APPENDIX A
STUDIES CONDUCTED POST 2015 FRIP

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Introduction

The Fox River Study Group (FRSG) and other organizations have conducted several studies since the 2015 FRIP submittal. The FRSG has included the description of these studies in its annual reports to the Illinois Environmental Protection Agency (EPA) since 2018 *(Attachment 1: FRSG Annual Reports*). These studies were used to support the development of the 2022 FRIP and are briefly described below.

Studies Undertaken by the FRSG

United States Geological Survey Sonde Studies

The 2015 FRIP model showed low dissolved oxygen (DO) issues at the tailwater of Algonquin Dam. To assess whether this issue exists in reality, FRSG contracted with the United States Geological Survey (USGS) in 2016 to install and maintain a water quality monitoring station at the existing Algonquin gaging station (USGS 05550001 Fox River at Algonquin, IL) from spring through fall for three years. The USGS added DO, temperature, specific conductance, and pH to the existing stage and discharge measurements from June 30, 2016, and provided real-time, publicly available data. The water quality data collection at this location ended in October 2018.

After discussions with Geosyntec Consultants (Geosyntec) regarding the data needed for the 2015 FRIP model updates, the FRSG contracted with the USGS to install a new water quality monitoring station in August 2018 at the Stratton Dam (USGS 05549500 Fox River near McHenry). The same parameters above, plus total chlorophyll and turbidity, are collected at the new station. The USGS also collects discrete measurements at the Stratton Dam gaging station to characterize the upstream boundary condition. The discrete samples are collected every month during station equipment calibration. They are analyzed for chlorophyll-*a*, Nitrogen-Ammonia (NH3-N), Nitrogen Nitrate + Nitrite (NO2+NO3), Total Nitrogen (includes filtered organics, TN), Phosphate-Orthophosphate (PO4-P), and Total Phosphorus (TP). The FRSG intends to continue to fund the data collection at this gage.

Carpentersville Dam Pre-removal Studies

The FRSG worked with several agencies and consultants to conduct pre-dam removal studies for the Carpentersville Dam to document the impact of its removal. The Carpentersville Dam is owned by the Forest Preserve District of Kane County (FPDKC). The FPDKC is leading the efforts for its removal, currently scheduled in 2023, contingent on the approval of required permits.

During the summer of 2020, Illinois Department of Natural Resources (DNR) fisheries biologists conducted fish surveys above and below the dam. Illinois EPA biologists monitored macroinvertebrates. Both agencies carried out these studies as an in-kind contribution to this study.

The FRSG also contracted with the Illinois Natural History Survey (INHS) to conduct a mussel survey before removing the dam. Mussel field surveys were conducted in the summer of 2021 at three sites – one impact site at the Carpenter Dam location, one reference site upstream of the dam near Algonquin, and one reference site downstream of the dam near West Dundee. The INHS field sampling results were presented at the FRSG annual meeting on November 2, 2021. The INHS scope of work also includes mussel tagging during dam removal and subsequent tracking and other post-removal studies in the future.

The FRSG hired Deuchler Engineering Corporation (Deuchler) to conduct pre-removal water quality monitoring in the dam pool and at an upstream free-flowing stretch of the river (Deuchler, 2021). The water quality monitoring consisted of continuous and discrete measurements at the two locations from July 22 to October 27, 2022. Continuous measurements of DO, pH, temperature and specific conductivity were taken at 15-minute intervals using a multimeter water quality sonde (YSI EXO3). The upstream location sonde also included an EXO Total Algae PC Sensor that collected total algae and blue-green algae data. Deuchler collected six water quality samples at both locations during the study period that were analyzed for Biochemical Oxygen Demand (BOD), chlorophyll-*a* (sestonic), TP, dissolved phosphorus, TKN, NH3, NO2, NO3, total suspended solids, volatile suspended solids, chloride, and turbidity. Deuchler also conducted benthic algae sampling at the upstream location during each of the six sampling visits. The study found higher diurnal DO fluctuation in the dam pool compared to the upstream location. In addition, relatively high levels of benthic algae ranging from 240 to 420 micrograms per liter (µg/L) were reported for the upstream location.

The FRSG plans to undertake similar studies post-removal of the Carpentersville Dam.

FRSG Monthly Monitoring Studies

The FRSG conducts monthly discrete water quality sampling at seven mainstem locations and seven tributary locations along an 80-mile stretch of the Fox River from McHenry to Yorkville. Citizen volunteers and staff from other wastewater facilities participate in the data collection. Laboratory analysis and data management are donated as in-kind services by the City of Elgin, the Fox River Water Reclamation District, and the Fox Metro Water Reclamation District (FMWRD). The samples are analyzed for DO, pH, conductivity, temperature, and turbidity. The collected samples are analyzed for BOD, chlorophyll-*a*, NH3-N, NO2+NO3, TN, TP, Dissolved Phosphorus, chloride, and turbidity. These data have been utilized to support the modeling efforts over the years. The Illinois State Water Survey (ISWS) updates the FoxDB for the FRSG, a publicly available online water quality monitoring database found at ilrdss.sws.uiuc.edu/fox/. The ISWS is currently in the process of updating the FoxDB database with more recent data. The FRSG data was utilized to support the development of the current FRIP.

FRSG Low-Flow Intensive Monitoring

The FRSG conducted an intensive low-flow monitoring program at six locations in the mainstem Fox River in 2016 to support the modeling efforts. The monitoring effort included continuous monitoring of DO, temperature, pH, and specific conductance over several days. Discrete water quality samples were collected on September 6 and 7, 2016, and analyzed for sestonic chlorophyll-*a*, NH4, NO3, and TP. Riverbed samples were also collected during the same period and analyzed for benthic algae. An issue with the chlorophyll-*a* measurement technique of a third-party laboratory resulted in inaccurate measurements of sestonic and benthic algae. This is described in *Appendix D: Fox River Water Quality Modeling Update.*

FMWRD Monthly Monitoring and Sondes

Deuchler Engineering Corp (Deuchler) collected monthly grabs samples for the FMWRD at four (4) locations along the Fox River. The FMWRD lab analyzed the samples for BOD and nutrients. Deuchler also maintains continuous water quality sondes at Sullivan Road, North Ave., Ashland Ave., and Route 34 locations in the Fox River that measure DO, pH, temperature, specific conductance, and total algae. A sensor for measuring total chlorophyll-*a* and blue-green algae was recently added to the Orchard Road and Route 34 stations.

Illinois Fish Tissue Contamination Data Analysis

The Illinois Department of Public Health (IDPH) issued an updated consumption advisory for sport fish caught in Illinois waters on May 22, 2018. This advisory indicated that polychlorinated biphenyl (PCB) remained a contaminant of concern for the common carp, channel catfish, and the freshwater drum in the Fox River. In response to the advisory, the FRSG requested fish tissue analysis data from the Illinois EPA for the entire length of the Fox River in Illinois. Illinois EPA provided the FRSG with results of tissue studies from 2000, 2002, 2007, and 2012 (partial results). The FRSG analyzed the data and concluded that the PCB levels have decreased in fish from the Fox River. In addition, the 2012 PCB levels in the fish are below the US Food and Drug Administration (FDA) advisory levels for “Infant and Junior Foods” of 0.200 µg/L. FRSG summarized these findings in a January 31, 2019, letter to IDPH. The letter requested IDPH to reconsider the consumption advisory for the Fox River based on the analysis.

Public Outreach Efforts on Dam Removal Opportunities

The FRSG undertook several efforts to understand public thoughts and feelings about the Fox River and its dams. These efforts also informed the Fox River watershed community on dam removal opportunities currently available from the Illinois DNR Dam Safety Fund and likely in the future from the US Army Corps of Engineers (USACE).

The FRSG initially contracted with Bluestem Communications in 2018 for public outreach efforts. In 2018, Bluestem met with three focus groups to assess public opinion on dam removals. The three focus groups consisted of community members with an interest in economic vitality, community members with an interest in local history, and residents with a property near a Fox River dam. Bluestem also conducted a December 2018 workshop for FRSG members focused on answering the questions that the public has about potential changes to the river and its dams, which included ideas on creating messages that resonate with residents. Bluestem also prepared a final report on these efforts (Bluestem, 2018).

The FRSG also contracted with Aileron Communications to perform public outreach messaging, branding for the FRSG, and a survey. Aileron conducted a phone survey of residents' attitudes toward the Fox River in February 2020. Findings included that 46 percent think the Fox River is somewhat or very polluted and 23 percent think the Fox River is somewhat or very unsafe for paddling, fishing, or recreation. The FRSG, working with Aileron, prepared and released a general factsheet on dam removal in 2021 (*Attachment 2: Removing Dams Restores the Fox River*).

Other Ongoing Studies Supported by the FRSG

USACE Fox River Connectivity & Habitat Study

The FRSG was instrumental in getting the USACE to restart the Fox River Habitat & Connectivity Study, which was placed on hold in August 2015 due to the lack of a State of Illinois budget. Illinois DNR is the local sponsor of the study. The FRSG entered into a Joint Funding Agreement with Illinois EPA to reimburse Illinois DNR for the local share of the study costs. The FRSG has also participated in several meetings with the USACE since the restart of the study and will work with the USACE on public outreach for dam removal.

Subwatershed Studies

The FRSG supported the Chicago Metropolitan Agency for Planning in developing Watershed-Based Plans for the Mill Creek and Indian Creek subwatersheds. The FRSG provided additional funding for updating hydrologic and water quality models used for plan development. In addition, several of the FRSG members served on the Technical Advisory Committees for these plans.

References

Bluestem (2018). Public Sentiment of the Fox River and its Dams: Findings from Three Focus Groups

Deuchler (2020). Pre-Carpentersville Dam Removal Water Quality Study Sampling. Deuchler Engineering Corporation, November 13, 2020.

Attachments

1. FRSG Letter to IDPH
2. Removing Dams Restores the Fox River

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Attachment 1:

FRSG Letter to IDPH

Fox River Study Group

682 Rt. 31, Oswego, IL 60543
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January 31, 2019

Director Nirav D. Shah
Illinois Department of Public Health
122 S. Michigan Avenue, 7th and 20th Floors
Chicago, IL 60603

RE: State Health Department Fish Advisory for the Illinois Fox River

Dear Dr. Shah,

On May 22, 2018 your department issued an updated consumption advisory for sport fish caught in Illinois waters. This advisory indicated polychlorinated biphenyl (PCB) remained a contaminant of concern for the common carp, channel catfish and the freshwater drum. It is the purpose of this letter to question whether these advisories remain appropriate for the Fox River and, if not appropriate, to seek the lifting of those advisories.

On July 16, 2018 Ms. Karen Clementi of Deuchler Environmental submitted a Freedom of Information request (FOIA) to the Illinois EPA seeking data regarding fish tissue analyses along the entire length of the Fox River in Illinois. On July 23, in response to that request, Anwar Johnson of IEPA returned a spreadsheet with results of tissue studies from 2000, 2002 and 2007.

Subsequent to receiving the data requested from Mr. Johnson, further information was provided by IEPA’s Brian Koch including an October 2 transmittal of the latest fish tissue data. The October 2 transmittal included partial results from the 2012 “catch”. The remainder of the 2012 analyses as well as the 2017 analyses have yet to be processed. We are grateful for the cooperation received from IEPA and hope we will soon receive the results of the pending laboratory work.

Our analysis of the fish tissue data from the 1974 sampling through the partial 2012 data set is summarized on the attached three graphics. What the data appear to show is PCB levels have been in a clear downward trend from 2000 to 2012. It appears that as of 2012 PCB levels in the Fox’s fish are below the USFDA advisory levels for “Infant and Junior Foods” of 0.200 µg/L. If these data are confirmed by the pending 2017 survey, will the IDPH reconsider the listing of fish from the Fox River as contaminated with PCBs?

A number of questions have arisen as we have reviewed the available data. Would you be able to answer them for us?

- What are the threshold contaminant levels that the Illinois Fish Contaminant Monitoring Program (IFCMP) uses to list each parameter?
- What are the specific criteria used to create the listings?
- How the lipid levels are used in the assessment?

The Fox River Study Group has worked for nearly 20 years with the scientific and engineering communities to provide our stakeholders with science-based analysis and decision making towards the end of meeting national water quality goals for the Fox. Our reading of the fish tissue data received to-date from IEPA suggests after a century of water pollution control efforts a milestone may have been reached where its fish no longer need to be listed as contaminated with PCBs.

We would appreciate the cooperation of your office in the review of your May 22 finding as it relates to the Fox River and PCB levels in its fishes, and work towards a timely update, if appropriate. It is our belief that our work towards fixing the Fox River would best be served by public awareness and celebration of the successes achieved to date. Lifting of the fish advisory would be an important milestone towards that end.

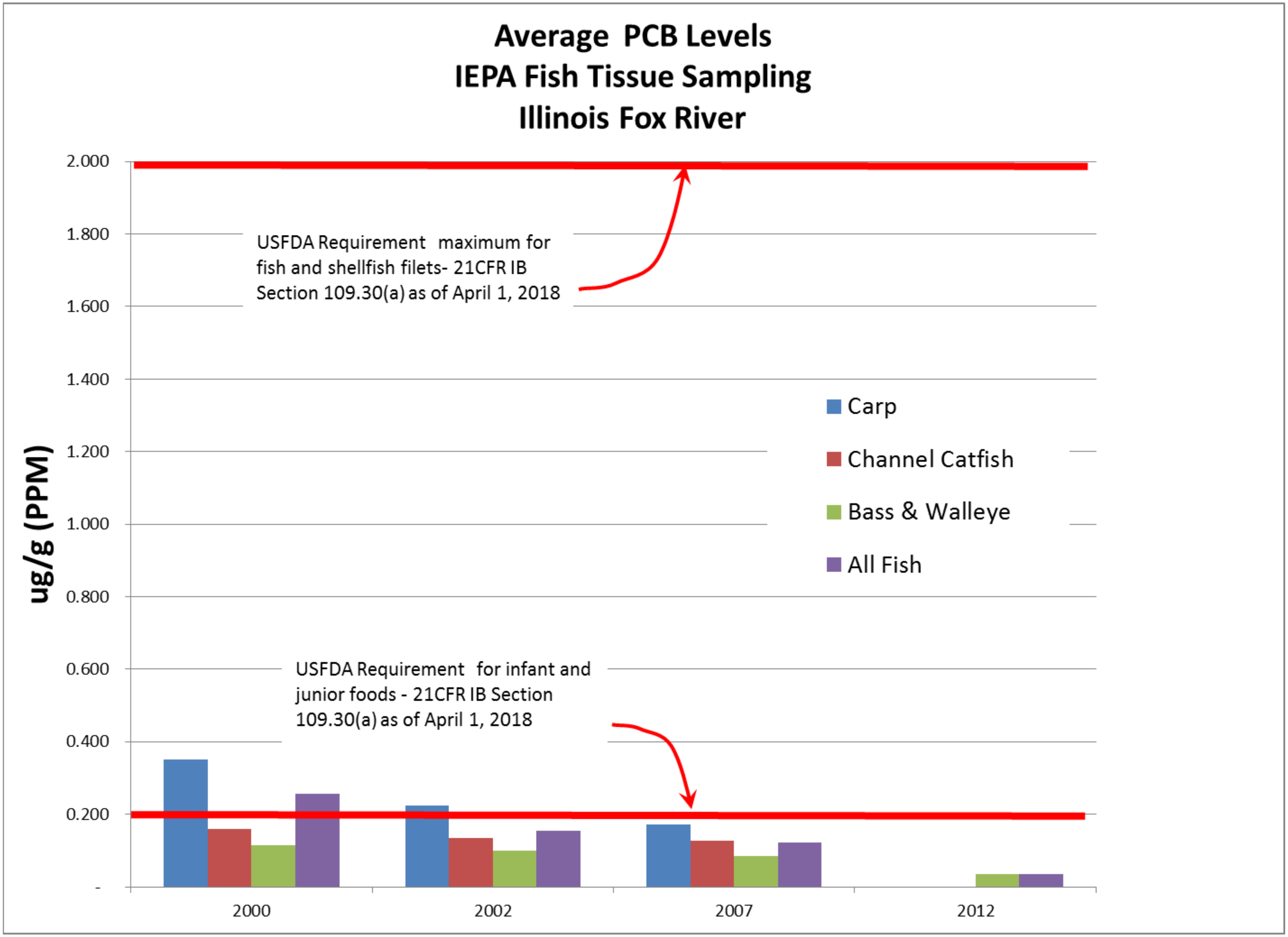
Thank you for your attention to this matter. If appropriate, board members of the Fox River Study Group will be available to meet with your staff to discuss concerns and a plan to move forward.

