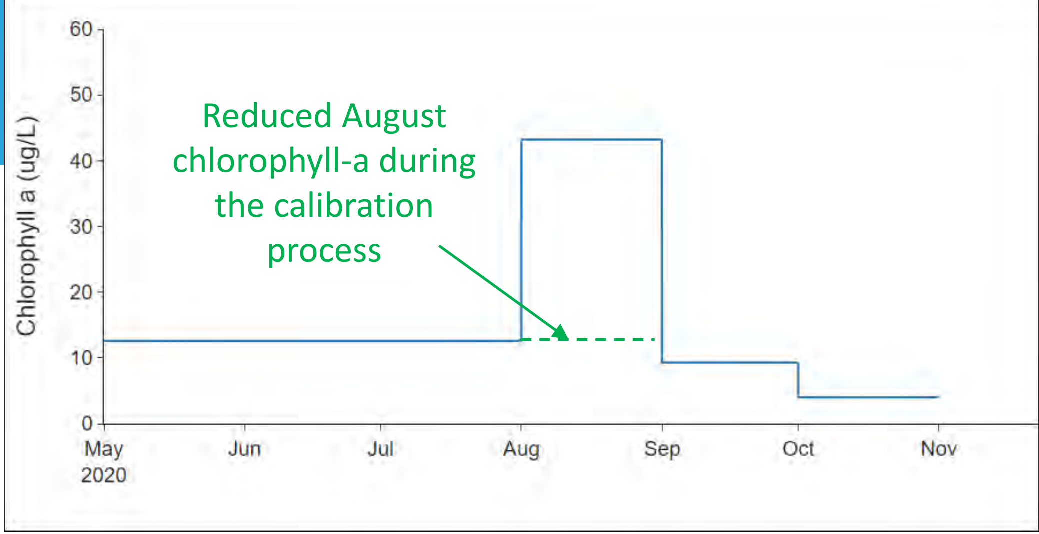



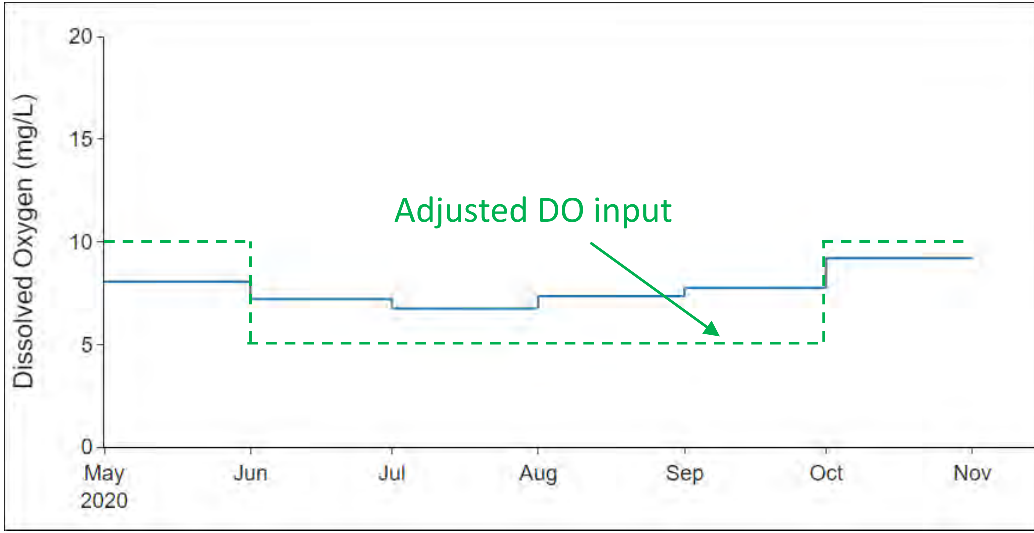



# Tributaries

- Chlorophyll-a & dissolved oxygen
  - Average monthly observed tributaries data
- CBOD
  - Upstream 2.38 mg/L



# Wastewater Treatment Plants

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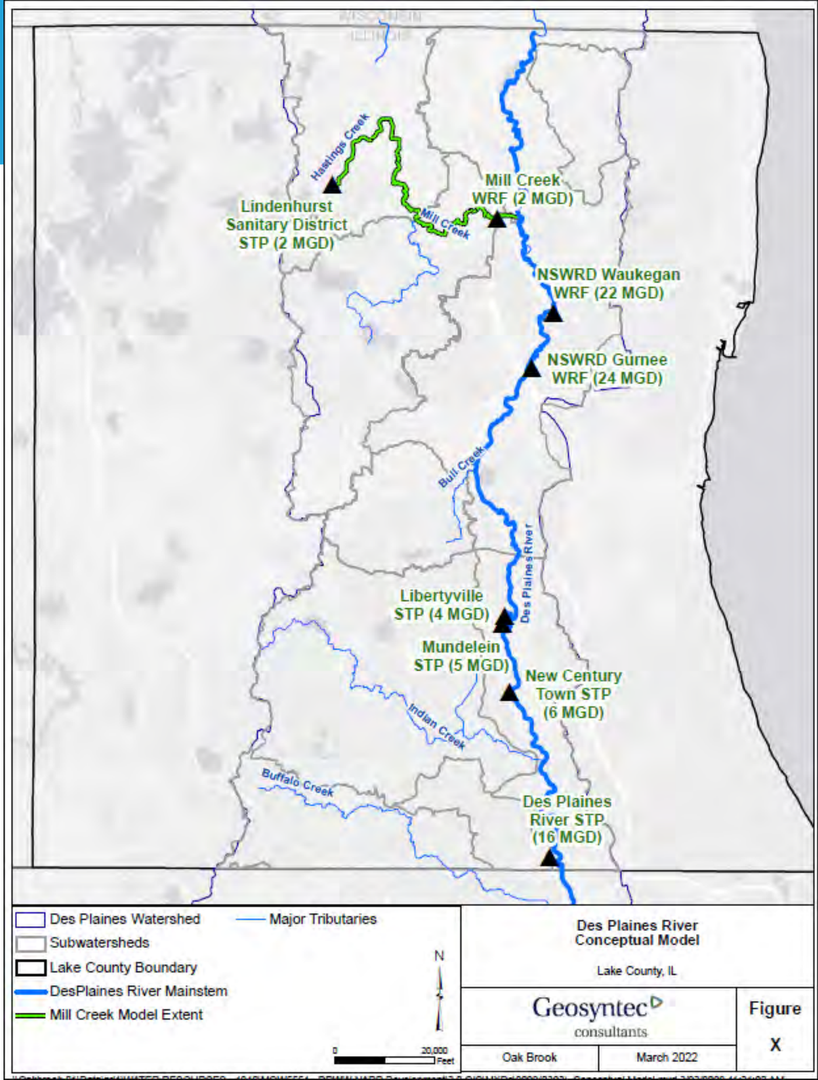
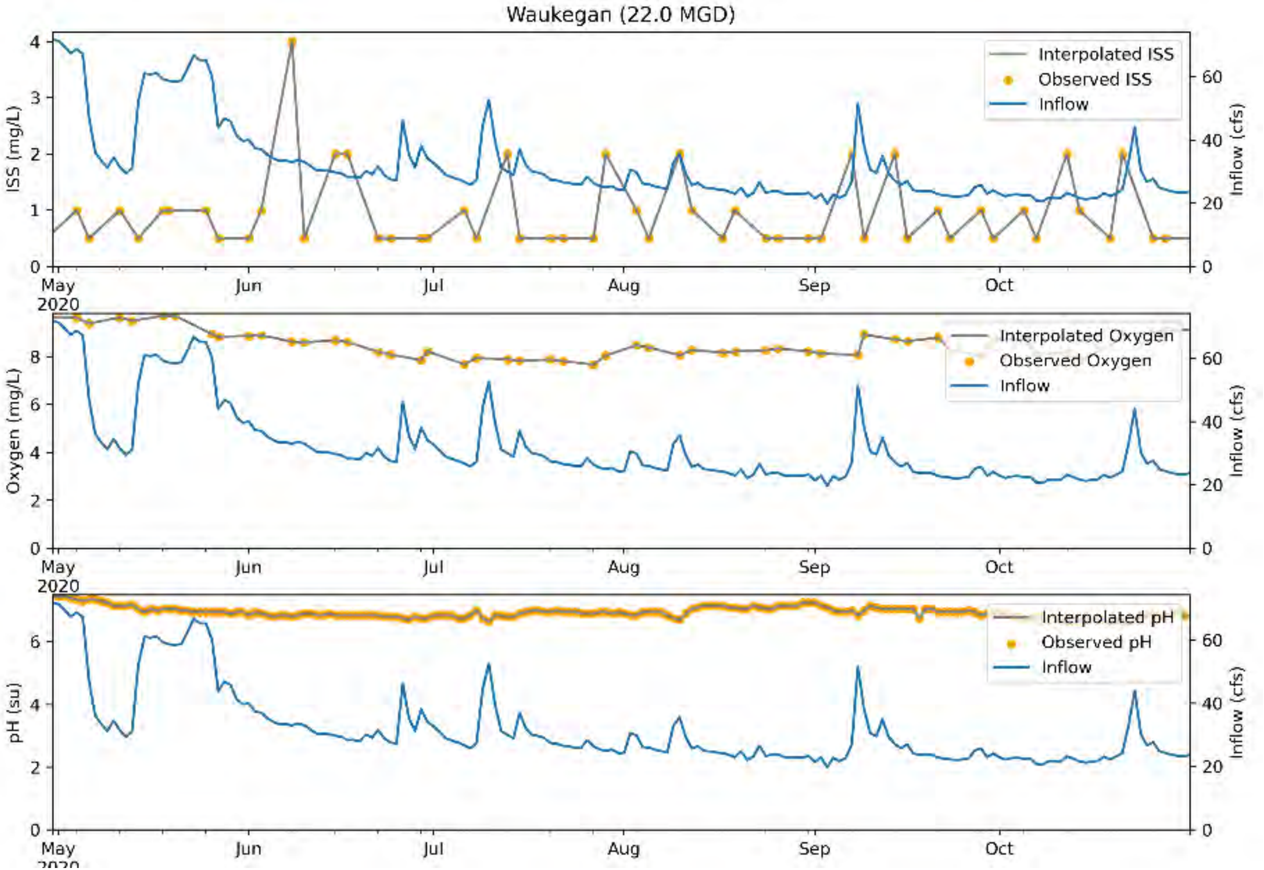
# Point Sources

- Six plants on the mainstem
  - NSWRD Waukegan
  - NSWRD Gurnee
  - Libertyville
  - Mundelein
  - New Century Town
  - Des Plaines River
- Interpolated between daily measured data



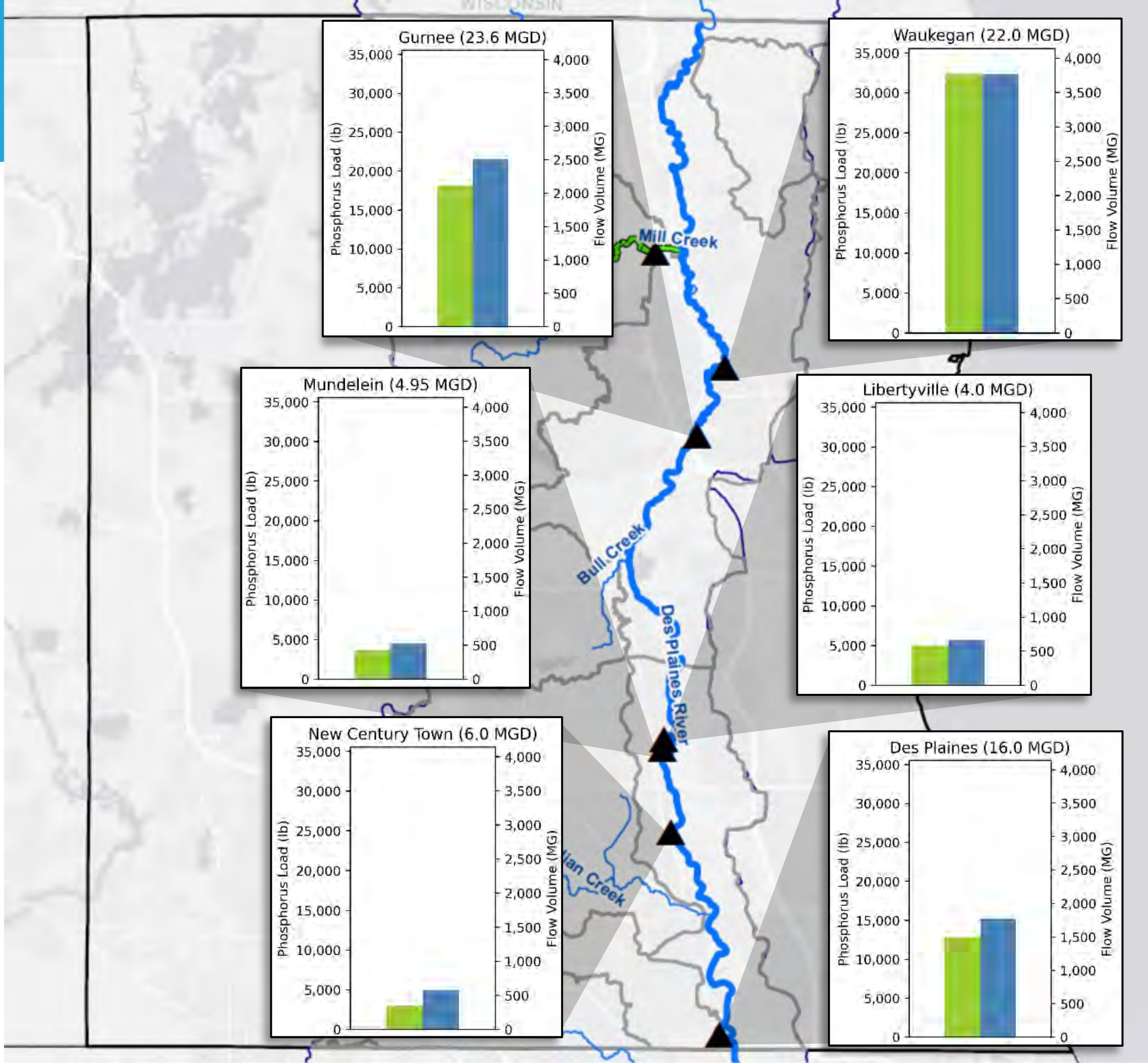
# Point Sources

- Example of Data Interpolation (NSWRD Waukegan)



# TP Conceptual Model

- May to October 2020 WWTPs Total Flow volumes and phosphorus loads.




Phosphorus Load Flow Volume

# Water Quality Calibration Results

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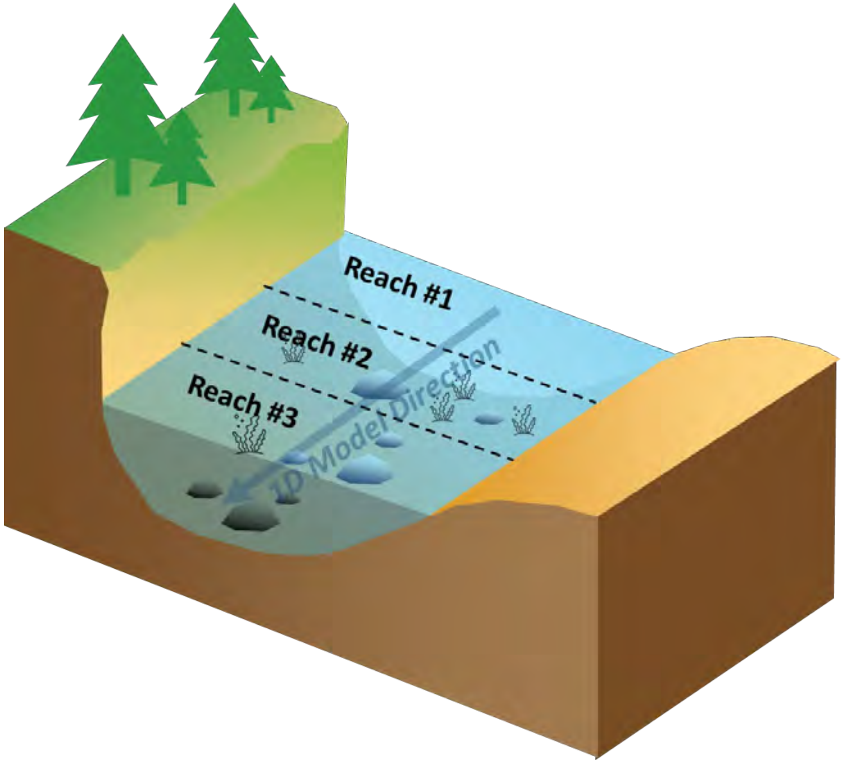
# Qual2kw 1D Models

- Qual2kw 1D model represents a river as a series of reaches with constant hydraulic and water quality characteristics

- In reality, factors influencing water quality might change in the 2D or even 3D
  - Model simulations might not capture all variations in observed data
  - Observed data depends on where the sondes were exactly deployed within each reach



# Model Calibration Error Statistics

- Relative Root Mean Square Error (RRMSE)*
  - RRMSE < 10% → Excellent
  - 10% < RRMSE < 20% → Good
  - 20% < RRMSE < 30% → Fair
  - RRMSE > 30% → Poor

$$\text{RRMSE} = \sqrt{\frac{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(\hat{y}_i)^2}}$$

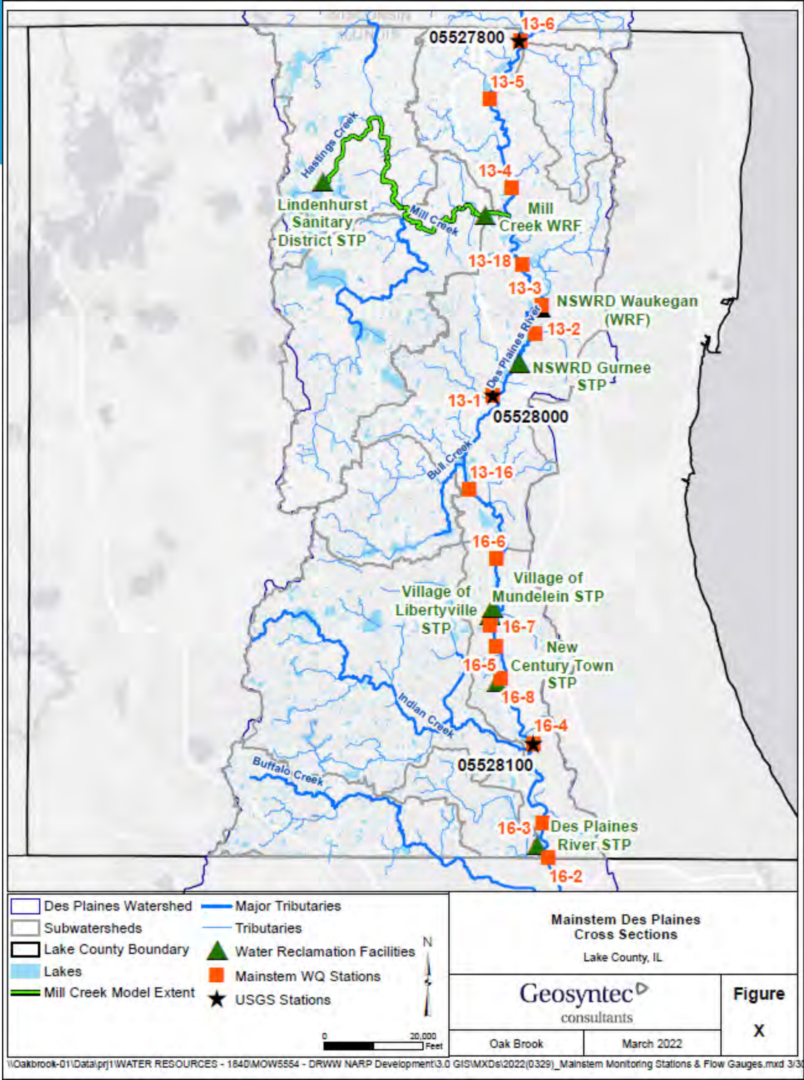


*Evaluation Metric for Regression Models - Analytics Vidhya

# Stations

- 14 water quality stations on the mainstem
  - 2 continuous
  - 11 discrete

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |



# Temperature

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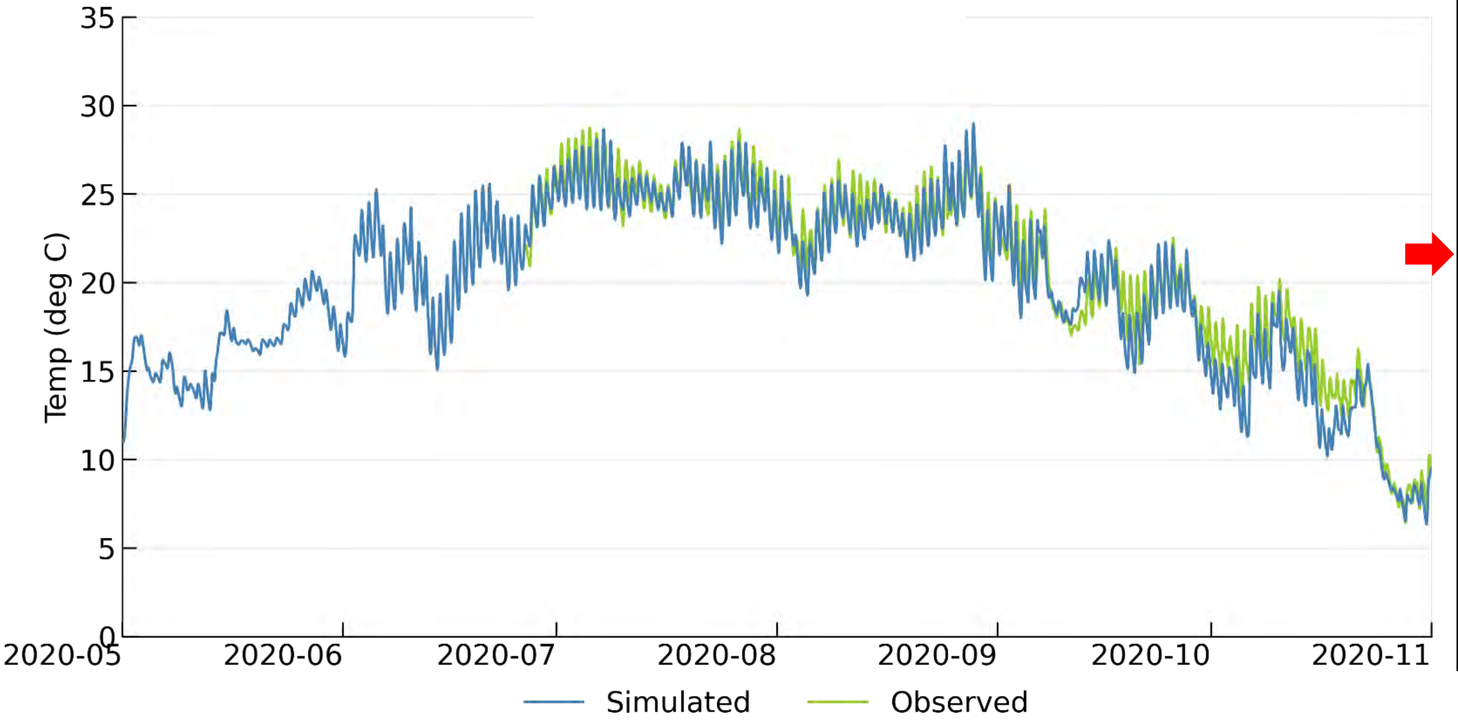
# Rt. 120
# RM: 20.8, Model Seg.#9, Temperature




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
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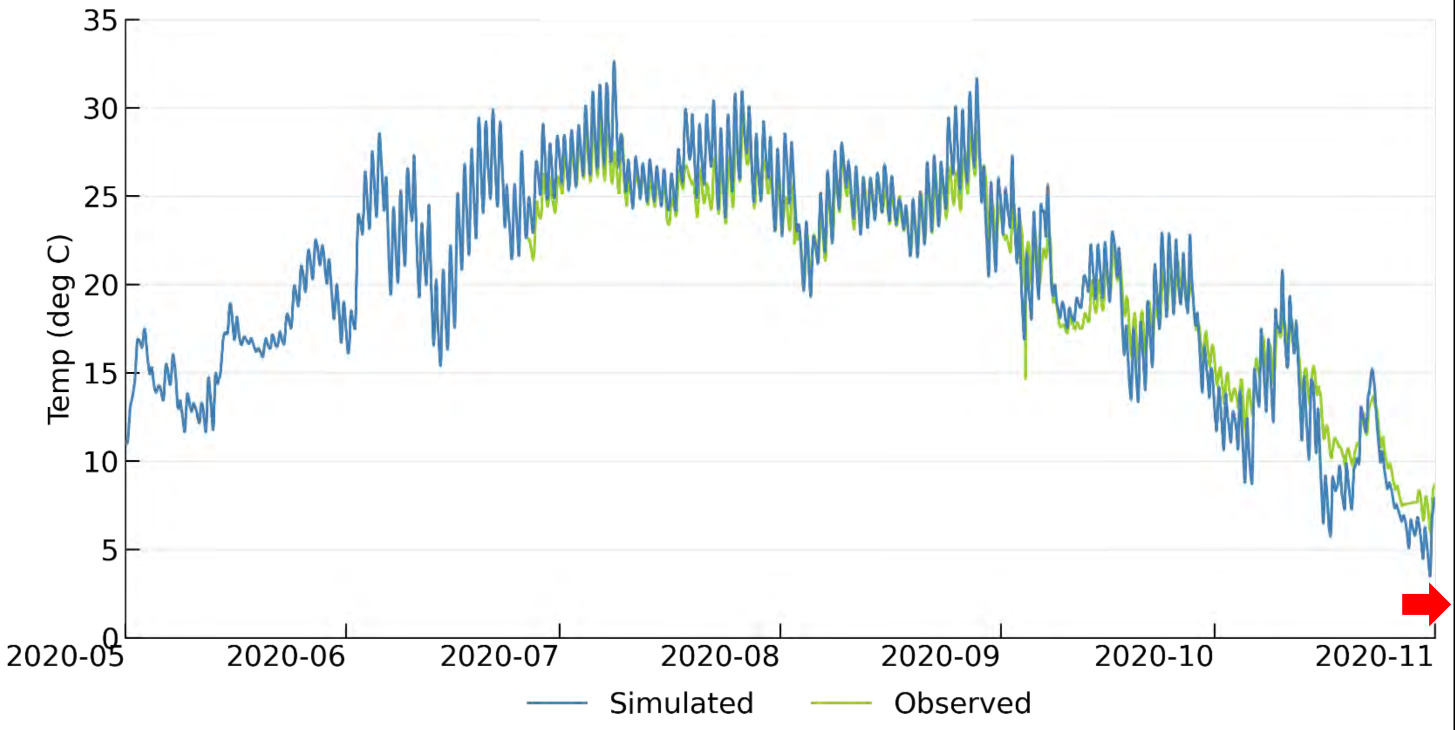
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rt. 22
# RM: 6.7, Model Seg.#17, Temperature




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Total Phosphorus

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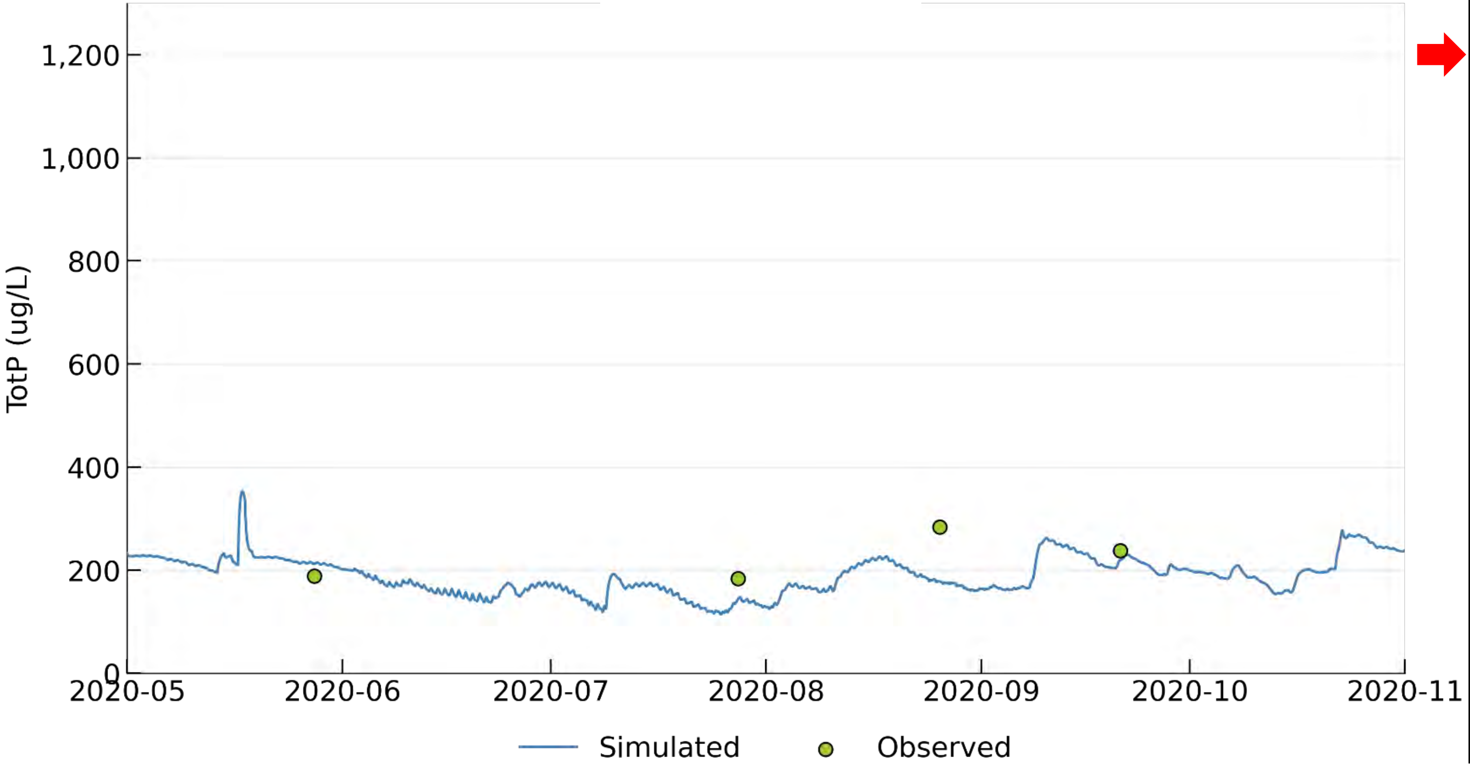
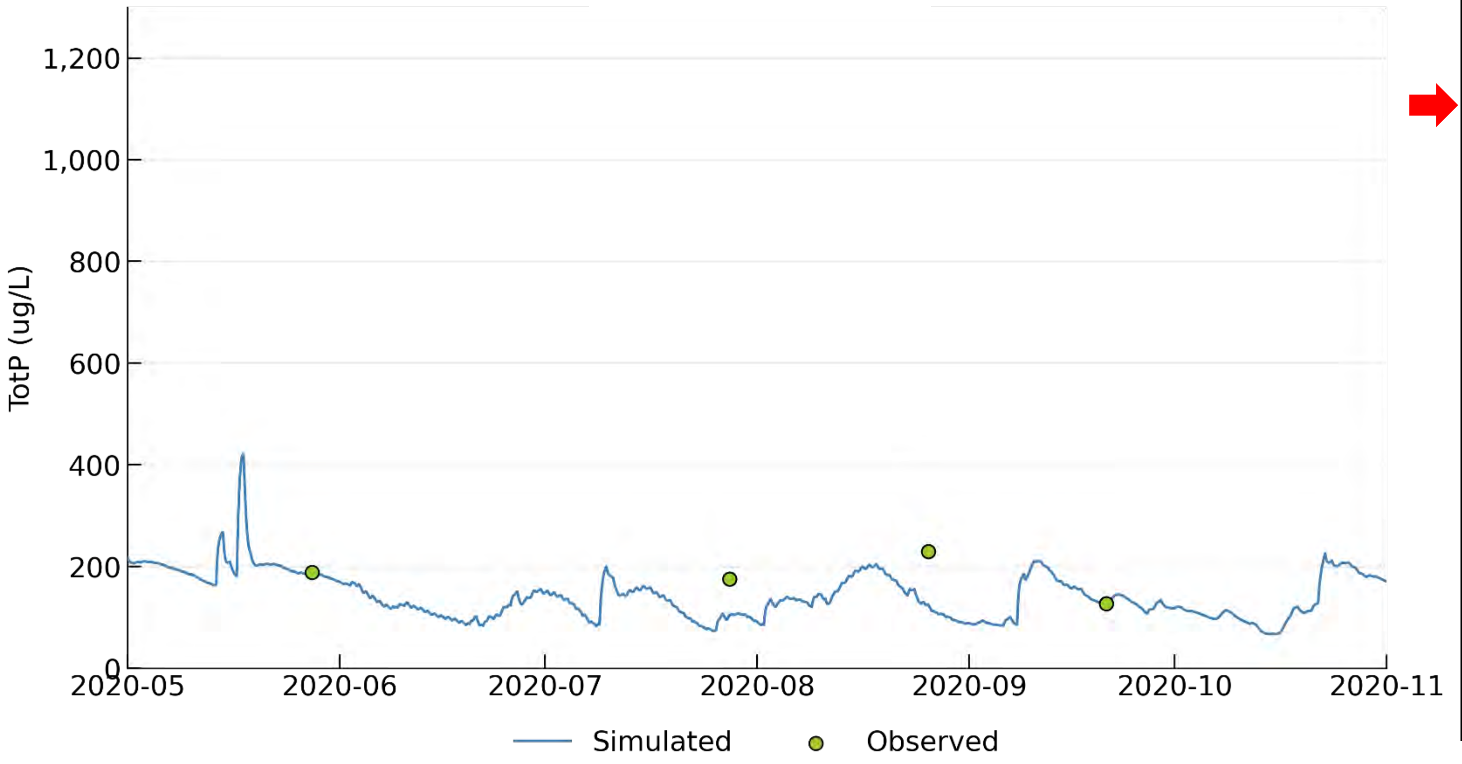
# HWY 173
# RM: 33.0, Model Seg.#1, Total Phosphorus



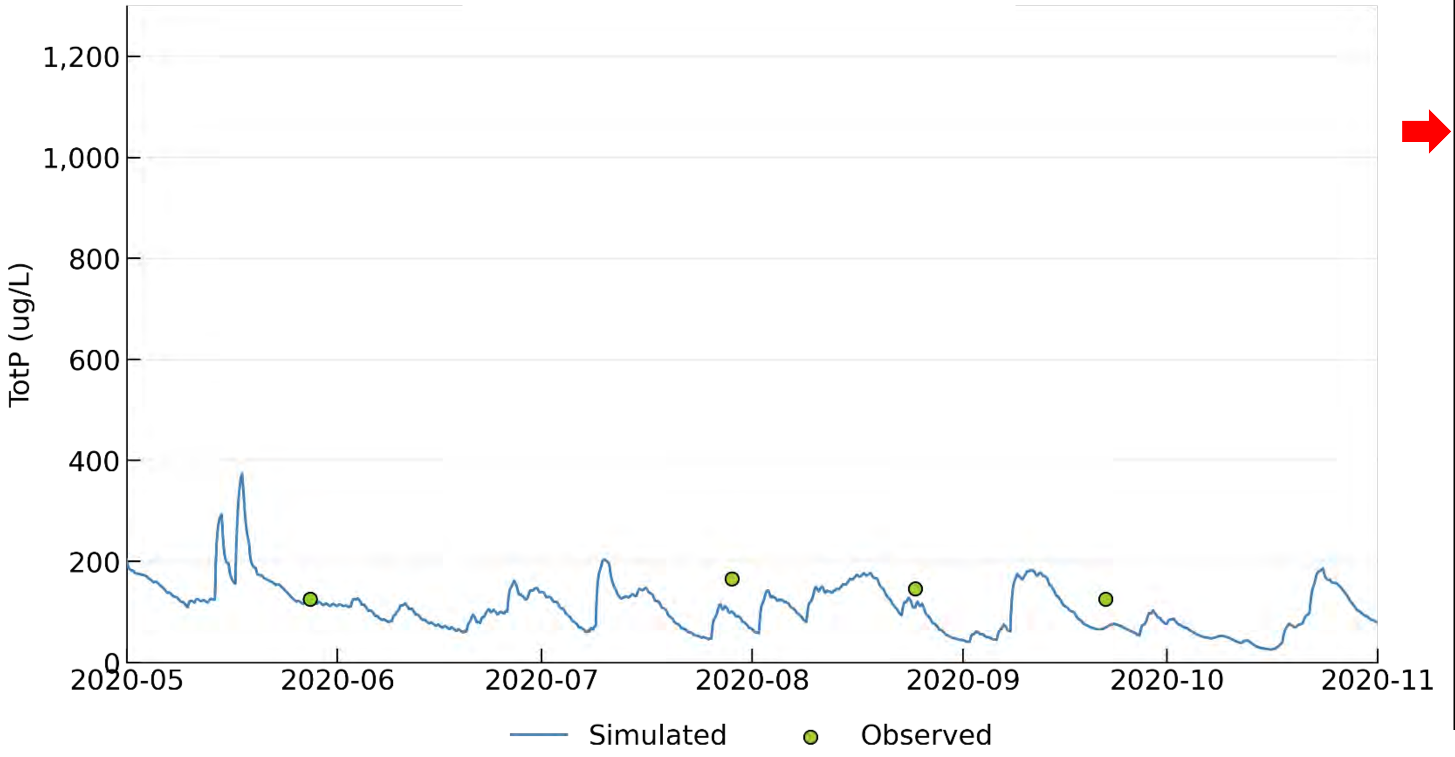

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Wadsworth Rd.
# RM: 29.3, Model Seg.#3, Total Phosphorus



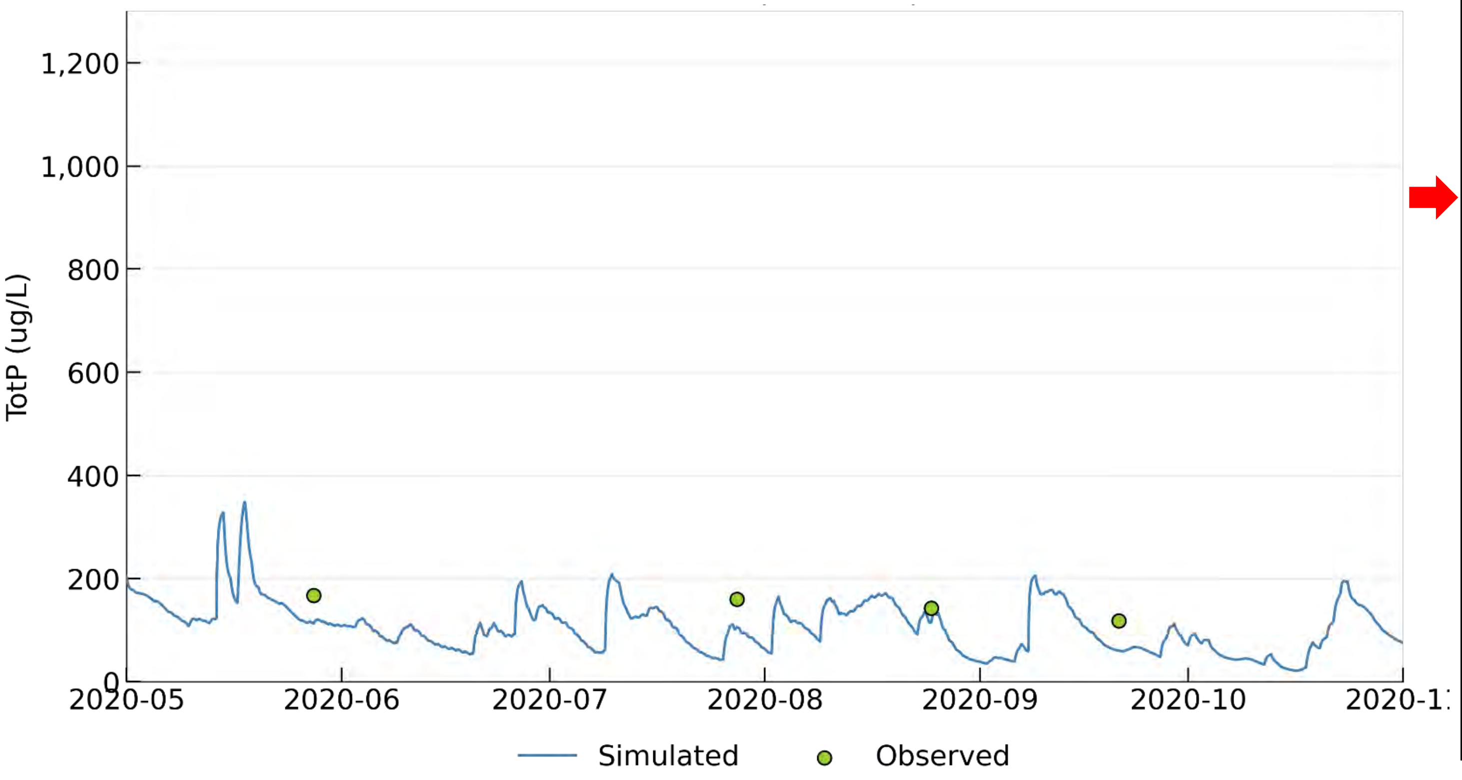

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# US. Wetland Research Inc.
# RM: 26.3, Model Seg.#4, Total Phosphorus



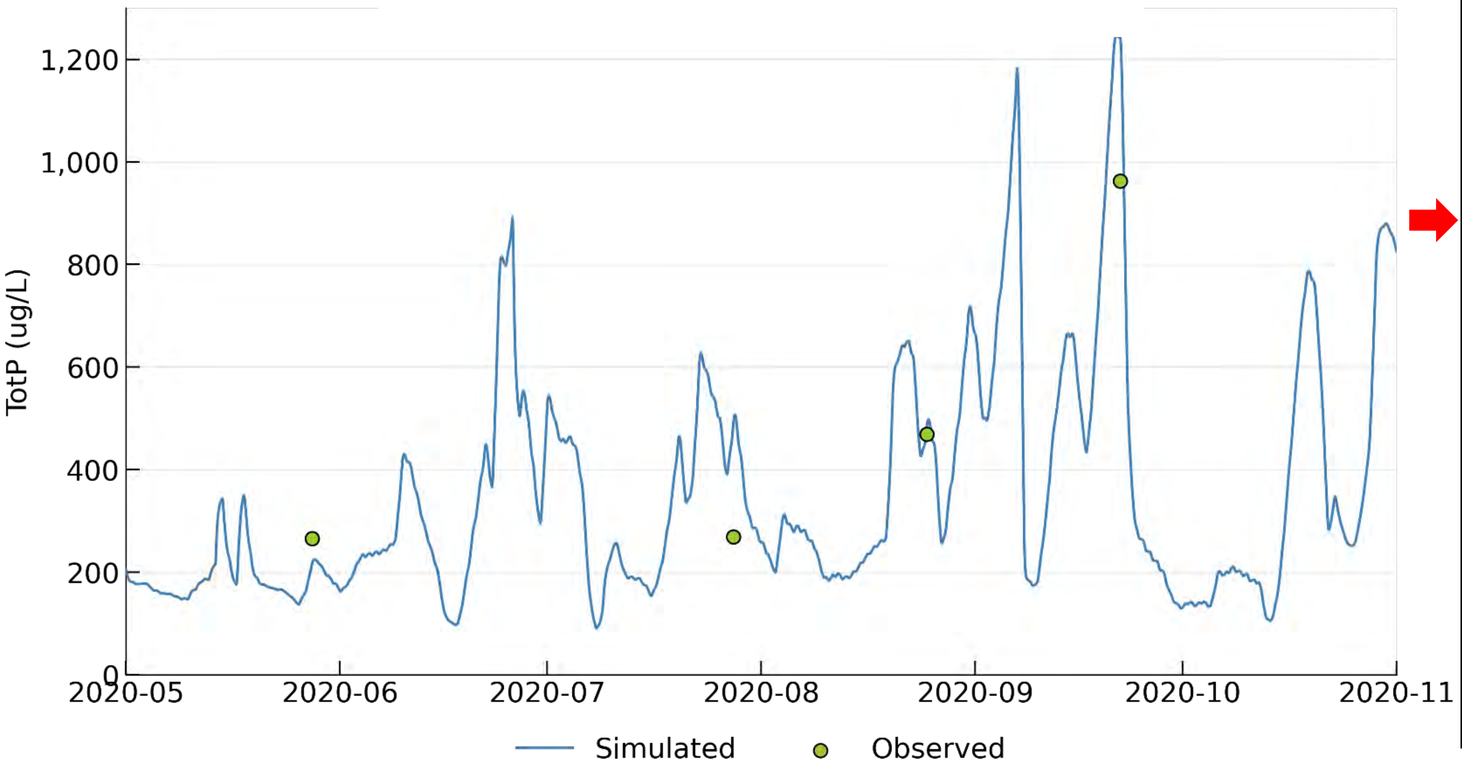

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# HWY 41
# RM: 24.7, Model Seg.#5, Total Phosphorus



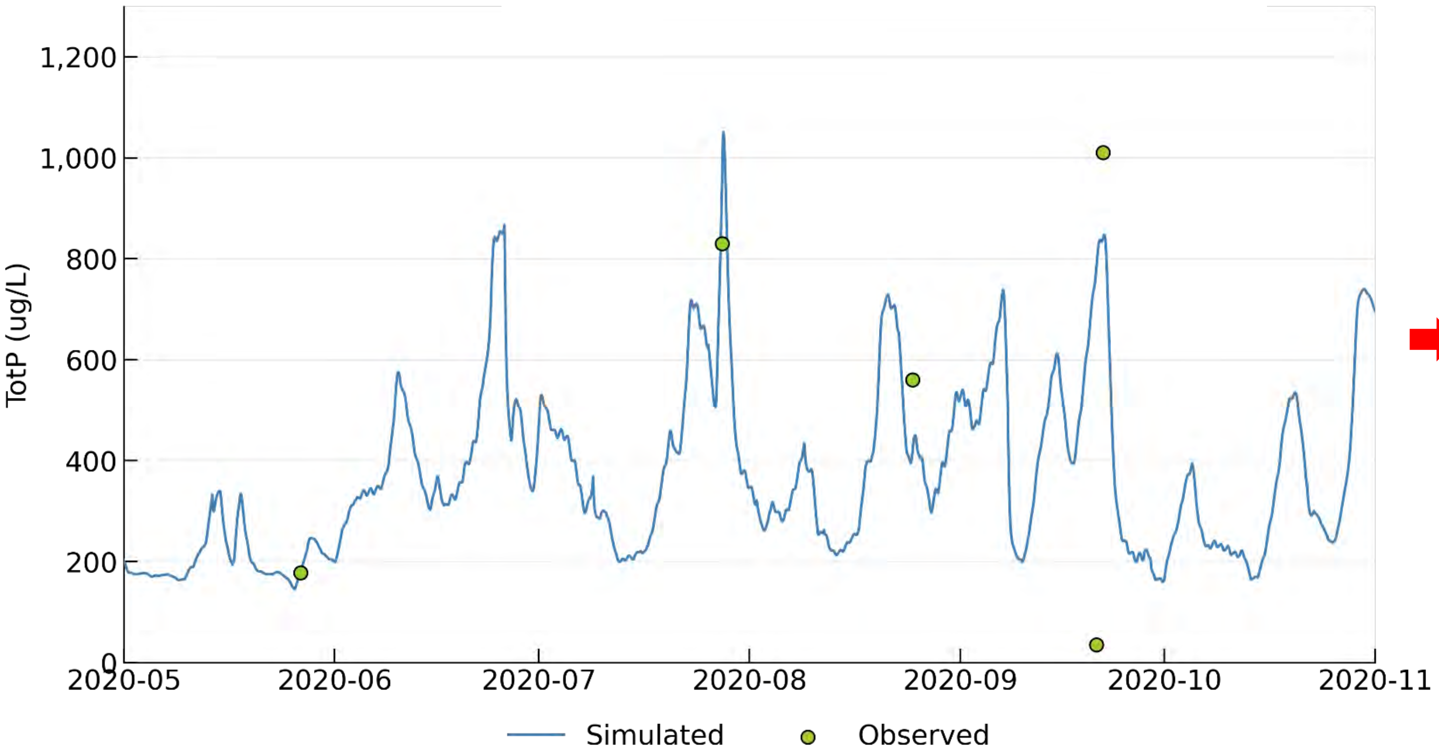

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# McClure Ave.
# RM: 23.3, Model Seg.#6, Total Phosphorus



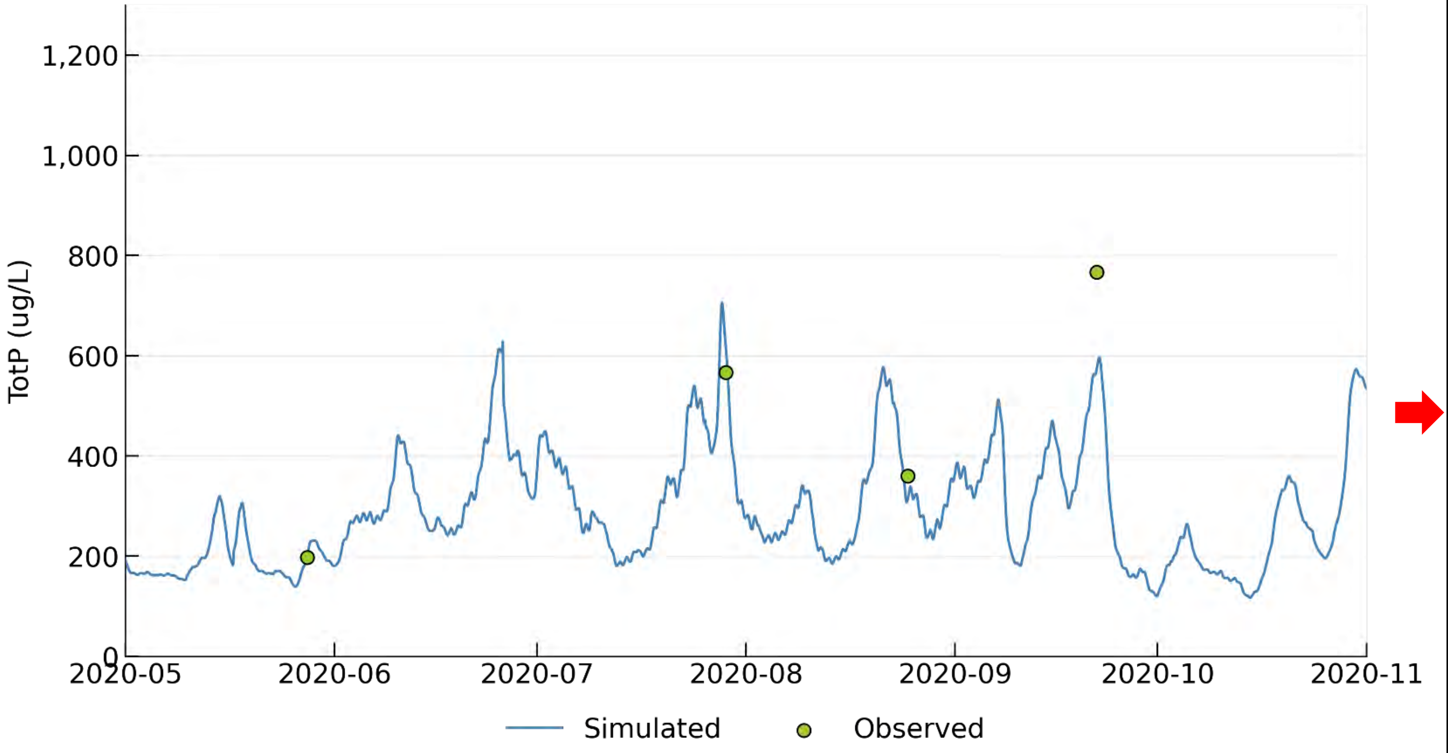

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# HWY 120
# RM: 20.8, Model Seg.#9, Total Phosphorus



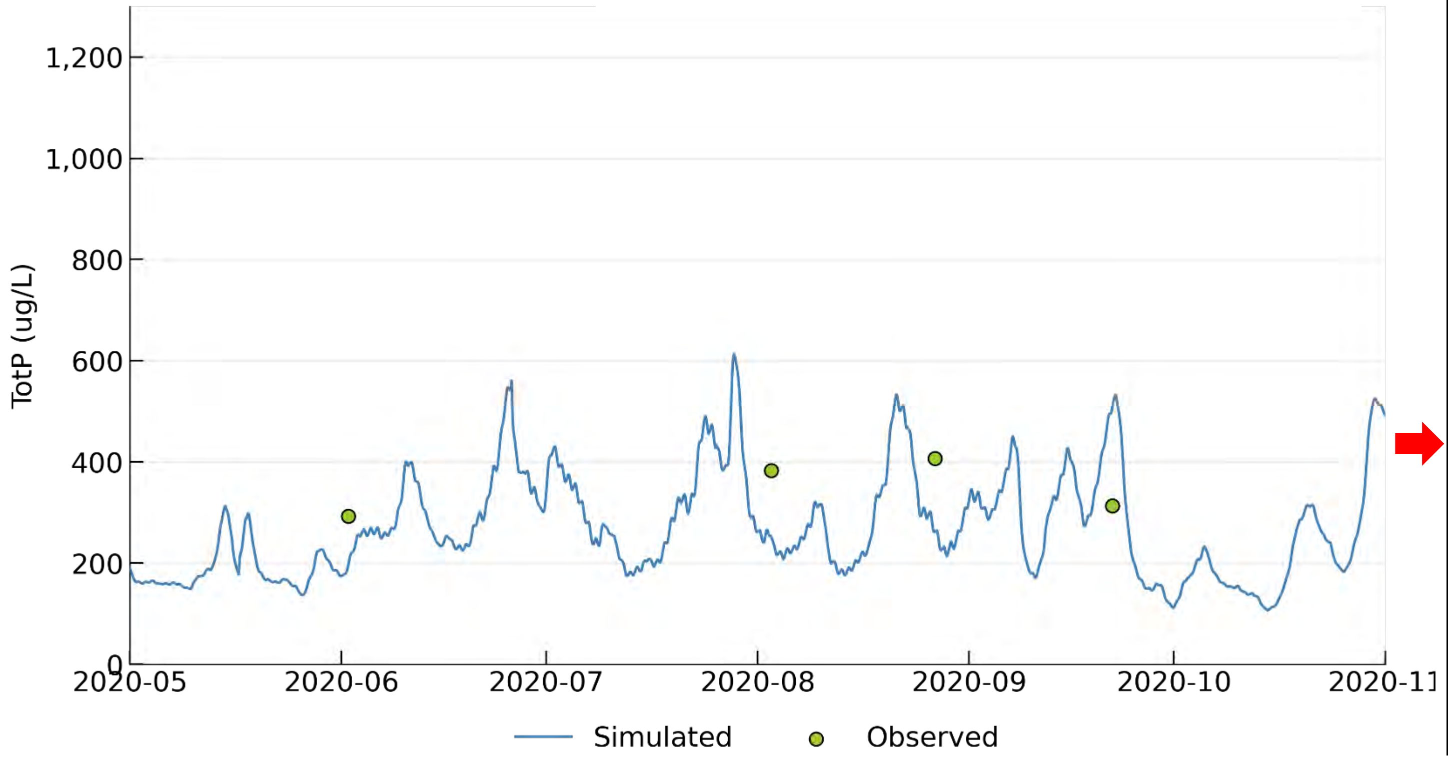

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Buckley Rd.
# RM: 16.5, Model Seg.#11, Total Phosphorus



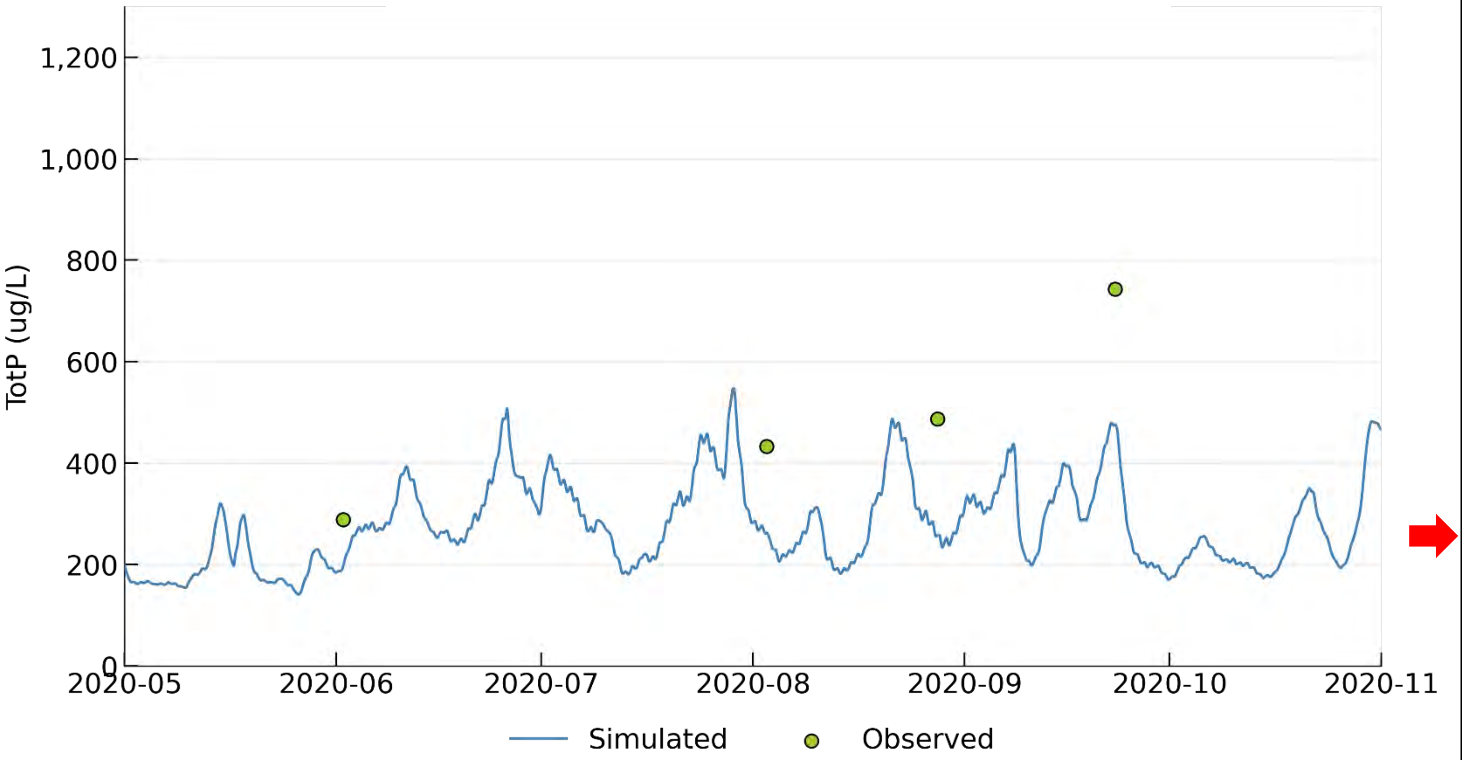

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rockland Rd.
# RM: 14.4, Model Seg.#12, Total Phosphorus



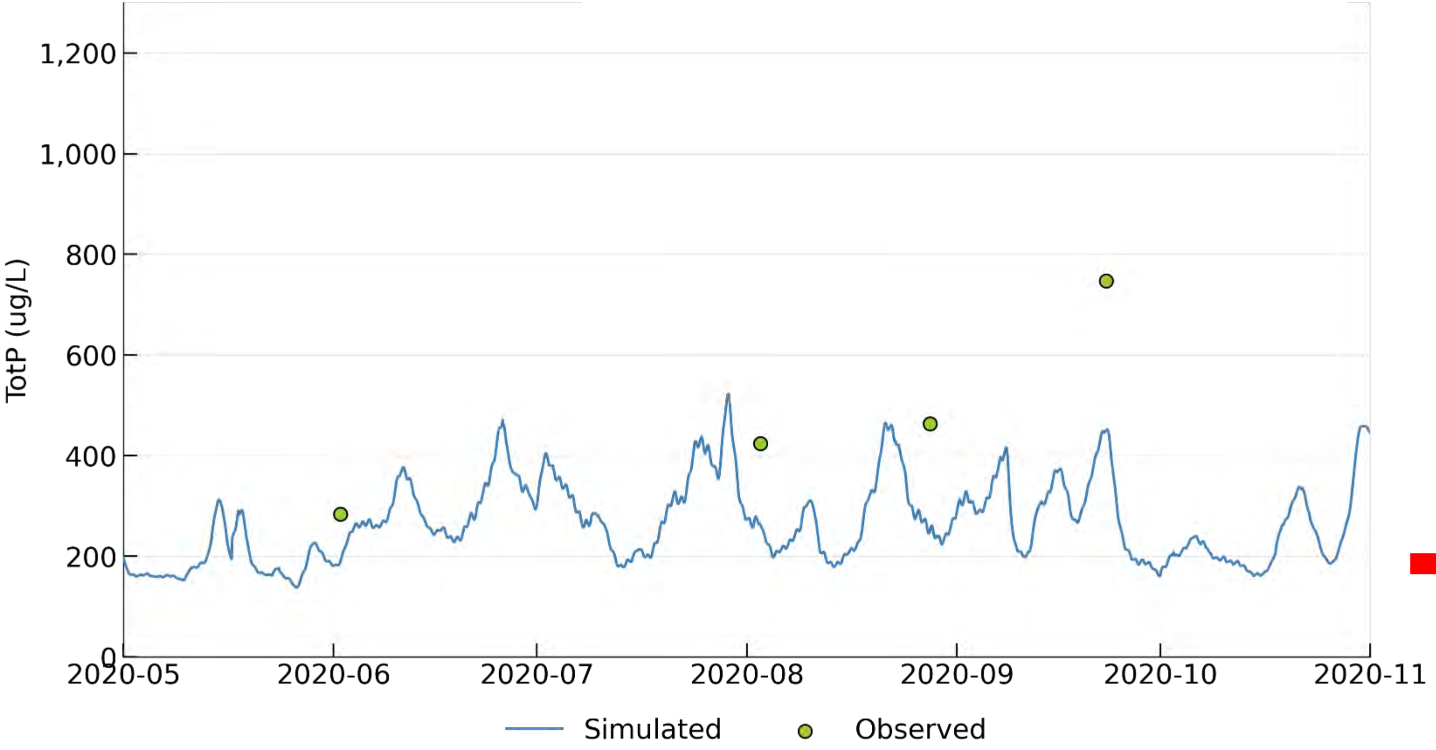

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Hollister Dam
# RM: 10.5, Model Seg.#14, Total Phosphorus



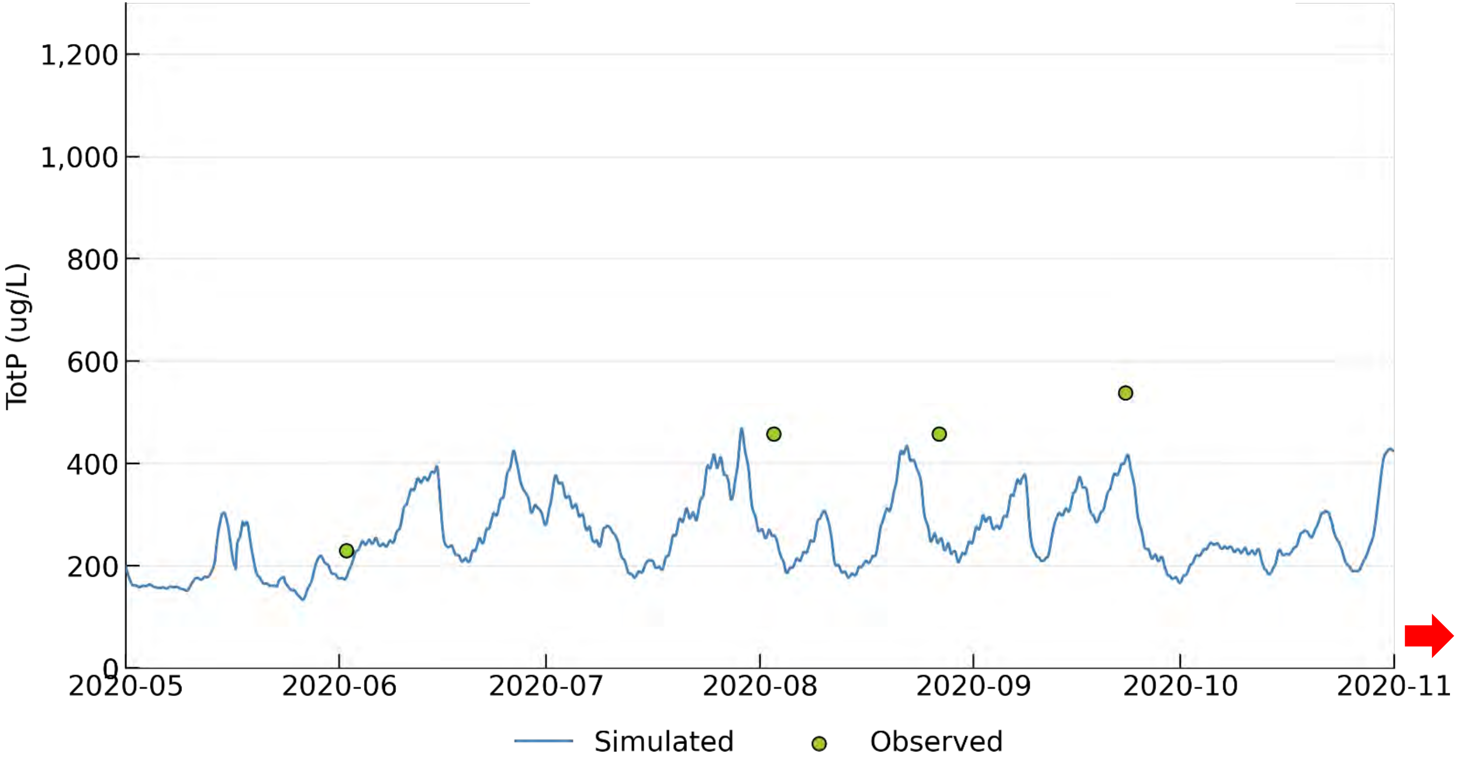

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Wright Woods Dam
# RM: 9.3, Model Seg.#15, Total Phosphorus



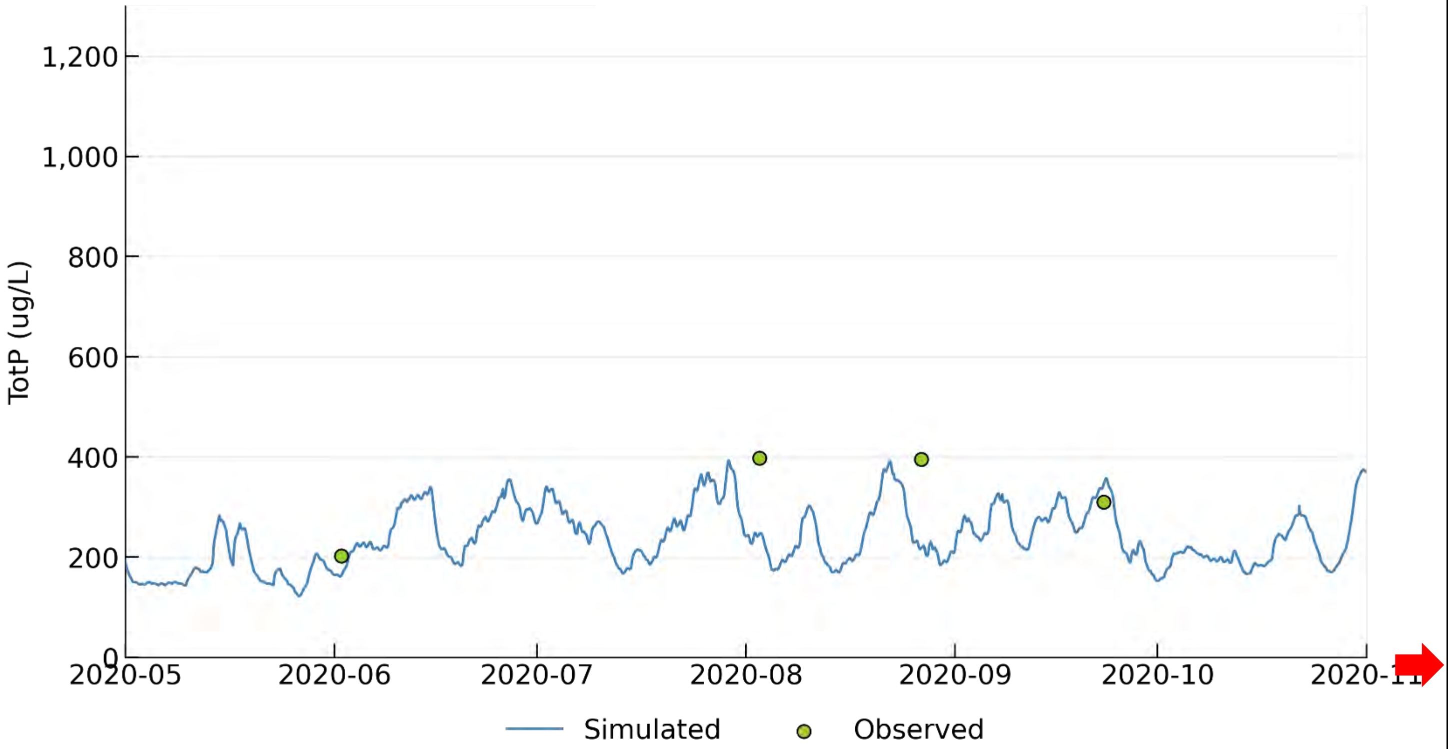

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rt. 22
# RM: 6.7, Model Seg.#17, Total Phosphorus



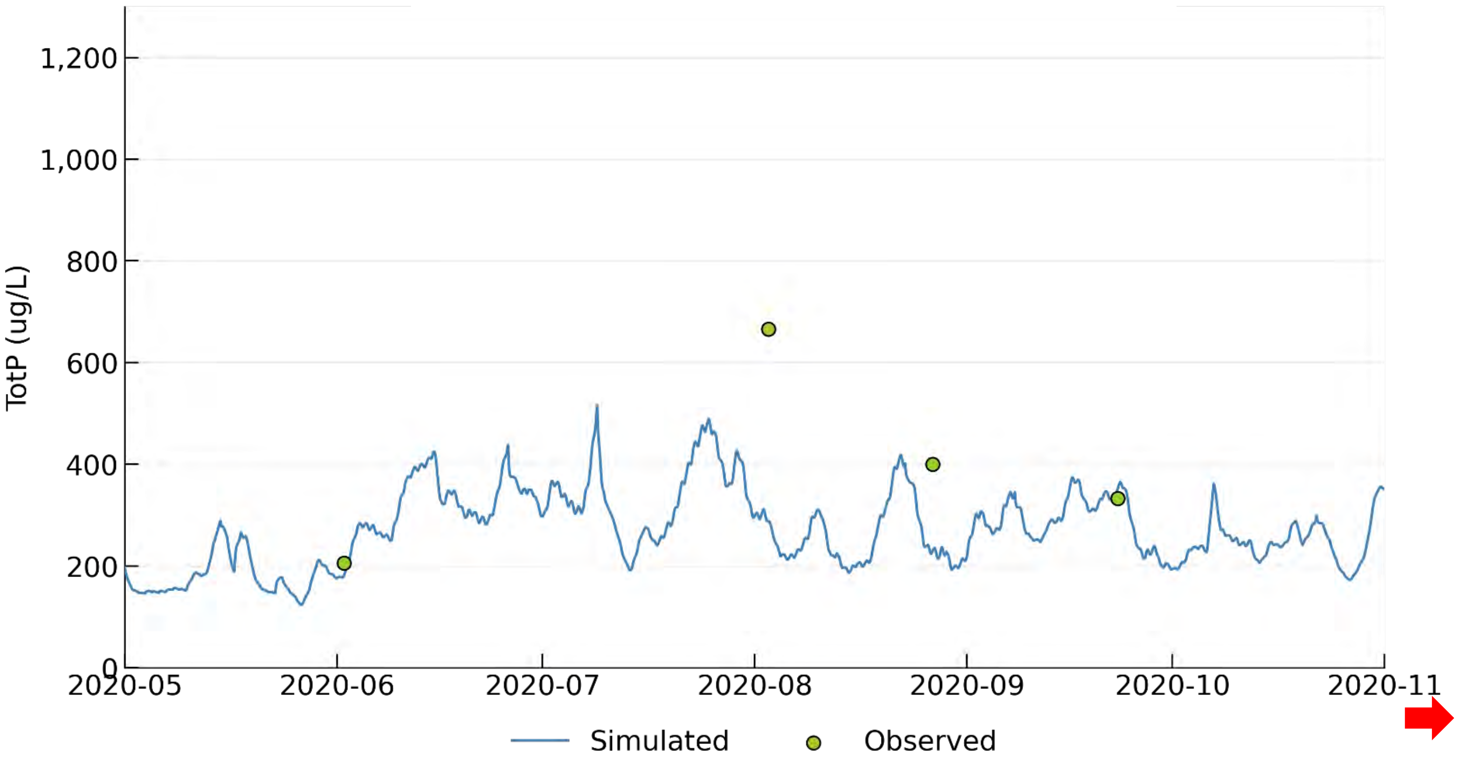

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Deerfield Rd.
# RM: 3.3, Model Seg.#18, Total Phosphorus




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# E. Lake Cook Rd.
# RM: 2.4, Model Seg.#19, Total Phosphorus

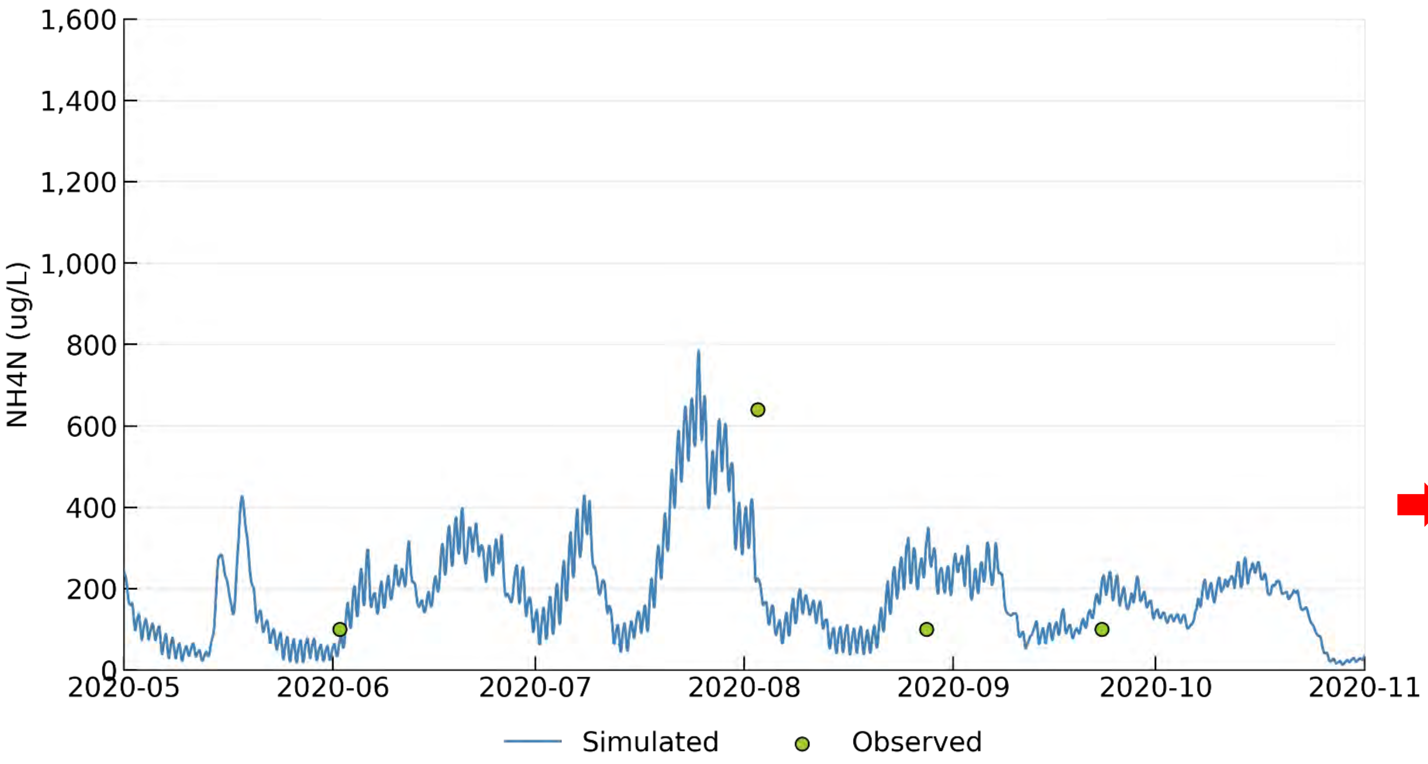



| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Ammonia

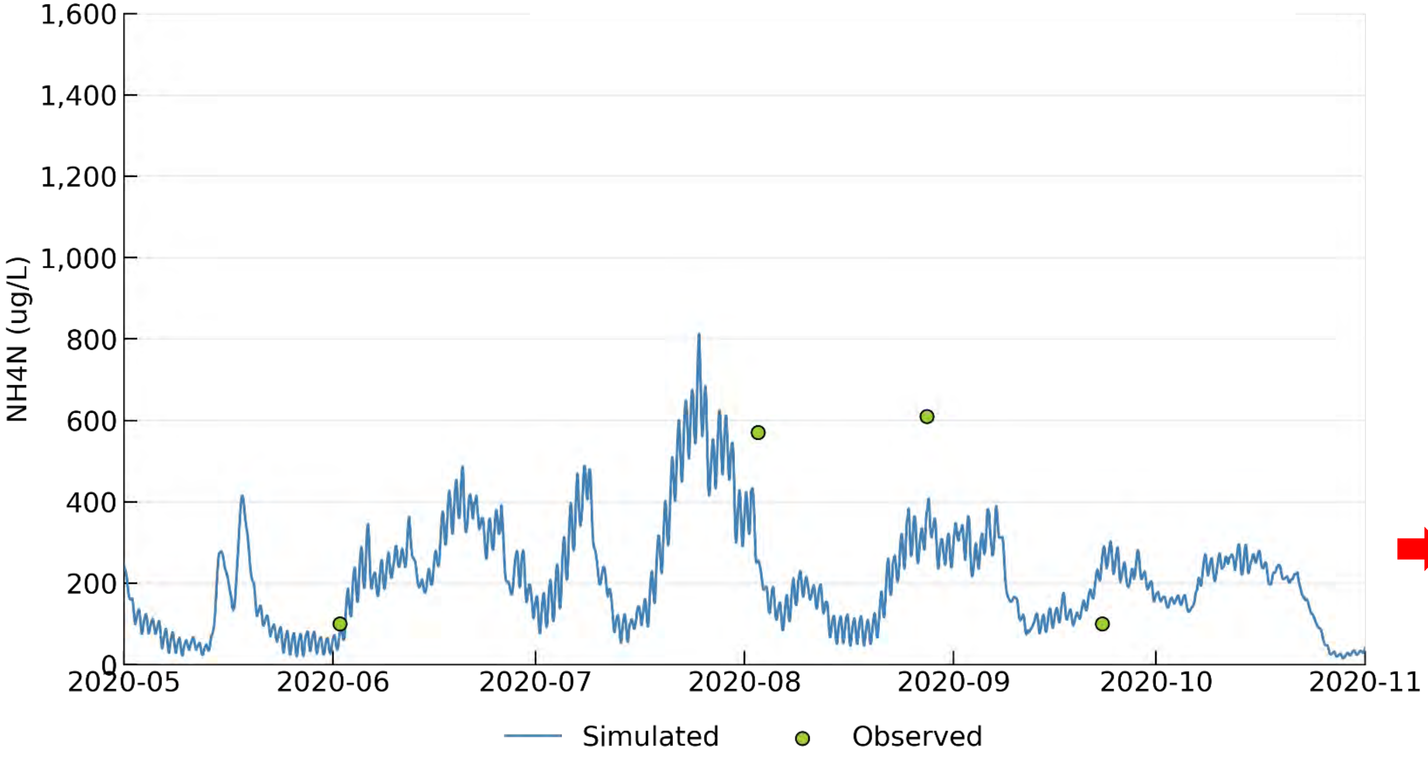
Geosyntec consultants

# Hollister Dam
# RM: 10.5, Model Seg.#14, Ammonia



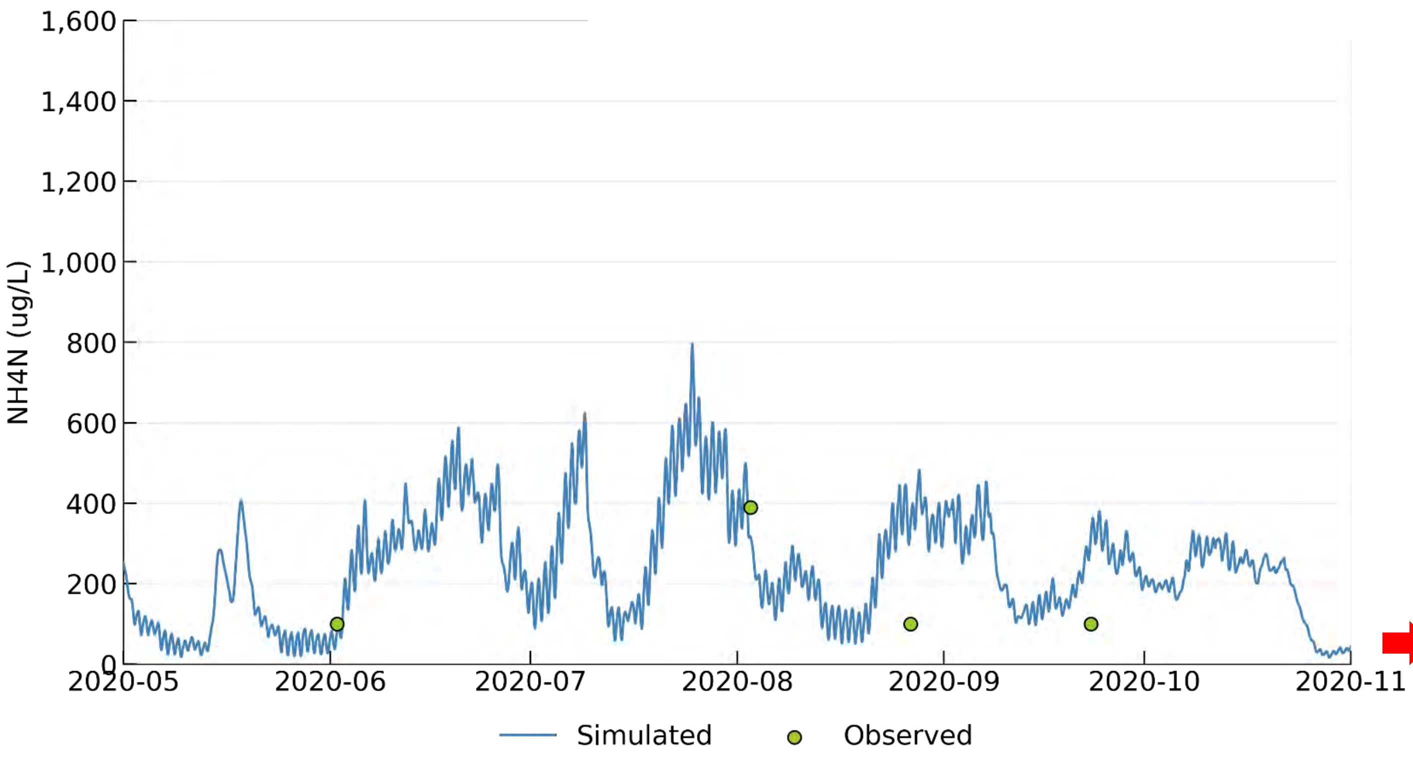

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Wright Woods Dam
# RM: 9.3, Model Seg.#15, Ammonia




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rt. 22
# RM: 6.7, Model Seg.#17, Ammonia