Sincerely,

Art Malm PE, Board member
Karen Clementi, Consultant to the Board
Cindy Skrukrud PhD, Chair

info@foxriverstudygroup.org

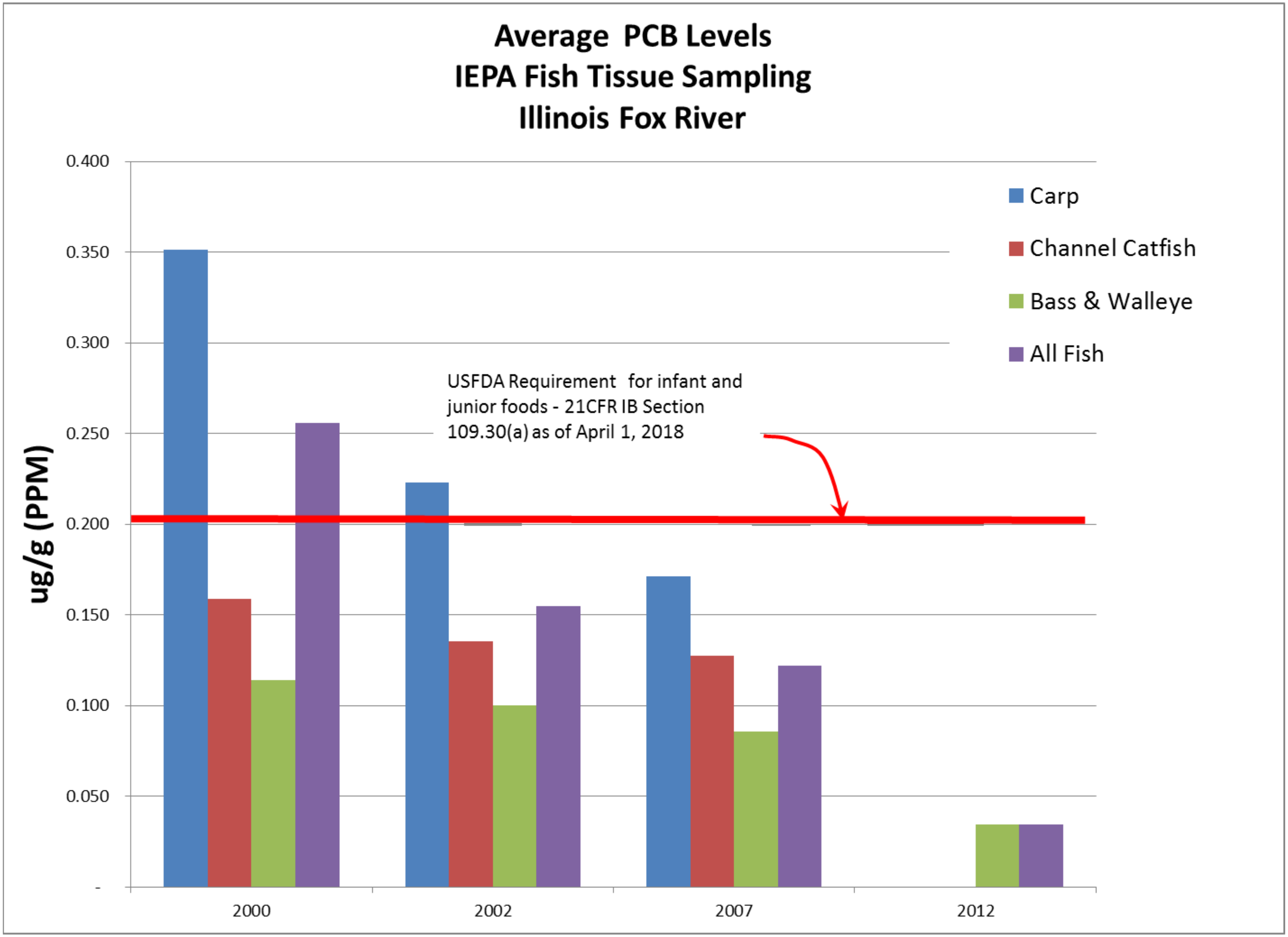
cc: Brian Koch, IEPA *via email to brian.koch@illinois.gov*



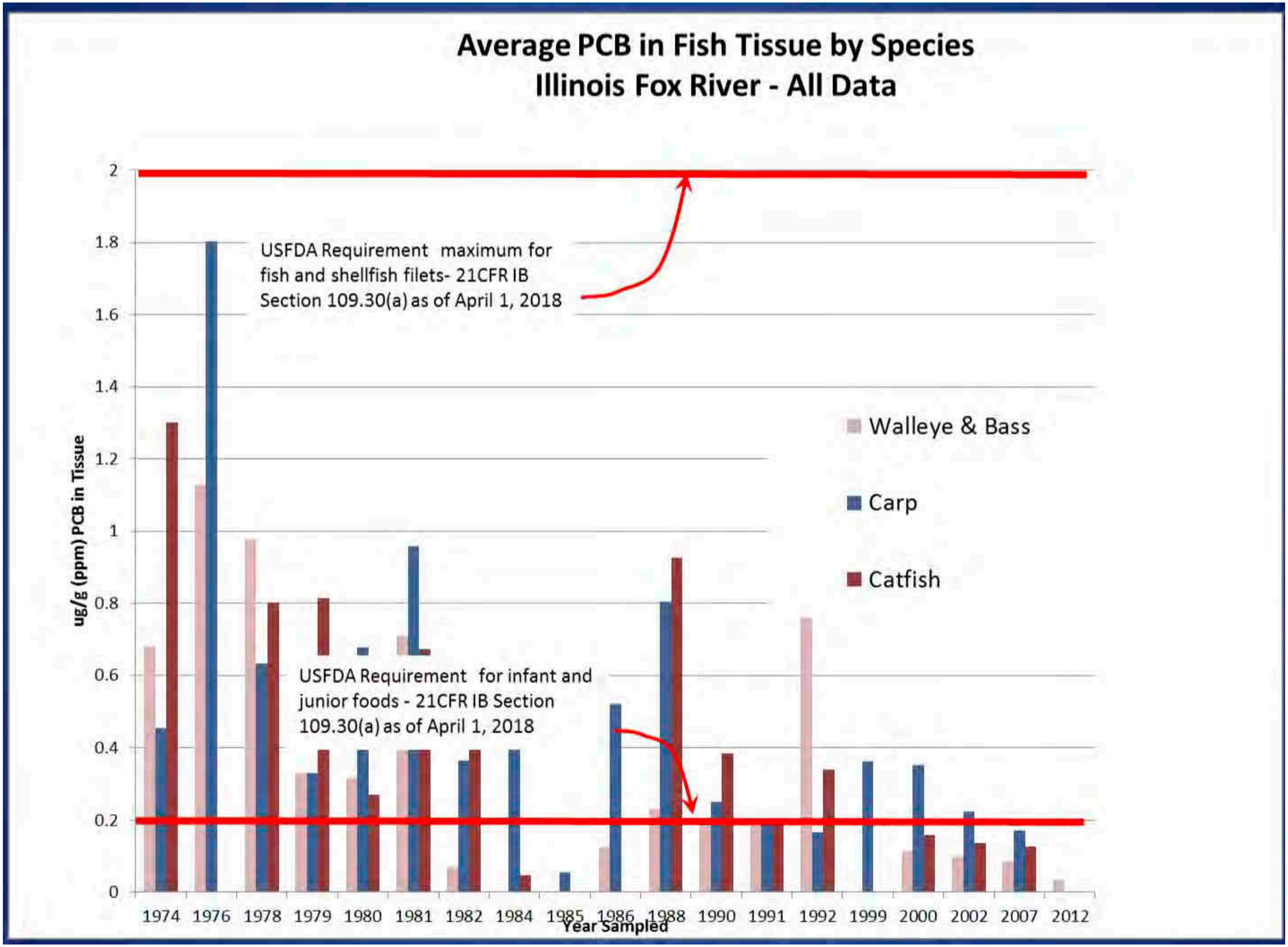
Average PCB Levels
IEPA Fish Tissue Sampling
Illinois Fox River

USFDA Requirement maximum for fish and shellfish filets- 21CFR IB Section 109.30(a) as of April 1, 2018

USFDA Requirement for infant and junior foods - 21CFR IB Section 109.30(a) as of April 1, 2018



USFDA Requirement for infant and junior foods - 21CFR IB Section 109.30(a) as of April 1, 2018



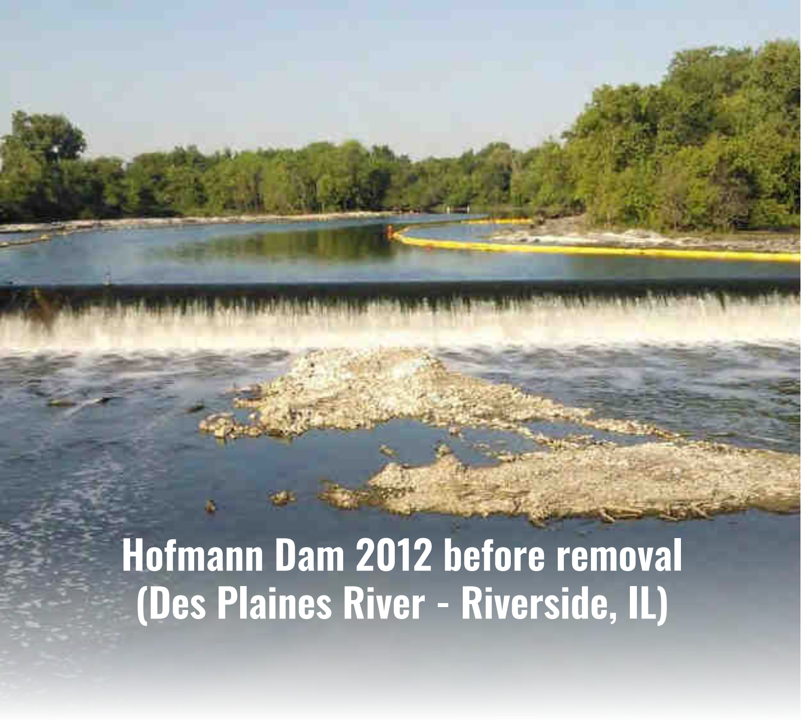
Average PCB in Fish Tissue by Species
Illinois Fox River - All Data

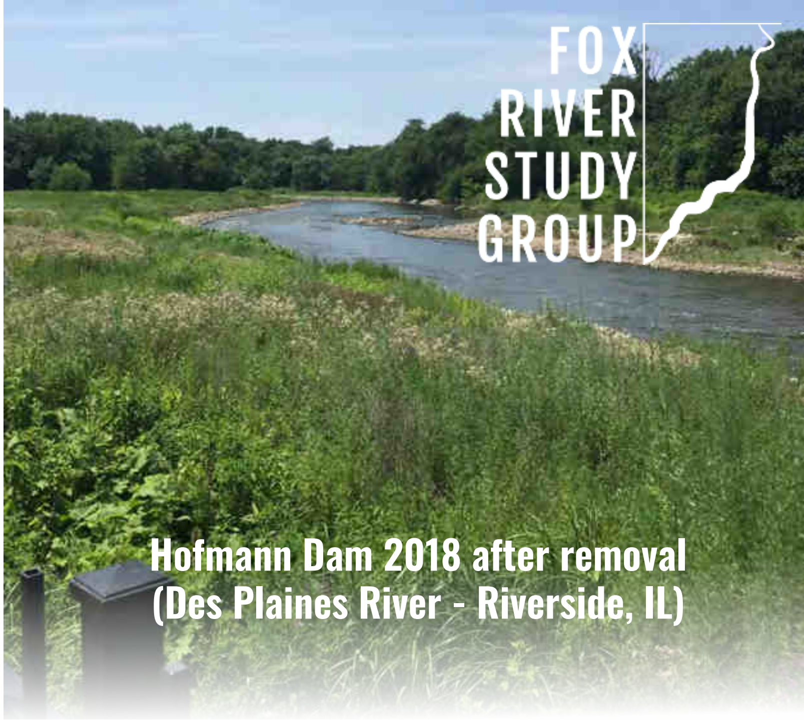
USFDA Requirement maximum for fish and shellfish filets- 21CFR IB Section 109.30(a) as of April 1, 2018

USFDA Requirement for infant and junior foods - 21CFR IB Section 109.30(a) as of April 1, 2018

Attachment 2:

Removing Dams Restores the Fox River


Hofmann Dam 2012 before removal
(Des Plaines River - Riverside, IL)



Hofmann Dam 2018 after removal
(Des Plaines River - Riverside, IL)

Removing Dams Restores the Fox River

The Fox River is a source of drinking water, a hub for recreation and a key landmark in communities that nearly one million people call home. The biggest threats to water quality, safety and recreation on the Fox River today are obsolete dams. Removing dams that no longer serve a purpose will protect our health, save us money and benefit the environment.

Dam removals improve water quality in the Fox River, which supplies drinking water to over 300,000 people.

Removing dams resolves a major cause of algae blooms and sedimentation, which cause oxygen depletion and the buildup of organic pollution that strains local water treatment plants. Removing dams helps rivers keep themselves clean and helps ensure we will always have a dependable source of clean drinking water for communities in the Fox River watershed.

Dam removal can save lives and improve public safety.

Dams on the Fox River have caused dozens of drownings and many more near-fatal accidents. Our local leaders can improve public safety and protect first responders by removing dams.

Dam removals will create a free-flowing river that better supports fish, wildlife and recreation.

Returning the river to a more natural state will immediately benefit the fish, wildlife and natural beauty of the Fox that residents cherish. We have an opportunity to reconnect the Fox River and reestablish its natural flow by removing dams that no longer serve a useful purpose.

Dam removals are necessary to keep utility bills affordable.

Federal laws require that the Fox River meet strict water quality standards. Attempting to meet those standards without dam removals would cost the Fox Valley community an estimated $150 million in new wastewater treatment infrastructure.

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APPENDIX B
CURRENT LOADING SOURCES IN THE WATERSHED

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CURRENT LOADING SOURCES IN THE WATERSHED

Introduction

Geosyntec Consultants (Geosyntec) was tasked by the Fox River Study Group (FRSG) to update the technical memo prepared by the Illinois State Water Survey (ISWS) dated May 20, 2014 (ISWS, 2014). The ISWS memo, which was used to inform the Fox River Implementation Plan, described point and non-point sources contributing to total phosphorus (TP) load in each tributary watershed, downstream of Stratton Dam. The ISWS memo was based on the Hydrologic Simulation Program – Fortran (HSPF) model results for the period of 1990 to 2011. As part of current work for the FRSG, Geosyntec updated these HSPF models for the period of 2011 to 2016 to reflect the existing conditions and hydrology in the watershed. The HSPF model simulates the loading from non-point sources based on calibrated parameters (e.g. wash-off coefficients) documented in Bartosova et al., 2007.

This memo describes the existing point, non-point, and upstream sources contributing to the TP loading downstream of Stratton Dam.

Methodology

TP load presented in this memo include point source loading from major[1] municipal wastewater treatment plant (WWTP) facilities, non-point source loading from surface and subsurface runoff from tributaries and loading from areas upstream of Stratton Dam. Point source loading was estimated using available effluent flow and TP concentration data using the methodology described in *Appendix D: Fox River Water Quality Model Update* (2020). Non-point source TP loading was estimated using the updated HSPF model results and grouped into three categories:

- **Agriculture:** TP load generated from corn and soy land uses specified in the HSPF models
- **Urban runoff:** TP load generated from urban high density, urban low/medium density, and urban open space land uses specified in the HSPF models
- **Other:** TP load generated from forest, rural grassland, surface water, and wetlands land uses specified in the HSPF models

The HSPF model results for the year 2011 are impacted by the model initial conditions and therefore excluded from the analysis. Available instream flow and water quality data was utilized to estimate upstream loading.

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[1] Design flow of greater than 1 million gallons per day (MGD).

Total annual and average annual TP load were calculated from the different sources for the period of 2012 to 2016. Load were summarized for the entire Fox River, Upper Fox River, and Lower Fox River. The Upper Fox is the watershed between Stratton Dam and the confluence of Fox River and Ferson Creek. The Lower Fox is the watershed between the confluence of Fox River and Ferson Creek to the confluence of Fox River and the Illinois River (**Figures 1 and 2**).

Load from projected point sources load were calculated to estimate the impact to upcoming TP effluent limits of mg/L and 0.5 mg/L. Load were calculated by multiplying the timeseries of effluent flow by 1 mg/L and 0.5 mg/L.

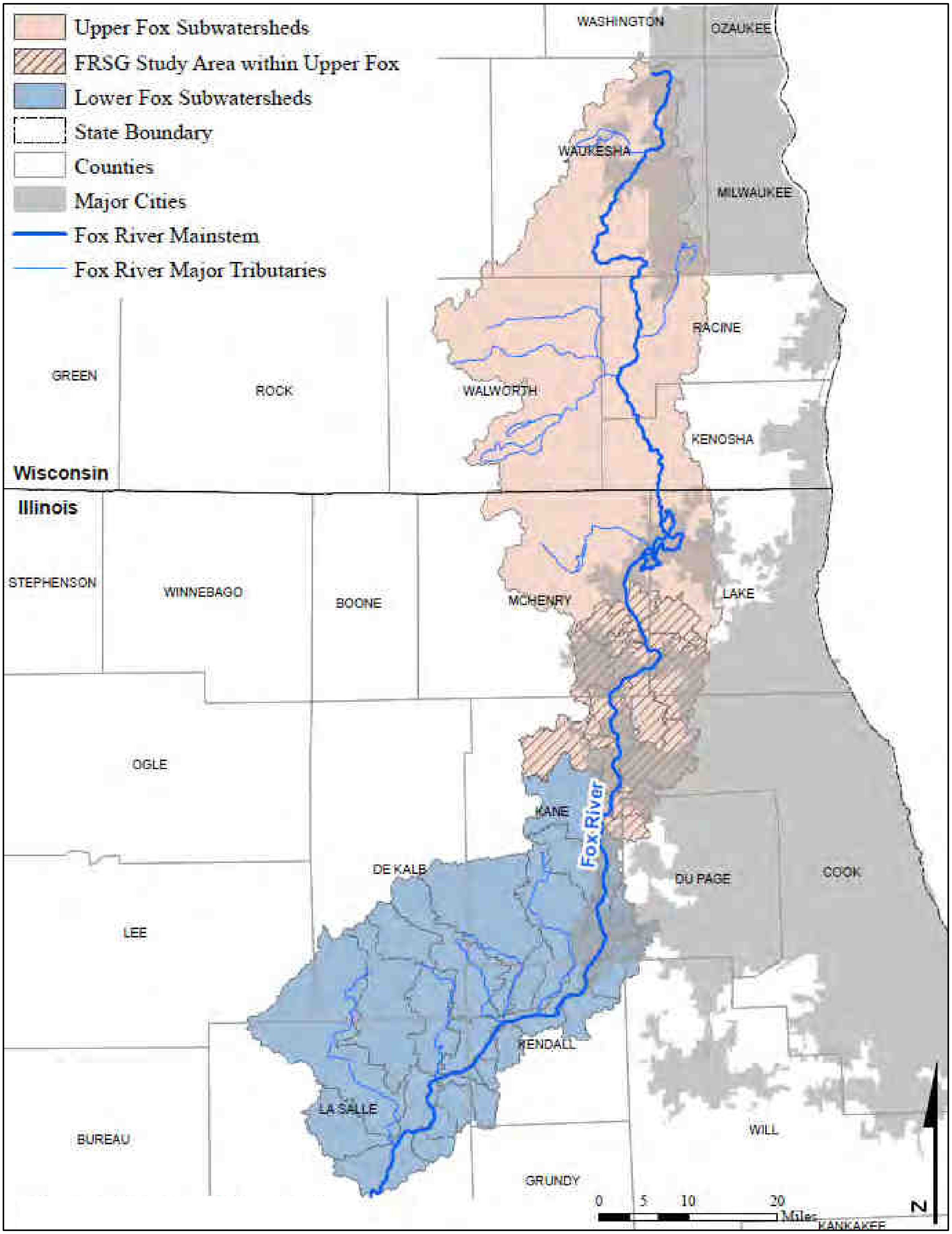

Figure 1: Fix River Watershed

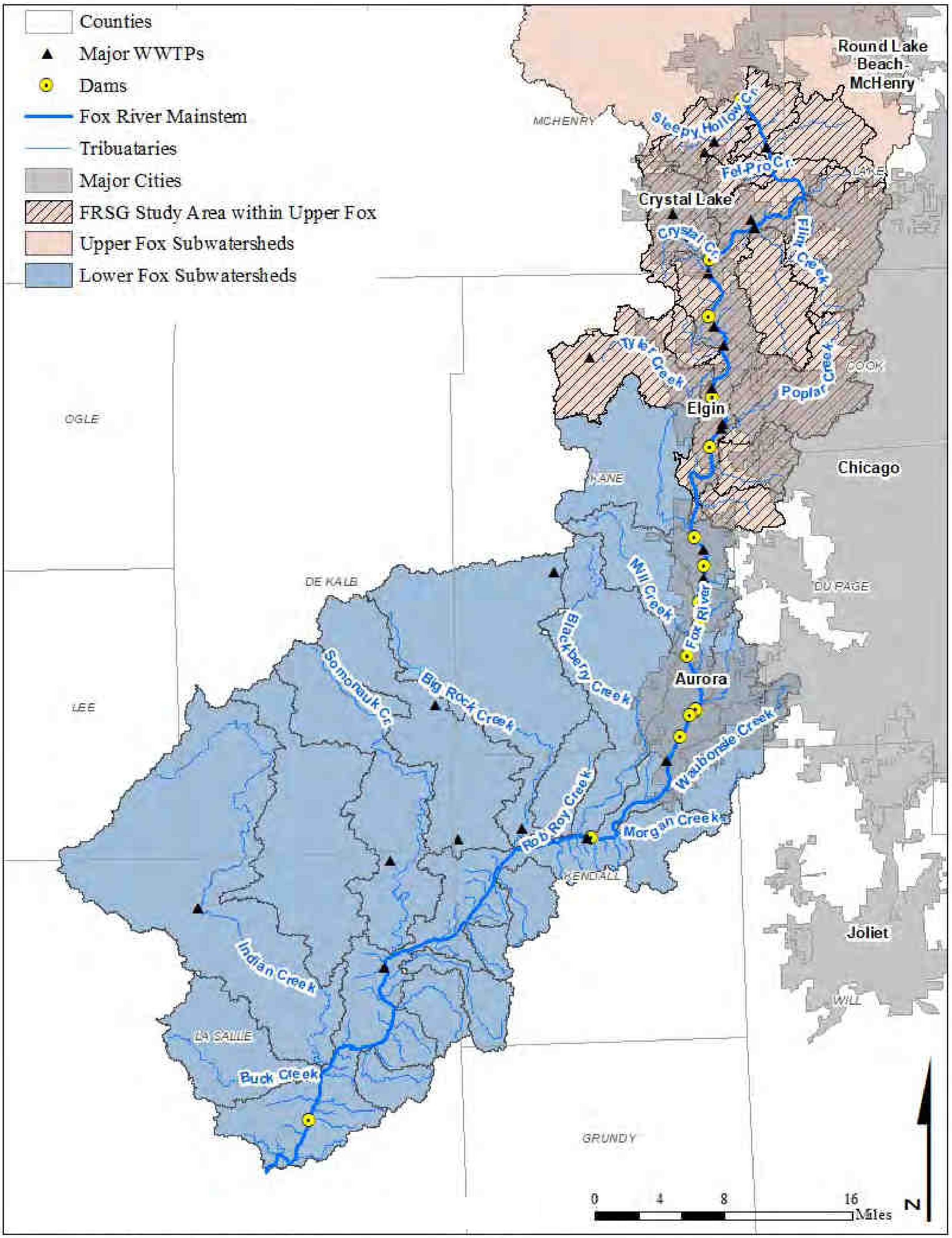

Figure 2: Upper and Lower Fox River Subwatersheds

Results

Figure 3 shows the estimated annual average (2012-2016) TP load from different sources that enter the Fox River watershed. The TP load from the area upstream of Stratton dam (upstream boundary) are 211,801 pounds per year (lbs/yr). The total load to the Upper Fox River watershed (excluding upstream contributions) is 350,796 lbs/yr. The total load to the Lower Fox watershed (excluding upstream contributions) is 1,317,886 lbs/yr. The total TP load for the entire Fox River watershed is 1,880,483 lb/yr.

load

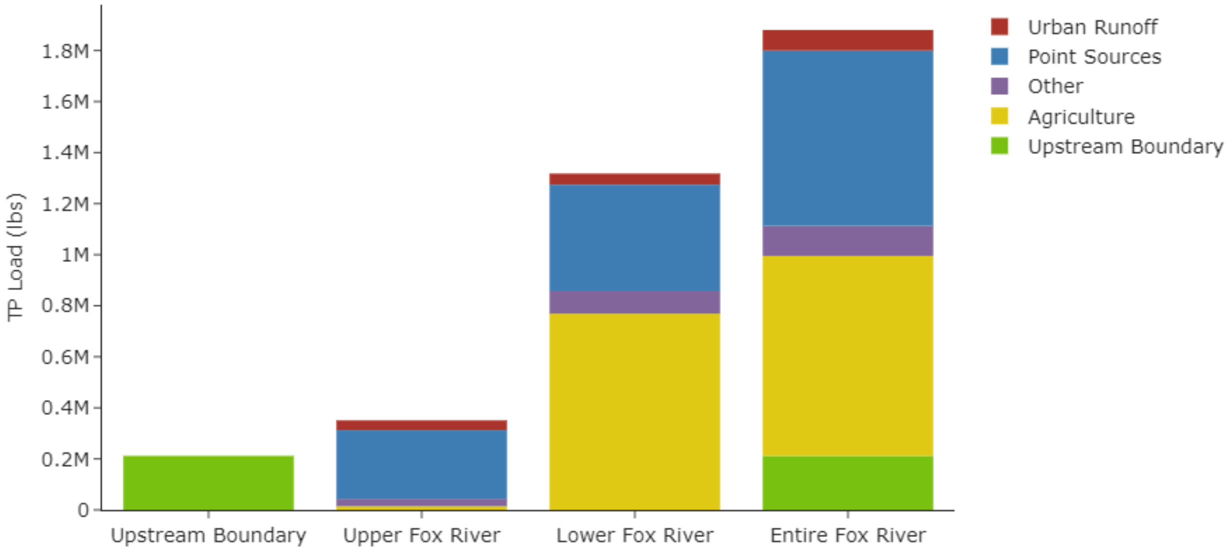

Figure 3: Average Annual TP Load (2012-2016) for Entire Fox, Upper Fox, and Lower Fox River Watersheds

Table 1 provides the percentage contribution from different sources for the Upper, Lower, and entire Fox River watersheds. Approximately 42 percent of the annual TP load entering the Fox River watershed is from agricultural sources, while 37 percent comes from point sources. Urban runoff accounts for only 4 percent of the average annual TP load to the entire Fox River. While agricultural TP load is not significant to the Upper Fox River subwatershed, they account for a significant input of TP load to both the Lower Fox and the entire Fox River. The upstream contributions account for 11 percent of the annual average TP load in the entire Fox River watershed.

Table 1: Percent of TP Load (2012-2016) For Entire Fox, Upper Fox, and Lower Fox

	Upper Fox River	**Lower Fox River**	**Entire Fox River**
Urban Runoff	11%	3%	4%
Point Sources	77%	32%	37%
Other	8%	7%	6%
Agriculture	4%	58%	42%
Upstream	*	*	11%

**Upstream TP input is not represented for Upper and Lower Fox River subwatersheds.*

Figure 4 shows the breakdown of TP load by tributary in the subwatersheds draining to the Upper Fox River subwatershed and its mainstem. Point sources discharging to the mainstem Upper Fox River are the largest contributor of TP load.

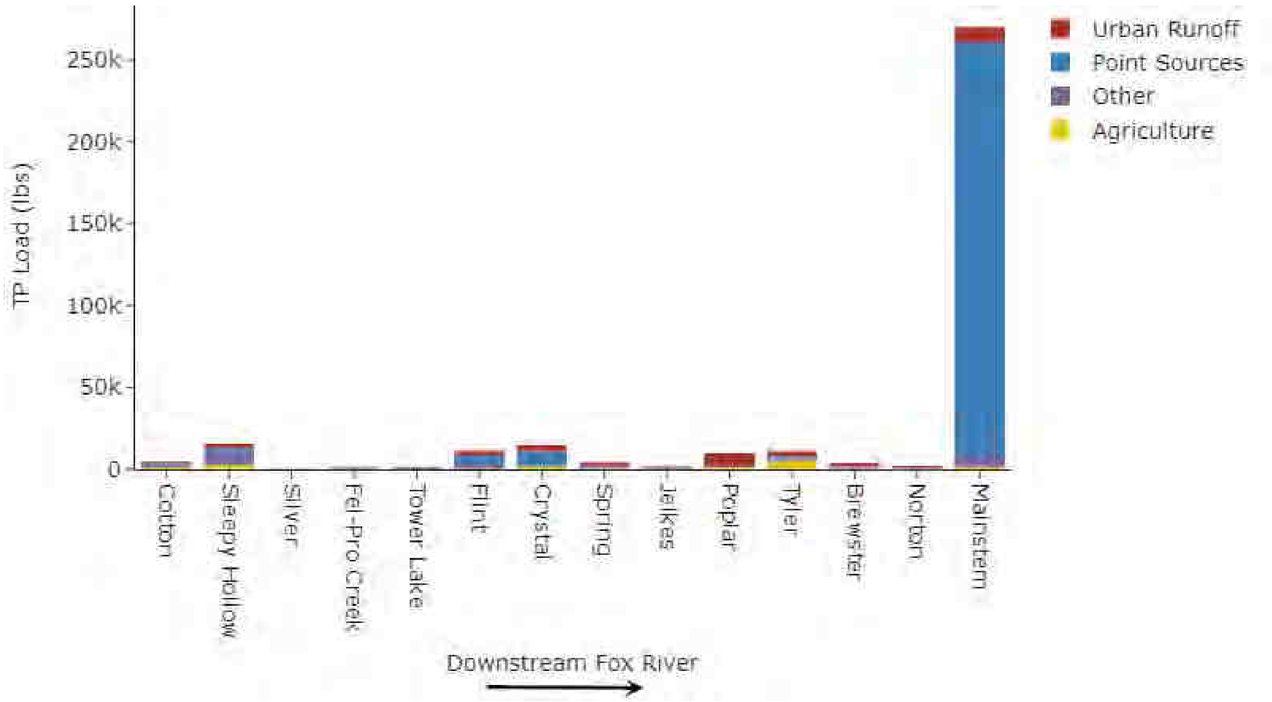

Figure 4: Average Annual TP Load (2012-2016) from Tributaries and Mainstem Discharges to the Upper Fox River Watersheds

Figure 5 shows the distribution of TP load in the Upper Fox tributary subwatersheds (not including the mainstem). Point sources are the largest contributor of TP load in the Flint Creek and Crystal Creek subwatersheds. TP loading in the Poplar Creek, Brewster Creek, Jelkes Creek, and Norton Creek subwatersheds is dominated by urban runoff, while runoff from agriculture sources constitutes the majority of loading in the Tyler Creek subwatershed. Runoff from other land uses (forest, rural grassland, surface water, and wetlands) dominates TP loading in the Sleepy Hollow watershed.

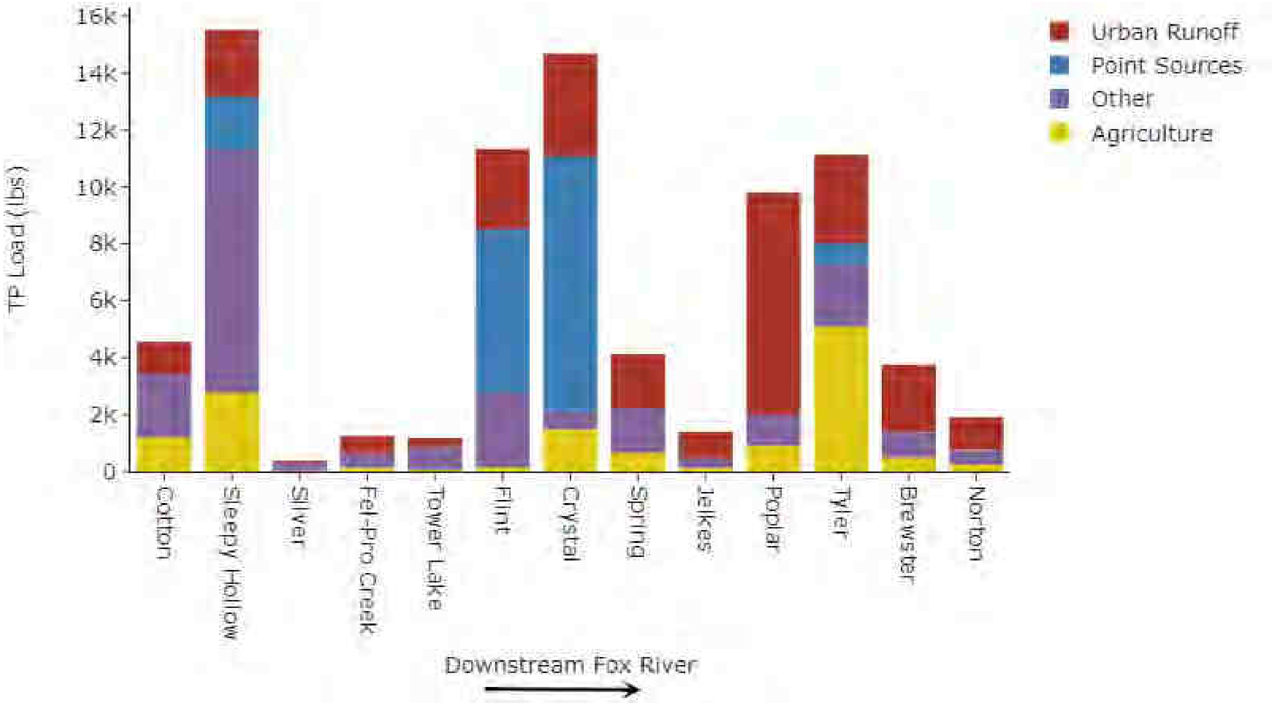

Figure 5: Average Annual TP Load (2012-2016) from Tributaries to the Upper Fox River Watershed

The majority of TP load entering the Lower Fox River watershed originates from agricultural land uses, particularly from the Indian Creek (South) subwatershed (**Figure 6**). The next largest source of TP load is point source discharges to the mainstem.

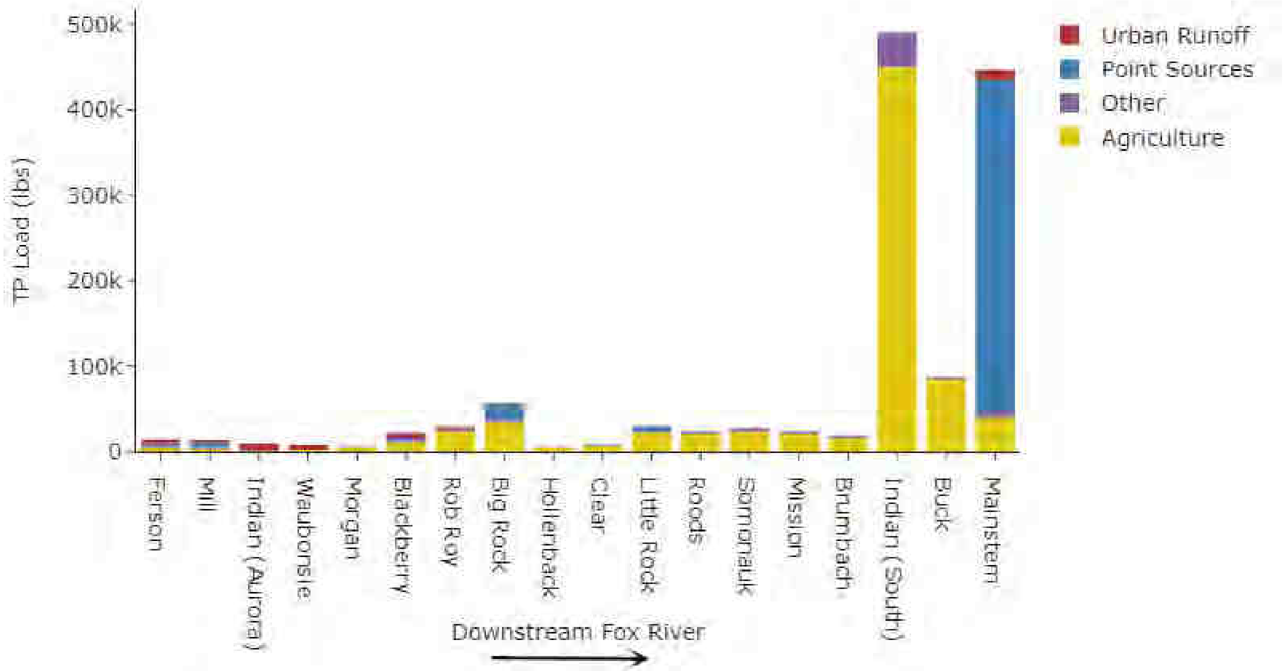

Figure 6: Average Annual TP Load (2012-2016) from Tributaries and Mainstem Discharges to the Lower Fox River Watershed

Figure 7 shows the distribution of TP load to all of the tributaries to the Lower Fox River watershed, with the exception of Indian Creek (South) which is omitted due to the size of the load. As discussed above, the predominant source of TP load is agriculture, with the exception of the Mill Creek and Indian Creek (Aurora) subwatersheds, where urban runoff and point sources respectively are the largest contributors. Point sources in the Mill Creek, Big Rock, and Little Rock subwatersheds have noticeable contributions to total TP load.