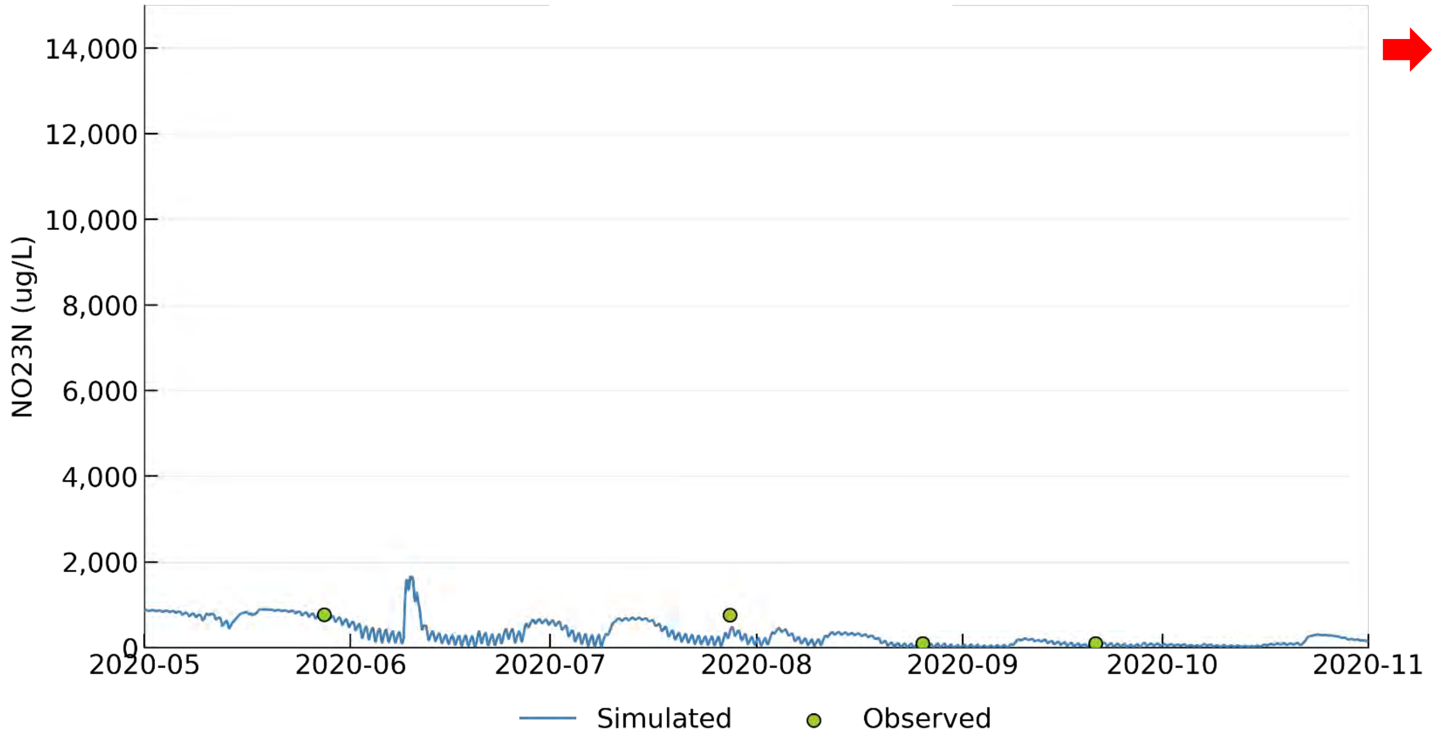



| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Nitrate-Nitrite

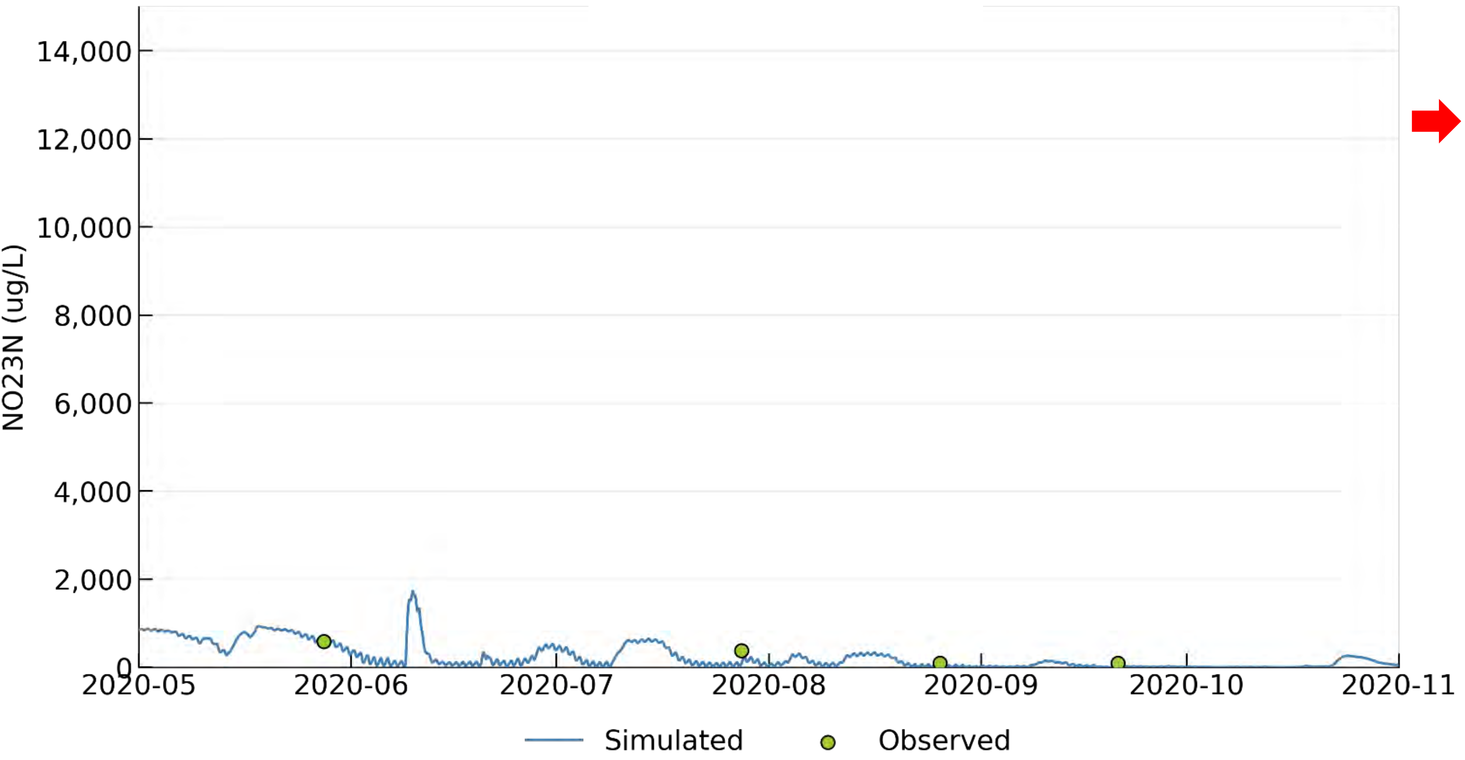
Geosyntec consultants

# HWY 173
# RM: 33.0, Model Seg.#1, Nitrate-Nitrite



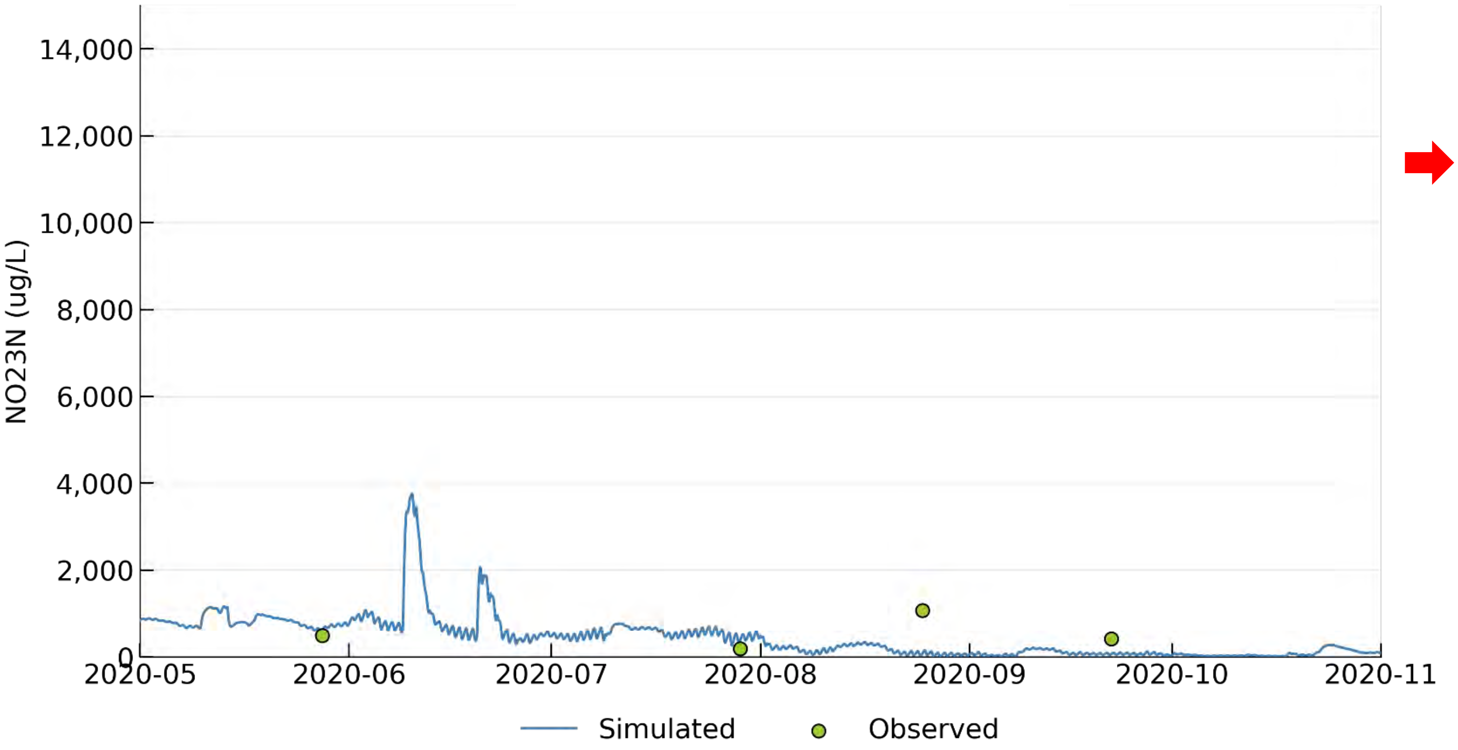

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Wadsworth Rd.
# RM: 29.3, Model Seg.#3, Nitrate-Nitrite



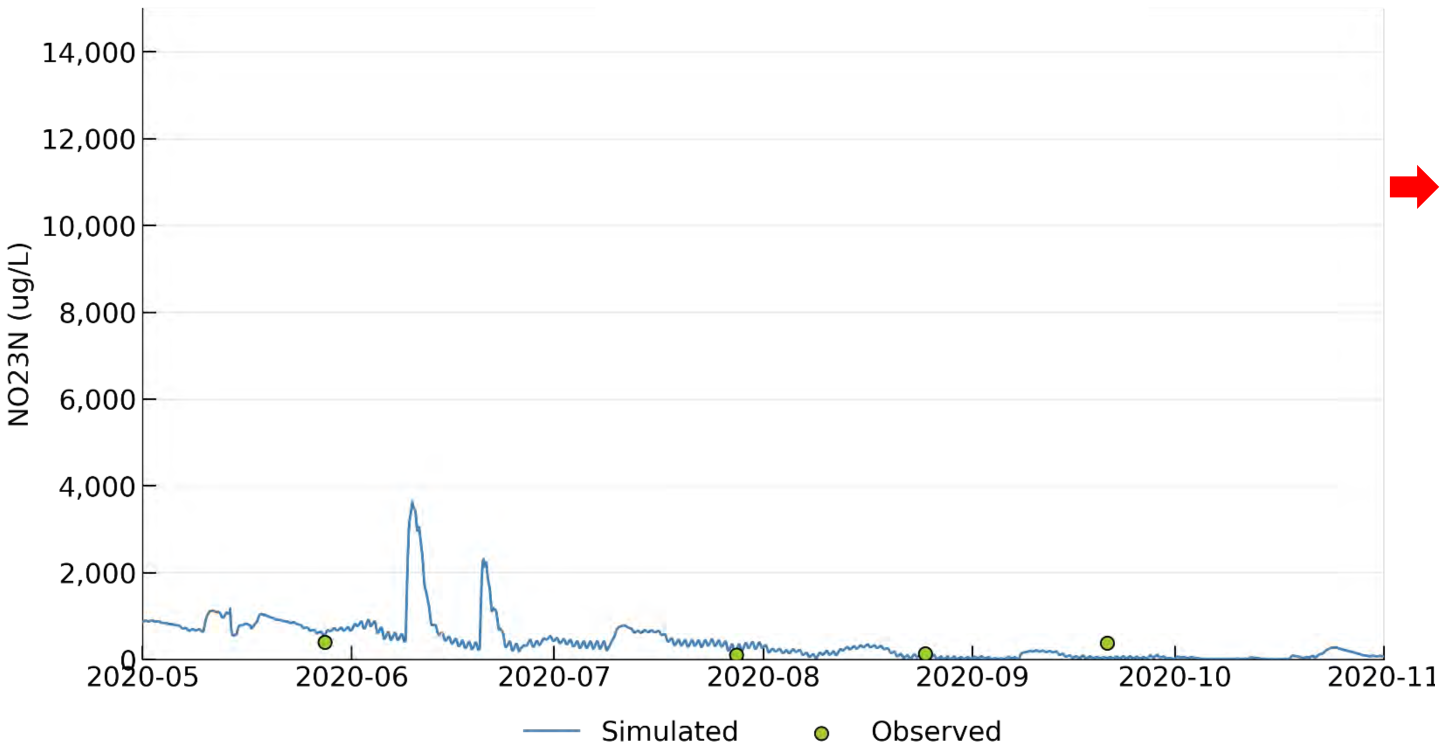

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# US. Wetland Research Inc.
# RM: 26.3, Model Seg.#4, Nitrate-Nitrite



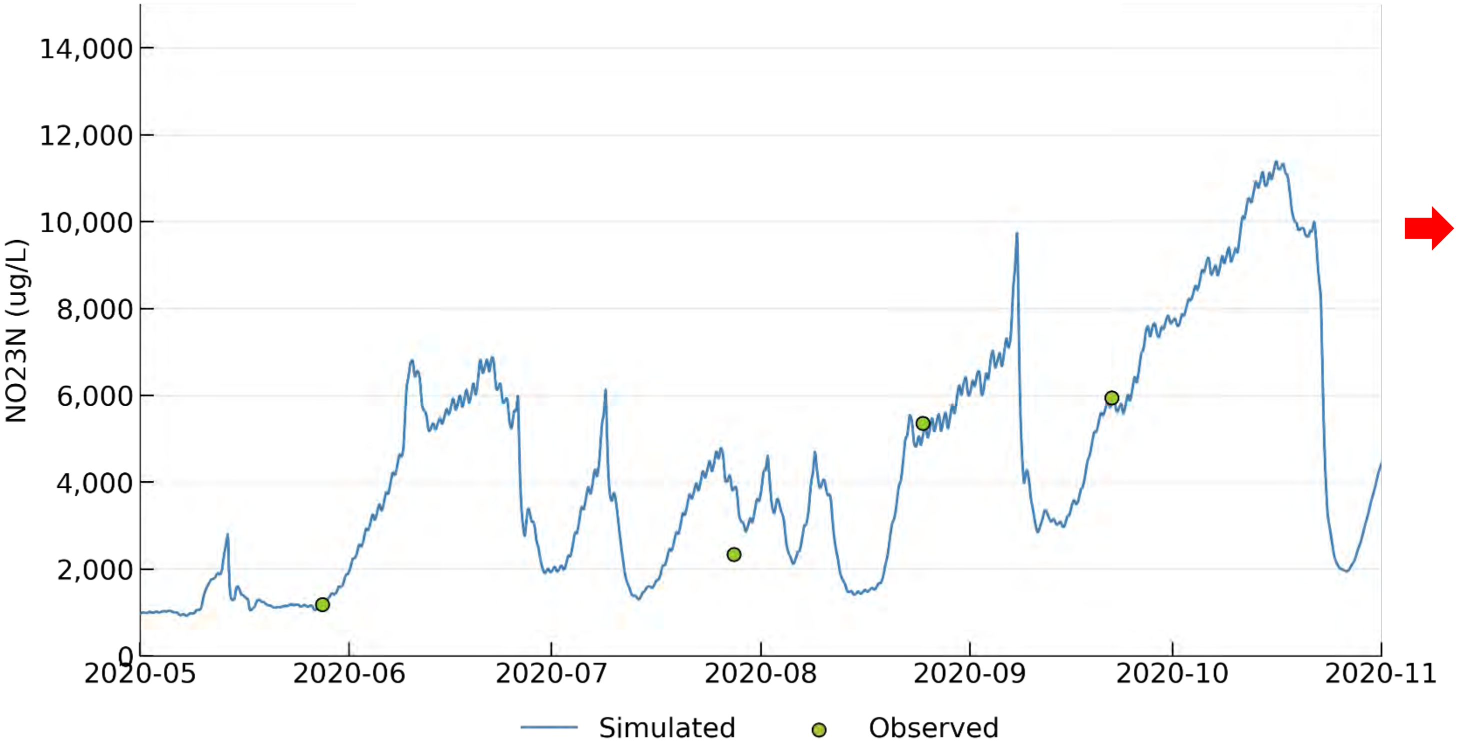

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# HWY 41
# RM: 24.7, Model Seg.#5, Nitrate-Nitrite



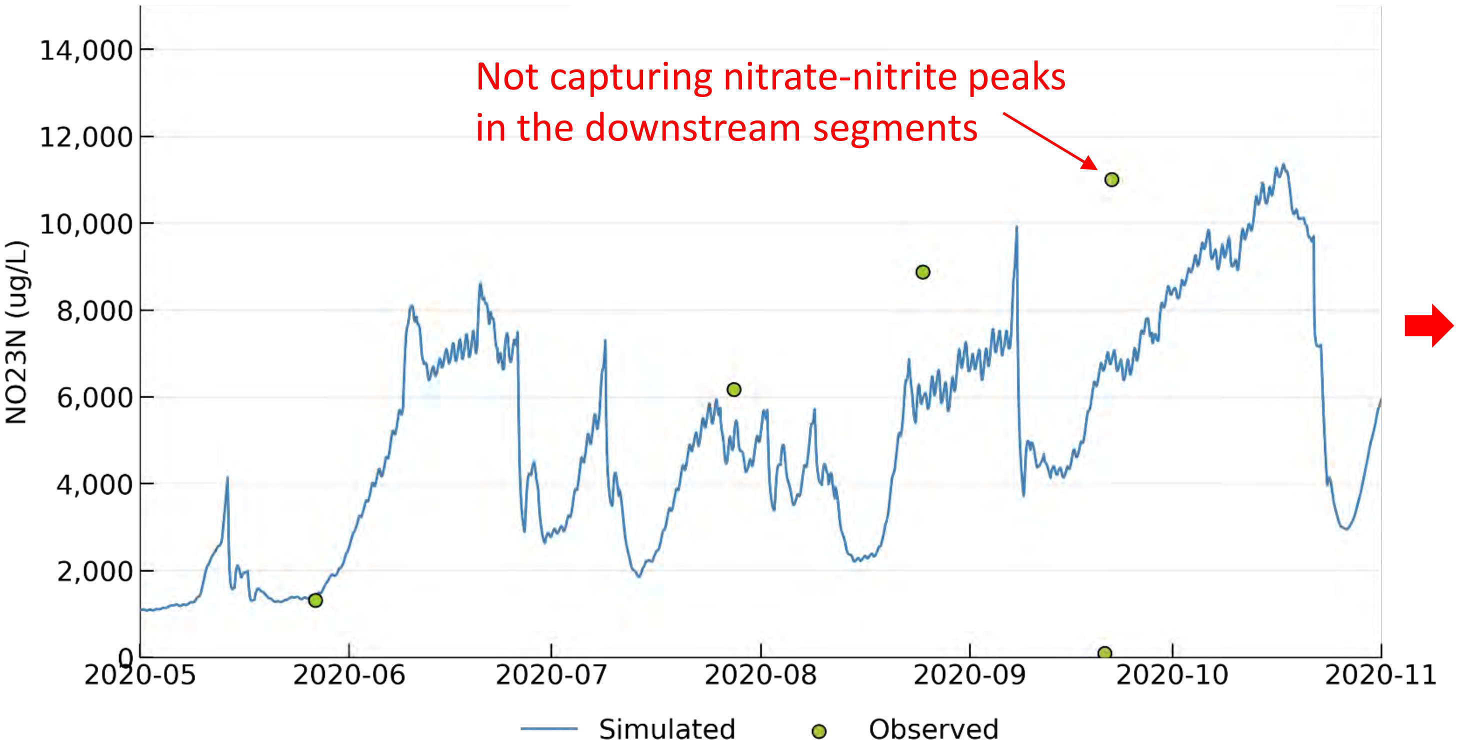

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# McClure Ave.
# RM: 23.3, Model Seg.#6, Nitrate-Nitrite



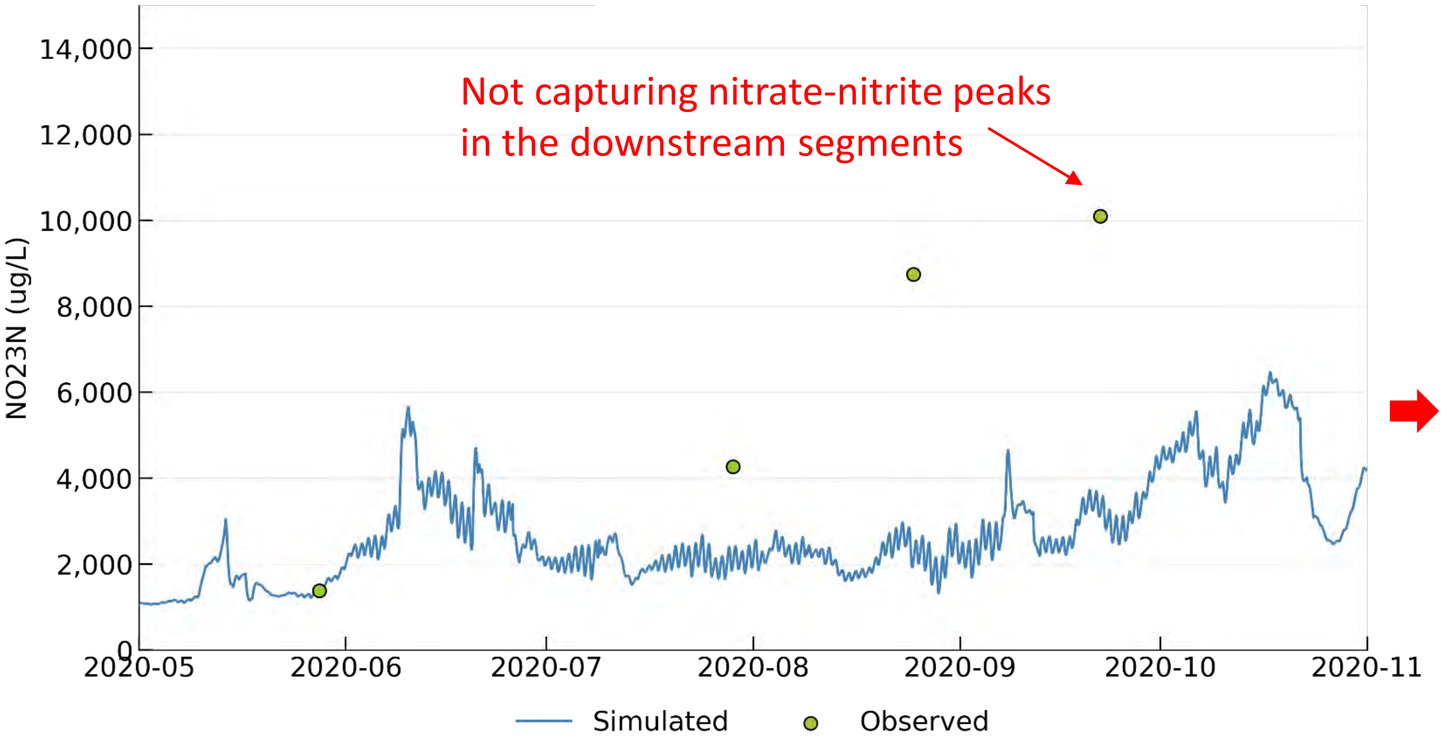

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# HWY 120
# RM: 20.8, Model Seg.#9, Nitrate-Nitrite



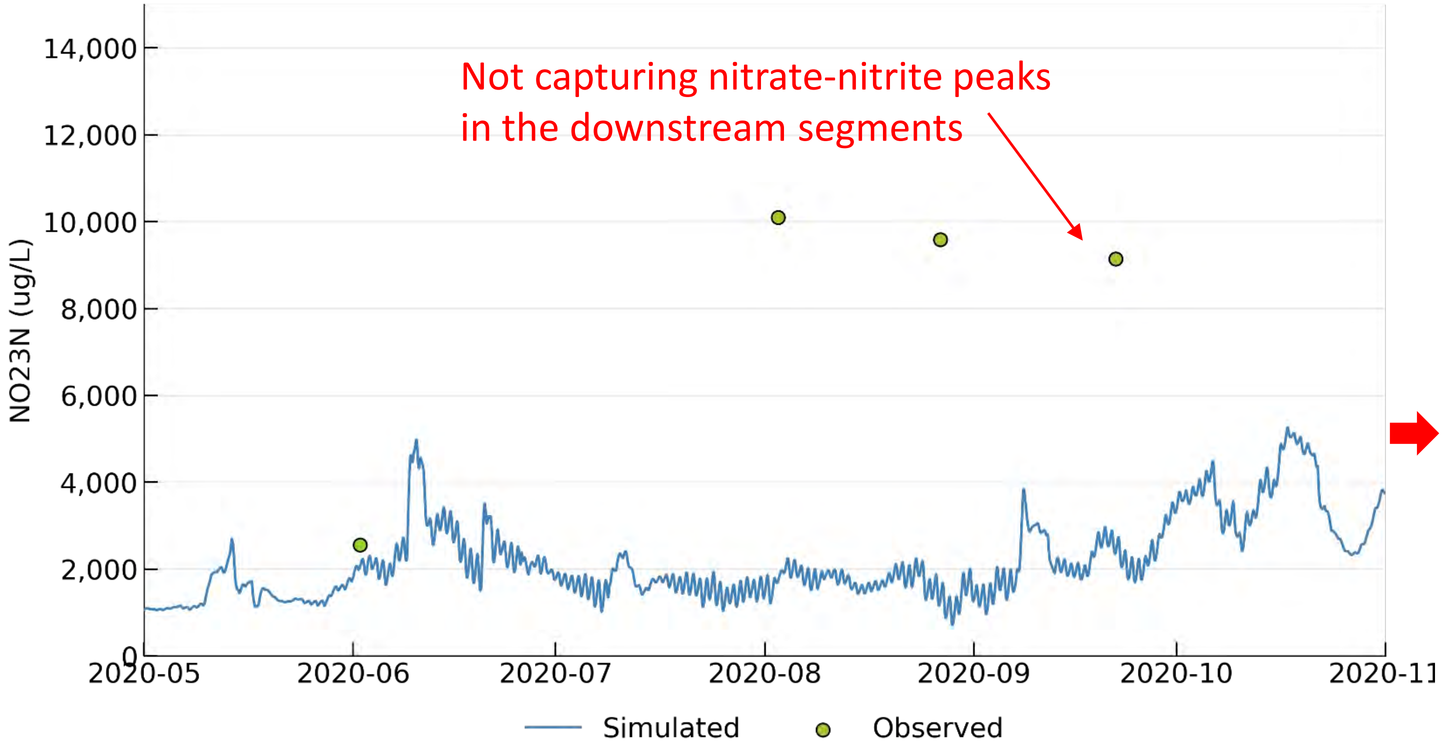

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Buckley Rd.
# RM: 16.5, Model Seg.#11, Nitrate-Nitrite



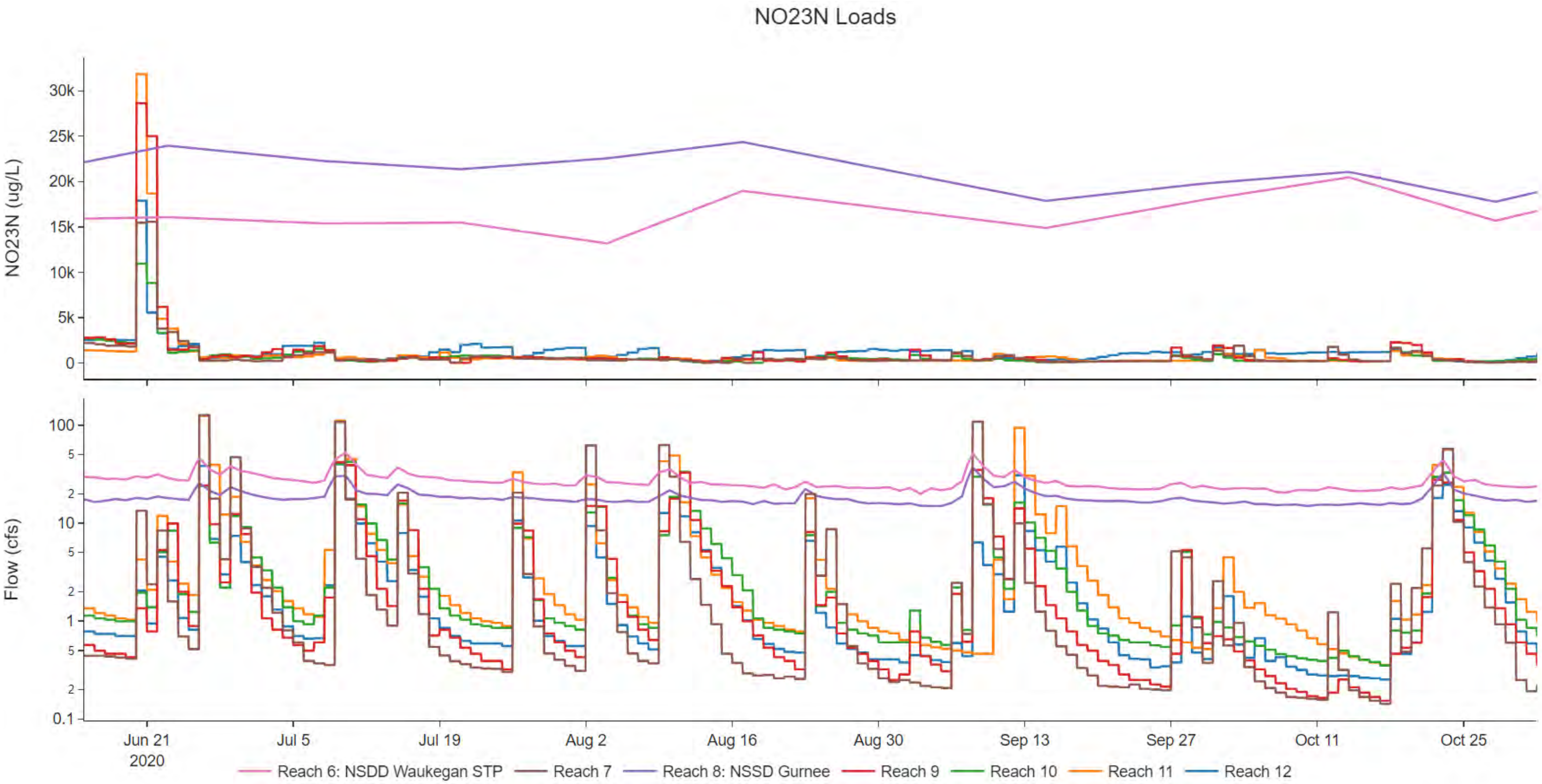

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rockland Rd.
# RM: 14.4, Model Seg.#12, Nitrate-Nitrite




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

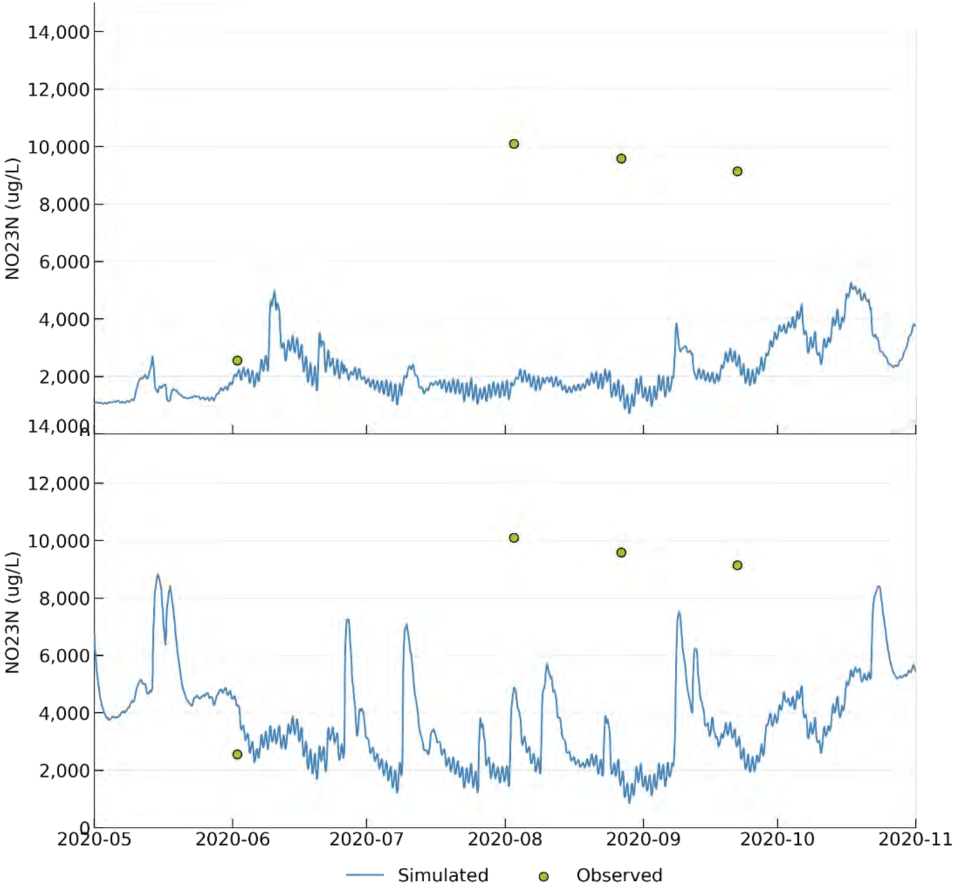
# Timeseries Flows and Nitrate-Nitrite



# Rockland Rd.
# RM: 14.4, Model Seg.#12, Nitrate-Nitrite

Raw SWAT Output

Set NO23N to 10,000 ug/L




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Total Nitrogen

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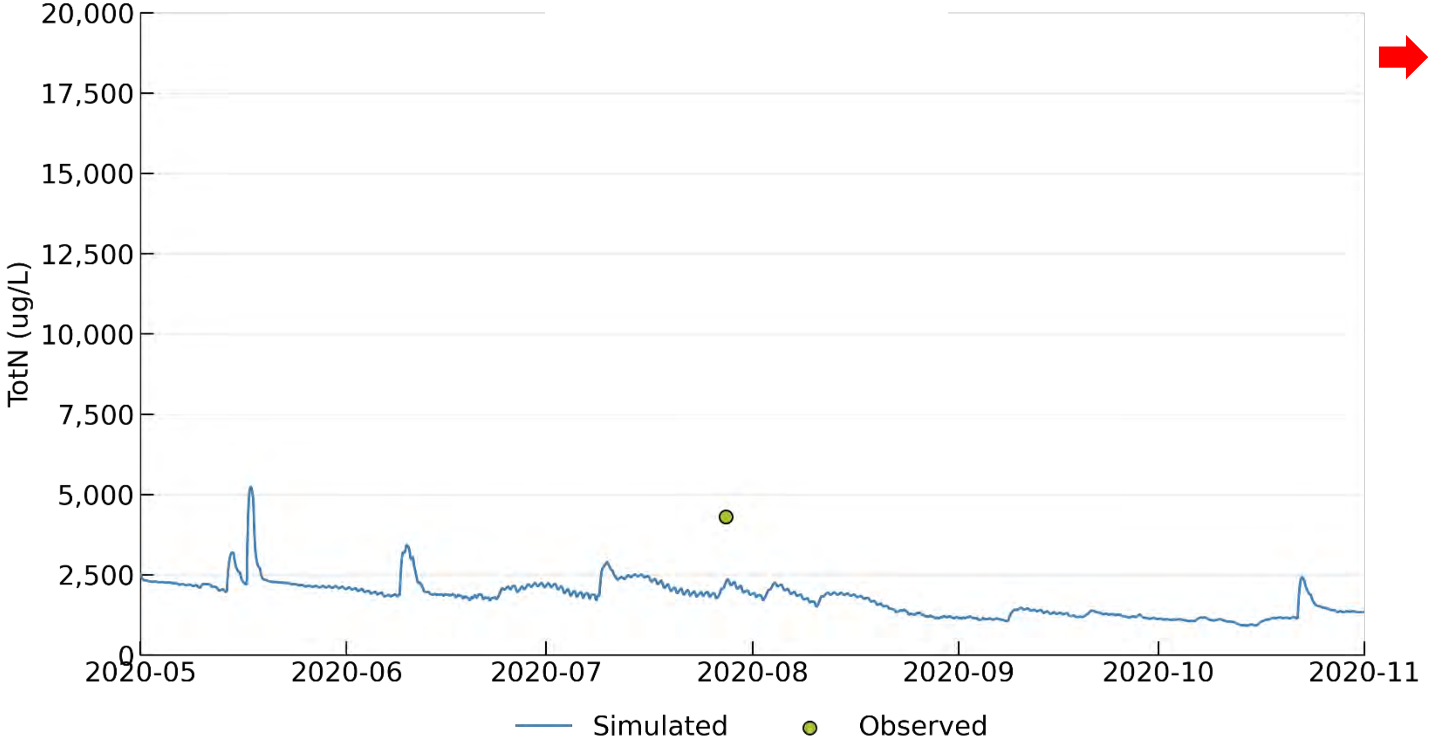
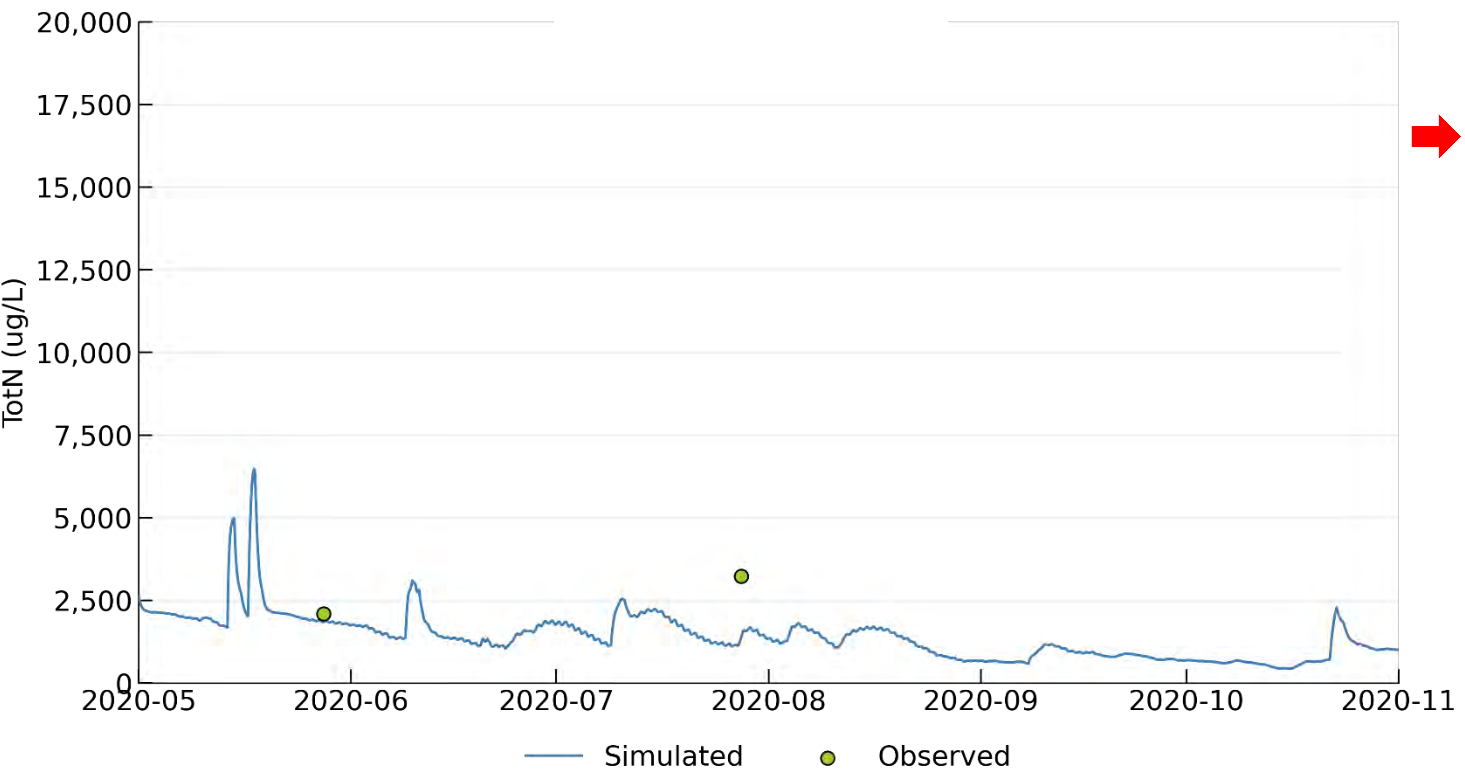
# HWY 173
# RM: 33.0, Model Seg.#1, Total Nitrogen



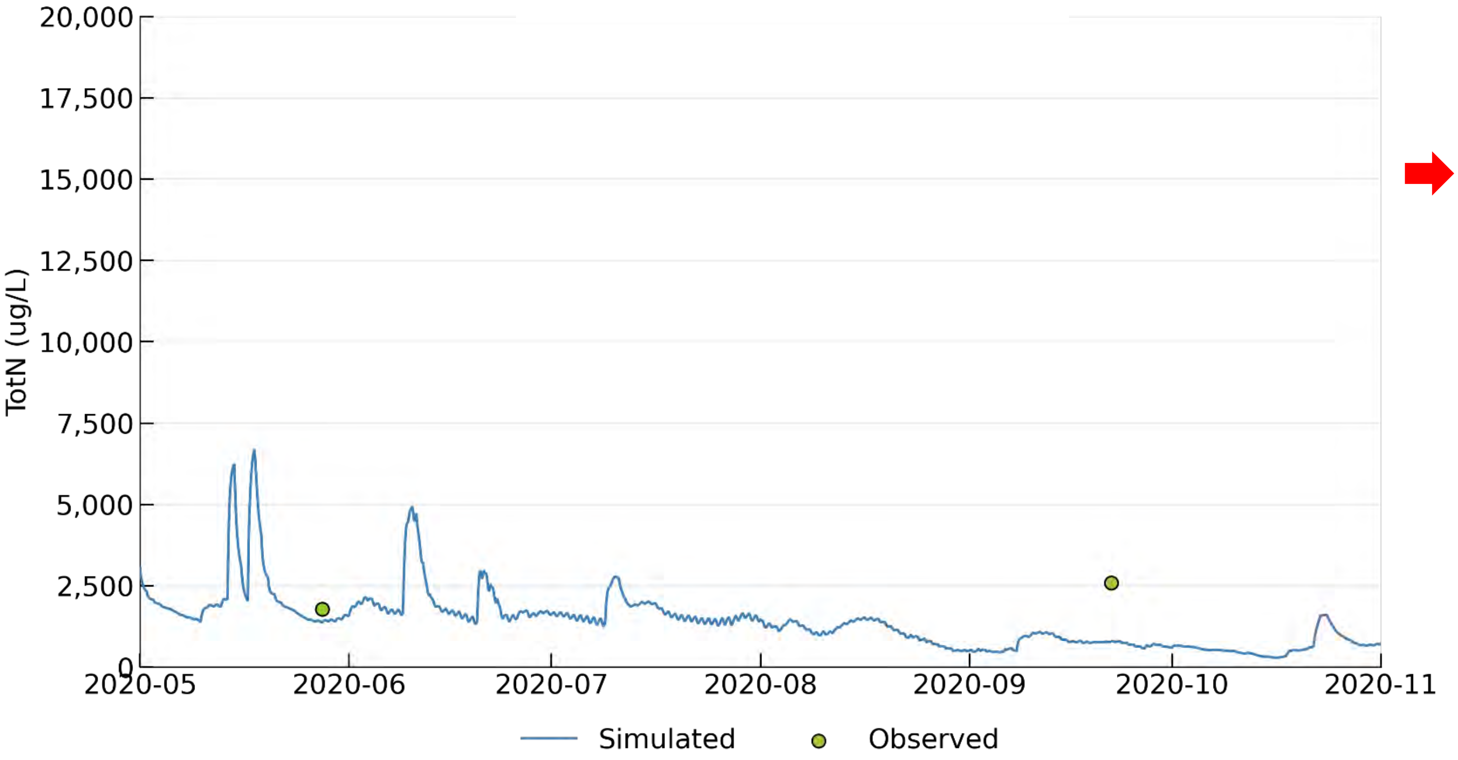

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Wadsworth Rd.
# RM: 29.3, Model Seg.#3, Total Nitrogen



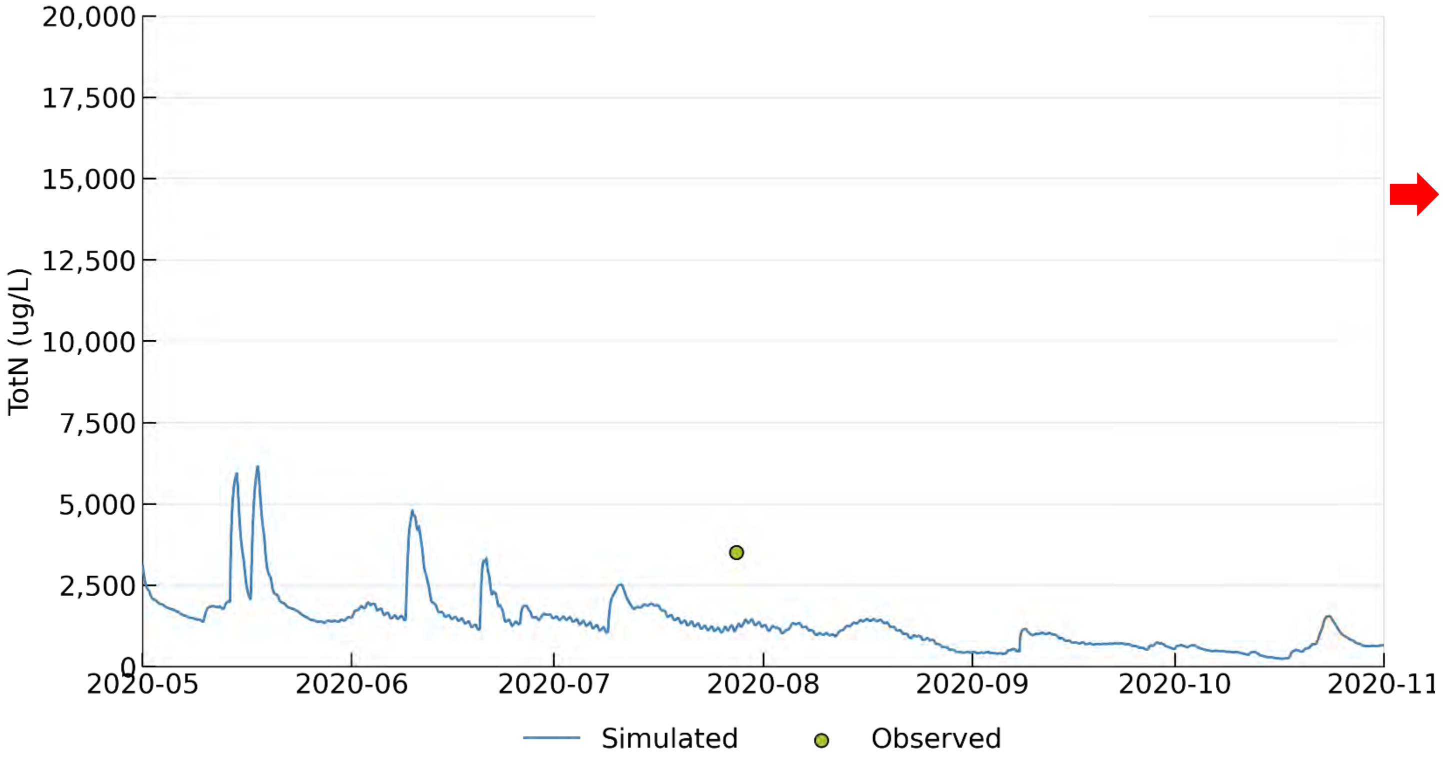

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# US. Wetland Research Inc.
# RM: 26.3, Model Seg.#4, Total Nitrogen



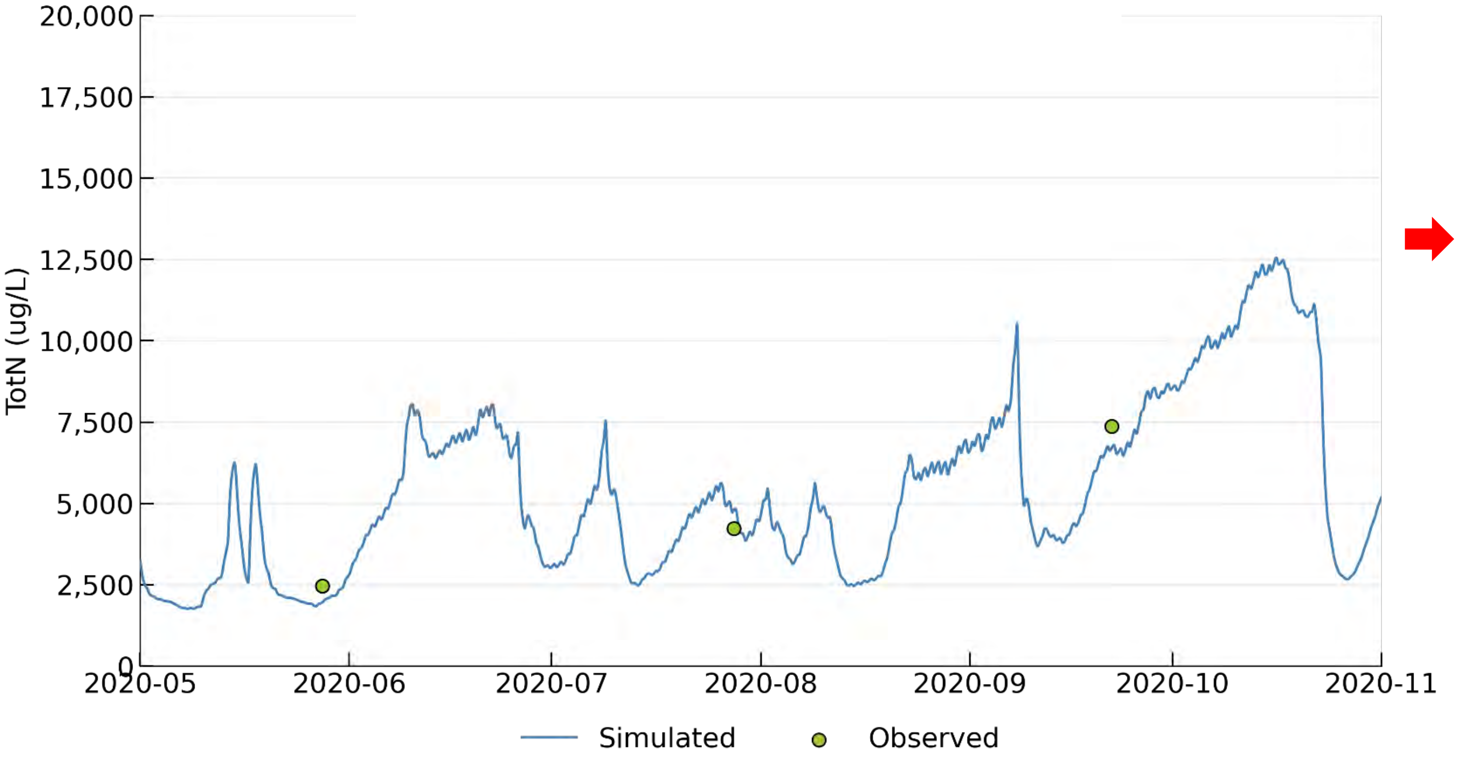

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# HWY 41
# RM: 24.7, Model Seg.#5, Total Nitrogen



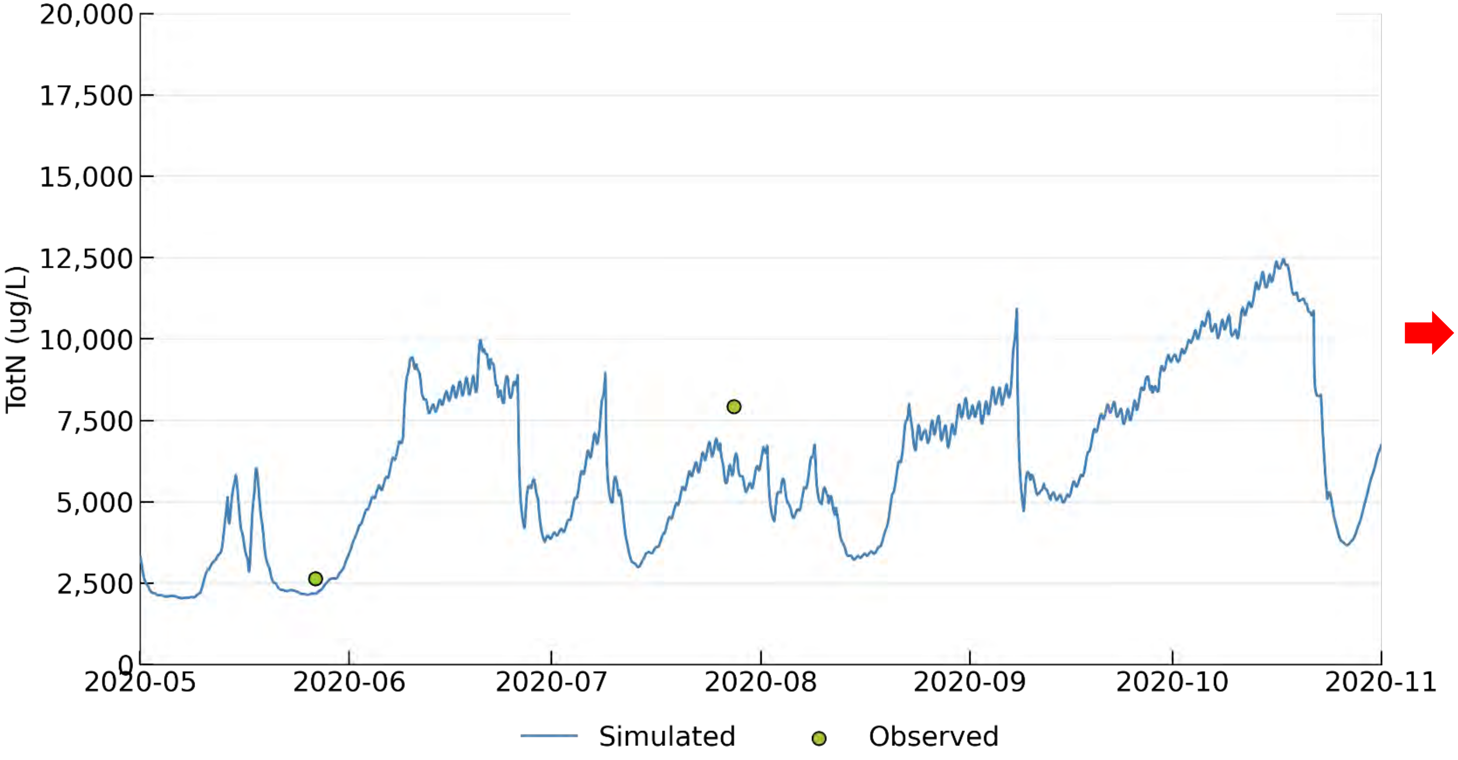

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# McClure Ave.
# RM: 23.3, Model Seg.#6, Total Nitrogen



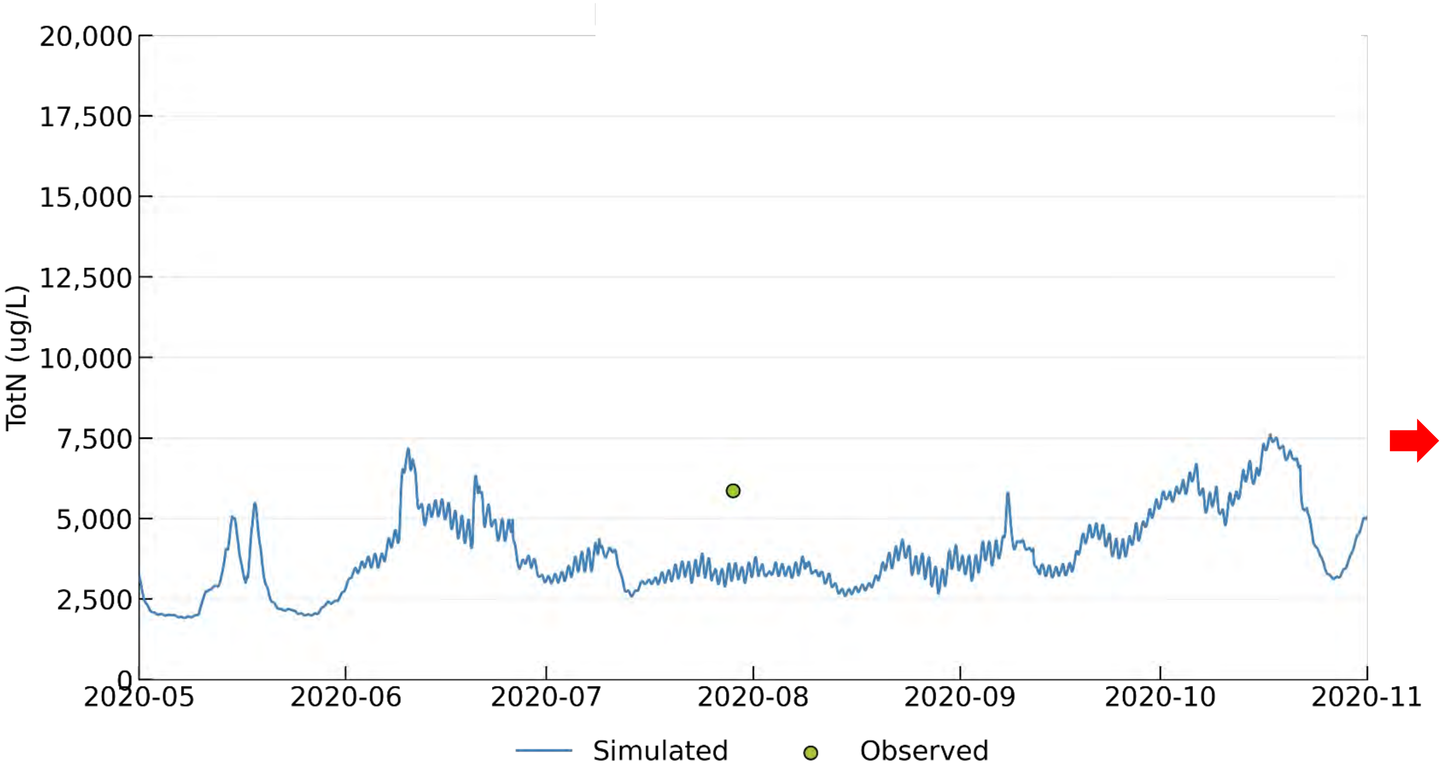

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# HWY 120
# RM: 20.8, Model Seg.#9, Total Nitrogen



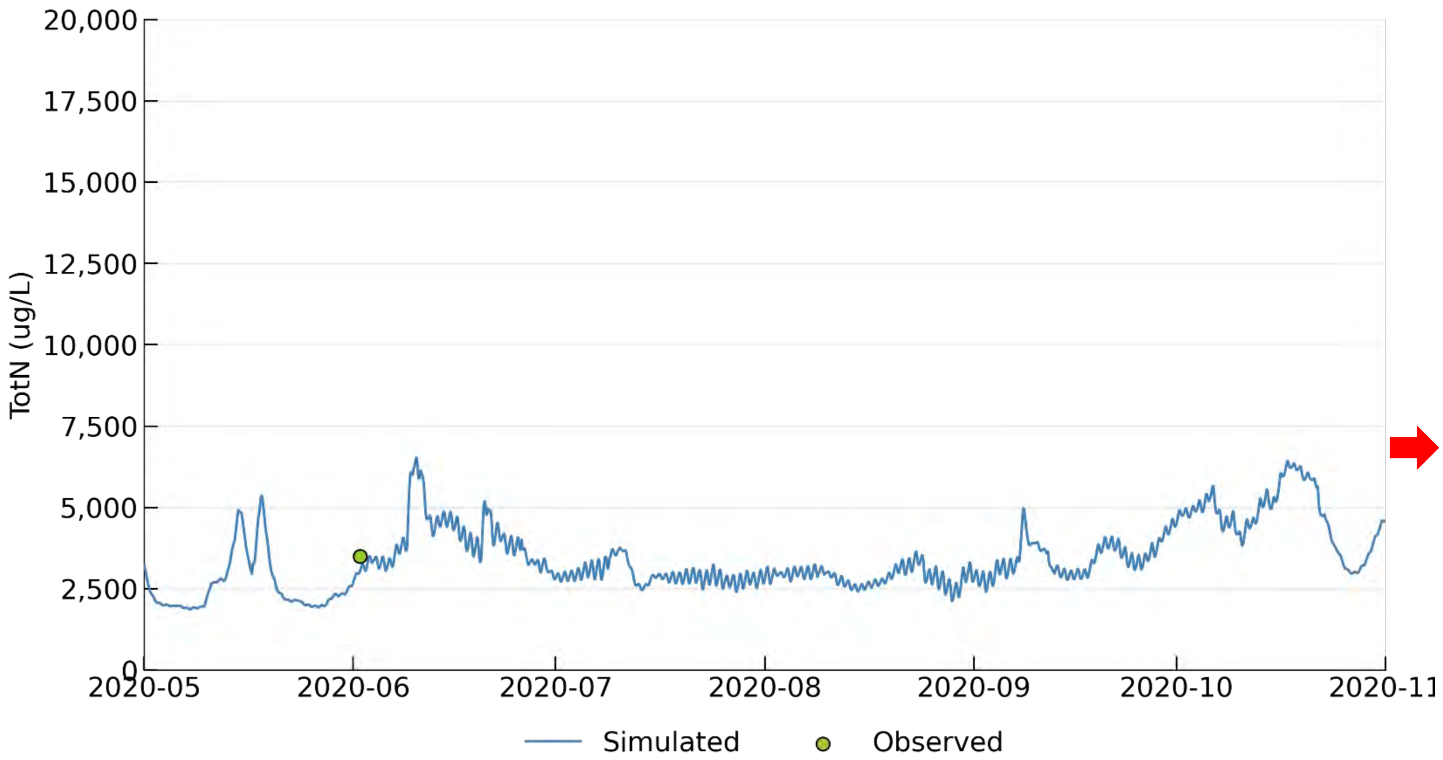

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Buckley Rd.
# RM: 16.5, Model Seg.#11, Total Nitrogen



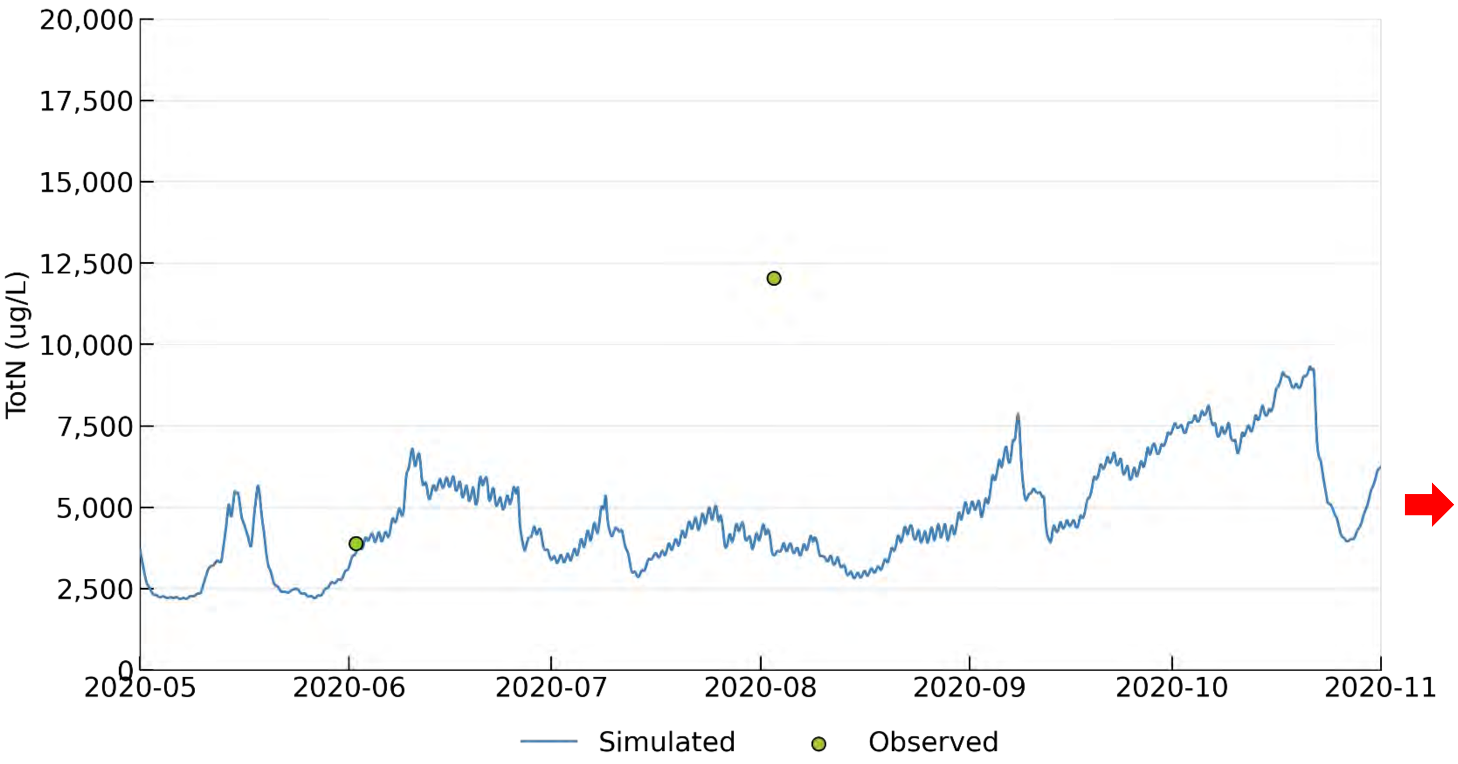

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rockland Rd.
# RM: 14.4, Model Seg.#12, Total Nitrogen



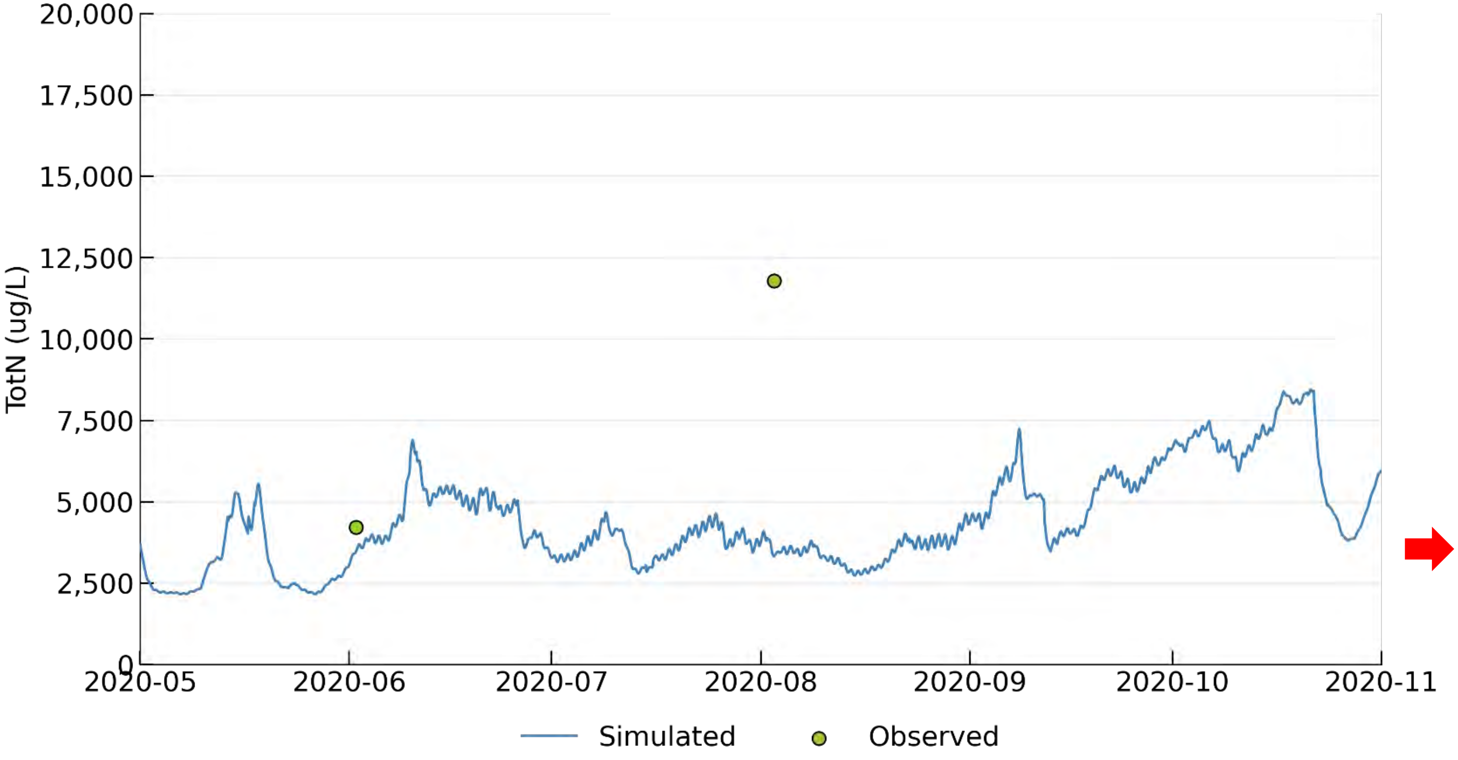

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Hollister Dam
# RM: 10.5, Model Seg.#14, Total Nitrogen



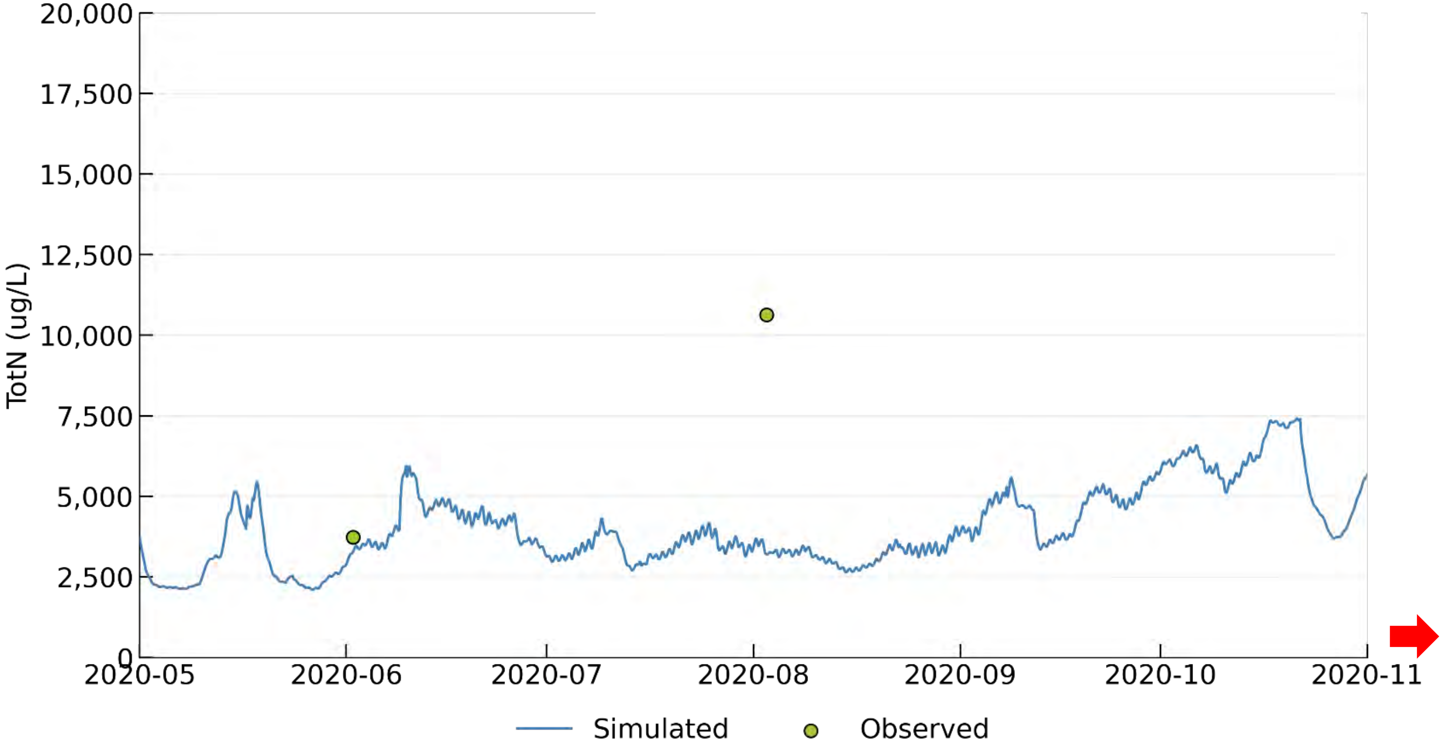

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Wright Woods Dam
# RM: 9.3, Model Seg.#15, Total Nitrogen



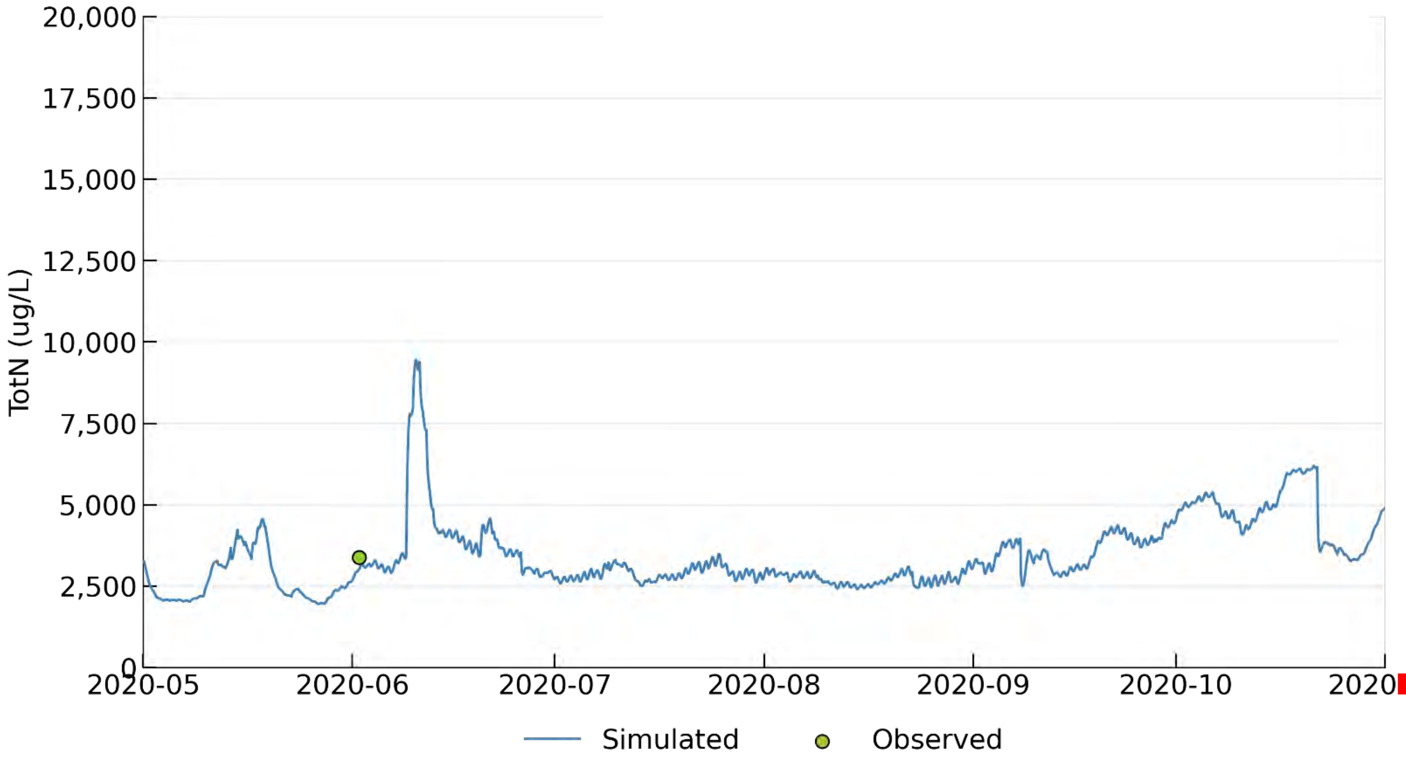

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rt. 22
# RM: 6.7, Model Seg.#17, Total Nitrogen



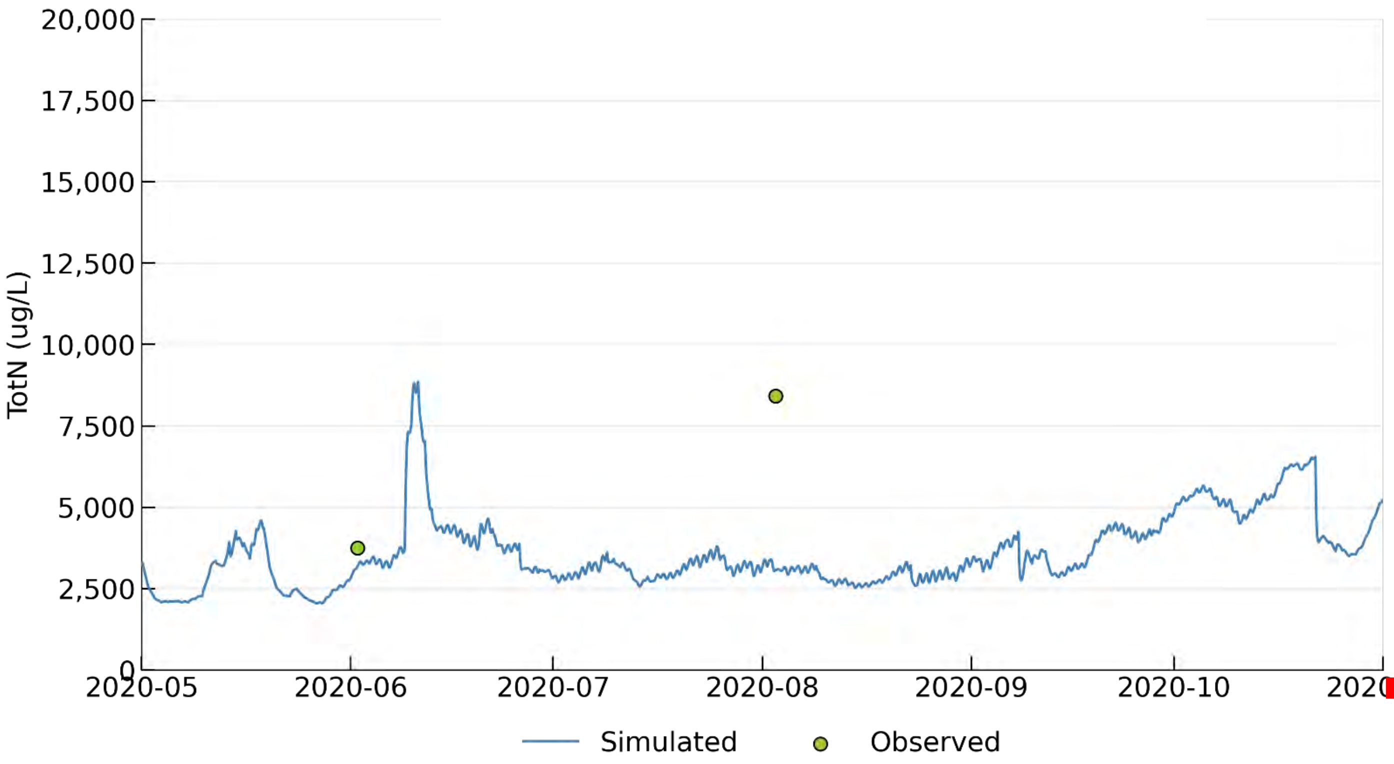

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Deerfield Rd.
# RM: 3.3, Model Seg.#18, Total Nitrogen




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# E. Lake Cook Rd.
# RM: 2.4, Model Seg.#19, Total Nitrogen

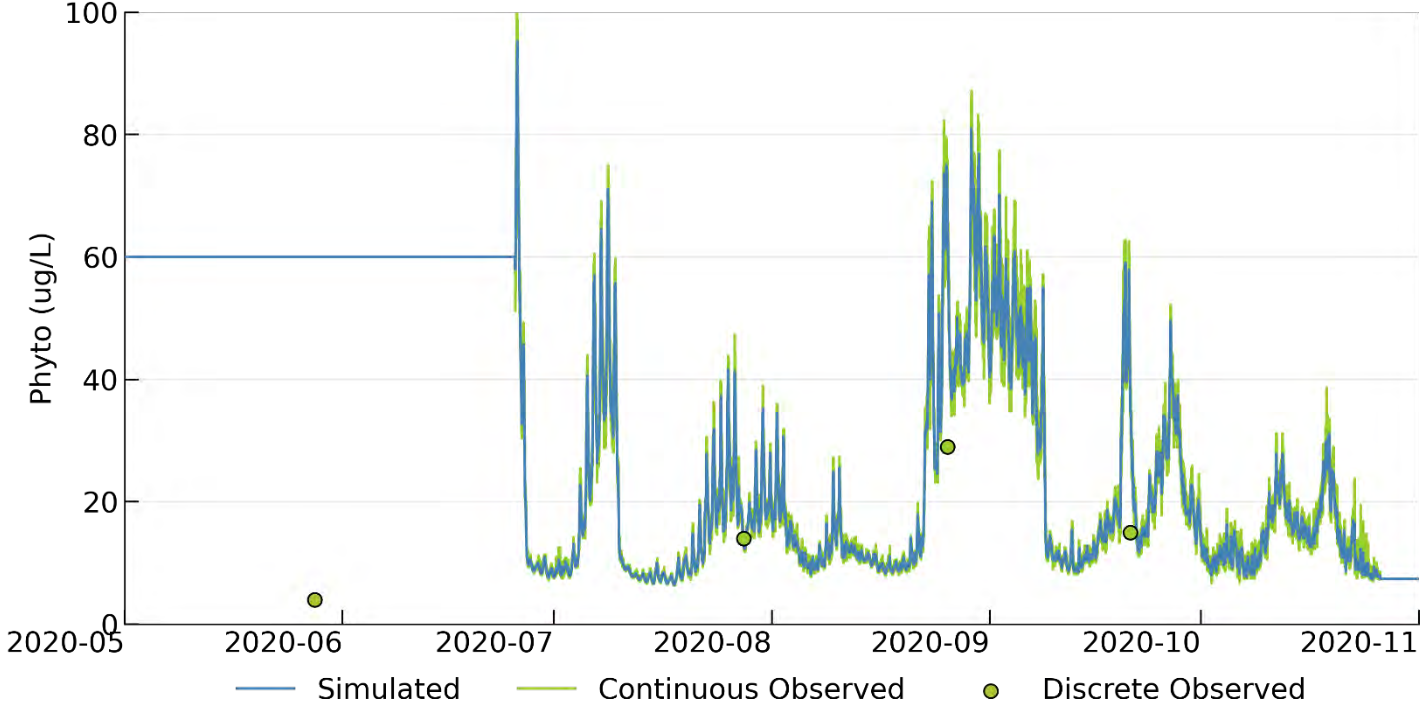



| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Chlorophyll-a

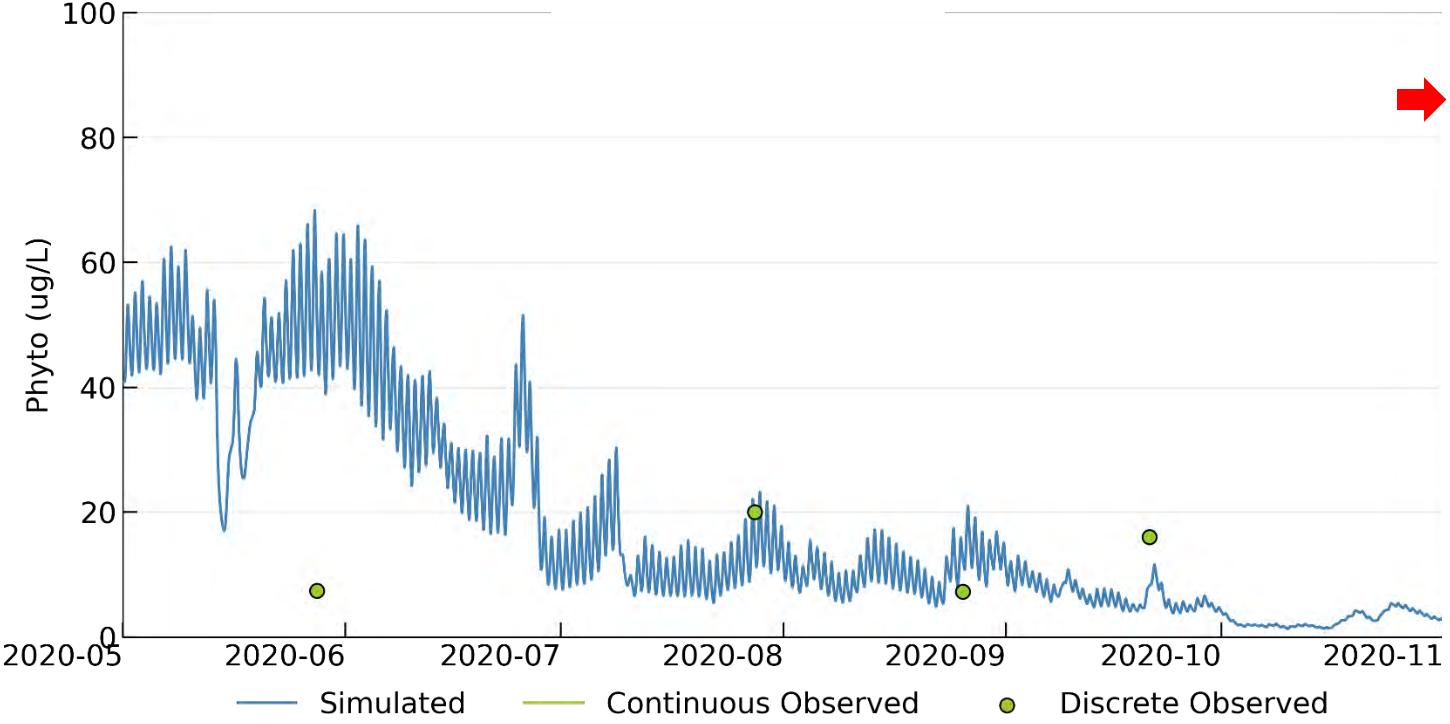
Geosyntec consultants

# Upstream, Chlorophyll-a



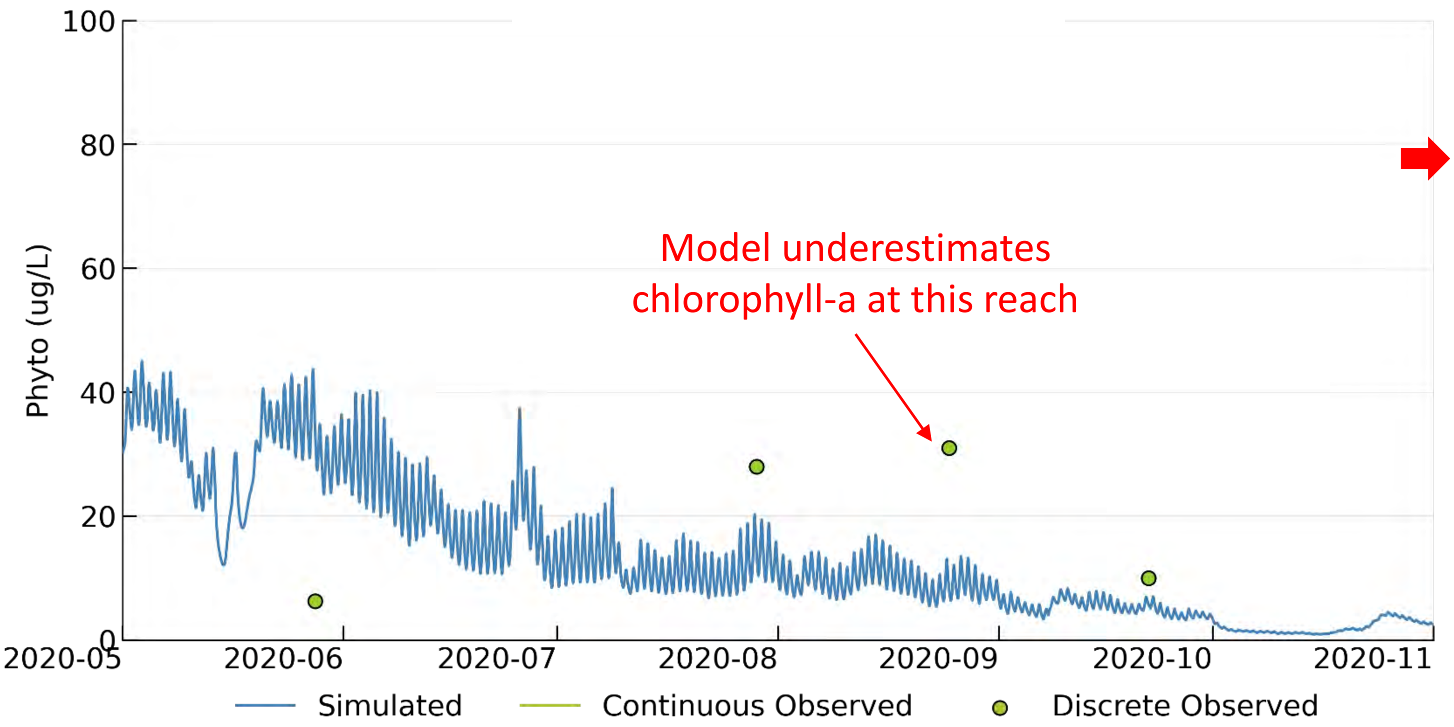

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Wadsworth Rd.
# RM: 29.3, Model Seg.#3, Chlorophyll-a



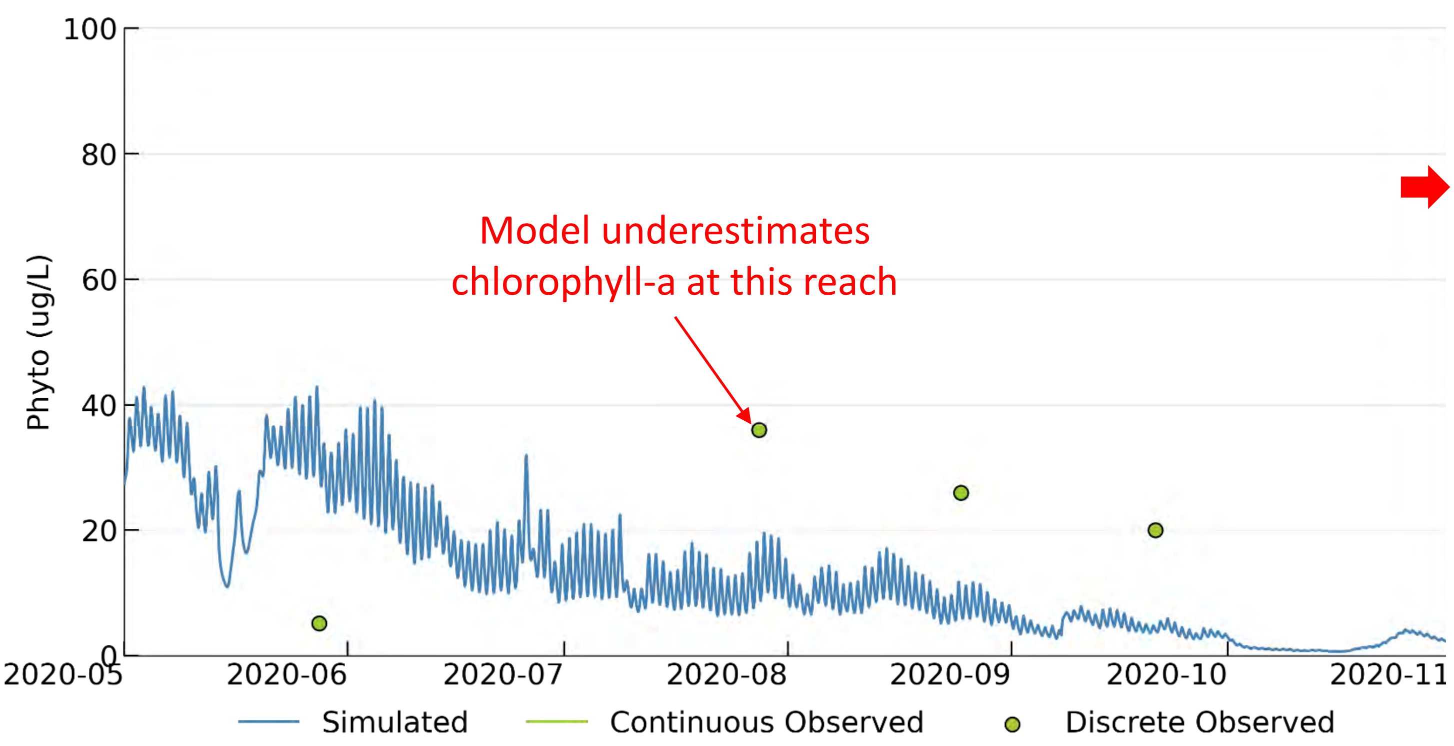

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# US. Wetland Research Inc.
# RM: 26.3, Model Seg.#4, Chlorophyll-a



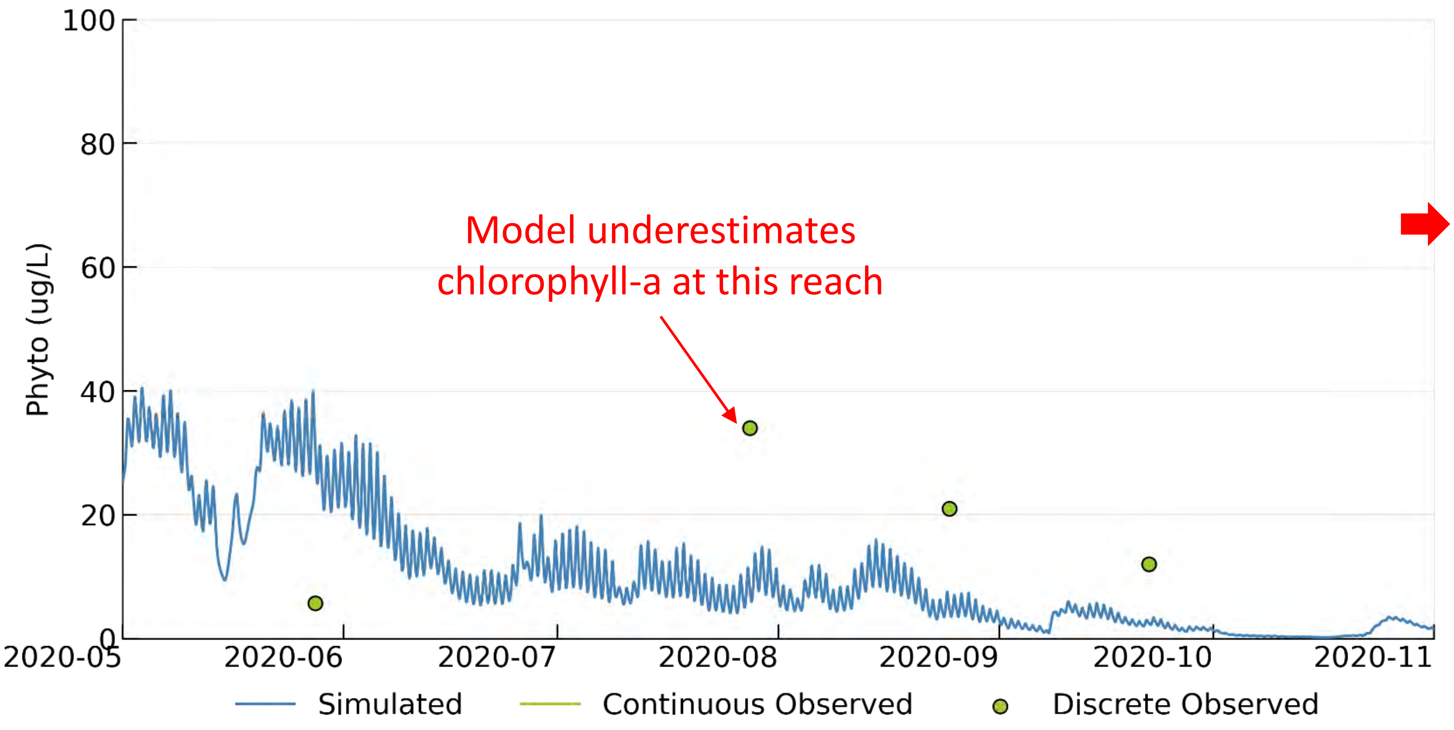

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# HWY 41
# RM: 24.7, Model Seg.#5, Chlorophyll-a



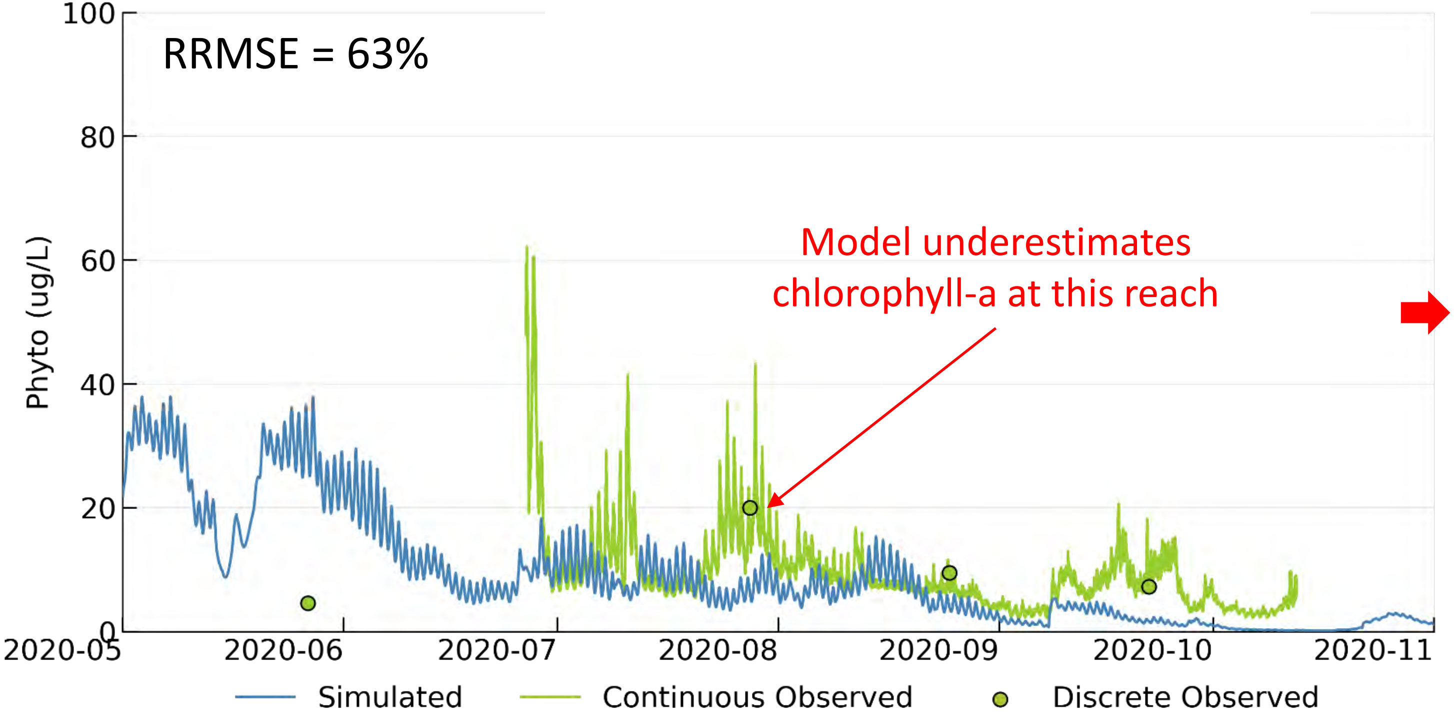

| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# McClure Ave.
# RM: 23.3, Model Seg.#6, Chlorophyll-a




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

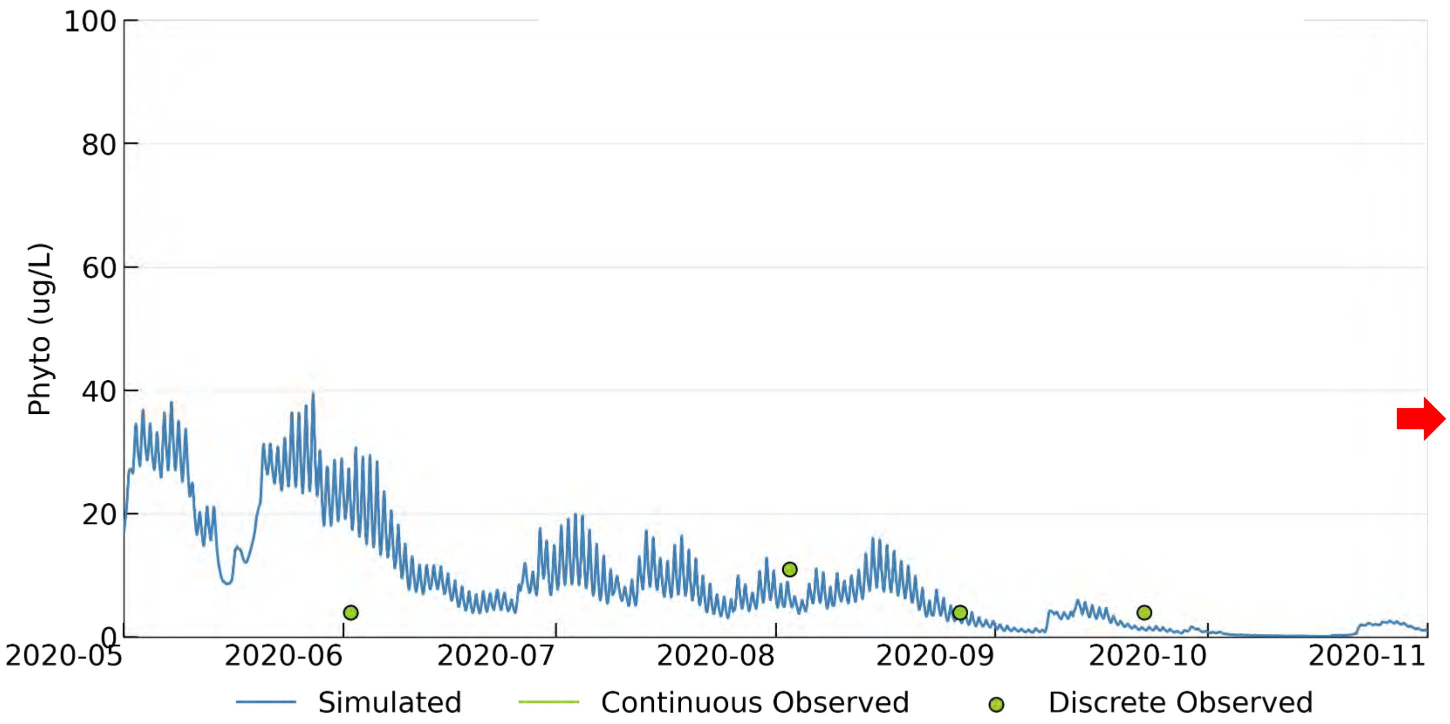
# HWY 120
# RM: 20.8, Model Seg.#9, Chlorophyll-a




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

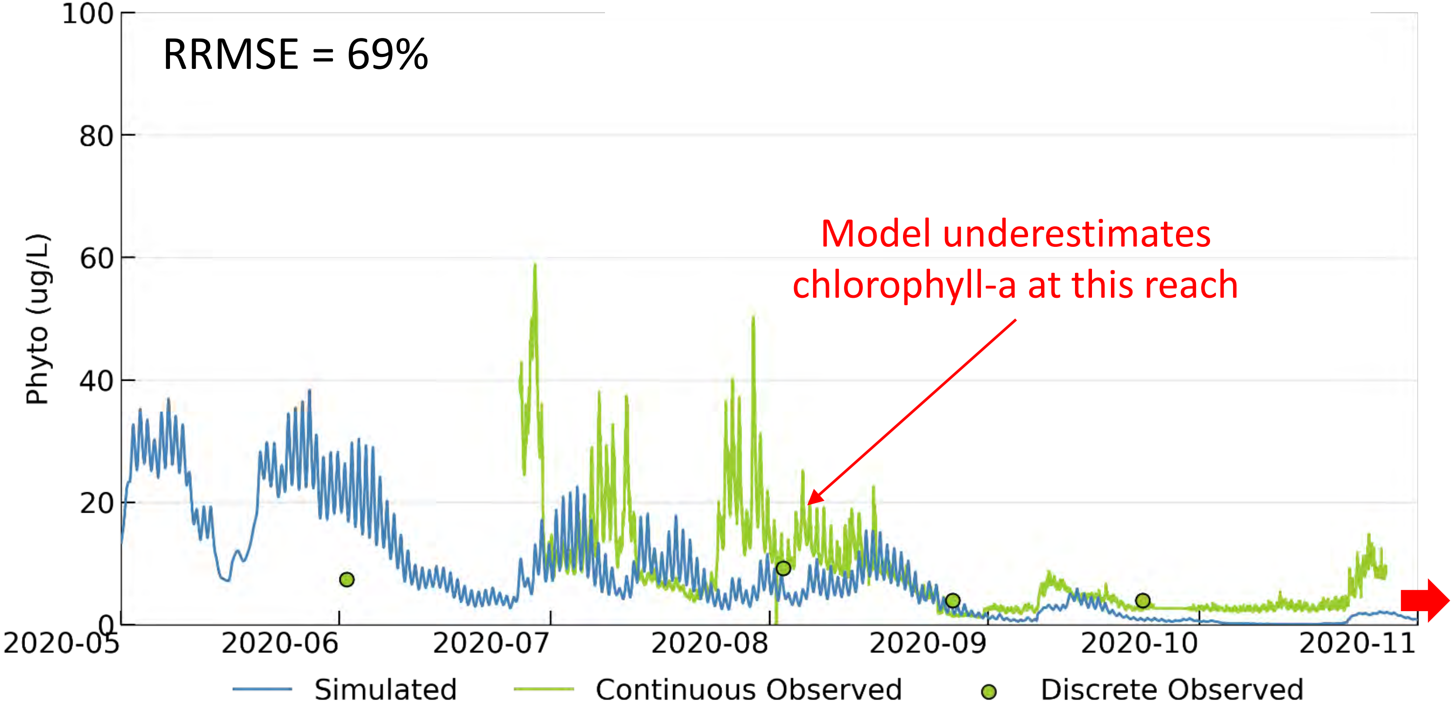
| | | | | |
|---|---|---|---|---|
| 5/27/2020 | 13-1 | Chlorophyll a | 4.6 | mg/L |

# Rockland Rd.
# RM: 14.4, Model Seg.#12, Chlorophyll-a




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rt. 22
# RM: 6.7, Model Seg.#17, Chlorophyll-a




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

| | | | | |
|---|---|---|---|---|
| 6/2/2020 | 16-4 | Chlorophyll a | 7.4 | mg/L |

# Benthic Algae

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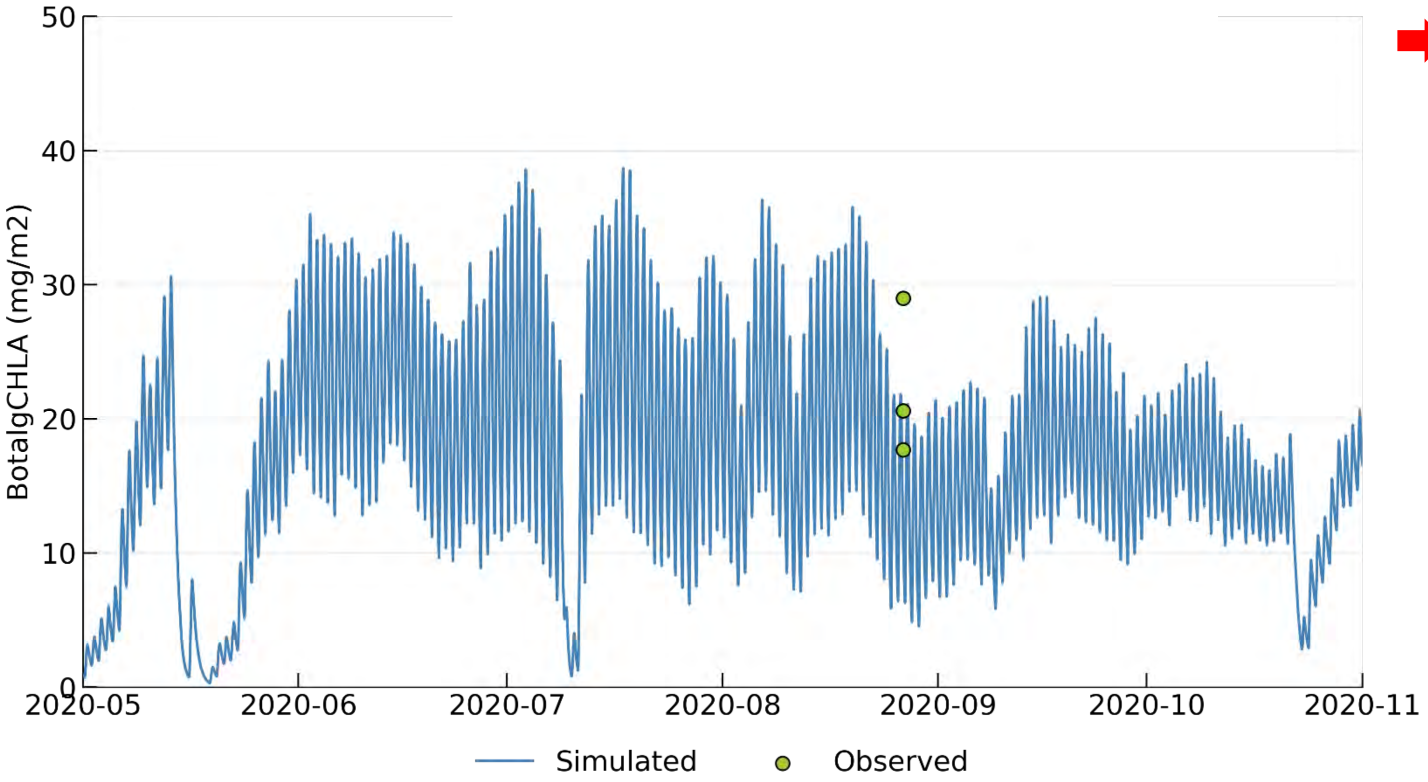
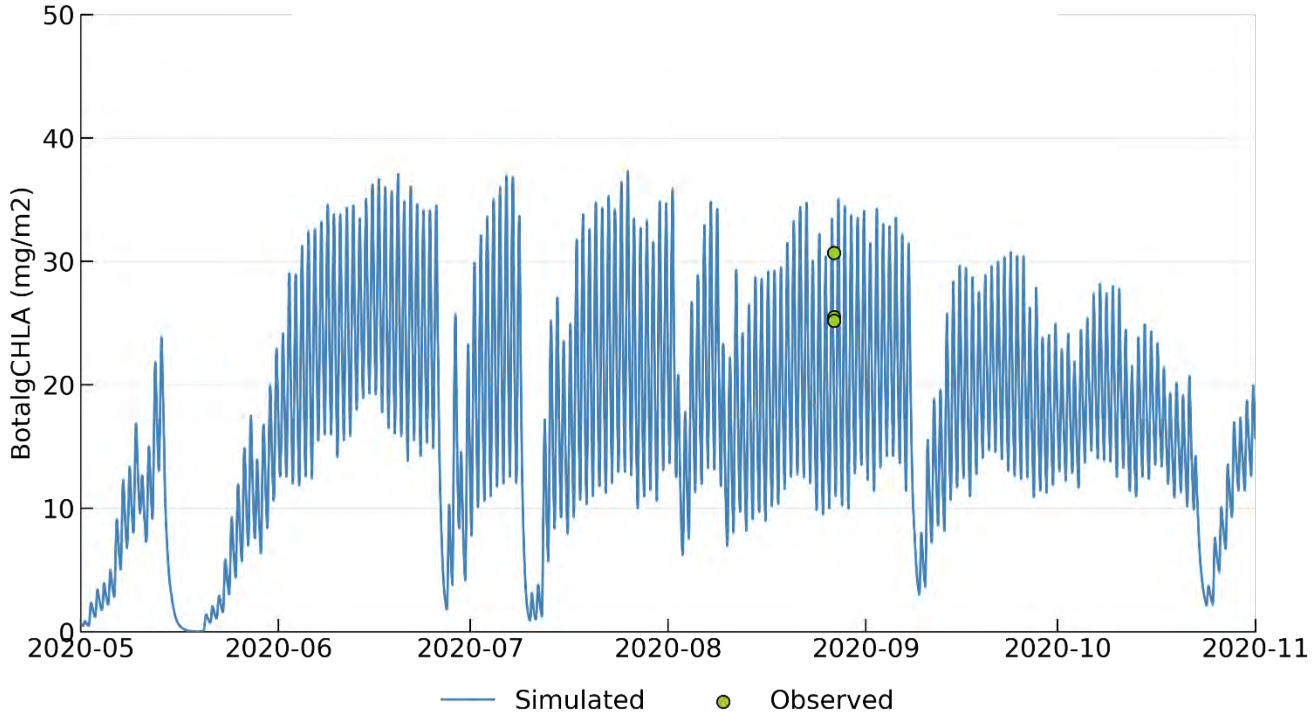
# HWY 173
# RM: 33.0, Model Seg.#1, Benthic Algae




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
| 6 | NSSD WAUKEGAN STP, 32 cfs |
| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
| 9 | SWAT, 7 cfs |
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# McClure Ave.
# RM: 23.3, Model Seg.#6, Benthic Algae




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
| 4 | MILL CREEK, 89 cfs |
| 5 | SWAT, 11 cfs |
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| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
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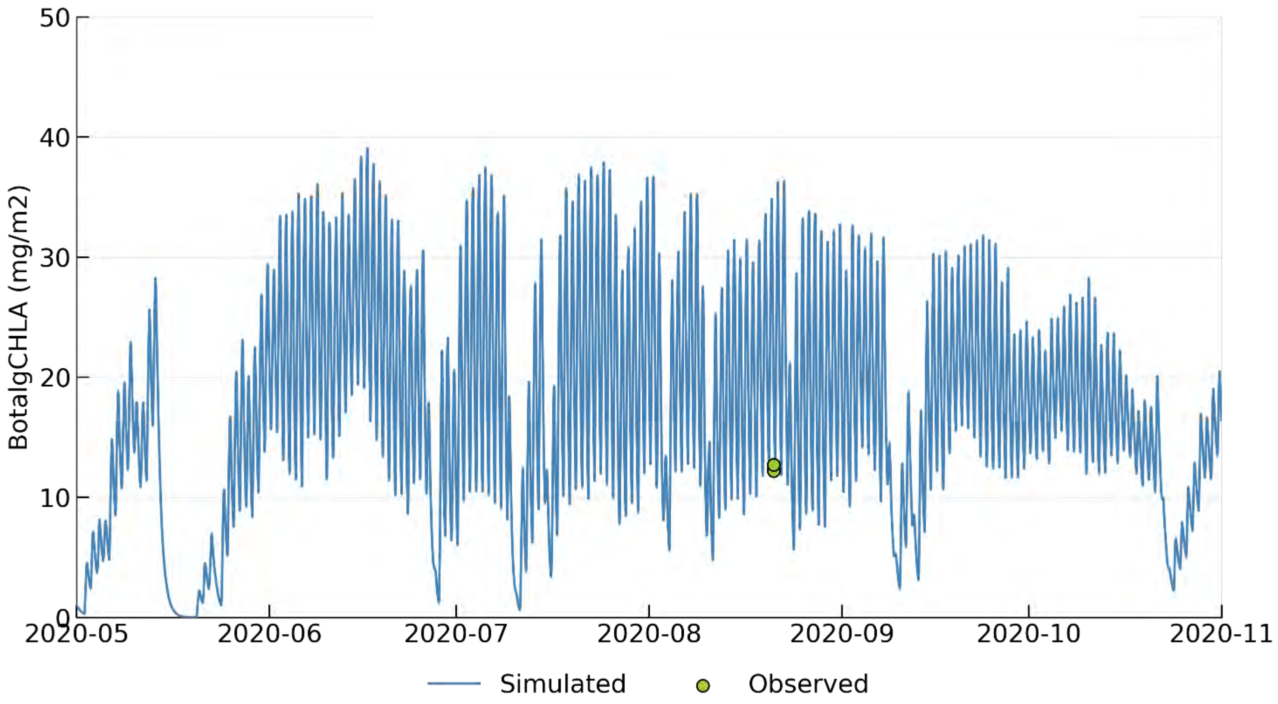
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rt. 22
# RM: 6.7, Model Seg.#17, Benthic Algae




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
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| 5 | SWAT, 11 cfs |
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| 7 | SWAT, 12 cfs |
| 8 | NSSD GURNEE, 21 cfs |
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| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
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| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Dissolved Oxygen

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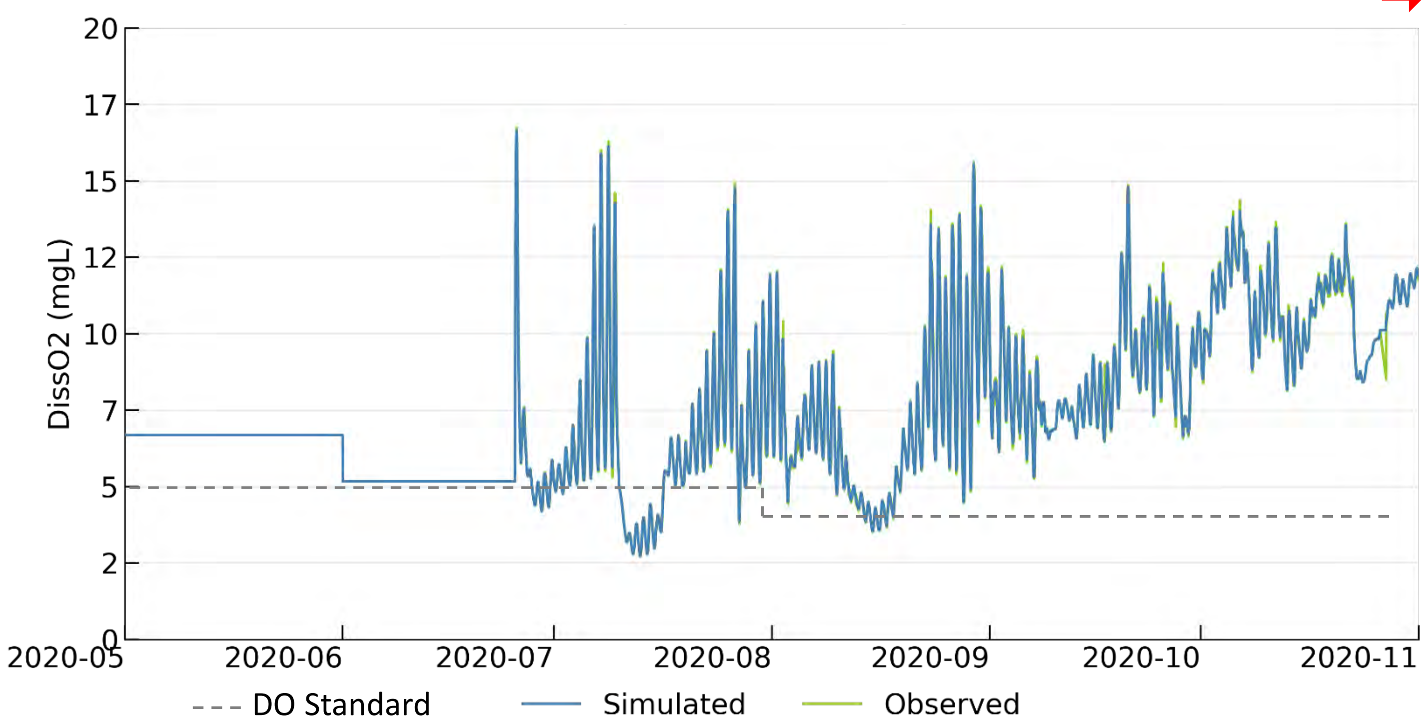
# Upstream, Dissolved Oxygen




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
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| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
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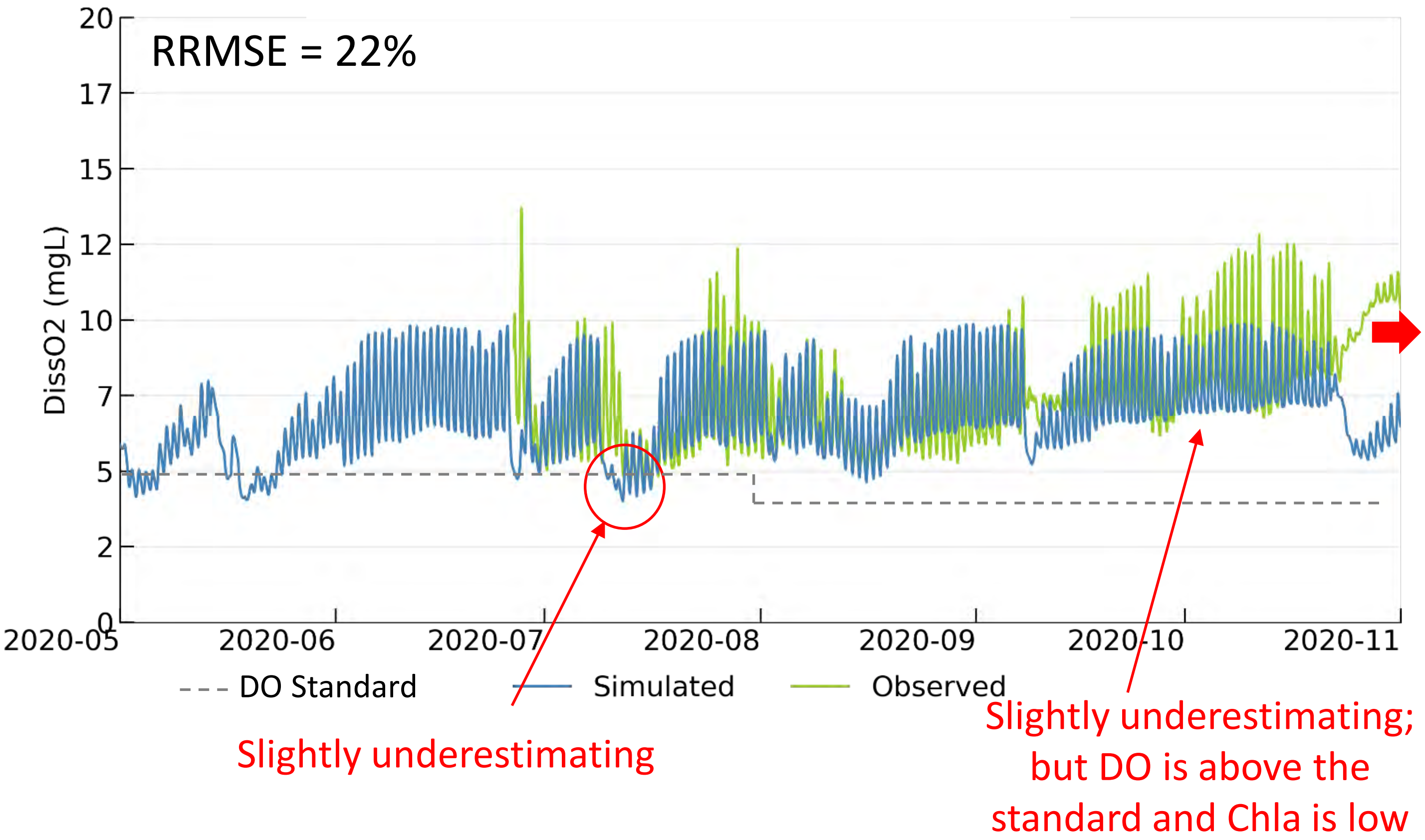
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rt. 120
# RM: 20.8, Model Seg.#9, Dissolved Oxygen




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
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| 7 | SWAT, 12 cfs |
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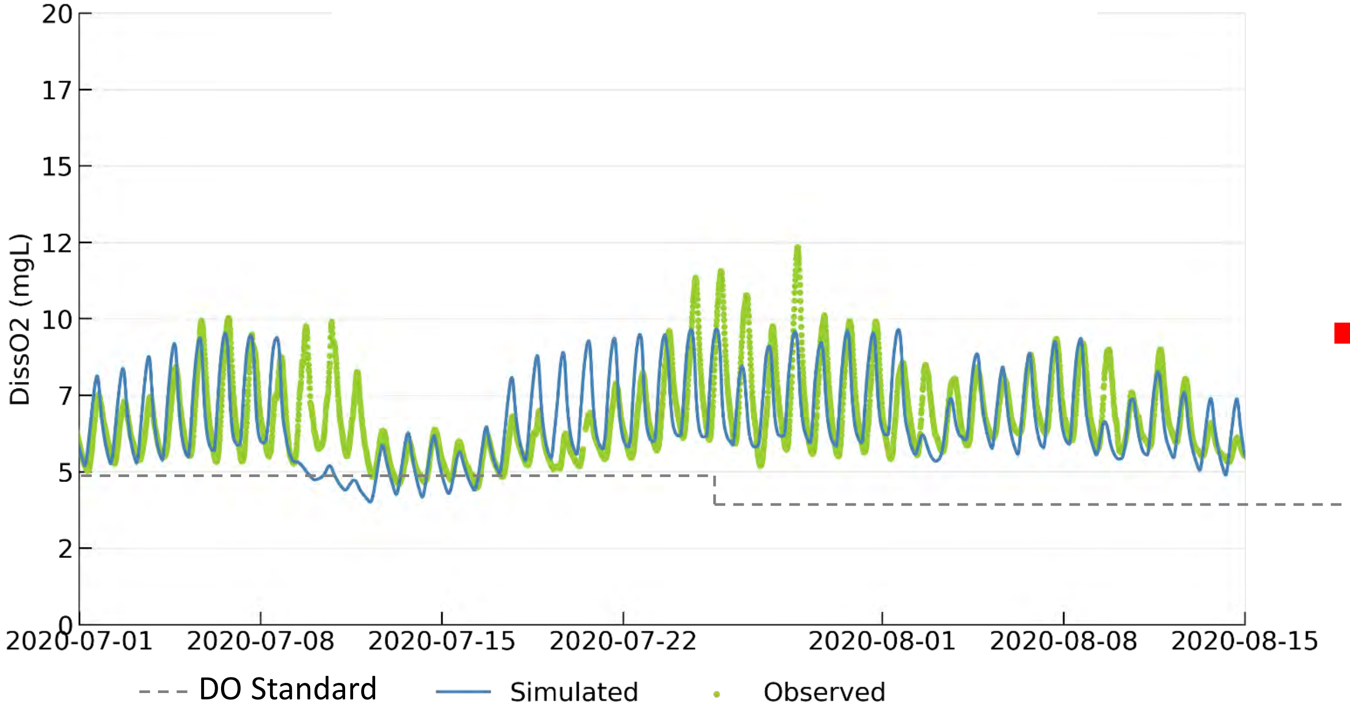
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rt. 120
# RM: 20.8, Model Seg.#9, Dissolved Oxygen




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
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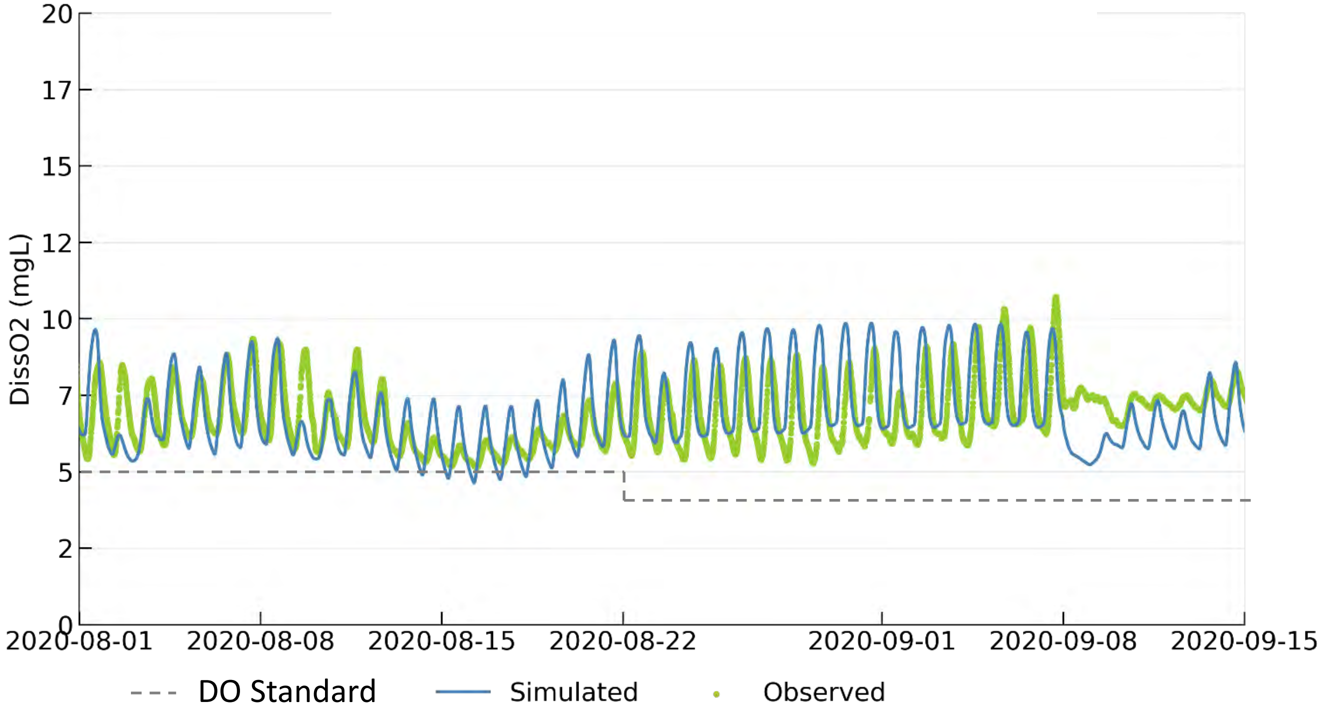
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rt. 120
# RM: 20.8, Model Seg.#9, Dissolved Oxygen




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
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| 10 | SWAT, 11 cfs |
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| 13 | SWAT, 2 cfs |
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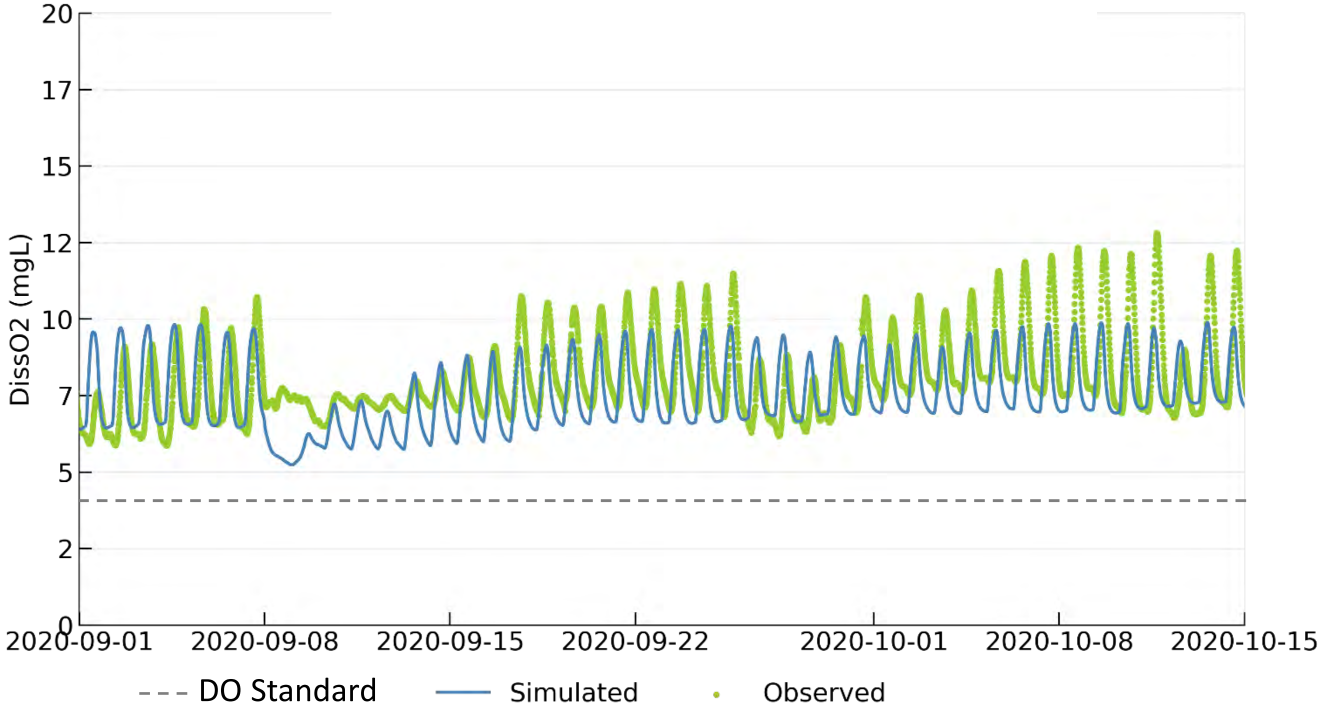
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rt. 120
# RM: 20.8, Model Seg.#9, Dissolved Oxygen




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
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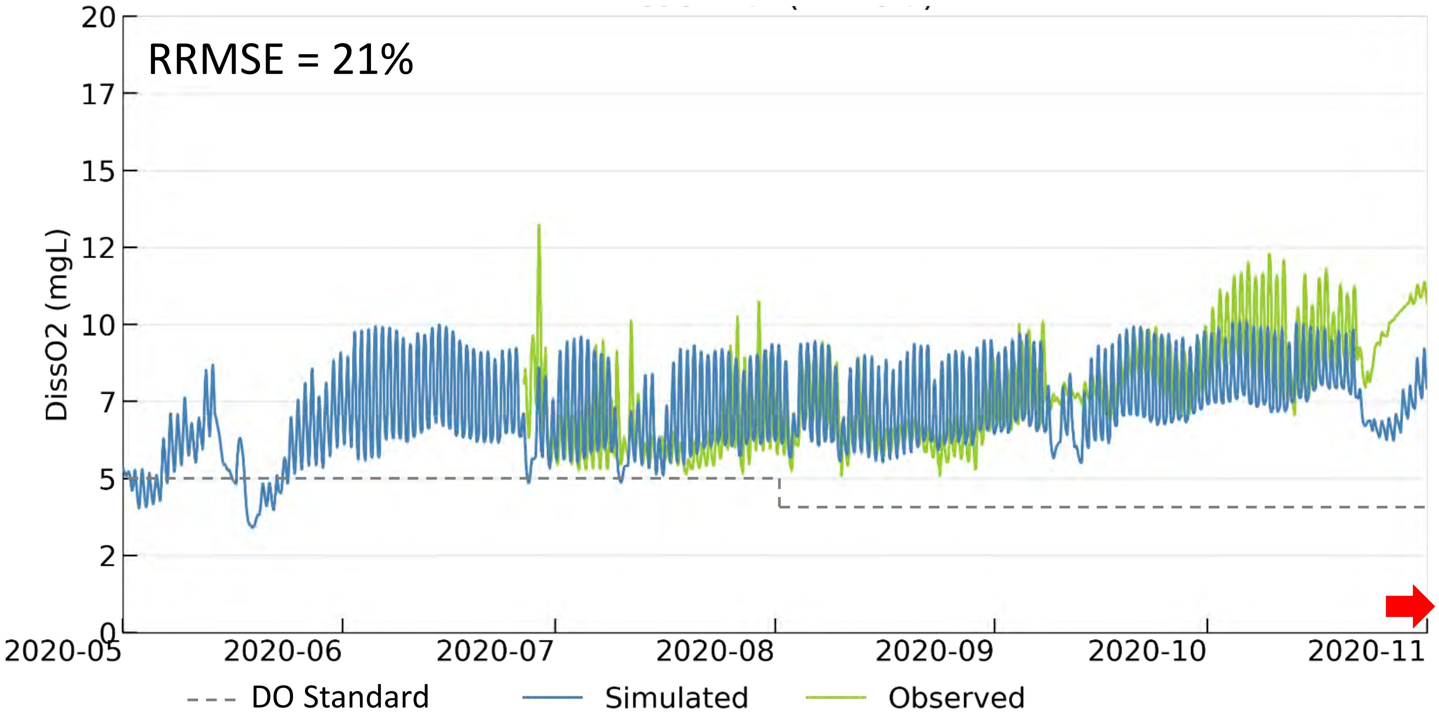
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rt. 22
# RM: 6.7, Model Seg.#17, Dissolved Oxygen




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
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| 7 | SWAT, 12 cfs |
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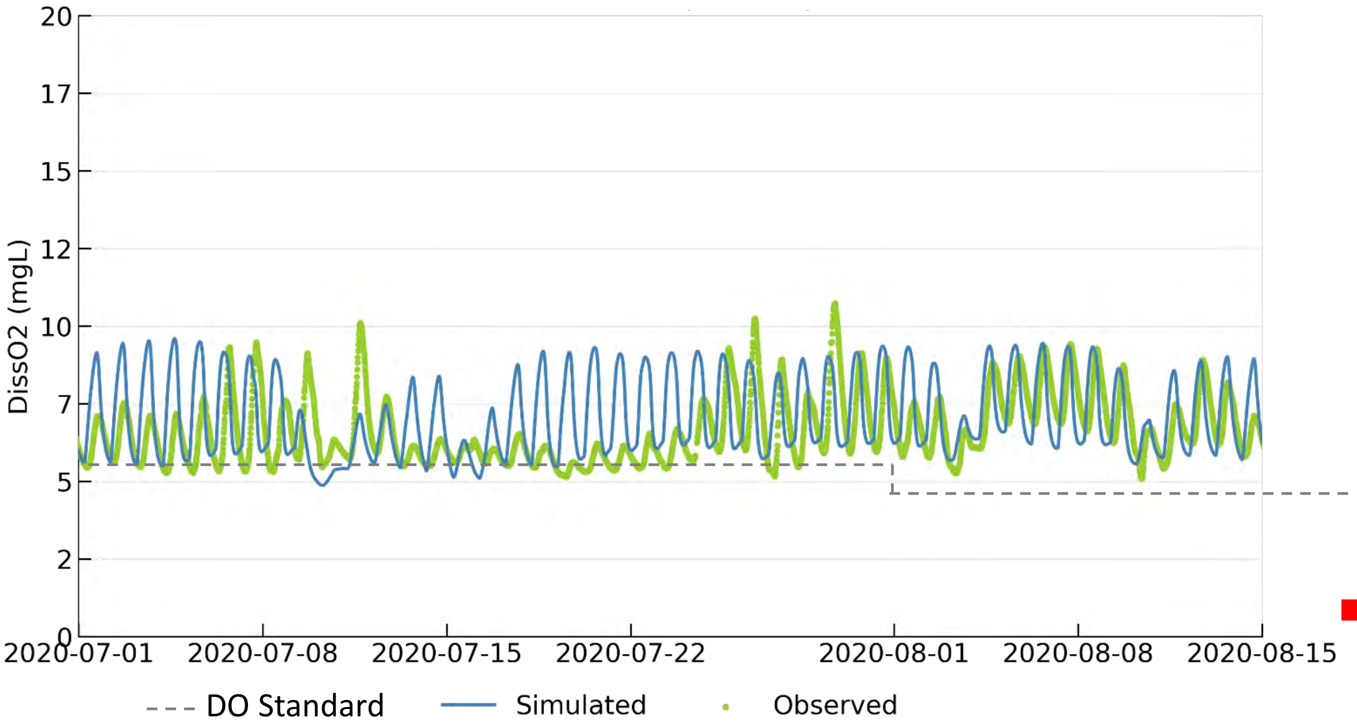
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rt. 22
# RM: 6.7, Model Seg.#17, Dissolved Oxygen




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
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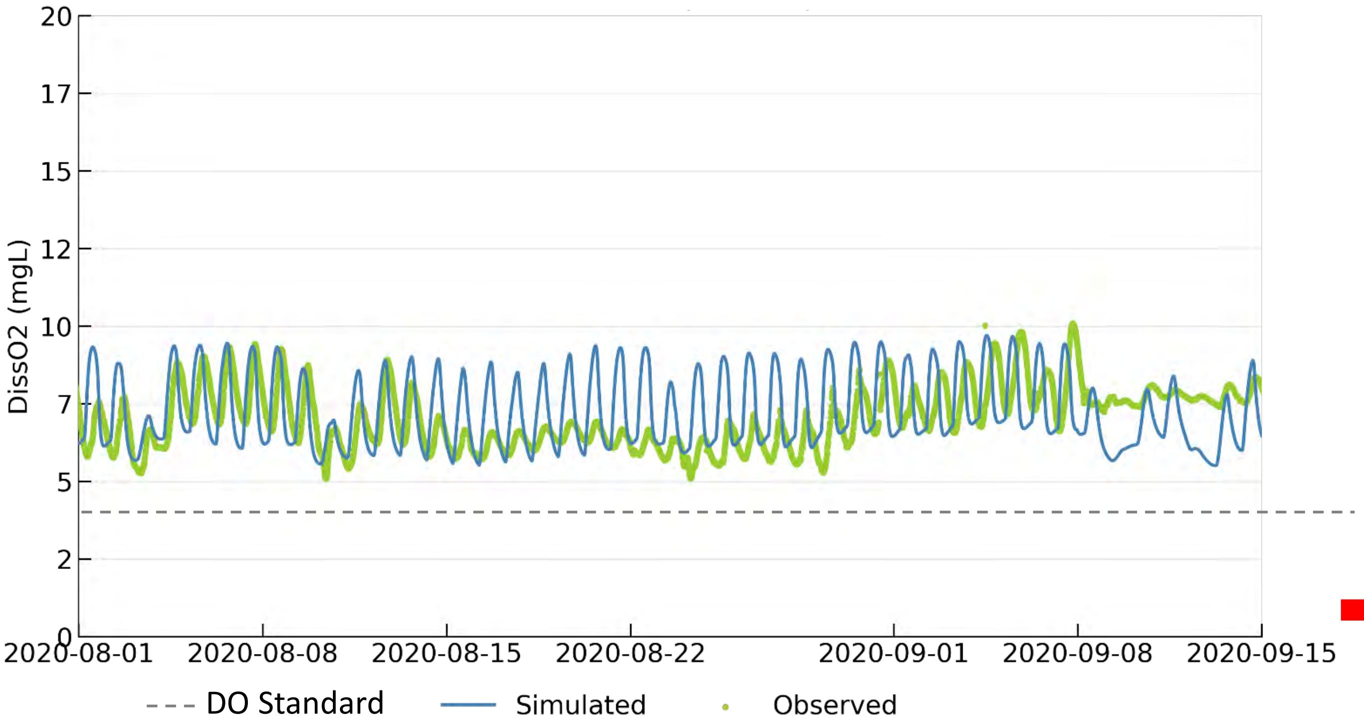
| 10 | SWAT, 11 cfs |
| 11 | SWAT, 16 cfs |
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rt. 22
# RM: 6.7, Model Seg.#17, Dissolved Oxygen




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
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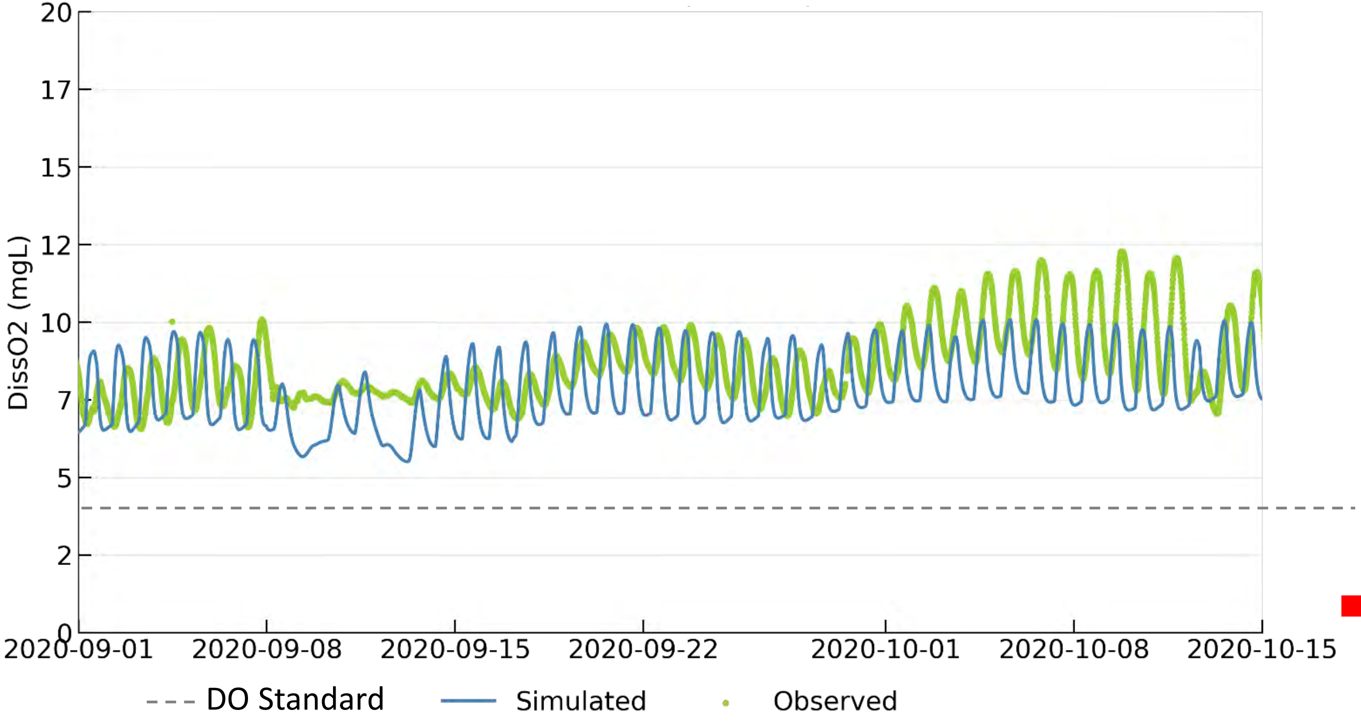
| 12 | SWAT, 8 cfs |
| 13 | SWAT, 2 cfs |
| 14 | LIBERTYVILLE & MUNDELEIN, 10 cfs |
| 15 | SWAT, 10 cfs |
| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Rt. 22
# RM: 6.7, Model Seg.#17, Dissolved Oxygen




| # | Model Input, Average Flow |
|---|---|
| 0 | Headwater, 158 cfs |
| 1 | SWAT, 12 cfs |
| 2 | SWAT, 5 cfs |
| 3 | SWAT, 9 cfs |
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| 16 | LCDPW-NEW CENTURY TOWN, 5 cfs |
| 17 | SWAT, 5 cfs |
| 18 | SWAT, 71 cfs |
| 19 | LCDPW-DES PLAINES, 15 cfs |
| 20 | SWAT, 4 cfs |

# Next Steps

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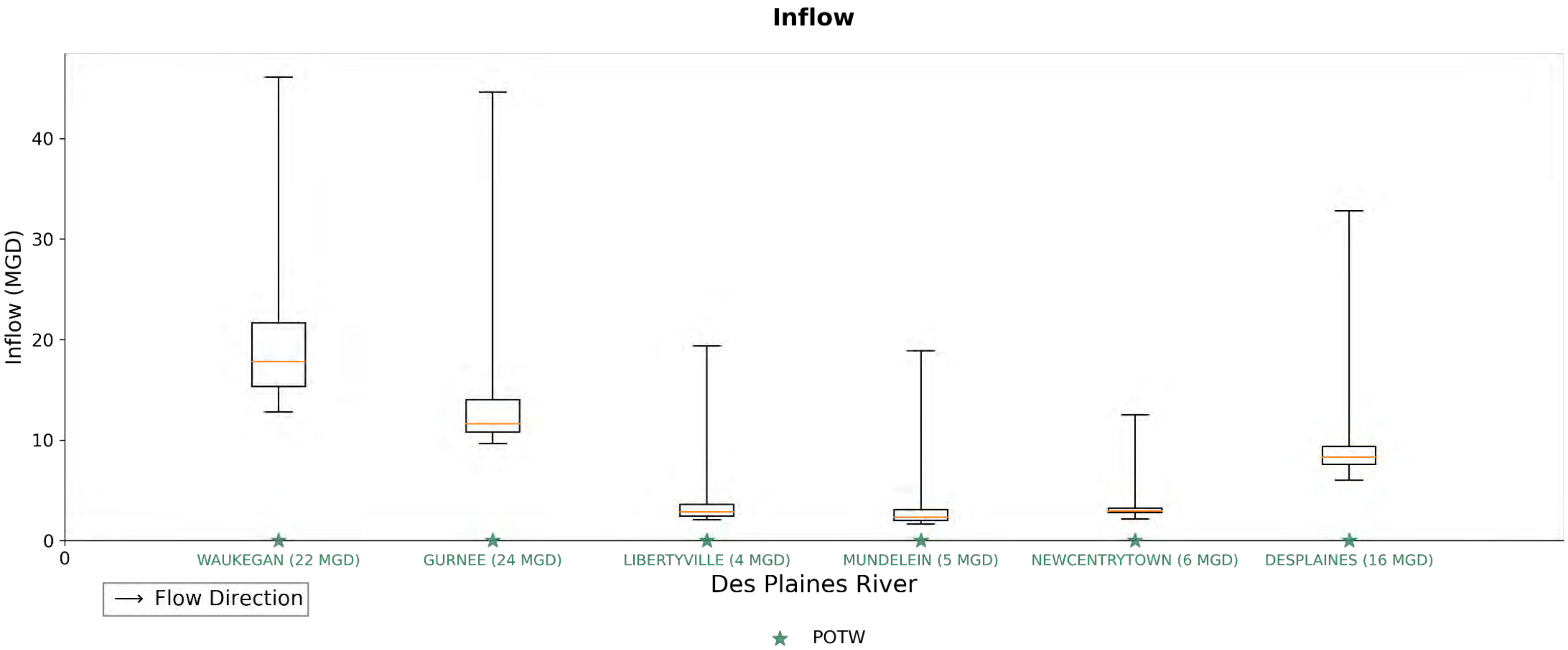
# Next Steps

- Address comments from the team
  - Decide on the chlorophyll-a and dissolved oxygen calibration
    - Move forward with the watershed management scenarios and revisit the calibration if results do not agree with reality
- Wrap up the Mill Creek model calibration
  - Mill Creek WRP and Lindenhurst effluent TP
- Prepare an appendix summarizing model development and calibration
- Watershed management scenarios
  - Identify the list of scenarios
  - Run and post-process the model results

- Questions?

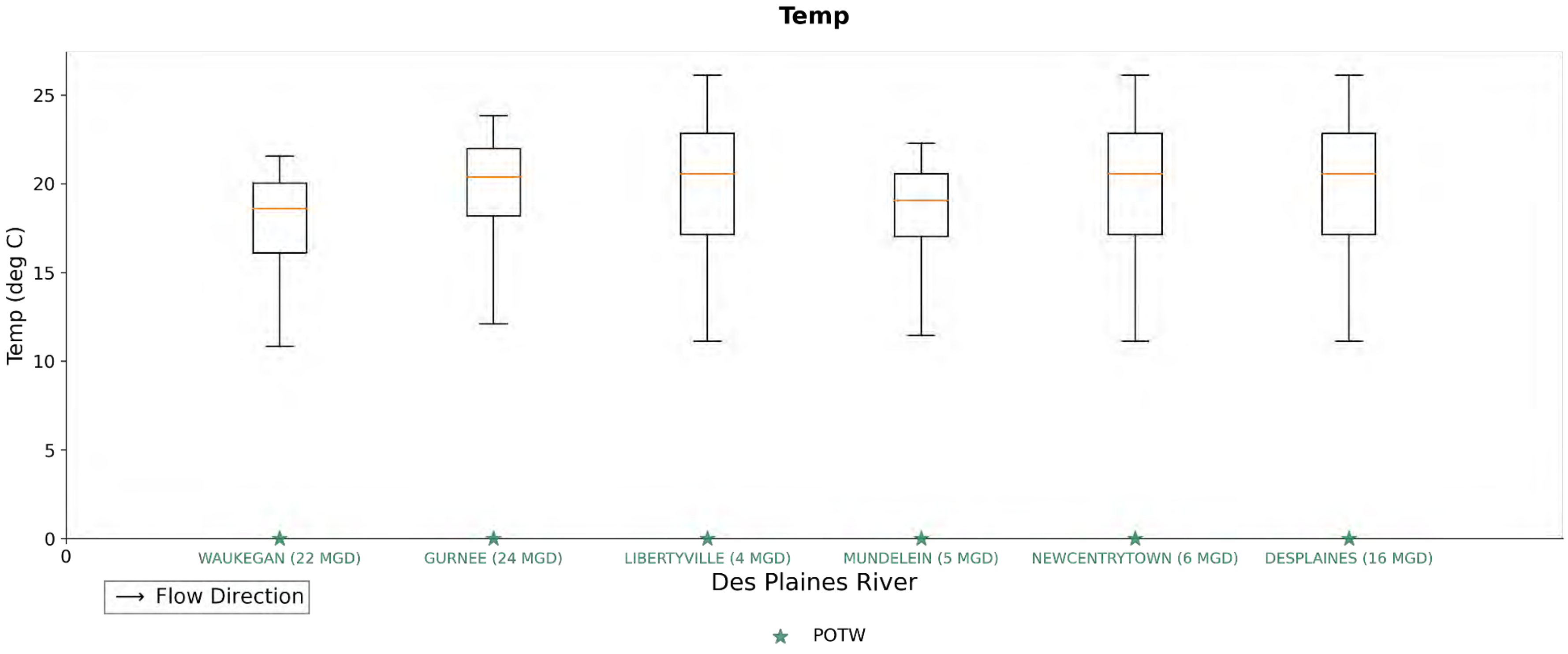
# Point Sources Water Quality Input

May – October 2020



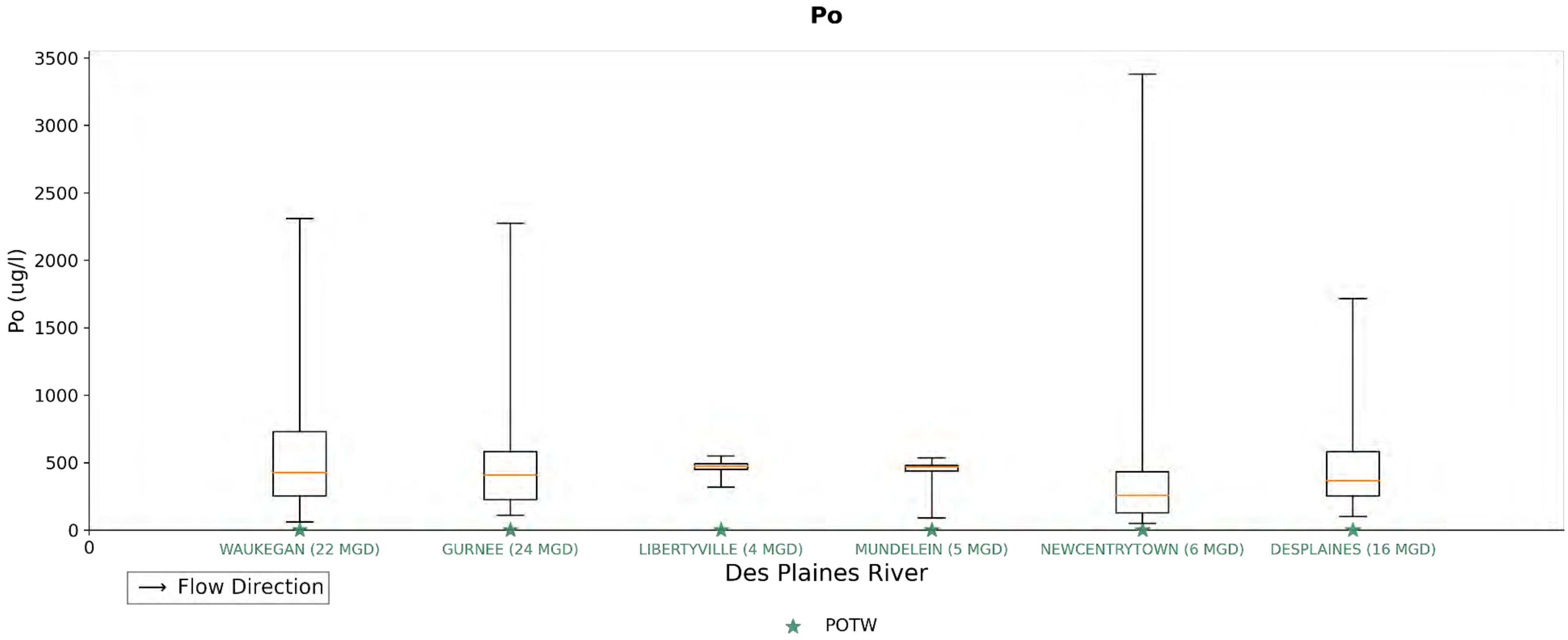
# Point Sources Water Quality Input

May – October 2020



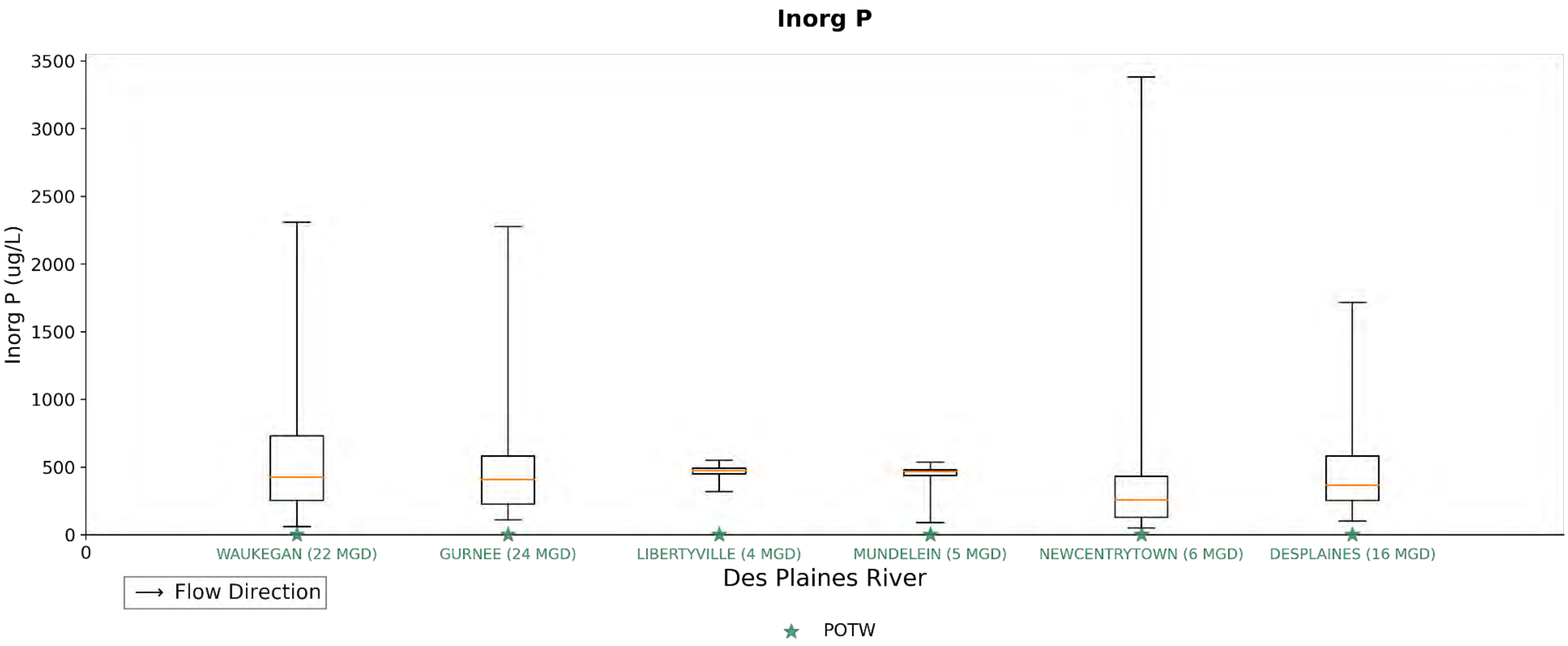
# Point Sources Water Quality Input

May – October 2020



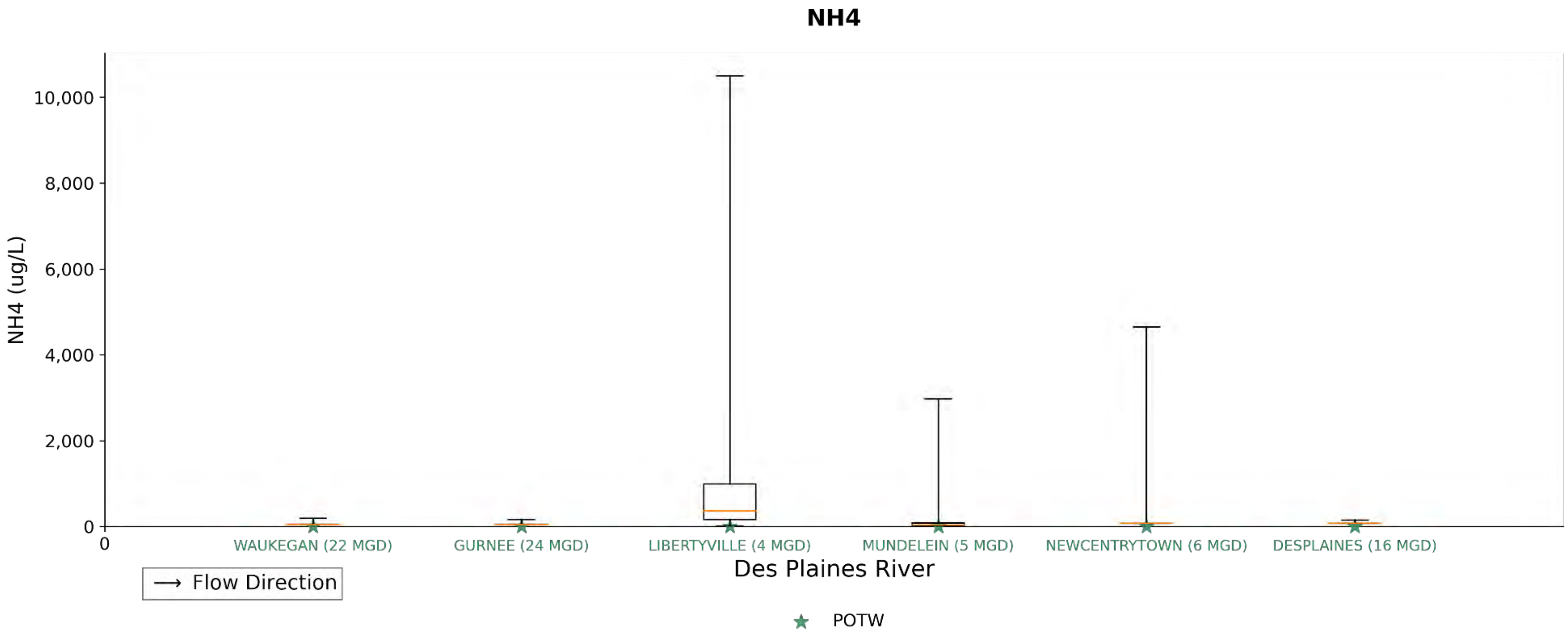
# Point Sources Water Quality Input

May – October 2020



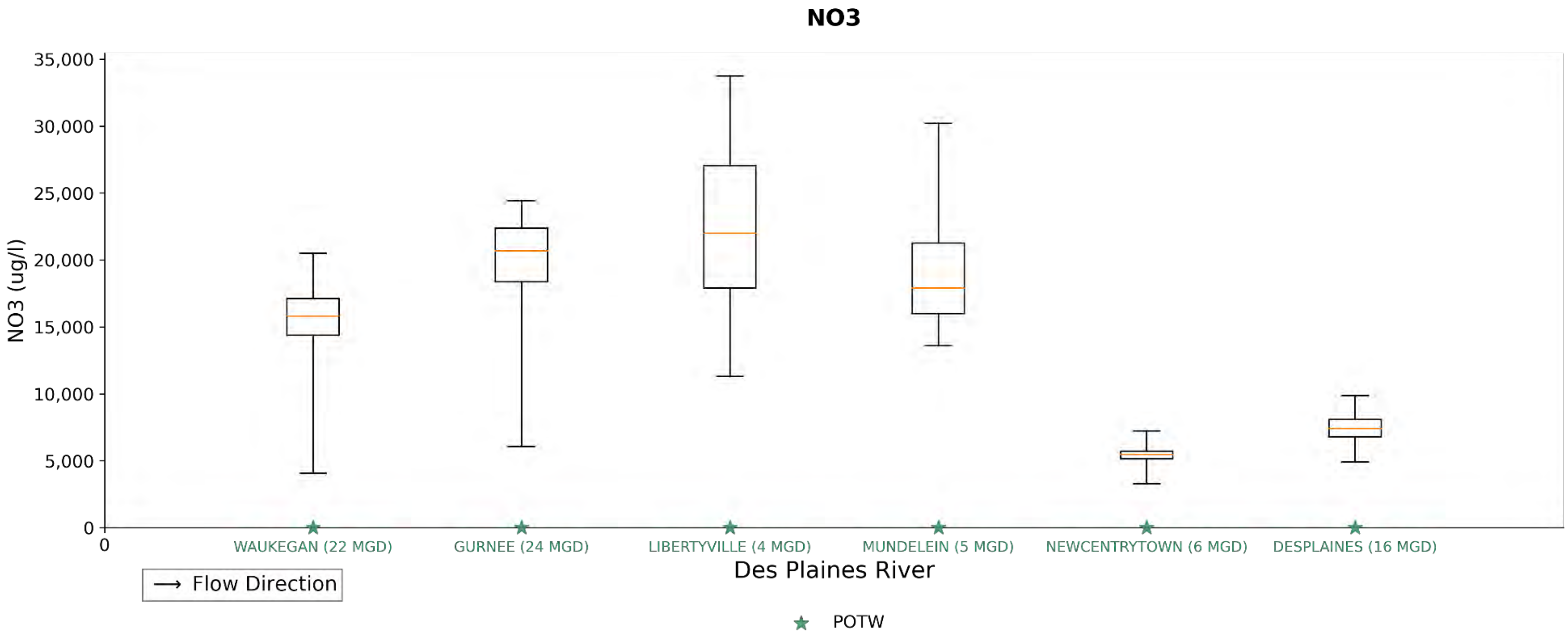
# Point Sources Water Quality Input

May – October 2020



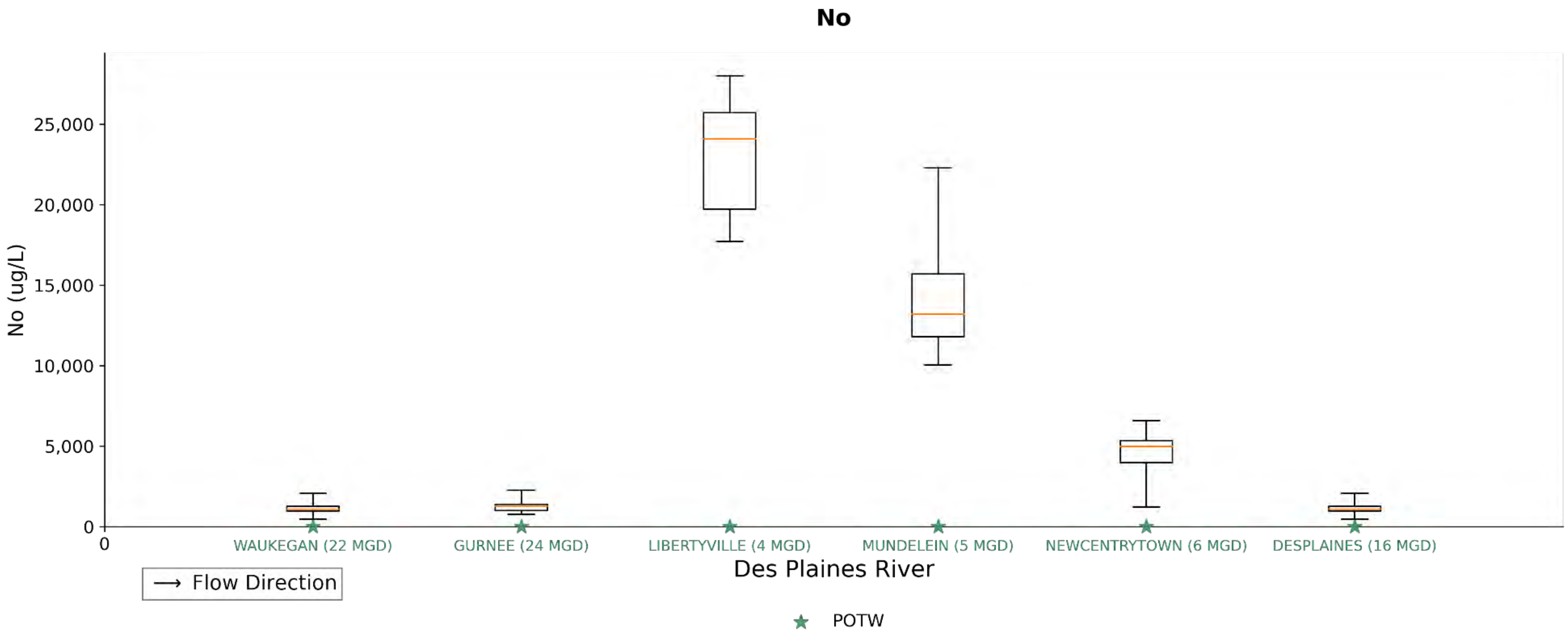
# Point Sources Water Quality Input

May – October 2020



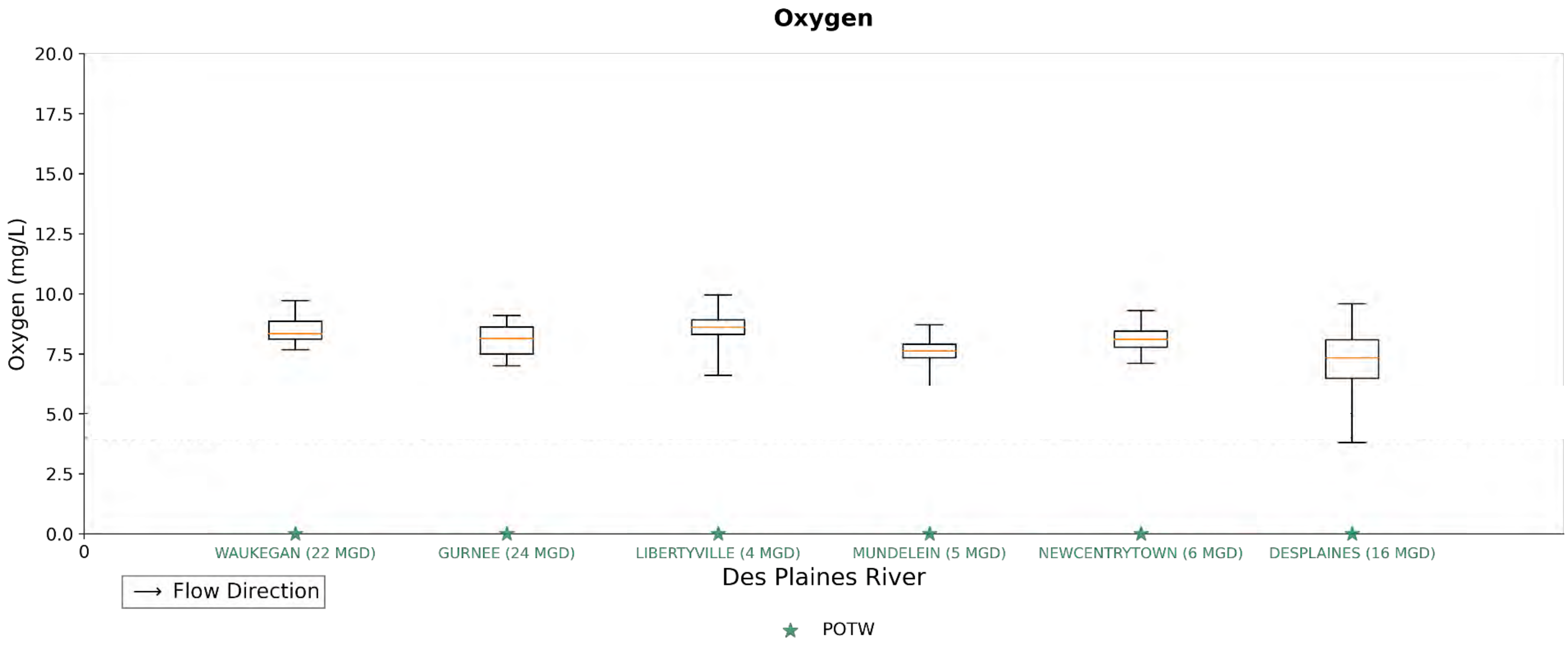
# Point Sources Water Quality Input

May – October 2020



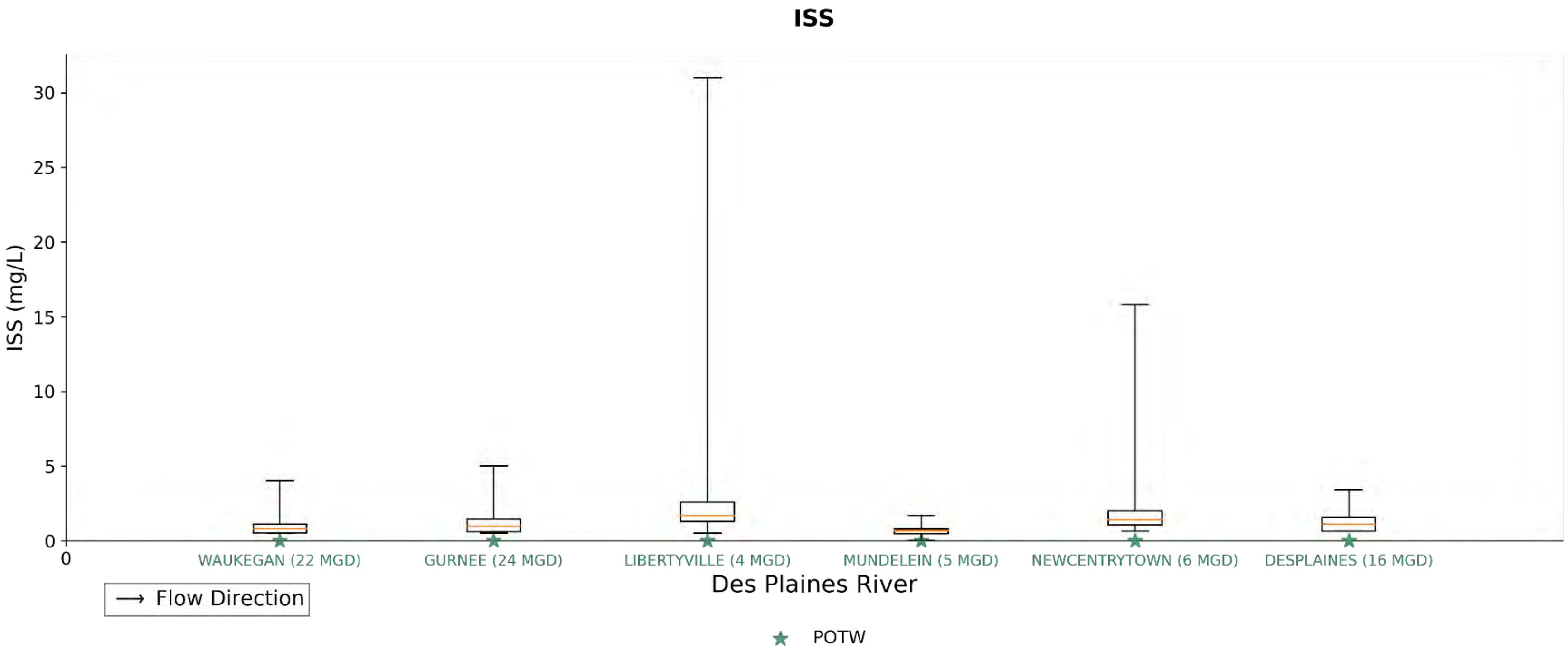
# Point Sources Water Quality Input

May – October 2020



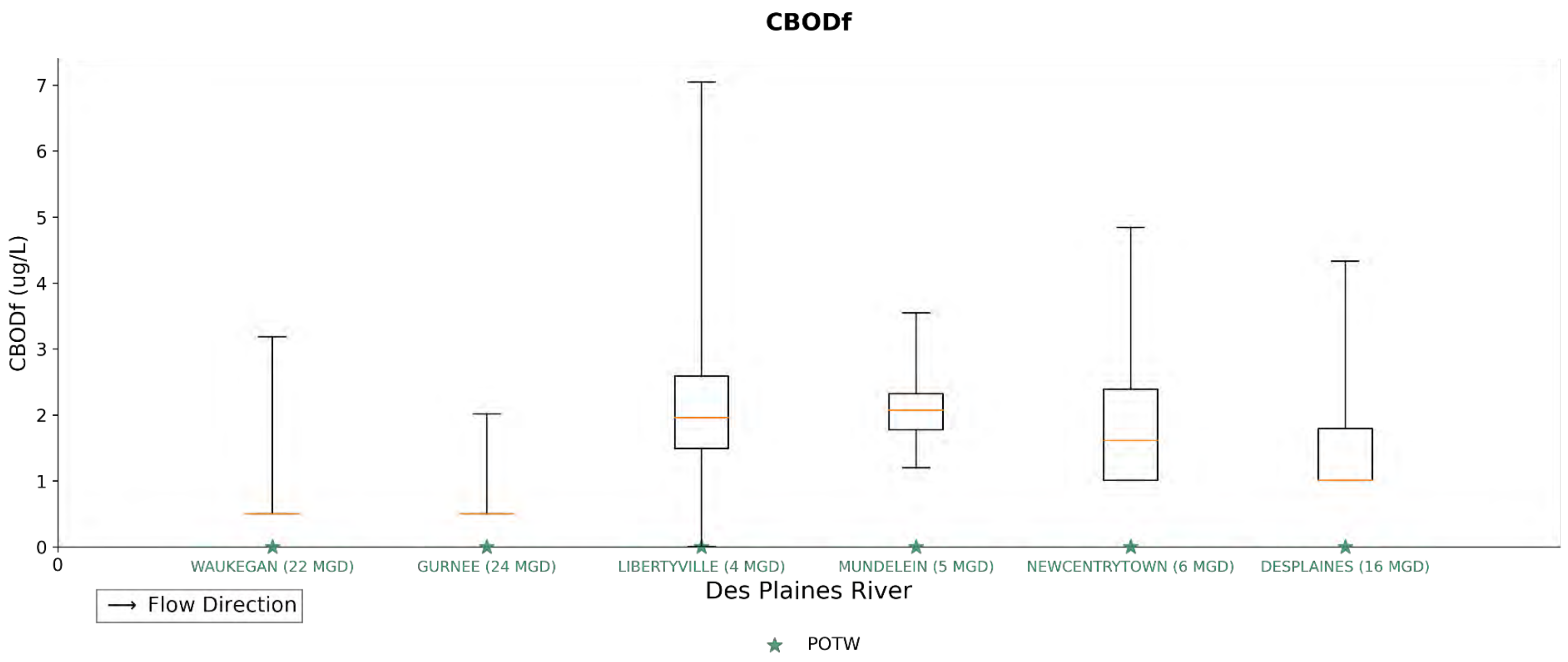
# Point Sources Water Quality Input

May – October 2020



# Point Sources Water Quality Input

May – October 2020



# Attachment 4

## Sensitivity Analysis and Watershed Management Scenarios Discussion PowerPoint Presentation (December 12, 2022)

Geosyntec consultants

# Watershed Management Scenarios

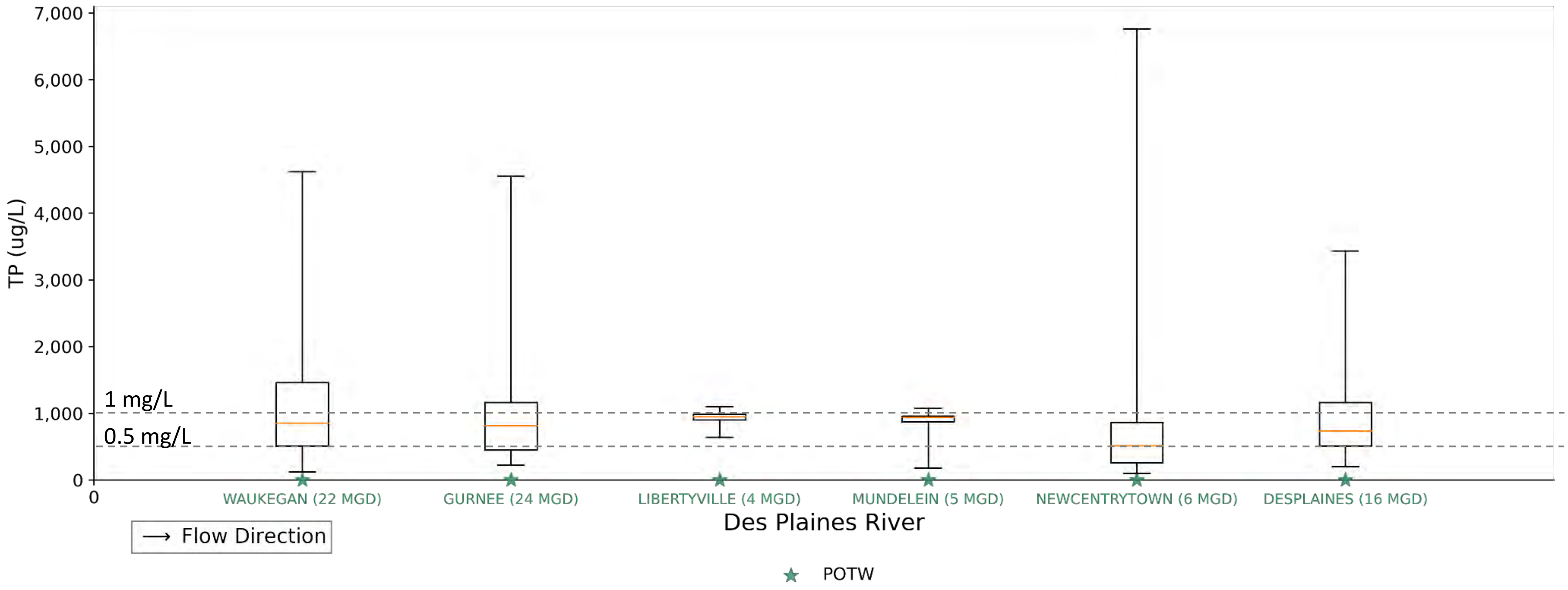
December 12, 2022

# Agenda

- Existing wastewater treatment plant performance
- Phosphorus load sources relative contribution
- Model response to phosphorus reduction
- Proposed watershed management scenarios
- Watershed management scenarios feasibility