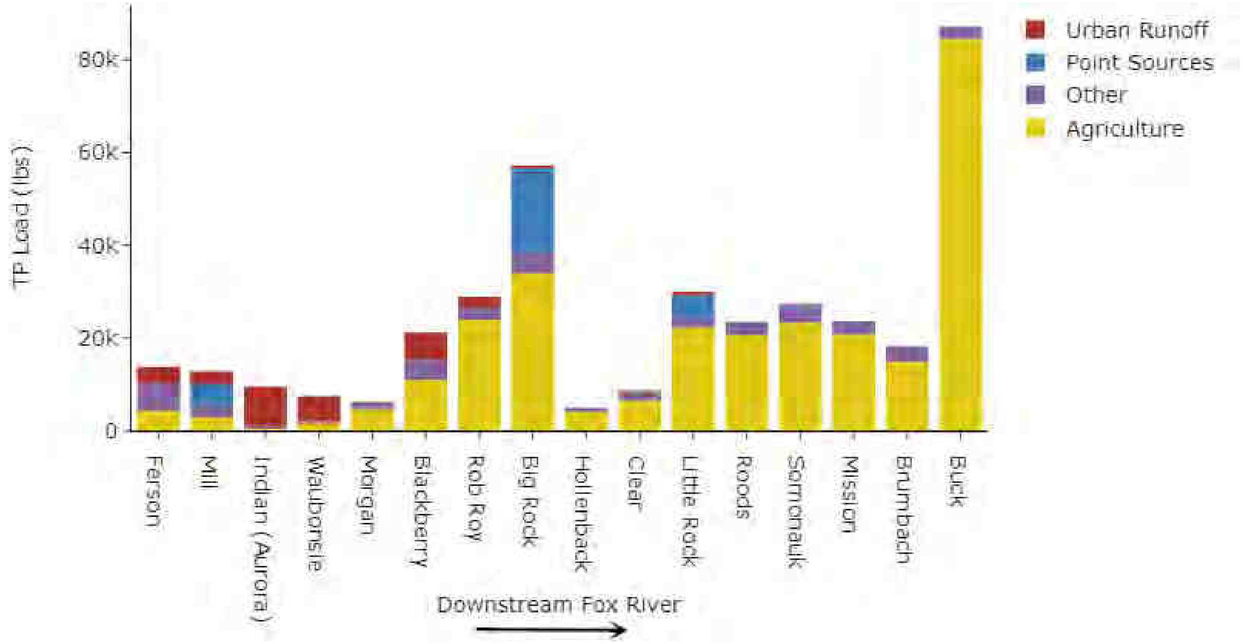

Figure 7: Average Annual TP Load (2012-2016) from Selected Tributaries to the Lower Fox River Watershed

Figure 8 shows the distribution of TP load to all of the tributaries to both Upper and Lower Fox watersheds. Lower Fox watershed TP load contribution is generally higher than the Upper Fox watershed, especially from agriculture land uses.

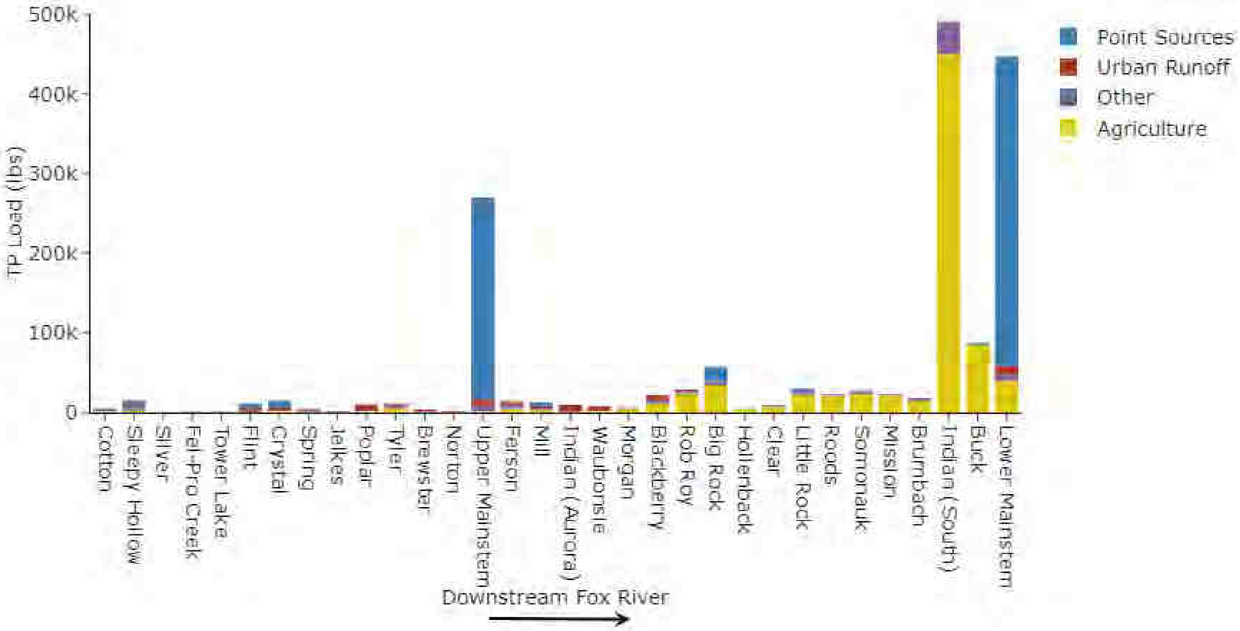

Figure 8: Average Annual TP Load (2012-2016) from Tributaries and Mainstem Discharges to the Fox River Watershed

Figure 9 compares the percentage contribution of different sources based on 2012-2016 estimated annual average with the projected TP load for meeting WWTP effluent limits of 1 mg/L and 0.5 mg/L, respectively. The estimated load for agriculture, other and urban runoff was not updated for the projected load under this analysis. Results are presented for the entire Fox River, Upper Fox, and Lower Fox watersheds. These results show that the relative contribution of point sources to total TP load has decreased in recent years (2012-2016) and will be reduced significantly with anticipated WTTP upgrades to meet TP effluents limits of 1 mg/L and 0.5 mg/L.

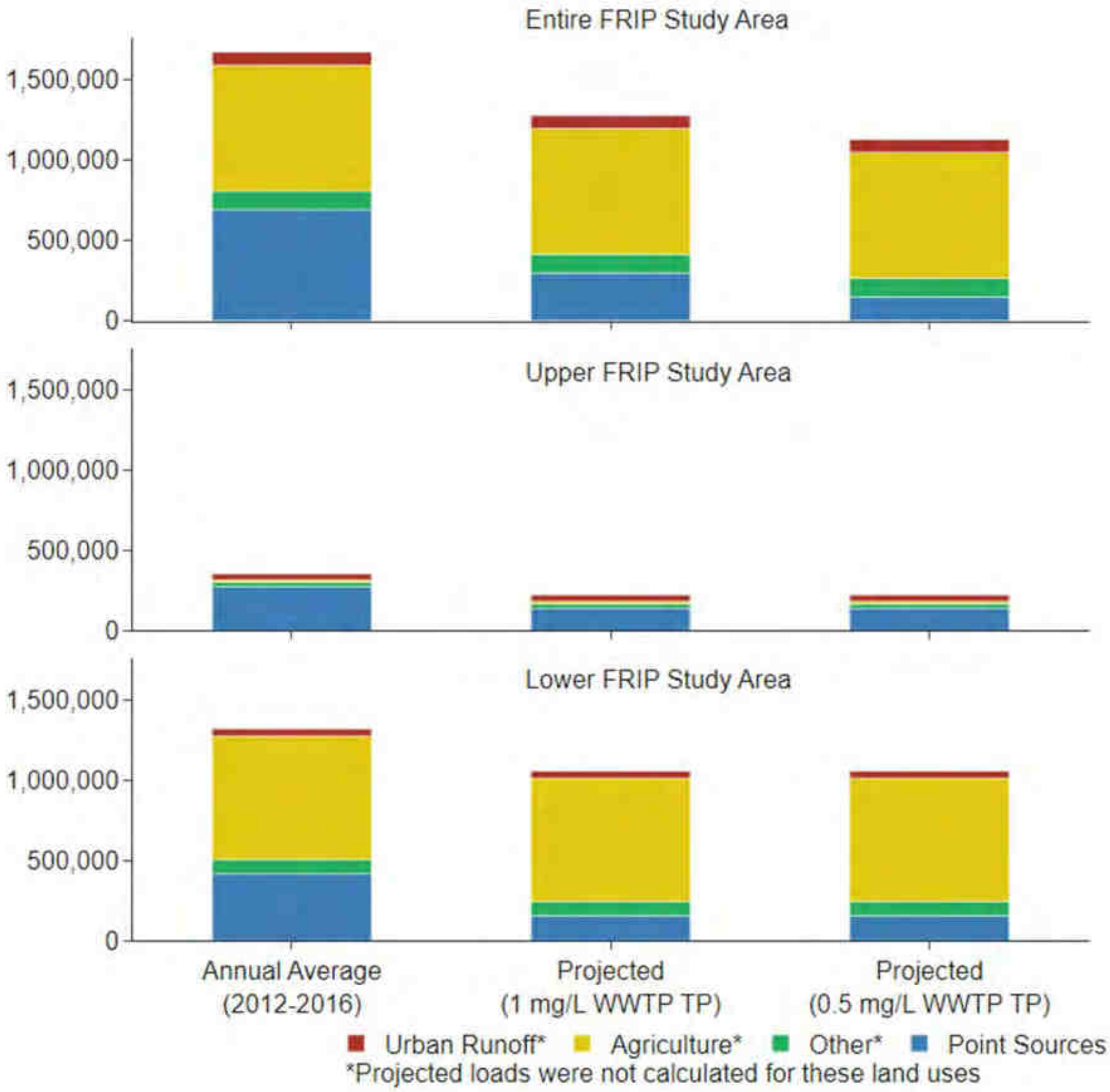

Figure 9: Estimated percentage of Total Phosphorus (TP) Load 2012-2016 Annual Average, Projected TP Corresponding to 1.0 mg/L and 0.5 mg/L TP Effluent Limits.

Conclusions

Based on the diversity of sources of TP load in the individual subwatersheds of the Fox River, diverse management scenarios are necessary to target primary TP load contributors. For example, implementation of urban best management practices in the Poplar, Brewster, and Norton Creek subwatersheds should significantly reduce the TP loading entering these creeks. Management strategies targeting agricultural areas can significantly reduce TP loading in the majority of the Lower Fox watersheds, although there are some watersheds that can benefit from managing urban runoff. The relative contribution of point sources to total TP loading in the Fox River watershed has reduced over the recent years from 2012 to 2016 and is expected to be reduced significantly when WWTP TP effluent limits of 1 mg/L are implemented by 2022 and the limit is reduced for all major WWTPs to 0.5 mg/L in 2030.

References

Bartosova, A., J. Singh, M. Rahim, and S. McConkey. 2007. Fox River Watershed Investigation: Stratton Dam to the Illinois River PHASE II, Hydrologic and Water Quality Simulation Models, Part 3: Validation of Hydrologic Simulation Models for the Brewster, Ferson, Flint, Mill, and Tyler Creek Watersheds. Illinois State Water Survey Contract Report 2007-07, Champaign, IL.

ISWS. 2014. Contribution of point and non-point sources to total phosphorus load in the Fox River watershed downstream of Stratton Dam. Illinois State Water Survey (ISWS), Champaign, IL. May 20, 2014.

Geosyntec Consultants (Geosyntec). 2020. Fox River Water Quality Model Update Fox River, IL. April 10, 2020.

Attachments

1. Upper Fox, Lower Fox, and Entire Fox River watersheds total TP load for each year.
2. Upper Fox River watershed total TP load by subwatershed for each year.
3. Lower Fox River watershed total TP load by subwatershed for each year.

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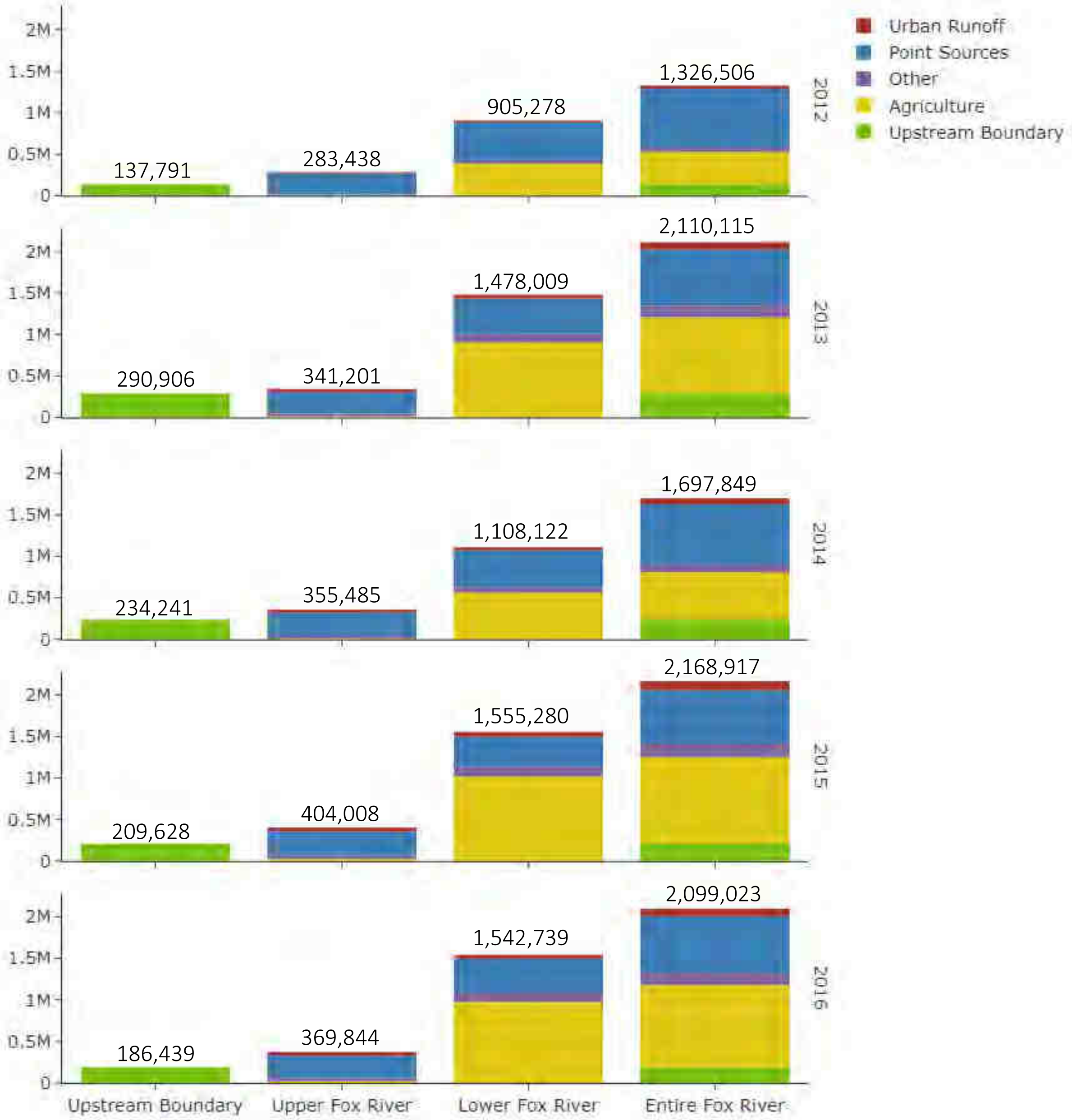
Attachment 1

Upper Fox, Lower Fox, and Entire Fox River Total TP Load for Each Year


Urban Runoff
Point Sources
Other
Agriculture
Upstream Boundary
2M
1.5M
1M
0.5M
0
2012
137,791
283,438
905,278
1,326,506
2013
290,906
341,201
1,478,009
2,110,115
2014
234,241
355,485
1,108,122
1,697,849
2015
209,628
404,008
1,555,280
2,168,917
2016
186,439
369,844
1,542,739
2,099,023
Upstream Boundary
Upper Fox River
Lower Fox River
Entire Fox River