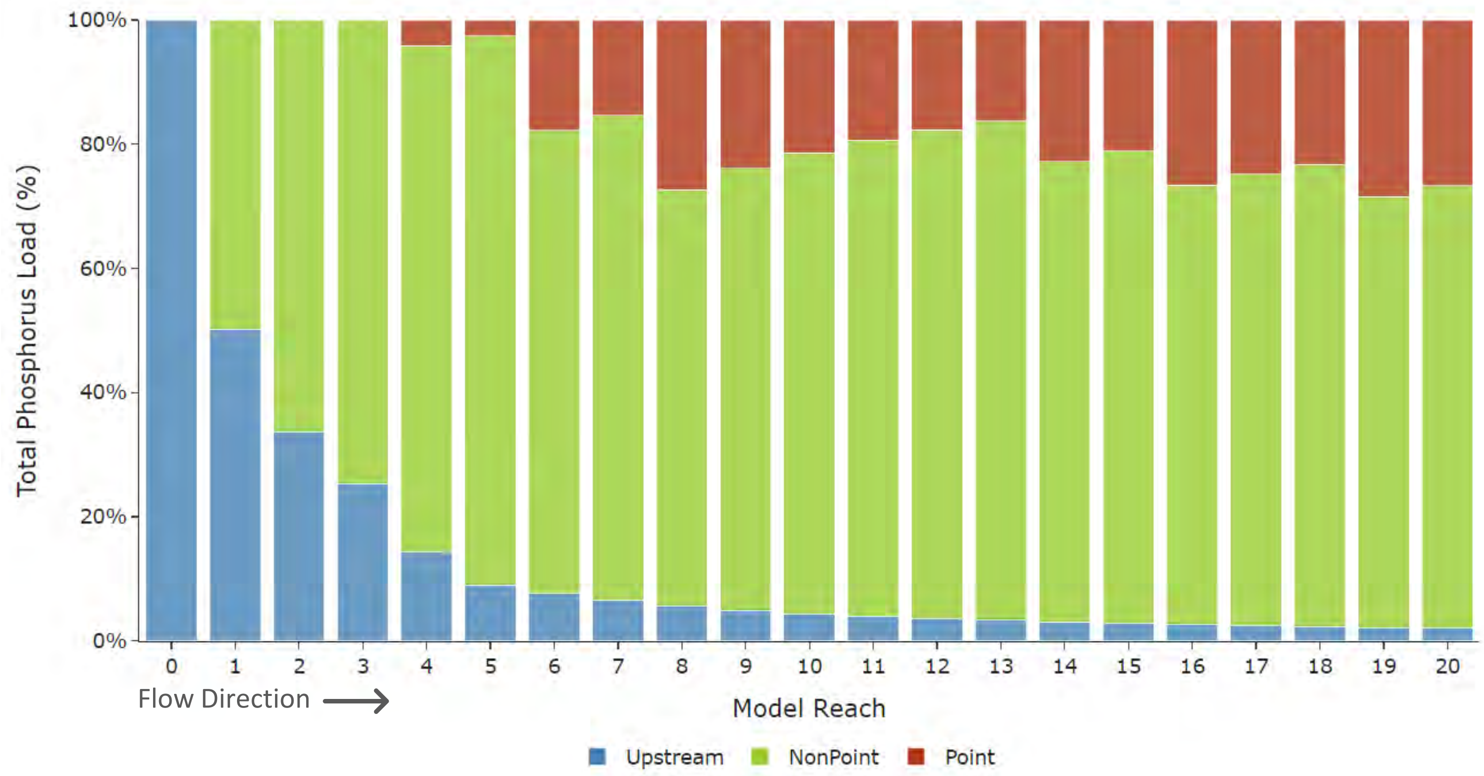
# Existing Wastewater Treatment Plant TP Performance

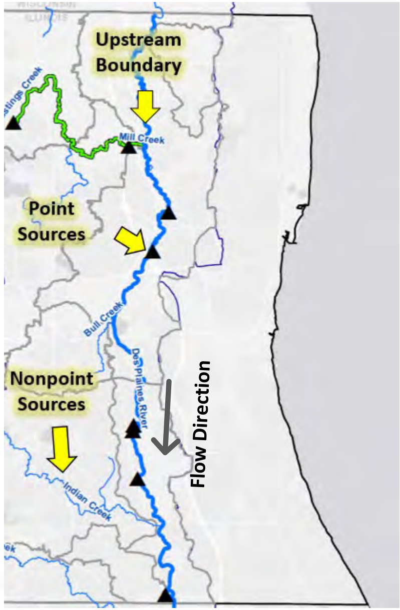
May – October 2020



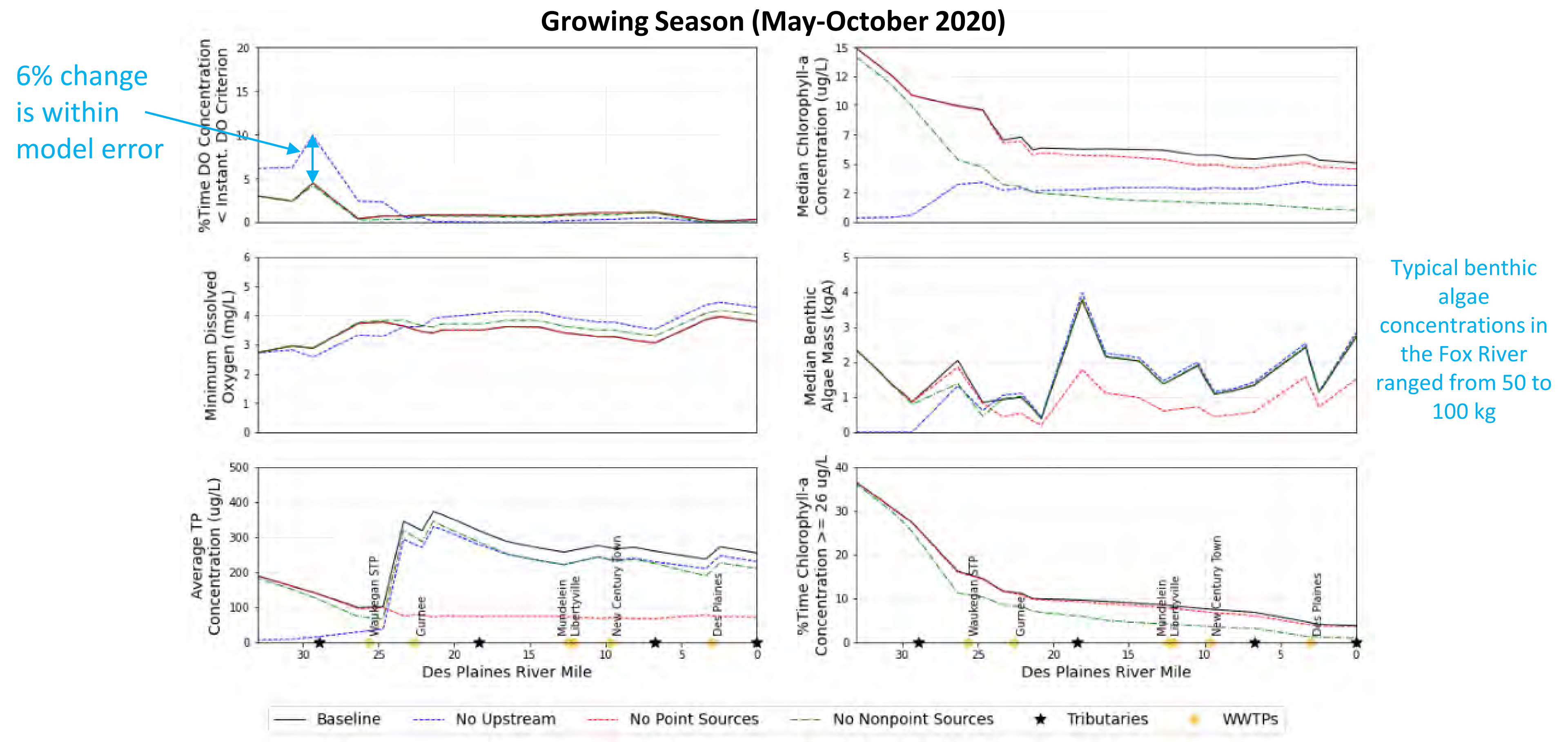
# Phosphorus load sources relative contribution over the growing season

Phosphorus load relative contribution changes along the Des Plaines River



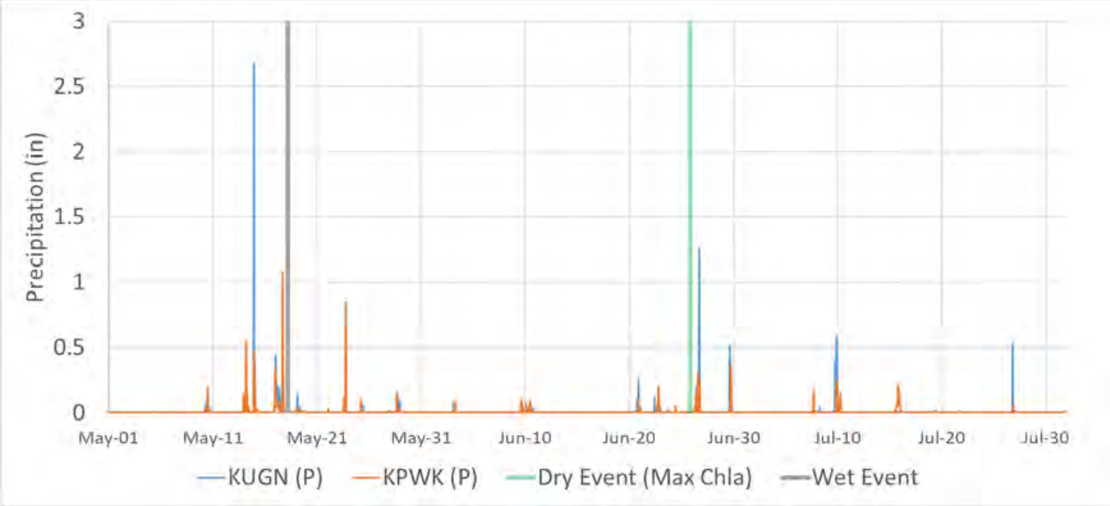



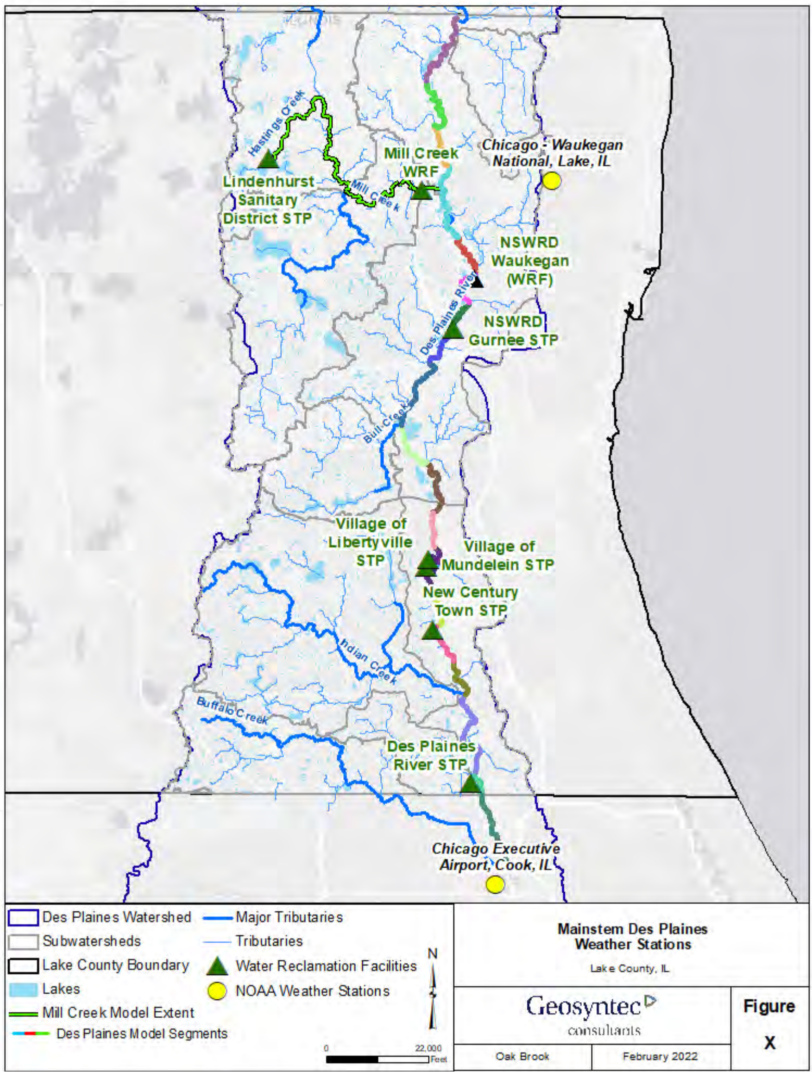
# Model Response to Phosphorus Load Reduction



# Wet and Dry Events Selection

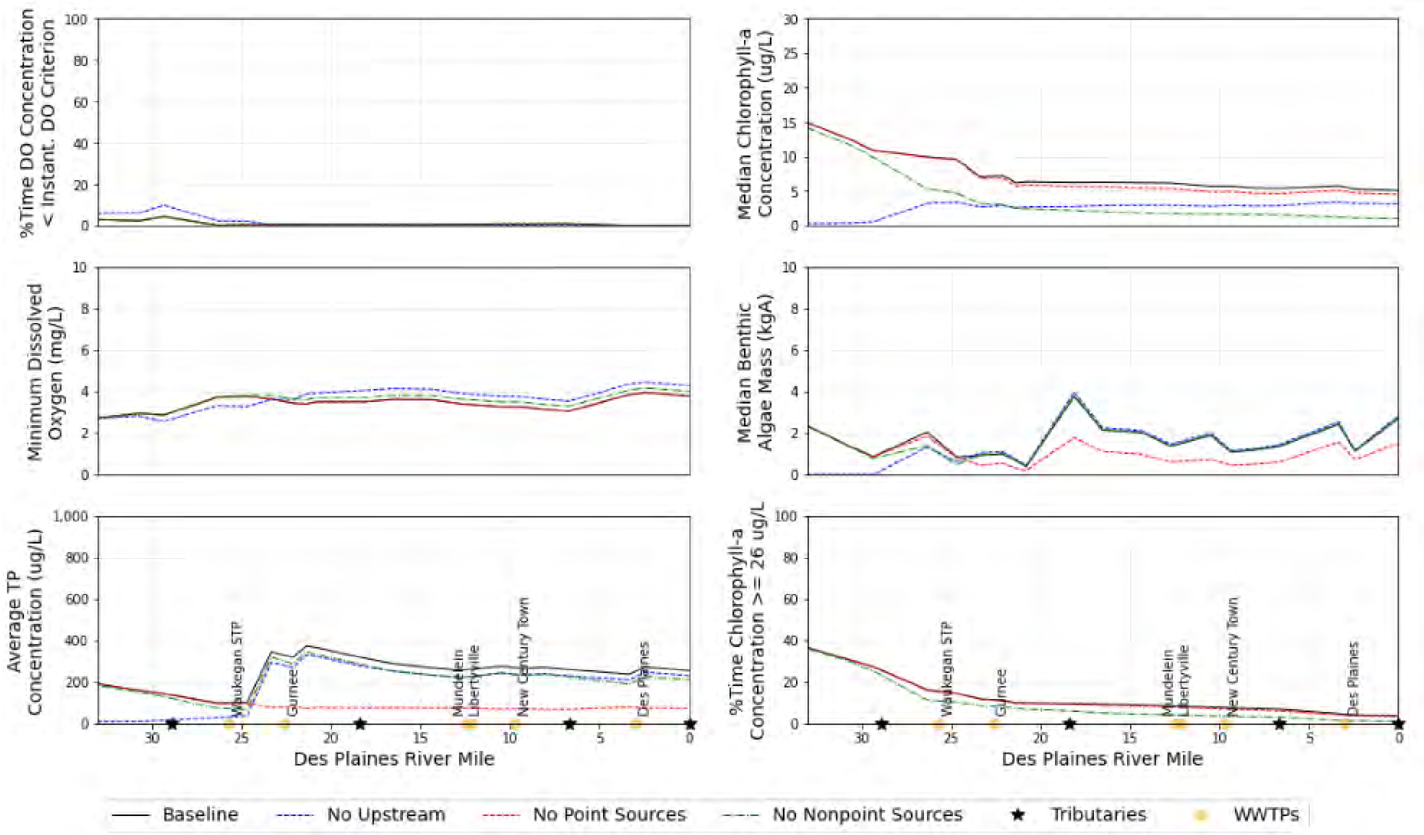
- Two meteorological stations



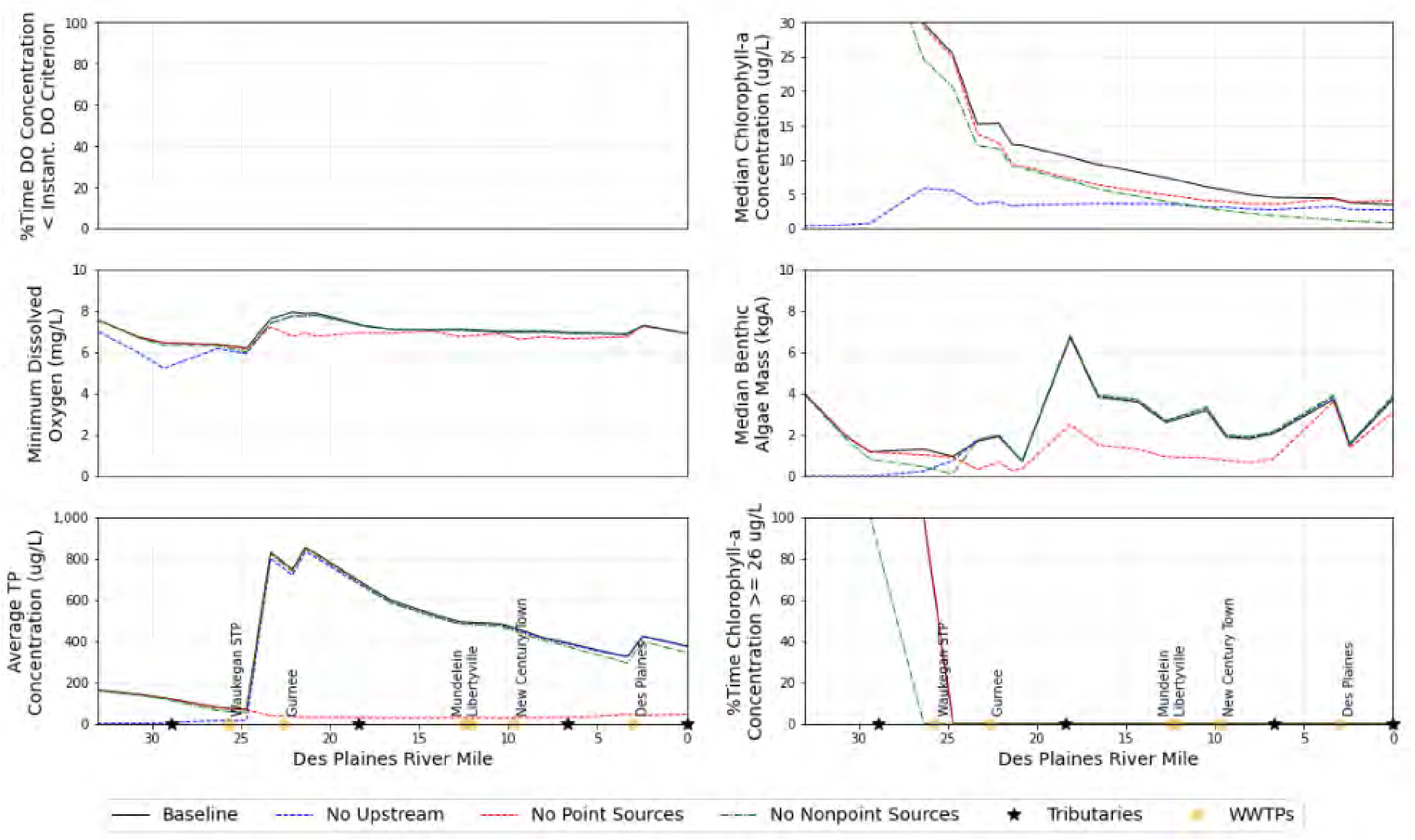
# Model Response to Phosphorus Load Reduction

**Growing Season (same scale for comparison)**



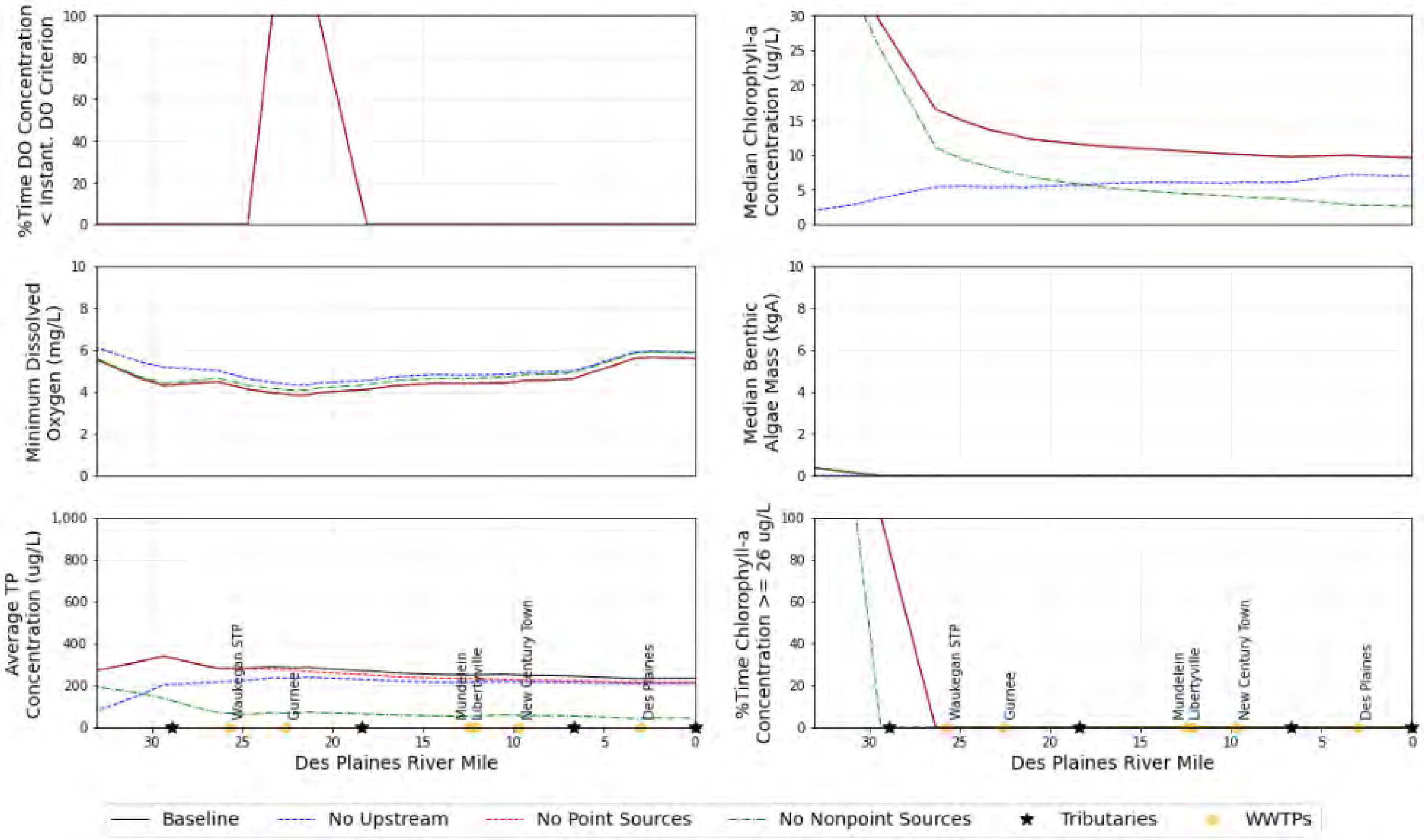
# Model Response to Phosphorus Load Reduction

**Dry Event: 6/25/2020 (Max Chlorophyll-a = 95.2 ug/L)**



# Model Response to Phosphorus Load Reduction

**Wet Event: 5/18/2020**



# Proposed Watershed Management Scenarios

- Point source phosphorus reduction (0.5 and 0.1 mg/L)
  - Approach: set all the plants to a constant effluent limit
- Nonpoint source phosphorus load reduction
  - 50%?
  - 75%
- Upstream phosphorus load reduction
  - 50%?
  - 75%
- Two feasible combined scenarios
  - 0.5 mg/L, 50% Nonpoint, 75% Upstream

# Watershed Management Scenarios Feasibility

- Feasibility discussion needs to be informed by implementation and schedule
- Upstream phosphorus load reduction
  - It is unclear if Illinois EPA expects workgroups to evaluate the feasibility of upstream reductions
- If additional scenarios are needed to find a more feasible management alternatives, additional funds will be needed

# Questions?

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# Attachment 5

Watershed Management Scenarios Results PowerPoint Presentation (January 19, 2023)

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# Watershed Management Scenarios

January 19, 2023

# Agenda

- DRWW Publicly Owned Treatment Works (POTWs) NARP Requirement
  - Impairment
  - Observed data
- Watershed Management Scenarios
  - List of scenarios
  - Modeling approach
  - Main takeaways
  - Detailed results
    - Upstream total phosphorus (TP) reductions
    - Nonpoint source TP reductions
    - POTW TP reductions
- Feasible Management Scenarios Discussion

# DRWW POTWs
# NARP Requirement

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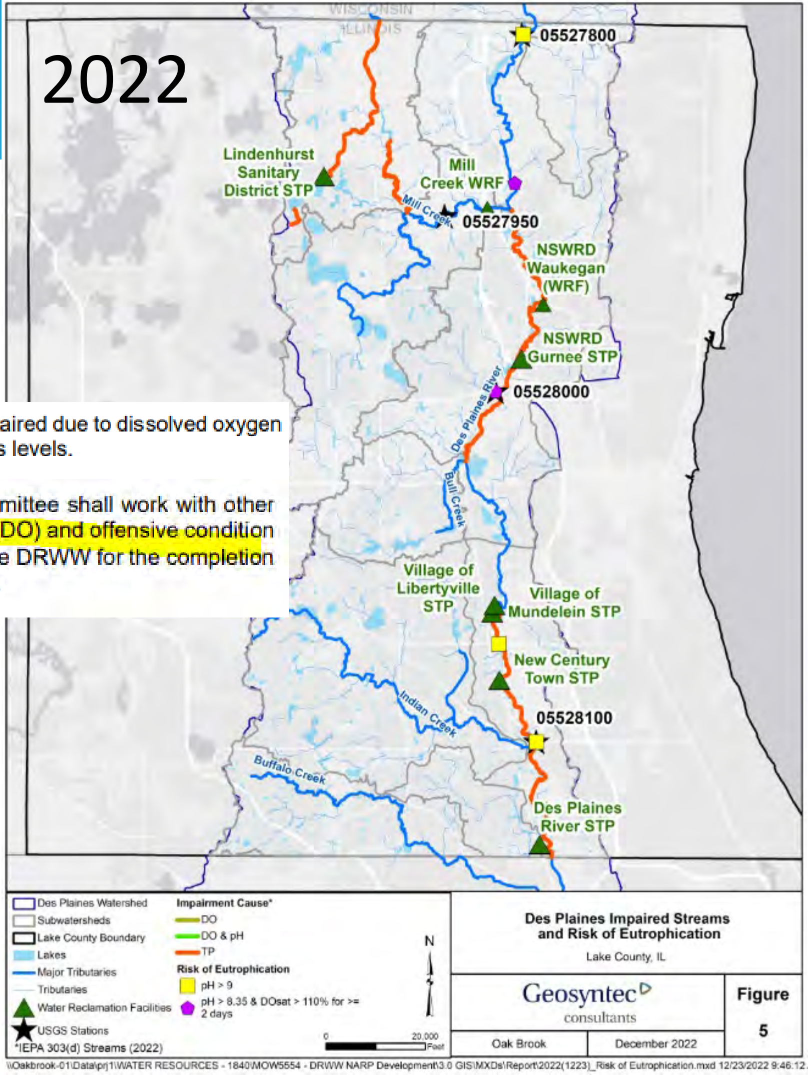
# DRWW NARP Requirement

- POTWs received a NARP requirement because they discharge to a phosphorus-related impaired stream

A phosphorus related impairment means that the downstream waterbody or segment is listed by the Agency as impaired due to dissolved oxygen and/or offensive condition (algae and/or aquatic plant growth) impairments that is related to excessive phosphorus levels.

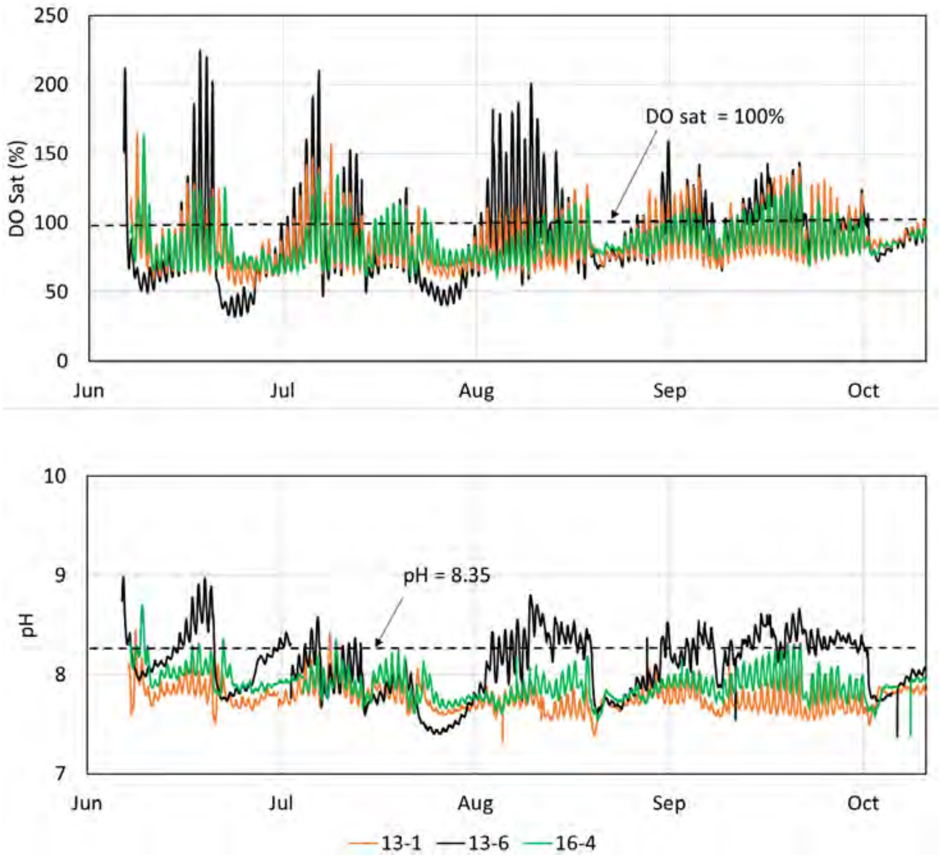
The Permittee is currently participating in the Des Plaines River Watershed Workgroup (DRWW). The Permittee shall work with other watershed members of the DRWW to determine the most cost-effective means to remove dissolved oxygen (DO) and offensive condition impairments in the Des Plaines River Watershed to the extent feasible. The Permittee shall participate in the DRWW for the completion of the Bioassessment Monitoring Program Plan of the Des Plaines River Watershed Bioassessment Quality.

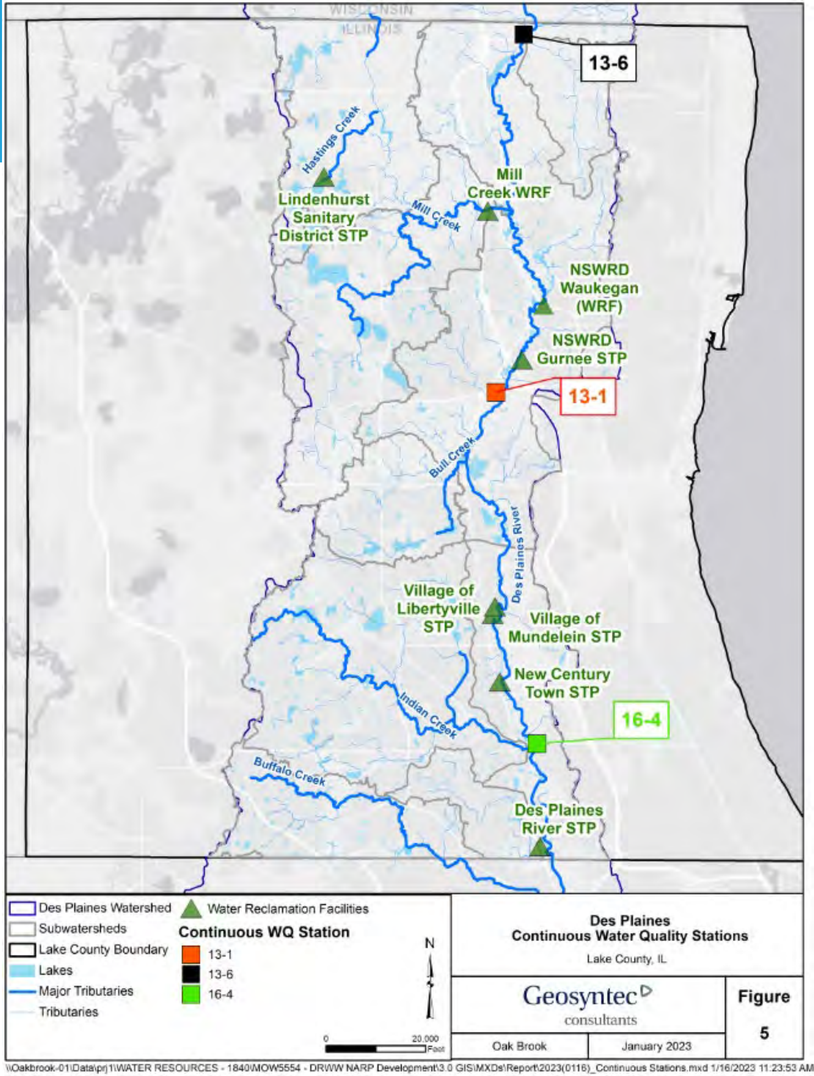
- The upstream boundary station is at risk of eutrophication (using 2017-2021 data)
  - pH > 9
  - pH > 8.35 & DOsat > 110% for >= 2 days



# DRWW NARP Requirement

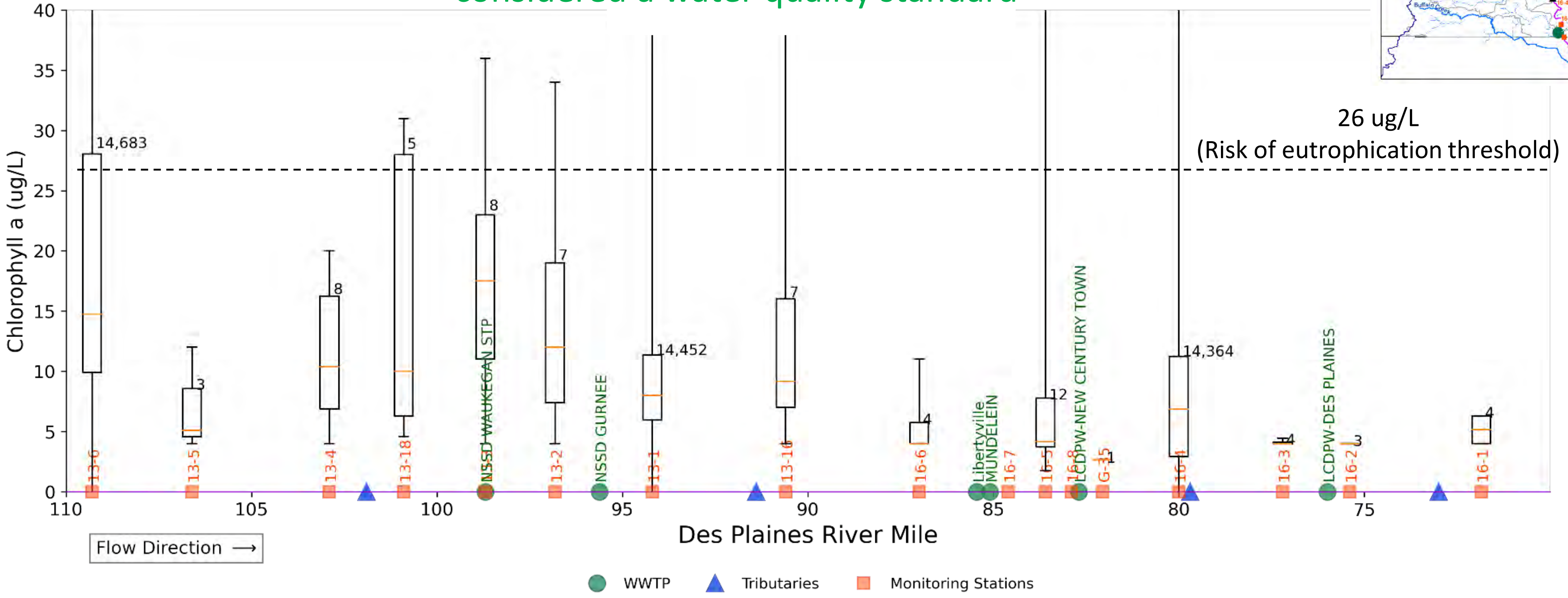
2020 Data

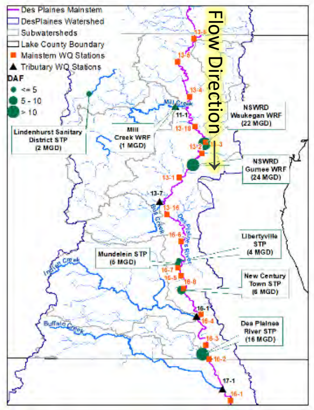


# Chlorophyll-a (May – Oct.) 2017-2021

Median Chlorophyll-a < 26 ug/L. This value will be used to compare scenarios and should not be considered a water quality standard



# Watershed Management Scenarios

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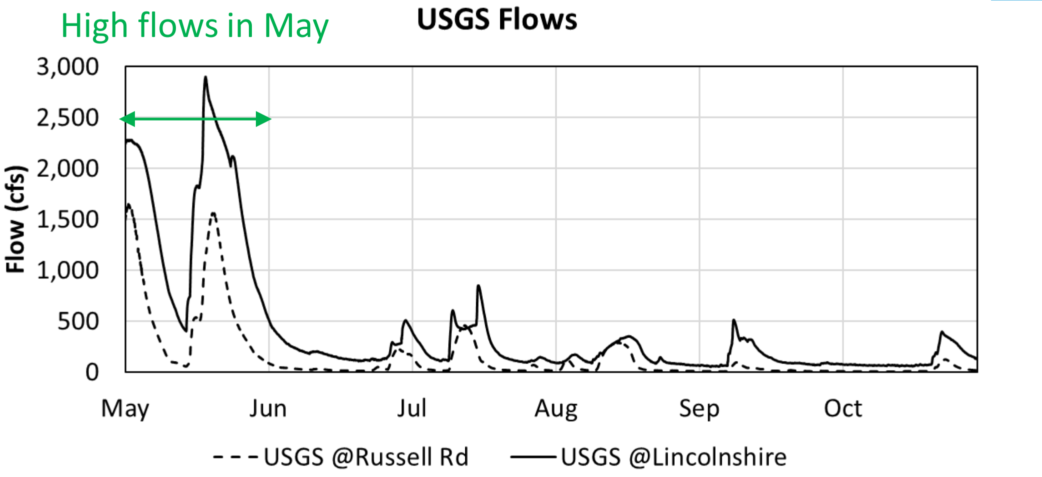
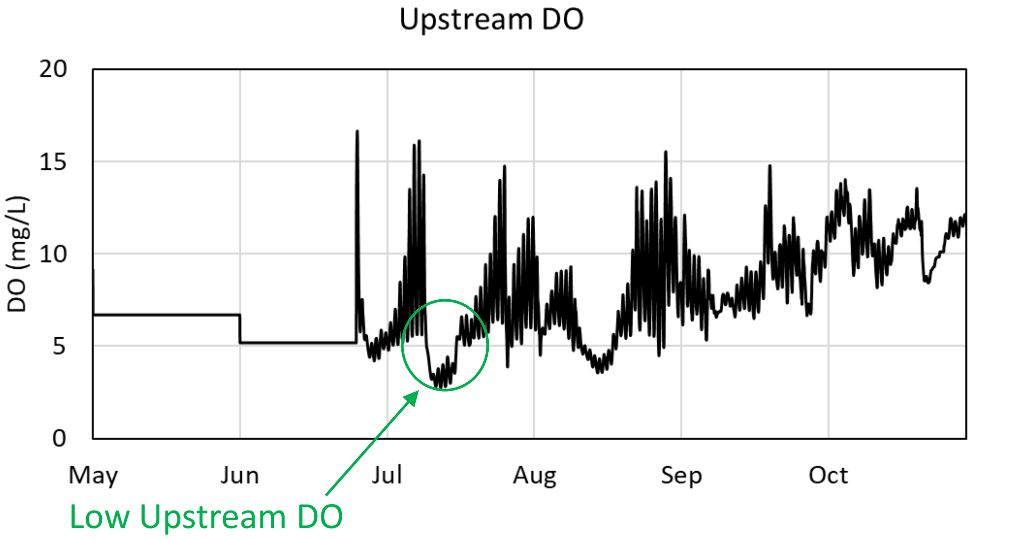
# Baseline Scenario

- Based on calibrated existing condition model
  - Presented to Monitoring Committee on 11-7-2022

- Simulation period
  - Growing Season
    - May 1- Oct. 31

- Periods selected for comparison
  - Growing season
  - Low DO Period: Jul.10 –17
  - High Flow Period: May 1 – 31



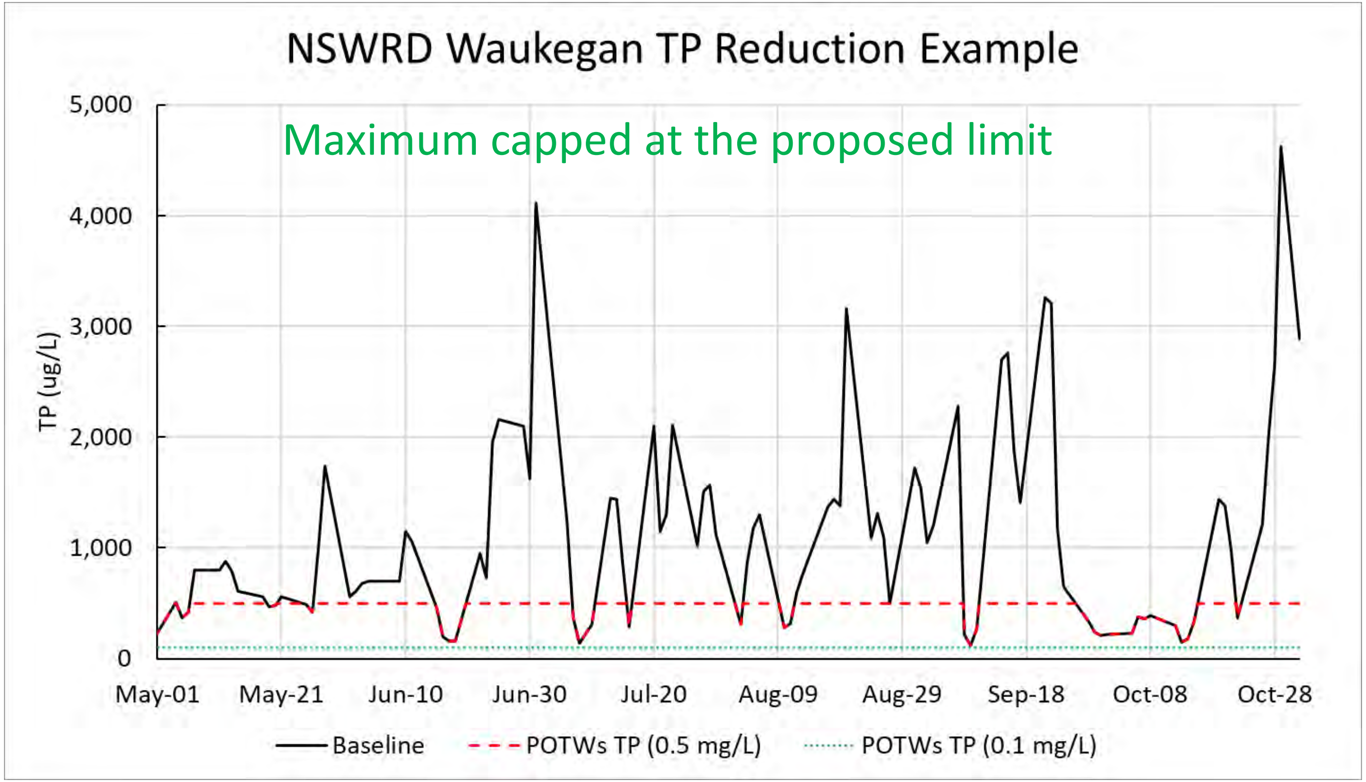



# Watershed Management Scenarios

- Upstream phosphorus load reduction
  - 75% reduction
- Nonpoint source phosphorus load reduction
  - 75% reduction
- POTW phosphorus reductions
  - Maximum TP capped at 0.5 mg/L
  - Maximum TP capped at 0.1 mg/L
- Two feasible combined scenarios
  - TBD

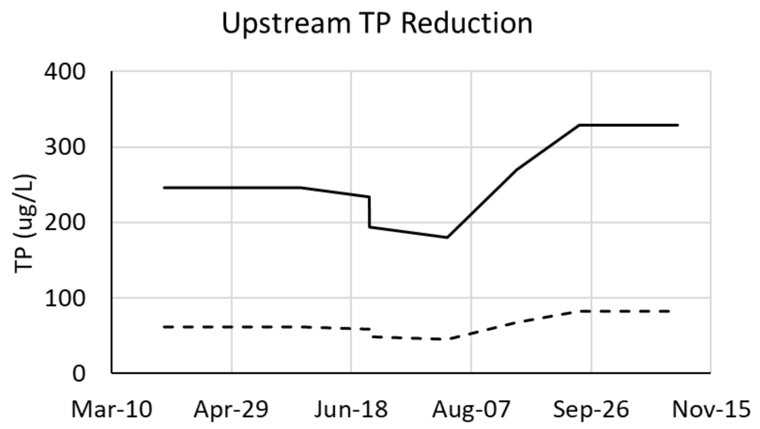
# POTW Reduction Modeling Approach

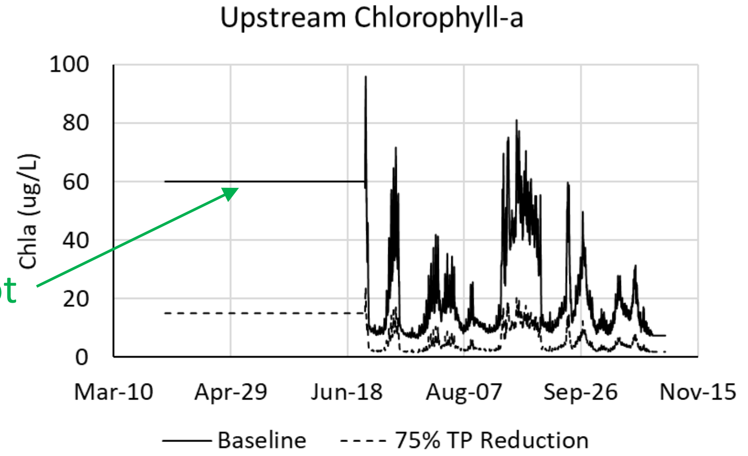
- POTW phosphorus reduction (0.5 and 0.1 mg/L)



# Nonpoint Sources and Upstream Boundary Reduction Approach

- Applied the TP reduction to the three TP components:
  - Organic P
  - Inorganic P
  - Internal P based on the model ratio (Chl-a: P → 1:1)



# Watershed Management Scenario Results

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# Key Takeaways

- Takeaway #1: Upstream TP reduction reduces sestonic Chl-a and  improves DO following large flow events

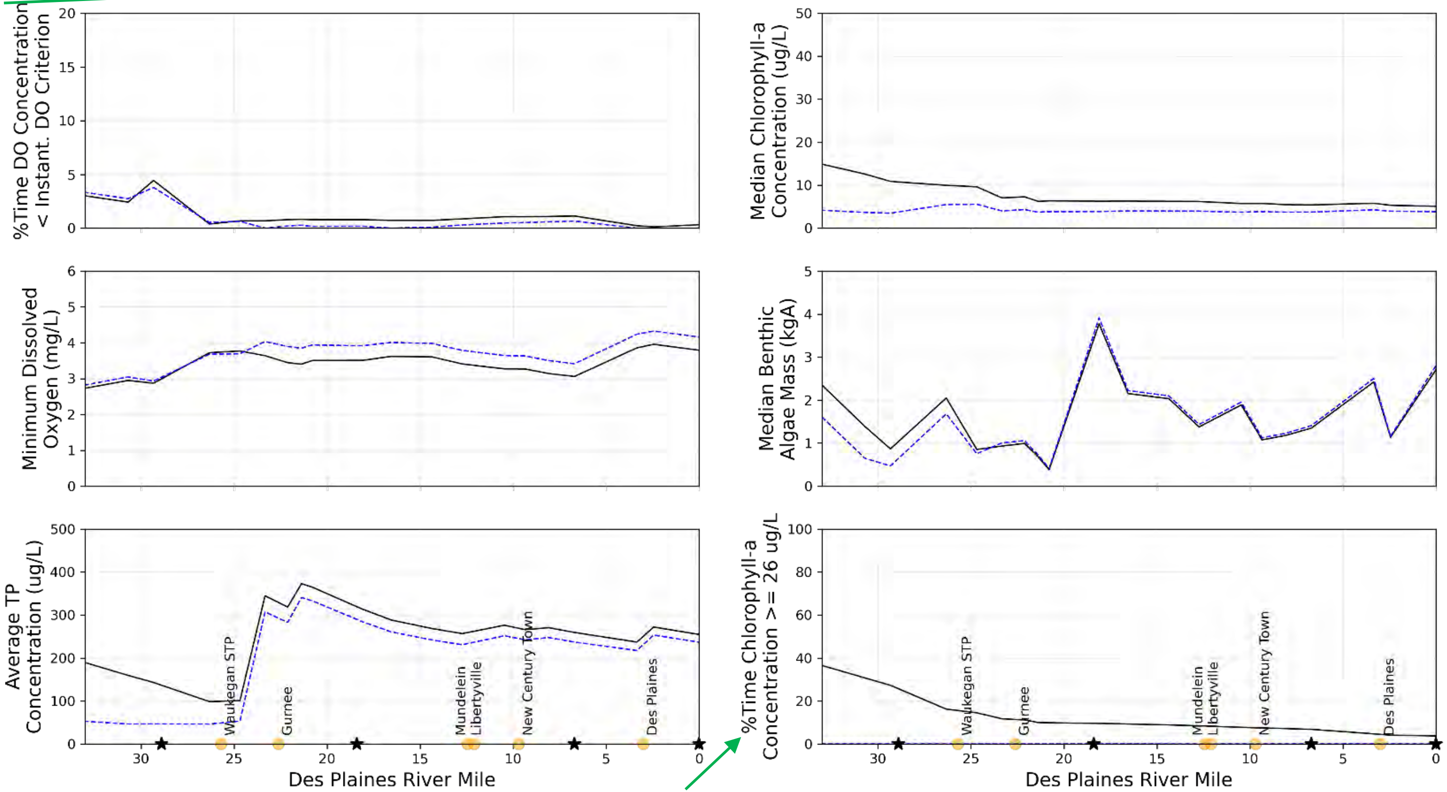
- Takeaway #2: Tributary TP reductions reduce sestonic Chl-a but has minimal impact on DO

- Takeaway #3: POTW TP reductions have minimal impact on water quality

# Results Presentation Format

Analysis Period: Growing season, low DO period, or high flow period

**Analysis Period**




WWTP

Tributaries

Baseline

75% Upstream Reduction

75% Nonpoint Reduction

0.5 mg/L POTWs effluent

0.1 mg/L POTWs effluent

For comparing scenarios, not a "threshold"

# Upstream Reduction

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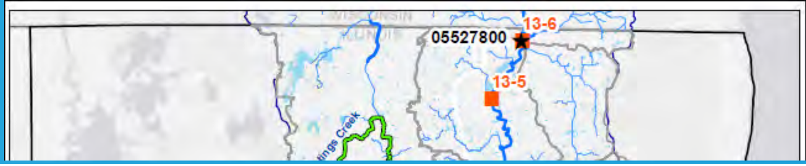
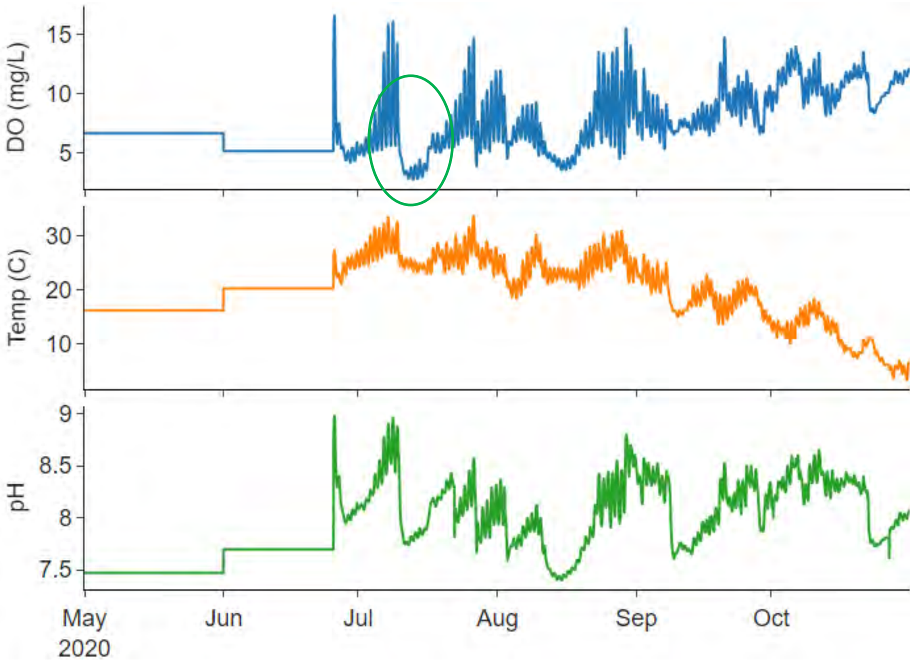
# Low Upstream DO




- Upstream DO below the 5 mg/L standard
  - Jul.10 – 17

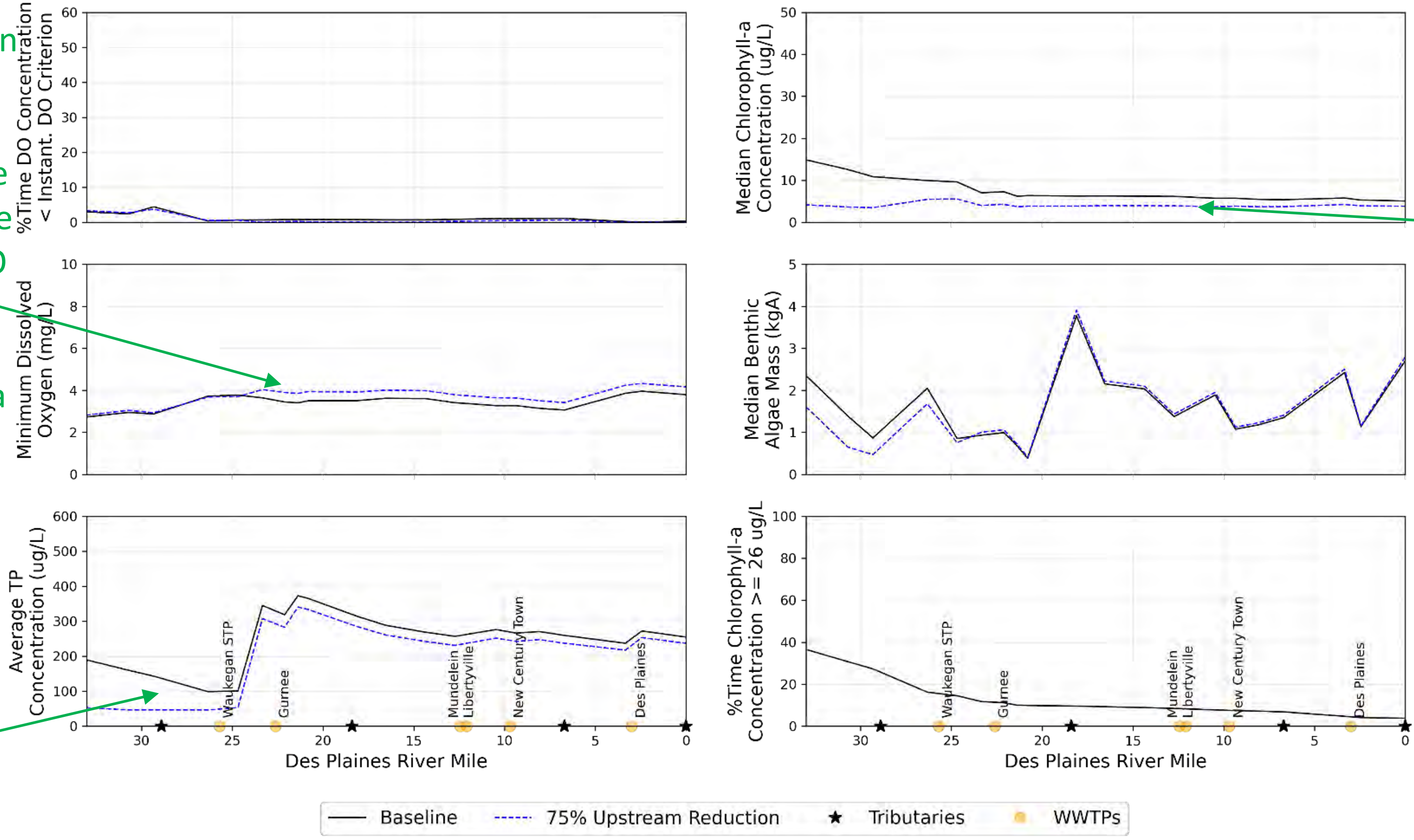


# Baseline and 75% Upstream Reduction – Longitudinal

**Growing Season (May-October 2020)**

Improvement in minimum DO after RM 25 following large wet events due to reduced DO swings with reduced upstream Chla and increased benthic algae

Reduction in TP due to reduction in upstream TP




Reduction in Chl-a, due to reduction in upstream Chl-a boundary

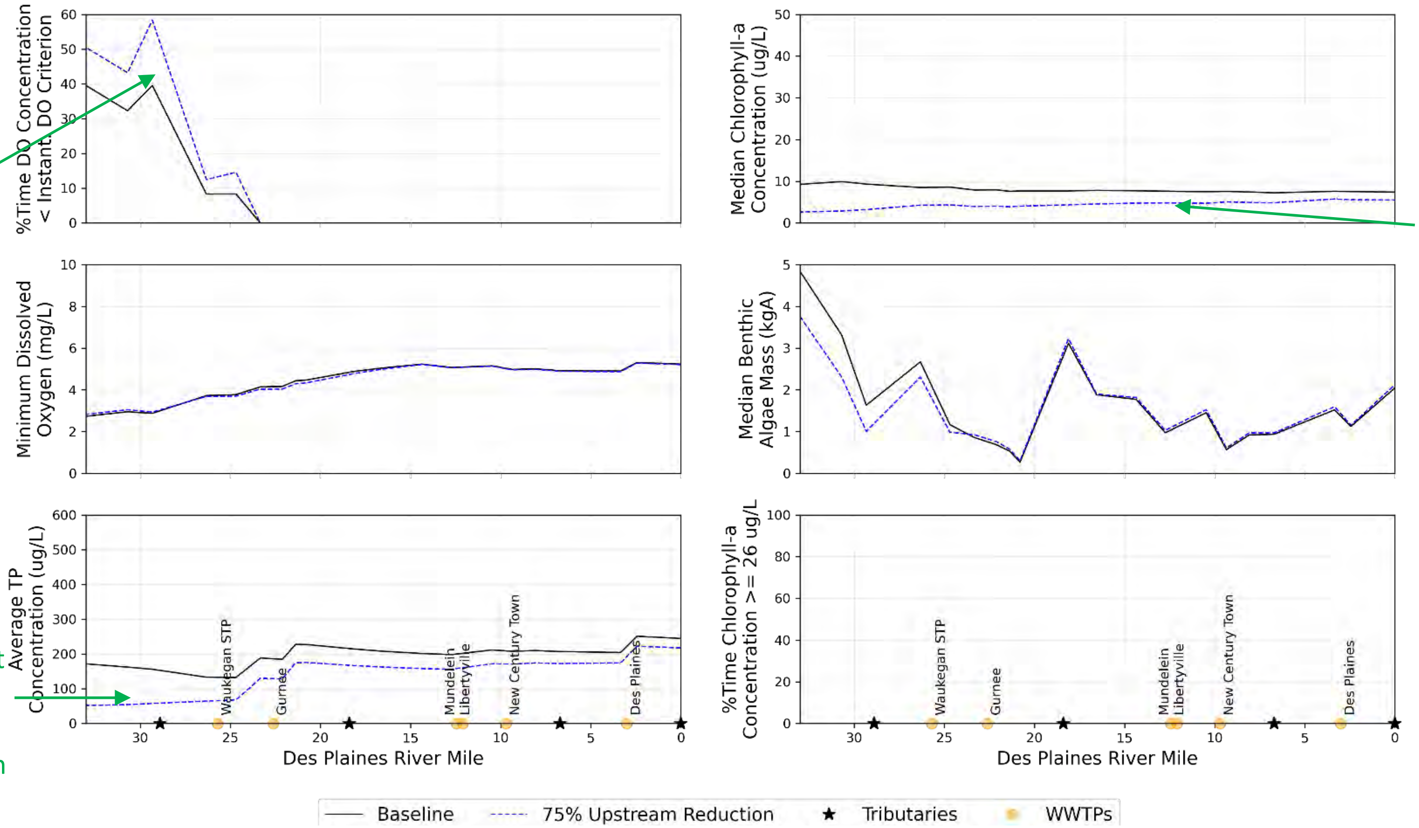
# Baseline and 75% Upstream Reduction – Longitudinal

**Low DO Period: July 10 – 17, 2020**

Increase in %Time DO less than the criterion due to reduced upstream TP resulting in reducing Chla and Benthic algae production

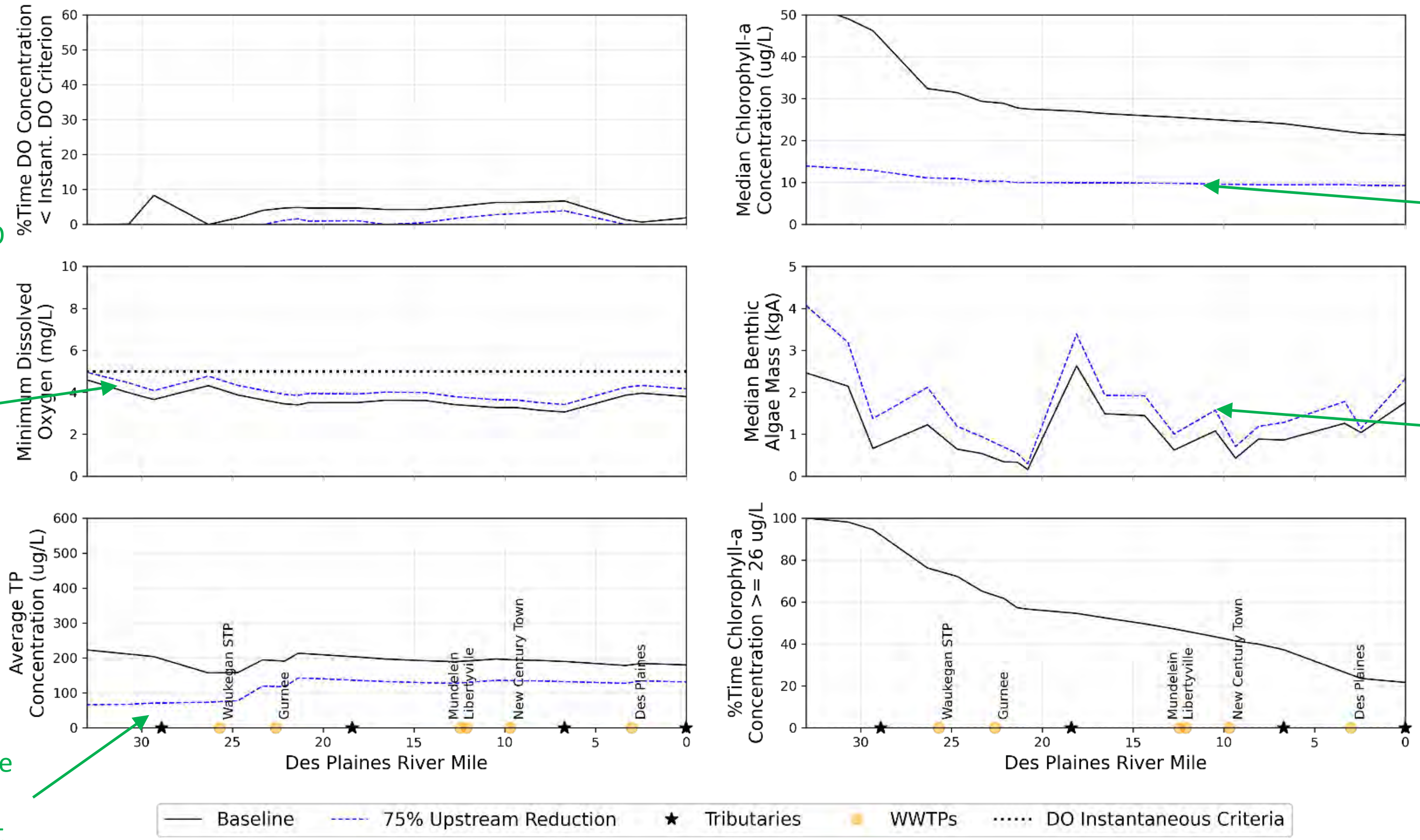
Reduction in Chla due to reduced upstream TP and Chla

Reduction in TP at the upstream reaches due to reduced upstream TP input



# Baseline and 75% Upstream Reduction – Longitudinal

**High Flow Period: May 1 – 31, 2020**




Increased min DO due to reduced Chla, increased benthic algae, and reduced DO swings

Reduction in Chla due to reduced upstream TP and Chla

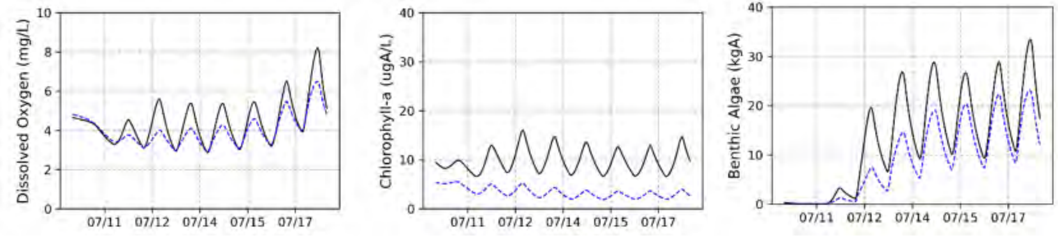
Increased bentic algae due to reduced upstream TP and Chla

Reduction in TP due to reduced upstream TP input

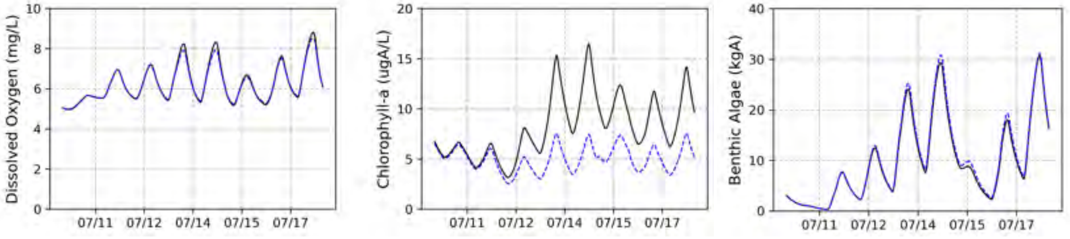
# Baseline and 75% Upstream Reduction – Summary

- Reducing upstream TP reduces Chl-a:
  - Low DO period
    - Slightly increases %Time DO < Inst. Criterion due to reduced benthic algae and Chla at upstream reaches

**Jul. 10-17, 2020: Reach 3**



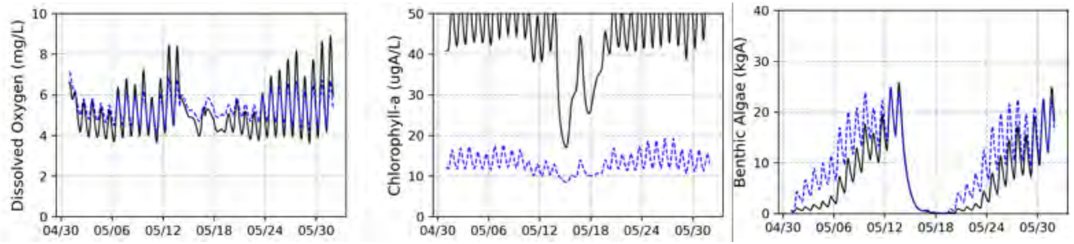

**Jul. 10-17, 2020: Reach 15**



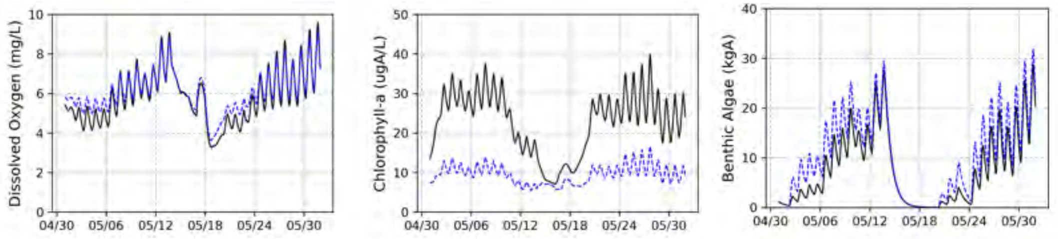
# Baseline and 75% Upstream Reduction – Summary

- Reducing upstream TP reduces Chl-a:
  - Following the high flow events
    - Increases benthic algae
    - Reduces DO swings
    - Improves minimum DO, mostly at reaches after the confluence with Mill Creek during high-flow period

**May 1-31, 2020: Reach 3**




**May 1-31, 2020: Reach 15**



# Nonpoint Source Reductions

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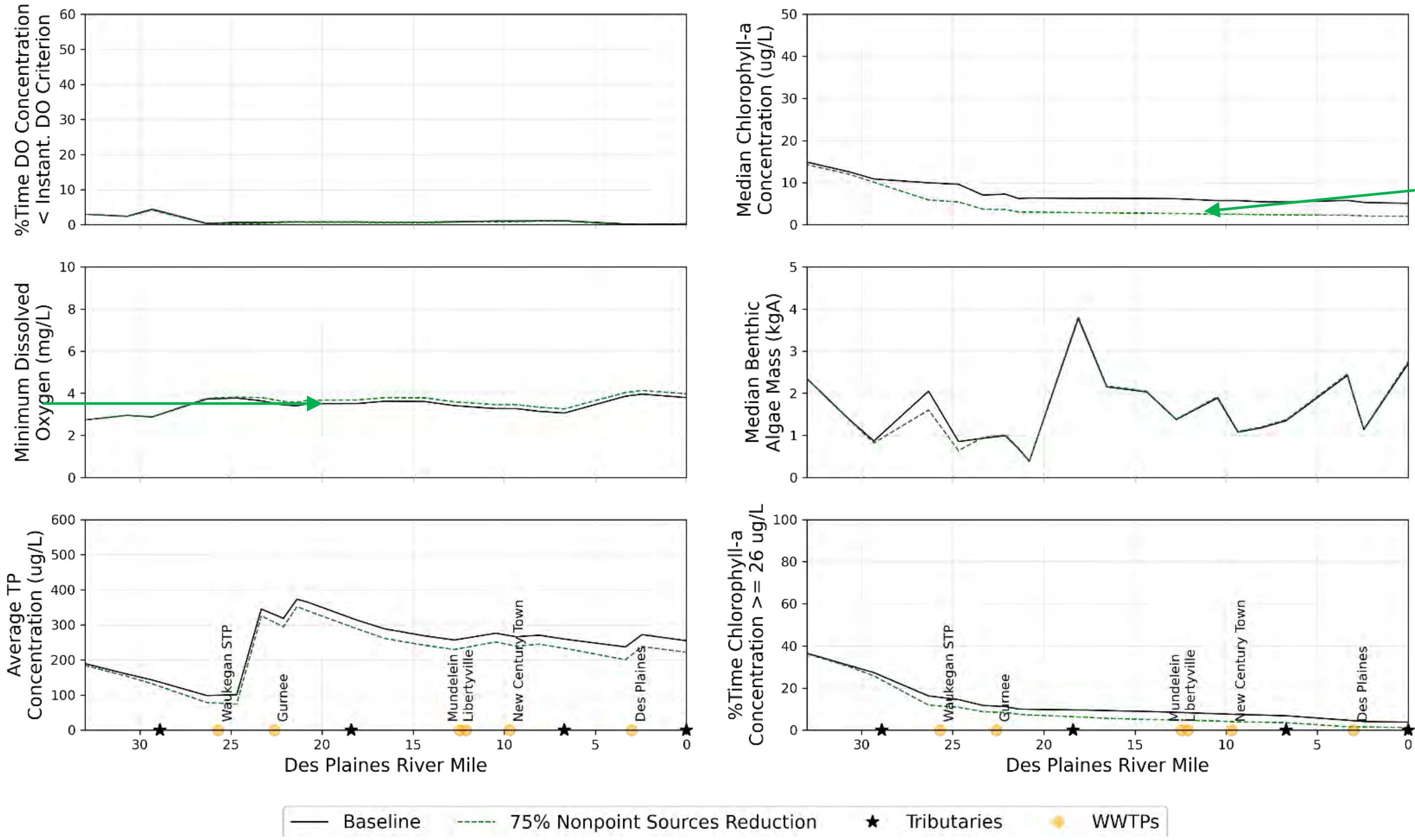
# Baseline and 75% Nonpoint Reduction – Longitudinal

**Growing Season (May-October 2020)**

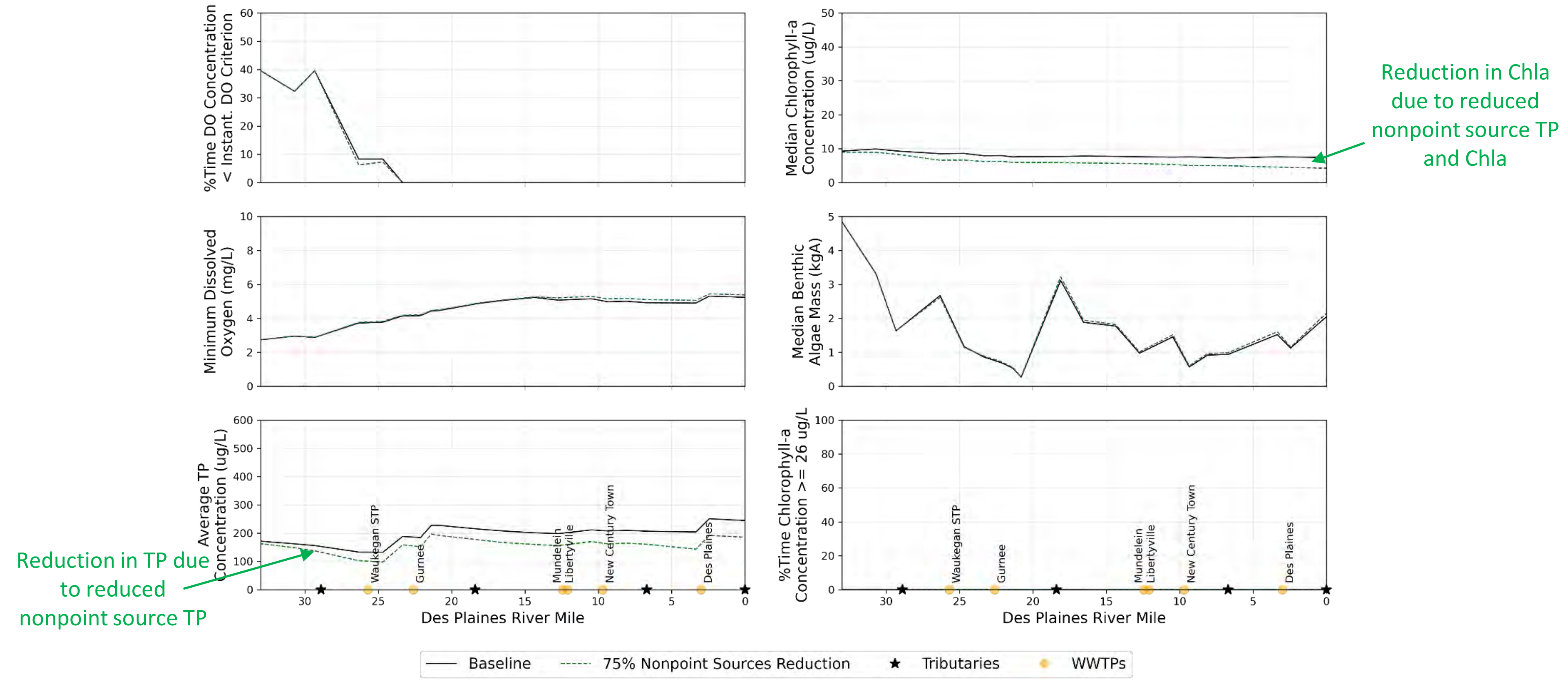
No significant impact on DO




Slight reduction in Chl-a due to reduced nonpoint sources Chl-a and TP

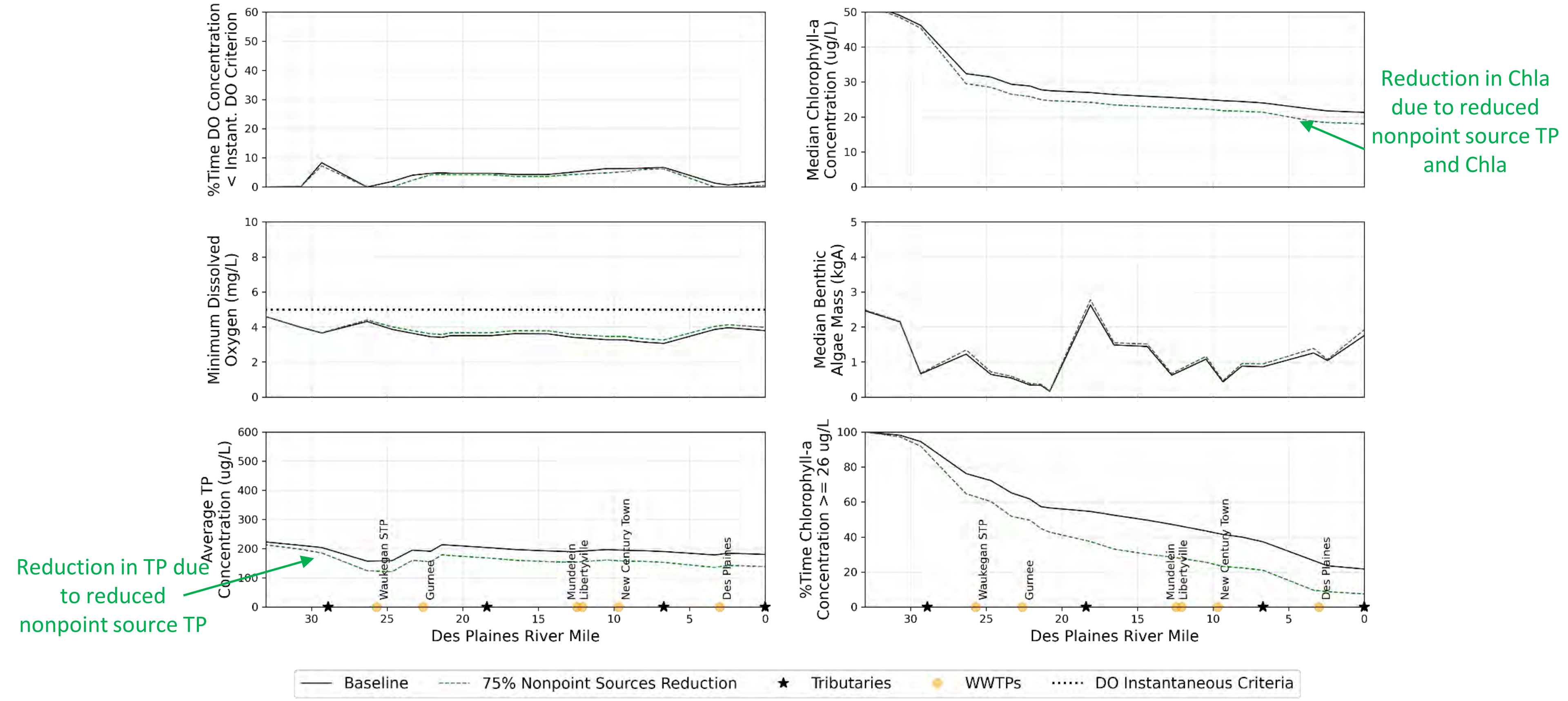
# Baseline and 75% Nonpoint Reduction – Longitudinal

**Low DO Period: July 10 – 17, 2020**



# Baseline and 75% Nonpoint Reduction – Longitudinal

## High Flow Period: May 1 – 31, 2020



# Nonpoint Reduction Summary

- Reducing nonpoint source TP reduces Chl-a:
  - Reduces instream TP during high flow periods
  - Does not have a major impact on DO

# POTW TP Reductions

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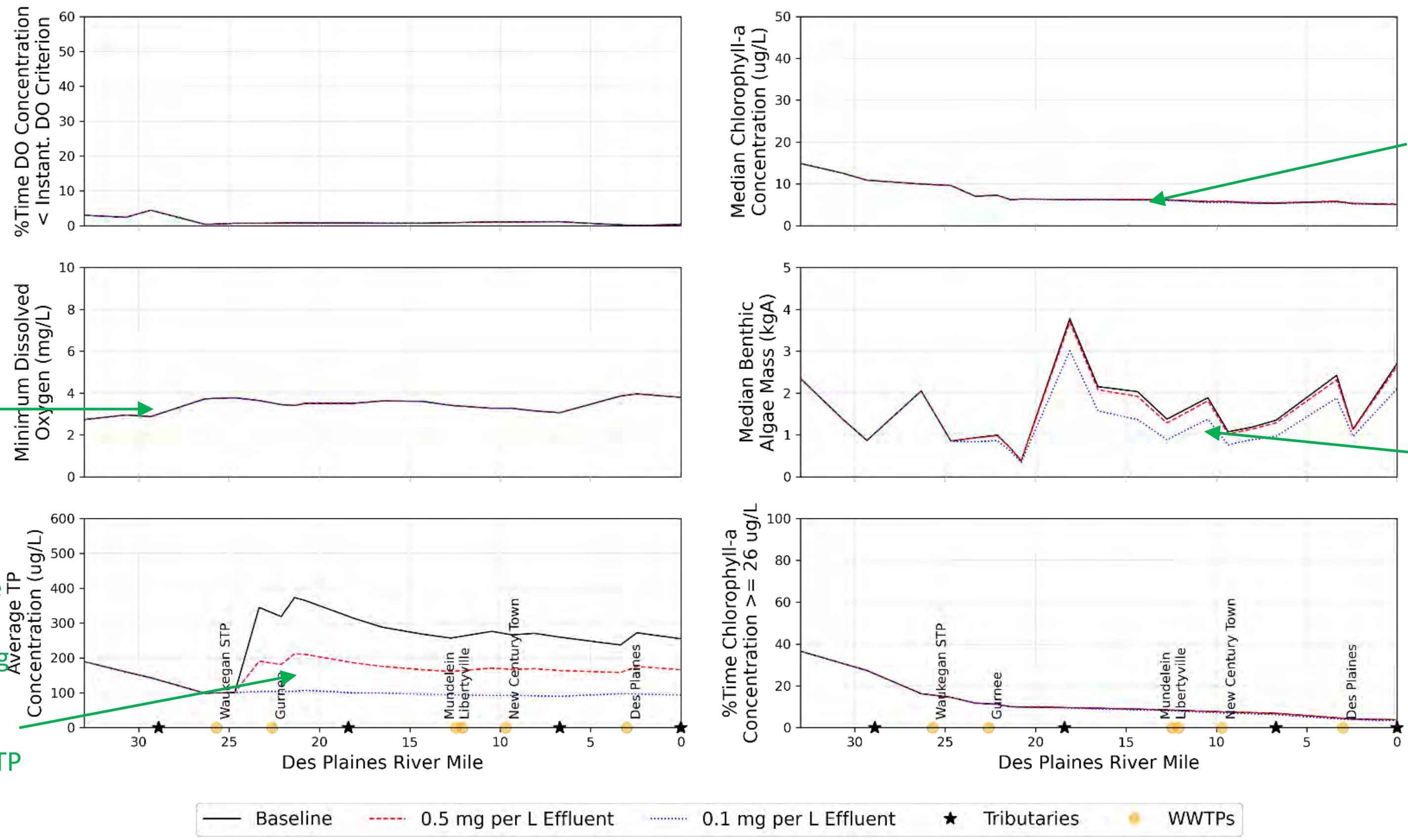
# Baseline and POTW Reductions – Longitudinal

**Growing Season (May-October 2020)**




No significant change in median Chl-a because algae starts utilizing inorganic nitrogen when phosphorus is limited

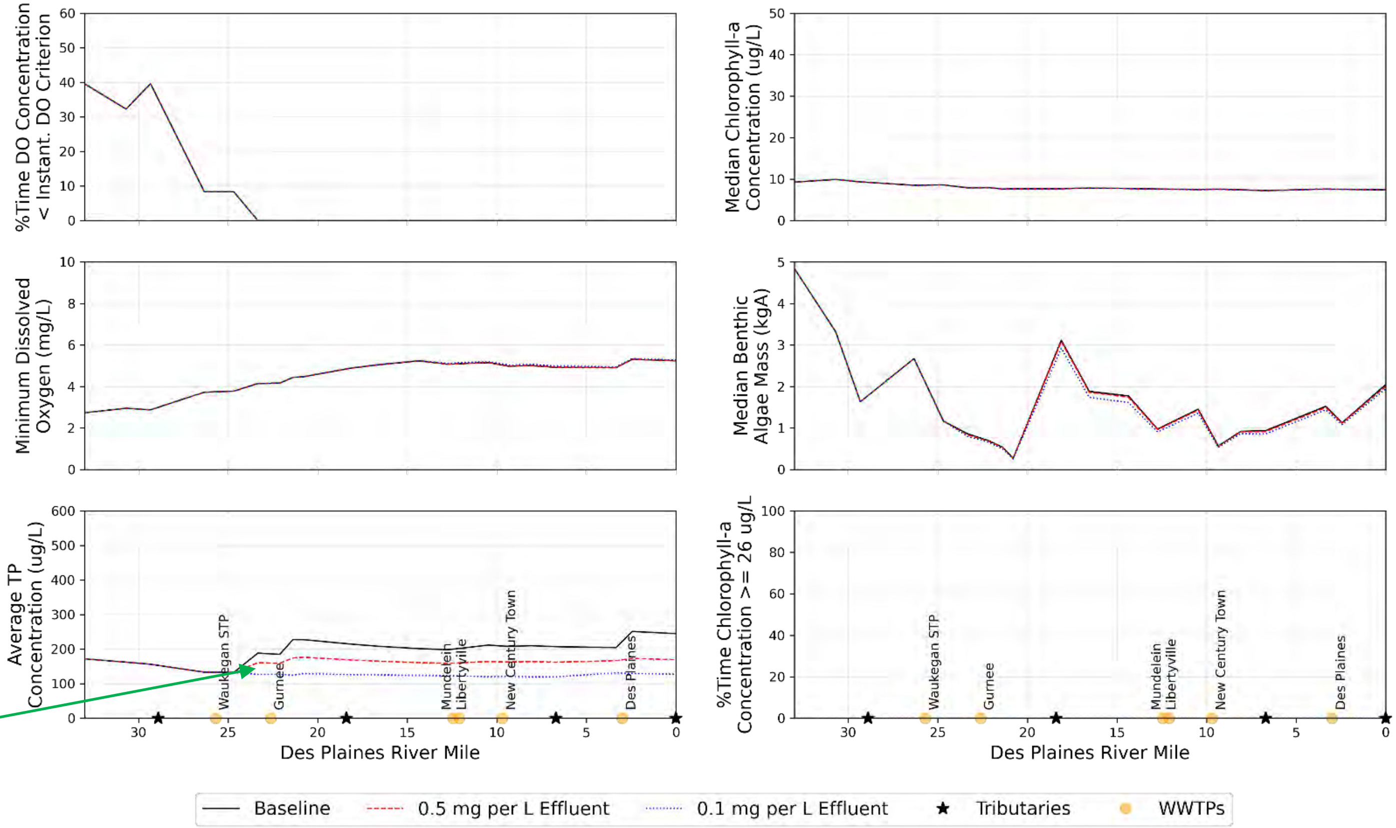
No significant change in min DO

Reduction in benthic algae due to reduced TP

Reduction in the instream TP in reaches following the POTW inputs due to reduced effluent TP

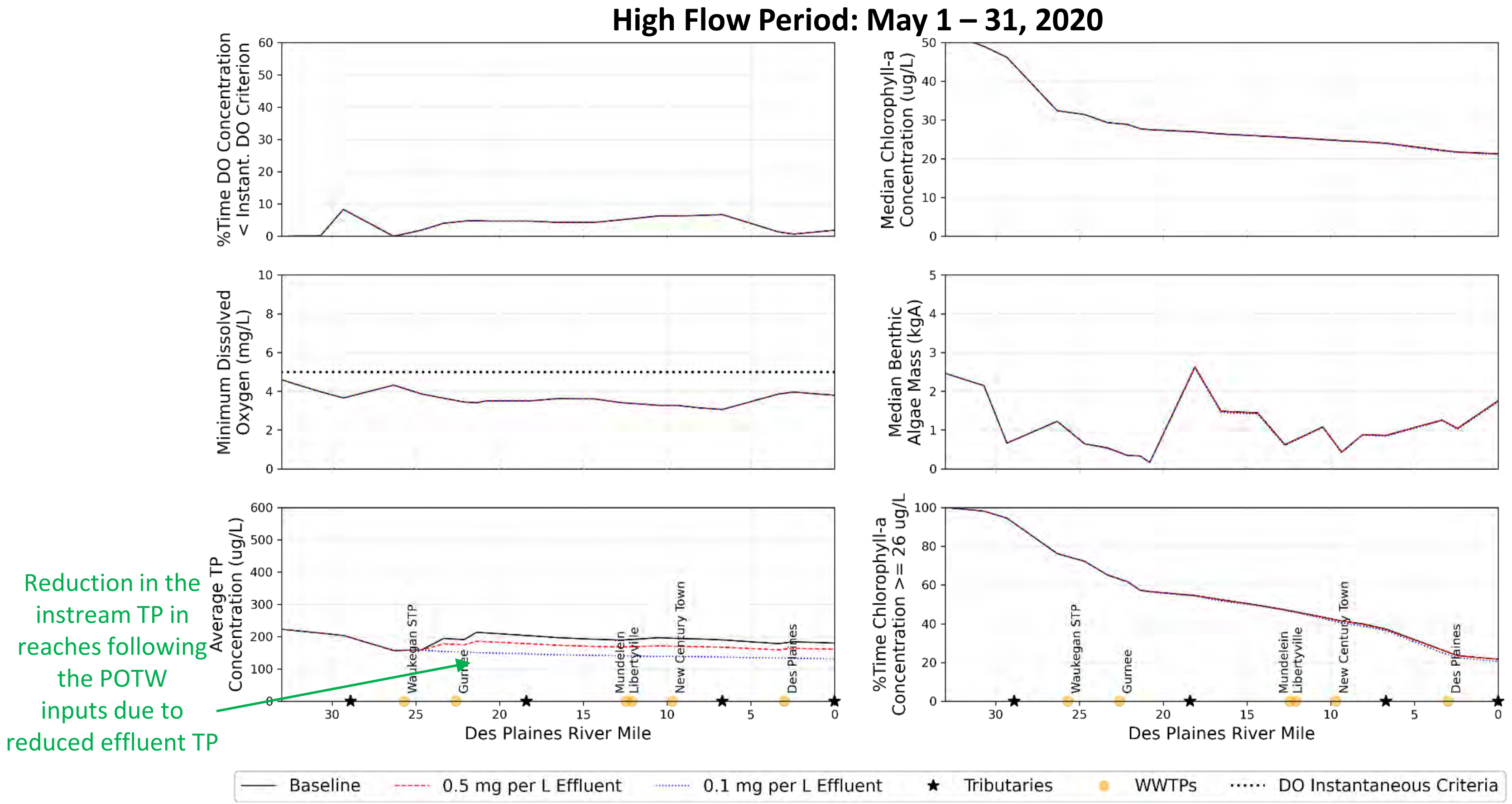
# Baseline and POTWs Reduction – Longitudinal

**Low DO Period: July 10 – 17, 2020**




Reduction in the instream TP in reaches following the POTW inputs due to reduced effluent TP

# Baseline and POTWs Reduction – Longitudinal



# Baseline and POTWs Reduction – Summary

- Reducing POTW TP
  - Reduces instream TP
  - Slightly reduces DO swings

# Watershed Management Scenarios Summary

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# Key Takeaways

- Takeaway #1: Upstream TP reduction reduces sestonic Chl-a and  improves DO during high flows

- Takeaway #2: Tributary TP reductions reduce sestonic Chl-a but has minimal impact on DO

- Takeaway #3: POTW TP reductions have minimal impact on water quality

# Feasible Management Scenarios Discussion

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# Feasible Management Scenarios Discussion

- Two additional feasible management scenarios
  - Scenario #1: 50% Upstream, 50% Nonpoint sources, 0.5 effluent TP.
  - Scenario #2: 50% Upstream, 25% Nonpoint sources, 0.5 effluent TP.

# Next Steps

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# Next Steps

- Address comments
- Discuss the two additional scenario runs
- Finalize the watershed management scenarios
  - Run and post-process the scenarios
  - Documentation

# Questions?

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# Upstream Reduction

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# Low DO Period: July 10-17

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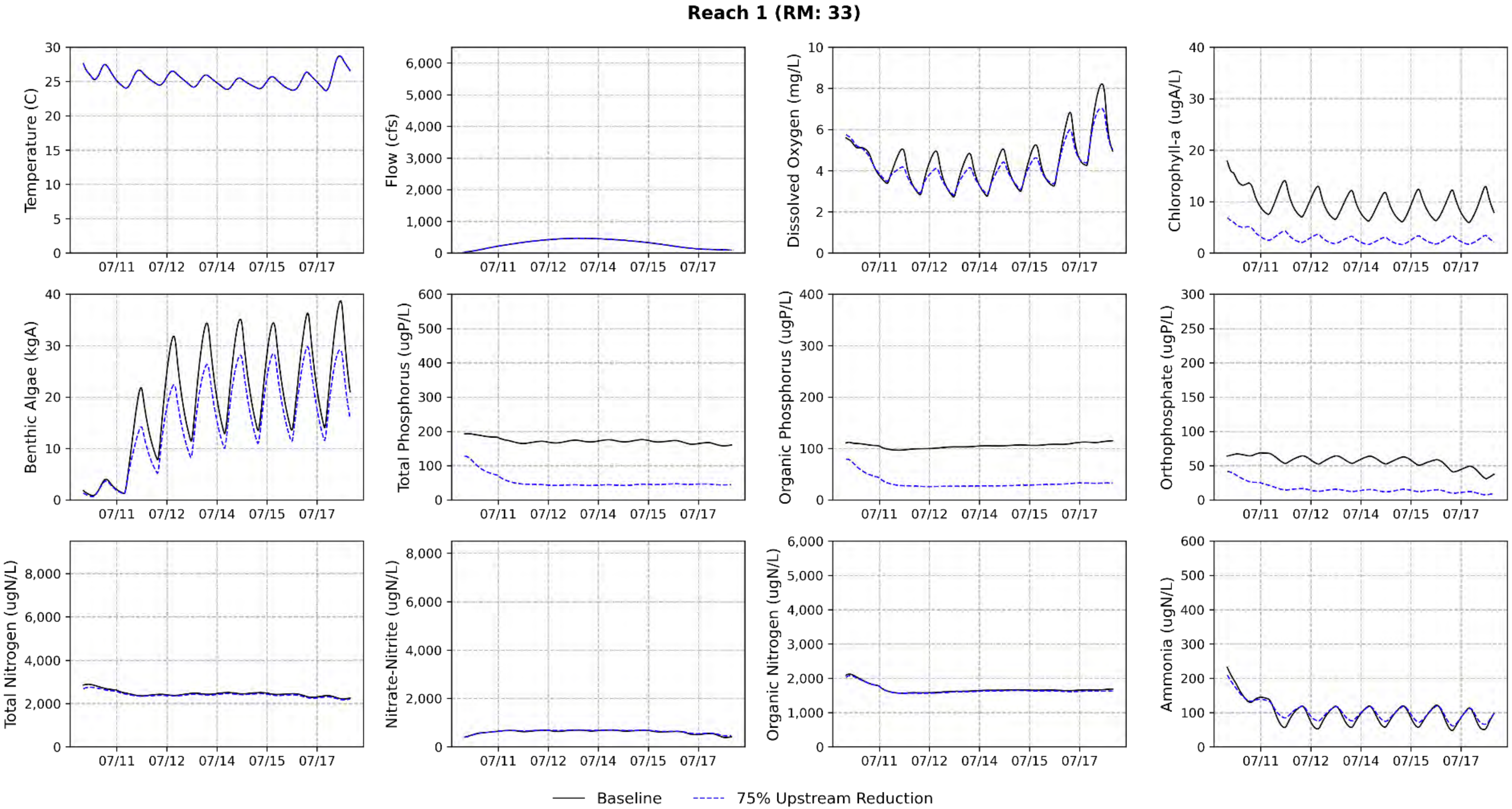
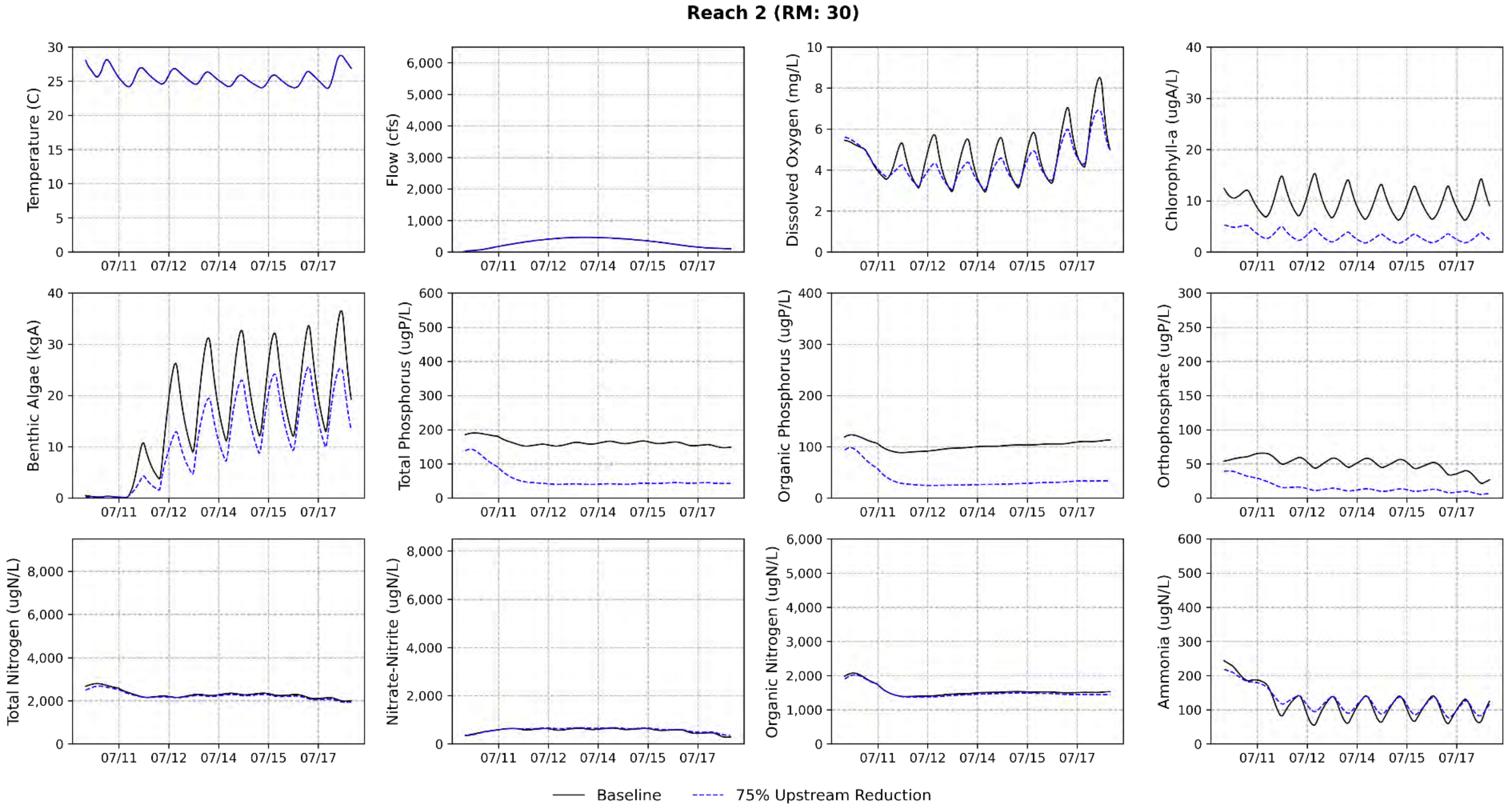
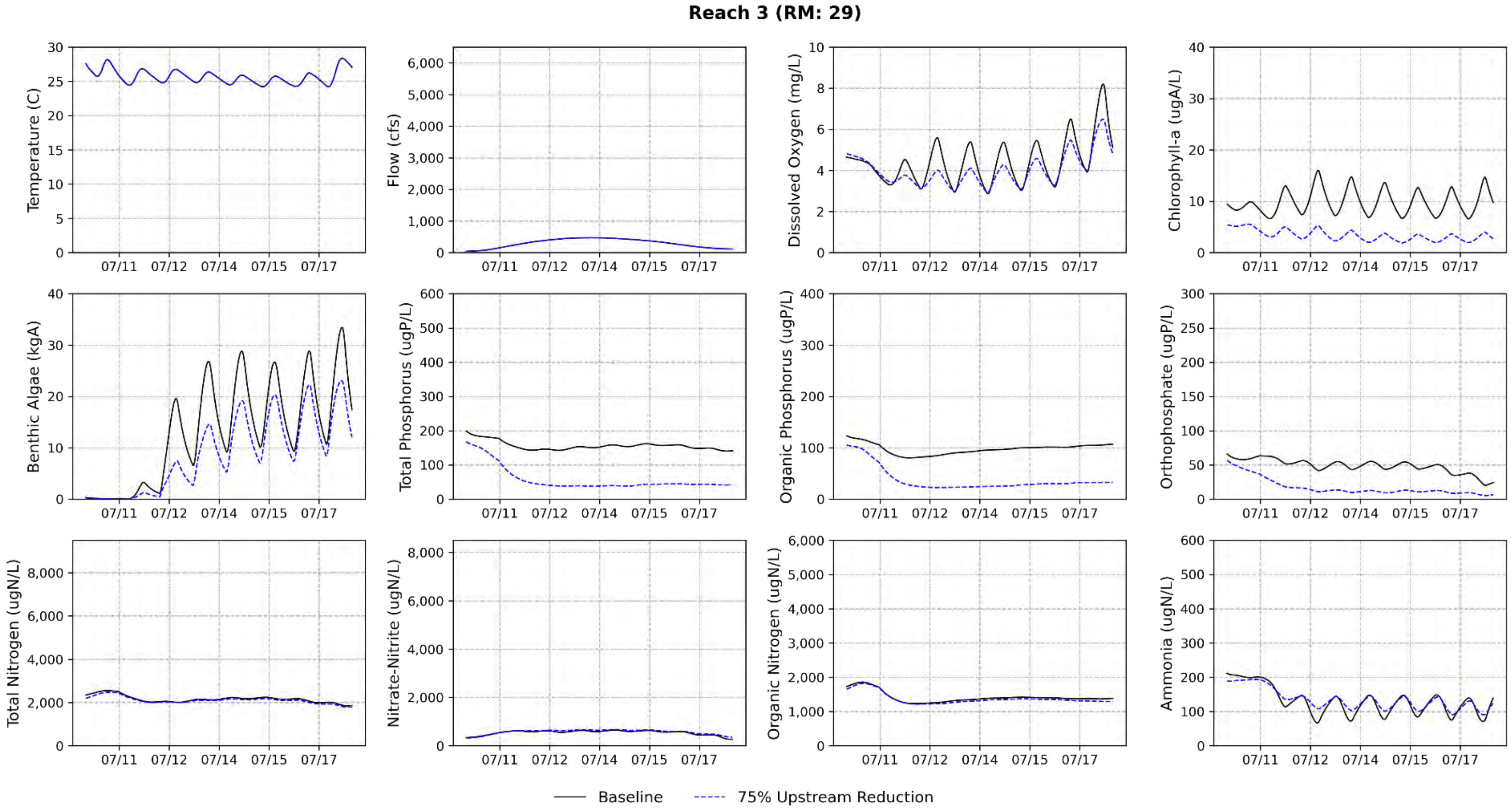
# Baseline and 75% Upstream Reduction
# 7/10 – 17, 2020



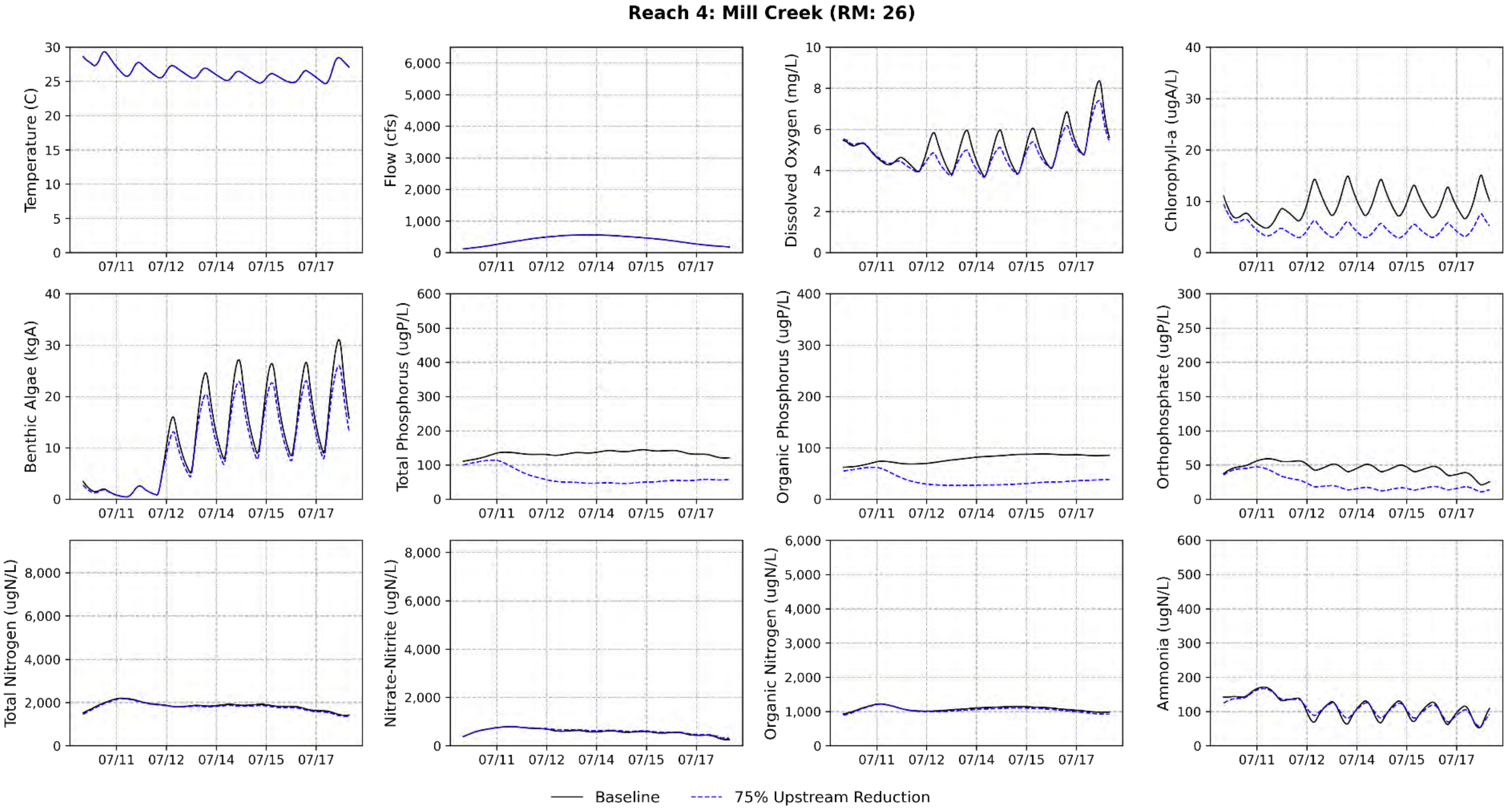
# Baseline and 75% Upstream Reduction 7/10 – 17, 2020



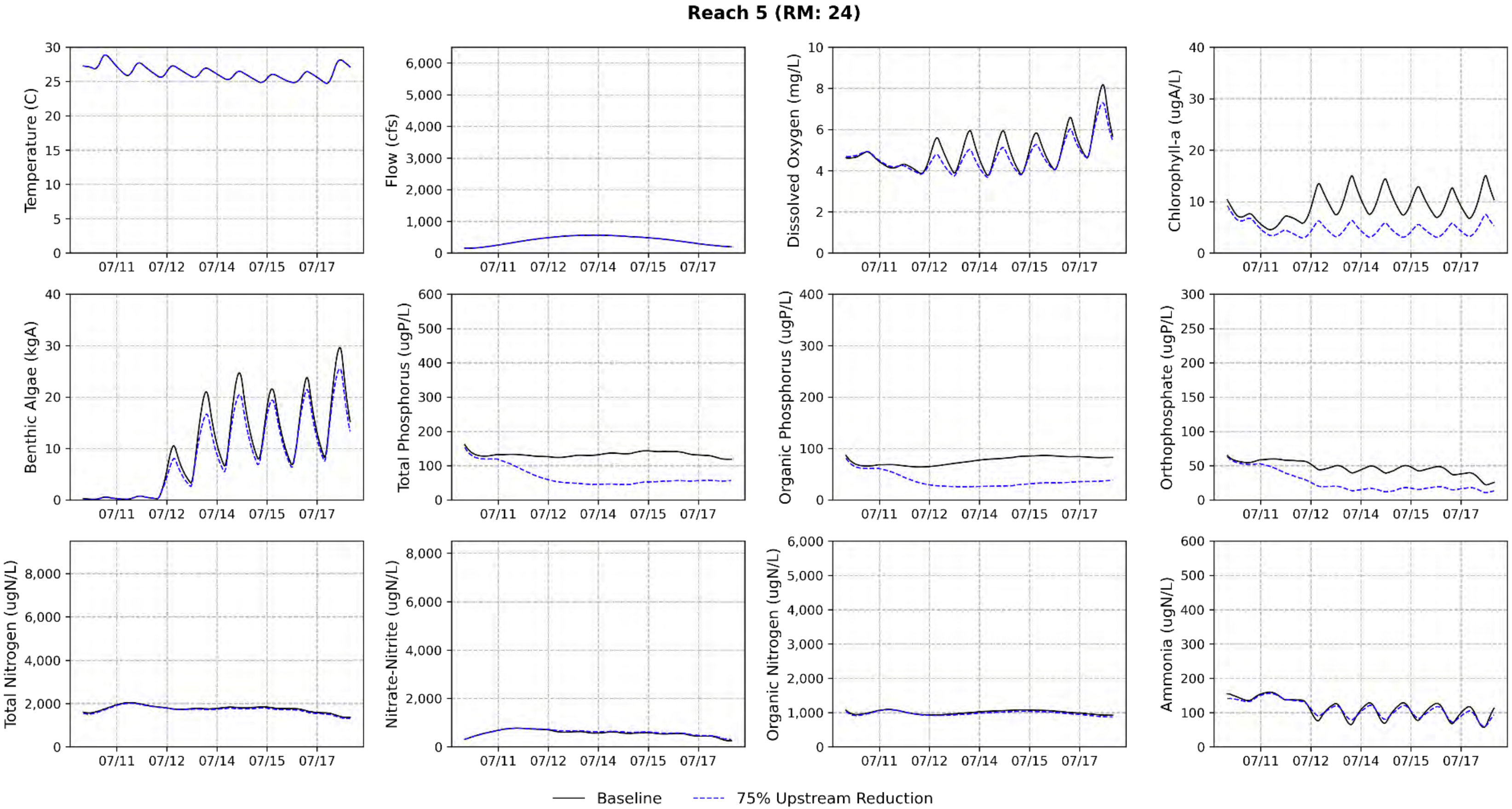
# Baseline and 75% Upstream Reduction 7/10 – 17, 2020



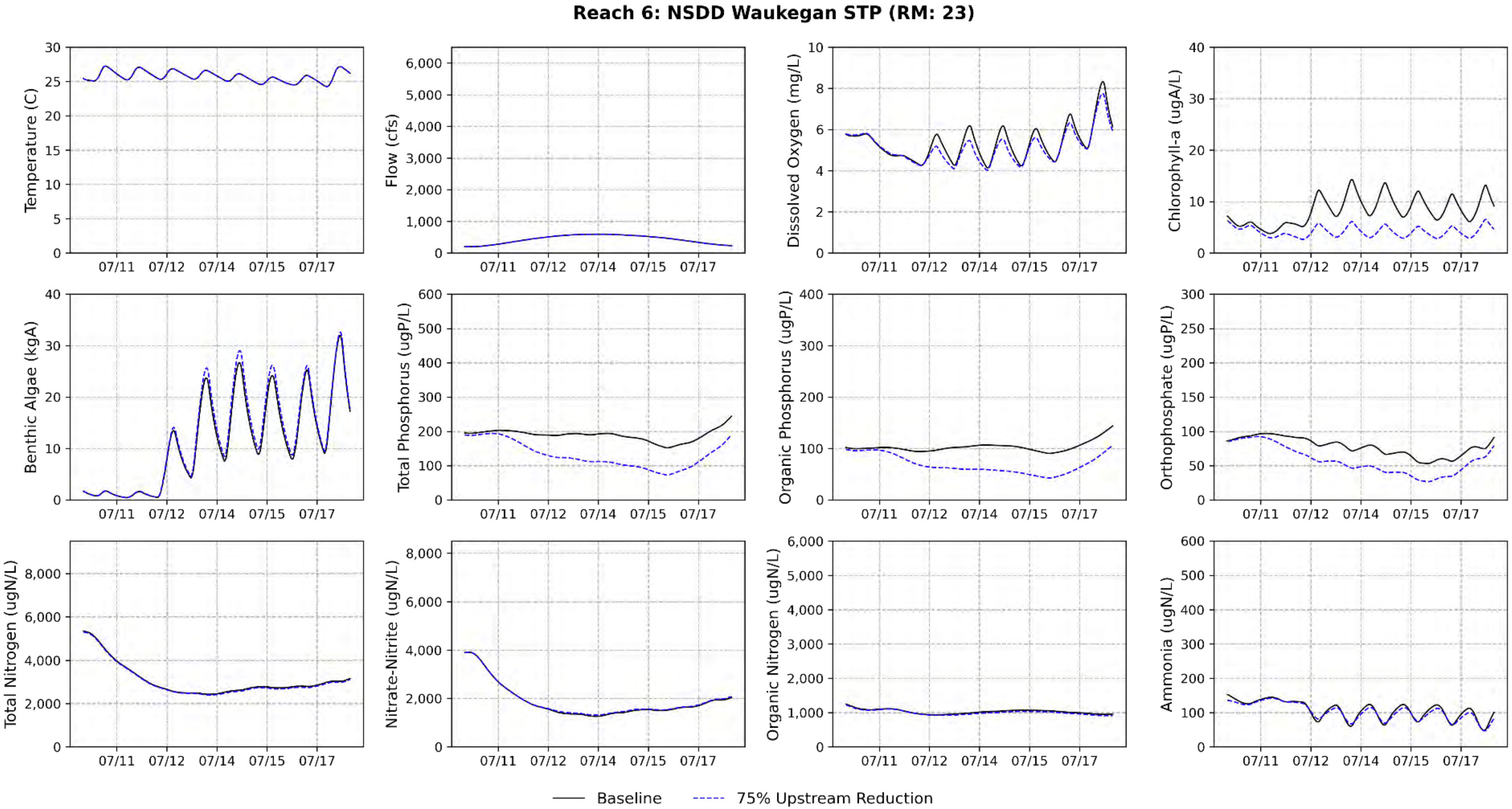
# Baseline and 75% Upstream Reduction 7/10 – 17, 2020



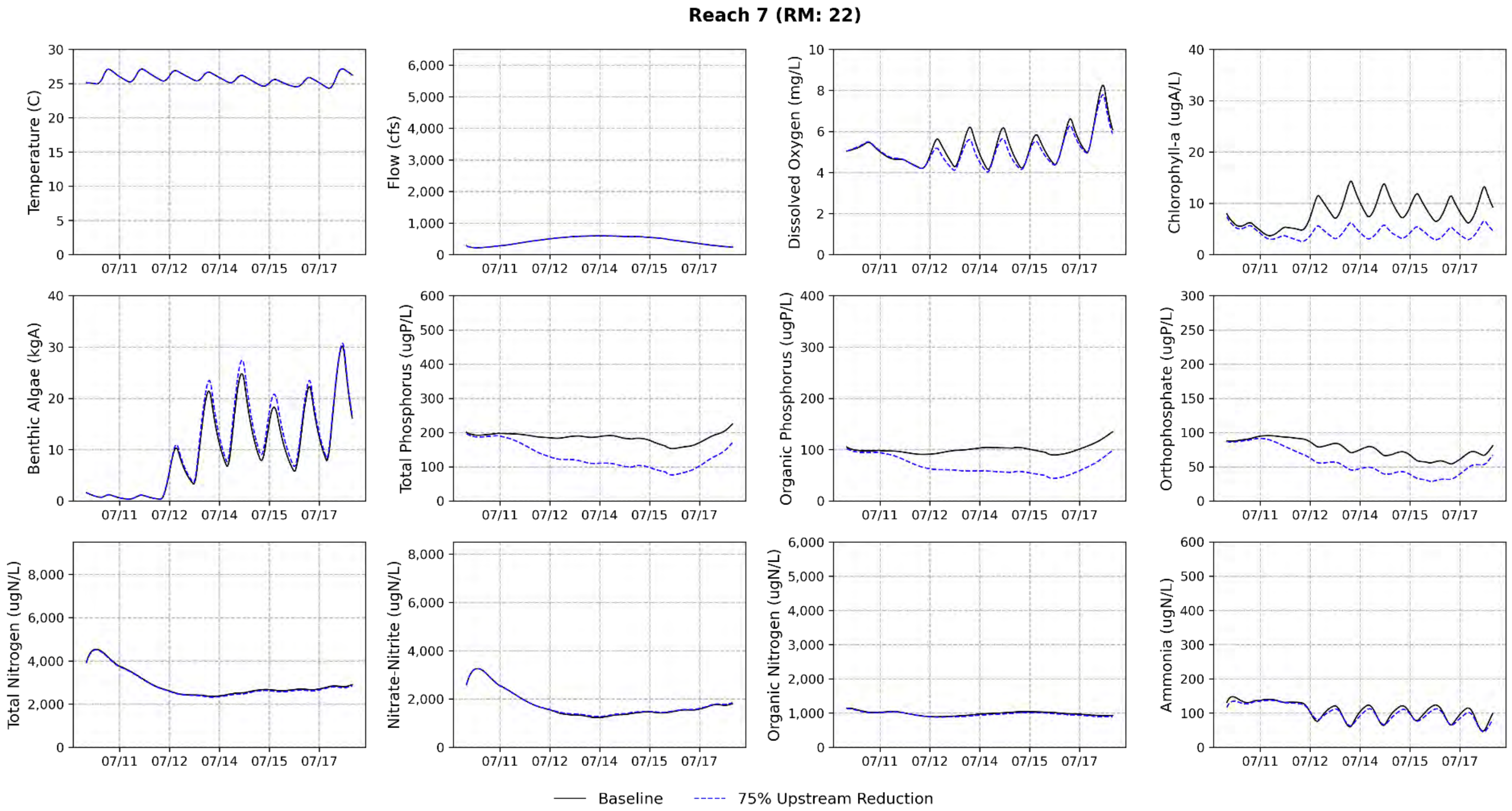
# Baseline and 75% Upstream Reduction
# 7/10 – 17, 2020



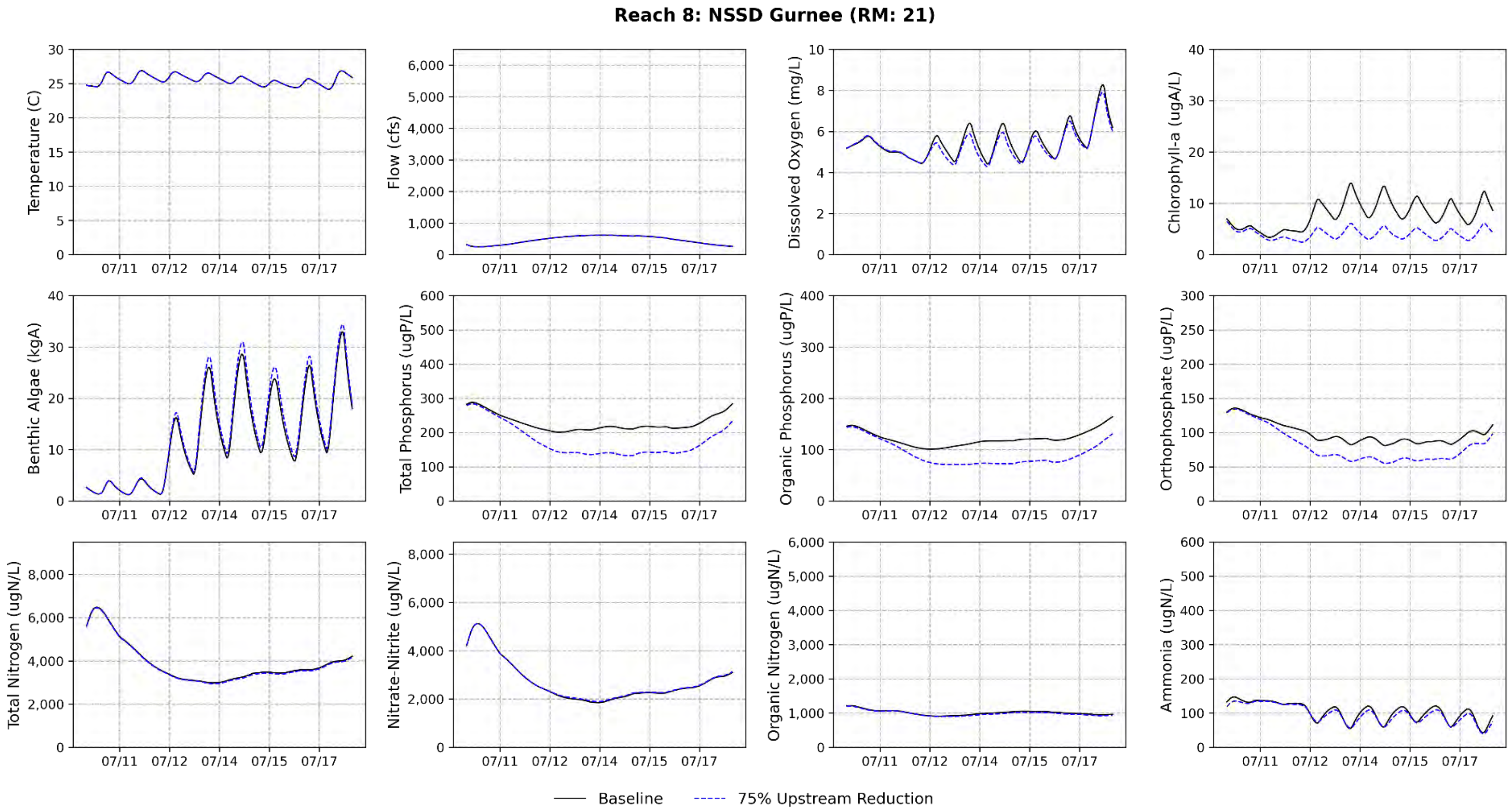
# Baseline and 75% Upstream Reduction 7/10 – 17, 2020



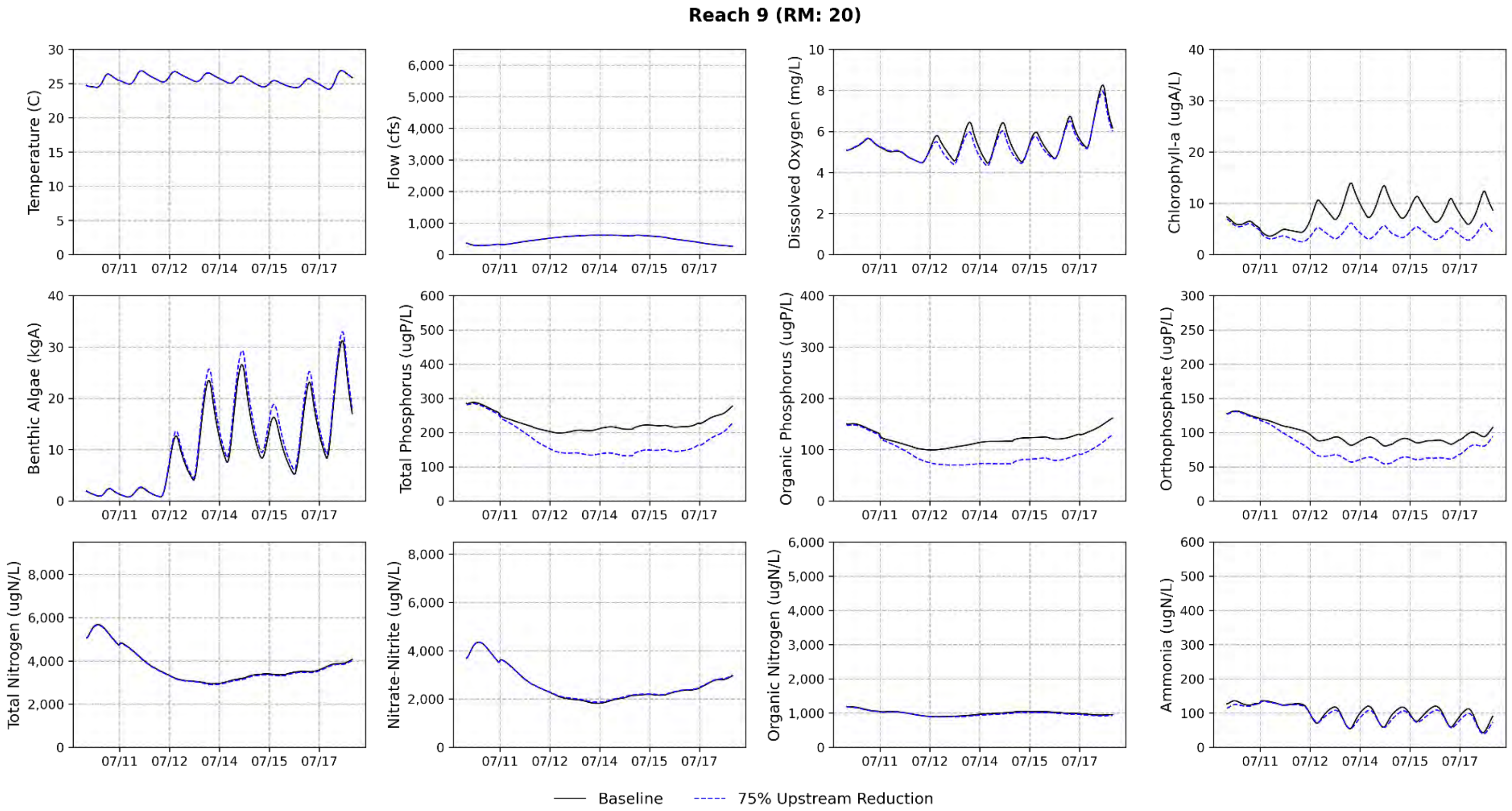
# Baseline and 75% Upstream Reduction 7/10 – 17, 2020



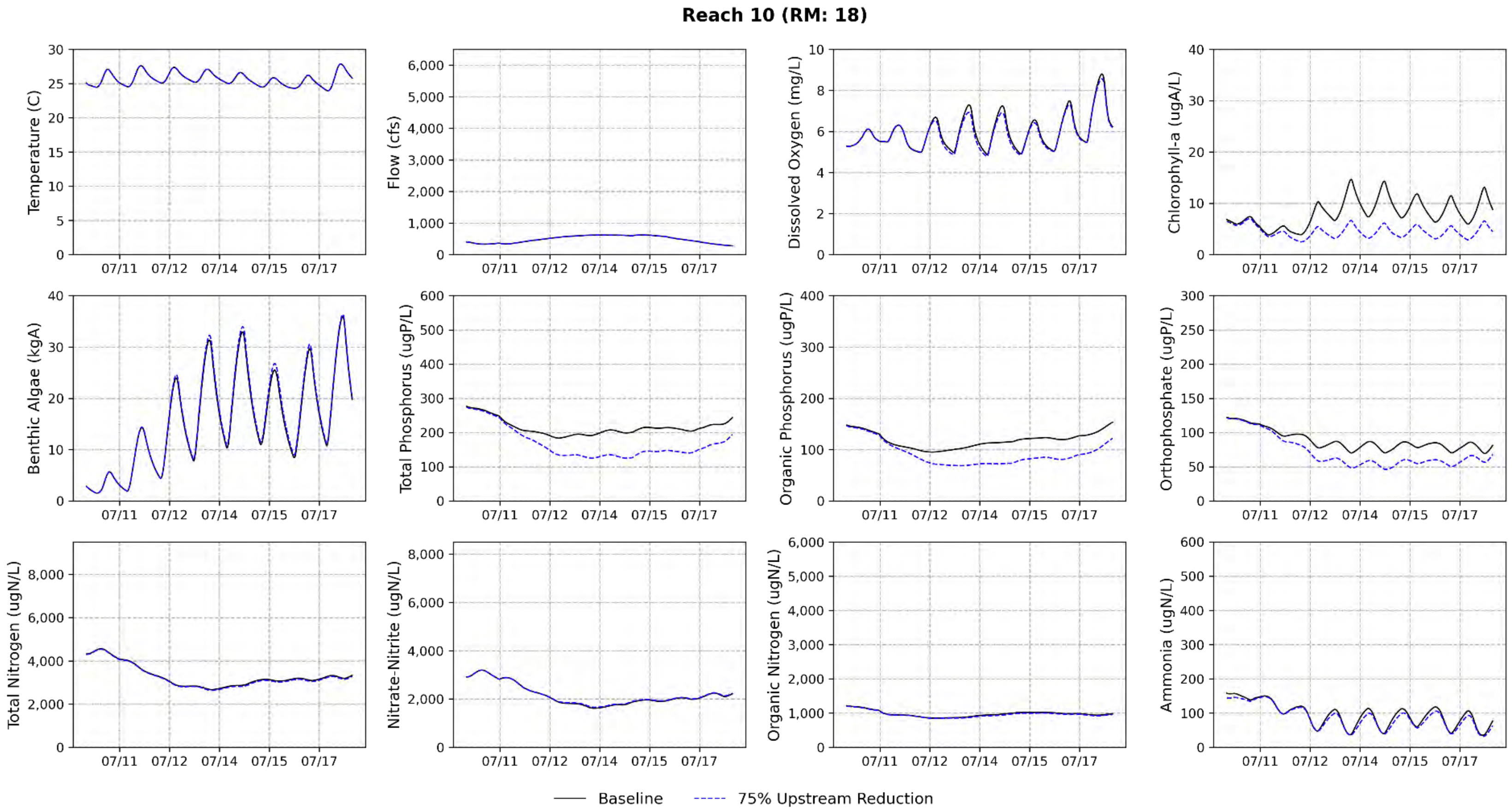
# Baseline and 75% Upstream Reduction 7/10 – 17, 2020



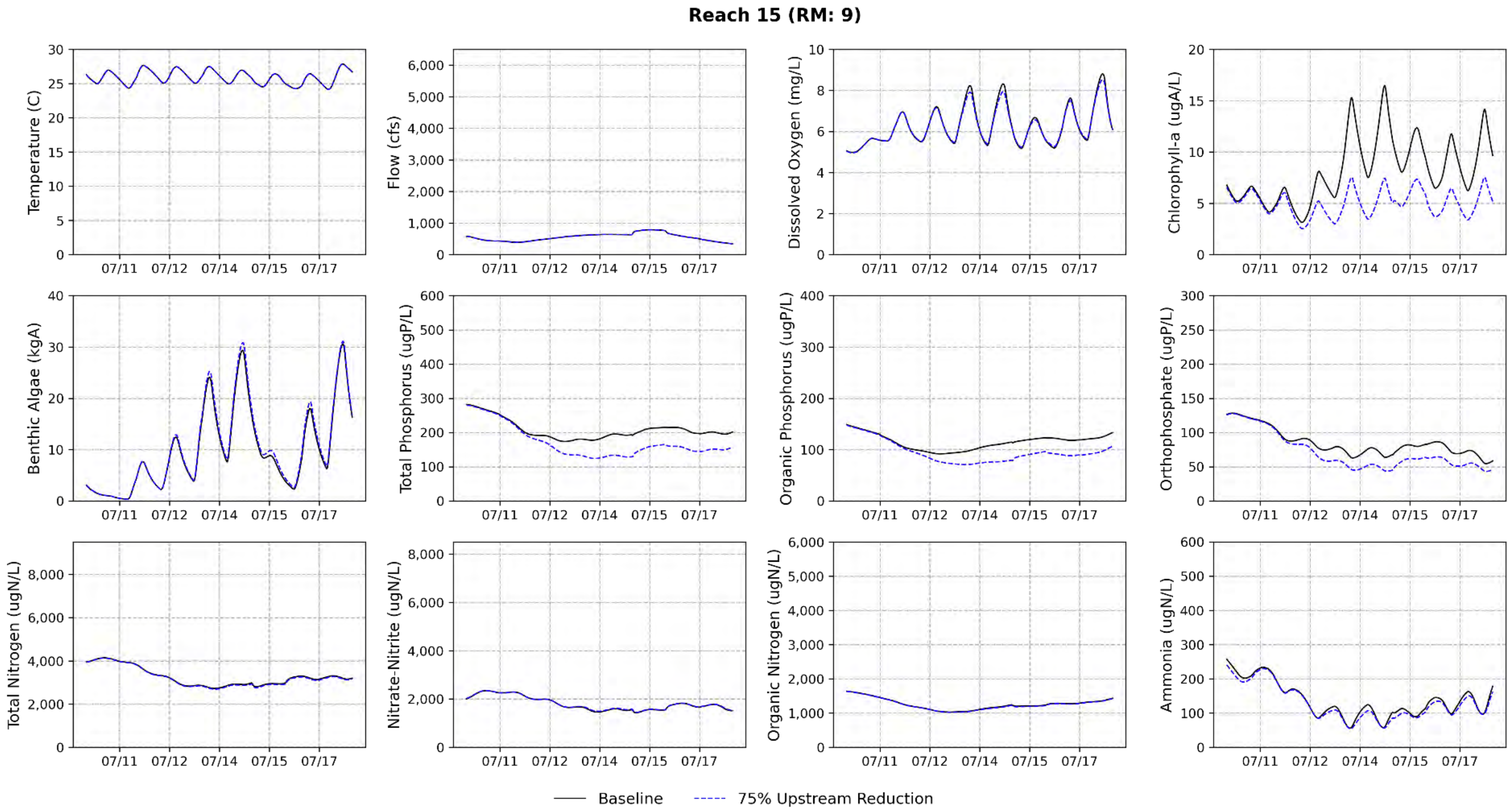
# Baseline and 75% Upstream Reduction 7/10 – 17, 2020



# Baseline and 75% Upstream Reduction 7/10 – 17, 2020



# Baseline and 75% Upstream Reduction 7/10 – 17, 2020



# High Flow Period: May 1-31

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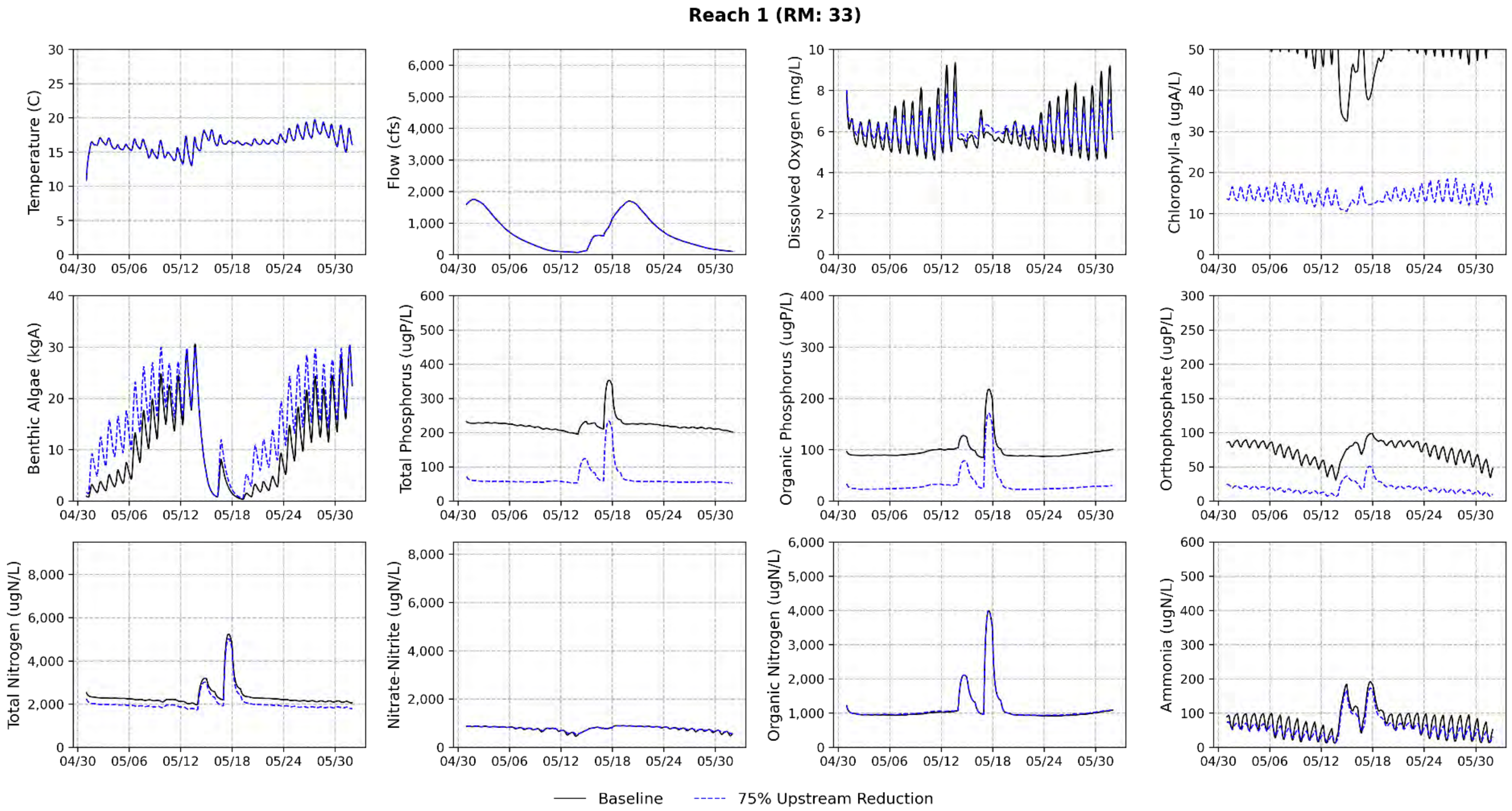
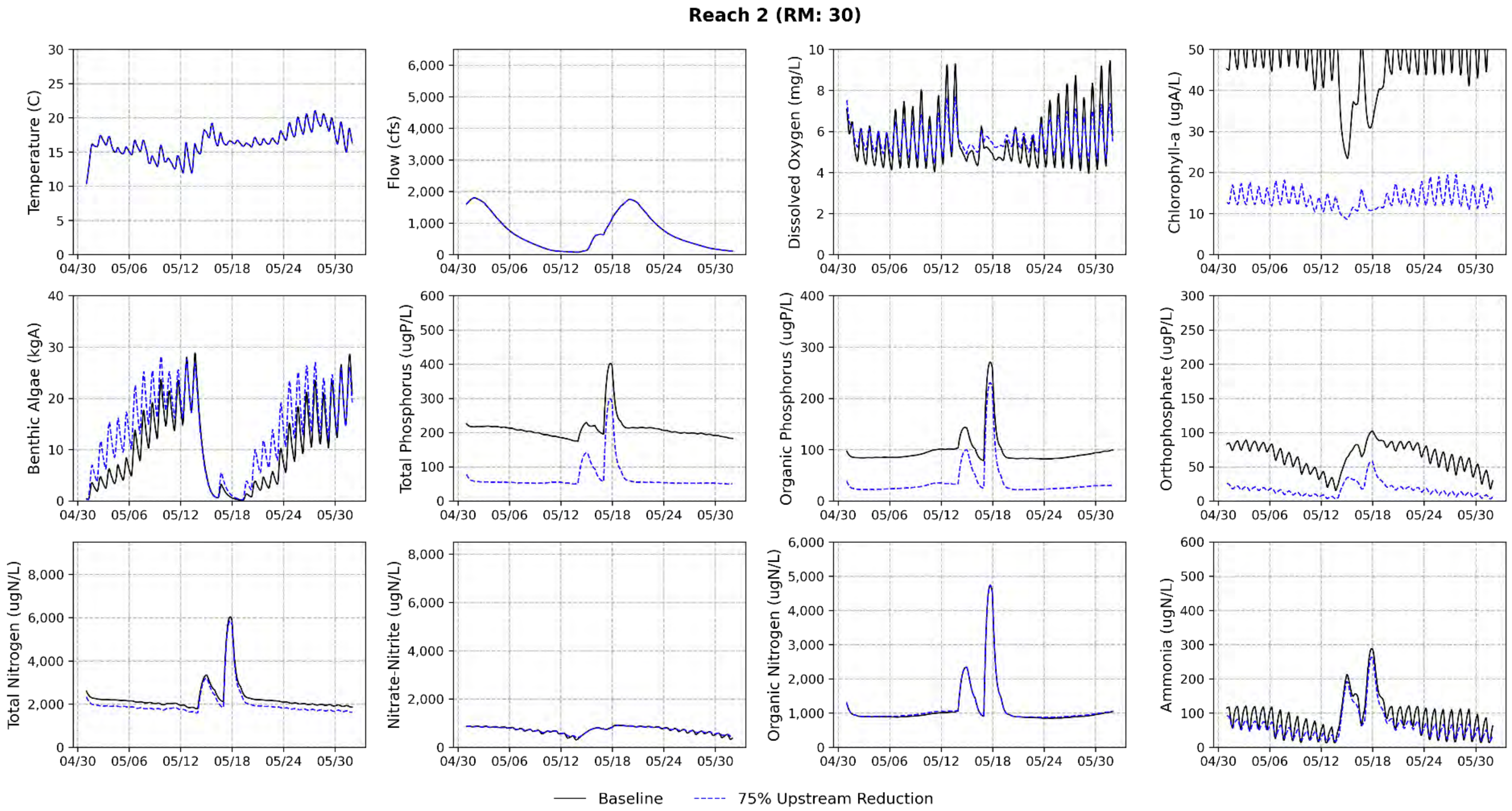
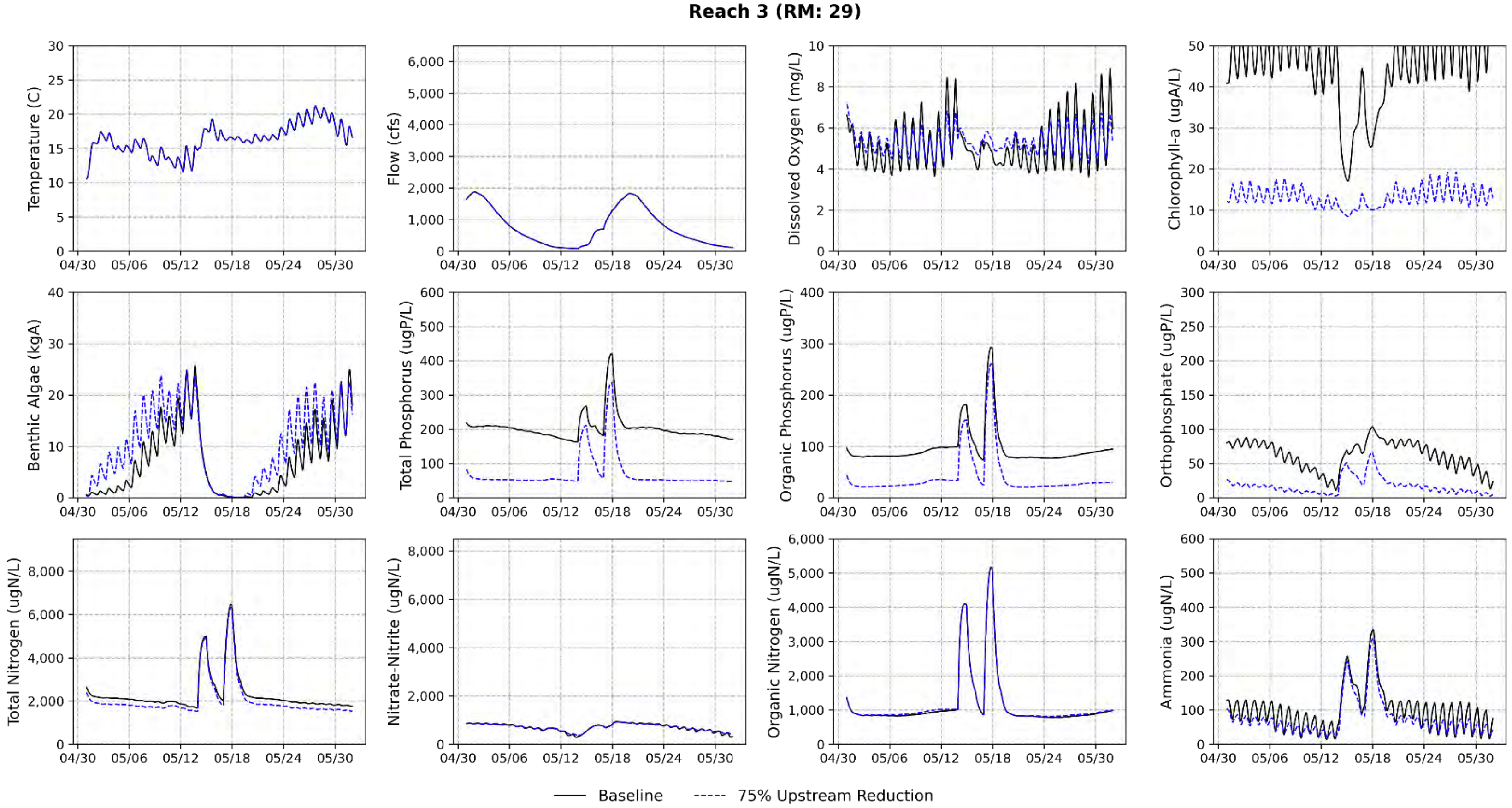
# Baseline and 75% Upstream Reduction
# 5/1- 31, 2020



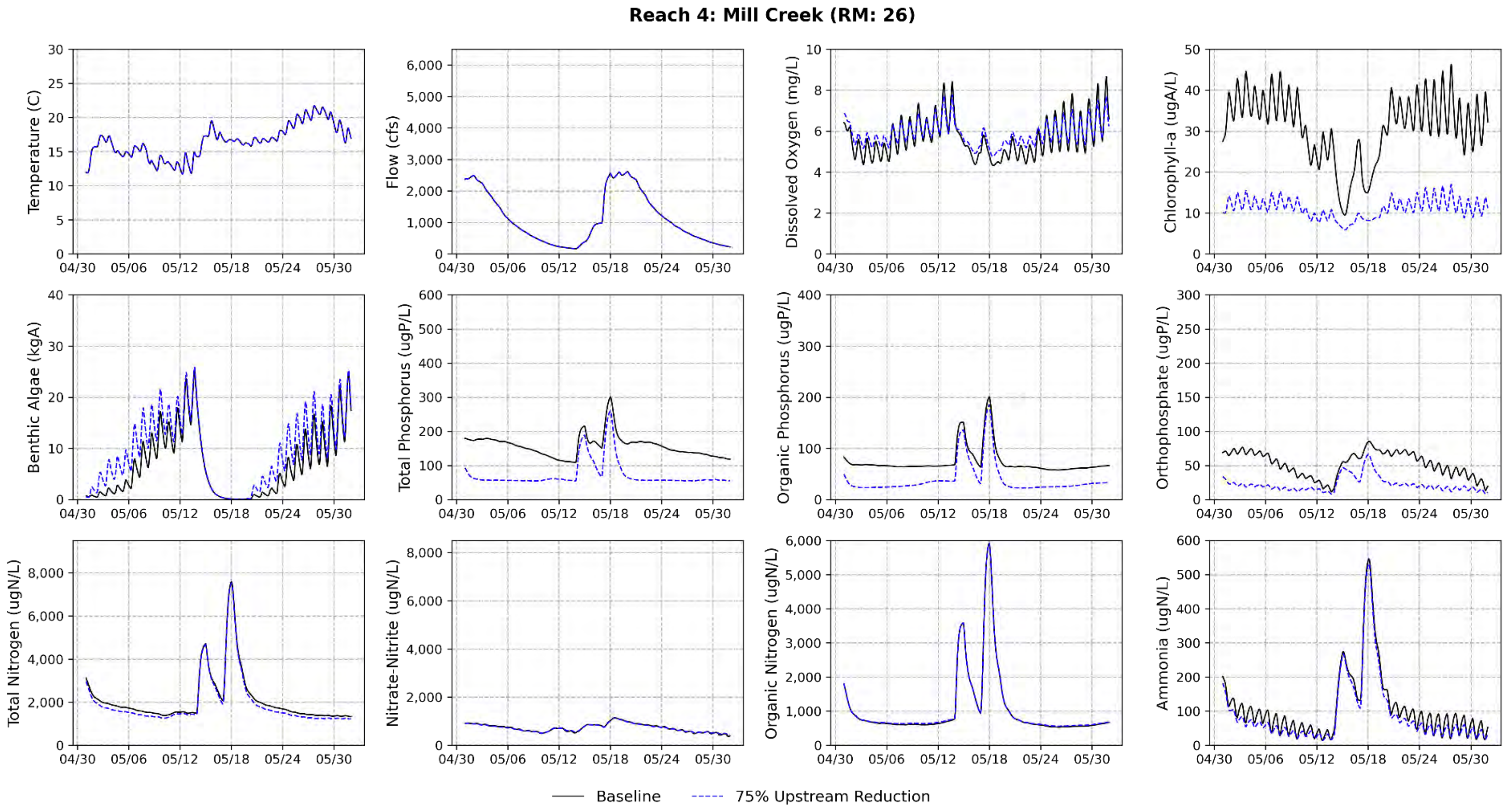
# Baseline and 75% Upstream Reduction 5/1- 31, 2020



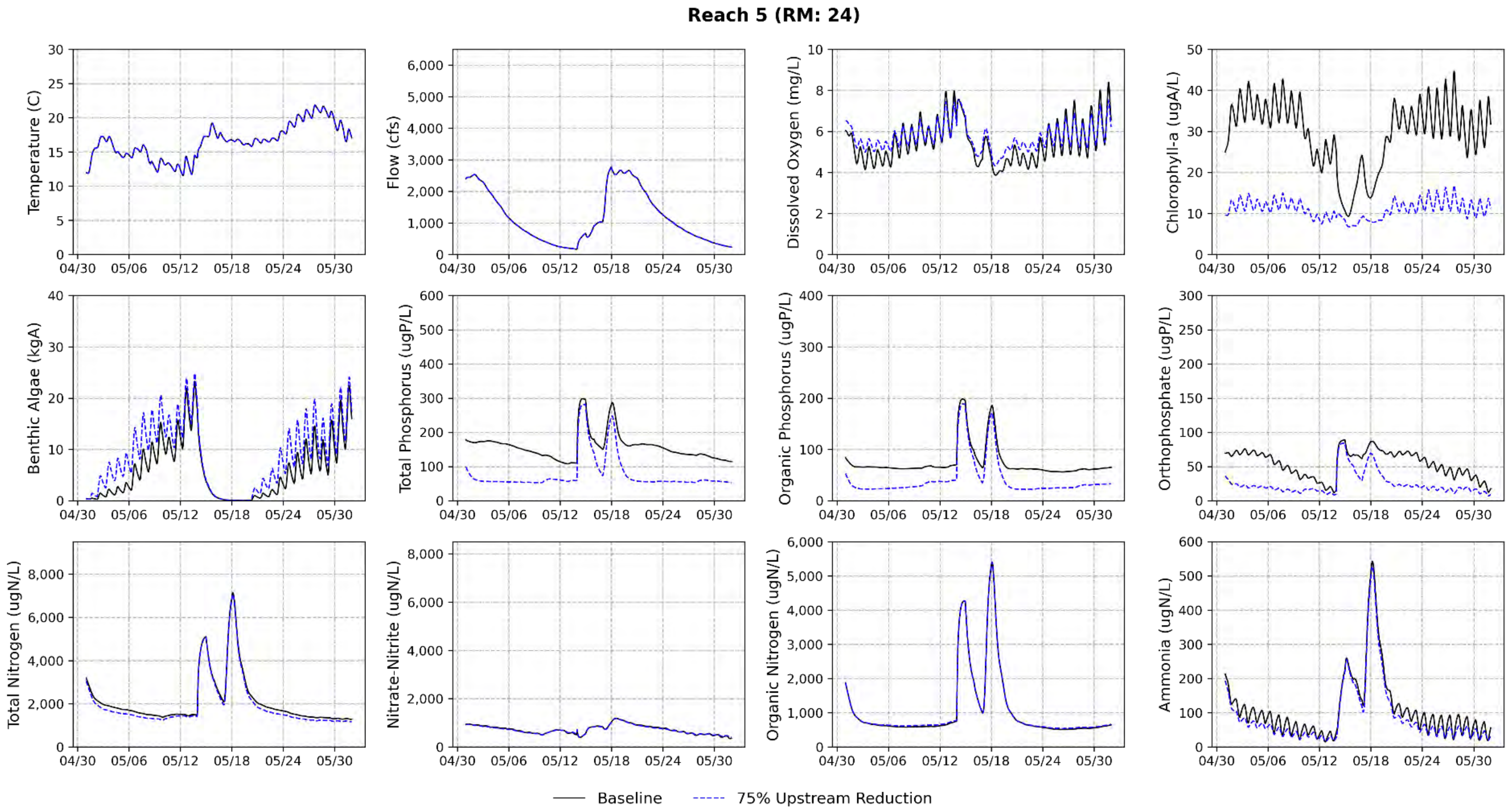
# Baseline and 75% Upstream Reduction 5/1- 31, 2020



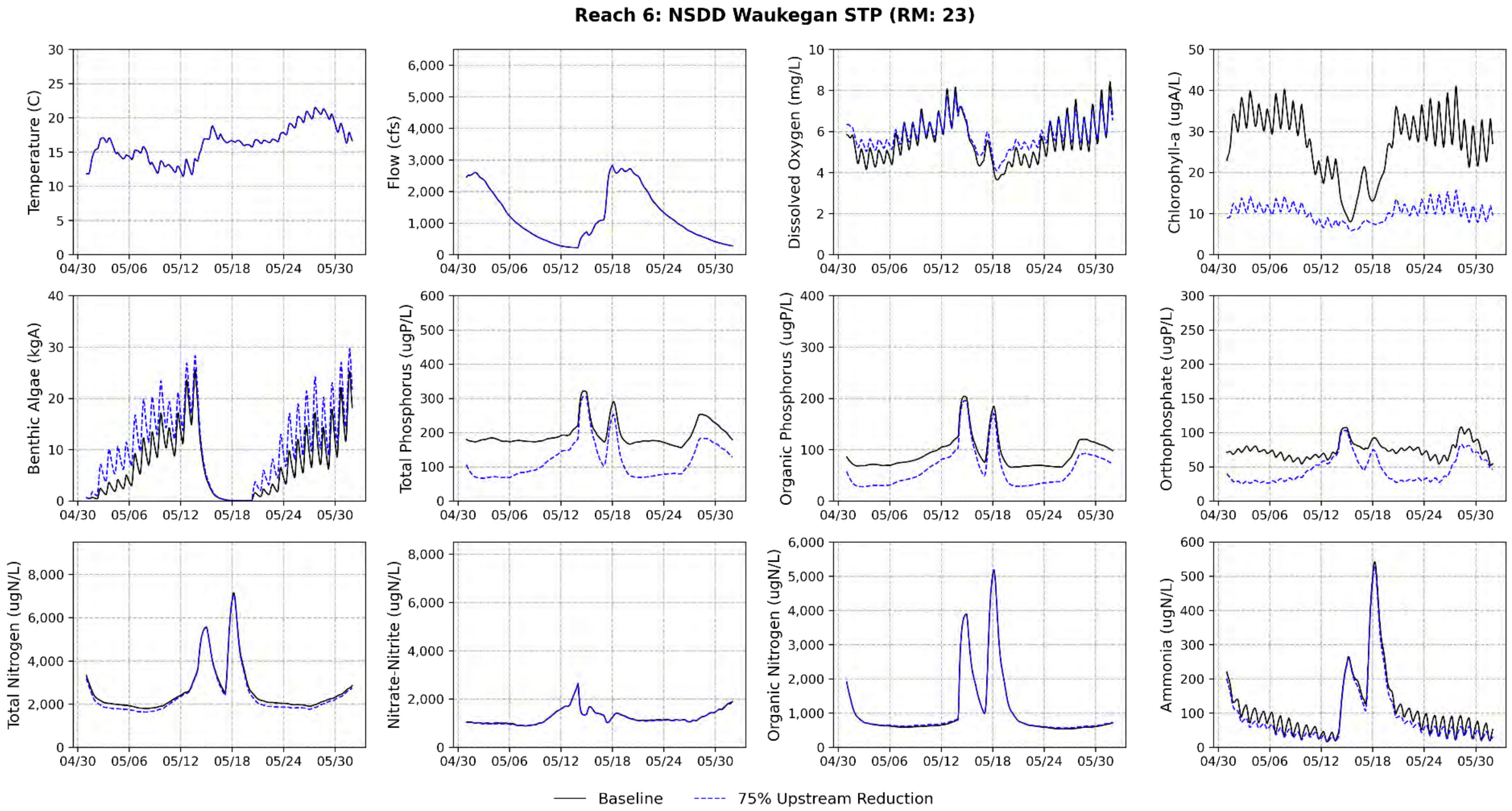
# Baseline and 75% Upstream Reduction 5/1- 31, 2020



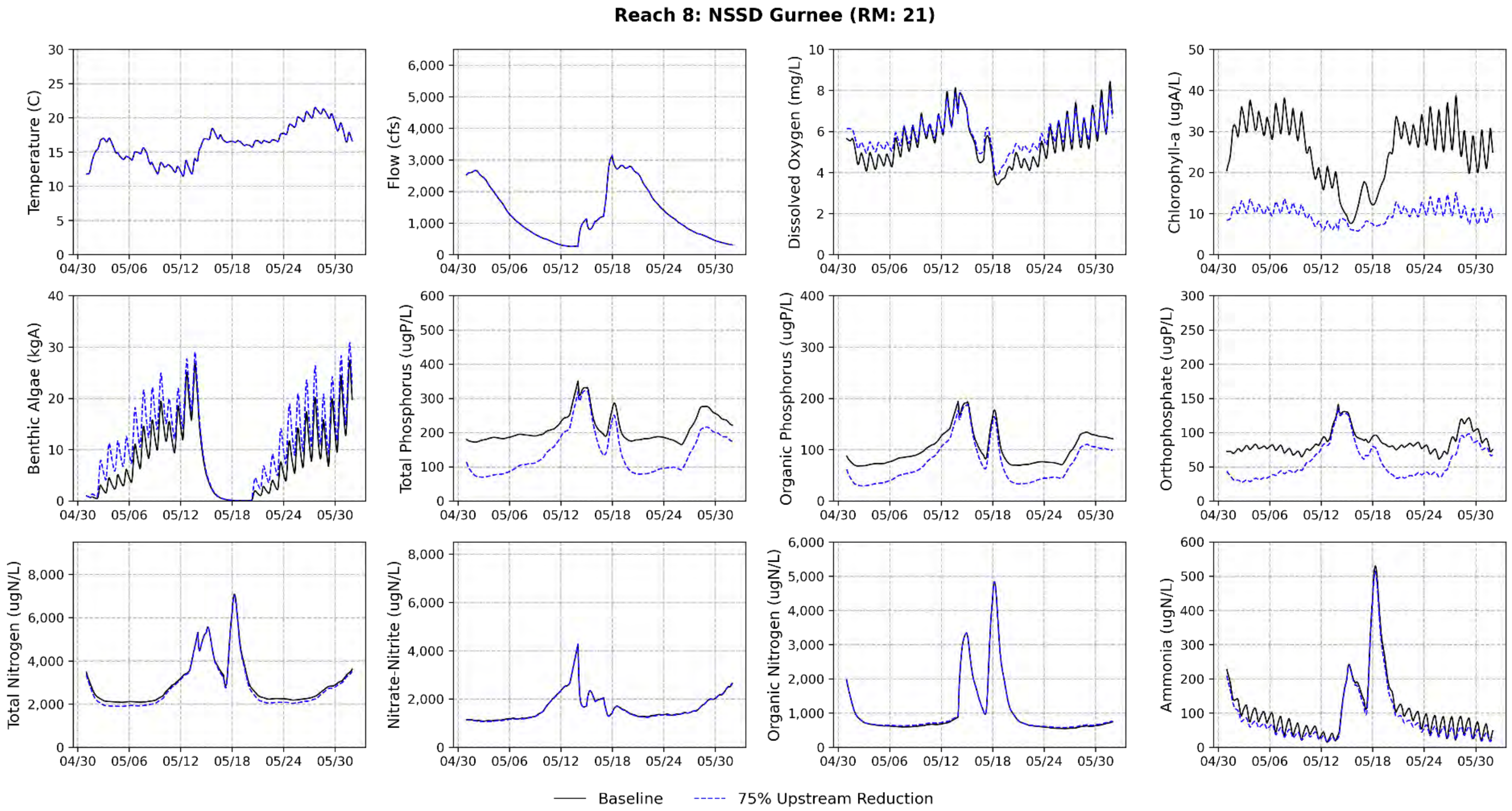
# Baseline and 75% Upstream Reduction 5/1- 31, 2020



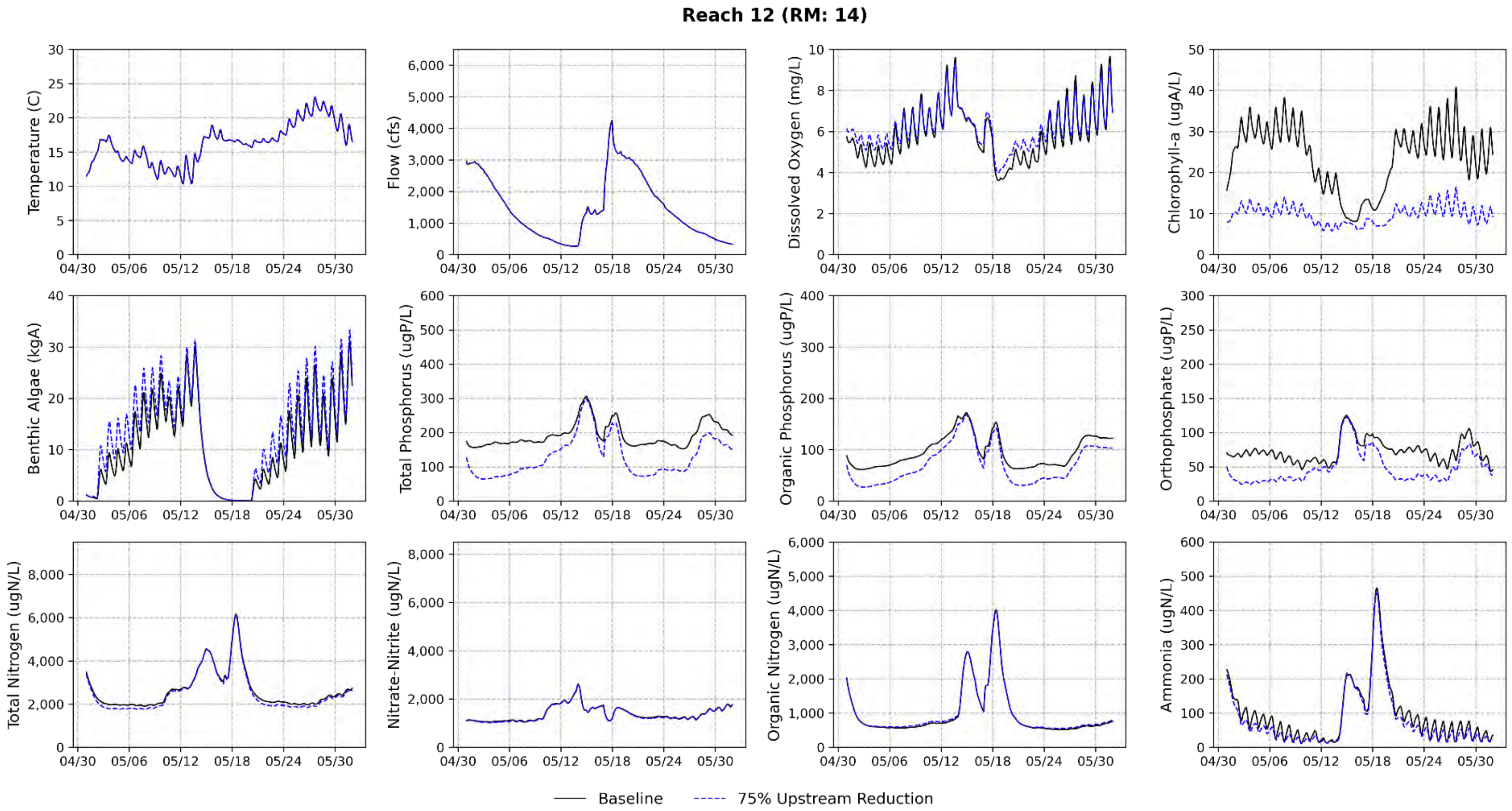
# Baseline and 75% Upstream Reduction 5/1- 31, 2020



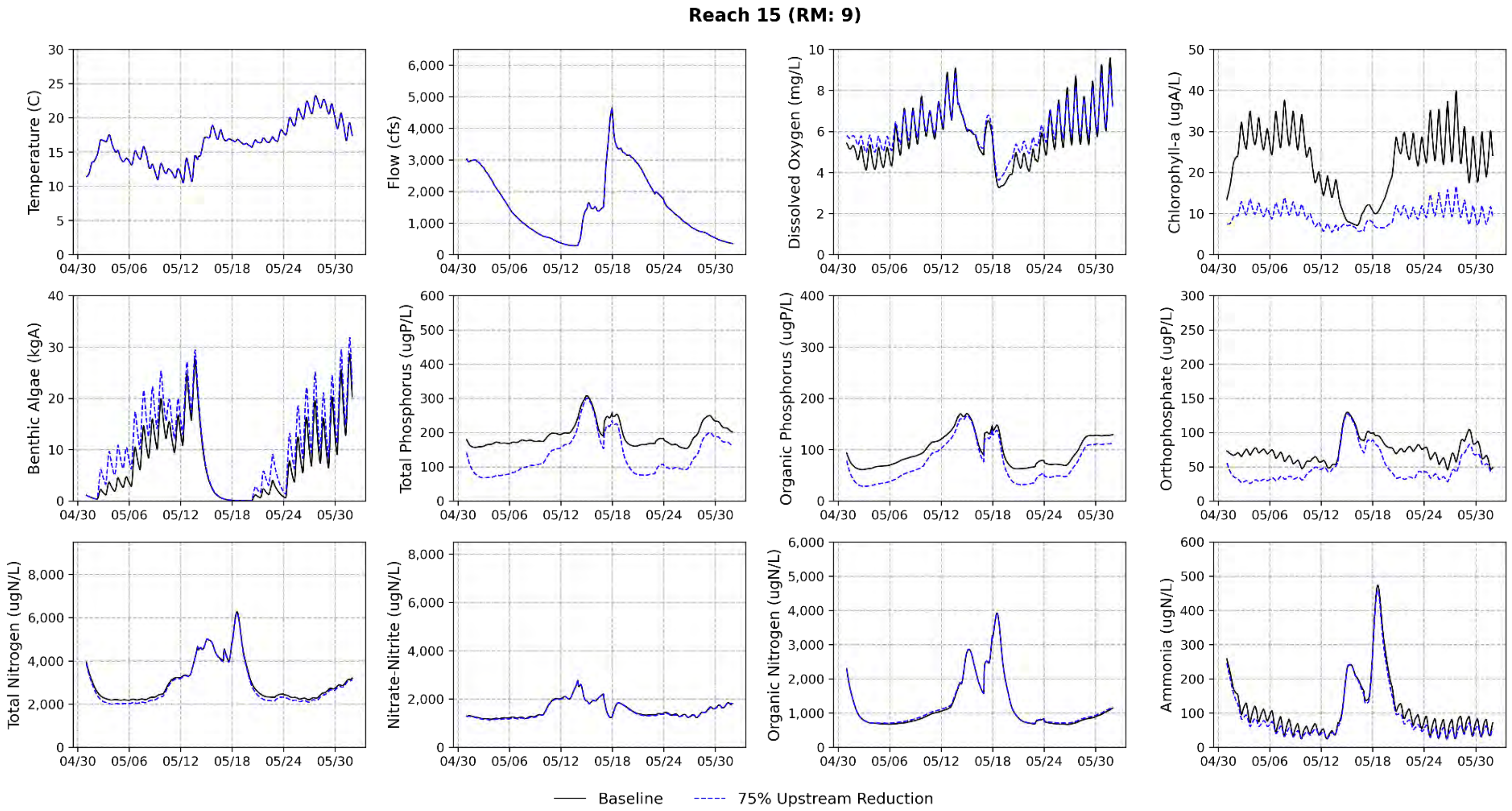
# Baseline and 75% Upstream Reduction 5/1- 31, 2020



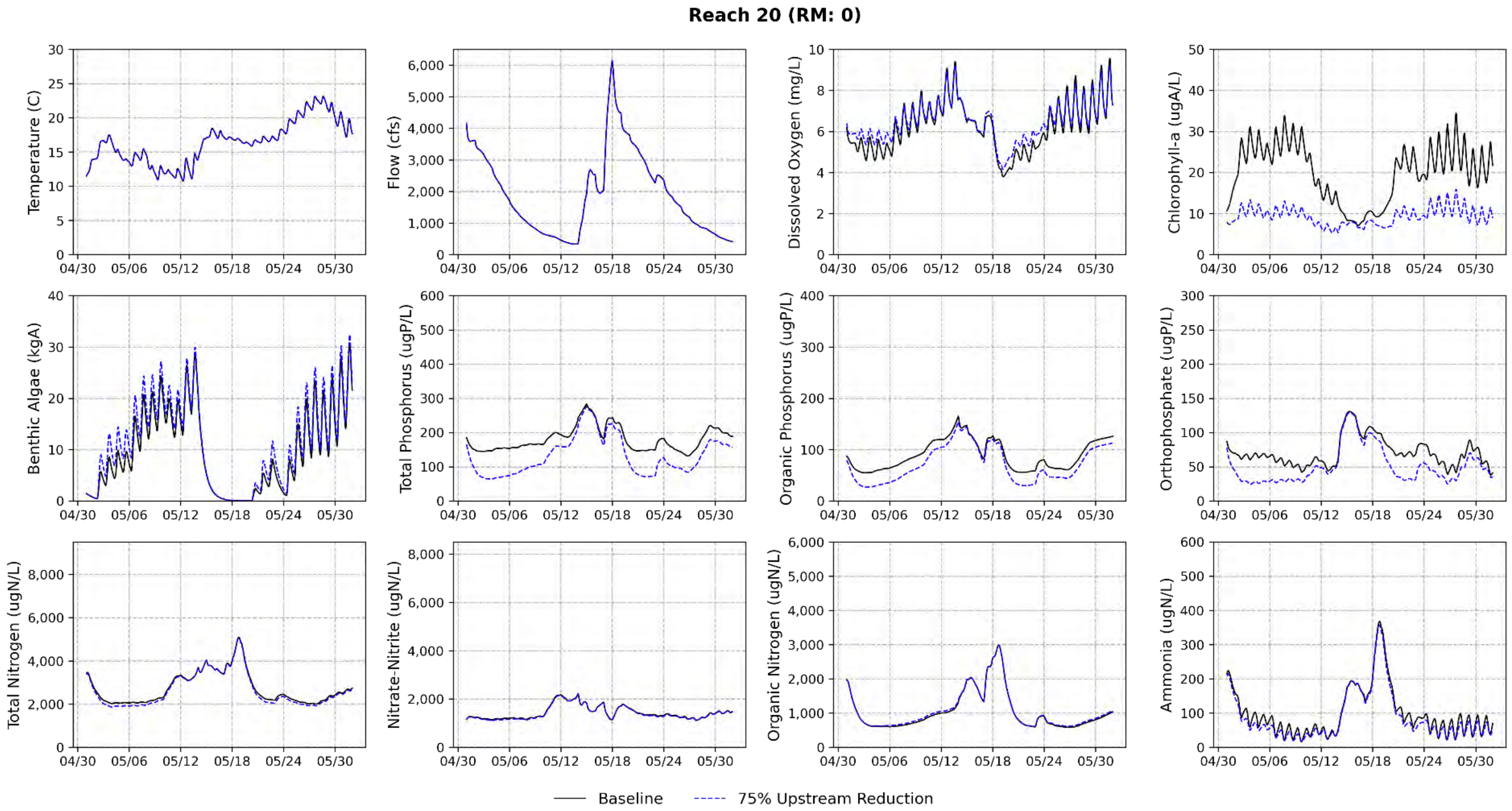
# Baseline and 75% Upstream Reduction 5/1- 31, 2020