Attachment 2

Upper Fox River Watershed Total TP Load by Watershed for Each Year

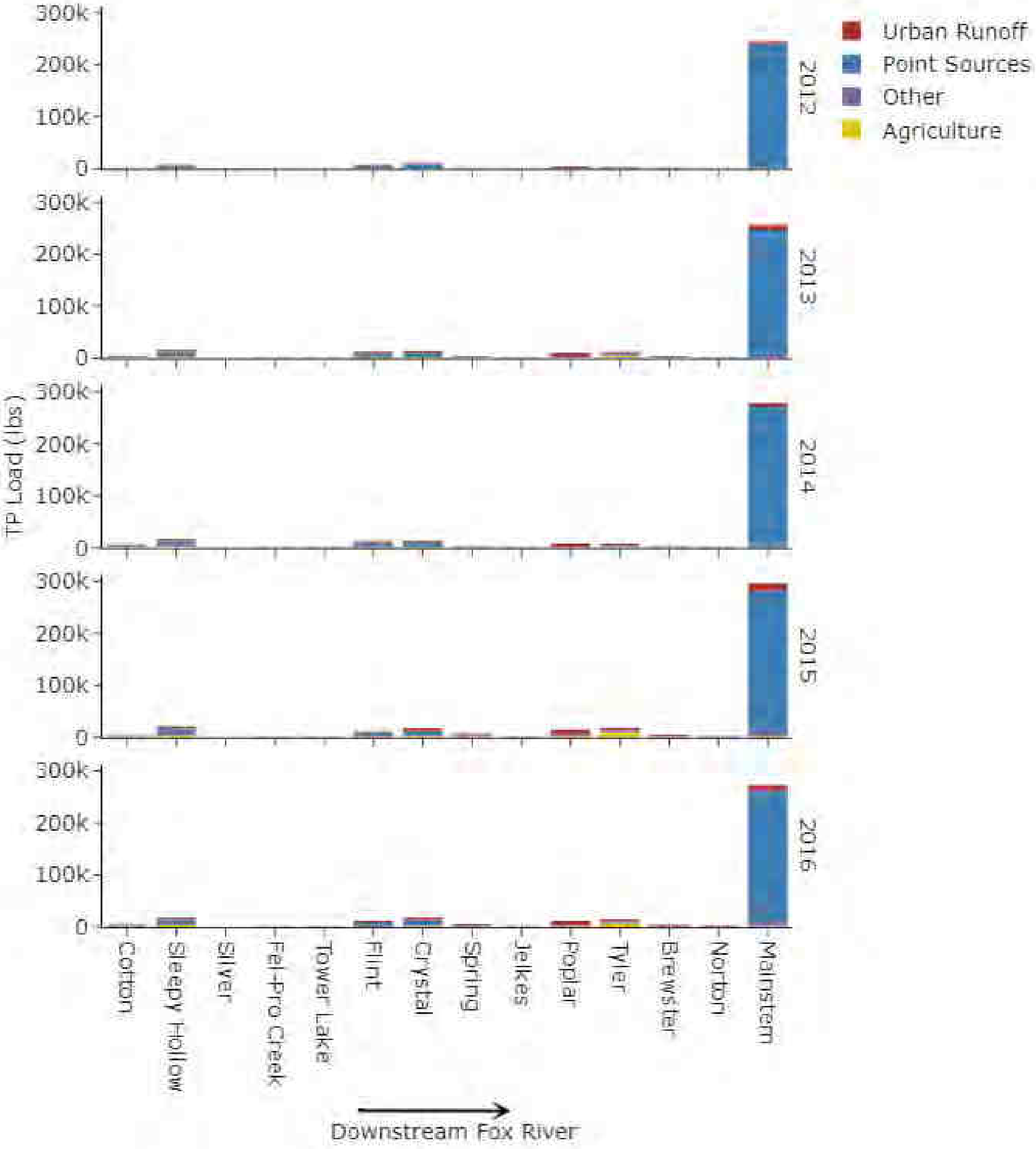


Figure 2-1: Upper Fox River Watersheds Total TP Load for Each Year

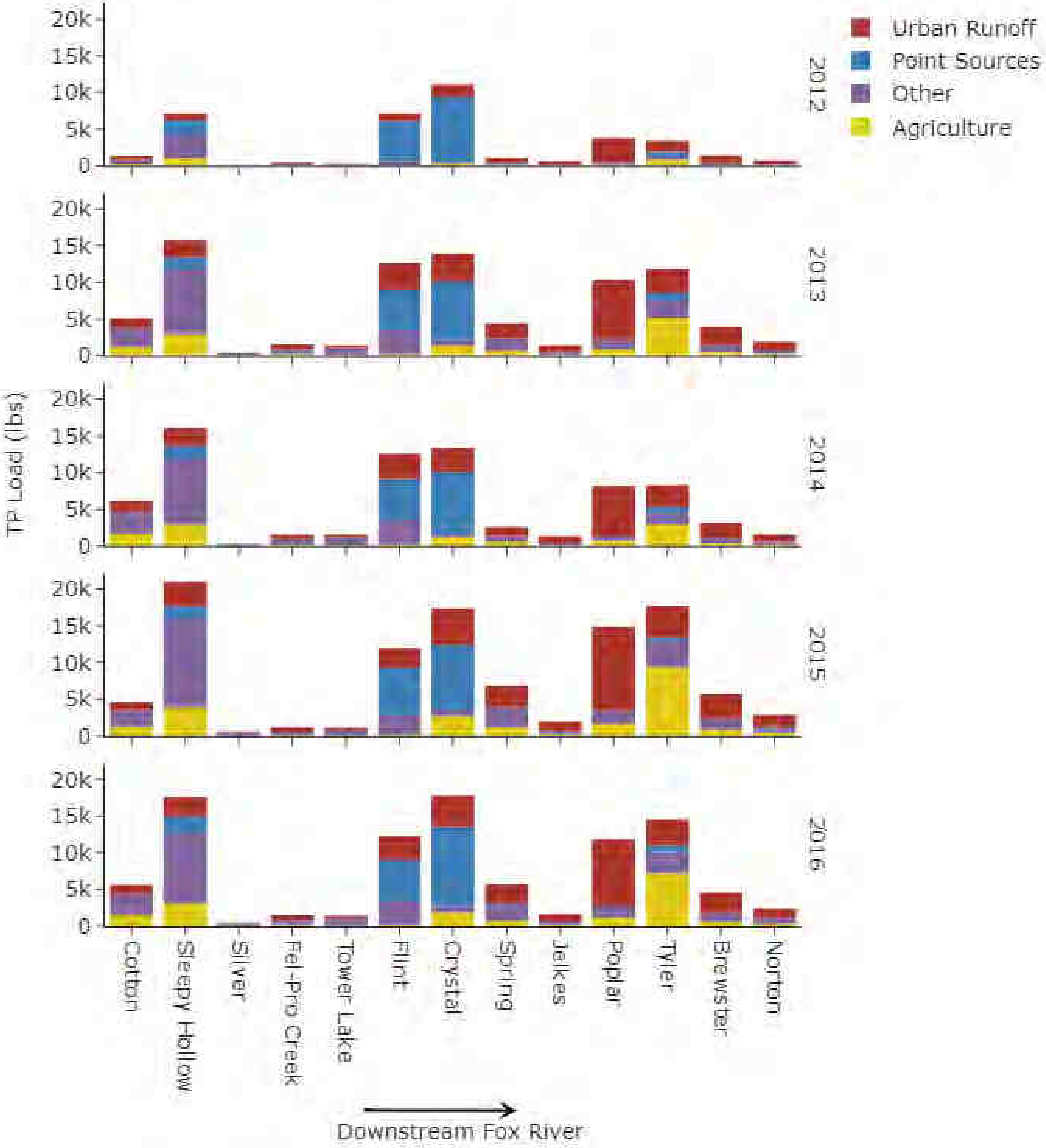


Figure 2-2: Upper Fox River Watersheds Total TP Load for Each Year without the Mainstem

Attachment 3

Lower Fox River Watershed Total TP Load by Watershed for Each Year

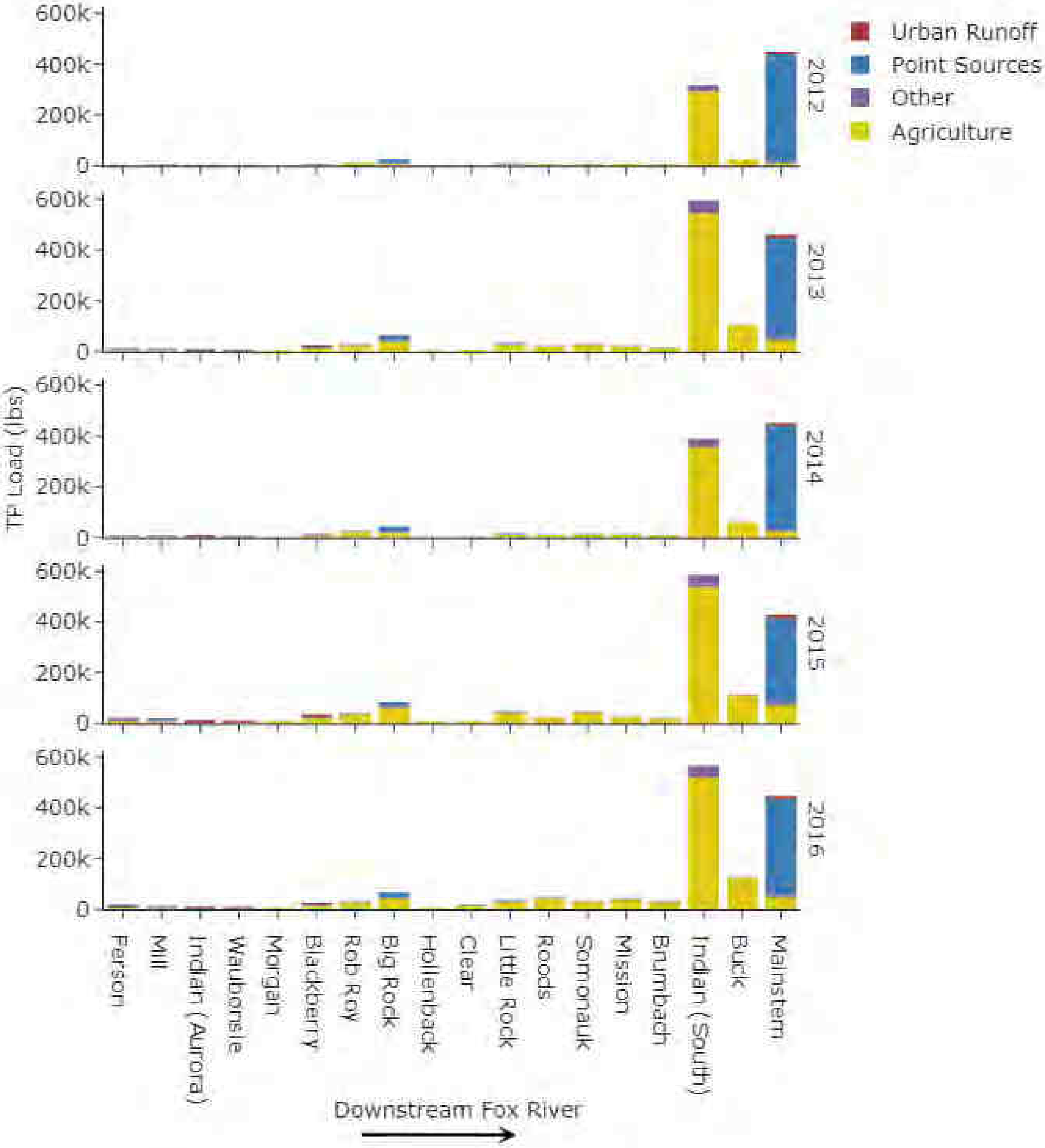


Figure 3-1: Lower Fox River Watersheds Total TP Load for Each Year

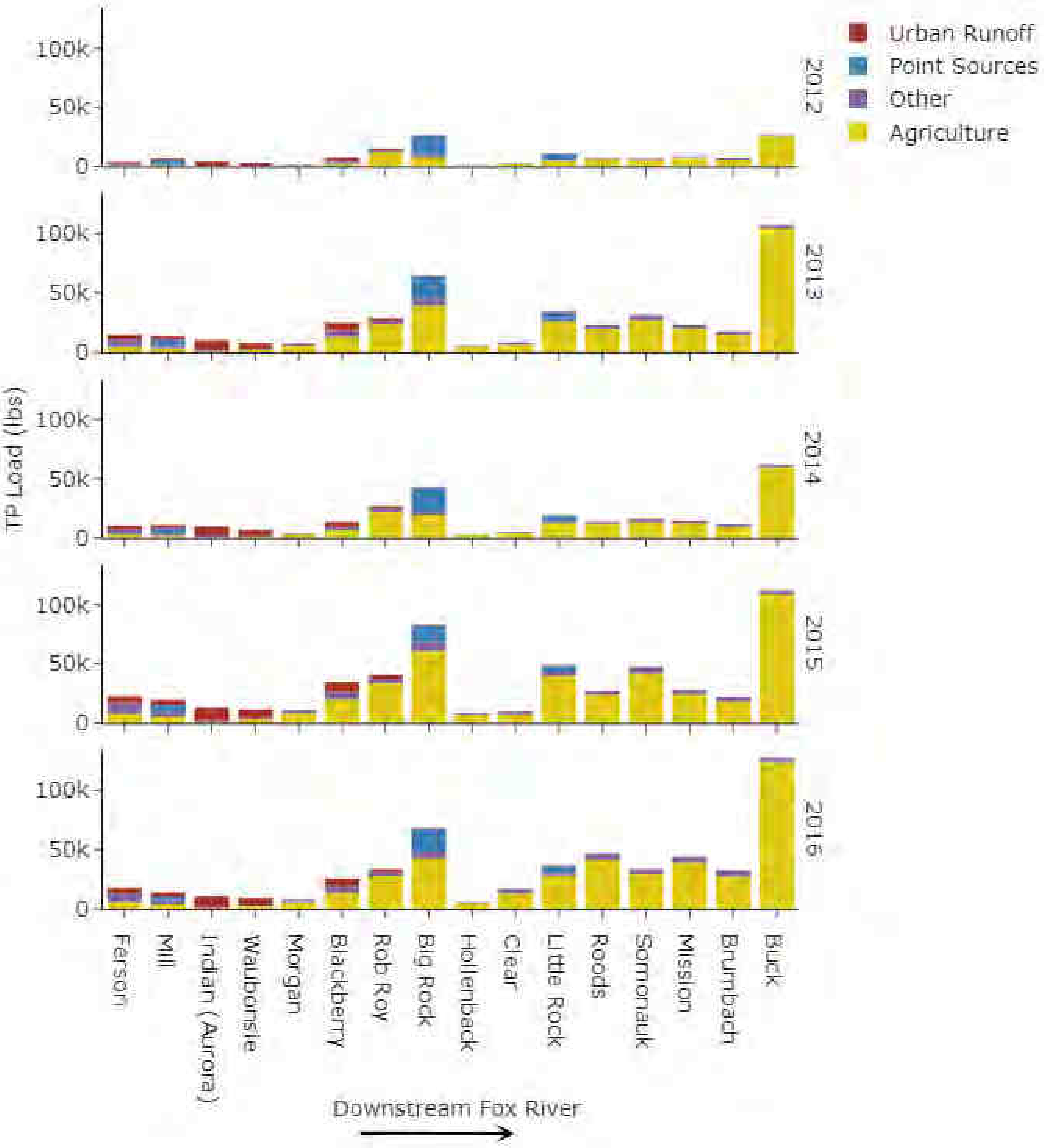


Figure 3-2: Lower Fox River Watersheds Total TP Load for Each Year without Indian (South) and the Mainstem

APPENDIX C

WATER QUALITY TREND ANALYSIS FOR THE FOX RIVER WATERSHED: STRATTON DAM TO THE ILLINOIS RIVER

(Getahun et. al, 2019)

ISWS CONTRACT REPORT 2019-04

Water Quality Trend Analysis for the Fox River Watershed: Stratton Dam to the Illinois River

Elias Getahun, Laura Keefer, Sangeetha Chandrasekaran, and Atticus Zavelle

February 2019

ILLINOIS
Illinois State Water Survey
PRAIRIE RESEARCH INSTITUTE

Water Quality Trend Analysis for the Fox River Watershed: Stratton Dam to the Illinois River

by

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Prepared for
Fox River Study Group

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Drs. Momcilo Markus and Zhenxing Zhang reviewed the report. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the Illinois State Water Survey, Prairie Research Institute, or the University of Illinois.

Executive Summary

This report presents a trend analysis conducted for nutrient-related water quality parameters collected at monitoring stations located on the Fox River main stem and tributaries and compiled and maintained in a database, FoxDB. An exploratory data analysis (EDA) was performed on a total of 141 water quality parameters across the 18 monitoring stations to summarize and extract the characteristics of the water quality data. Based on the EDA analysis, the Seasonal Kendall Test (SKT) for trends was selected as the core analysis method, and the EnvStats software R-package was used to perform the water quality trend analysis and EDA. A suite of procedures and workflows that use the EnvStats library of codes for the analysis were written using R programing language to extract selected water quality data from the FoxDB (i.e., the water quality database for the Fox River watershed) and perform the analysis. In addition to the nonparametric analysis using the SKT method, trend analyses of water quality concentration and fluxes (loads) were conducted for one Fox River main stem and two tributary monitoring stations that have not only long-term concentration data, but also the corresponding continuous daily discharge data. A total of 19 parametric models using concentration and flow data across the three stations were developed using the Weighted Regression on Discharge, Time, and Season (WRTDS) method for estimating trends in flow-normalized concentration and fluxes.

For all monitoring stations, the SKT trend analysis generally showed that most of the nutrient-related water quality parameters exhibited either a decreasing or no trend across all seasons. No upward annual trend was exhibited for organic nitrogen (Org-N), ammonia nitrogen, total suspended solids (TSS), or chlorophyll-A (CHL-A) at any of the monitoring stations. At the most downstream station on the main stem, the Fox River at Yorkville, no increasing trend was detected, with most of the water quality parameters showing a decreasing trend across all seasons. Most of the upward trend was detected for dissolved phosphorus (DP), particularly in spring and summer months. In comparison, total phosphorus (TP) showed an increasing annual trend only for Poplar Creek near the Mouth-Elgin station. For more than half of the stations, the pH showed a downward or no trend. In the case of pH, an upward or downward trend from the median, which is within the pH limits for freshwater, would indicate a declining water quality. All remaining water quality parameters exhibited decreasing longitudinal trends downstream of the Fox River at Algonquin, indicating improvement of the river's water quality, except for dissolved oxygen (DO), which rather implies a declining water quality trend.

The results of the trend analysis conducted using the WRTDS method generally indicate that flow-normalized concentration and fluxes (loads) of most water quality parameters decreased across all seasons from 2006 to 2016 for the Fox River at Montgomery, which is the only station in the main stem with the required concentration and flow data. A few exceptions were concentration and fluxes of total suspended solids (TSS) in spring and chlorophyll A (CHL-A) in summer, which showed increasing trends. If not in the percentage amount, the flux and concentration trends are largely similar for this station (i.e., they are in the same downward or upward direction). The only difference observed was between the spring ammonia nitrogen (NH3-N) concentration and its corresponding flux, which showed opposing trends, indicating that concentration trends are not necessarily informative of flux trends. Large decreases in summer DP, NH_3-N, and nitrate nitrogen (NO_3-N); winter TP, TSS, and CHL-A; and spring for DO, Org-N, and total kjeldahl nitrogen (TKN) concentrations were obtained for the Fox River at Montgomery station. A decreasing trend in concentration across all seasons, unlike for DO, is indicative of an improving water quality trend. In comparison with other water quality parameters, flow-normalized fluxes of TP and DP also appeared to have larger decreases across all seasons between 2006 and 2016. Similar downward trends of nitrate nitrogen (NO_3-N) fluxes were obtained in summer and fall seasons.

For the two tributaries, Blackberry Creek at Rt. 47 and Poplar Creek near Mouth-Elgin, most of the water quality concentration and fluxes showed larger upward trends with a few exceptions. The NH_3-N concentration exhibited the largest annual and seasonal increasing trends at both stations. Concentrations of TP, DP, and DO showed decreasing annual and seasonal trends for Blackberry Creek at Rt. 47, except in fall for DO and in summer for TP and DO concentrations. For Poplar Creek near Mouth-Elgin, the DP and DO concentrations showed improving water quality trends across all seasons. The flow-normalized DP and TKN fluxes exhibited decreasing annual and seasonal trends for Poplar Creek near Mouth-Elgin and Blackberry Creek at Rt. 47, respectively. The seasonal concentration trends largely conform to the annual trends for all three monitoring stations.