# Baseline and 75% Upstream Reduction 5/1- 31, 2020



# Baseline and 75% Upstream Reduction 5/1- 31, 2020



# Nonpoint Sources Reduction

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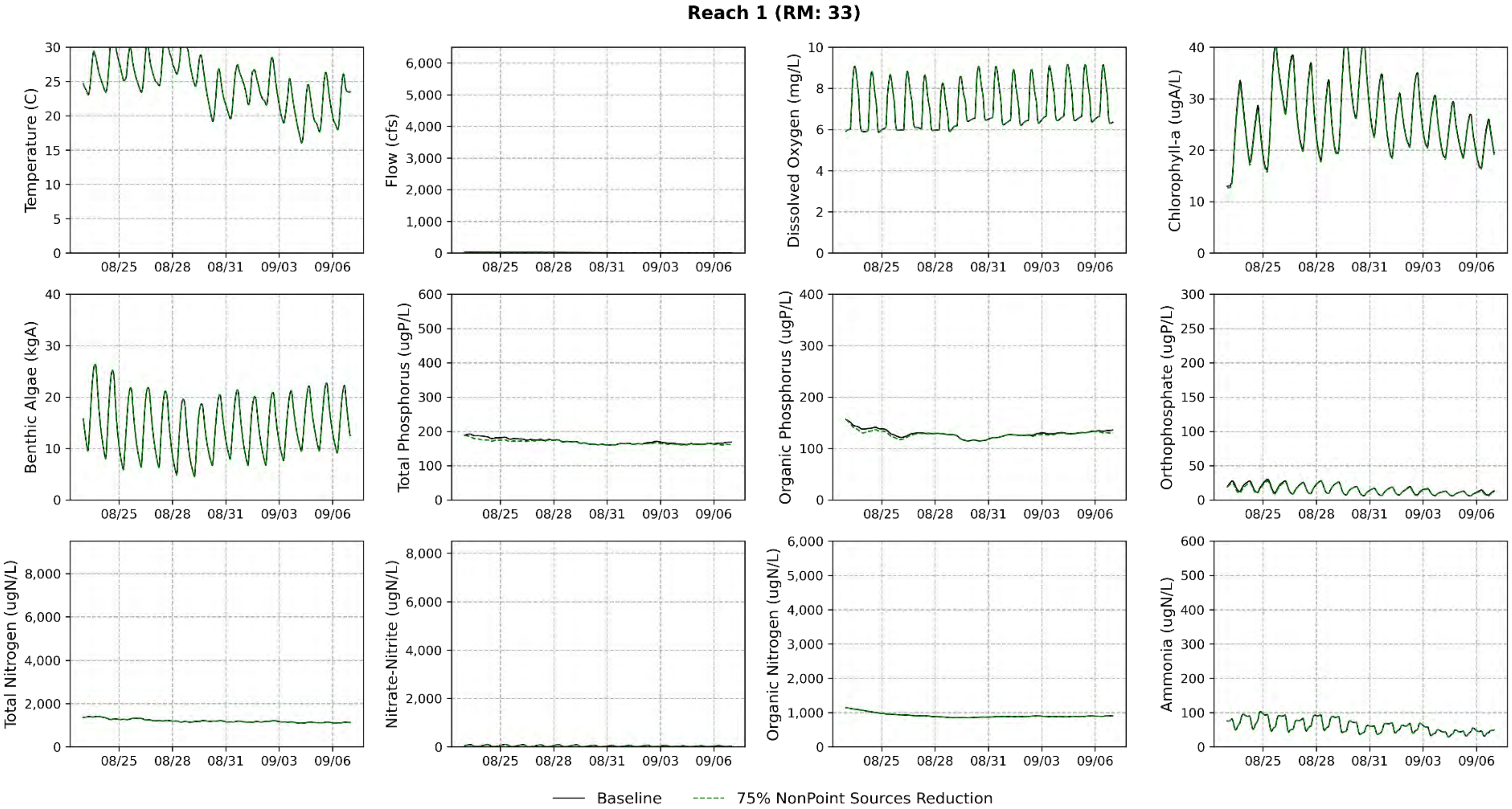
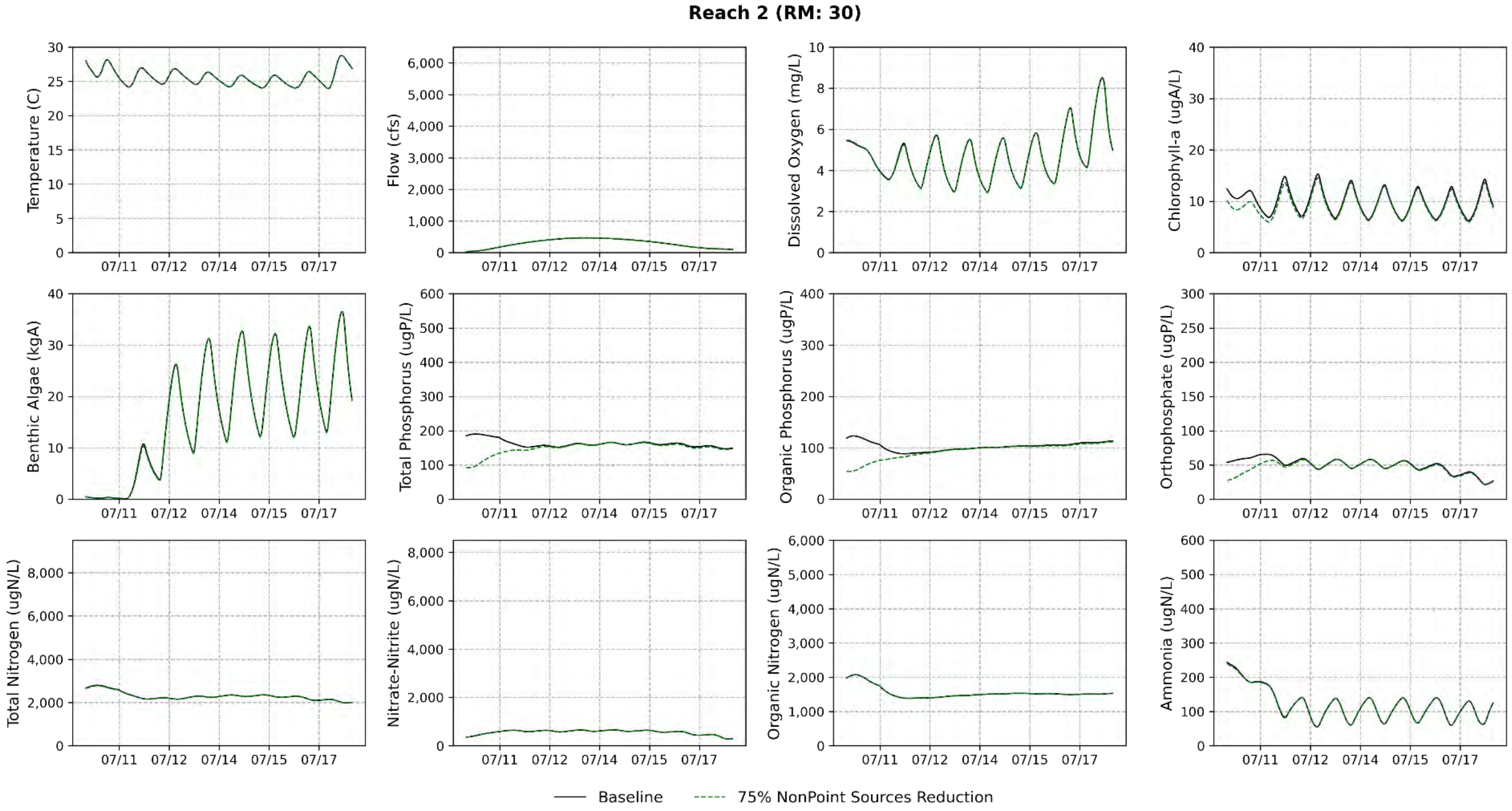
# Low DO Period: July 10-17

Geosyntec consultants

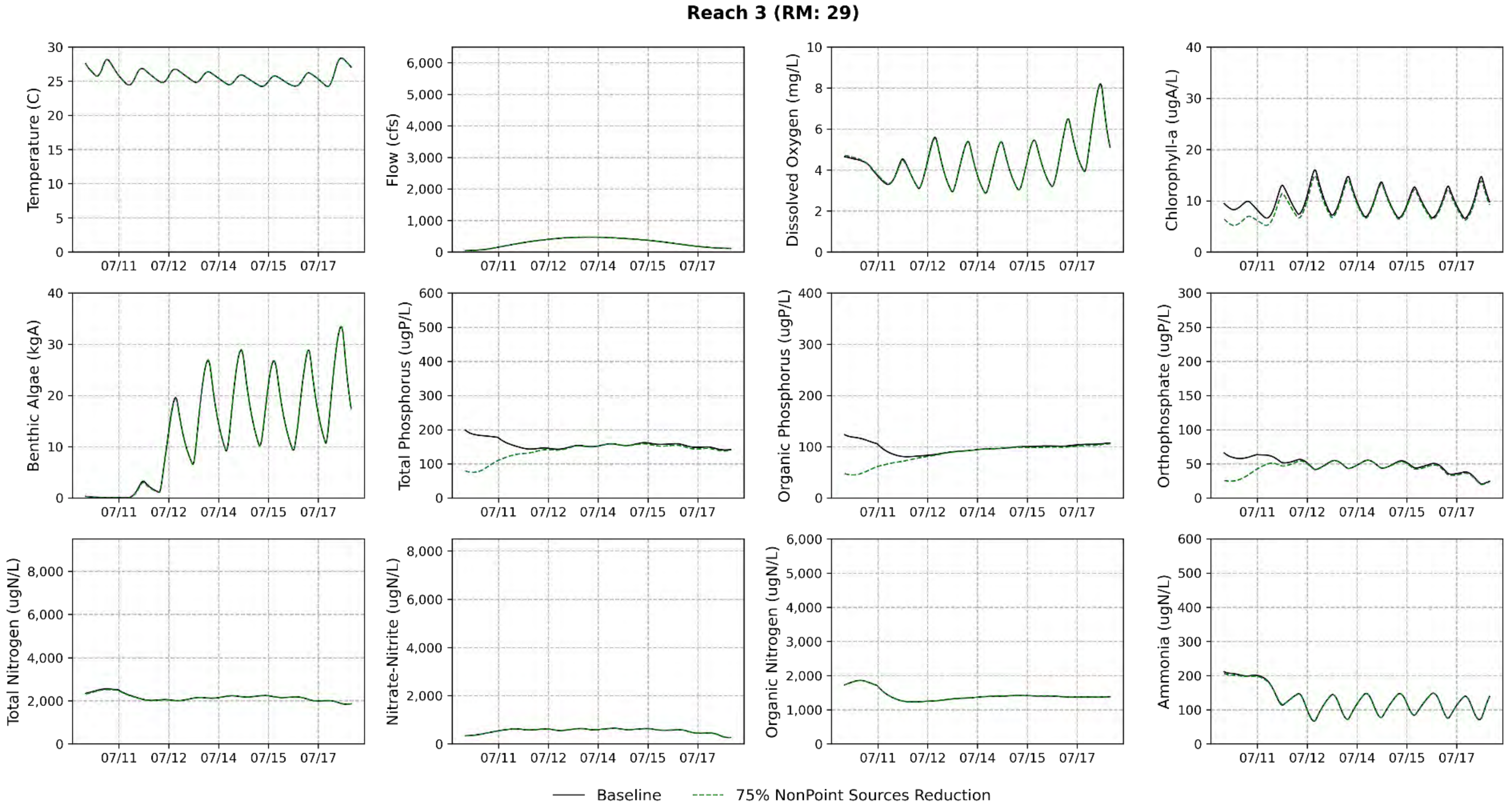
# Baseline and 75% Nonpoint Reduction
# 7/10 – 17, 2020



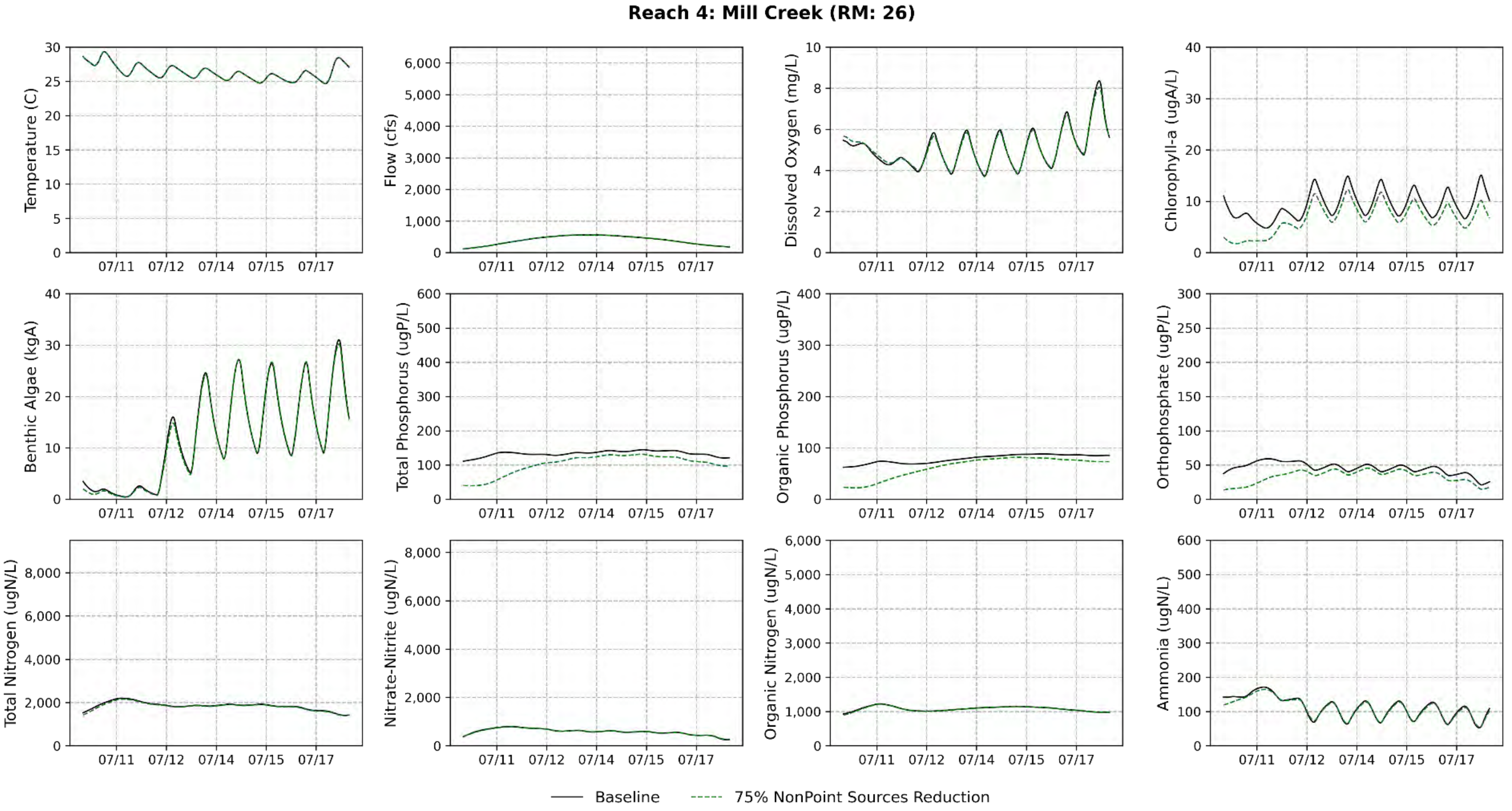
# Baseline and 75% Nonpoint Reduction 7/10 – 17, 2020



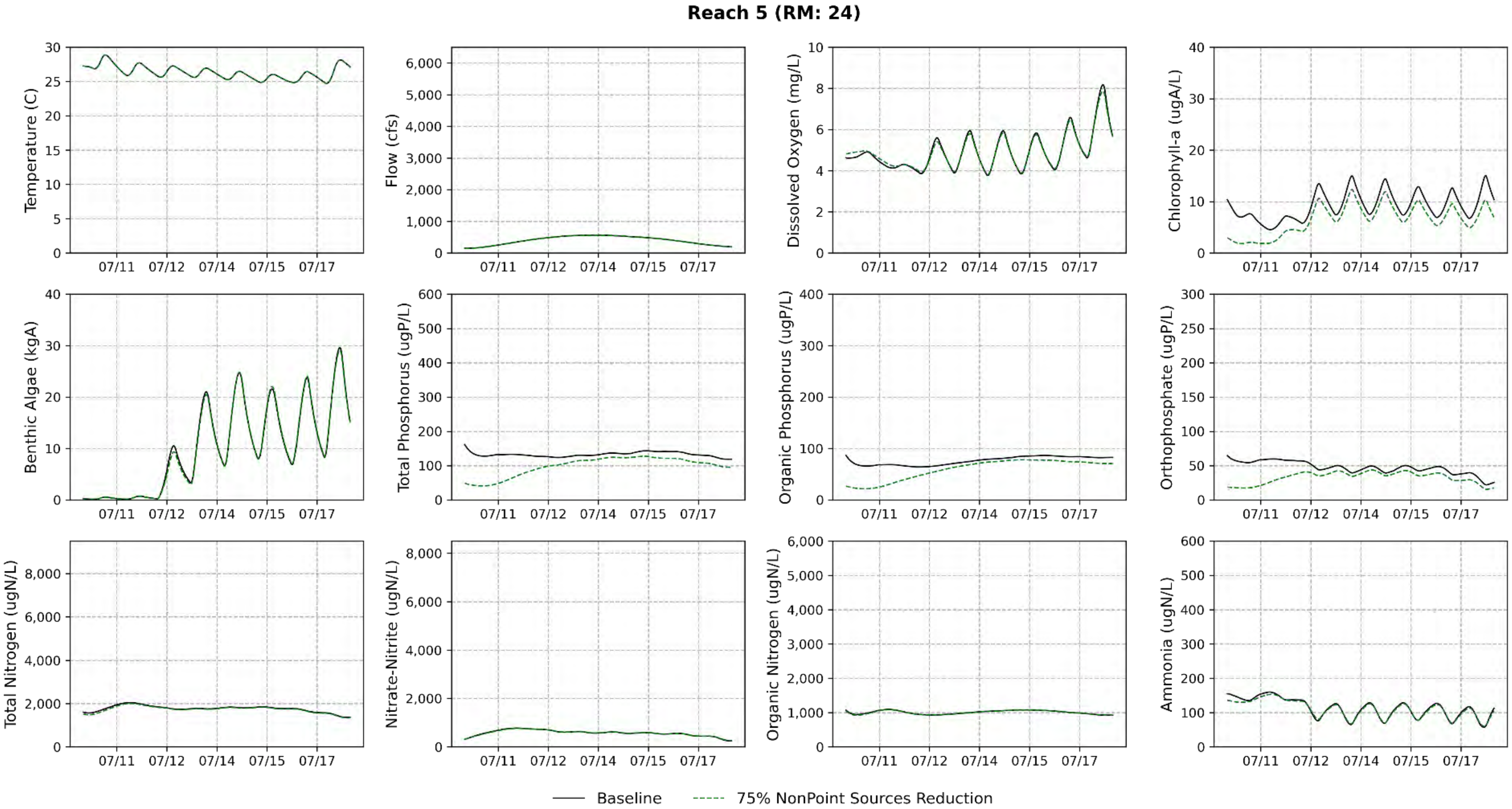
# Baseline and 75% Nonpoint Reduction 7/10 – 17, 2020



# Baseline and 75% Nonpoint Reduction 7/10 – 7/17, 2020



# Baseline and 75% Nonpoint Reduction 7/10 – 17, 2020



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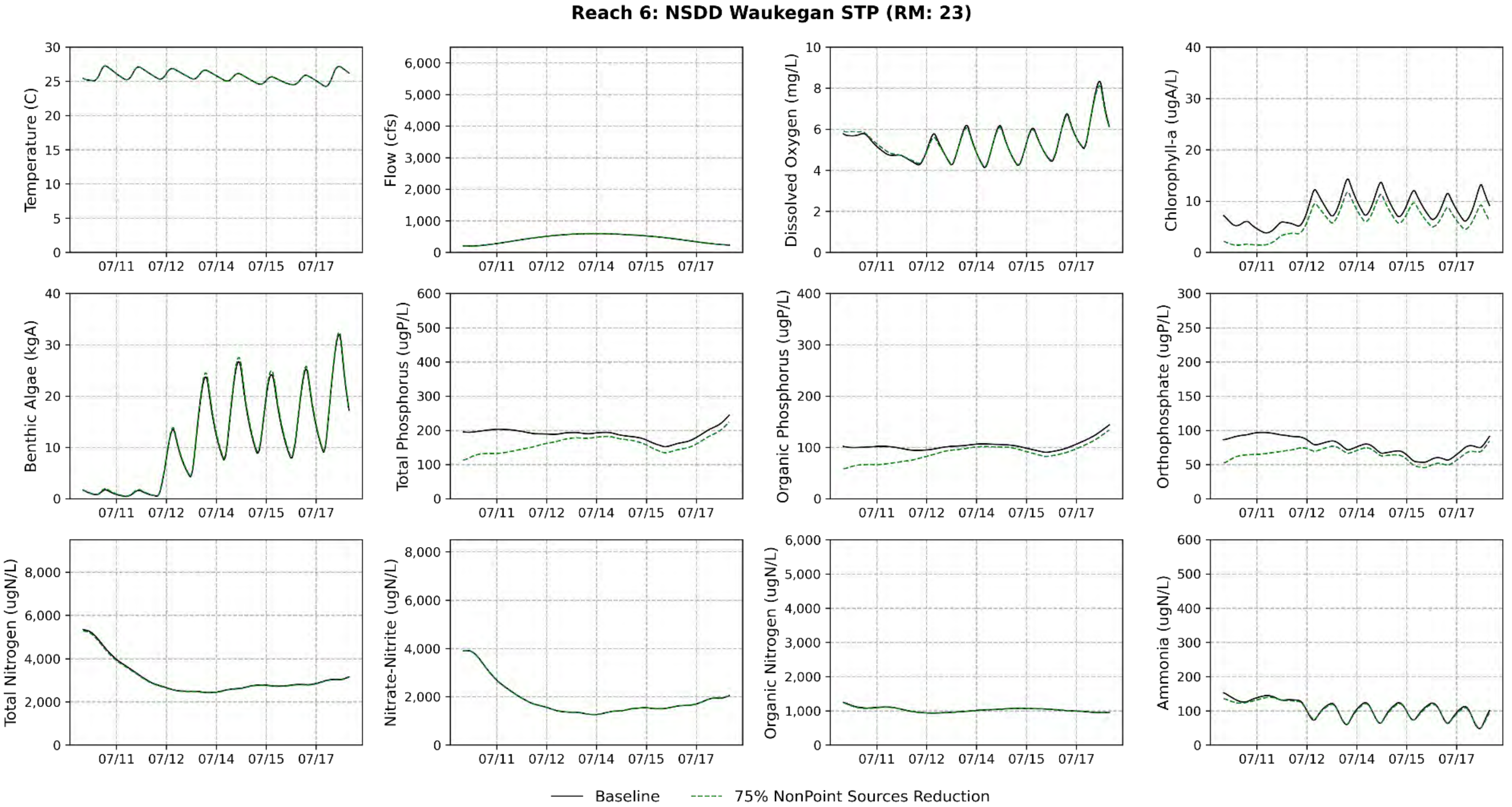
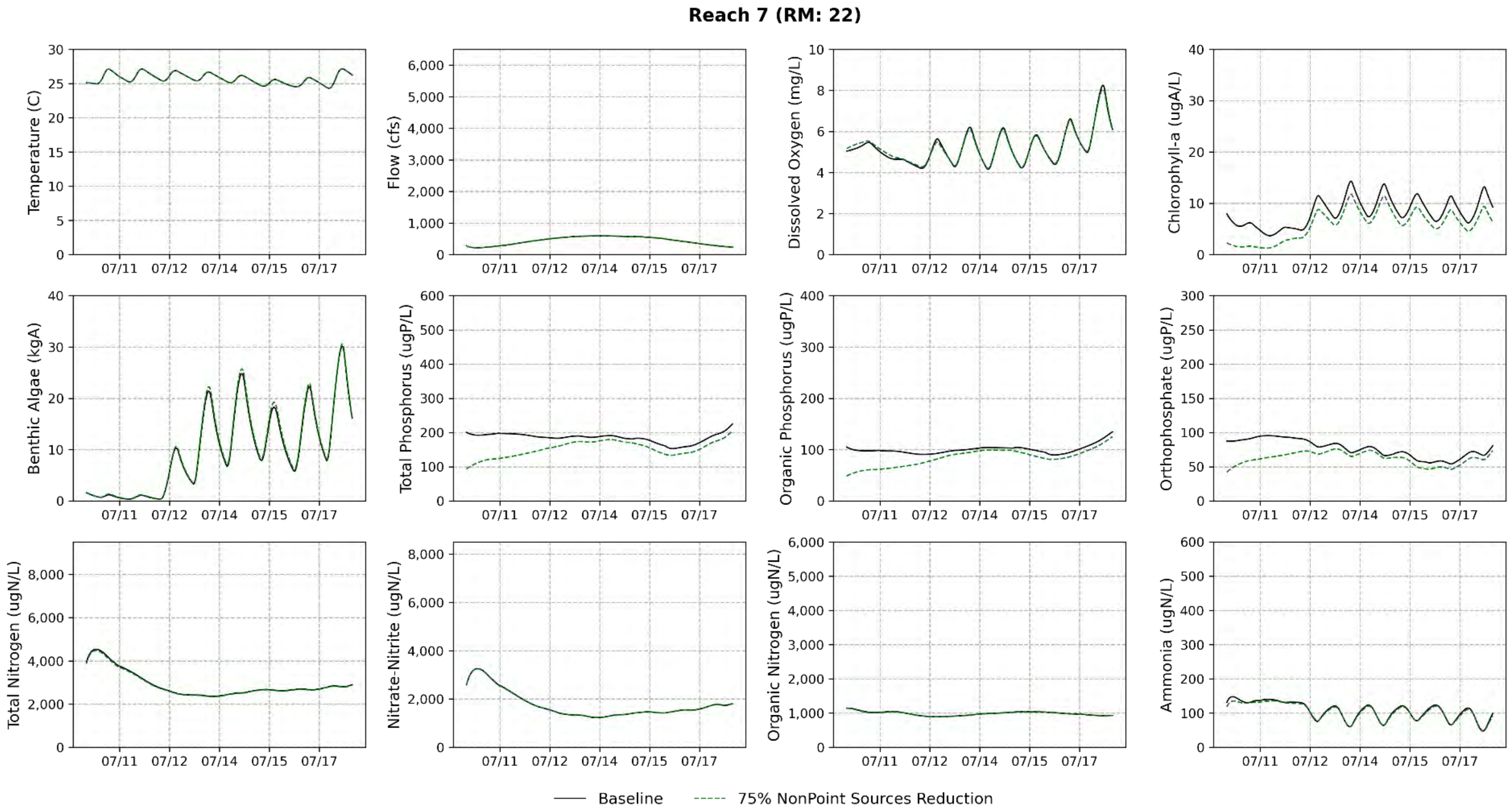
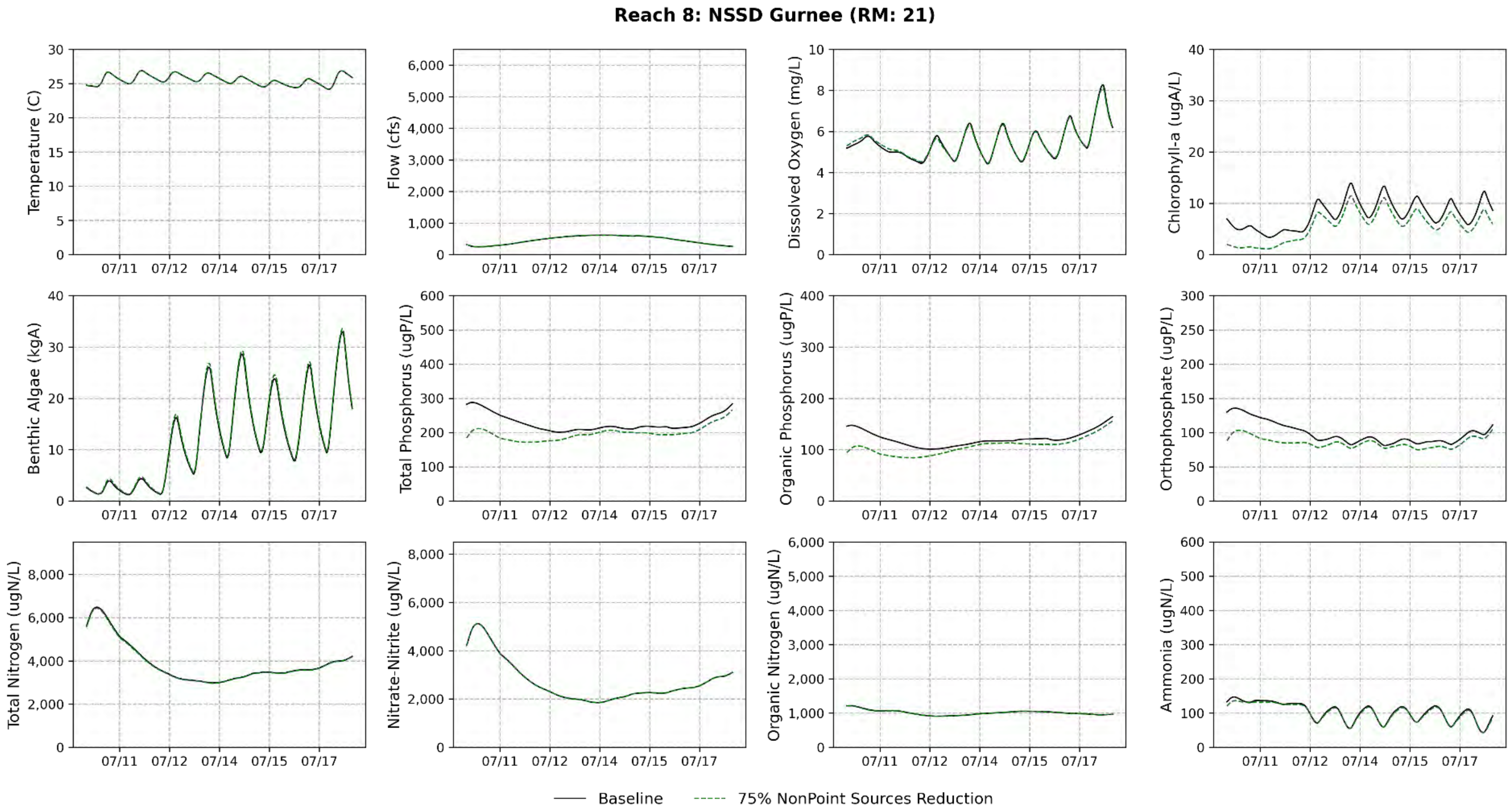


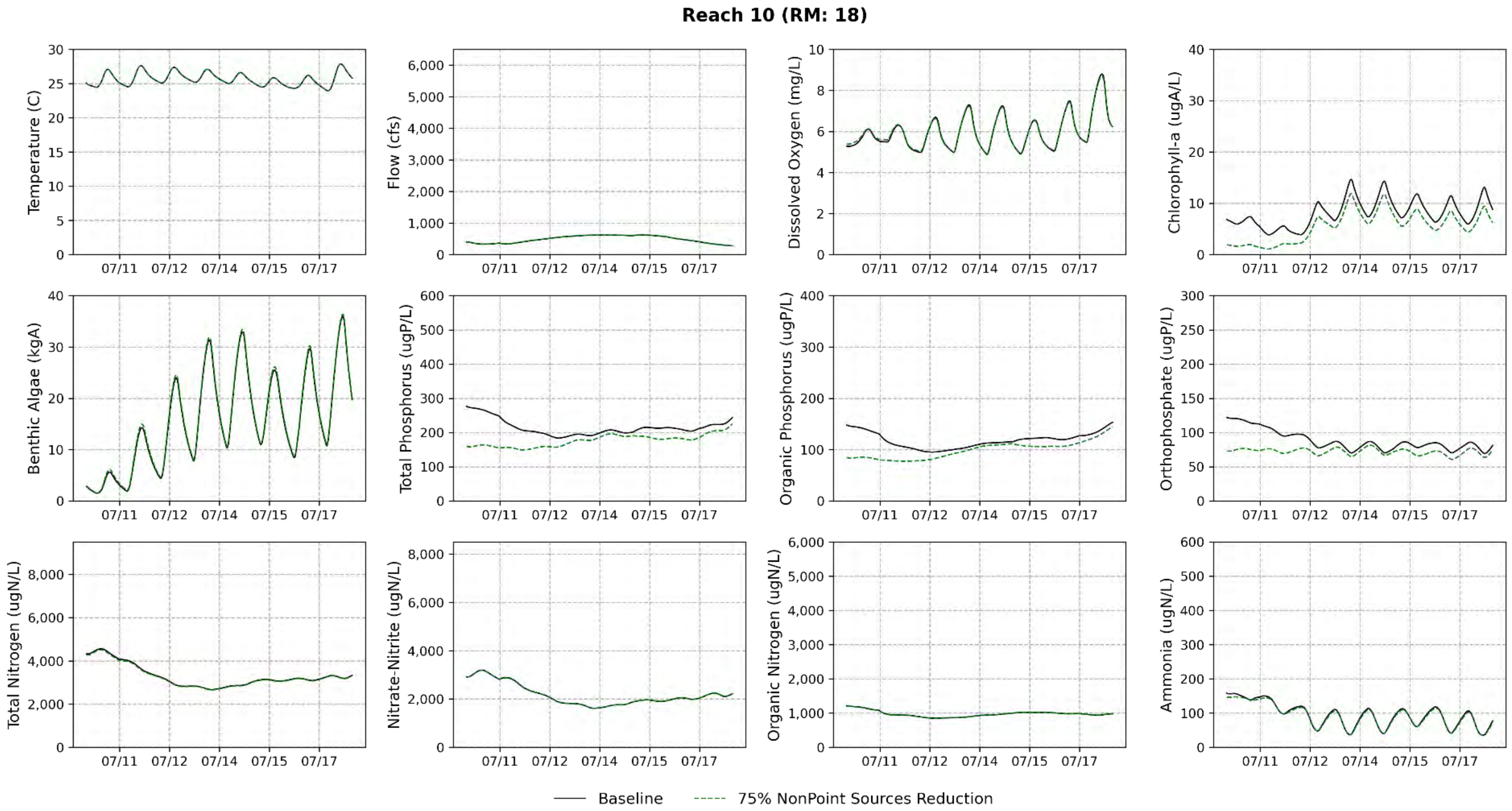
# Baseline and 75% Nonpoint Reduction
# 7/10 – 17, 2020



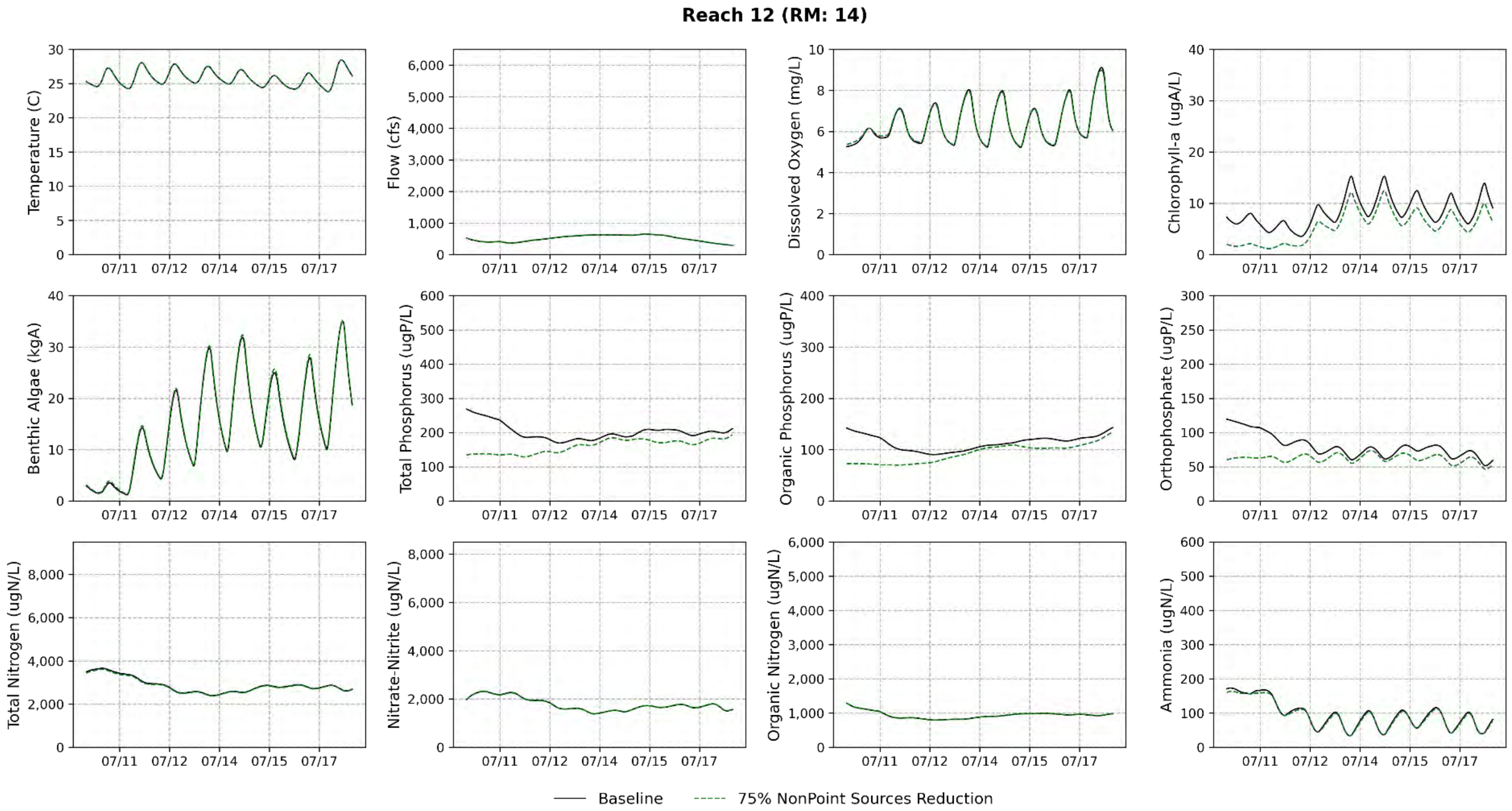
# Baseline and 75% Nonpoint Reduction 7/10 – 17, 2020



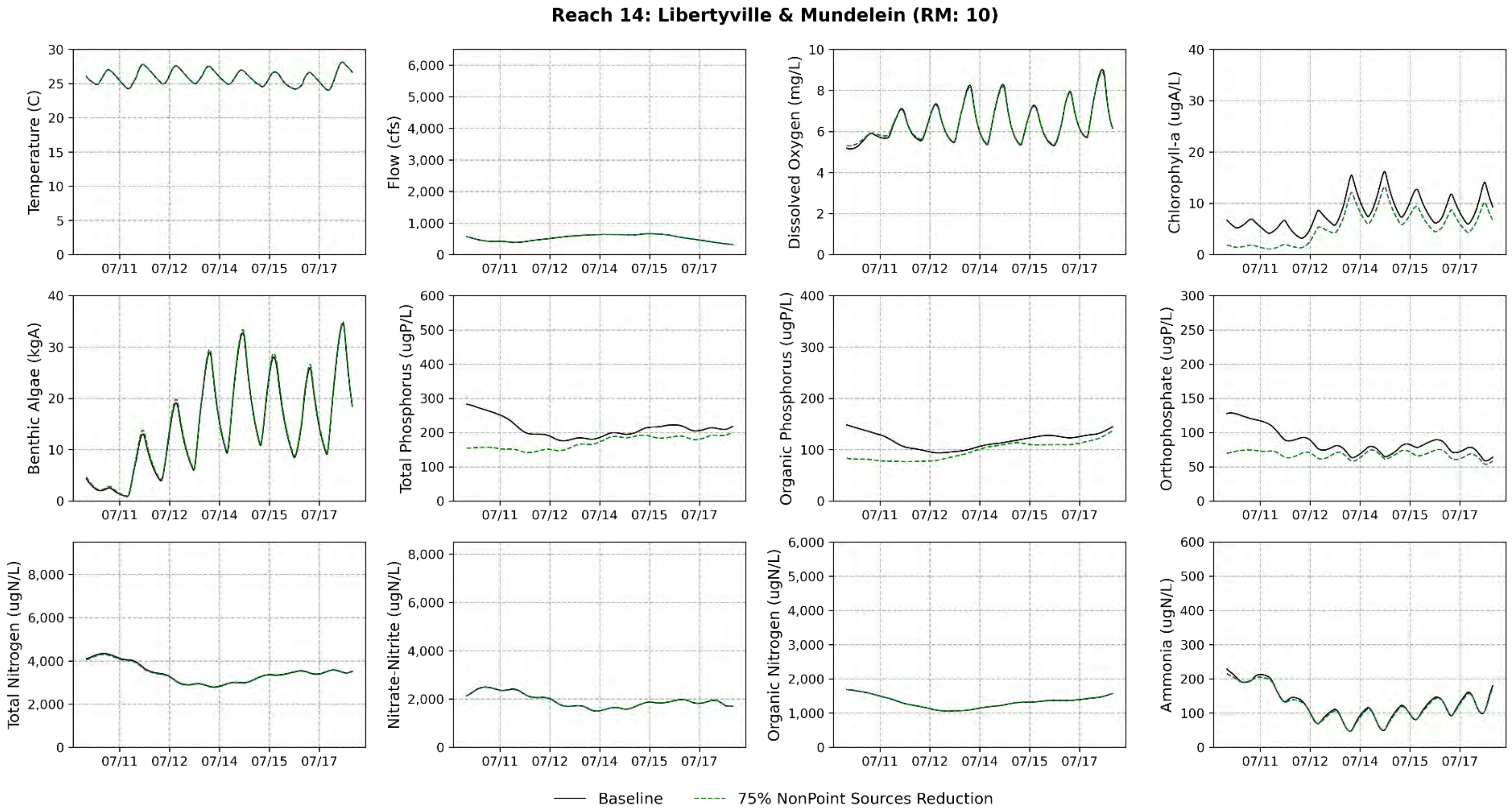
# Baseline and 75% Nonpoint Reduction 7/10 – 17, 2020



# Baseline and 75% Nonpoint Reduction 7/10 – 17, 2020



# Baseline and 75% Nonpoint Reduction 7/10 – 17, 2020



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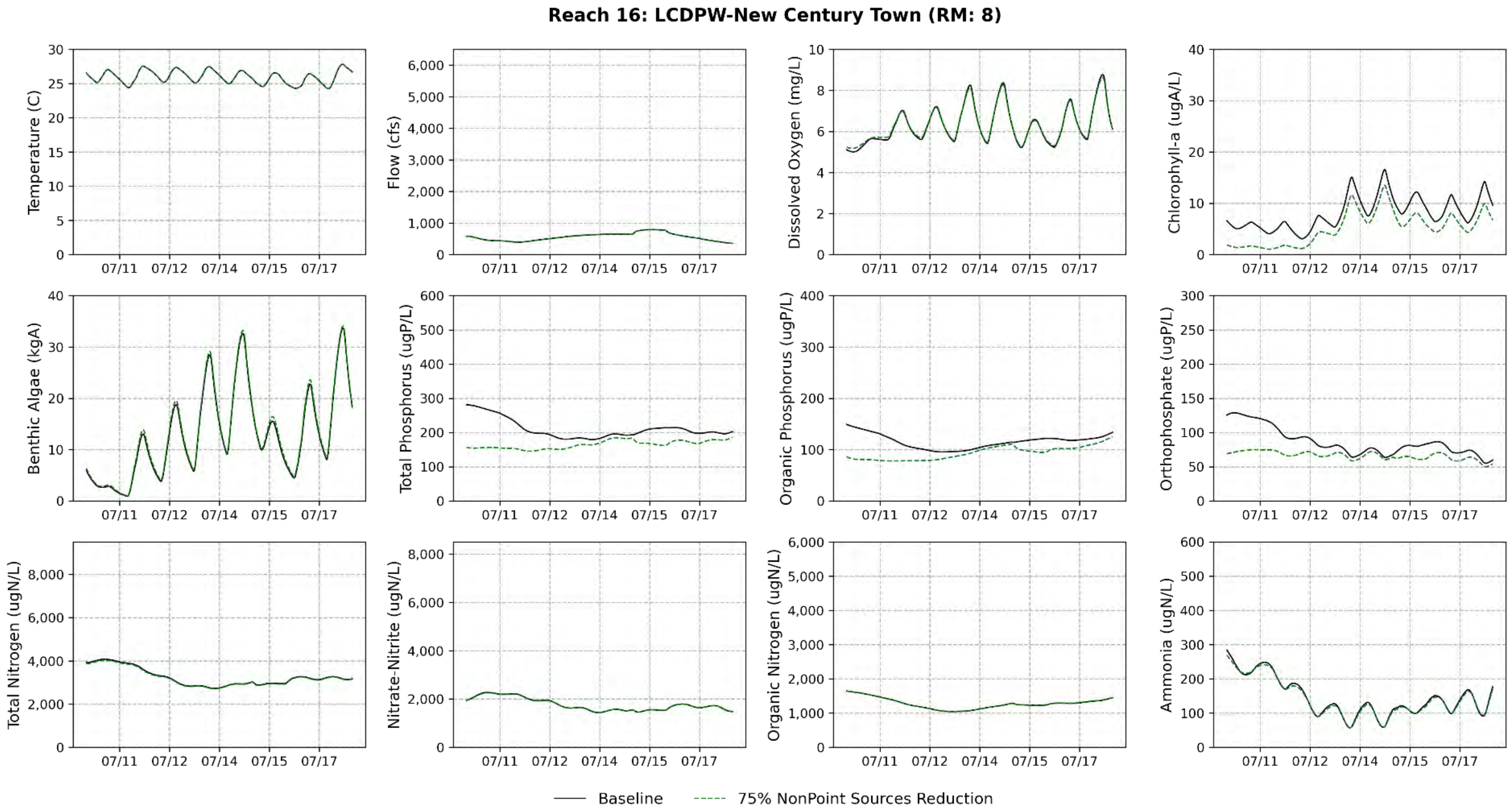
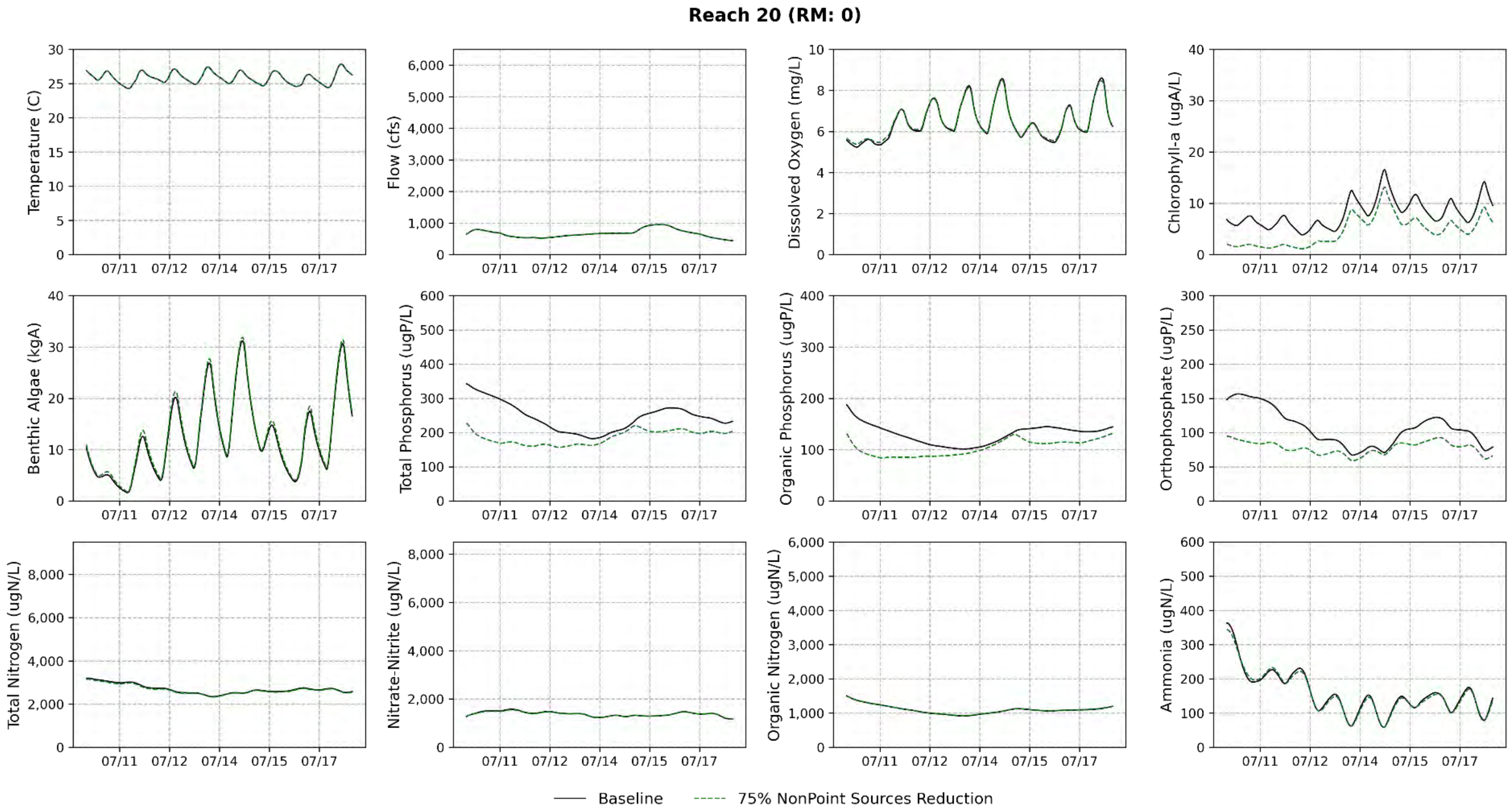


# Baseline and 75% Nonpoint Reduction
# 7/10 – 17, 2020



# High Flow Period: May 1-31

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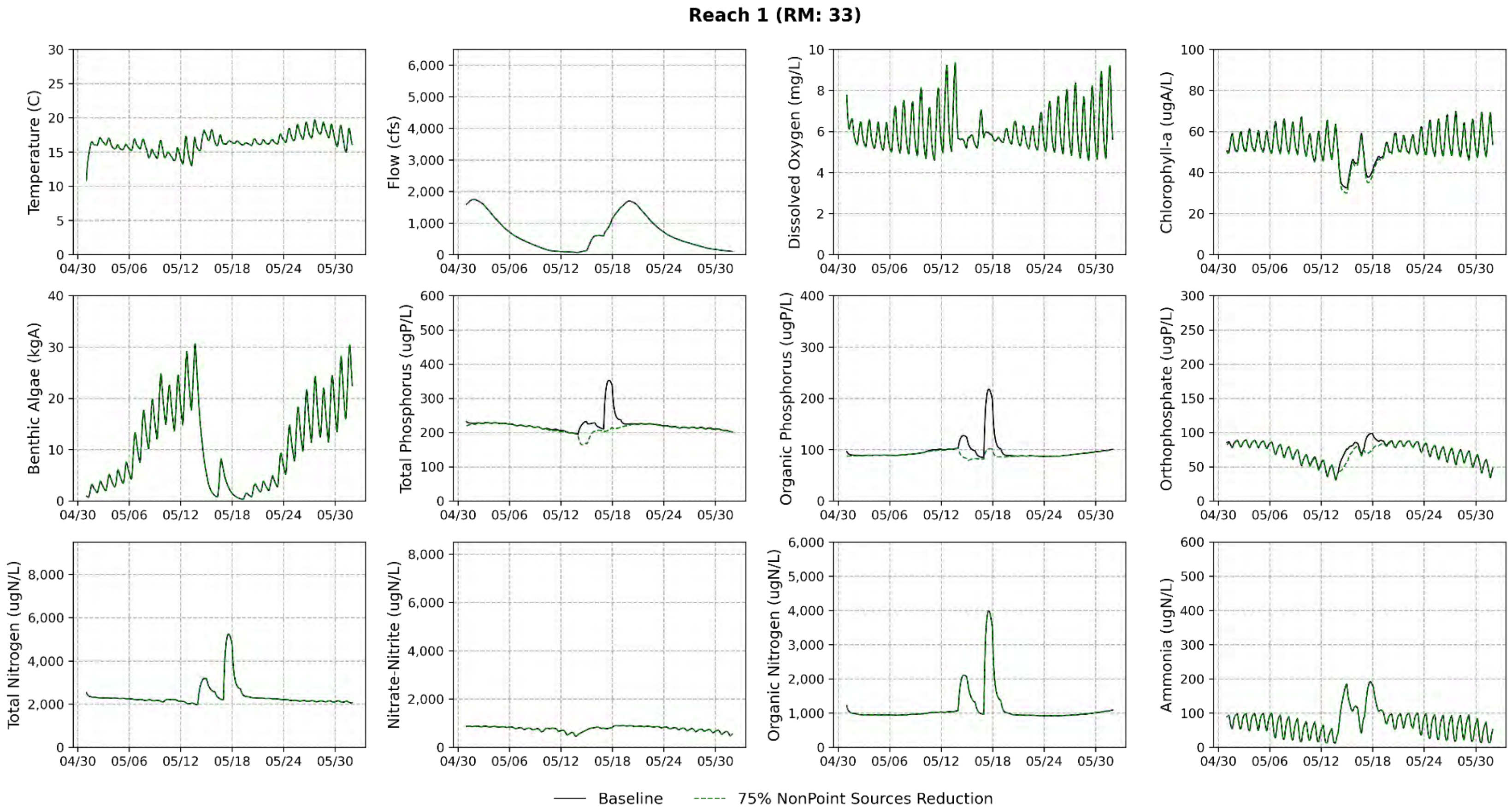
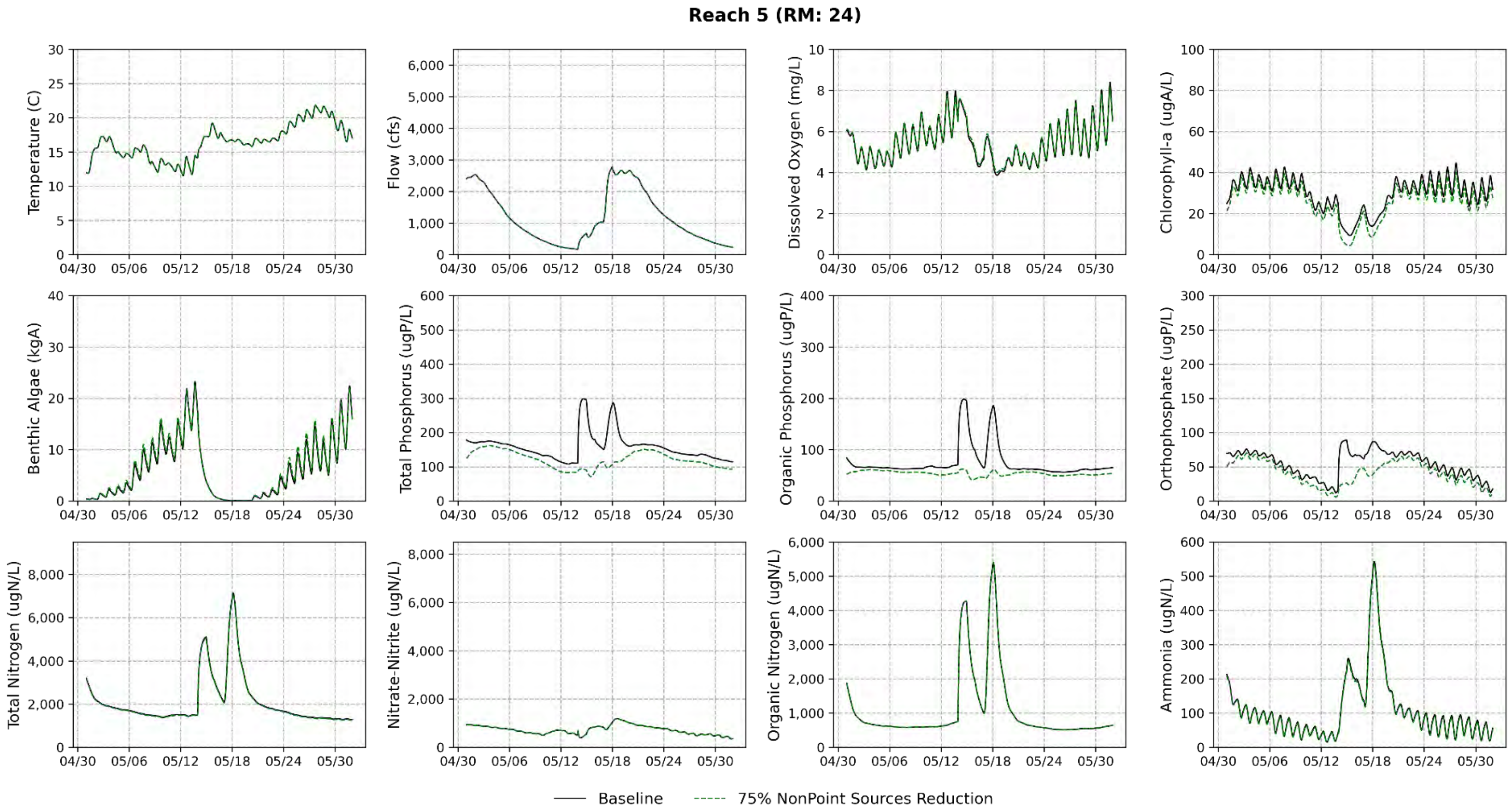
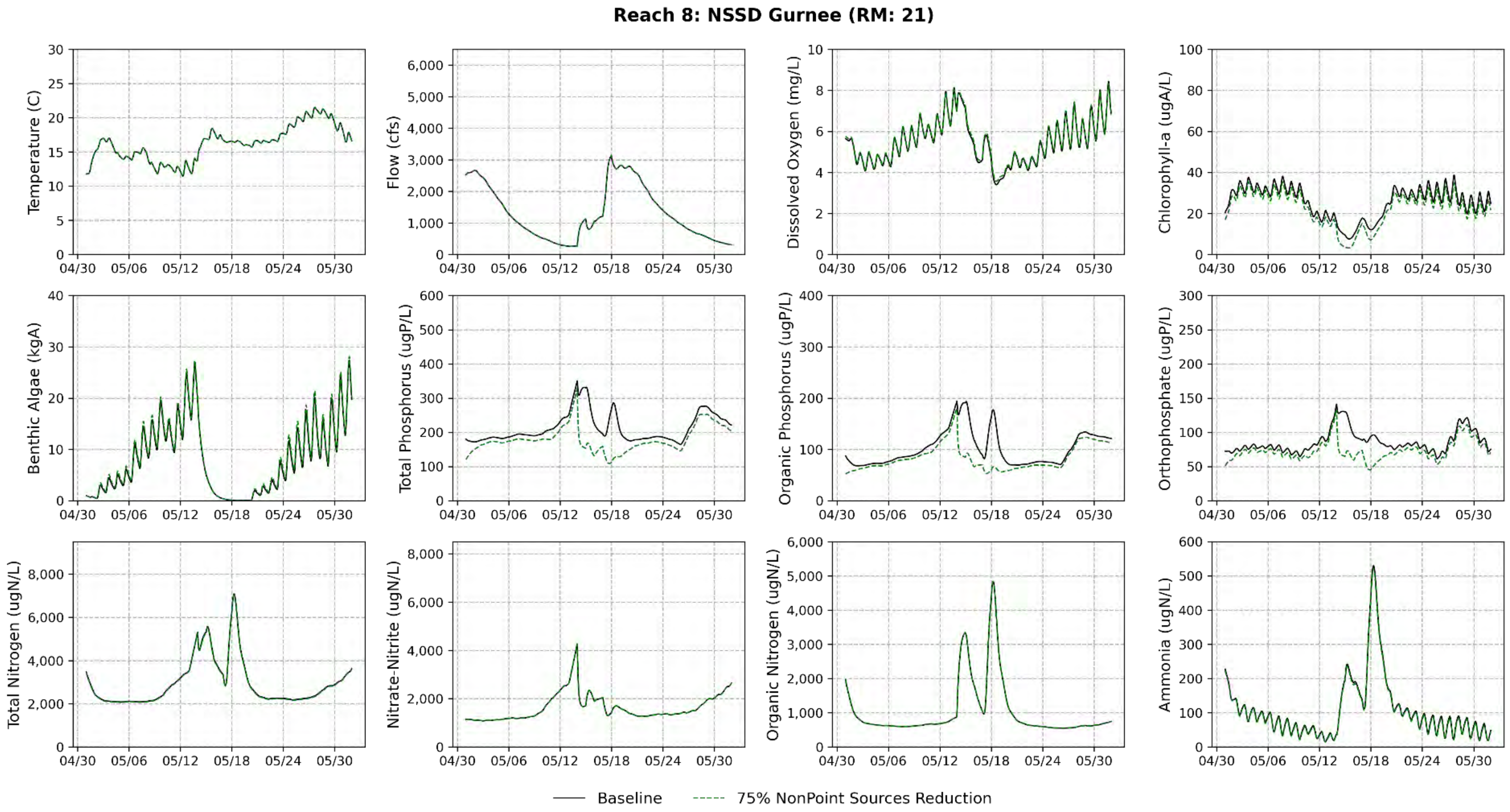
# Baseline and 75% Nonpoint Reduction 5/1 – 31, 2020



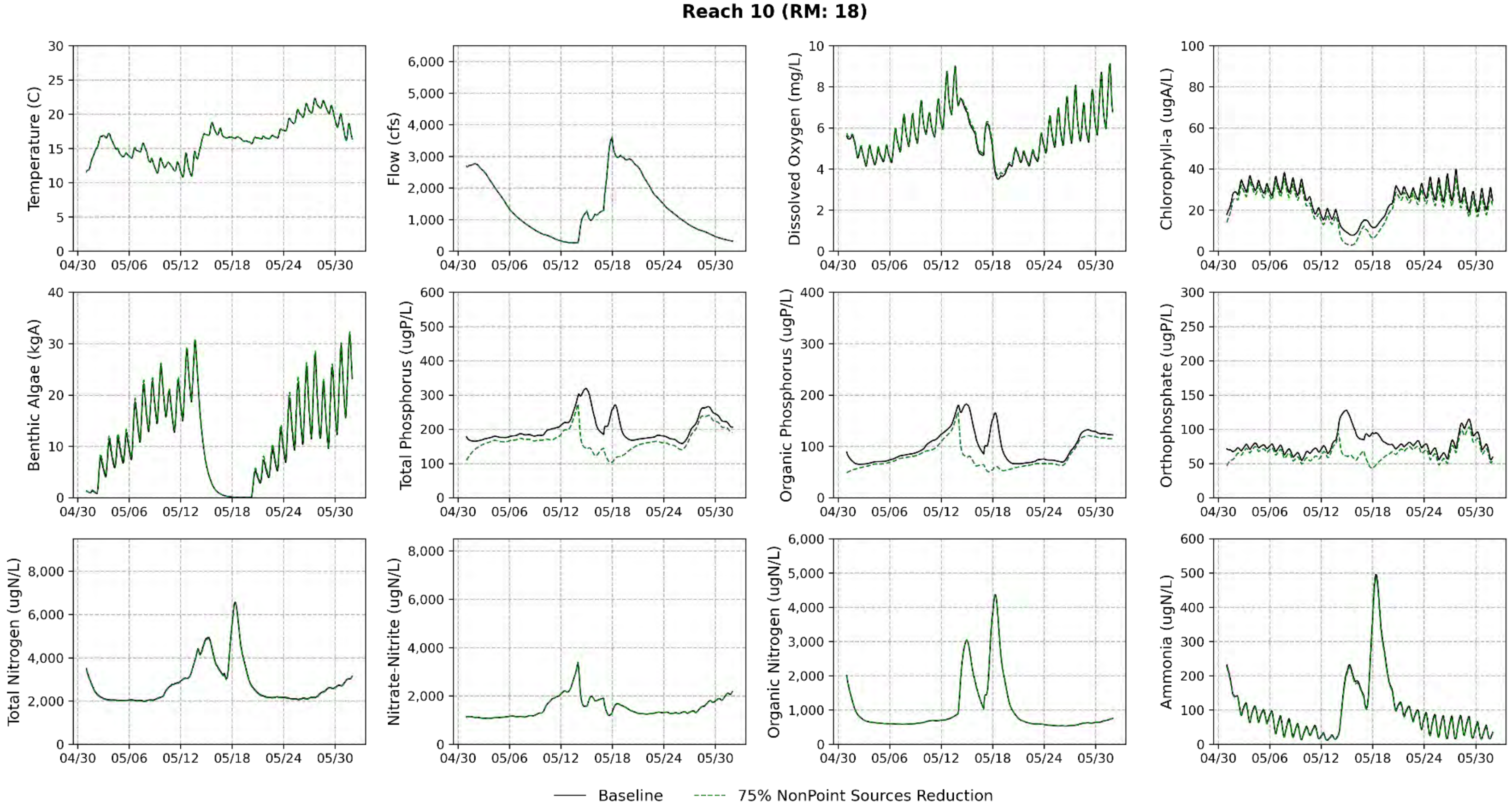
# Baseline and 75% Nonpoint Reduction 5/1 – 31, 2020



# Baseline and 75% Nonpoint Reduction 5/1 – 31, 2020



# Baseline and 75% Nonpoint Reduction
# 5/1 – 31, 2020



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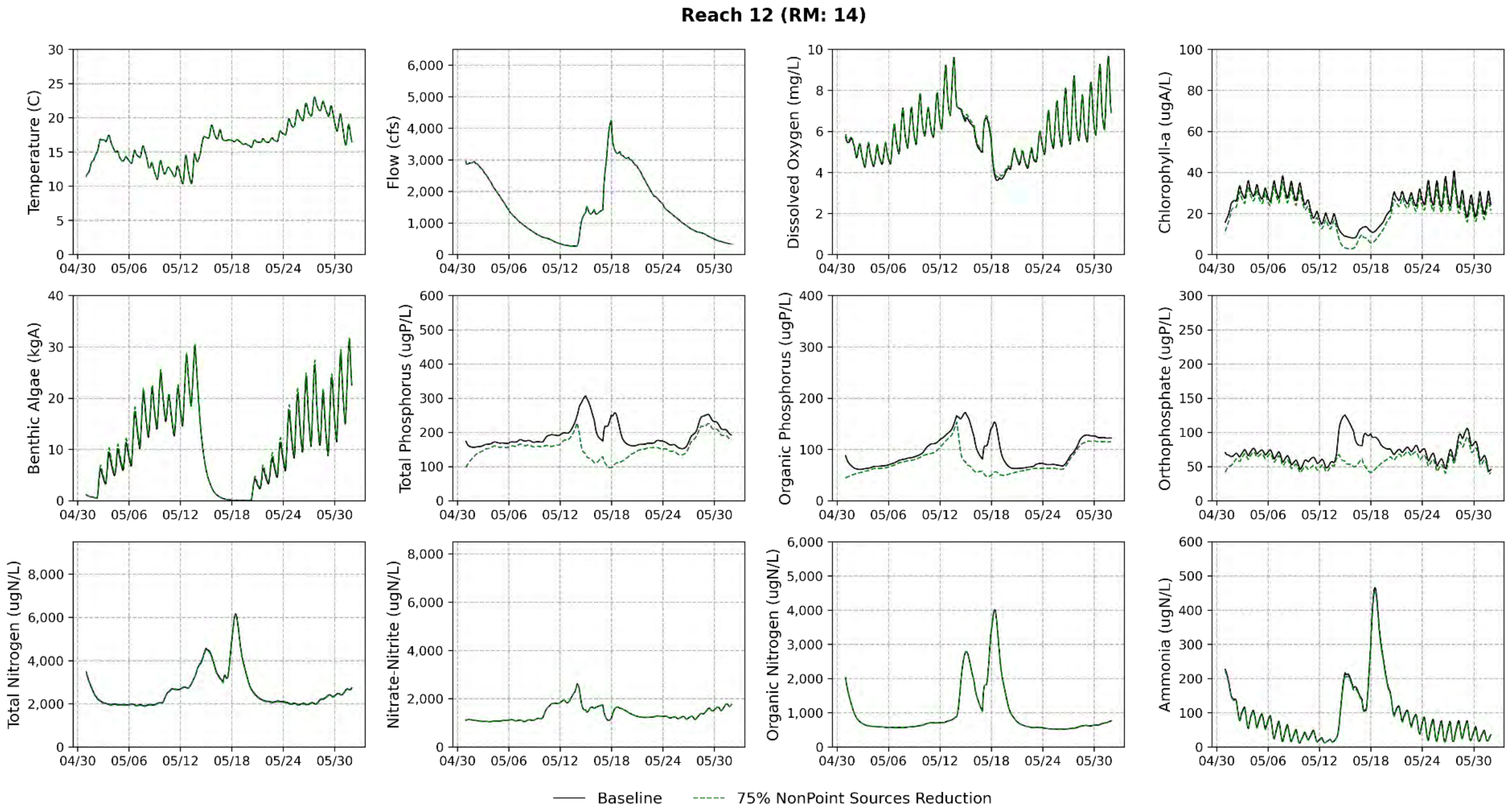

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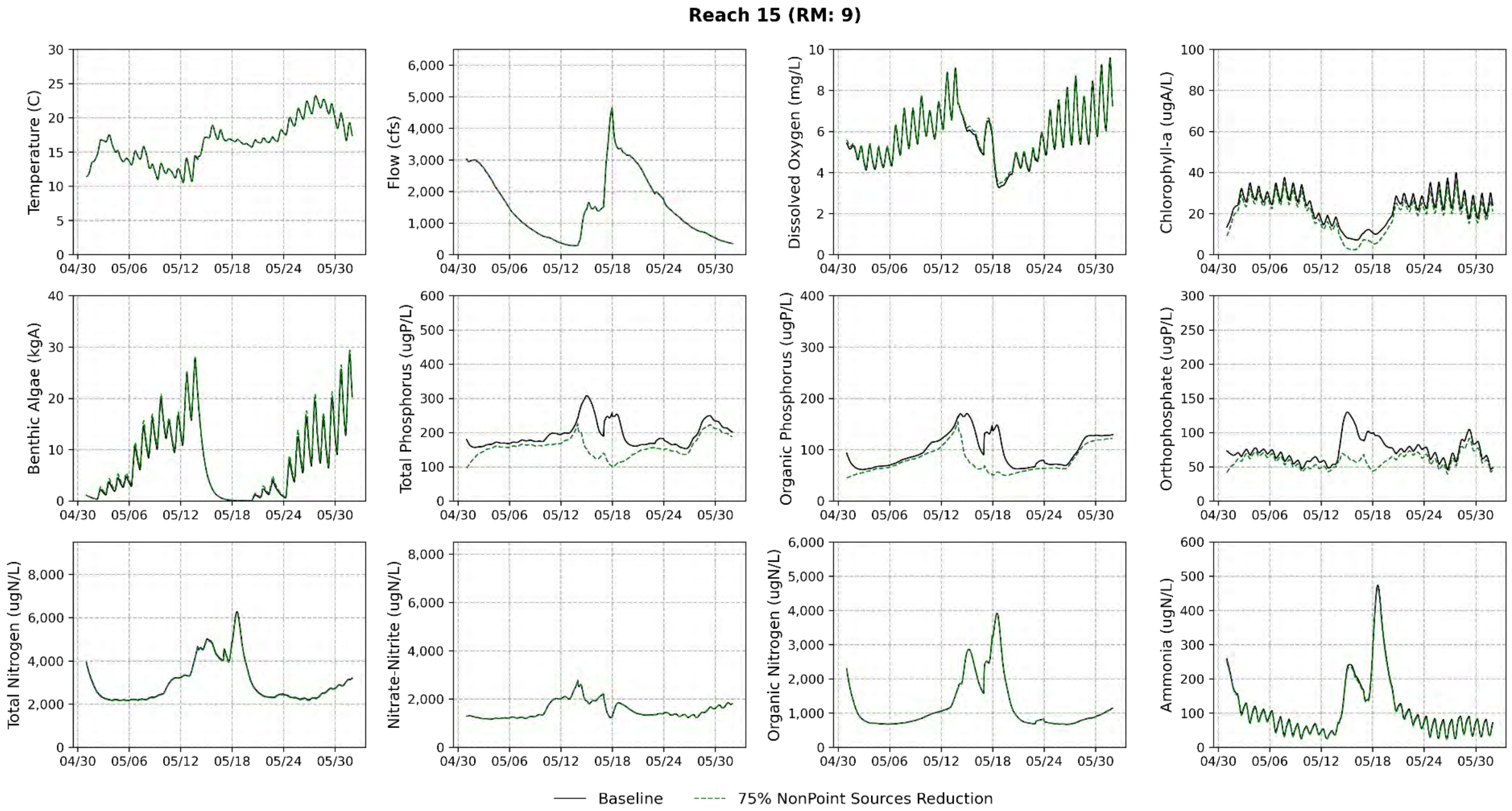
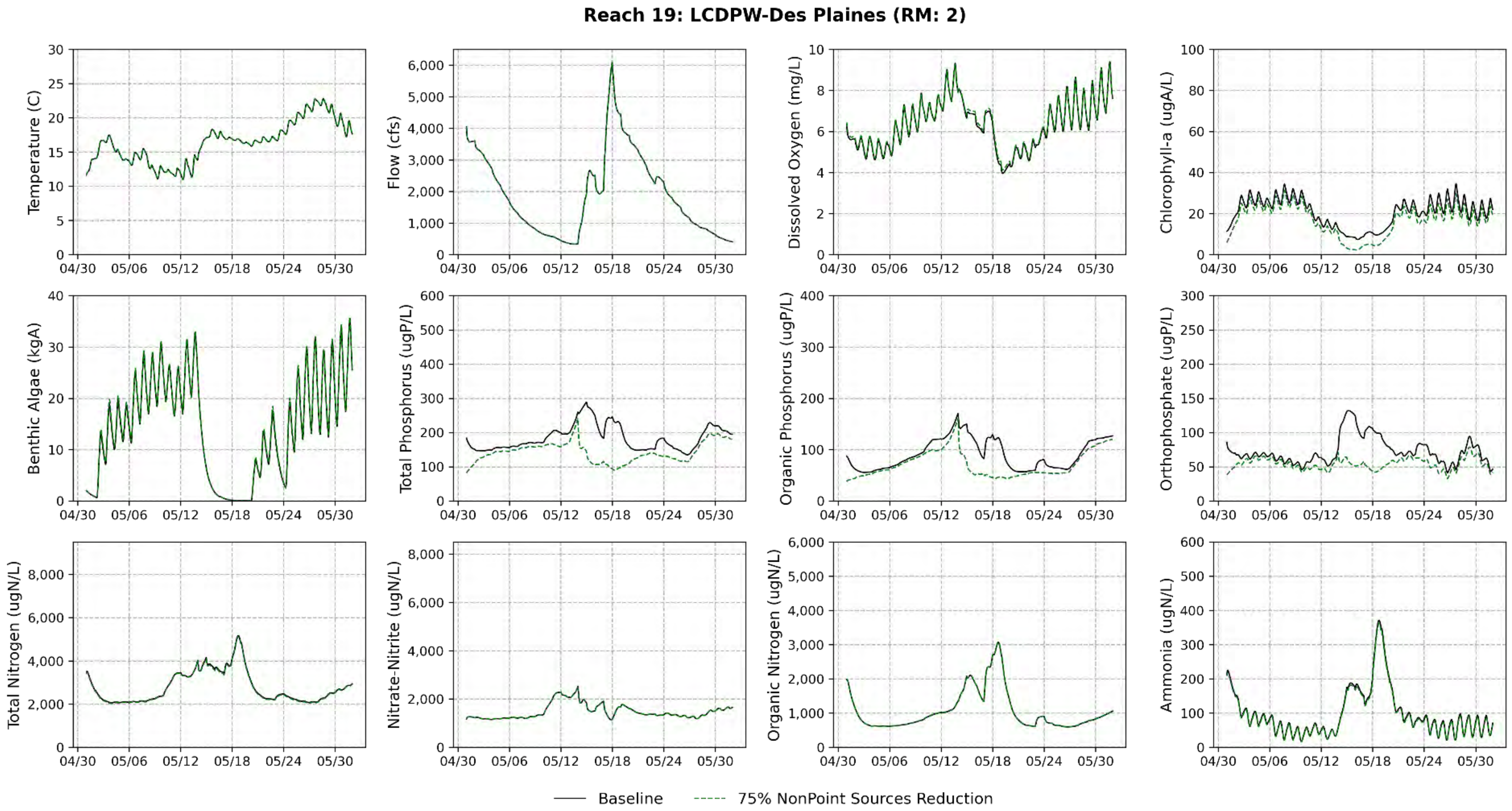


# Baseline and 75% Nonpoint Reduction
# 5/1 – 31, 2020



# POTW Reductions

# Low DO Period: July 10-17

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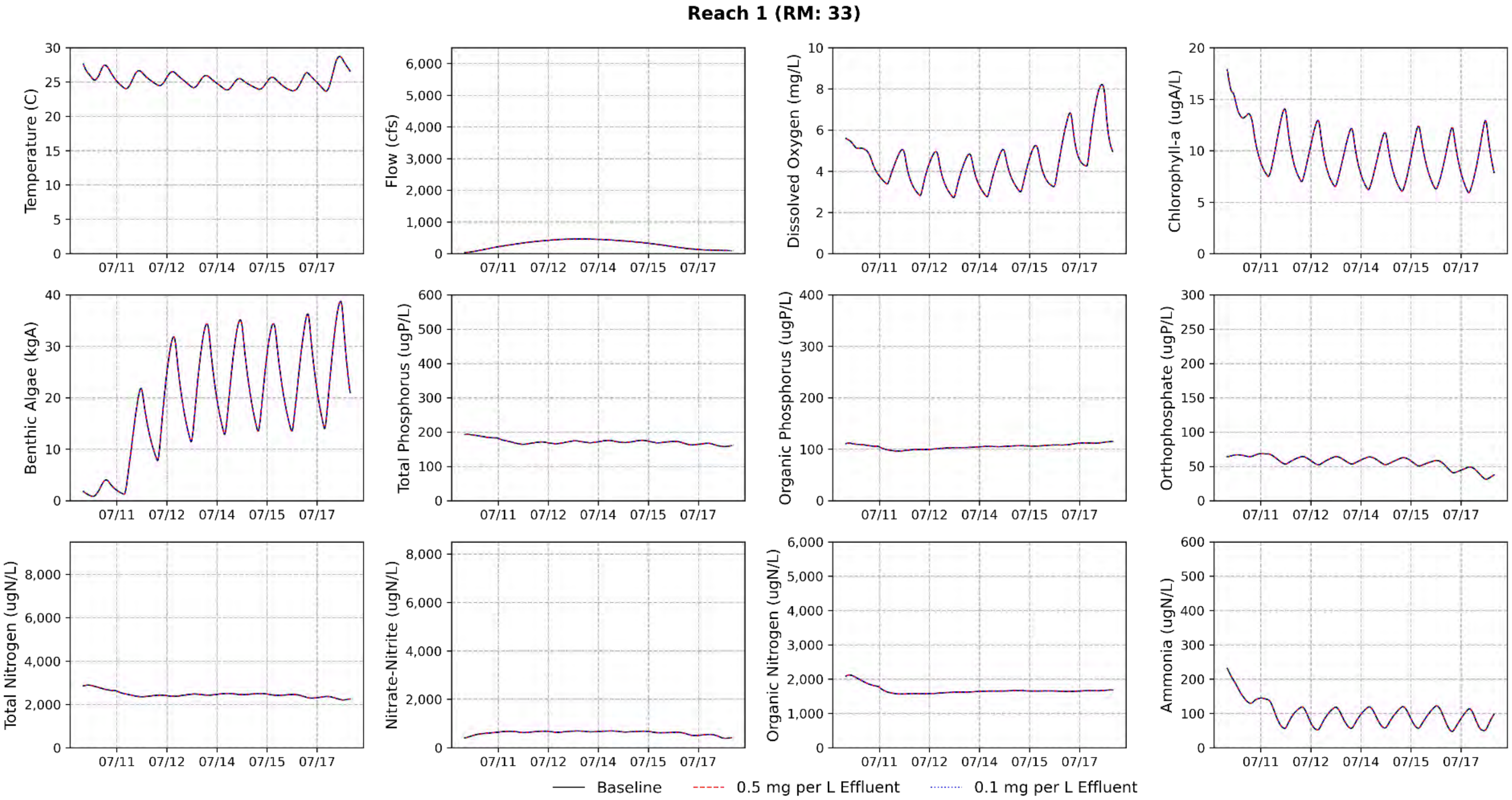
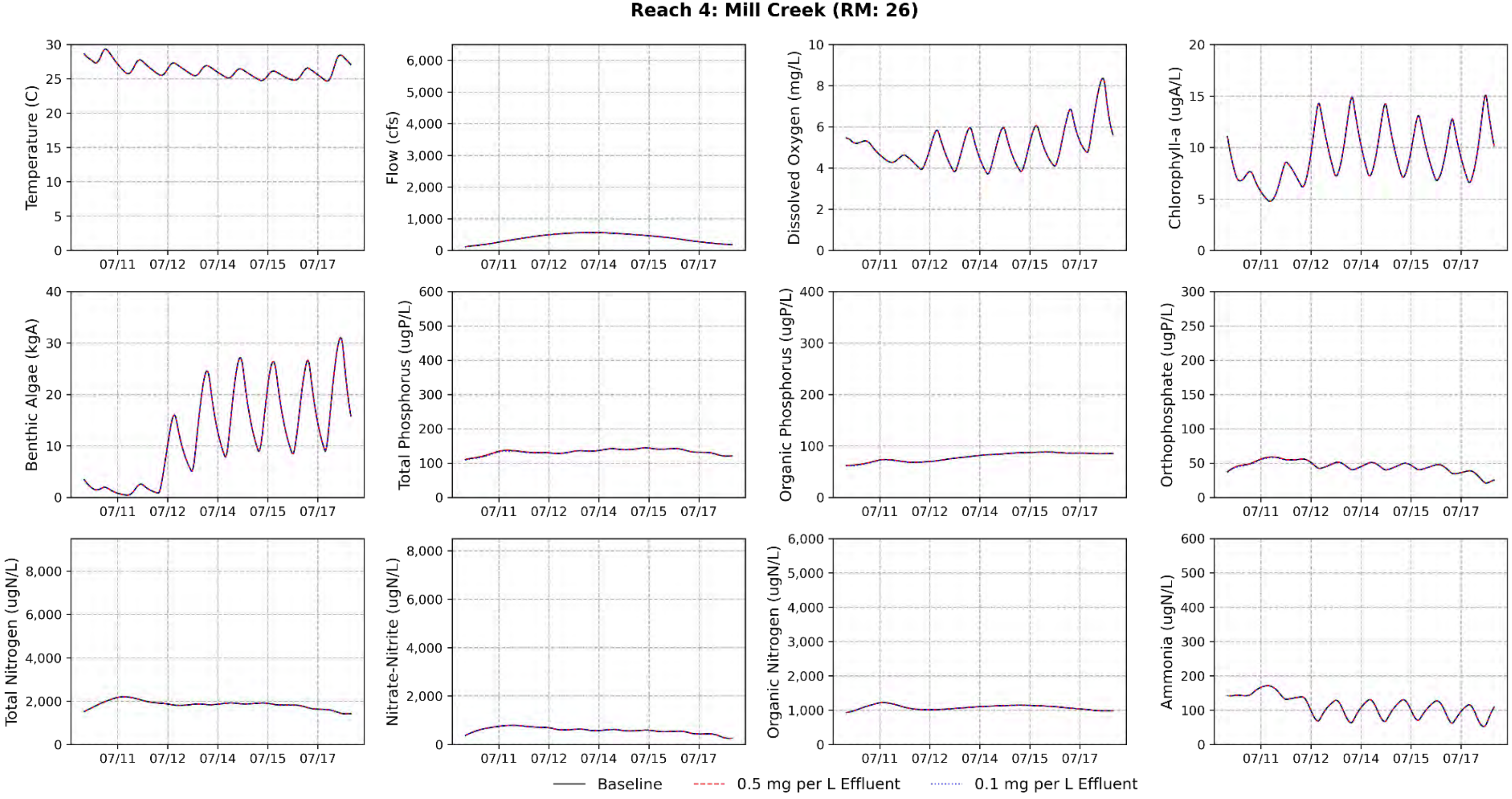
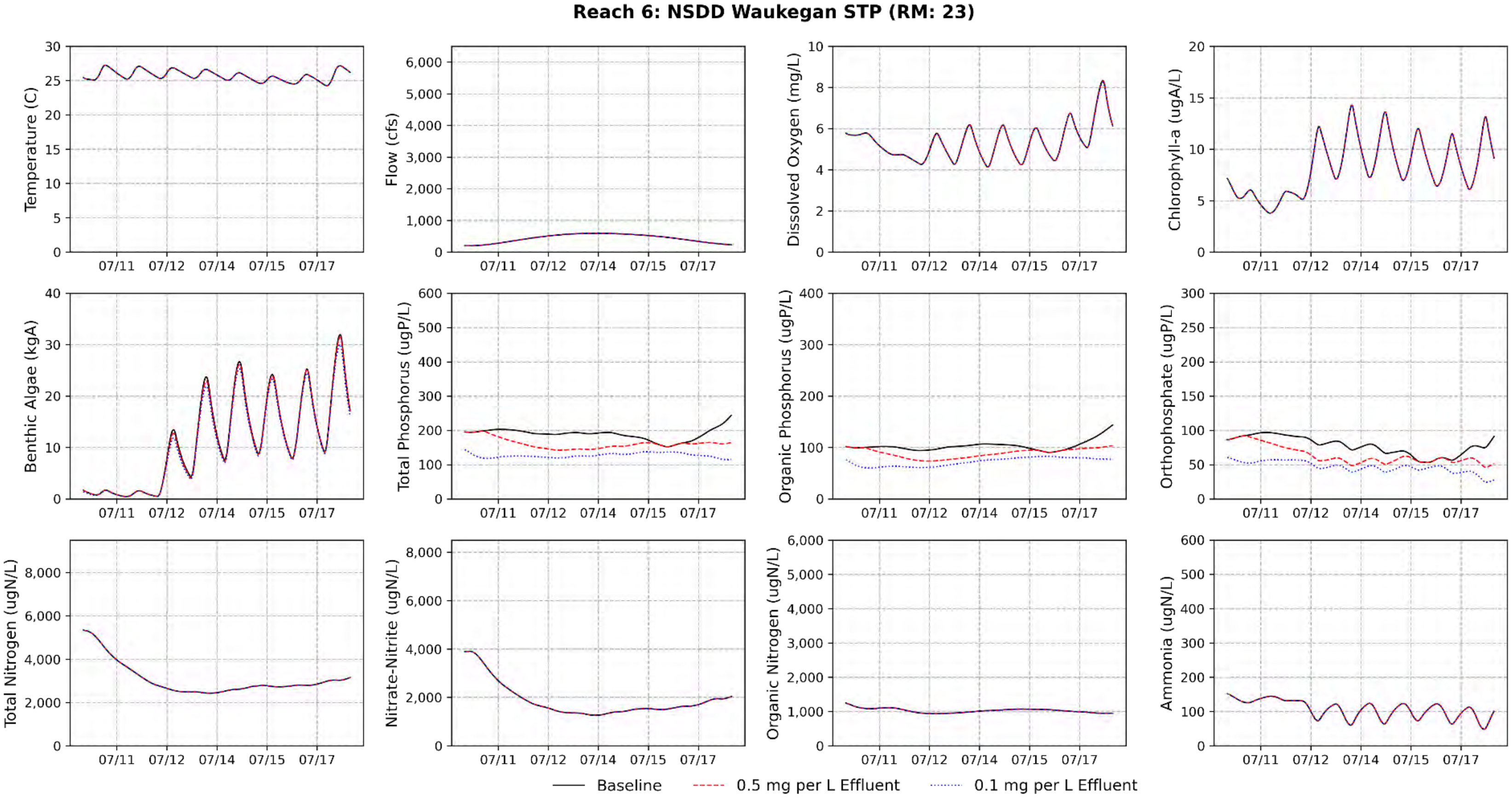
# Baseline and POTWs Reduction
# 7/10 – 17, 2020



# Baseline and POTWs Reduction 7/10 – 17, 2020



# Baseline and POTWs Reduction 7/10 – 17, 2020



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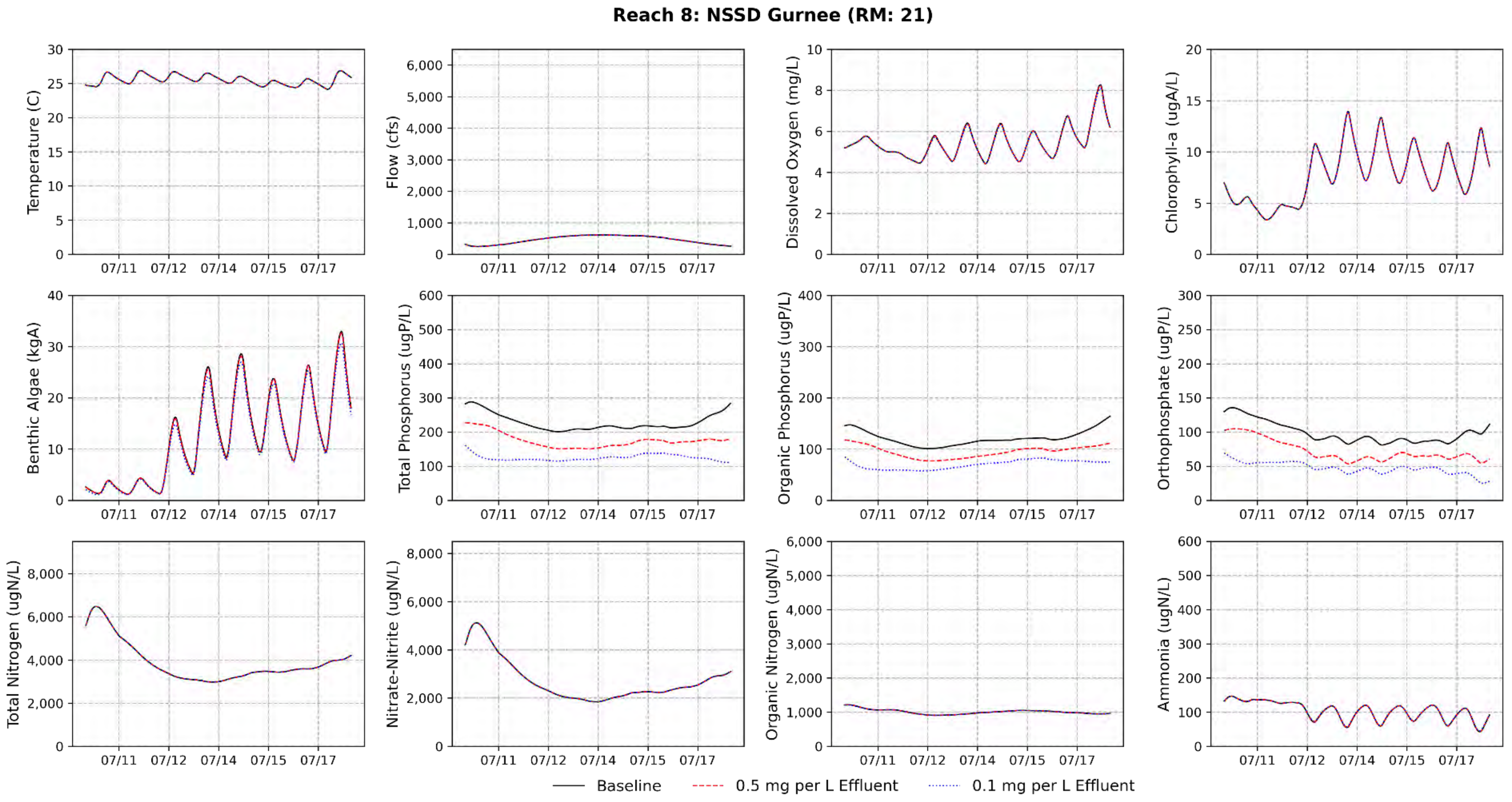