In addition to water quality trends, flow durations and trends of selected streamflow statistics including mean, 7-day minimum, and 1-day maximum flows are calculated to evaluate their changes through the years as they relate to water quality. The flow durations allow characterizing the ranges of flows in the river that are common or extreme during an entire year or season. The results indicate that the highest and lowest flow variability occurred in summer and spring seasons, respectively. The mean flow provides information about the central tendency of the multiyear hydrologic variability, whereas the minimum and maximum flow trends may explain part of the increase or decrease in constituent concentrations and fluxes. However, to explicitly attribute the change in water quality trends to some changes in hydrologic factors, the extent of other potential factors influencing water quality, such as conservation efforts, land use changes, etc., also need to be examined. Between 2006 and 2016, the mean and 7-day minimum flows exhibited an increasing trend with varying magnitudes across all seasons except for the spring 7-day minimum flow. Generally, the annual and seasonal 7-day minimum flows seem to show large increases during the period of analysis. The annual and seasonal 1-day maximum flows show increasing trends for Blackberry Creek at Rt. 47. For Poplar Creek near Mouth-Elgin, however, the 1-day maximum flow exhibited a decreasing trend in winter, spring, and fall seasons, whereas its annual and summer values had increased.

1. Introduction

This report presents a trend analysis of nutrient-related water quality data that have been collected throughout the Fox River watershed downstream of the Stratton Dam. A compilation of water quality data collected by the Fox River Study Group (FRSG), Illinois Environmental Protection Agency (IEPA), Fox Metro Water Reclamation District (Fox Metro), United States Geological Survey (USGS), Fox River Water Reclamation District (FRWRD), Illinois State Water Survey (ISWS), and Deuchler Environmental, Inc. (DEI) was stored in the environmental database, FoxDB, and used to construct the time series data for this analysis, spanning a period from 1997 to 2016. The FoxDB was created and is maintained by ISWS for compiling water chemistry and related data, such as sediment and flow in the Fox River watershed (McConkey et al., 2004).

The objectives of this analysis were to identify the presence or absence of trends in several nutrient-related water quality data collected in the Fox River watershed and to estimate rates of change if trends exist. Establishing the cause of a trend, if any, is beyond the scope of this study and requires a different study design that investigates the hydrologic processes, aquatic biogeochemistry, land uses, and anthropogenic activities in its entirety within the watershed. Streamflow histories were analyzed to provide insight into how flow variability, durations, and trends may have affected the water quality concentration and/or fluxes in the Fox River watershed. Long-term water quality data were required to conduct a trend analysis. In United States Environmental Protection Agency (USEPA) TechNotes 6 by Meals et al. (2011), monthly data of a five-year period has been suggested as the minimum for monotonic trend analysis. Most monitoring stations used in this study have five or more years of water quality data. Therefore, the core method of analysis used in this study is the Seasonal Kendall Test (SKT), which is a nonparametric test for monotonic trends (upward or downward trends). In cases where corresponding flow data are available in addition to long-term concentration data, a parametric test using the Weighted Regression on Time, Discharge, and Season (WRTDS) method has been implemented to evaluate trends in water quality concentrations and fluxes (loads), complementing the SKT analysis, which is used only for trends in water quality concentrations.

In the FoxDB, 18 monitoring stations in the Fox River and its tributaries were identified as meeting the minimum of at least five years of data for the trend analysis. The location of these monitoring stations, station ID, and descriptions are presented in Table 1 and in Figure 1, respectively. To be consistent, the same station ID numbers in the FoxDB are used in this report. The number of water quality parameters in each monitoring station varies from 2 to 10, and it includes total phosphorus (TP), dissolved phosphorus (DP), organic nitrogen (Org-N), ammonia nitrogen (NH_3-N), nitrate-nitrogen (NO_3-N), total kjeldahl nitrogen (TKN), dissolved oxygen (DO), pH, total suspended solids (TSS), and chlorophyll-A (CHL-A).

Exploratory data analysis (EDA) was performed on a total of 141 water quality parameters across the 18 monitoring stations to uncover the underlying data structure. EDA allows the thorough examination of data of interest to explore patterns, gaps, and trends. Summary statistics for each water quality parameter were computed to describe the information contained in the data in terms of its central tendency, spread, skewness, etc. The EDA analysis results for each water quality parameter can be used to evaluate the status of Fox River water quality in comparison with use-specific water quality standards. In Table 2, existing and additional water quality standards and criteria for the Illinois portion of the Fox River and its tributaries are provided. Some of the water quality standards in the table are extracted from Part 302 (water quality standards) of Title 35 of the Illinois Administrative Code, provided by the Illinois Pollution Control Board at https://pcb.illinois.gov/SLR/IPCBandIEPAEnvironmentalRegulationsTitle35.

Based on the results of the EDA analysis, the SKT method (Helsel and Hirsch, 2002) was selected as the primary process for conducting trend analyses on water quality concentration data. SKT is a distribution-free test, which is suitable for datasets that exhibit seasonality, autocorrelation, and missing values. The SKT analysis was performed for each of the 141 water quality parameters. The EnvStats R-package for environmental statistics (Millard, 2013) was used to perform the EDA and SKT analyses. EnvStats includes some of the major statistical methods and uses the R software environment, facilitating the programming of workflows and access to other features of R, such as plotting.

For three of the monitoring stations, the water quality concentration data have corresponding continuous flow data. Therefore, for those stations, trend analyses of both water quality concentration and fluxes (loads) were explored using the WRTDS method (Hirsch et al., 2010). The WRTDS method allows the estimation of long-term trends, not only of concentration, but also flux, and this procedure is part of the Exploration and Graphics for RivEr Trends (EGRET) software, which is an R-package developed by the USGS.

Table 1. Water Quality Parameters Analyzed by Monitoring Stations

Station ID	Station name	Water quality parameters by Station									
236	*Nippersink Cr at Spring Grove*	TP	DP	-	NH$_3$-N	-	TKN	DO	pH	TSS	-
1	*Nippersink Cr above Wonder Lake*	TP	DP	-	-	-	-	-	-	-	-
184	**Fox River at Johnsburg**	TP	DP	Org-N	NH$_3$-N	NO$_3$-N	TKN	DO	pH	-	CHL-A
23	**Fox River at Rt 176**	TP	DP	-	NH$_3$-N	NO$_3$-N	TKN	DO	pH	TSS	-
258	**Fox River at Oakwood Hills**	TP	DP	Org-N	NH$_3$-N	NO$_3$-N	TKN	DO	pH	-	CHL-A
4	*Flint Cr at Kelsey Rd-Lk Barrington*	TP	DP	-	NH$_3$-N	-	TKN	-	-	-	-
271	*Crystal Cr at Rt 31*	TP	DP	Org-N	NH$_3$-N	NO$_3$-N	TKN	DO	pH	-	CHL-A
24	**Fox River at Algonquin**	TP	DP	Org-N	NH$_3$-N	NO$_3$-N	TKN	DO	pH	TSS	CHL-A
268	*Tyler Cr at Rt. 31-Elgin*	TP	DP	Org-N	NH$_3$-N	NO$_3$-N	TKN	DO	pH	-	CHL-A
25	*Poplar Cr near Mouth-Elgin*	TP	DP	-	NH$_3$-N	-	TKN	DO	pH	TSS	-
26	**Fox River at South Elgin**	TP	DP	Org-N	NH$_3$-N	NO$_3$-N	TKN	DO	pH	TSS	CHL-A
14	*Ferson Cr at Rt 34*	TP	DP	-	NH$_3$-N	-	TKN	-	-	-	-
79	*Ferson Cr near Mouth-Elgin*	TP	DP	Org-N	NH$_3$-N	NO$_3$-N	TKN	DO	pH	-	CHL-A
40	**Fox River at Geneva**	TP	DP	Org-N	NH$_3$-N	NO$_3$-N	TKN	DO	pH	-	CHL-A
27	**Fox River at Montgomery**	TP	DP	Org-N	NH$_3$-N	NO$_3$-N	TKN	DO	pH	TSS	CHL-A
34	**Fox River at Yorkville**	TP	DP	Org-N	NH$_3$-N	NO$_3$-N	TKN	DO	pH	-	CHL-A
28	*Blackberry Cr at Rt 47*	TP	DP	-	NH$_3$-N	-	TKN	DO	pH	TSS	-
287	*Blackberry Cr near Mouth*	TP	DP	Org-N	NH$_3$-N	NO$_3$-N	TKN	DO	pH	-	CHL-A

Note: Stations are in upstream-to-downstream order, and are in bold for Fox River main stem and in italics for tributaries.

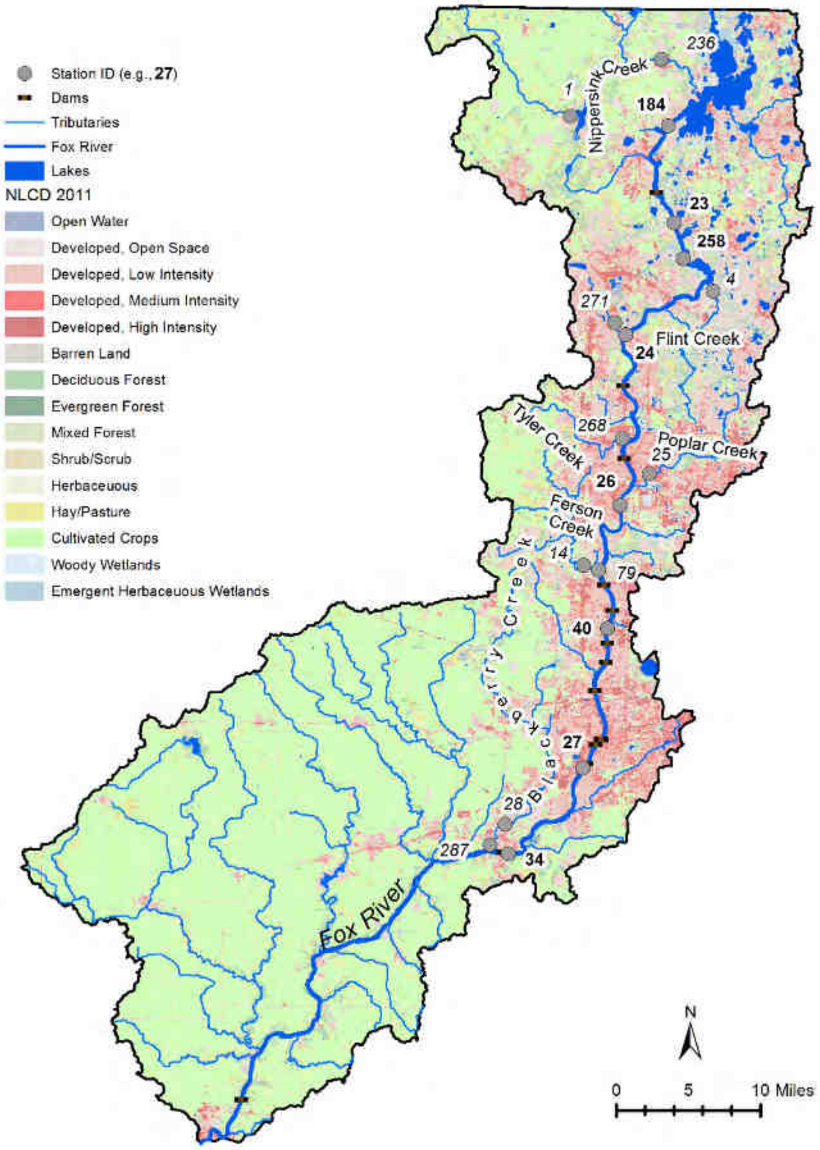


Figure 1. Fox River watershed – Stratton Dam to Illinois River

Table 2. Fox River Water Quality Standards

Water Quality Parameter	Existing Water Quality Standards for Fox River and its tributaries in Illinois	Other Water Quality Standards & Criteria
Total P (TP)	None	• Illinois lakes > 20 acres, including the Chain O'Lakes and other lakes within the Fox River watershed shall not exceed 0.05 mg/L (see Part 302.205) • The Wisconsin portion of the Fox River has a phosphorus standard of 0.1 mg/L. (available at https://dnr.wi.gov/topic/SurfaceWater/phosphorus.html) • Ecoregional criterium for Region VI Corn Belt and N Great Plains: 0.07625 mg/L. (https://www.epa.gov/nutrient-policy-data/ecoregional-criteria)
Dissolved P (DP)	None	
Organic-N (Org-N)	None	
Ammonia N (NH_3-N)	• Total NH3-N must in no case exceed 15 mg/L. • Acute standard is dependent on pH. Mean pH values in the Fox River range from 7.85 to 8.48. The acute standard at pH 8.2 is 5.73 mg/L. • Chronic standard differs for periods when Early Life Stage is present (March-October) and absent. It is dependent on temperature and pH. For pH 8.2, the Early Life Stage present value at 24C is 0.97 mg/L. For pH 8.2, the Early Life Stage absent value at 10C is 2.40 mg/L. The 30-day average concentration must not exceed the chronic standard except in those waters in which mixing is allowed.	• The most recent 2013 USEPA criterion document recognizes the sensitivity of freshwater mussels to ammonia levels. These new standards have not yet been adopted in Illinois. For pH 8.2 and 24C, the acute criterion is 1.9 mg/L (1-hour average). For pH 8.2 and 24C, the chronic criterion is 0.44 mg/L (30-day rolling average). Not to be exceeded more than 1 in 3 years on average. (https://www.epa.gov/wqc/aquatic-life-criteria-ammonia)
Nitrate N (NO_3-N)	• Public and food processing water supply standard. Waters of the State are generally designated for public and food processing use: 10 mg/L	
TKN	None	
Total N (= TKN+NO_3-N)	None	• USEPA recommends 2-6 mg/L of Total N. (https://www.epa.gov/sites/production/files/2015-09/documents/totalnitrogen.pdf) • Ecoregional criterium for Region VI Corn Belt and N Great Plains: 2.18 mg/L. (See https://www.epa.gov/nutrient-policy-data/ecoregional-criteria)
Dissolved Oxygen (DO)	• All waters except enhanced DO stretch below: Mar-July: not less than 5.0 mg/L at any time, 6.0 as daily mean avg'd over 7 days. Aug-Feb: not less than 3.5 mg/L at any time, 4.0 as daily minimum avg'd over 7 days, 5.5 as daily mean avg'd over 30 days. • Enhanced DO stretch (LAT/LONG): 41° 37' 3.7194"/-88° 33' 21.0162" to 41° 45' 59.5296"/-88° 18' 36.0858" Mar-July: not less than 5.0 mg/L at any time, 6.25 as daily mean avg'd over 7 days. Aug-Feb: not less than 4.0 mg/L at any time, 4.5 as daily minimum avg'd over 7 days, 6.0 as daily mean avg'd over 30 days.	
pH	6.5 to 9.0	
TSS	None	
Cholorophyll-A (CHL-A)	None	• Ecoregional criterium for Region VI Corn Belt and N Great Plains: 2.70 µg/L. (https://www.epa.gov/nutrient-policy-data/ecoregional-criteria)

2. Exploratory Data Analysis

Exploratory data analysis (EDA) is a graphical examination of the water quality data to detect any existing temporal patterns, such as seasonality, trends, step-changes, gaps, and outliers in the datasets. In this study, the EDA analysis was performed for all water quality parameters using the EnvStats R package and batches of R scripts. In addition, several other libraries of R-programs such as ROBDC (https://cran.r-project.org/web/packages/RODBC/index.html), which implements open database connectivity (ODBC), were used in conjunction with EnvStats. The ROBDC provides functions that allow direct access to a database file (in this particular case the FoxDB), eliminating the need to create intermediate data files with different formats and querying and manipulation of the required data for further analysis.

The availability of nutrient-related water quality parameters varies throughout the watershed. Only three stations have all ten of the water quality parameters: Fox River at Algonquin, Elgin, and Montgomery. Ten of the 18 stations have all the water quality parameters except TSS, which is available only for 7 stations. Phosphorus data are available for all monitoring stations, and NH_3-N and TKN are available for all but one station.

In Table 3, the period of record used in the EDA analysis for each water quality parameter is presented for each monitoring station, ranging from 5 to 20 years, excluding data gaps. It must be noted that the period of record for Blackberry near Mouth (station 287) includes data collected both before (2004–2011) and after the dam removal (2011–2016). The mean and median values of the water quality parameters are shown in Table 4; for DO, TSS, and all nutrient data, the unit is the concentration in milligrams per liter (mg/L). For CHL-A and pH data, the units are micrograms per liter (µg/L) and the standard unit, respectively. The mean and median values differ since the water quality data are generally skewed to the right, with the exception of pH, which tends to have similar means and medians. As shown in Table 4, the median values are typically less than that of the mean values because of the right-skewedness of the water quality data distribution. Summary statistics for 141 water quality parameters across the 18 monitoring stations are presented in Tables A.1 to A.10 in Appendix A.

Table 3. Periods of Records by Water Quality Parameter and Monitoring Station

Station ID	Station Name	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	TSS	CHL-A
236	*Nippersink Cr at Spring Grove*	1997-2016	1997-2016	-	1997-2016	-	1997-2016	1997-2015	1999-2015	2003-2016	-
1	*Nippersink Cr above Wonder Lak*	1997-2009	1997-2001	-	-	-	-	-	-	-	-
184	**Fox River at Johnsburg**	1997-2016	2002-2016	2002-2016	1997-2016	1997-2016	2002-2016	1997-2016	2002-2016	-	2002-2016
23	**Fox River at Rt 176**	1997-2016	1997-2016	-	1997-2016	1997-2011	1997-2016	1997-2015	1999-2015	2003-2016	-
258	**Fox River at Oakwood Hills**	1997-2016	2003-2016	2003-2016	1997-2016	1997-2016	2003-2016	1997-2016	2003-2016	-	2003-2016
4	*Flint Cr at Kelsey Rd-Lk Barringto*	2000-2011	2000-2011	-	2002-2011	-	2000-2011	-	-	-	-
271	*Crystal Cr at Rt 31*	2003-2016	2003-2016	2003-2016	2003-2016	2003-2016	2003-2016	2003-2016	2003-2016	-	2003-2016
24	**Fox River at Algonquin**	1997-2016	1997-2016	2002-2016	1997-2016	1997-2016	1997-2016	1997-2012	1999-2016	2003-2016	2002-2016
268	*Tyler Cr at Rt. 31-Elgin*	1997-2012	2003-2012	2002-2012	1997-2012	1998-2012	1998-2012	1997-2012	2003-2012	-	2003-2012
25	*Poplar Cr near Mouth-Elgin*	1997-2016	1997-2016	-	1997-2011	-	1997-2016	1997-2015	1999-2015	2003-2016	-
26	**Fox River at South Elgin**	1997-2016	1997-2016	1998-2016	1997-2016	1998-2016	1997-2016	1997-2016	1999-2016	2003-2016	2001-2016
14	*Ferson Cr at Rt 34*	2000-2012	2000-2012	-	2000-2011	-	2000-2012	-	-	-	-
79	*Ferson Cr near Mouth-Elgin*	2003-2016	2003-2016	2003-2016	2003-2016	2003-2016	2003-2016	2003-2016	2003-2016	-	2003-2016
40	**Fox River at Geneva**	2002-2016	2002-2016	2002-2016	2002-2016	2002-2016	2002-2016	2002-2016	2002-2016	-	2002-2016
27	**Fox River at Montgomery**	1997-2016	1997-2016	2002-2016	1997-2016	1997-2016	1997-2016	1997-2016	1997-2016	2003-2016	2002-2016
34	**Fox River at Yorkville**	2002-2016	2002-2016	2002-2016	1997-2016	2002-2016	2002-2016	1997-2016	1997-2016	-	2002-2016
28	*Blackberry Cr at Rt 47*	1997-2016	1997-2016	-	1997-2016	-	1997-2016	1997-2015	1999-2015	2003-2016	-
287	*Blackberry Cr near Mouth*	2004-2016	2004-2016	2004-2016	2004-2016	2004-2016	2004-2016	2004-2016	2004-2016	-	2004-2016

Note: Stations are in upstream-to-downstream order, and are in bold for Fox River main stem and in italics for tributaries.

Table 4. Mean and Median Values of the Water Quality Parameters

Station ID	Station Name	TP (mg/L)	DP (mg/L)	Org-N (mg/L)	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	DO (mg/L)	pH (su)	TSS (mg/L)	CHL-A (µg/L)
236	*Nippersink Cr at Spring Grove*	0.13/0.12	0.04/0.03	-	0.15/0.11	-	0.98/0.87	10.48/10.18	8.12/8.12	29.82/25	-
1	*Nippersink Cr above Wonder Lake*	0.17/0.09	0.05/0.03	-	-	-	-	-	-	-	-
184	**Fox River at Johnsburg**	0.16/0.14	0.05/0.04	1.69/1.53	0.08/0.06	1.04/0.76	1.75/1.61	10.84/10.5	8.48/8.5	-	81.63/70.2
23	**Fox River at Rt 176**	0.14/0.12	0.03/0.02	-	0.1/0.06	1.26/0.93	1.65/1.6	10.48/10.2	8.27/8.3	27.01/25	-
258	**Fox River at Oakwood Hills**	0.17/0.16	0.05/0.04	1.76/1.62	0.07/0.05	0.86/0.61	1.84/1.68	10/9.61	8.26/8.42	-	94.06/85.65
4	*Flint Cr at Kelsey Rd-Lk Barringto*	0.29/0.24	0.21/0.15	-	0.11/0.07	-	1.96/1.7	-	-	-	-
271	*Crystal Cr at Rt 31*	0.5/0.32	0.43/0.25	0.94/0.82	0.09/0.07	3.77/3.42	1/0.9	9.2/8.48	8.11/8.2	-	29.74/18.85
24	**Fox River at Algonquin**	0.18/0.16	0.06/0.04	1.72/1.68	0.1/0.06	1.29/1.01	1.67/1.6	10.05/9.93	8.17/8.23	32.88/30	92.56/86.2
268	*Tyler Cr at Rt. 31-Elgin*	0.14/0.11	0.06/0.05	0.79/0.68	0.07/0.06	2.39/1.78	0.83/0.77	11.49/11.15	8.2/8.2	-	9.69/8.6
25	*Poplar Cr near Mouth-Elgin*	0.09/0.07	0.03/0.02	-	0.08/0.04	-	1.1/1	10.83/10.36	7.85/7.85	12.18/8	-
26	**Fox River at South Elgin**	0.29/0.23	0.16/0.12	1.63/1.54	0.11/0.06	1.72/1.51	1.66/1.58	10.22/9.63	8.35/8.39	31.11/30	86.68/78.8
14	*Ferson Cr at Rt 34*	0.15/0.12	0.06/0.05	-	0.08/0.03	-	1.42/1.2	-	-	-	-
79	*Ferson Cr near Mouth-Elgin*	0.11/0.1	0.06/0.05	0.75/0.67	0.06/0.05	1.15/0.86	0.79/0.71	9.93/9.43	7.95/8.01	-	13.26/10.7
40	**Fox River at Geneva**	0.33/0.27	0.16/0.13	1.66/1.52	0.07/0.04	1.67/1.5	1.73/1.6	11.24/10.58	8.2/8.28	-	105.3/87.95
27	**Fox River at Montgomery**	0.32/0.27	0.16/0.13	1.59/1.46	0.08/0.04	1.67/1.46	1.6/1.52	9.45/9.29	8.34/8.33	34.12/33	99.88/80.05
34	**Fox River at Yorkville**	0.48/0.41	0.3/0.25	1.62/1.46	0.09/0.05	2.08/1.86	1.67/1.51	10.24/9.9	8.33/8.3	-	98.15/80
28	*Blackberry Cr at Rt 47*	0.12/0.09	0.04/0.03	-	0.1/0.05	-	1.01/0.83	10.03/9.74	7.92/7.97	28.23/20	-
287	*Blackberry Cr near Mouth*	0.12/0.11	0.05/0.05	0.75/0.69	0.07/0.05	1.28/1.01	0.8/0.75	10.72/10.24	7.99/7.98	-	12.84/10.55

Note: Stations are in upstream-to-downstream order, and are in bold for Fox River main stem and in italics for tributaries.

To further illustrate the EDA analysis, total phosphorus (TP) data for the Fox River at Montgomery (station ID 27) were used, as the station has long-term data that various agencies collected. In addition, station 27 has flow data, which allowed to conduct parametric trend test for water quality fluxes (loads) in addition to concentration. Figure 2 shows one-dimensional scatter plots of the TP concentration data collected by various agencies, including FRSG, IEPA, FRWRD, ISWS, and DEI from 1997 to 2016. As shown by the number of data points (n) in the figure, FRSG and IEPA collected the largest number of TP concentration samples for this station. The mean and standard deviation of TP concentration samples (mg/L) collected by the different agencies range from 0.2 to 0.4 and 0.1 to 0.2, respectively, representing varying data periods as illustrated in Figure 2.

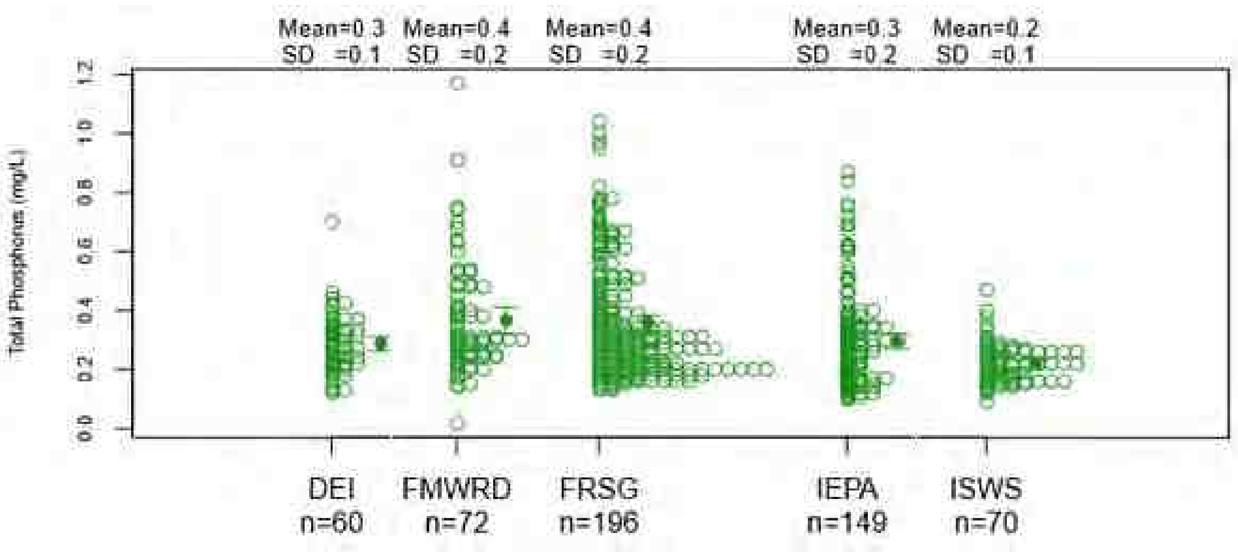
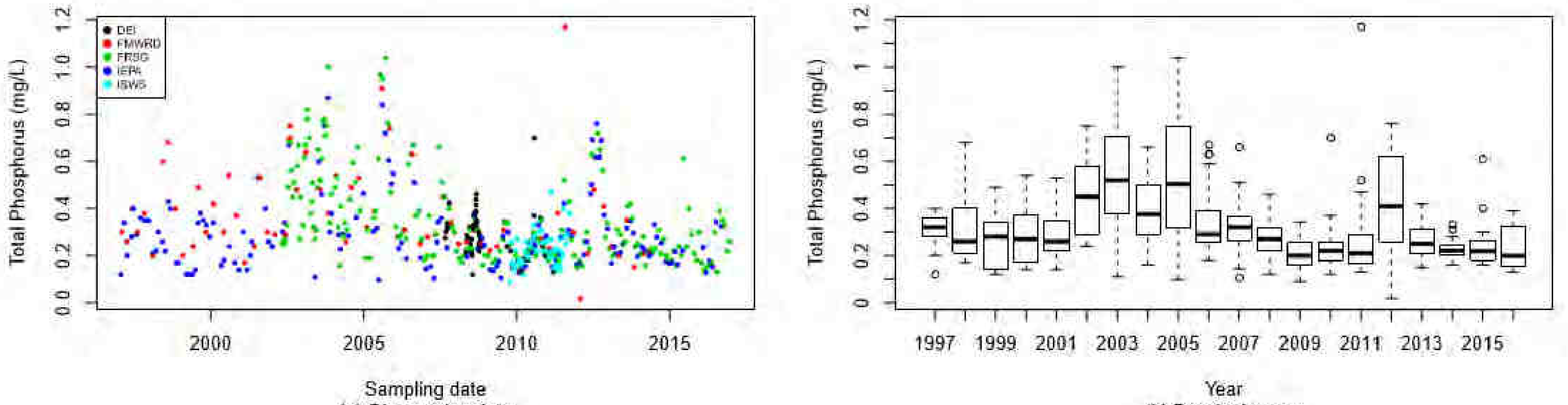


Figure 2. Strip plots of TP concentrations for Fox River at Montgomery

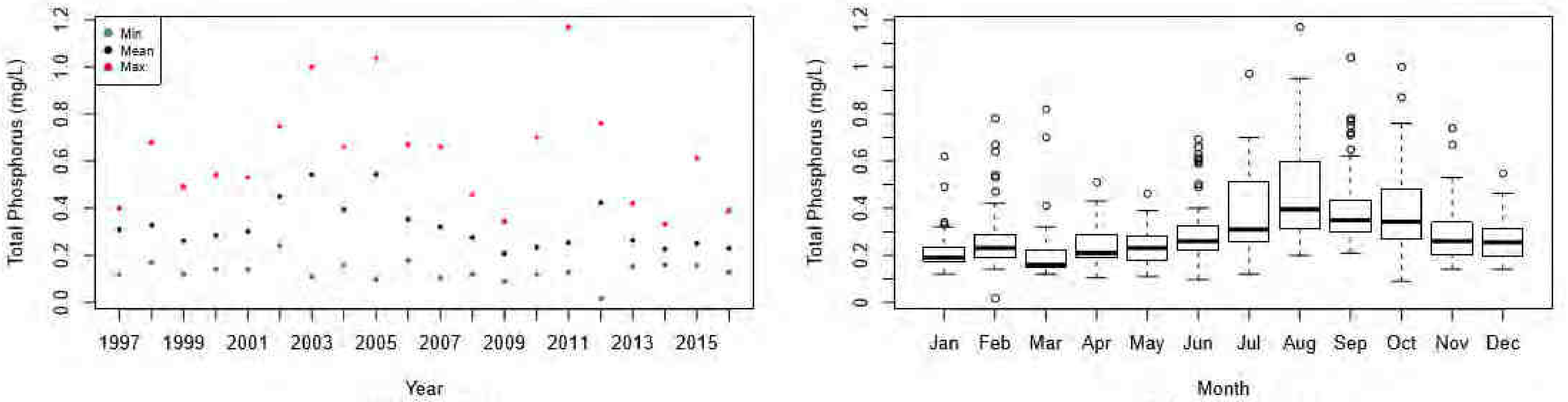
In Figure 3, the EDA results for TP concentrations at Fox River at Montgomery are presented and include (a) the combined time series of the samples collected by the different agencies; (b) yearly boxplots; (c) annual minimum, maximum, and mean values; and (d) monthly boxplot. The combined time series of the observation data and monthly time series data constructed using all the observations were used in the parametric and nonparametric trend analyses, respectively. The seasonality of the TP concentration data is clearly evident in the time series and monthly boxplots, which is true for nearly all water quality parameters analyzed in this study. This EDA analysis provided useful information for selecting an appropriate method of analysis for trends that account for the underlying data structure; for example, the seasonality exhibited in the TP concentration data. The yearly boxplot could provide preliminary insights into the existence of a trend or no trend. In the boxplots, the median concentration is shown by a line in the box that represents the interquartile range (IQR) between the first and the third quartile of the TP data in a month or year. Outliers are shown in circles and are defined as observations lying beyond 1.5 times the IQRs. The monthly boxplot shows that the median of the TP concentration is the highest in summer months, with the maximum occurring in August. The yearly boxplot generally indicates that the TP concentration exhibits a decreasing trend through the years since 2005. Low flows during the drought of 2012 may have caused the increase in TP concentration for that year.

For water quality stations with corresponding flow data, including Fox River at Montgomery, a parametric trend test was conducted which required that the water quality data or its log transformation be normally-distributed. As part of the EDA analysis, the Shapiro-Wilk Goodness-of-Fit test based on Chen and Balakrisnan (1995) was done for the TP concentration data, fitting it with a lognormal distribution. The result is presented in Figure 4. As shown in the figure, the histogram, plots of quantiles of TP versus quantiles of log-normal distribution (Q-Q), and the empirical cumulative density functions (CDFs) indicate that TP concentration observations could be assumed to have come from a lognormal distribution with at least a 99% confidence level.



(a) Observation data

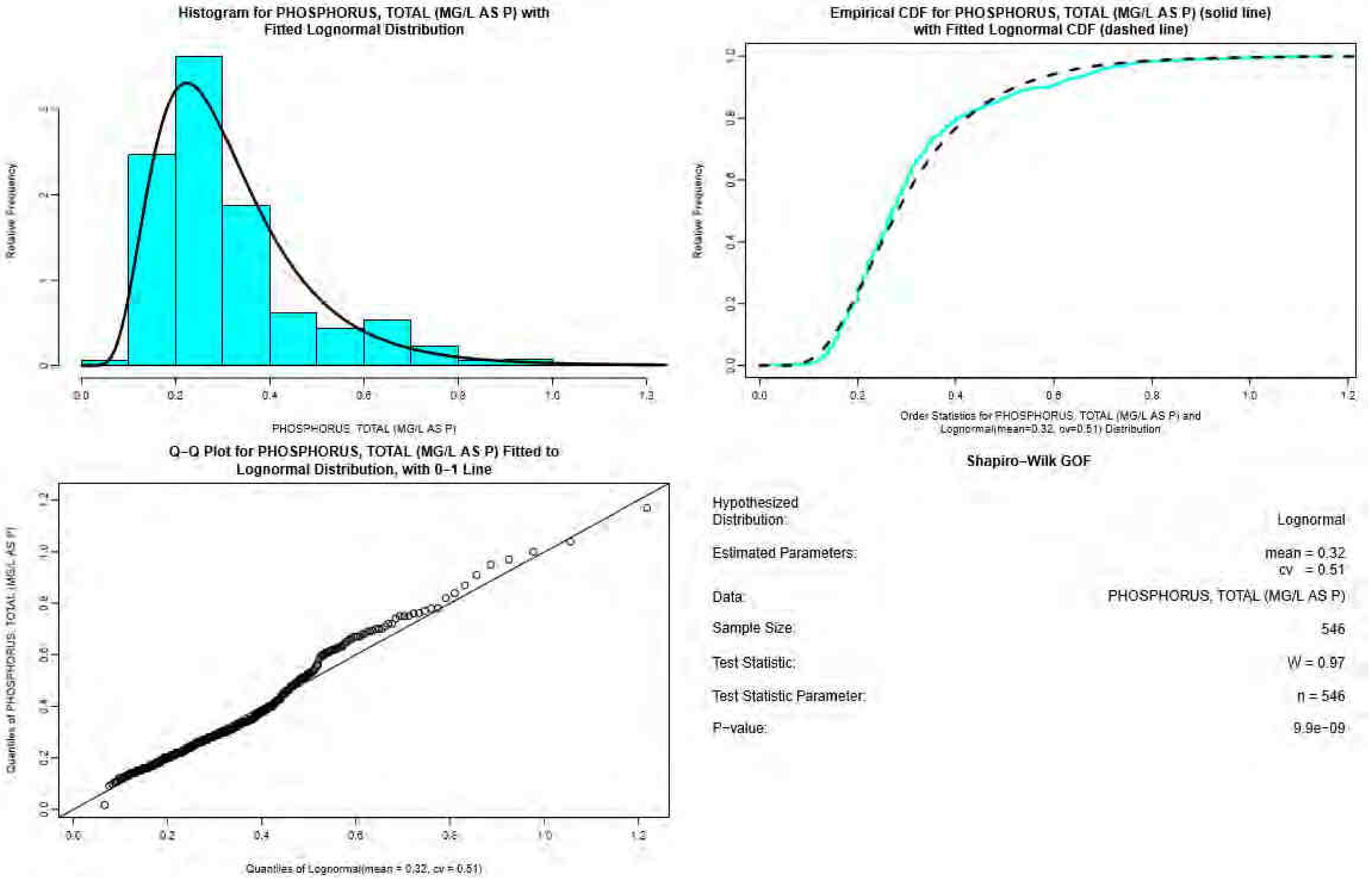
(b) Boxplot by year



(c) Annual values

(d) Boxplot by month

Figure 3. EDA results showing TP concentrations for Fox River at Montgomery



Hypothesized Distribution: Lognormal

Estimated Parameters: mean = 0.32 cv = 0.51

Data: PHOSPHORUS, TOTAL (MG/L AS P)

Sample Size: 546

Test Statistic: W = 0.97

Test Statistic Parameter: n = 546

P-value: 9.9e-09

Figure 4. Goodness-of-Fit test results for TP at Fox River at Montgomery

3. Water Quality Trend Analysis

The objectives of this analysis was to identify the presence or absence of trends in nutrient-related water quality data collected in the Fox River watershed and to estimate rates of change if trends exist. Establishing the cause of a trend, if any, is beyond the scope of this study and requires a different study design, including analysis of the hydrologic processes, aquatic biogeochemistry, land uses, and anthropogenic activities within the watershed. Eighteen monitoring stations in the FoxDB met the minimum monthly data of a five-year period for monotonic trend analysis. Most stations have five or more years of water quality data. Therefore, the core method of analysis used in this study is the Seasonal Kendall Test (SKT) method, which is a nonparametric test for monotonic trends. In cases in which corresponding flow data are available, a parametric test using the Weighted Regression on Time, Discharge and Season (WRTDS) method is implemented to evaluate trends in water quality concentrations and fluxes, complementing the SKT analysis for trends in water quality concentrations. Brief descriptions of the two methods of analyses selected for trend tests are presented in the following sections.