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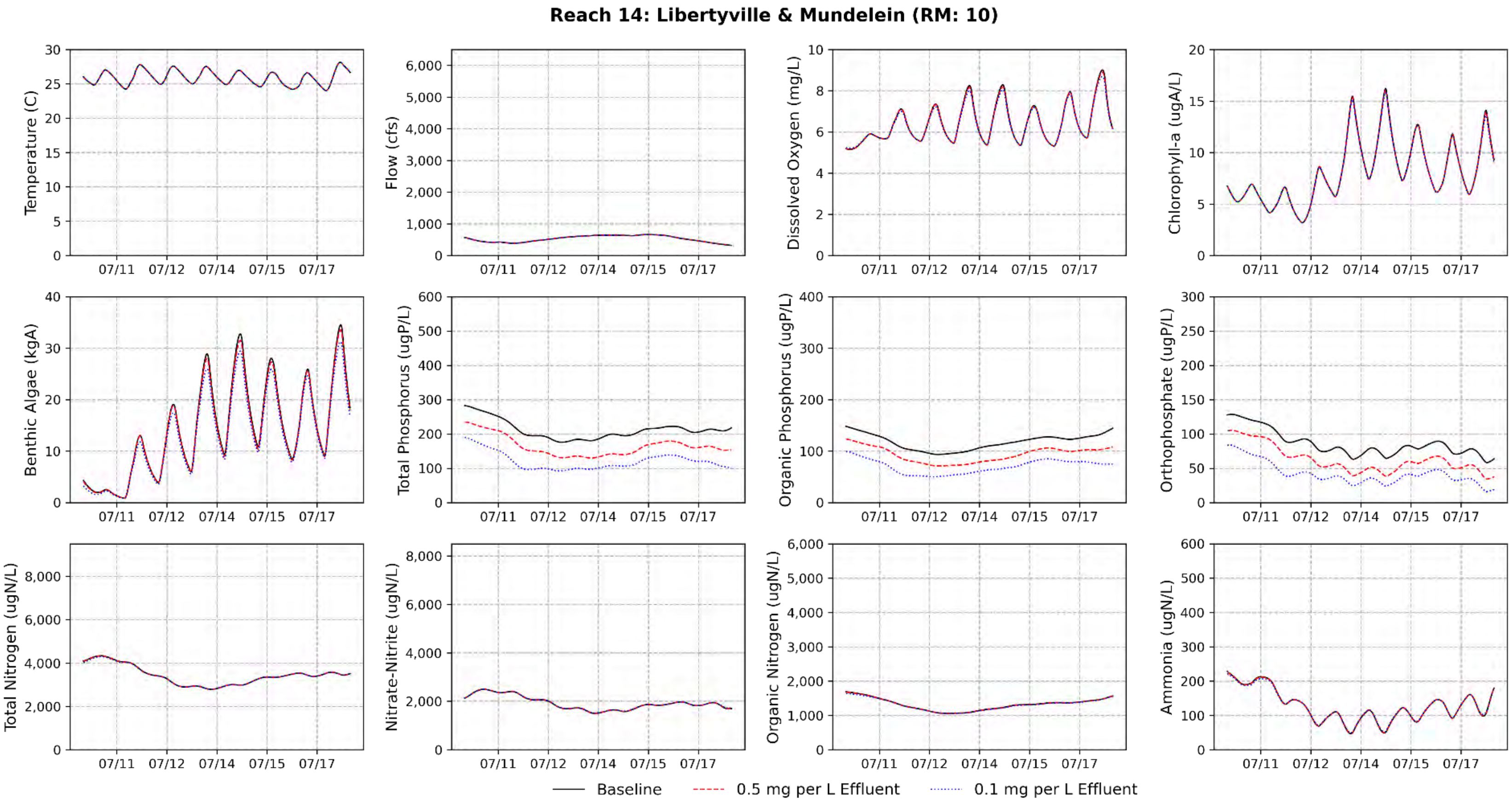
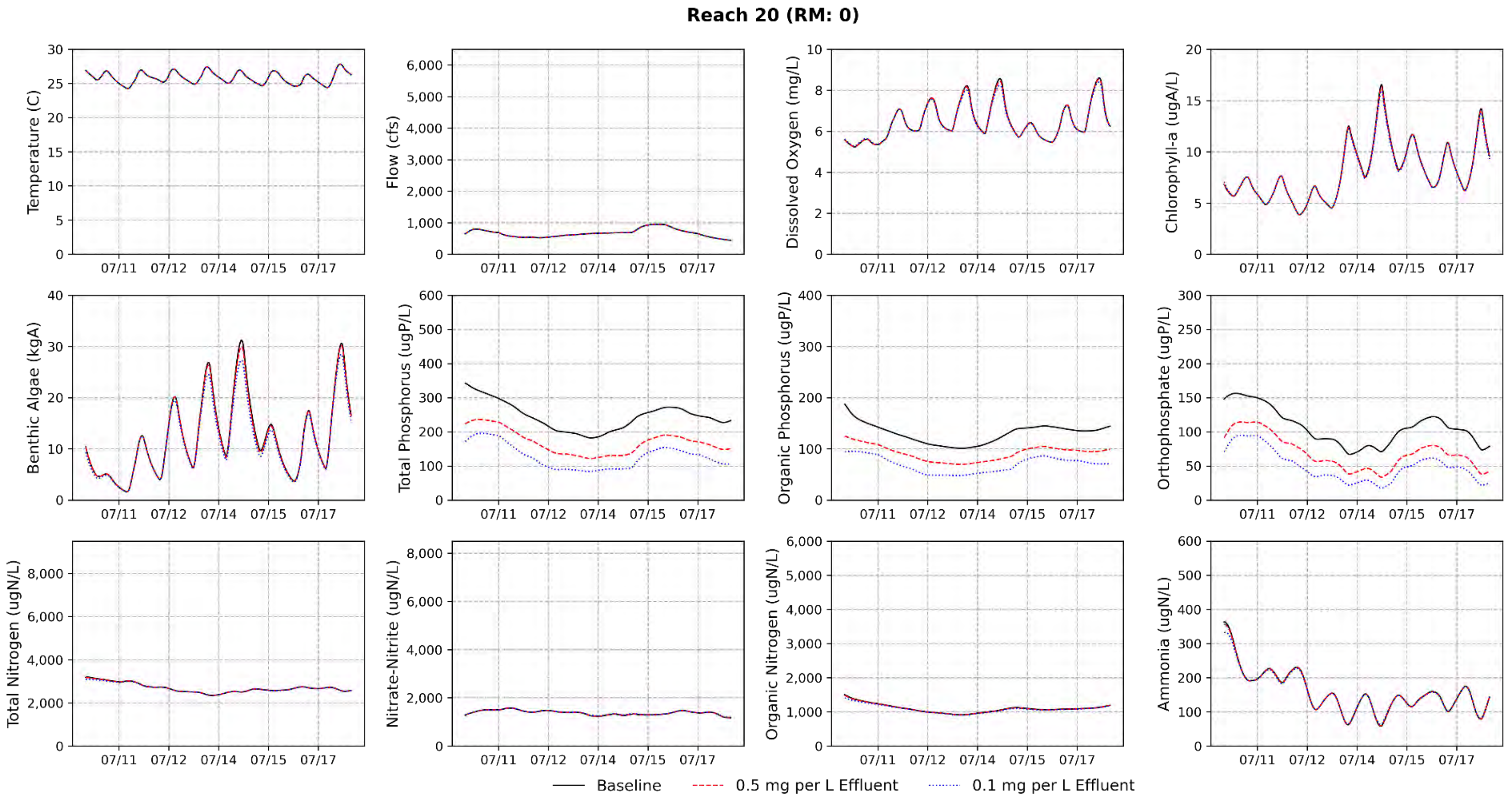
# 7/10 – 17, 2020



# Baseline and POTWs Reduction
# 7/10 – 17, 2020



# High Flow Period: May 1-31

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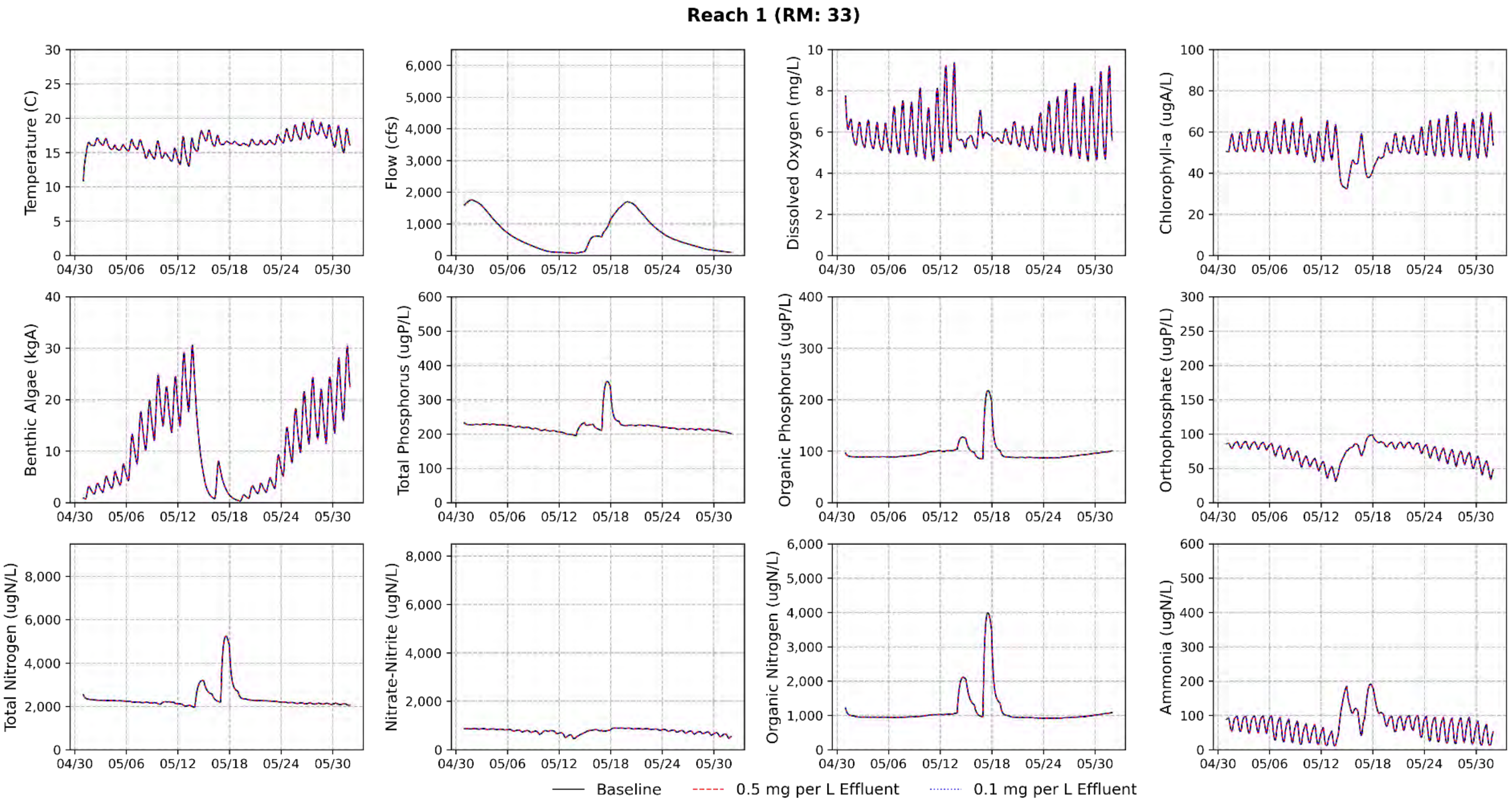
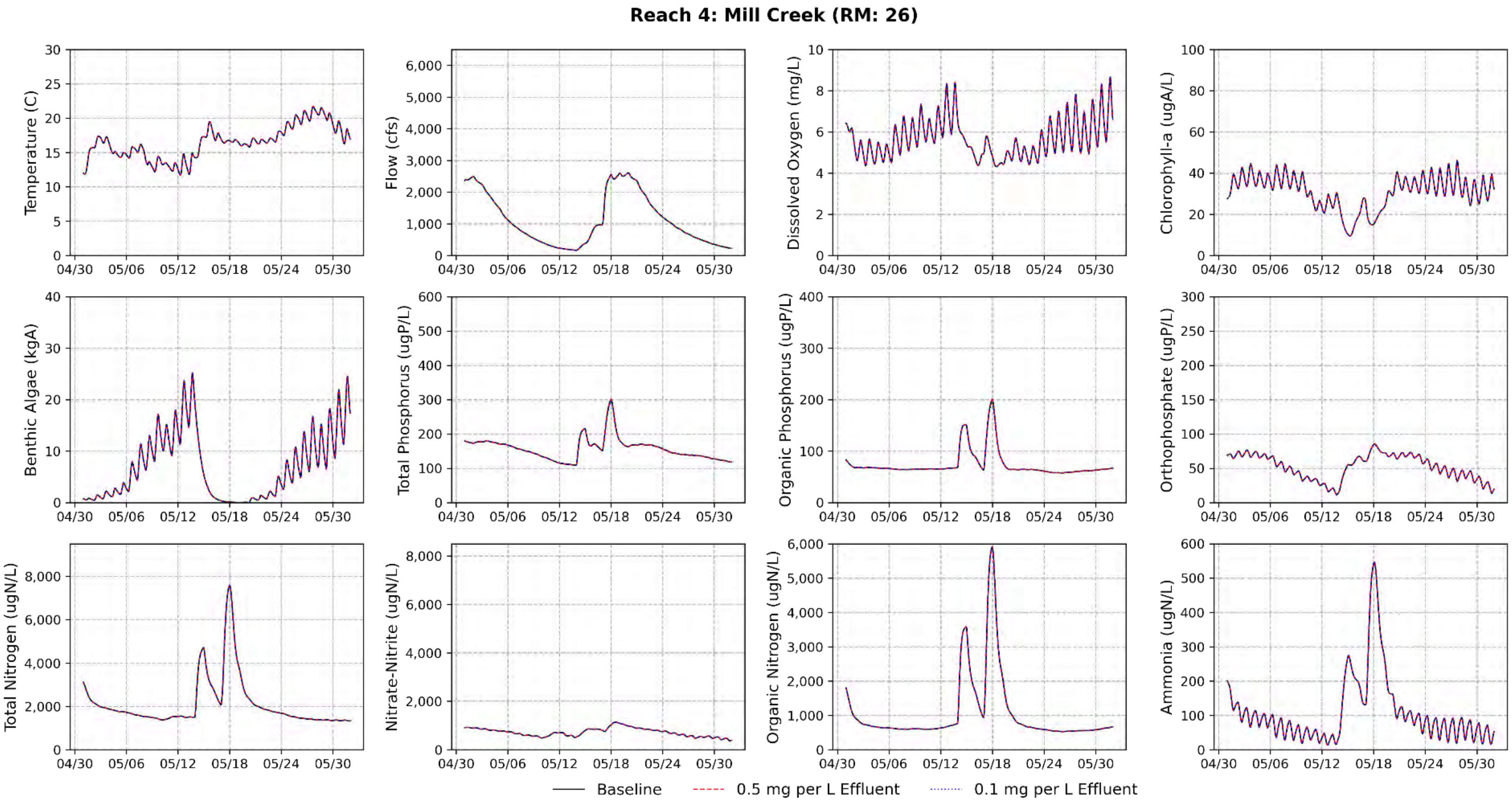
# Baseline and POTWs Reduction 5/1 – 31, 2020



# Baseline and POTWs Reduction
# 5/1 – 31, 2020



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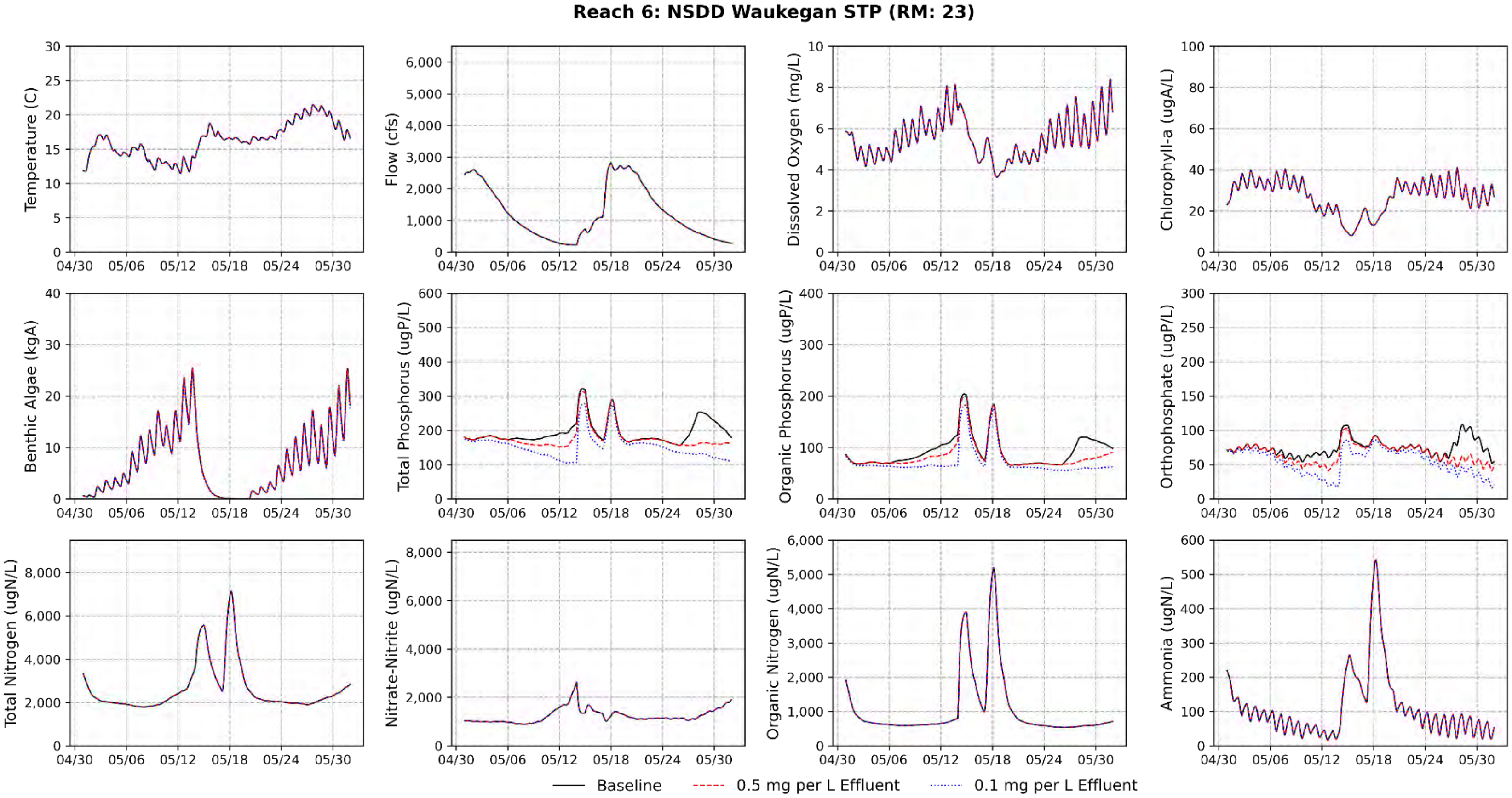
# 5/1 – 31, 2020



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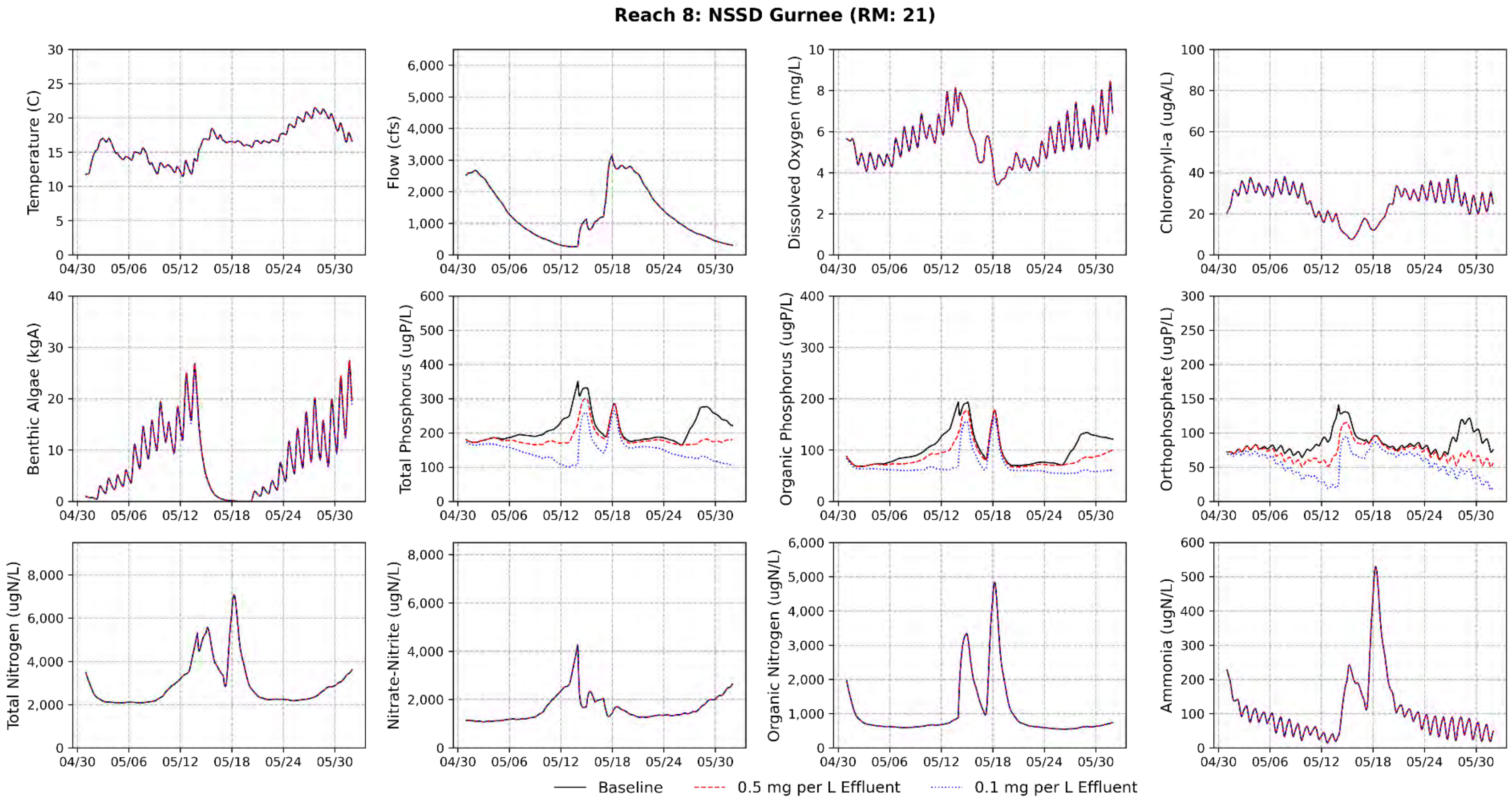
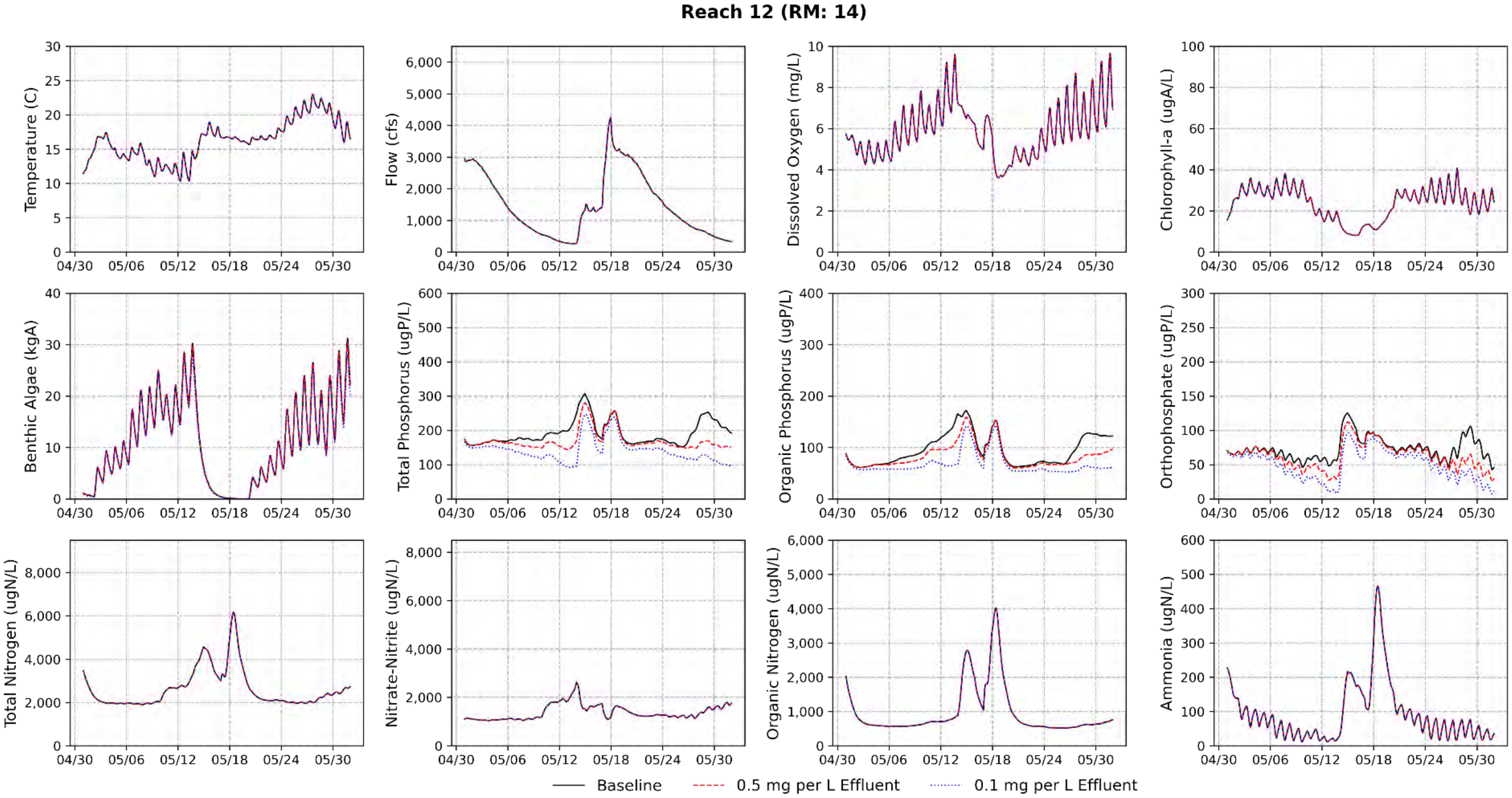
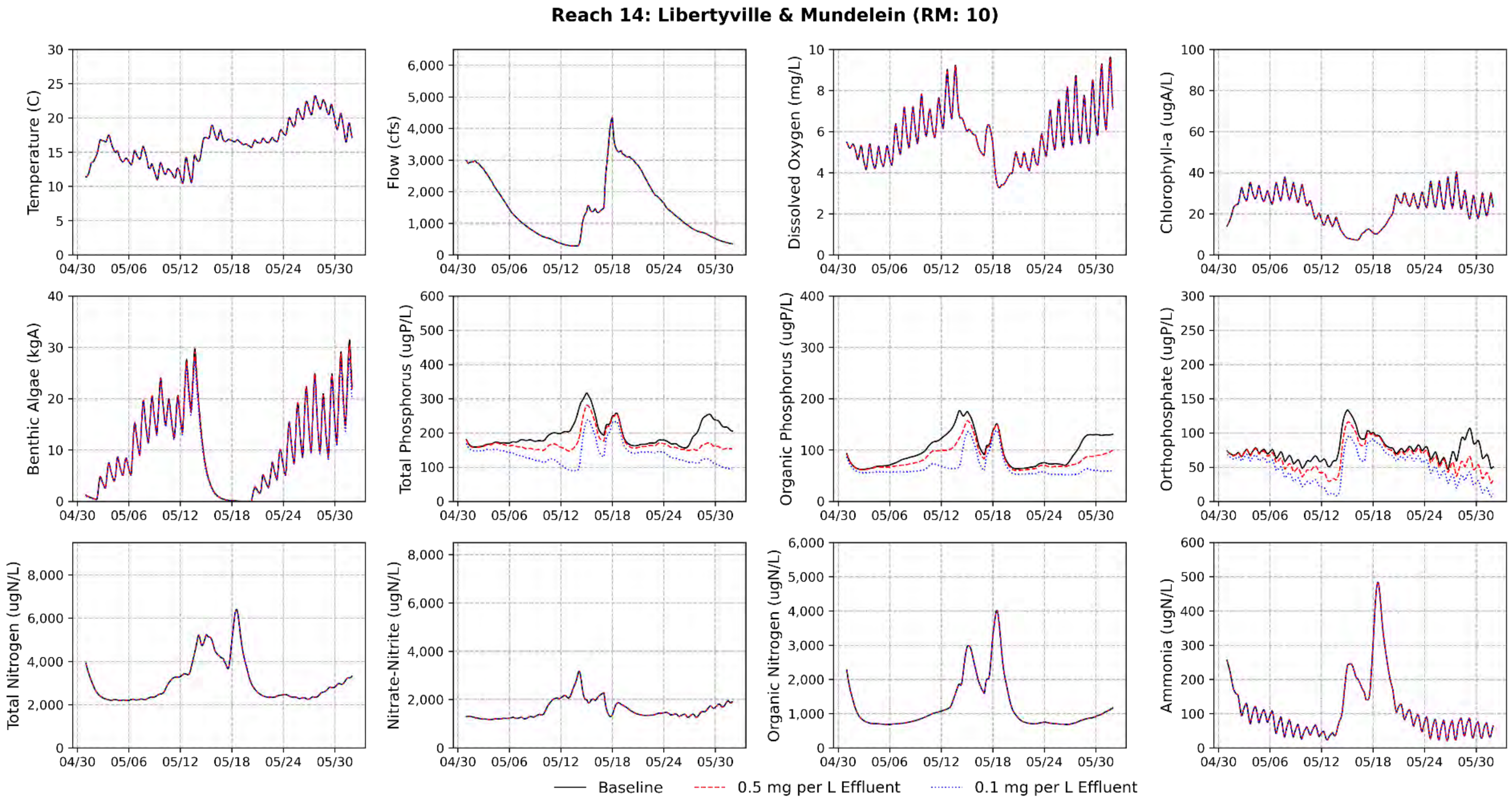


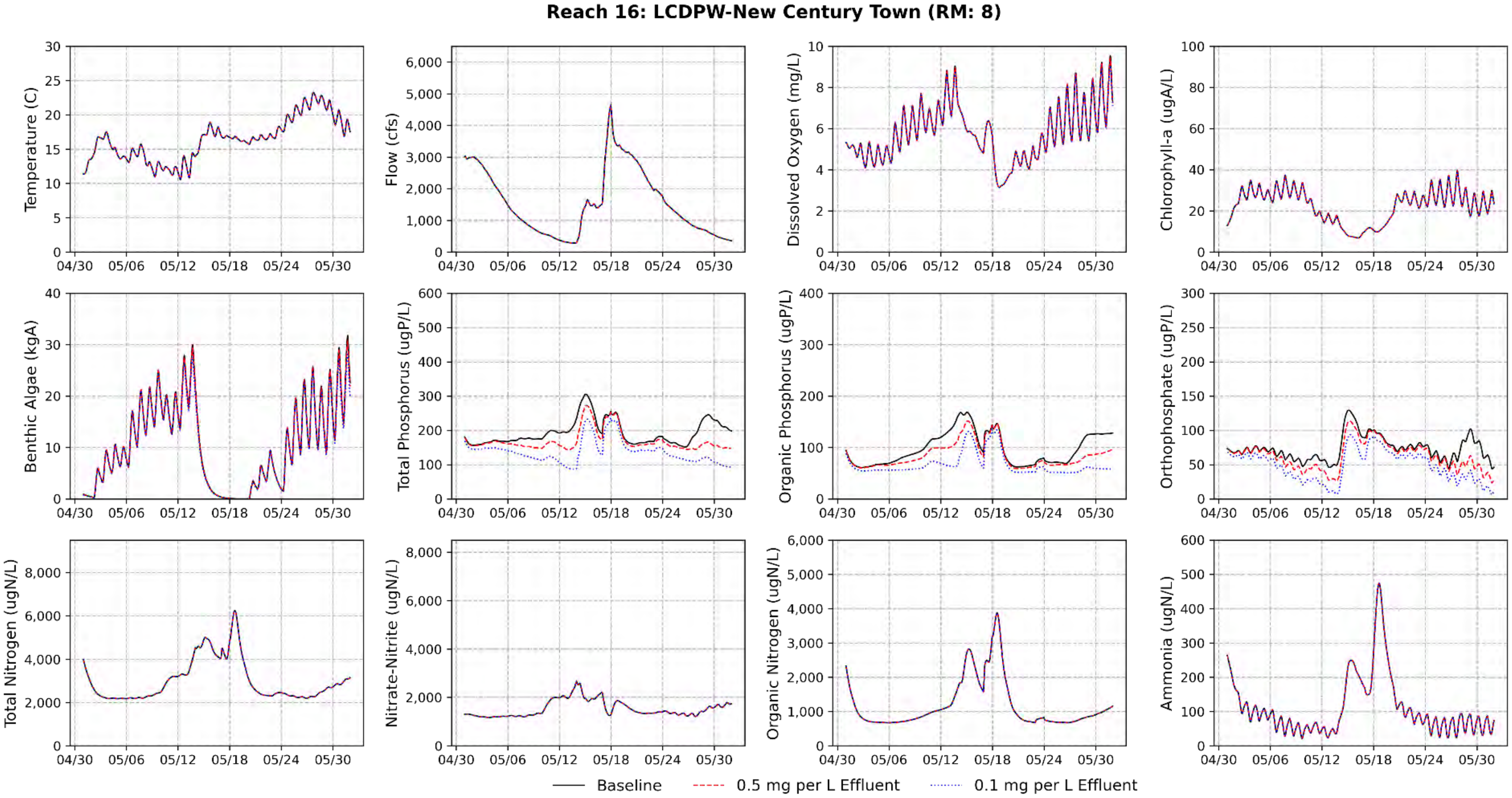
# Baseline and POTWs Reduction 5/1 – 31, 2020



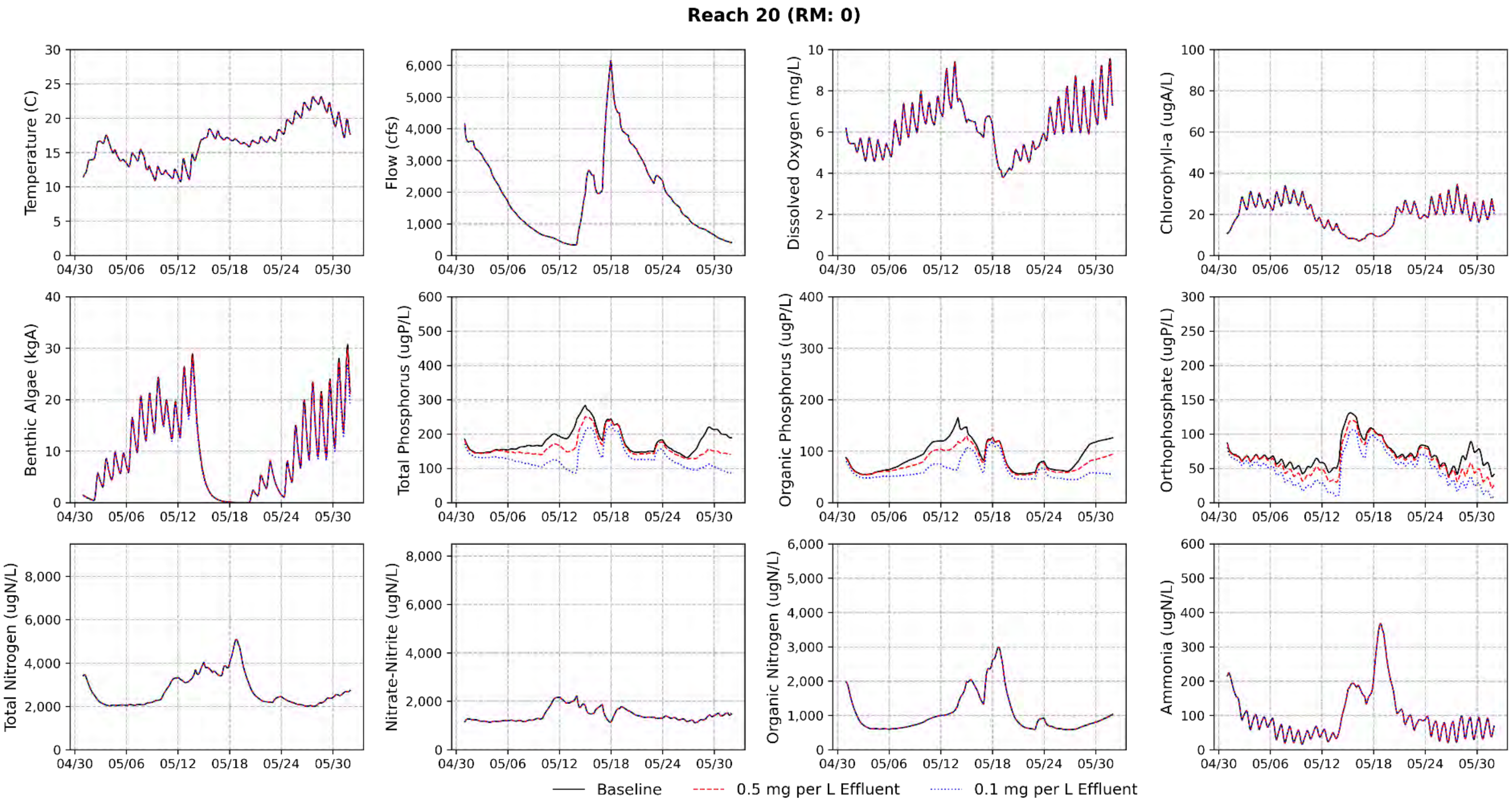
# Baseline and POTWs Reduction
# 5/1 – 31, 2020



# Baseline and POTWs Reduction 5/1 – 31, 2020



# Baseline and POTWs Reduction 5/1 – 31, 2020



# Chlorophyll-a Increase with Reduced Effluent Phosphorus

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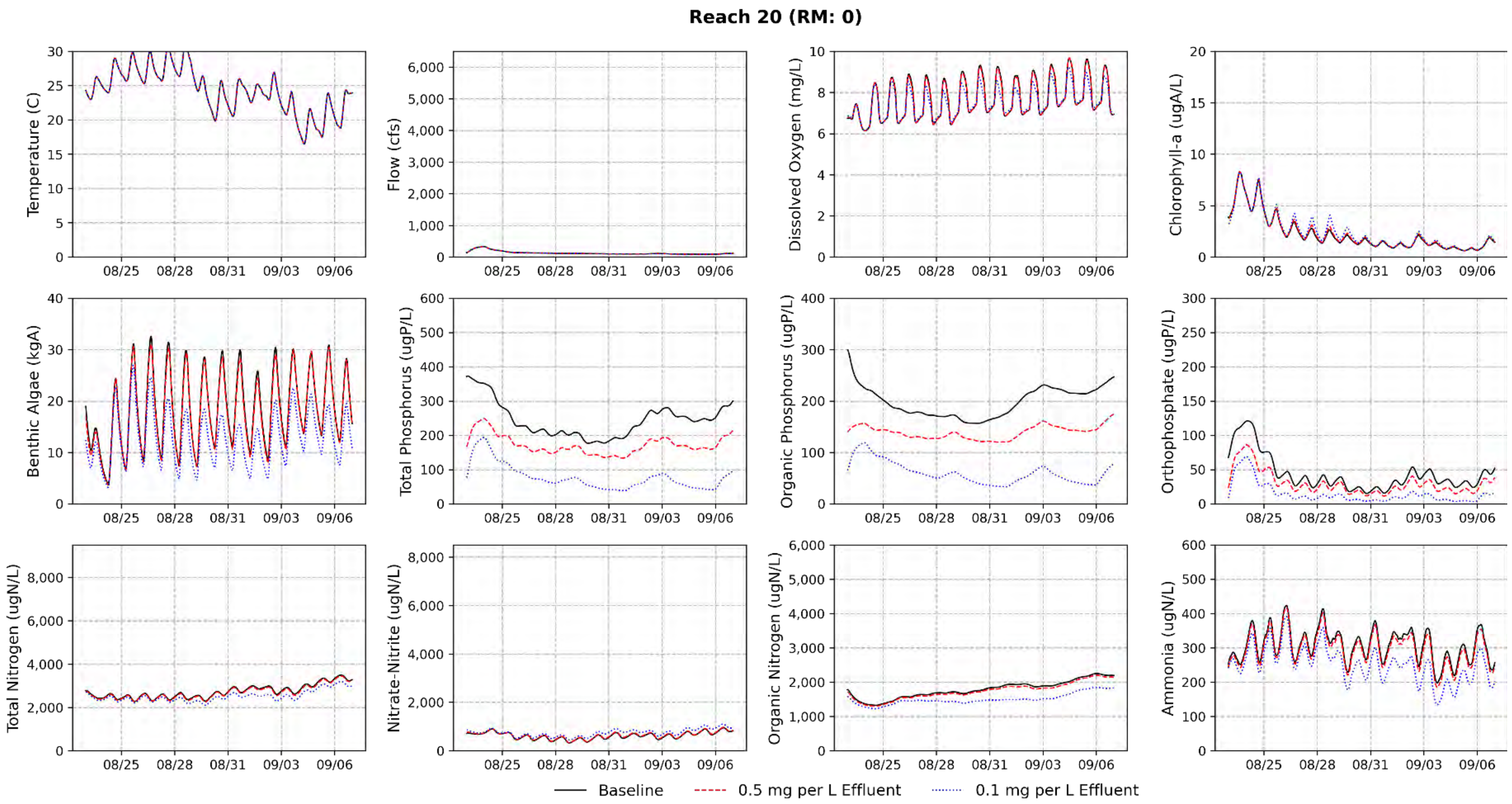
# Chlorophyll-a Increase with Reduced Phosphorus



# Chlorophyll-a Increase with Reduced Phosphorus

- Basic ecological principles
  - Sestonic Chla has a greater competitive advantage over benthic algae
    - Sestonic Chla can grow and reproduce quicker than benthic algae → have competitive advantage when nutrients are limited

*Zhang, X., Mei, X., Gulati, R. D., & Liu, Z. (2015). Effects of N and P enrichment on competition between phytoplankton and benthic algae in shallow lakes: a mesocosm study. Environmental Science and Pollution Research, 22(6), 4418-4424.*

# Chlorophyll-a Increase with Reduced Phosphorus

- Basic ecological principles
  - As TP decreases, algae might start using inorganic forms of nitrogen (e.g., ammonia and nitrate)
  - In Qual2kw, when Ammonia Preference is turned on, it allows algae to start utilizing ammonia when phosphorus is limited

# Attachment 6

Combined Scenarios Results PowerPoint Presentation (March 16, 2023)

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# Des Plaines River Watershed Workgroup
# NARP: Combined Scenarios

March 16, 2023

# Agenda

- Key takeaways from individual scenarios
- List of combined scenarios
- Combined scenario model results
  - Periods selected for comparison
  - Modeling approach
  - Main takeaways
  - Detailed results
- Next steps

# Key Takeaways from Individual Scenarios

- Takeaway #1: Upstream total phosphorus (TP) reduction
  - Reduces sestonic chlorophyll-a (Chl-a) and
  - Improves dissolved oxygen (DO) following large flow events

- Takeaway #2: Tributary TP reductions reduce sestonic Chl-a but have minimal impact on DO

- Takeaway #3: Publicly owned treatment works (POTW) TP reductions have minimal impact on water quality

# List of Combined Scenarios

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# List of Combined Scenarios

- Scenario #1: 50% Upstream, 25% Nonpoint sources, 0.5 mg/L POTWs effluent TP

- Scenario #2: 25% Upstream, 25% Nonpoint sources, 0.5 mg/L POTWs effluent TP

# Selected Periods for Comparison

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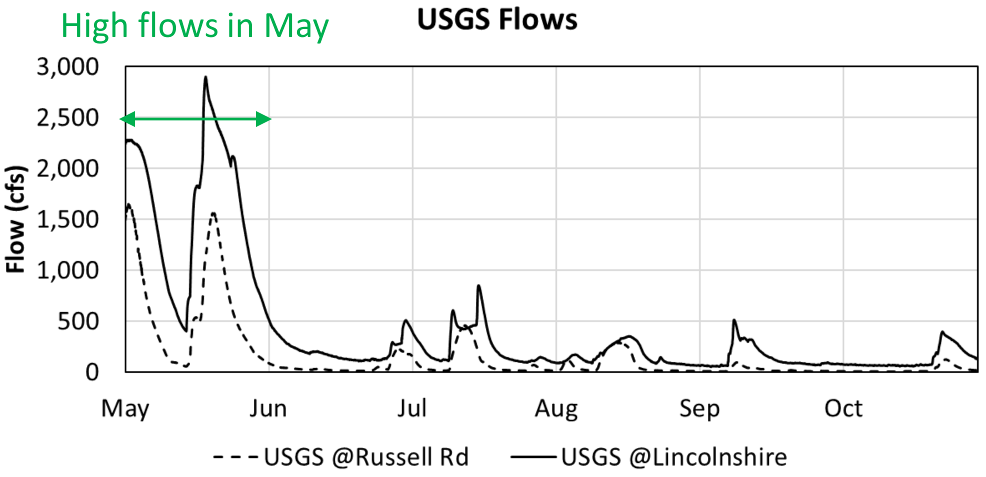
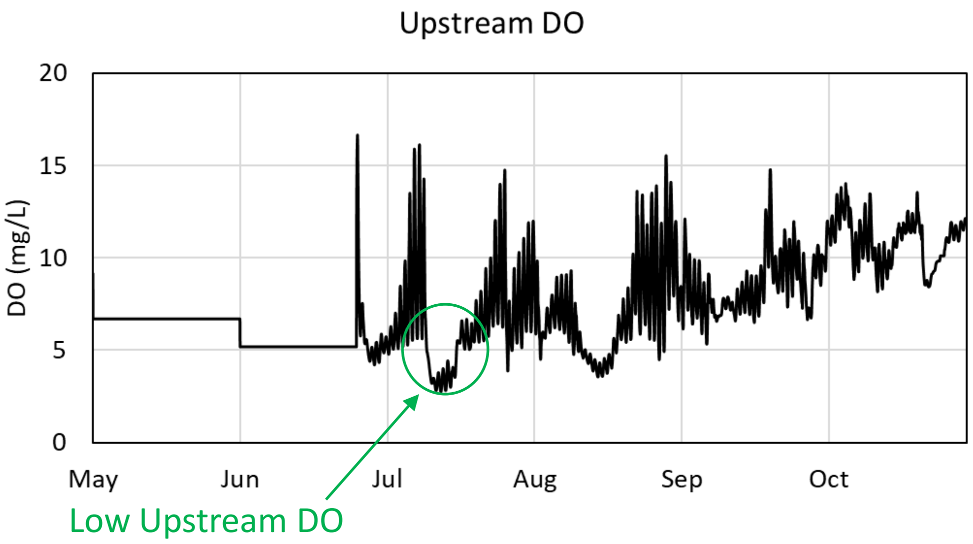
# Selected Periods

- Based on calibrated existing condition model
  - Presented to Monitoring Committee on 11-7-2022

- Simulation period
  - Growing Season
    - May 1 - Oct. 31, 2020

- Periods selected for comparison
  - Growing season
  - Low DO Period: Jul.10 –17
  - High Flow Period: May 1 – 31



# Modeling Approach

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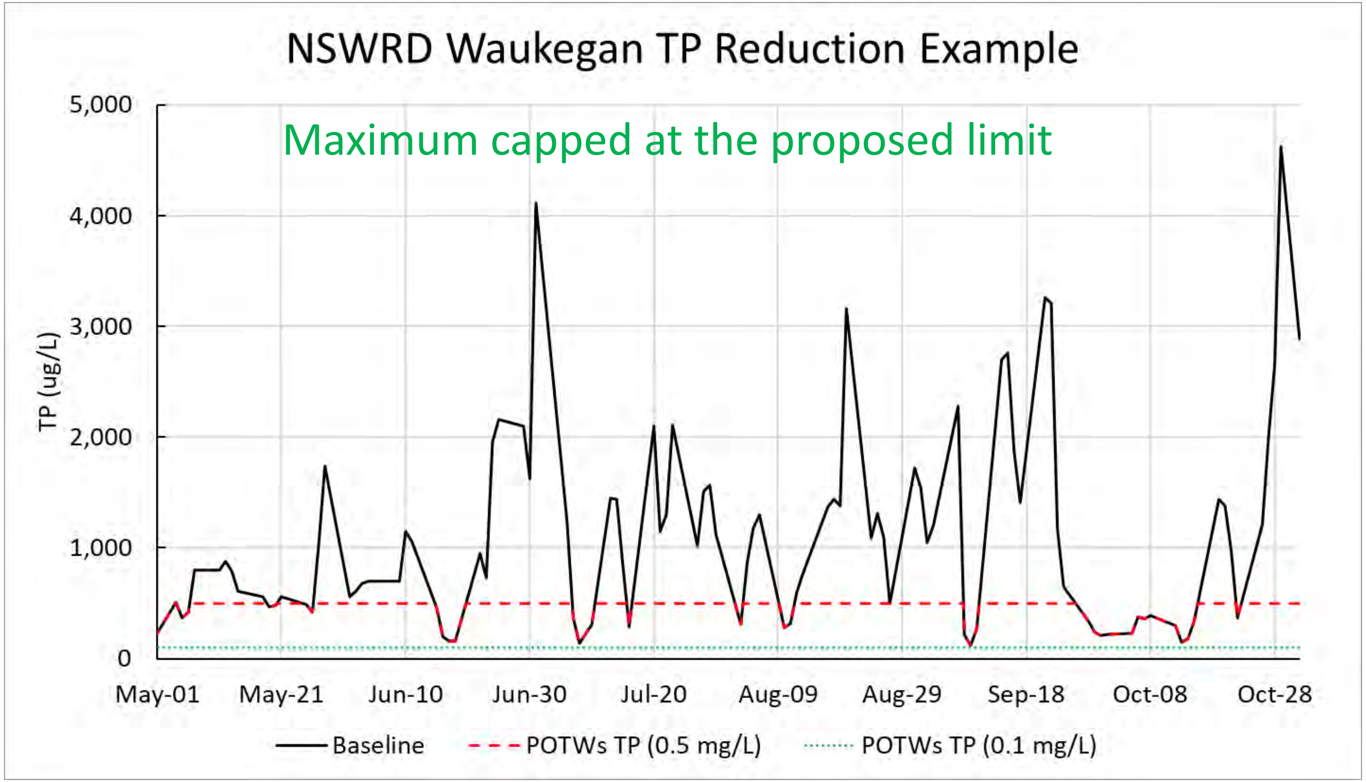
# POTW Reduction Modeling Approach

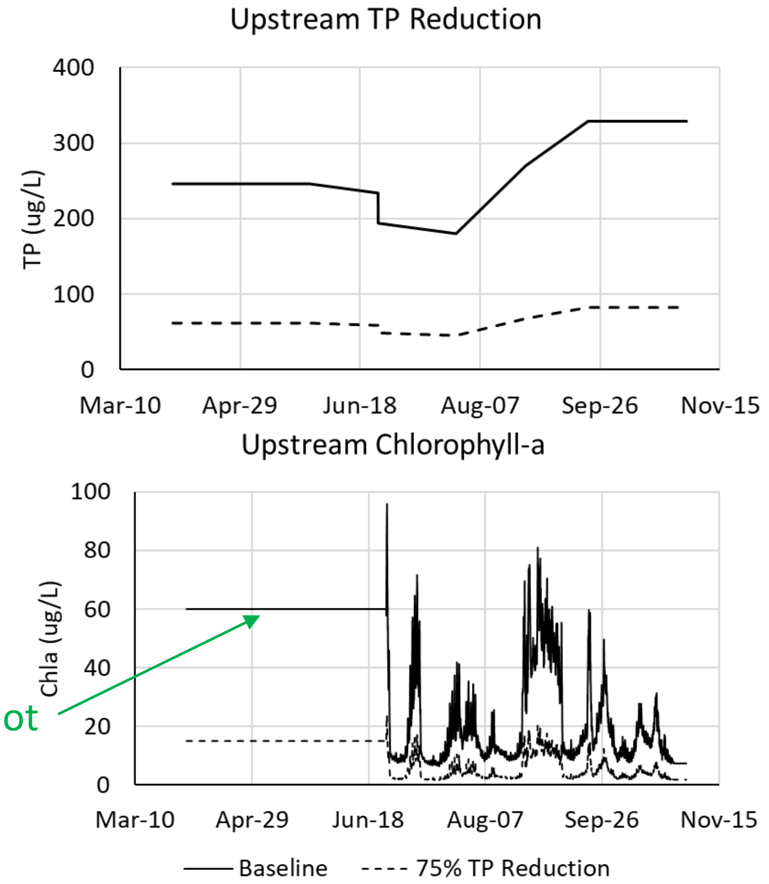
- POTW phosphorus reduction (0.5 mg/L)



# Nonpoint Sources and Upstream Boundary Reduction Approach

- Applied the TP reduction to the three TP components:
  - Organic P
  - Inorganic P
  - Internal P based on the model ratio (Chl-a: P → 1:1)

Upstream Chl-a data was not available for this period



# Combined Scenario Results

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# Key Takeaways

- TakeTakeaway #1: The low DO impairment in the upper reaches of the river is not improved by phosphorus-related control measures

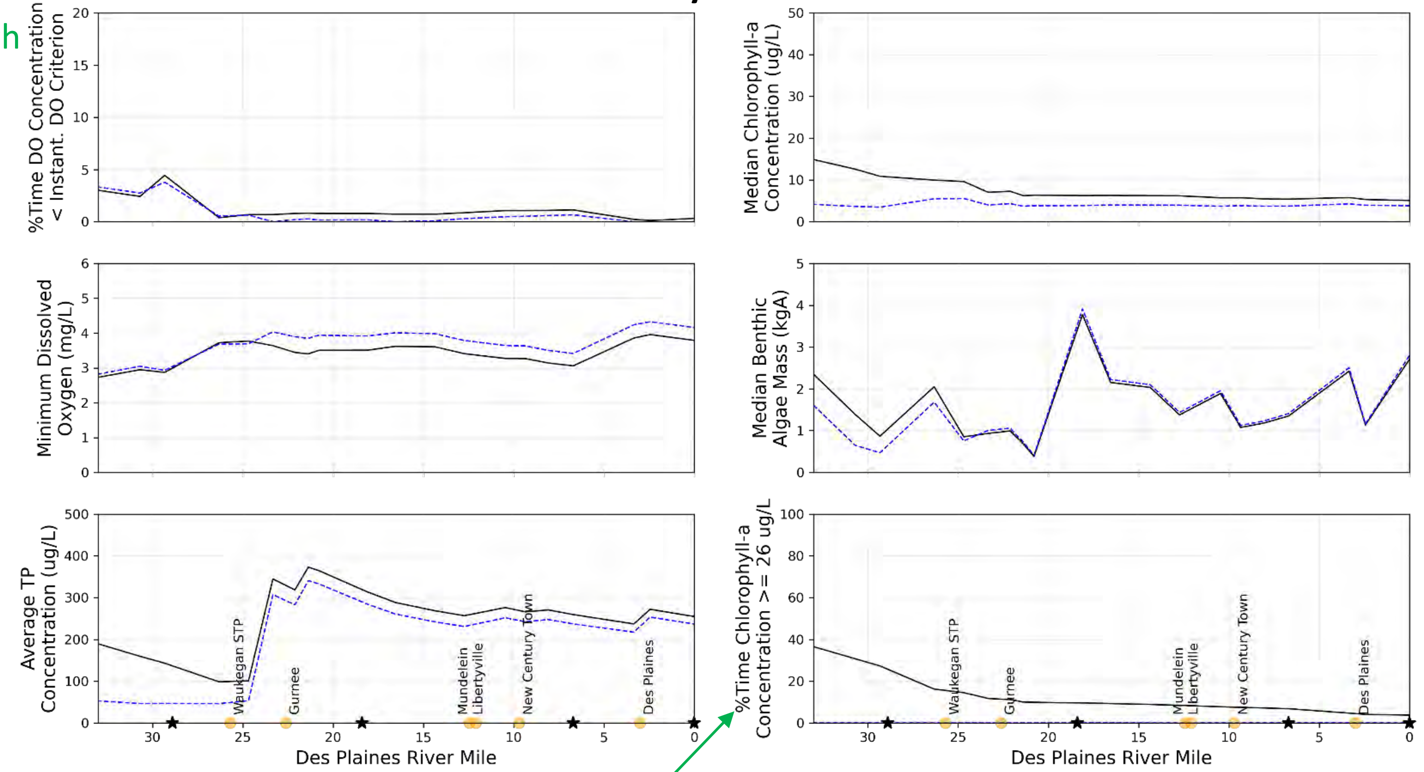
- away #2: Combining upstream and nonpoint source reductions with a 0.5 mg/L POTW effluent limit improves DO by reducing instream TP and Chl-a

- Takeaway #3: Further reducing upstream TP and  Chl-a leads to improved DO during high flow period (May 2020) when Chl-a was high

# Results Presentation Format

Analysis period (growing season, low DO period, or high flow period)

**Analysis Period**




WWTP

Tributaries

Baseline

0.5 mg/L POTWs effluent, 50% Upstream, and 25% Nonpoint Sources Reduction

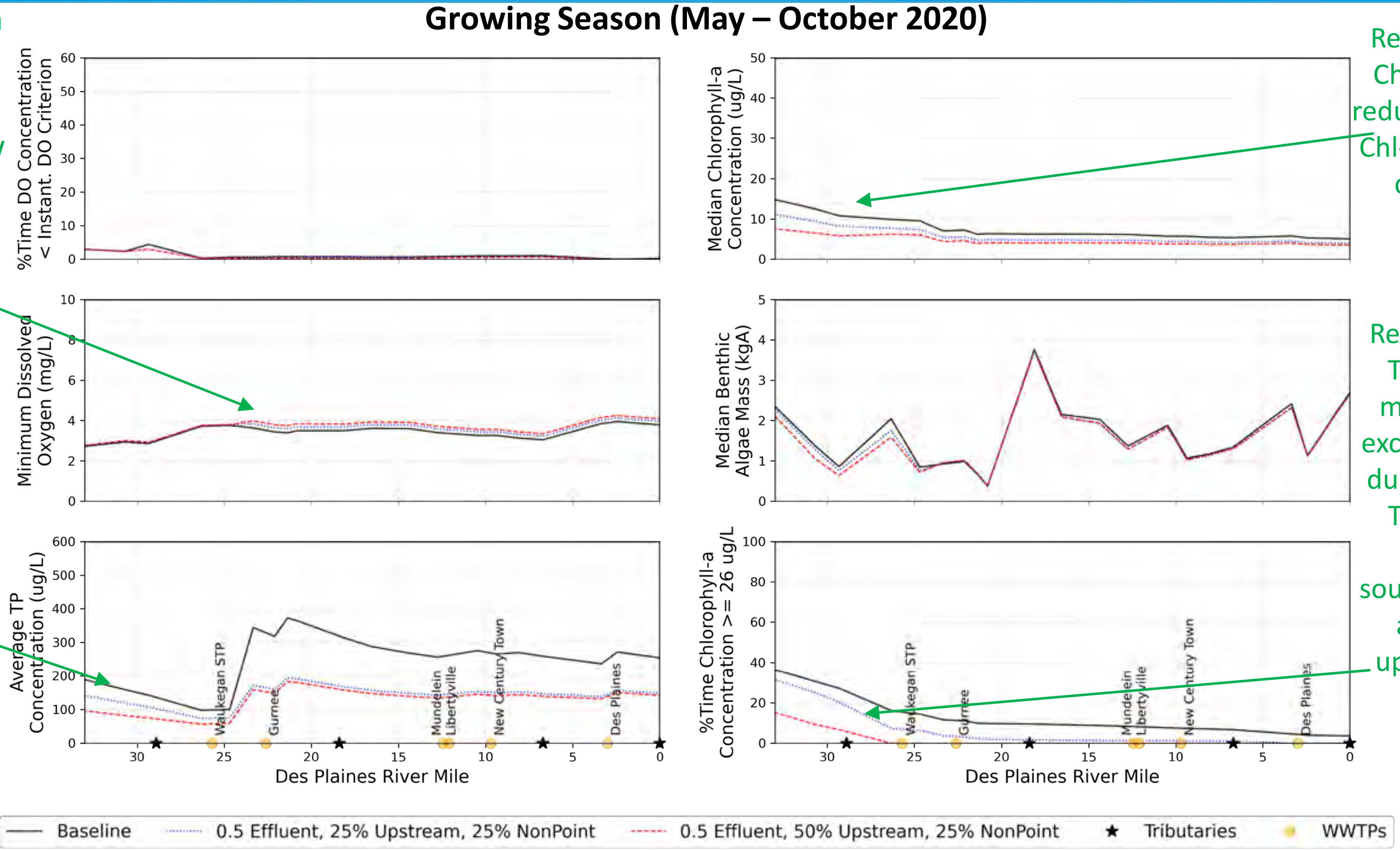
0.5 mg/L POTWs effluent, 25% Upstream, and 25% Nonpoint Sources Reduction

For comparing scenarios, not a “threshold”

# Combined Scenarios Results: Longitudinal Plots

Improvement in minimum DO after RM 25 during high flow periods due to reduced DO swings with reduced upstream Chl-a and increased benthic algae

Reduction in instream TP due to reduced TP from the different sources




Reduction in Chl-a due to reduced TP and Chl-a from the different sources

Reduction in % Time where median Chl-a exceeds 26 ug/L due to reduced TP from the different sources and Chl-a from the upstream and nonpoint sources

# Combined Scenarios Results: Longitudinal Plots

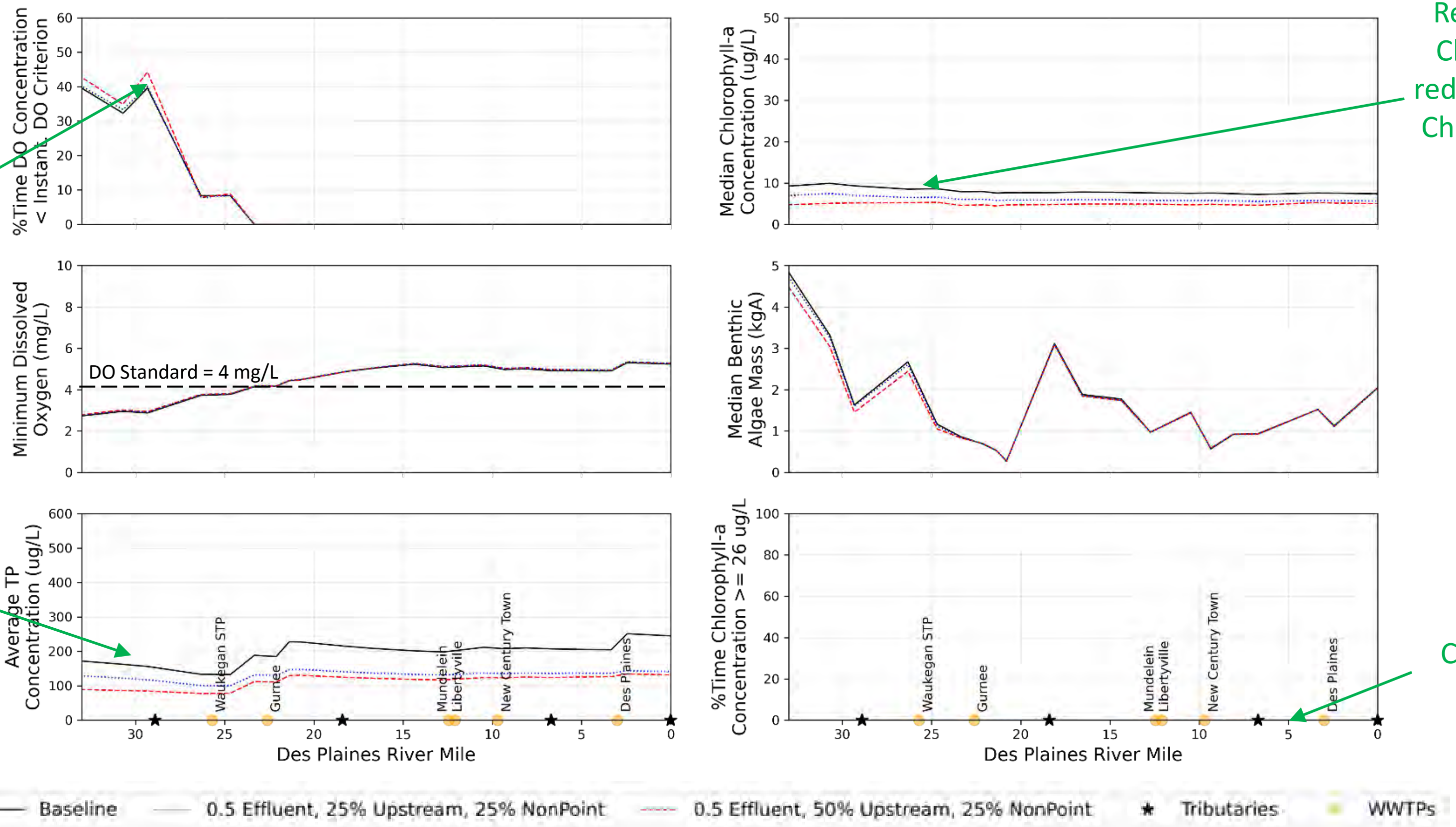
**Low DO Period: July 10 – 17, 2020**

Increase in %Time DO less than the criterion due to reduced upstream TP resulting in reducing Chl-a and benthic algae production

Reduction in Chl-a due to reduced TP and Chl-a from the different sources

Reduction in instream TP due to reduced TP from the different sources

Chla is not > 26 ug/L



# Combined Scenarios Results: Longitudinal Plots

**High Flow Period: May 1 – 31, 2020**

High upstream Chla at the upstream

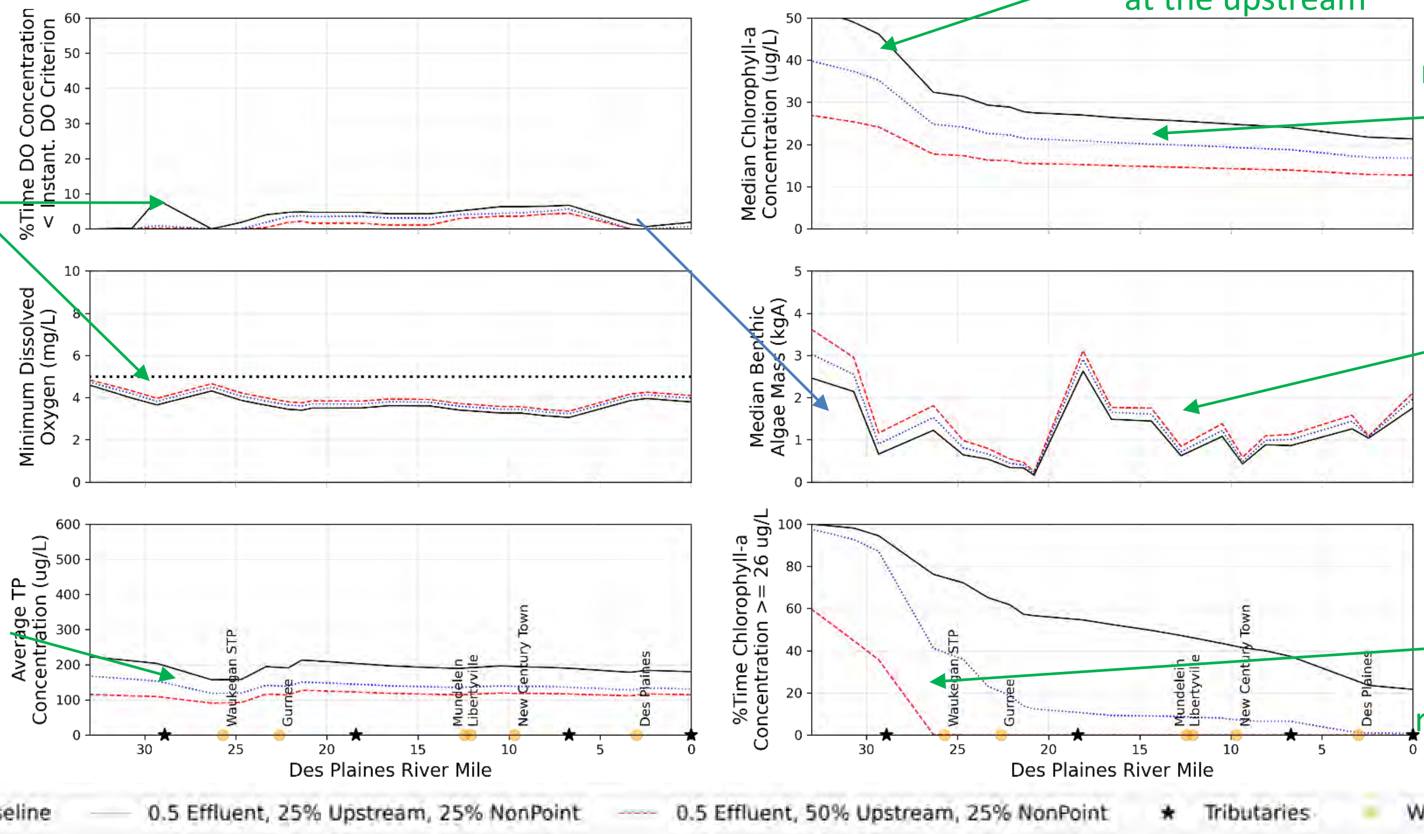
DO improvement due to reduced Chl-a

Substantial reduction in Chl-a due to reduced upstream TP and Chl-a

Increased benthic algae due to reduced upstream TP and Chl-a

Reduction in instream TP due to reduced TP from the different sources

Substantial reduction in %Time Chl-a is > 26 ug/L due to reduced upstream TP and Chl-a



# Key Takeaways

- TakeTakeaway #1: The low DO impairment in the upper reaches of the river is not improved by phosphorus-related control measures

- away #2: Combining upstream and nonpoint source reductions with a 0.5 mg/L POTW effluent limit improves DO by reducing instream TP and Chl-a

- Takeaway #3: Further reducing upstream TP and  Chl-a leads to improved DO during high flow period (May 2020) when Chl-a was high

# Next Steps

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# Next Steps

- Address comments
- Prepare model documentation
- Present results to Illinois EPA
- Prepare NARP implementation plan

# Questions?

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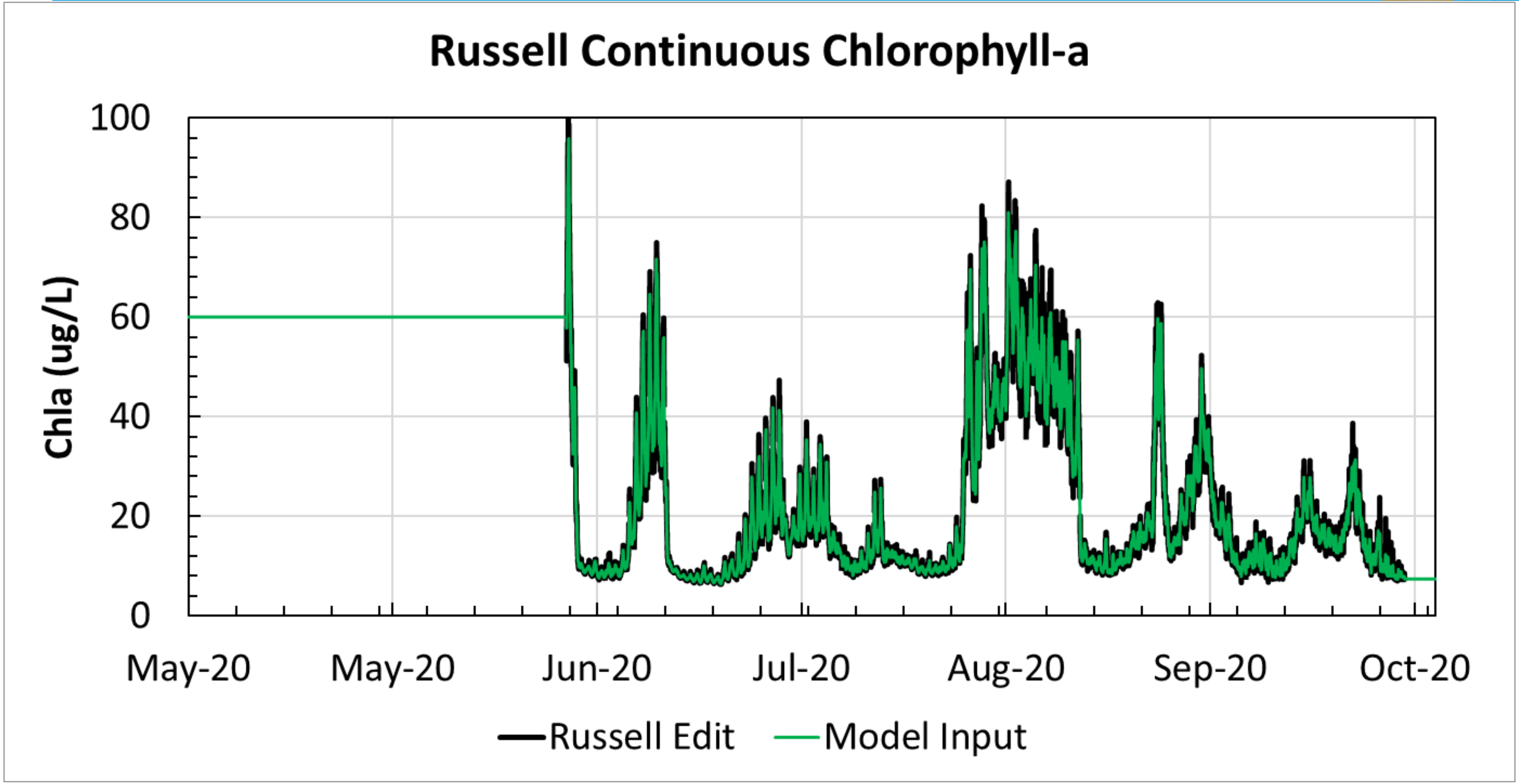
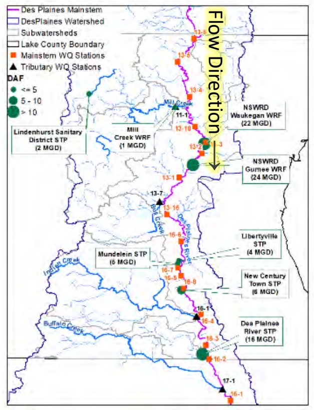
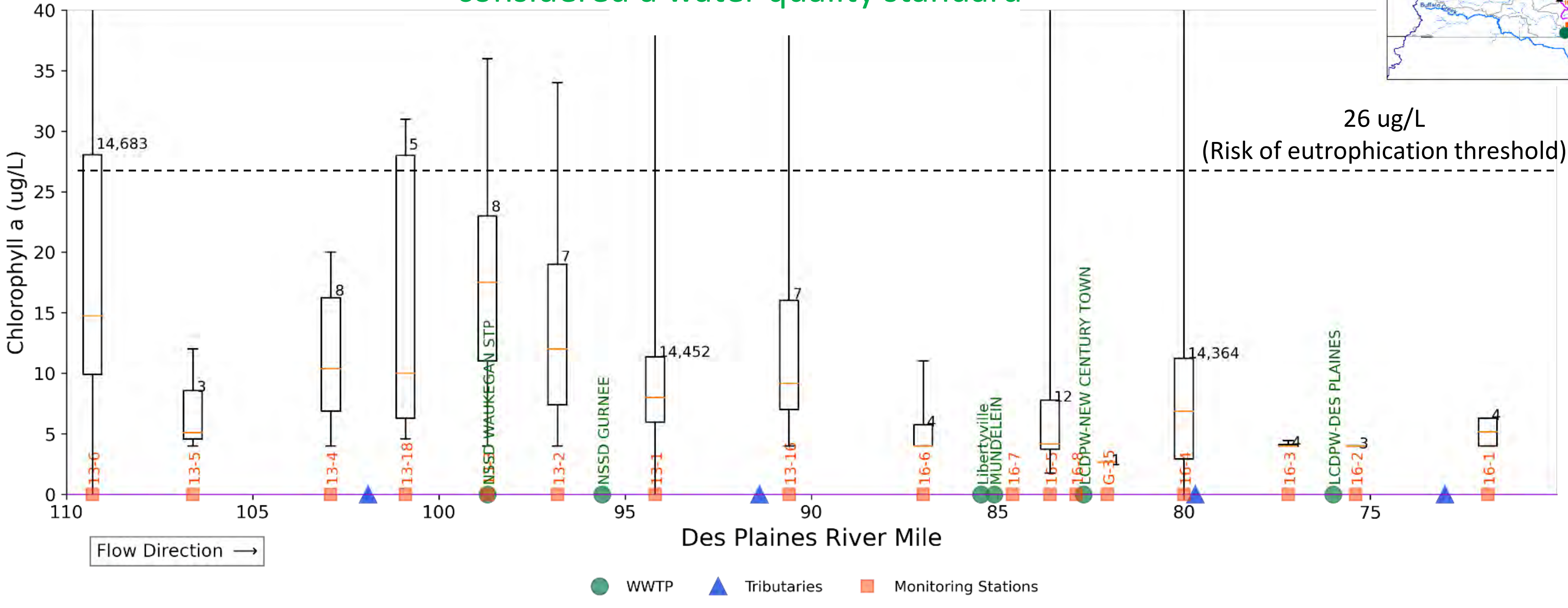
# Upstream Boundary



# Chlorophyll-a (May – Oct.) 2017-2021




Median Chlorophyll-a < 26 ug/L. This value will be used to compare scenarios and should not be considered a water quality standard



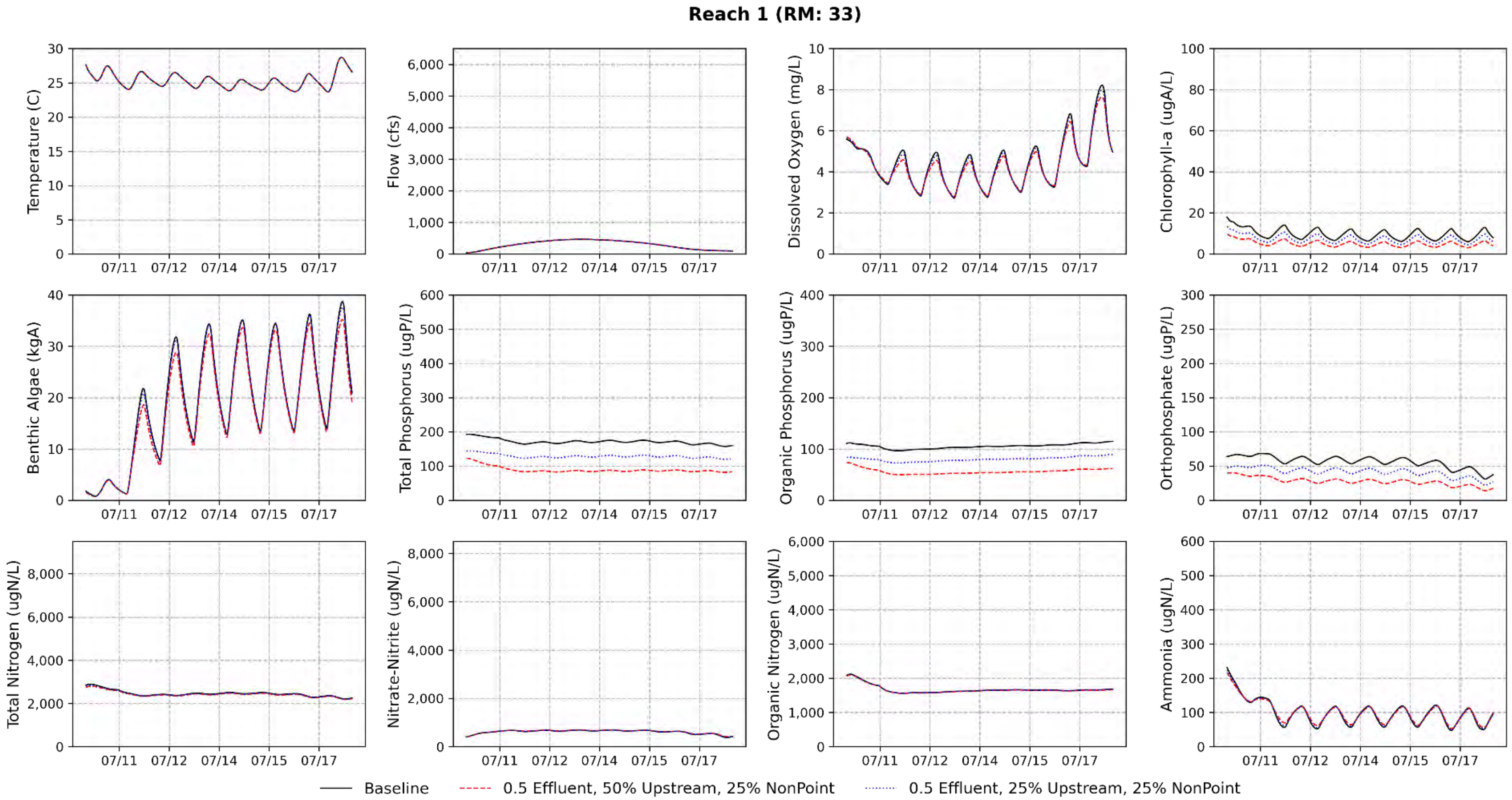
# Timeseries Plots

Geosyntec consultants

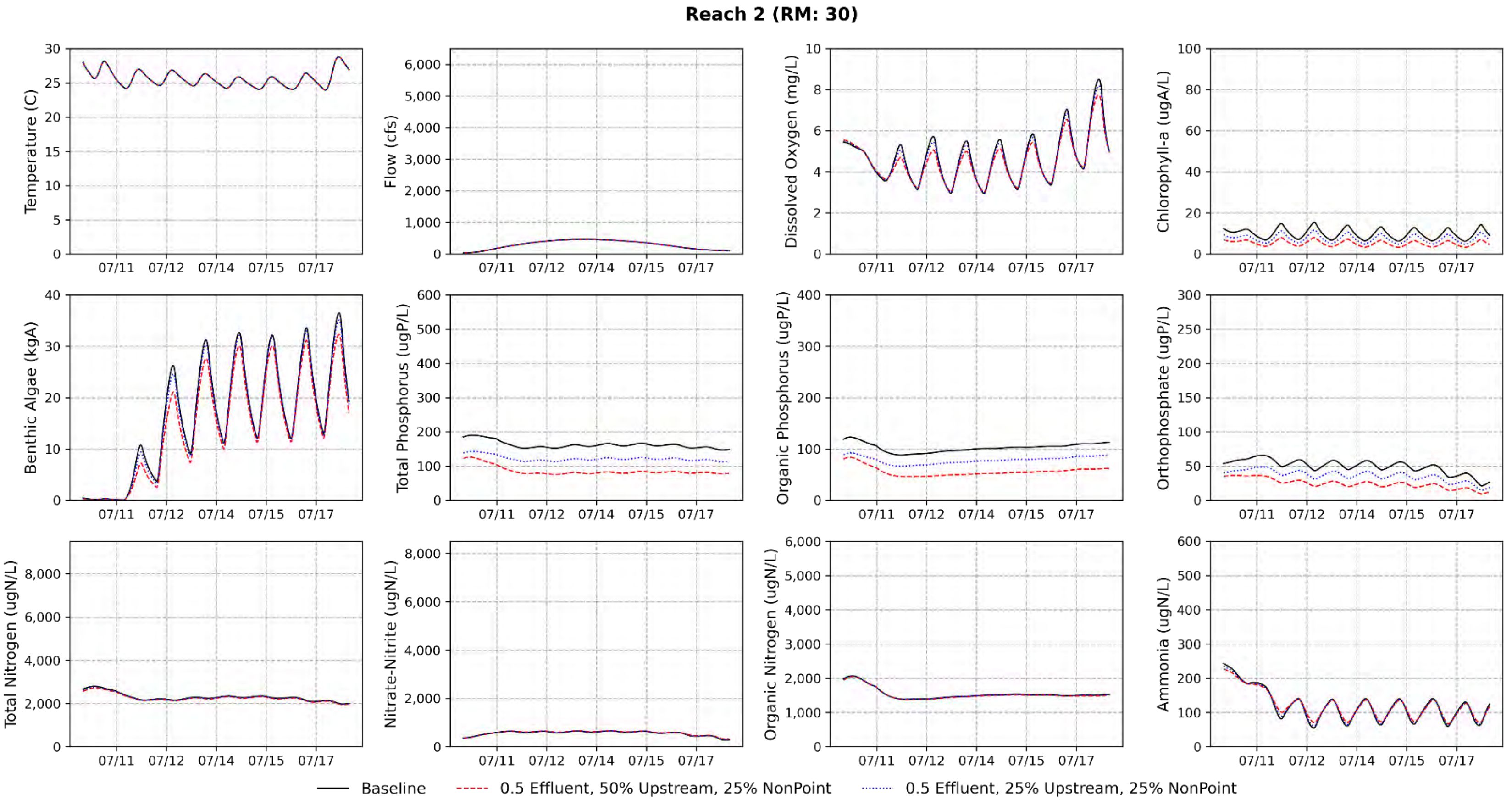
# Low DO Period: July 10-17

Geosyntec consultants

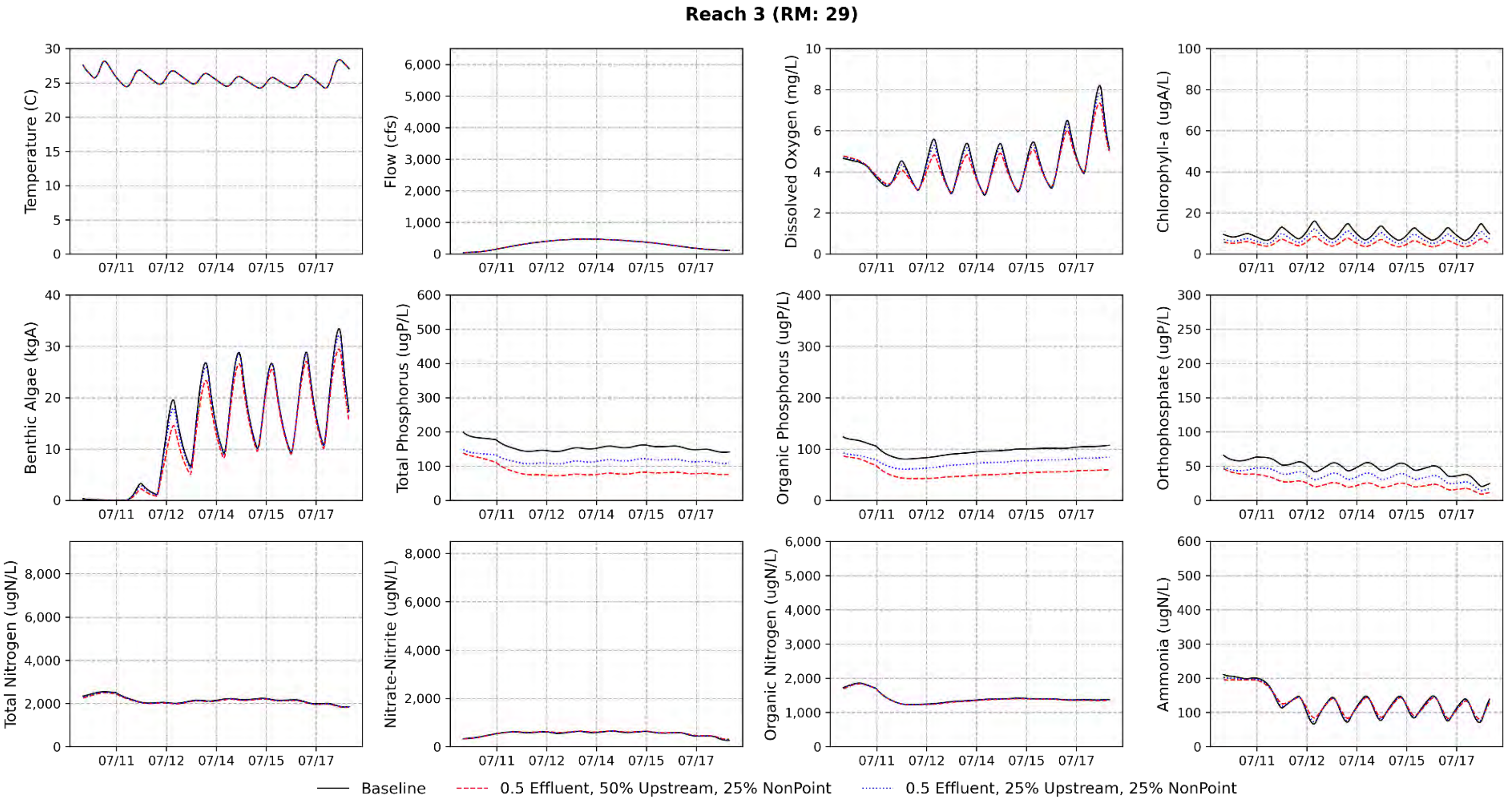
# 7/10 – 17, 2020


Reach 1 (RM: 33)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
07/11
07/12
07/14
07/15
07/17
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

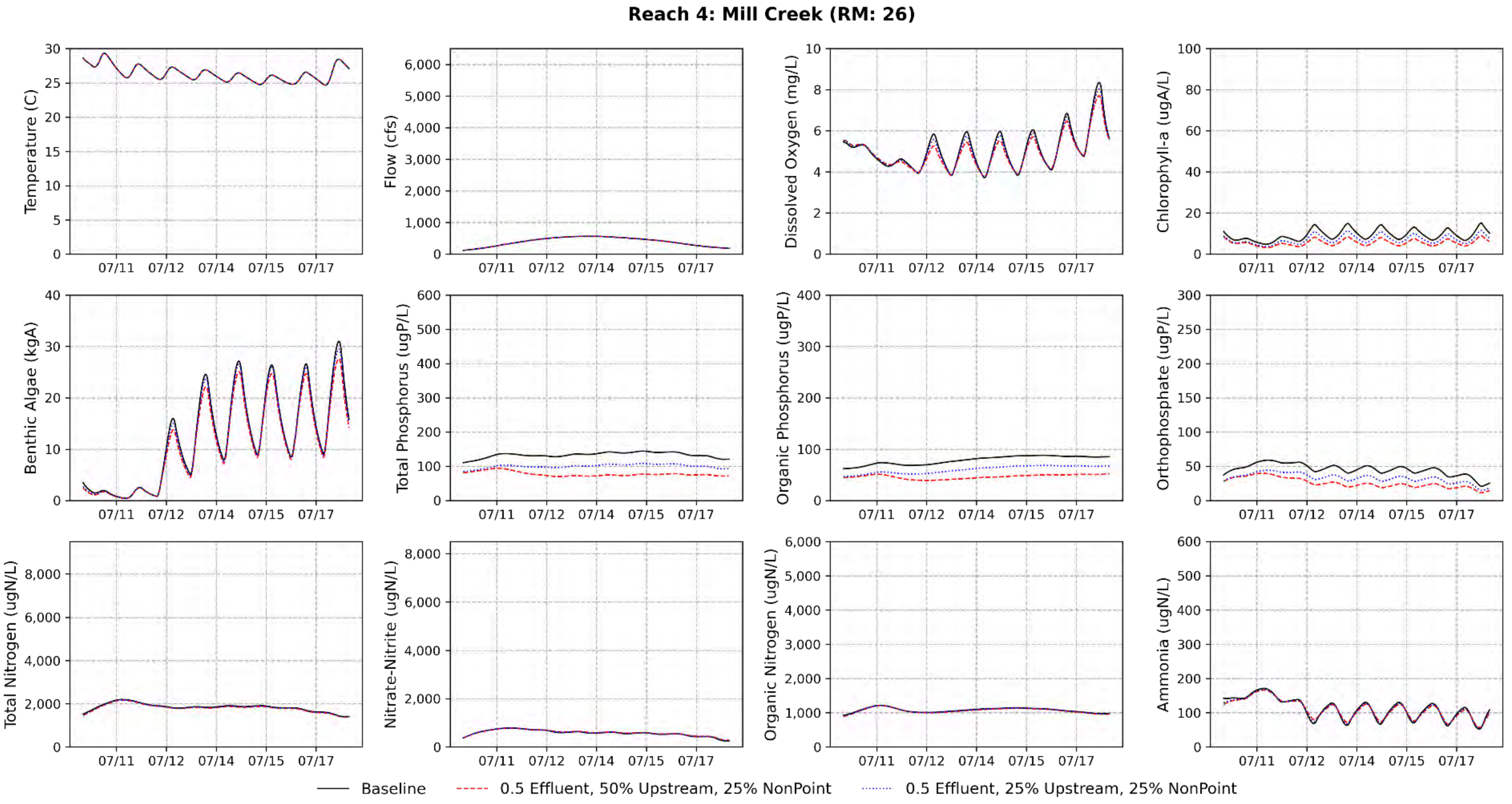
# 7/10 – 17, 2020


Reach 2 (RM: 30)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
07/11
07/12
07/14
07/15
07/17
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

# 7/10 – 17, 2020

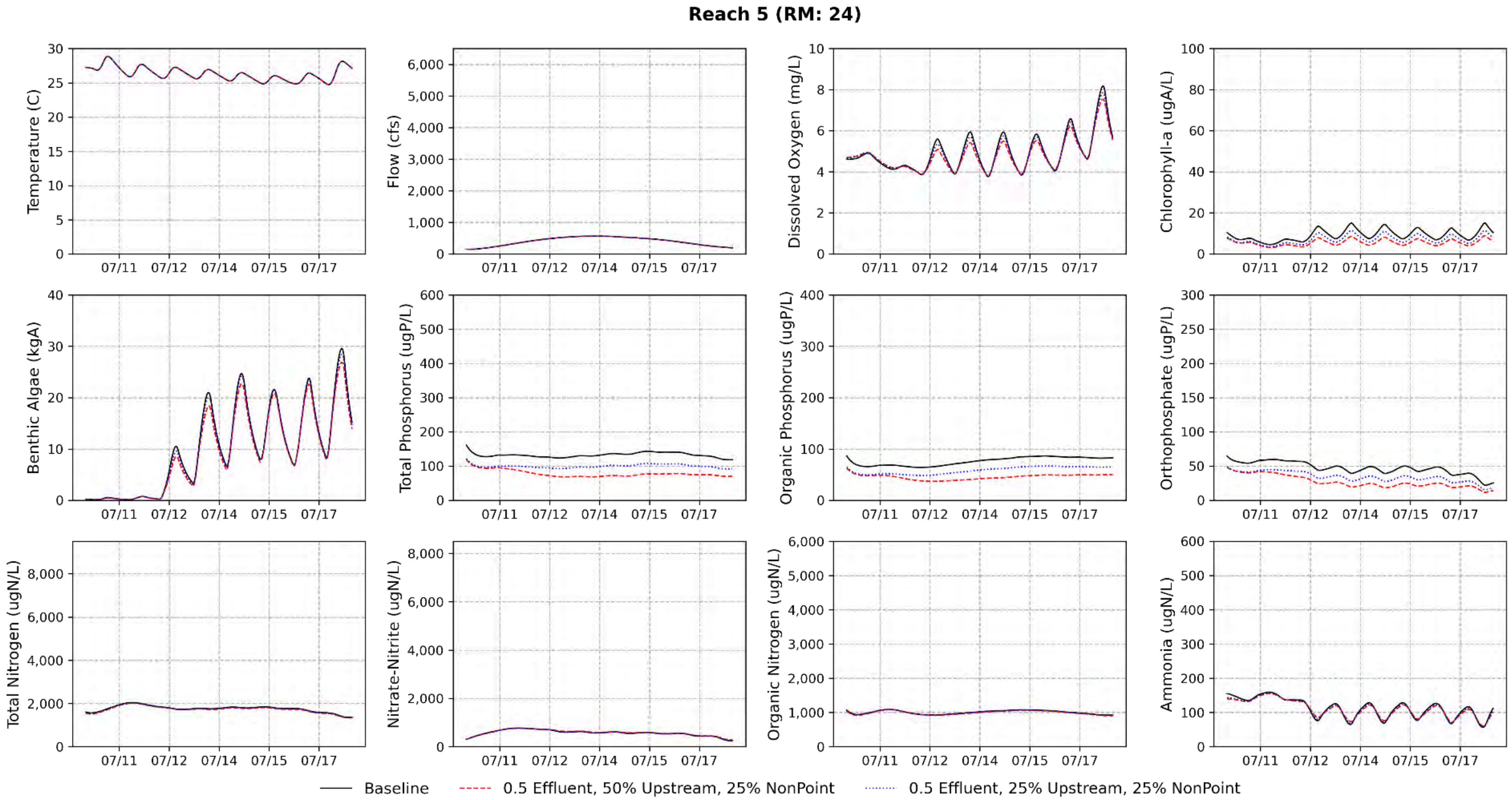

Reach 3 (RM: 29)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
07/11
07/12
07/14
07/15
07/17
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

# 7/10 – 17, 2020



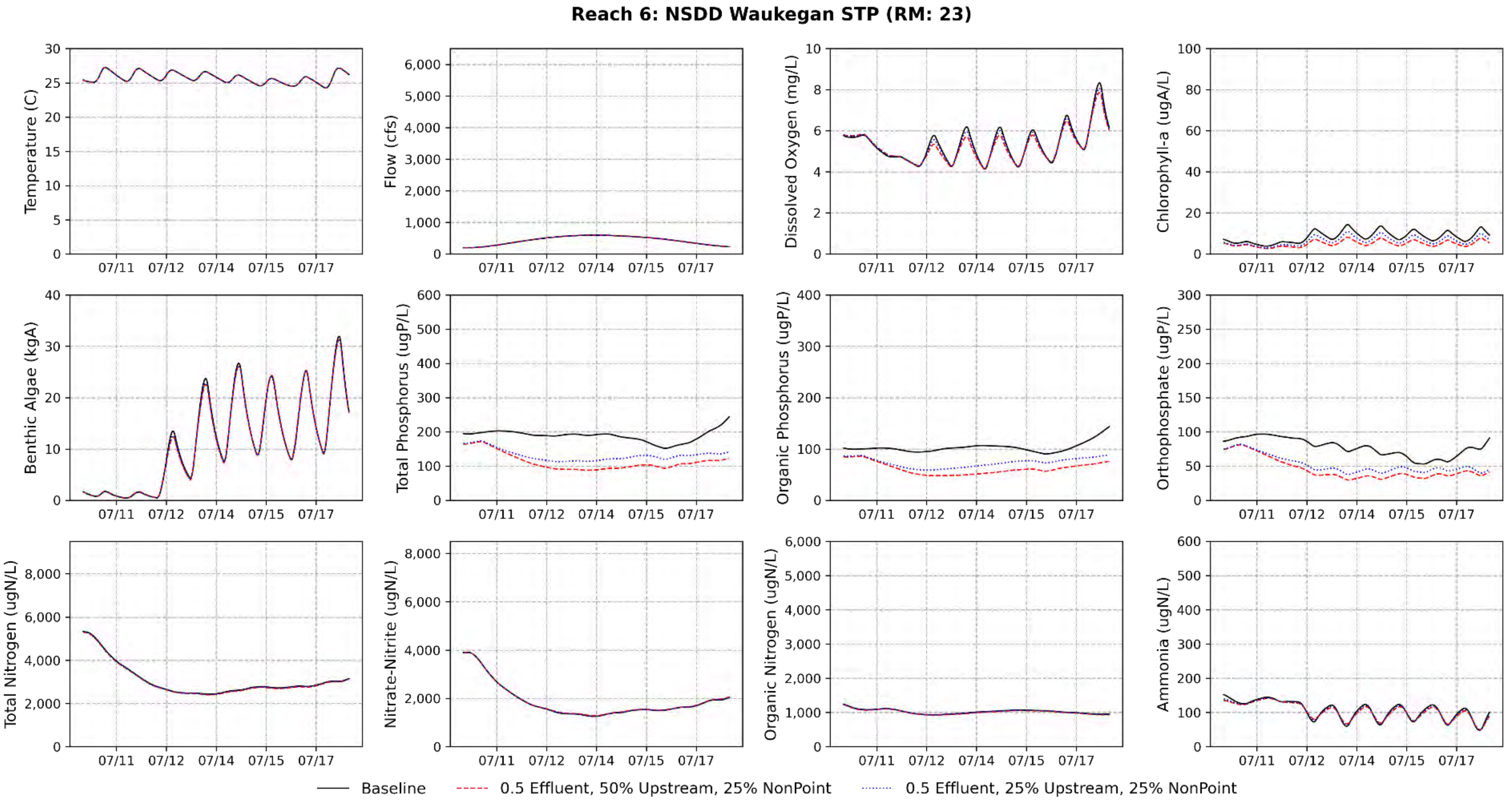
Reach 4: Mill Creek (RM: 26)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
07/11 07/12 07/14 07/15 07/17
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

# 7/10 – 17, 2020



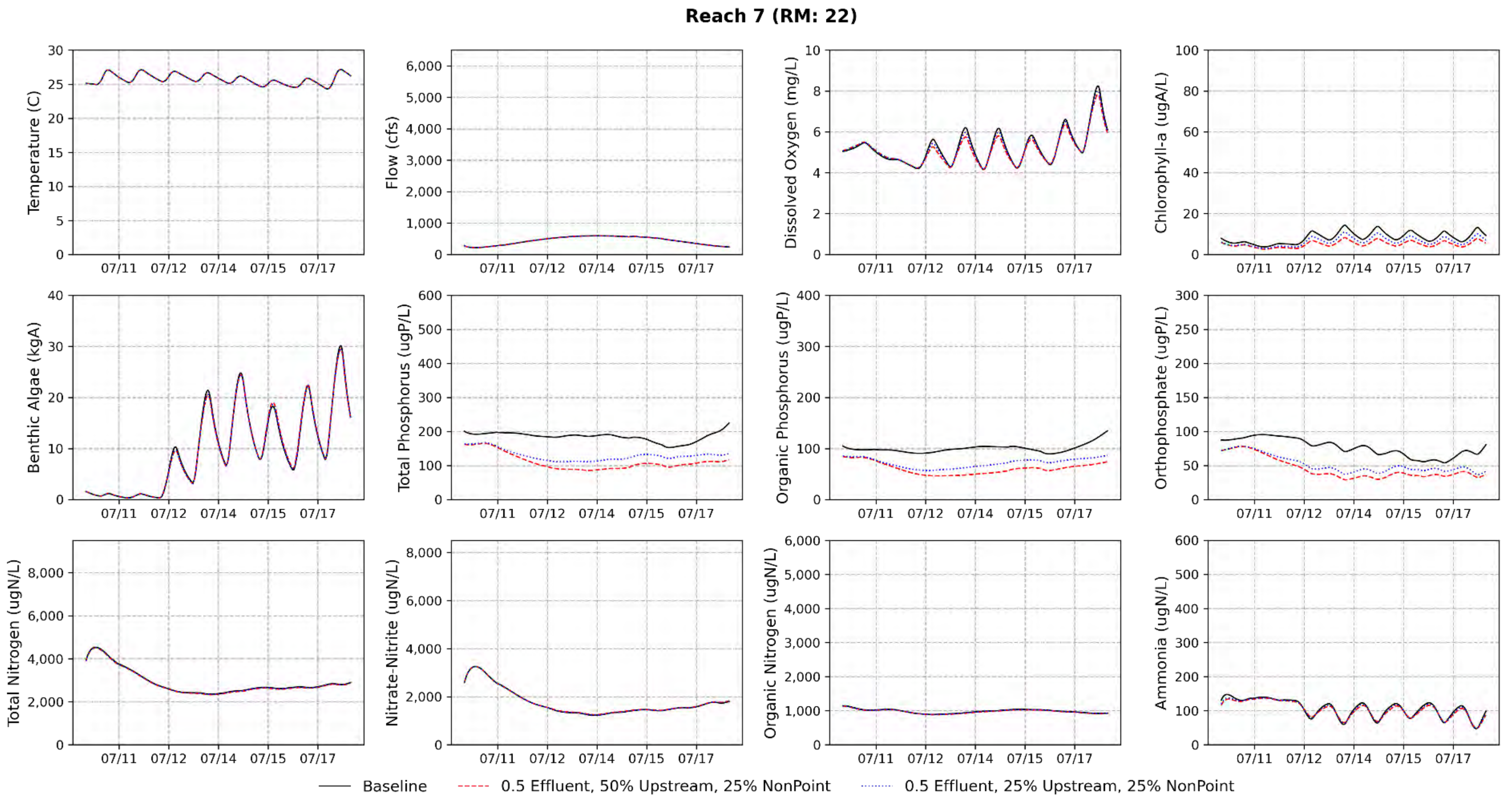
Reach 5 (RM: 24)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
07/11 07/12 07/14 07/15 07/17
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

# 7/10 – 17, 2020

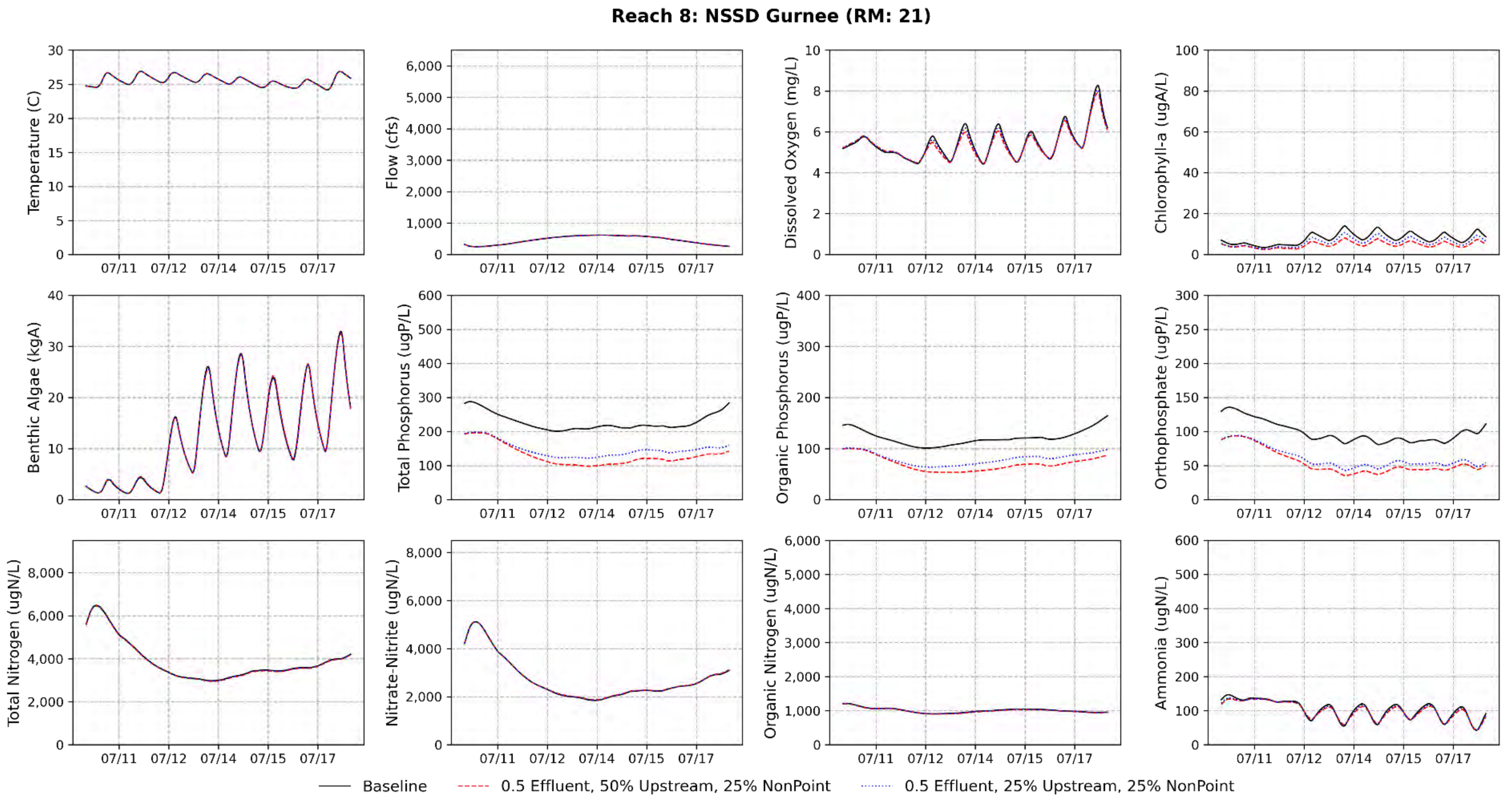


Reach 6: NSDD Waukegan STP (RM: 23)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
07/11
07/12
07/14
07/15
07/17
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

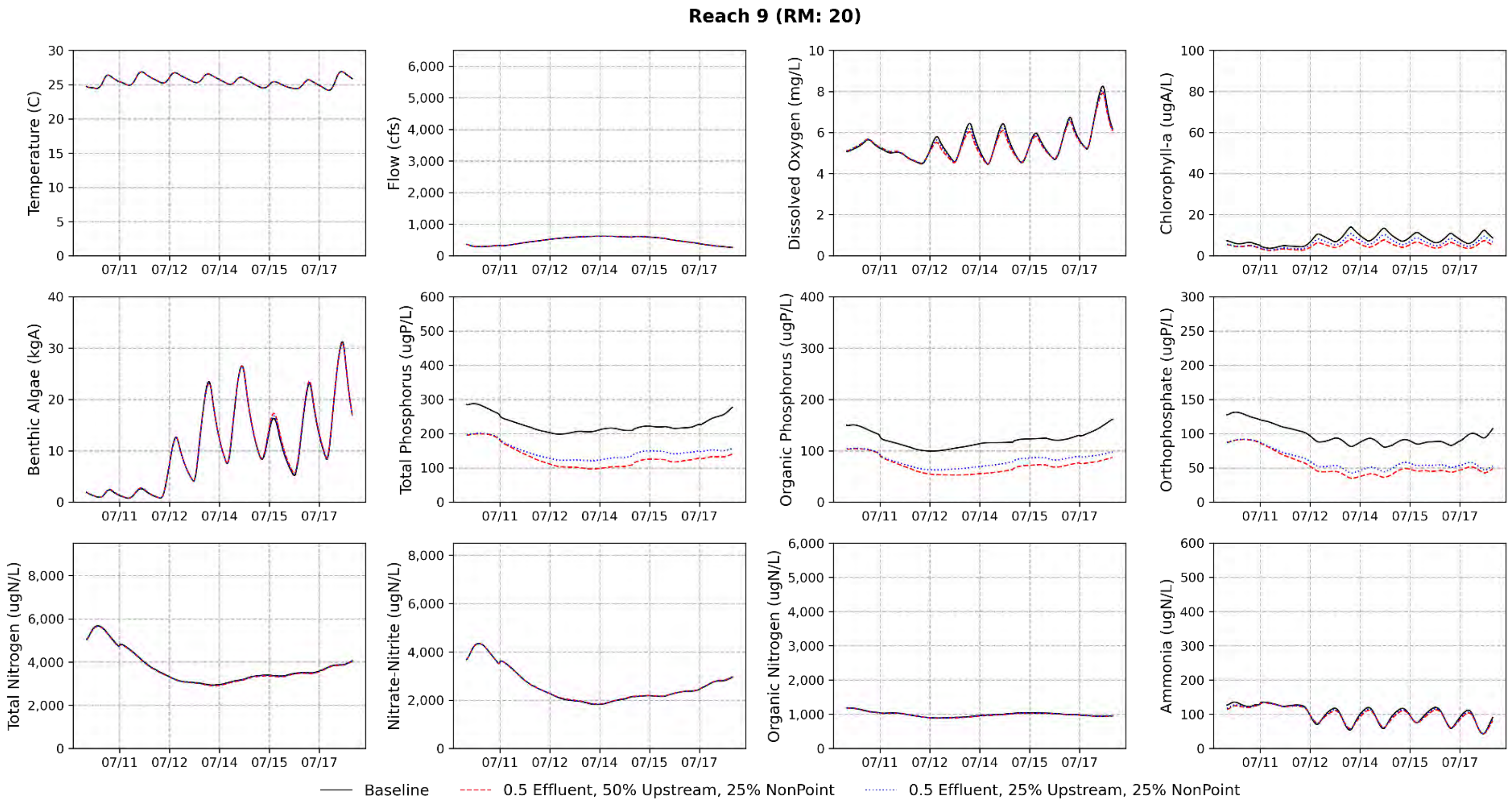
# 7/10 – 17, 2020


Reach 7 (RM: 22)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
07/11 07/12 07/14 07/15 07/17
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

# 7/10 – 17, 2020

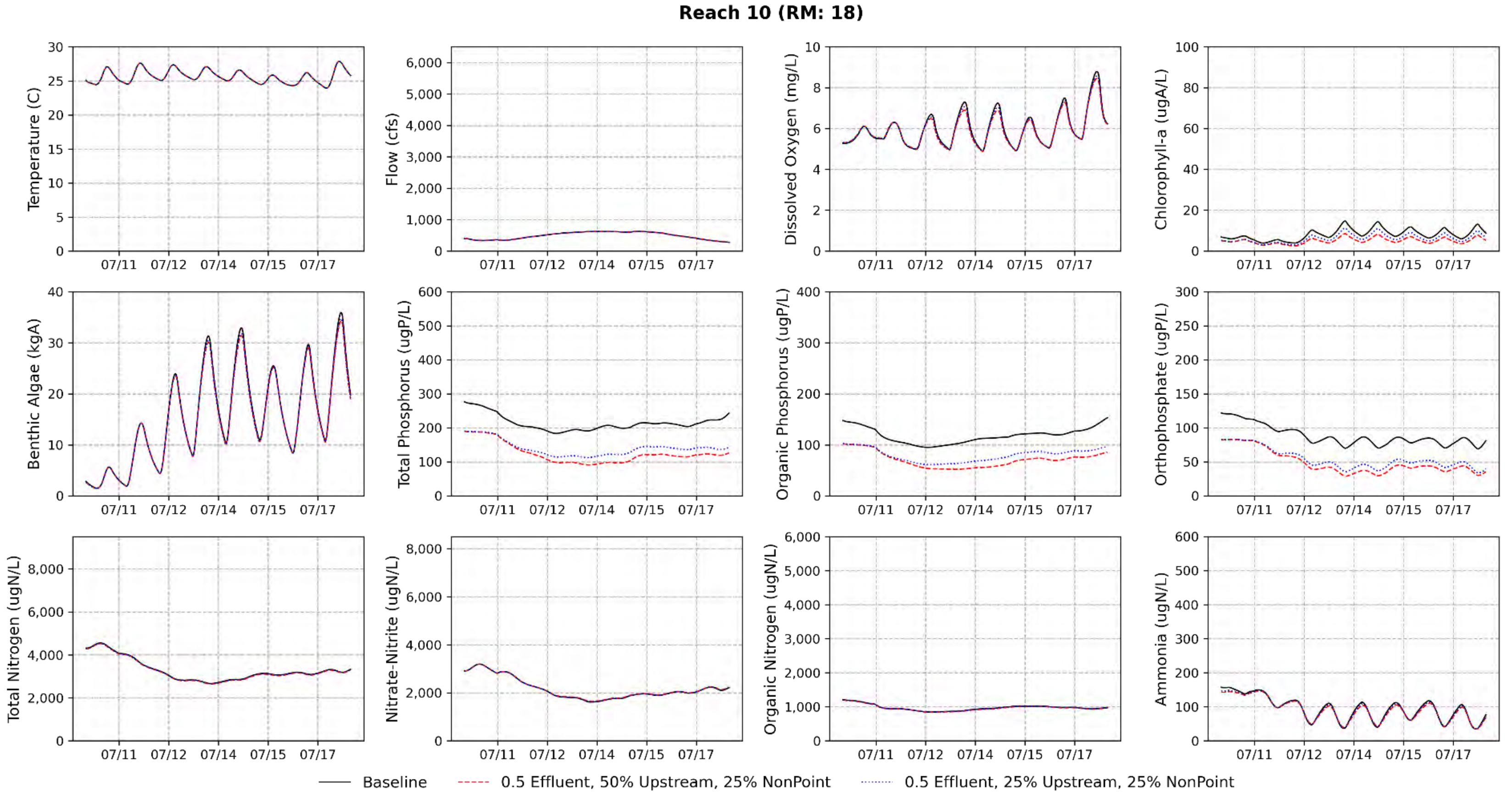

Reach 8: NSSD Gurnee (RM: 21)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
07/11 07/12 07/14 07/15 07/17
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

# 7/10 – 17, 2020



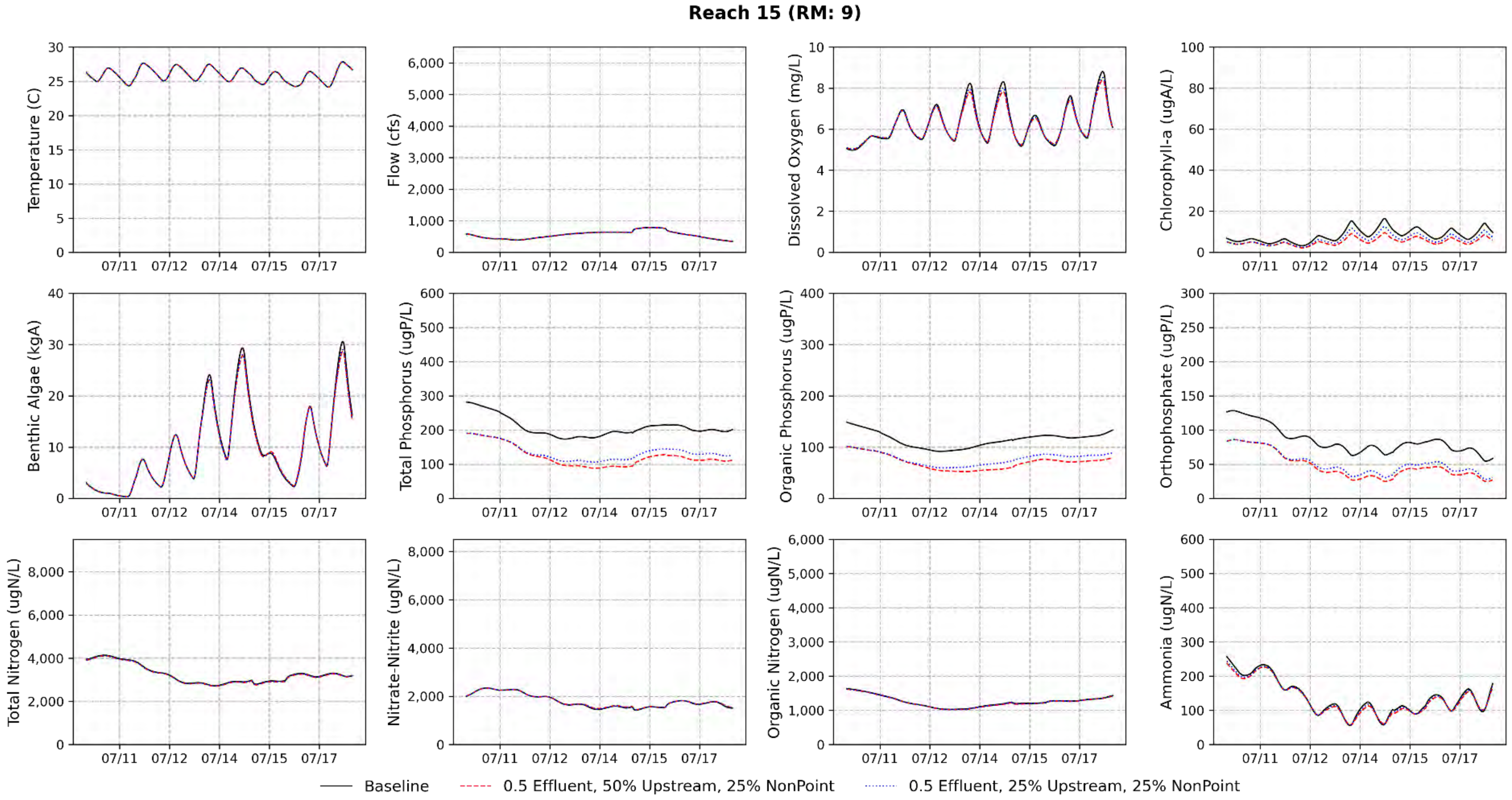
Reach 9 (RM: 20)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
07/11
07/12
07/14
07/15
07/17
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

# 7/10 – 17, 2020



Reach 10 (RM: 18)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
07/11
07/12
07/14
07/15
07/17
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

# 7/10 – 17, 2020

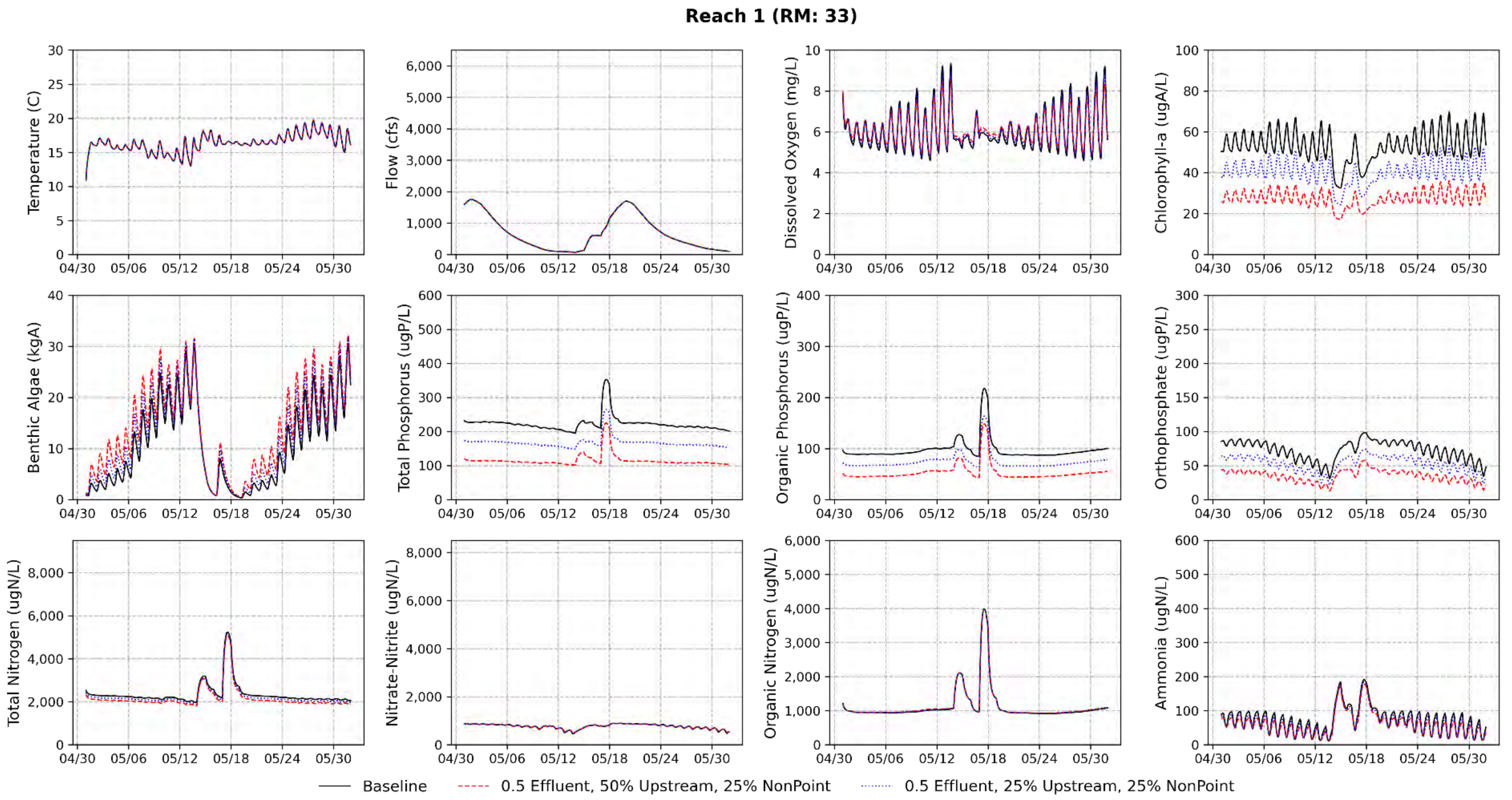


Reach 15 (RM: 9)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
07/11
07/12
07/14
07/15
07/17
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

# High Flow Period: May 1-31

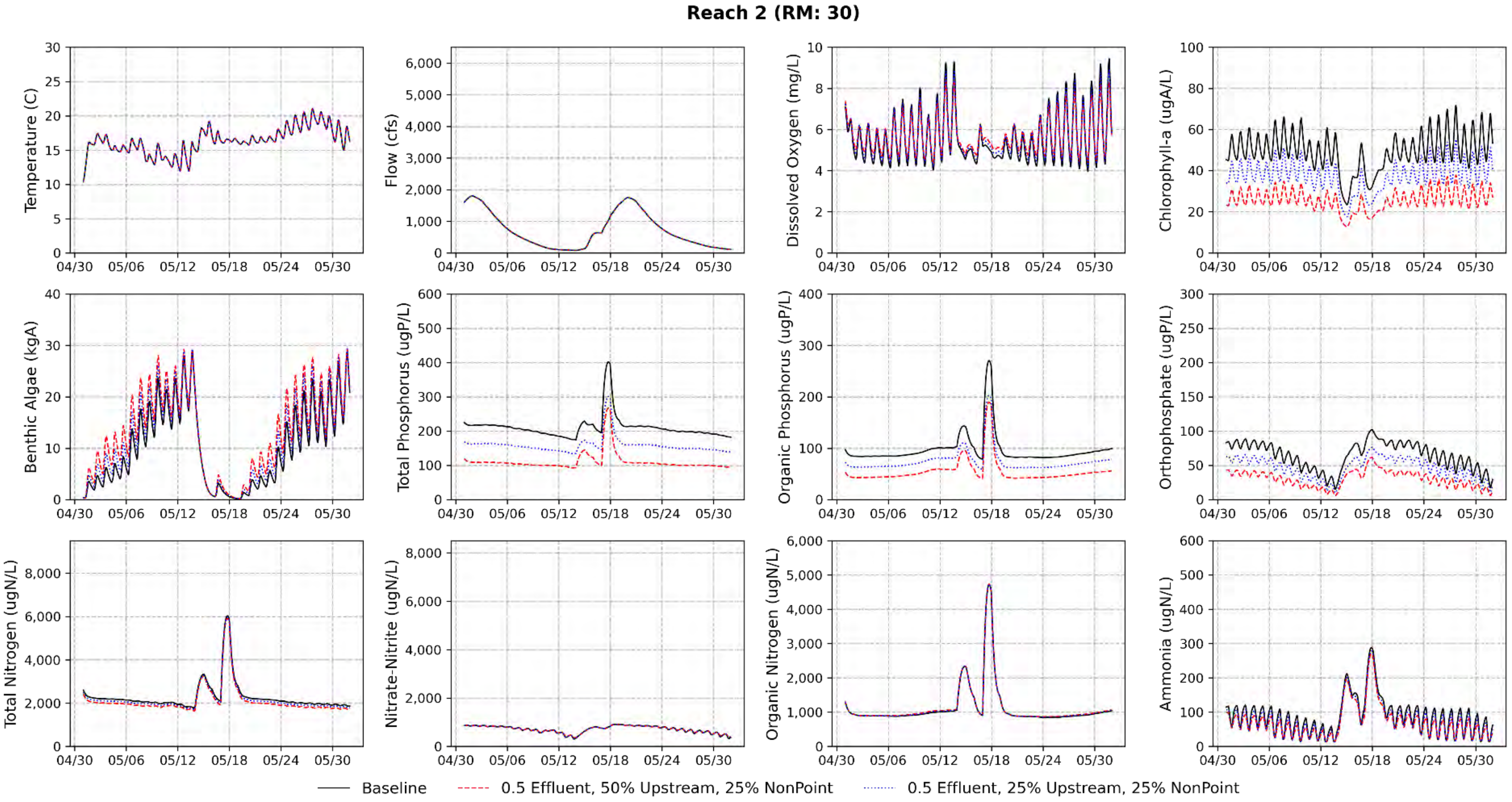
Geosyntec consultants

# 5/1- 31, 2020

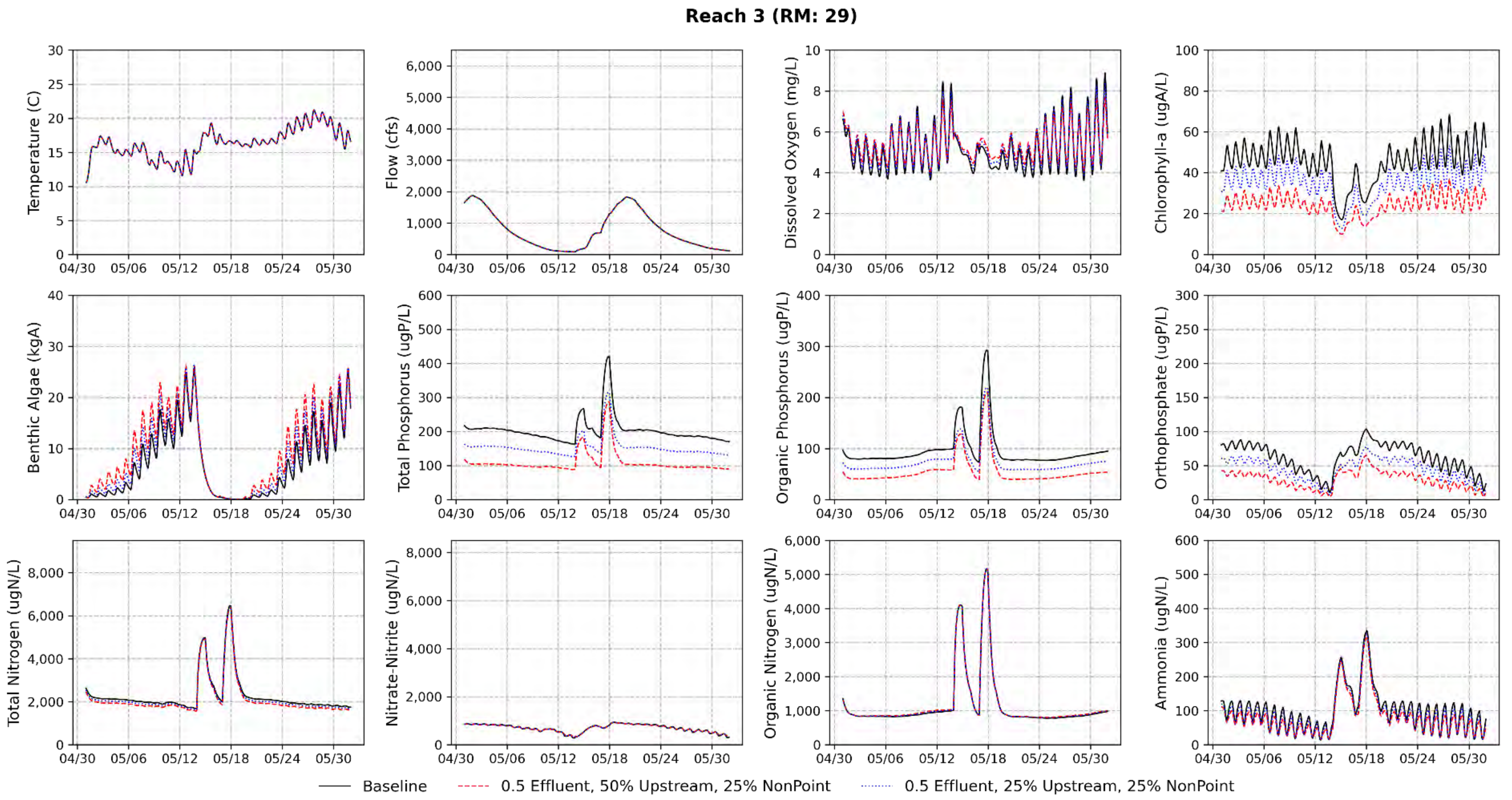


Reach 1 (RM: 33)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
04/30 05/06 05/12 05/18 05/24 05/30
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

# 5/1- 31, 2020

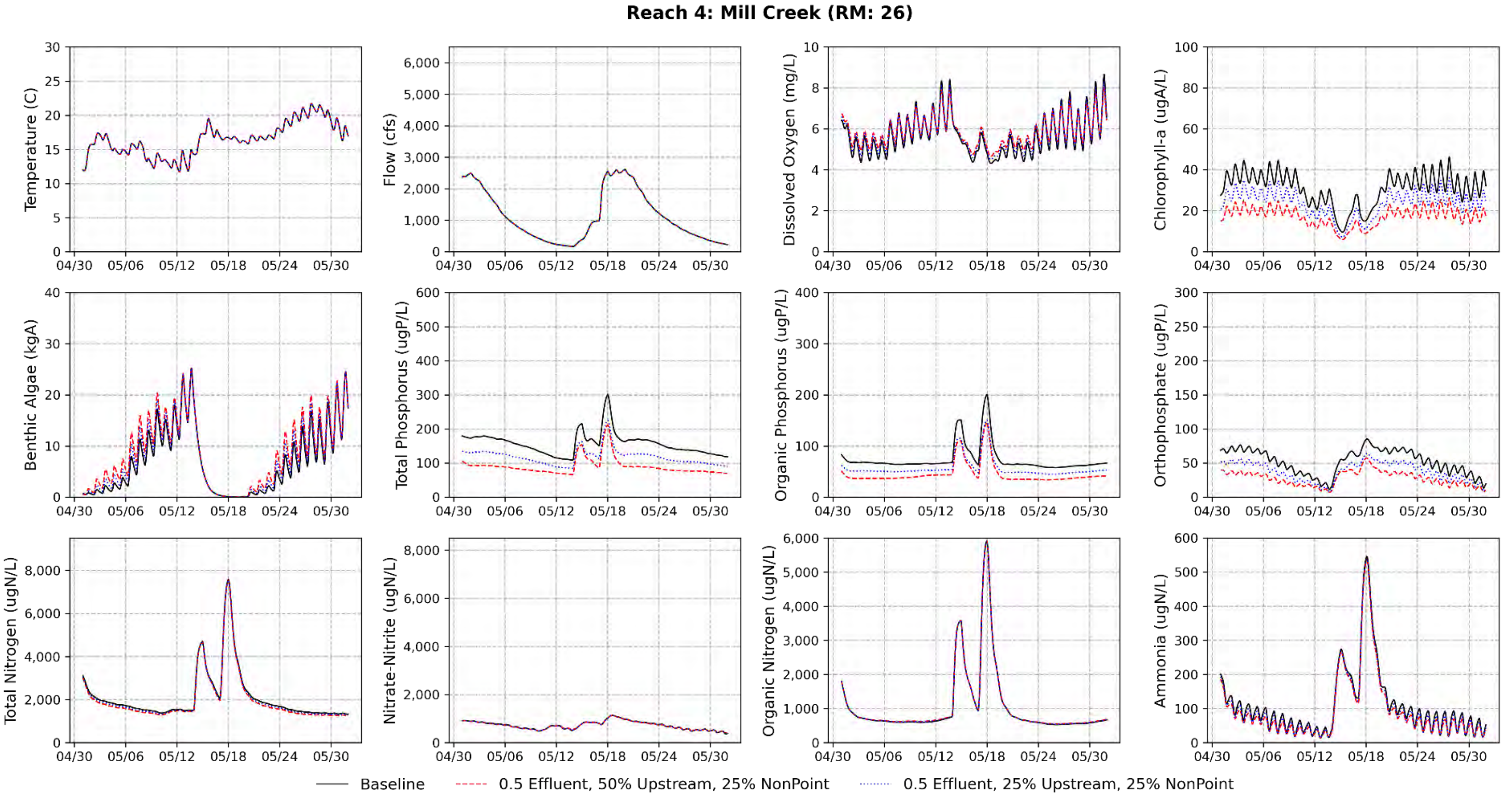

Reach 2 (RM: 30)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
04/30
05/06
05/12
05/18
05/24
05/30
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

# 5/1- 31, 2020



Reach 3 (RM: 29)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
04/30 05/06 05/12 05/18 05/24 05/30
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

# 5/1- 31, 2020



Reach 4: Mill Creek (RM: 26)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
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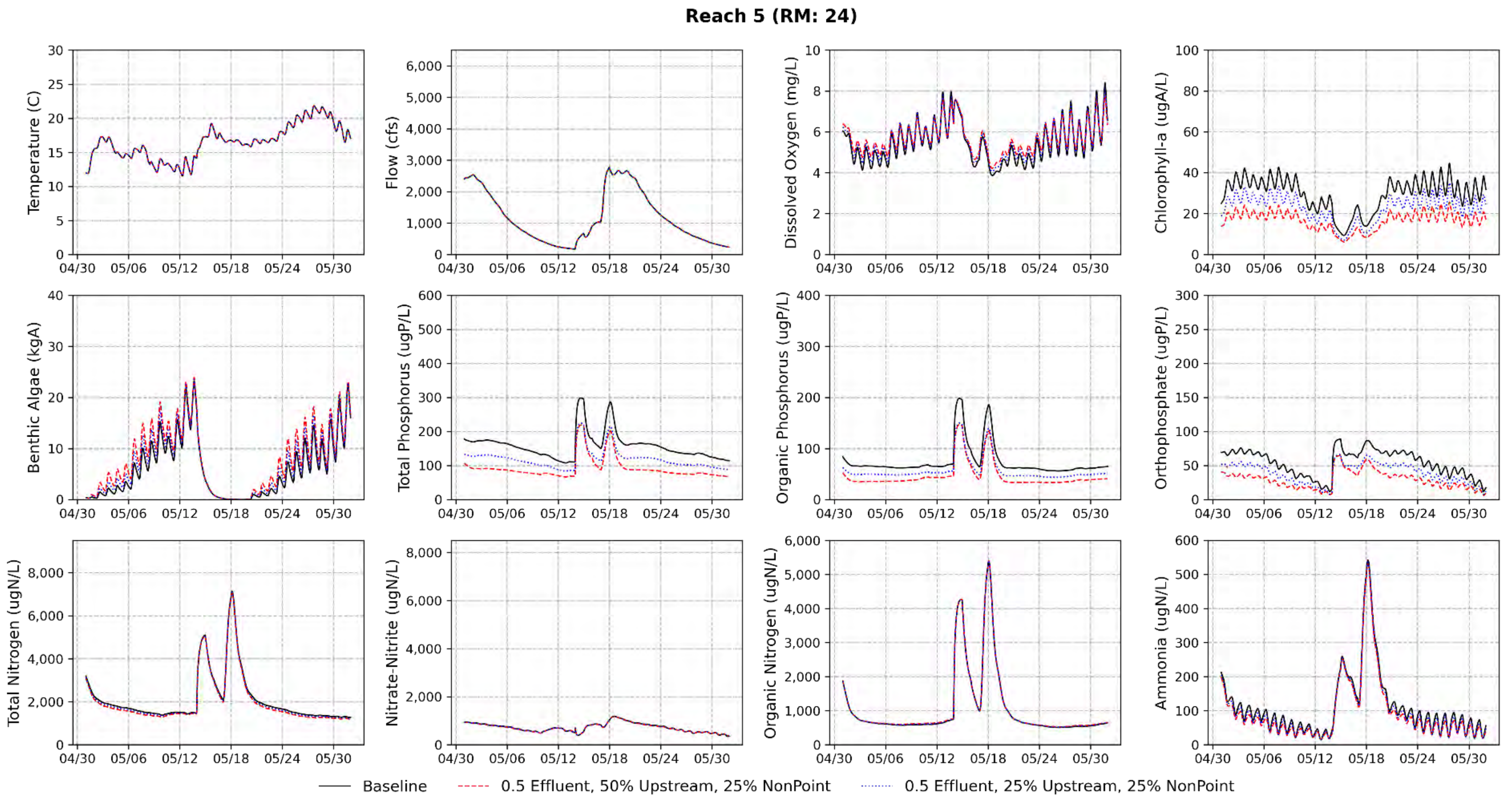
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
04/30
05/06
05/12
05/18
05/24
05/30
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

# 5/1- 31, 2020



Reach 5 (RM: 24)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
04/30 05/06 05/12 05/18 05/24 05/30
Baseline
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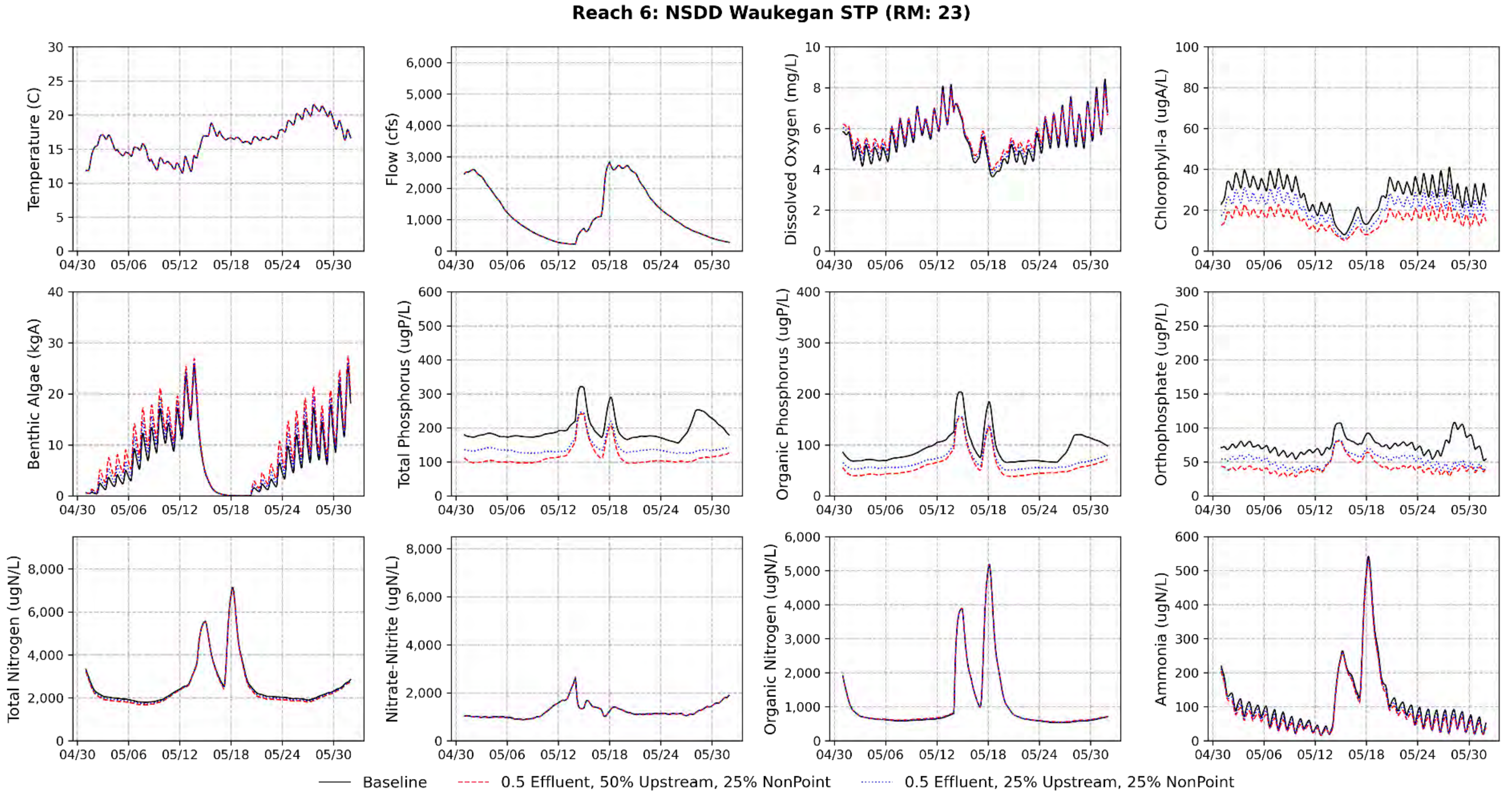
0.5 Effluent, 25% Upstream, 25% NonPoint

# 5/1- 31, 2020


Reach 6: NSDD Waukegan STP (RM: 23)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
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Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
04/30 05/06 05/12 05/18 05/24 05/30
Baseline
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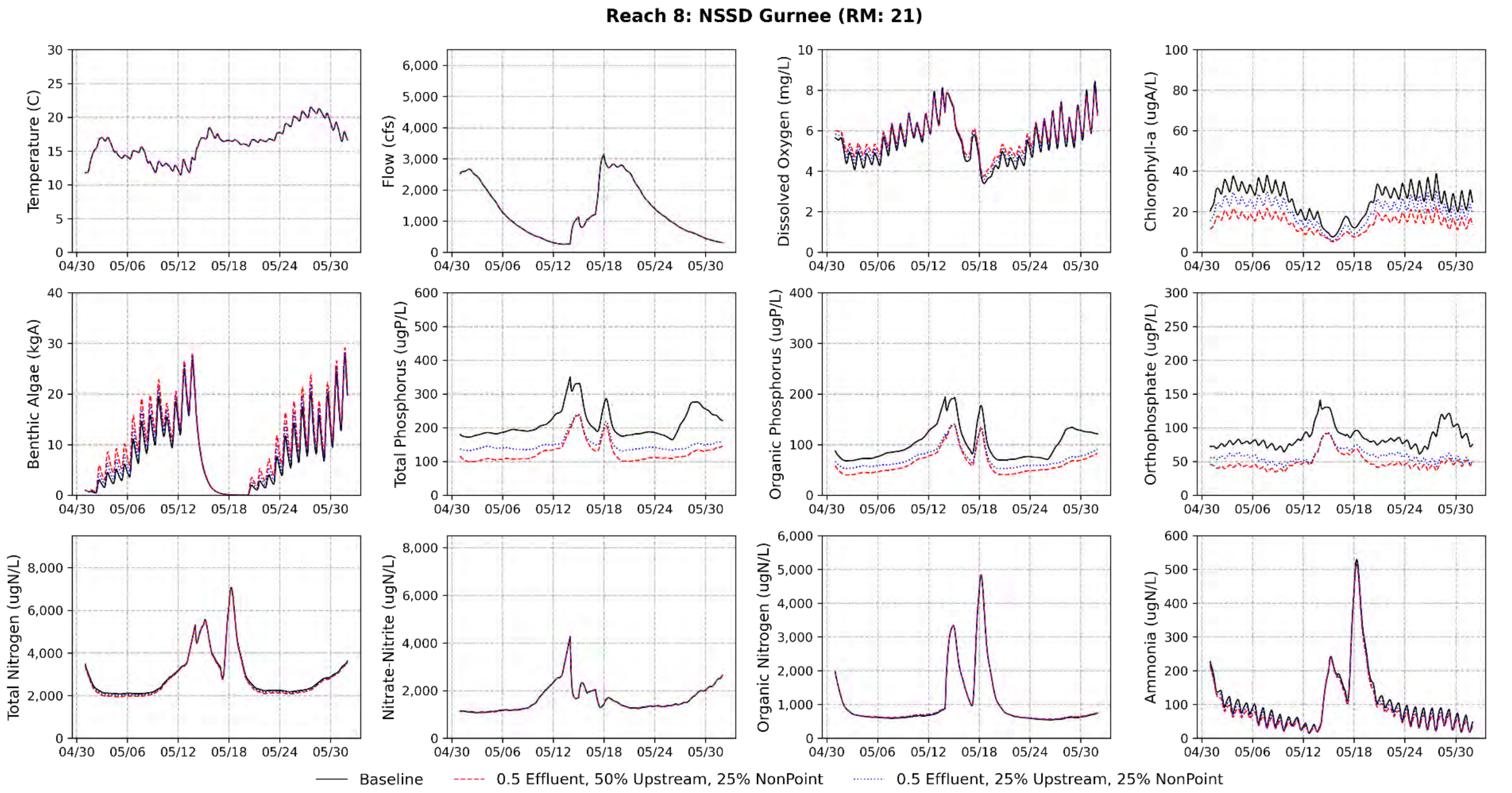
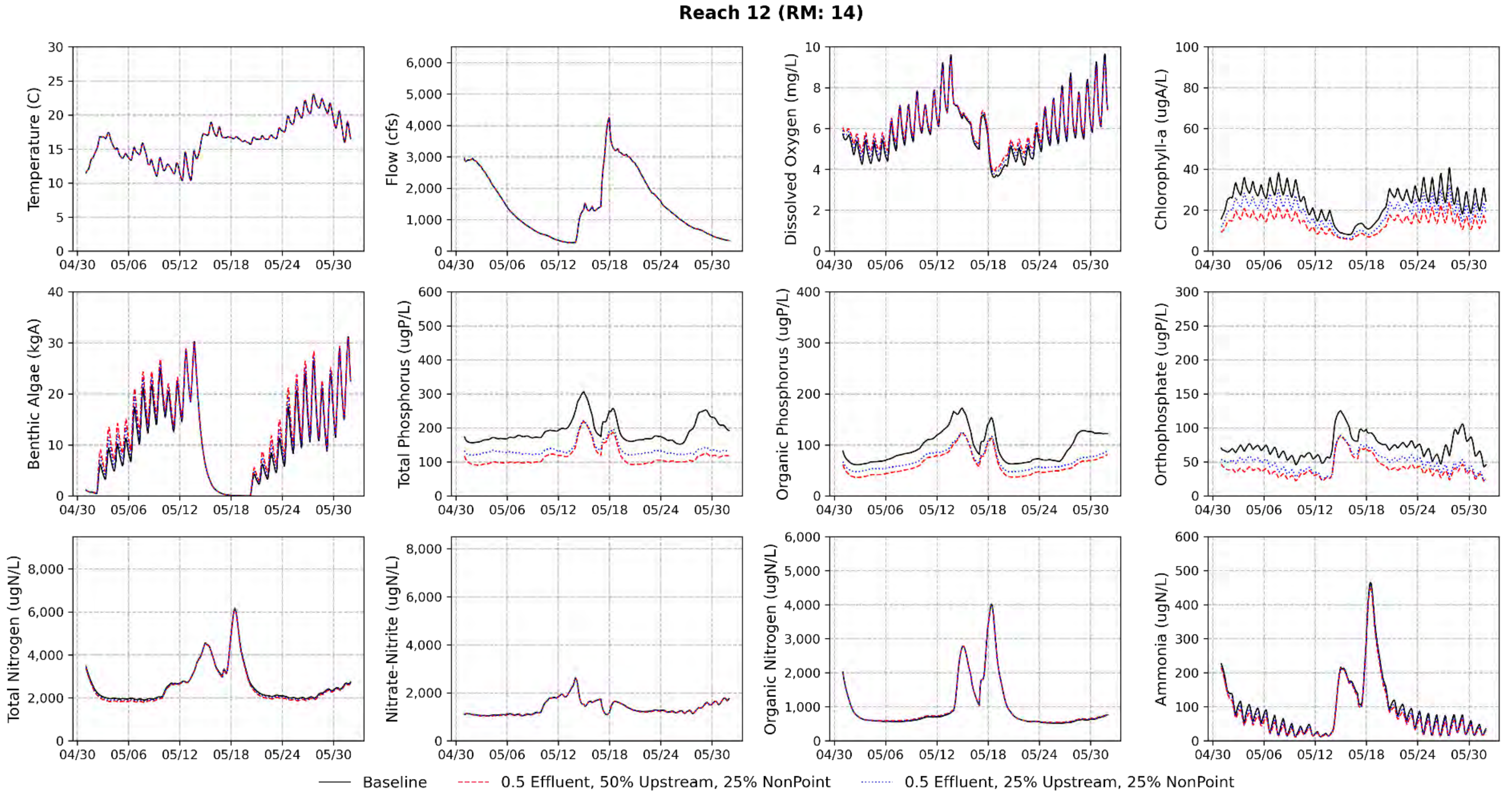
# 5/1- 31, 2020

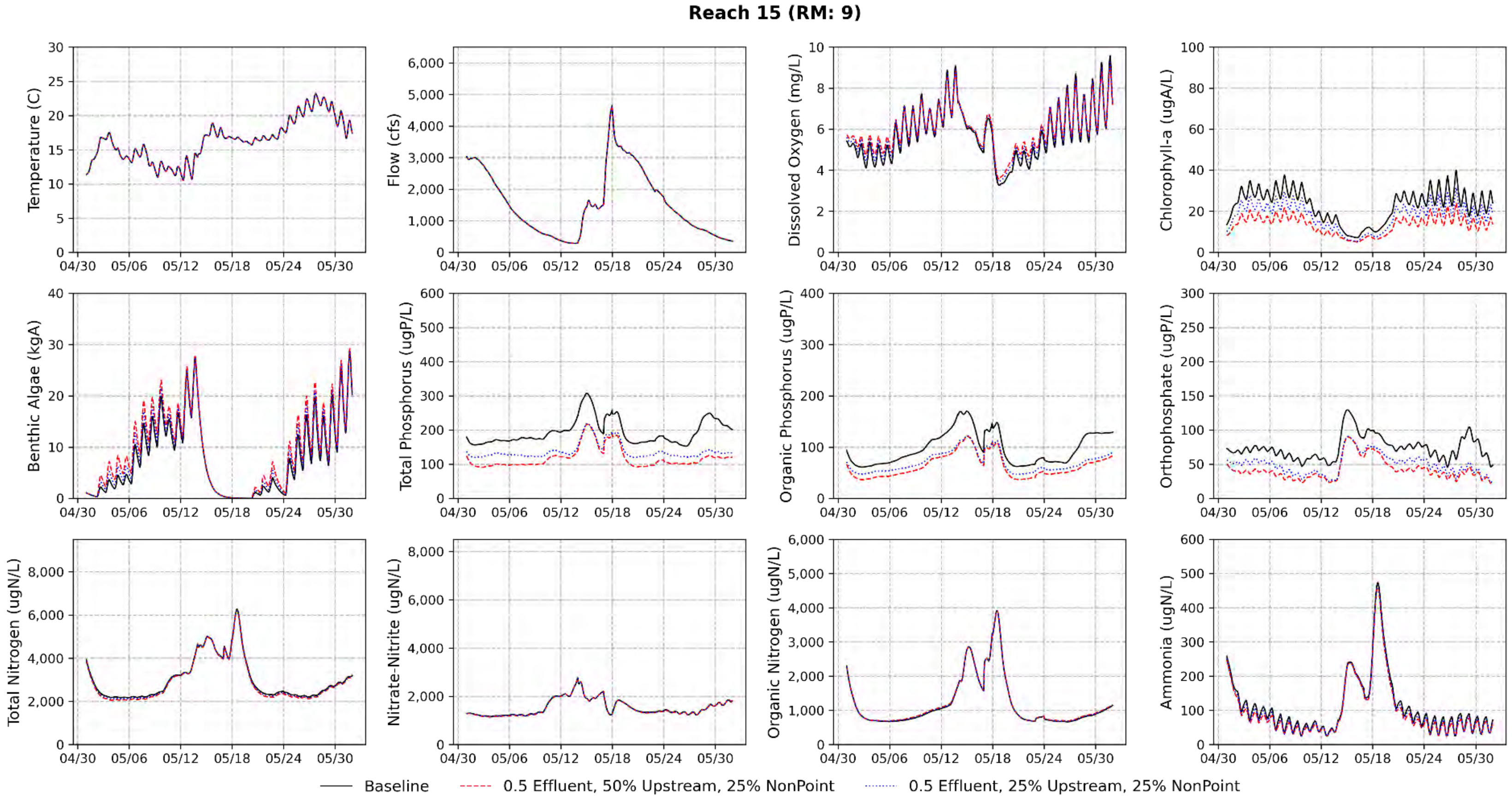

Reach 8: NSSD Gurnee (RM: 21)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
04/30 05/06 05/12 05/18 05/24 05/30
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

# 5/1- 31, 2020



Reach 12 (RM: 14)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
04/30
05/06
05/12
05/18
05/24
05/30
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

# 5/1- 31, 2020


Reach 15 (RM: 9)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
04/30
05/06
05/12
05/18
05/24
05/30
Baseline
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0.5 Effluent, 25% Upstream, 25% NonPoint

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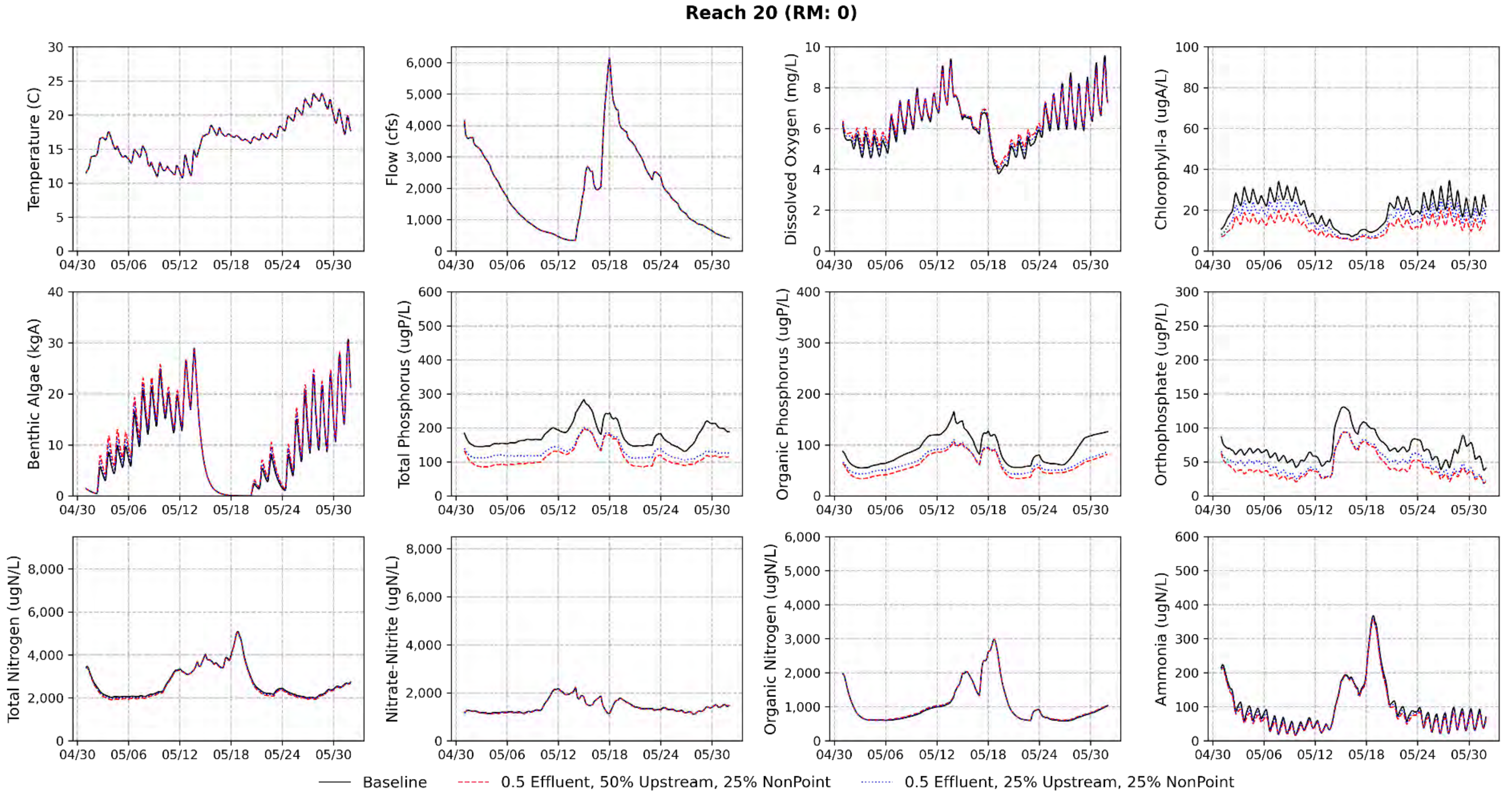


Reach 20 (RM: 0)
Temperature (C)
Flow (cfs)
Dissolved Oxygen (mg/L)
Chlorophyll-a (ugA/L)
Benthic Algae (kgA)
Total Phosphorus (ugP/L)
Organic Phosphorus (ugP/L)
Orthophosphate (ugP/L)
Total Nitrogen (ugN/L)
Nitrate-Nitrite (ugN/L)
Organic Nitrogen (ugN/L)
Ammonia (ugN/L)
04/30 05/06 05/12 05/18 05/24 05/30
Baseline
0.5 Effluent, 50% Upstream, 25% NonPoint
0.5 Effluent, 25% Upstream, 25% NonPoint

# APPENDIX C
## Project Recommendations

# 1 INTRODUCTON

This appendix discusses the specific project recommendations to provide ancillary benefits such as reducing loading from non-point sources and address impairments sedimentation and siltation, habitat degradation, hydromodification, and impacts from other contaminants. These recommendations are not meant to specifically address the NARP-related DO and nuisance related impairments but are meant to identify potential, voluntary opportunities for project implementation by stakeholders in the watershed.

## 2. NON-POINT SOURCE LOAD REDUCTION

A total of 597 projects from Des Plaines River Watershed-Based Plan (Lake County SMC, 2018) were assessed for TP load reduction potential and cost-effectiveness. Of these, 29 projects were identified with a potential phosphorus reduction greater than 50 pounds per year, while eight (8) projects were identified with a potential phosphorus reduction greater than 100 pounds per year.

Field borders, grass waterways, sediment forebays, streambank stabilization, and wetland creation/restoration were the only project categories identified with the potential to provide a potential phosphorus reduction greater than 100 pounds per year. Of these, grass waterways provide the most cost-effective benefit ($65/lb P), while wetland creation/restoration was the least cost-effective ($4,266/lb P).

When looking at projects with the potential to reduce phosphorus loads by 50 pounds per year or greater, there was a more diverse set of project types. Grass waterways, ponds, and stormwater management BMPs (Best Management Practices) are more cost-effective on a per-pound basis than practices such as streambank restoration and wetland creation but typically have smaller impacts. Grass waterways are substantially more efficient than other practices, making up the top four (5) options when analyzing the most efficient qualifying projects (**Table 1**).

**Table 1: Recommended Site-Specific Projects for TP Load Reduction from Nonpoint Sources**

| Project ID | Project Type | P Reduction (lbs/yr) | Cost ($) | Efficiency ($/lb P) |
|---|---|---|---|---|
| SBD28 | Streambank Stabilization | 284 | $1,594,046 | $560 |
| SBD23 | Streambank Stabilization | 236 | $4,625,191 | $1,964 |
| SSD96 | Sediment Forebay | 195 | $468,000 | $240 |
| SBD25 | Streambank Stabilization | 185 | $1,698,467 | $917 |
| DST8 | Streambank Stabilization | 173 | $1,458,864 | $843 |
| SSD95 | Sediment Forebay | 155 | $468,000 | $302 |
| DWS20 | Wetland Creation/Restoration | 142 | $2,899,449 | $2,045 |
| SBD31 | Streambank Stabilization | 125 | $1,446,615 | $1,157 |
| SSD142 | Grass Waterway | 59 | $13,600 | $23 |

| Project ID | Project Type | P Reduction (lbs/yr) | Cost ($) | Efficiency ($/lb P) |
|---|---|---|---|---|
| SSD75 | Grass Waterway | 56 | $17,600 | $31 |
| SSD28 | Grass Waterway | 73 | $24,000 | $33 |
| SSD58 | Grass Waterway | 58 | $29,600 | $51 |
| SSD77 | Pond | 51 | $50,000 | $98 |
| DST4 | Stormwater Management BMP | 86 | $250,000 | $289 |
| SSD94 | Wetland Creation/Restoration | 50 | $160,000 | $319 |
| SSD125 | Sediment Forebay | 80 | $468,000 | $585 |
| SBD34 | Streambank Stabilization | 54 | $608,373 | $1,128 |
| SBD21 | Streambank Stabilization | 67 | $1,131,869 | $1,689 |
| SBD30 | Streambank Stabilization | 81 | $1,377,247 | $1,702 |
| DWS1 | Wetland Creation/Restoration | 78 | $1,609,665 | $2,059 |

## 3. STREAM AND WETLAND RESTORATION

Stream restoration, hydraulic impediment removal, and wetland help to mitigate conditions that promote low DO and nuisance algae impairments.

### 3.1 Stream Restoration

Streams sections with low velocities result in low natural reaeration and provide conditions for algae growth due to large travel times. It is recommended to add stream riffles and pools on suitable stream sections to improve natural reaeration and reduce algae growth due to faster velocity. An example location for such a project is the Des Plaines River section near the IL-WI Border. Another 11-stream restoration project, which incorporated stream riffles to improve aeration in the main stem Des Plaines River were identified from DPR WBP. These projects are listed in **Table 2** below

**Table 2: Recommended Stream Restoration Projects to Improve Aeration in the Mainstem Des Plaines River**

| Project ID | Cost ($) | Length (ft) |
|---|---|---|
| SBD21 | $1,131,869 | 3273 |
| SBD23 | $4,625,191 | 13042 |
| SBD25 | $1,698,467 | 4912 |
| SBD27 | $385,207 | 1159 |
| SBD28 | $1,594,046 | 4688 |
| SBD29 | $459,978 | 1158 |
| SBD30 | $1,377,247 | 3966 |
| SBD31 | $1,446,615 | 4072 |
| SBD34 | $608,373 | 1653 |
| SBD36 | $766,886 | 2056 |
| SBD37 | $1,216,310 | 3429 |

A recommended design for the project includes the use of riffle bars (Fleming et al., 2014) and J-hook vanes (IDNR, 2018, **Figure 1**). Riffle bars utilize large stones and boulders to both direct flow away from the bank and introduce turbulence into the water. J-hook vanes protection reduces erosion, which can reduce phosphorus loading, while introducing turbulence into the water, increasing aeration.

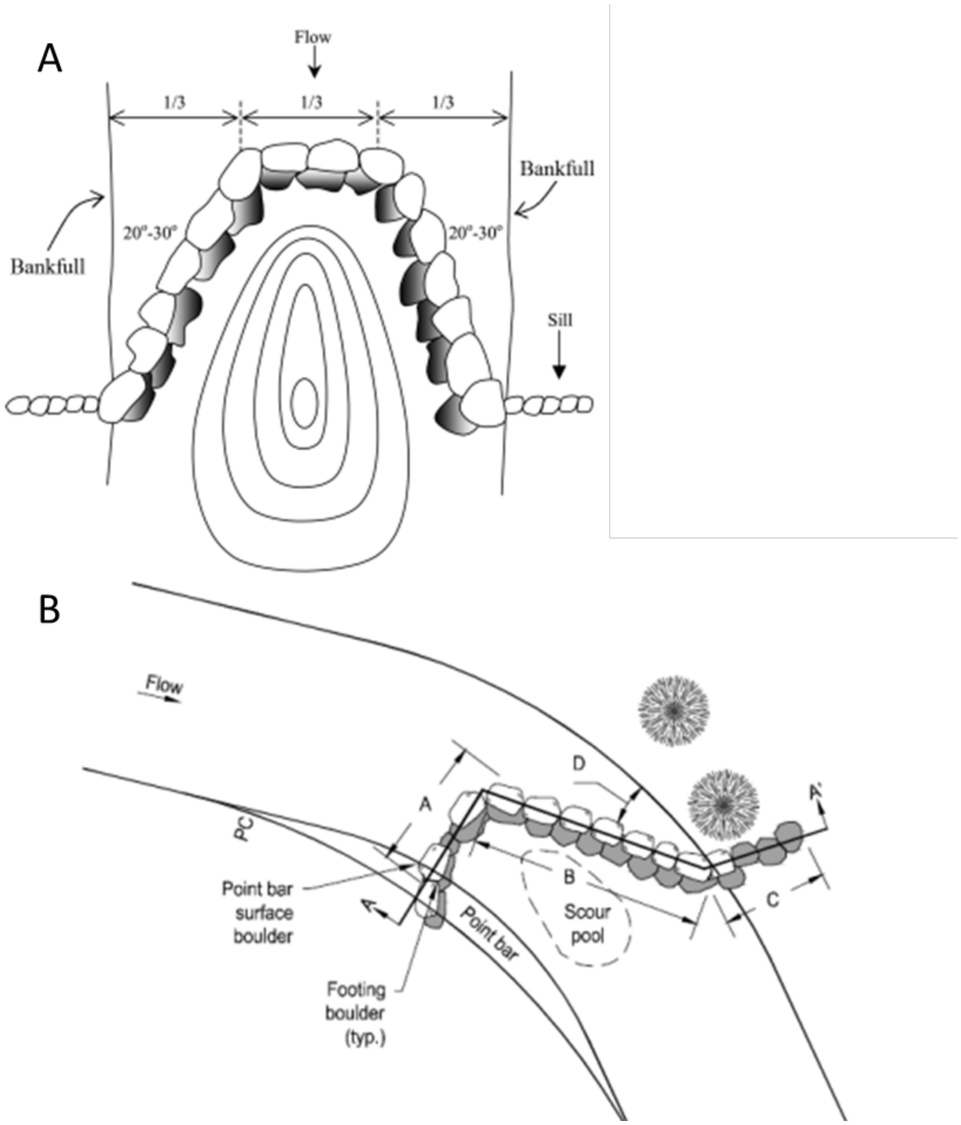



**Figure 1: Illustrations of riffle bar cross-vanes and J-hook vanes**

## 3.2 Hydraulic Impediment Removal

Impediments such as beaver dams, nonfunctional dams, and blocked culverts can slow down water, which promotes algae and reduces aeration. The removal of these hydrologic impediments would improve DO and reduce algae growth. For example, the North Mill Creek dam impounded Rasmussen Lake, which was listed by Illinois EPA as being impaired for a phosphorus-related impairment due to low DO. Water quality was greatly improved in the stream when the North Mill Creek dam was removed, and the Lake County Forest Preserve District undertook a stream restoration project.

Restored North Mill Creek after Removal of North Mill Creek Dam. Photo Courtesy: Interfluve

## 3.3 Wetland Restoration

Wetland restoration adjoining the stream improves the stream's water quality. Wetland restoration can help to maintain stream baseflow, provide waterway shading, promote retention of sediment and other particulates, stabilize shorelines and stream banks, and support nutrient uptake. The Lake County Wetland Restoration and Preservation Plan (WRAPP) identifies and assesses the functional significance of existing and potentially restorable wetlands in Lake County, Illinois (Lake County SMC 2020). The WRAPP identifies several potentially restorable wetlands adjoining the six stream segments listed as impaired for phosphorus.

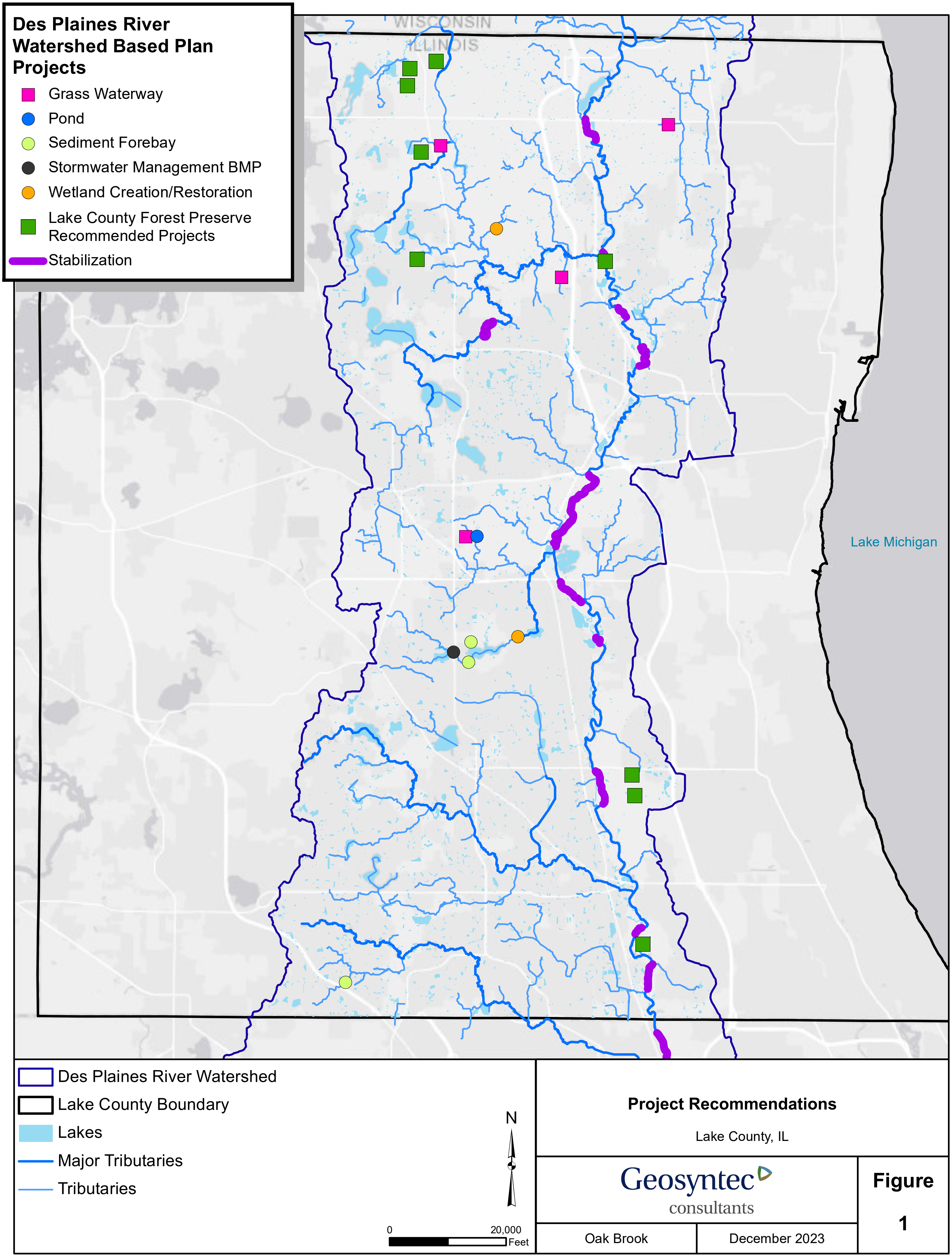
The Lake County Forest Preserve District is currently working on several projects in the NARP study that include stream remaindering, wetland restoration, upland restoration, and linear feet of drain tile disablement. These projects are anticipated to reduce phosphorus loading to the stream and improve stream habitat. **Table 3** provides a summary of these projects.

The location of recommended projects in this Appendix are shown in **Figure 2** below.

### Table 3: Recommended Projects from Lake County Forest Preserve District

| Project/Site | Cost ($) | Miles of Stream Remeandered | Estimated Wetland Restoration (Acres) | Estimated Upland Restoration Acres | Linear Feet of Drain Tile Disablement (Proposed) | Comments/Notes |
|---|---|---|---|---|---|---|
| Dutch Gap Forest Preserve | ~15,000,000 | 1.0 | 250 | 535 | 83,050 | Awaiting final plans from USACOE |
| Raven Glen Forest Preserve | TBD | 0.7 | 150 | 250 | 21,700 | Awaiting final plans from USACOE |
| Ryerson Conservation Area | ~15,000 | NA | 15 | 1 | 645 | LCFPD project, expected to begin winter 2023 |
| Grainger Woods Conservation Preserve (SMC WMB mitigation) | ~345,000 | NA | 44 | 8 | 3,785 | LCFPD project, expected to begin winter 2023 |
| Prairie Stream Forest Preserve (wetland mitigation) | TBD | NA | TBD | TBD | 9,050 | Wetland Mitigation to be performed by RES; awaiting final plans from consultant |
| Prairie Stream Forest Preserve (Army Corps project) | TBD | NA | 90 | 175 | 19,900 | USACOE has not started planning this project yet. Project will encompass the entire site (with the exception of the Wetland Mitigation project areas listed above). |
| Sedge Meadow Forest Preserve (Army Corps | TBD | TBD | TBD | TBD | NA | USACOE has not started planning this project yet. Project will encompass the entire site. |

| Project/Site | Cost ($) | Miles of Stream Remeandered | Estimated Wetland Restoration (Acres) | Estimated Upland Restoration Acres | Linear Feet of Drain Tile Disablement (Proposed) | Comments/Notes |
|---|---|---|---|---|---|---|
| project and/or America The Beautiful grant) | | | | | | |
| McDonald Woods Forest Preserve (SMC – STOCIP project to address failing storm sewer) | TBD | 0.25 – this is an exiting intermittent stream/ravine system that will be restored; however plans are still in development, remeandering may/may not be included in final plans, i.e. TBD | TBD | TBD | 0.0 | Project still in development; proposed project will address failing stormwater outfall that is impacting a 'ravine' at this preserve. Location map is attached. |
| Grainger Woods Conservation Preserve (Equestrian Stable Area) | ~500,000 | NA | 38 | 48 | 9,975 | Current land use (horse stable) will continue through 2027; expect to begin restoration after 2027; project area includes all of Grainger Woods north of the SMC-WMB project listed above. |

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## 4. REFERENCES

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