3.1 Seasonal Kendall Test for Trend

The Seasonal Kendall Test (Hirsch and Slack, 1984) is a test for monotonic (upward or downward) trends in time series data that are expected to change in the same direction for one or more seasons. A season could be defined as a single month or a couple of months (e.g., June to August as summer months). A monotonic upward or downward trend indicates a consistently increasing or decreasing pattern in the variable of interest for a given season that may not necessarily be linear. The SKT, which is the generalized form of the Mann-Kendall test, is a nonparametric test for a trend that does not require the time series data to be distributed normally. It can be used in cases where there exist seasonality and serial correlation in the data. The method is also applicable if the time series includes missing data points and/or data with detection limits.

A brief description of the SKT method is given as follows. In a SKT test, the null hypothesis H_0 states that there is no trend (i.e., for each season, the time series data are randomly ordered over the years), whereas the alternative hypothesis H_a is that an upward or downward monotonic trend exists over the years for one or more seasons. To describe the SKT method, a season is assumed to be a month. Let $X = (X_1, X_2, \dots, X_i, \dots X_{12})$ be the time series data (X_i) collected over the years for i^{th} month and $X_1 = (x_{1,1}, x_{1,2}, \dots, x_{1,k}, \dots, x_{1,n1})$ to $X_{12} = (x_{12,1}, x_{12,2}, \dots, x_{12,k}, \dots, x_{12,n12})$ be a subset of January to December data over the years. Note that $n1$ and $n12$ are the number of data points over the years for the months of January and December, respectively, and different months can have a different number of data points. The SKT test begins by calculating the Kendall tau for each month. The following are steps involved in the analysis:

1. List the data collected for the i^{th} month in order of years of data collection and calculate the sign of all possible differences (i.e., a total of $ni(ni-1)/2$ pairs of $(x_{i,j} - x_{i,k})$ for $j > k$) between data points for the i^{th} month:

$$sgn(x_{i,j} - x_{i,k}) = 1 \; if \; (x_{i,j} - x_{i,k}) > 0;$$

$$= \; 0 \; if \; (x_{i,j} - x_{i,k}) = 0 \text{ or}$$

$if\ (x_{i,j} - x_{i,k})$ cannot be determined; or

$$= -1\ if\ (x_{i,j} - x_{i,k}) < 0$$

For example, $if\ (x_{i,j} - x_{i,k}) < 0,$ this would mean that the concentration value measured for the i^{th} month of j^{th} year is less than the value for the same month of k^{th} year.

2. Determine S_i , which is calculated as the number of positive differences minus the number of negative differences for the i^{th} month, and its variance, $Var(S_i)$. If $S_i >$ 0, then the i^{th} month observations made in the later years are greater than those of earlier years for the same month, and vice-versa. S_i and $Var(S_i)$ are calculated as

$$S_i = \sum_{k=1}^{ni-1} \sum_{j=k+1}^{ni} sgn(x_{i,j} - x_{i,k})$$

$$Var(S_i) = \frac{1}{18}\left[ni(ni-1)(2ni+5) - \sum_{l=1}^{Li} t_{i,l}(t_{i,l}-1)(2t_{i,l}+5)\right]$$

where $sgn\ ()$ is defined as the sign function returning a value of 1, -1, or 0 for positive, negative, or zero value, respectively; L_i is the number of tied groups for the i^{th} month and $t_{i,l}$ is the number of data points in the l^{th}group for the i^{th} month. When ties exist because of equal data values or detection limits, the variance is adjusted for the ties. The Kendall tau (τ_i), which is the direction and magnitude of the trend and the Theil-Sen slope estimate (β_i) for i^{th} month can be expressed as

$$\tau_i = \frac{2S_i}{ni(ni-1)} \quad \text{and} \quad \beta_i = median\left(\frac{x_{i,j} - x_{i,k}}{j-k}\right)$$

Next, aggregate S_i and $Var(S_i)$ into $S'$and $Var(S')$, respectively, for m number of seasons (e.g., m=12 when the season is a month or m = 52 when the season is a week) as

$$S' = \sum_{i=1}^{m} S_i \text{ and } Var(S') = \sum_{i=1}^{m} Var(S_i)$$

Overall τ' and β' are computed as weighted averages of the seasonal estimates and the median of all two-point slope estimates within each season, or month in this particular case.

3. Finally, compute the SKT statistic, Z_{skt} that indicates the tendency of the data to increase or decrease (a positive or negative Z_{skt}) , calculated as

$$Z_{skt} = \frac{S' - 1}{\sqrt{Var(S')}} \quad if\ S' > 0$$

$$= 0 \quad if\ S' = 0$$

$$= \frac{S' + 1}{\sqrt{Var(S')}} \quad if\ S' < 0$$

To determine if a trend is statistically significant, a p-value $(\alpha\ )$ associated with Z_{skt} will be calculated, where α is the tolerable probability of rejecting the null hypothesis (i.e., no monotonic trend over time in this particular case). For this study, a p-value of $\alpha = 0.1$ is used, allowing a confidence level of 90% (i.e., $(100(1 - \alpha\ )$ percentile) to accept the presence of a trend.

3.2 SKT Results and Discussion

As SKT is the core method of trend analysis chosen for this study, it is applied to all nutrient-related water quality data observed at the 18 monitoring stations in the Fox River watershed. The SKT analysis conducted is demonstrated here using monthly total phosphorus (TP) data for the Fox River at Montgomery, as shown in Figures 2 and 3. Below is the result of the SKT trend analysis for the TP concentration using EnvStats:

Null Hypothesis: All 12 values of **tau** $(\boldsymbol{\tau_i})$ = 0 (i.e., no monotonic trend).
Alternative Hypothesis: The seasonal taus are not all equal.
(Chi-Square Heterogeneity Test)
At least one seasonal tau is not equal to 0 and all non-zero taus have the same sign (Z_{skt}Trend Test)
Test Name: Seasonal Kendall Test for Trend
Estimated Parameter(s): **Overall tau $(\boldsymbol{\tau'})$ = -0.236431**
Overall slope $(\boldsymbol{\beta'})$ = -0.005576
Intercept = 12.675937500
Sample Sizes for each month (1 to 12): 18, 20, 17, 19, 19, 20, 19, 20, 18, 17, 20, 18
Total Sample Size: 225
Test Statistics: Chi-Square (Het) = 4.309498
$\mathbf{Z_{skt}}$ (Trend) = -4.838630
Test Statistic Parameter (degree of freedom): df = 11
P-values: **Chi-Square (Het) = 9.599737e-01**
$\mathbf{Z_{skt}}$ (Trend) = 1.307374e-06
Confidence Interval for Slope (CL > 90%): **LCL = -0.007500; UCL = -0.003518**

Kendall S-Statistic (S_i) and its variance $Var(S_i)$:
month: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
$\mathbf{S_i}$: -50, -59, -22, -33, -31, -7, -43, -31, -51, -38, -80, -28
$\mathbf{Var(S_i)}$: 696.0, 949.0, 589.3, 817.0, 817.0, 949.0, 817.0, 949.0, 697.0, 589.3, 950.0, 696.0

Seasonal (monthly) Estimates:

month	tau ($\boldsymbol{\tau}_i$)	slope (β_i)	intercept
1	-0.32679739	-0.006428571	13.110357
2	-0.31052632	-0.007316964	14.912489
3	-0.16176471	-0.004048611	8.318111
4	-0.19298246	-0.002500000	5.225000
5	-0.18128655	-0.003047619	6.351238
6	-0.03684211	-0.000665733	1.632627
7	-0.25146199	-0.007750000	15.903000
8	-0.16315789	-0.005892857	12.241518
9	-0.33333333	-0.005818182	12.036125
10	-0.27941176	-**0.013333333**	27.115833
11	-0.42105263	-0.007171429	14.656971
12	-0.18300654	-0.006800000	13.921000

The value of $\mathbf{Z_{skt}}$ **(Trend) = -4.838630** and its associated p-value of **1.307374e-06** indicate that the TP concentration exhibits a decreasing trend of **-0.005576 mg/L per year** (i.e., **overall slope**, $\boldsymbol{\beta'}$) with more than a 90% confidence level. The lower and upper confidence levels for the estimated rate of change lie between **LCL = -0.007500 and UCL = -0.003518**. The monthly estimates of tau ($\boldsymbol{\tau}_i$) and slope ($\boldsymbol{\beta_i}$) show decreasing trends for all months, with the maximum rate of change for the month of October, which is -**0.013333 mg/L per year**. The Chi-Square Heterogeneity Test was also performed to determine if the trend varies for different months and its p-value of **9.599737e-01** indicates no evidence of varying monthly trends.

Similarly, the SKT trend analysis was performed for all water quality parameters. The results are summarized in Tables 4–8, showing annual and seasonal trends in water quality concentrations and pH for all stations. For all water quality parameters, the SKT trend results are illustrated in Figures B.1 to B.10 in Appendix B.

Nutrients

Nutrient data used in the trend analysis include two forms of phosphorus and four forms of nitrogen. These are total phosphorus (TP), dissolved phosphorus (DP), organic nitrogen (Org-N), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), and total kjeldahl nitrogen (TKN). As shown in Table 2, nutrient concentration data were available for most of the 18 stations. The Org-N, NH_3-N, NO_3-N, and TKN data are available for more than 10 stations, and all of the 18 stations have TP and DP concentration data. The record length of the nutrient data generally varies from 5 to 20 years with a majority of the stations having 12 or more years of data and only one station with 3 years of NO_3-N data.

The TP and DP concentration data are available for all 18 stations used in the trend analysis. The mean TP concentration ranges from 0.026 mg/L Poplar Creek near Mouth-Elgin to 0.427 mg/L for Crystal Creek at Rt. 31 at Algonquin. The minimum TP concentration of 0.002 mg/L was observed at Poplar Creek near Mouth-Elgin, Fox River at Algonquin, and Fox River at Rt. 176, whereas the maximum TP concentration value of 3.59 mg/L was recorded at the Fox River at the South Elgin station. Across the stations in the Fox River watershed, the mean DP concentration ranges from 0.053 mg/L for Blackberry near Mouth to 0.499 mg/L for Crystal Creek at Rt. 31 at Algonquin. The minimum DP concentration of 0.009 mg/L was observed at

Blackberry near Mouth, whereas the maximum concentration value of 3.59 mg/L was recorded at Fox River at South Elgin. Currently, no water quality standard exists for TP and DP in the Fox River and its tributaries. There is, however, a TP standard of less than 0.05 mg/L for Illinois lakes with a total surface area of 20 acres, including Chain O'Lakes and others in the Fox River watershed.

The mean Org-N concentration varies from 0.748 mg/L at Ferson Creek near Mouth-Elgin to 1.76 mg/L at the Fox River at Oakwood Hills. The maximum Org-N concentration of 6.48 mg/L was observed at Crystal Creek at Rt. 31, whereas the minimum concentration of 0.03 mg/L was recorded at Fox River at Yorkville. There is no water quality standard for Org-N in the Fox River watershed.

All 18 stations except Nippersink Creek above Wonder Lake have NH_3-N concentration data, the majority of which have 20 years of record. The mean NH_3-N concentration ranges from 0.061 mg/L at Ferson Creek near Mouth-Elgin to 0.15 mg/L at Nippersink Creek at Spring Grove, both of which are monitoring stations in the Fox tributaries. The minimum and maximum NH_3-N concentrations of 0.005 and 1.58 mg/L were observed at the Fox River at Montgomery and Fox River at Algonquin, respectively. The maximum NH_3-N concentration for the analysis period is well below the acute standard of 5.73 mg/L for the Fox River and its tributaries.

The NO_3-N concentration data are available for 12 of the 18 stations, a majority of which have more than 10 years of record. The range of the mean NO_3-N concentration lies between 0.864 mg/L for Fox River at Oakwood Hills and 3.766 mg/L for Crystal Creek at Rt. 31 at Algonquin. The minimum and maximum NO_3-N concentrations of 0.01 mg/L and 14.3 mg/L were recorded at the Fox River at Montgomery and Fox River at Algonquin stations, respectively. The maximum NO_3-N concentration at the Fox River at Algonquin is above 10 mg/L, which is the water quality standard for public and food processing use.

The TKN concentration data are available for all but one station with the same period of record as that of the NH_3-N data. The mean TKN concentration ranges from 0.792 mg/L at Ferson Creek near Mouth-Elgin to 1.959 mg/L at Flint Creek at Kelsey Rd-Lk Barrington. The Fox River at Algonquin and Flint Creek at Kelsey Rd-Lk Barrington have the minimum and maximum TKN concentrations of all gaging stations used in the trend analysis (i.e., 0.01 mg/L and 27.8 mg/L), respectively. Although there is no TKN water quality standard, the USEPA recommends a water quality standard of 2 to 6 mg/L for the Total Nitrogen (TN) concentration, which is a summation of TKN and NO_3-N.

Annual, Seasonal, and Longitudinal Trends

Total Phosphorus

In Figures 5 and 6, the annual and seasonal TP concentration trends and estimated values of change in mg/L per year, respectively, are presented. The TP concentration showed decreasing, increasing, and no trends in five, one, and two of the monitoring stations on the Fox River main stem, respectively. For the decreasing trend, the decrease in TP concentration ranges from 1.4% per year (0.003 mg/L per year) at Fox River at South Elgin to 4.9% per year (0.02 mg/L per year) at Fox River at Yorkville, which is the most downstream station on the main stem. The percentage change per year is computed as a function of the median concentration. The increasing TP trend of 1.6% per year (0.002 mg/L per year) was estimated for Fox River at

Rt. 176, an upstream monitoring station. No trend was detected on seven of the ten Fox tributary stations. Decreasing trends of TP were estimated for Crystal Creek at Rt. 31 (21.9% per year or 0.07 mg/L per year) and Tyler Creek at Rt. 31-Elgin (3% per year or 0.003 mg/L per year).

The seasonal TP trend largely conforms to the annual trend. The winter, fall, spring, and summer months used in computing seasonal trends are December to February, March to May, June to August, and September to November, respectively. Only two stations on the Fox River main stem and two on its tributaries exhibited decreasing TP trends in summer. No summer TP trend was detected in the remaining 12 of the 18 stations. Crystal Creek at Rt. 31 showed decreasing trends for all seasons with the maximum TP reduction of 0.085 mg/L per year (26.6% per year) occurred in summer. Fox River at Rt. 176 and Poplar Creek near Mouth-Elgin experienced increasing TP trends in at least one or more seasons, with the maximum reduction of 0.004 mg/L per year (5.4%) in spring. Only two stations on the Fox River, namely Fox River at Yorkville and Fox River at Montgomery, showed decreasing trends in all seasons with a TP reduction ranging from 0.009 to 0.032 mg/L per year.

Downstream of Fox River at Rt. 176, there seems to be a decreasing annual or seasonal TP trend along the Fox River. For most stations, no longitudinal TP trend was detected in summer.

Dissolved Phosphorus

Decreasing and increasing annual trends for DP were detected in four and three stations, respectively. For the increasing TP trend, the reduction ranges from 2.1% per year for Fox River at Johnsburg to 4.4% per year for Fox River at Rt. 176, whereas the decreasing rate of change was estimated between 1 and 4.9% per year. No annual DP trend was detected for Fox River at Oakwood Hills. The DP concentration in the tributaries showed no annual trend in two of the ten stations but indicate either a decreasing or increasing trend in the remaining stations. The annual trend at Crystal Creek at Rt. 31 showed the maximum reduction of 25.5% per year (or 0.064 mg/L per year), whereas the maximum increasing trend of 4% per year (0.002 mg/L) was calculated for Ferson Creek near Mouth-Elgin.

The DP concentration exhibited variations of upward, downward, or no seasonal trend. For stations in the Fox River main steam, the fall DP trend showed a decreasing trend downstream of Algonquin but no trend upstream. The most downstream station exhibited a decreasing DP trend of 10.2% (0.026 mg/L per year) in the fall, which is the maximum rate of change for any of the seasonal trends along the Fox River. Upstream of Fox River at South Elgin, an increasing DP trend was detected in spring, summer, and winter for most of the stations on the Fox River, which also conforms to the annual DP trend. The DP concentration for Crystal Creek at Rt. 31 shows the largest decreasing trend in all seasons with the maximum reduction of 31.6% per year (0.079 mg/L) in the fall. The winter DP concentration on the tributaries showed either a decreasing or no trend.

Showing some longitudinal trends, all stations downstream of Fox River at Algonquin exhibited a decreasing annual trend with the maximum DP reduction occurring at Fox River at Yorkville, which is 0.012 mg/L per year (4.9% per year). The fall DP trend conforms to the annual trend along the Fox River main stem. In all seasons, either a decreasing or no DP trend was detected for stations downstream of the Fox River at Algonquin.

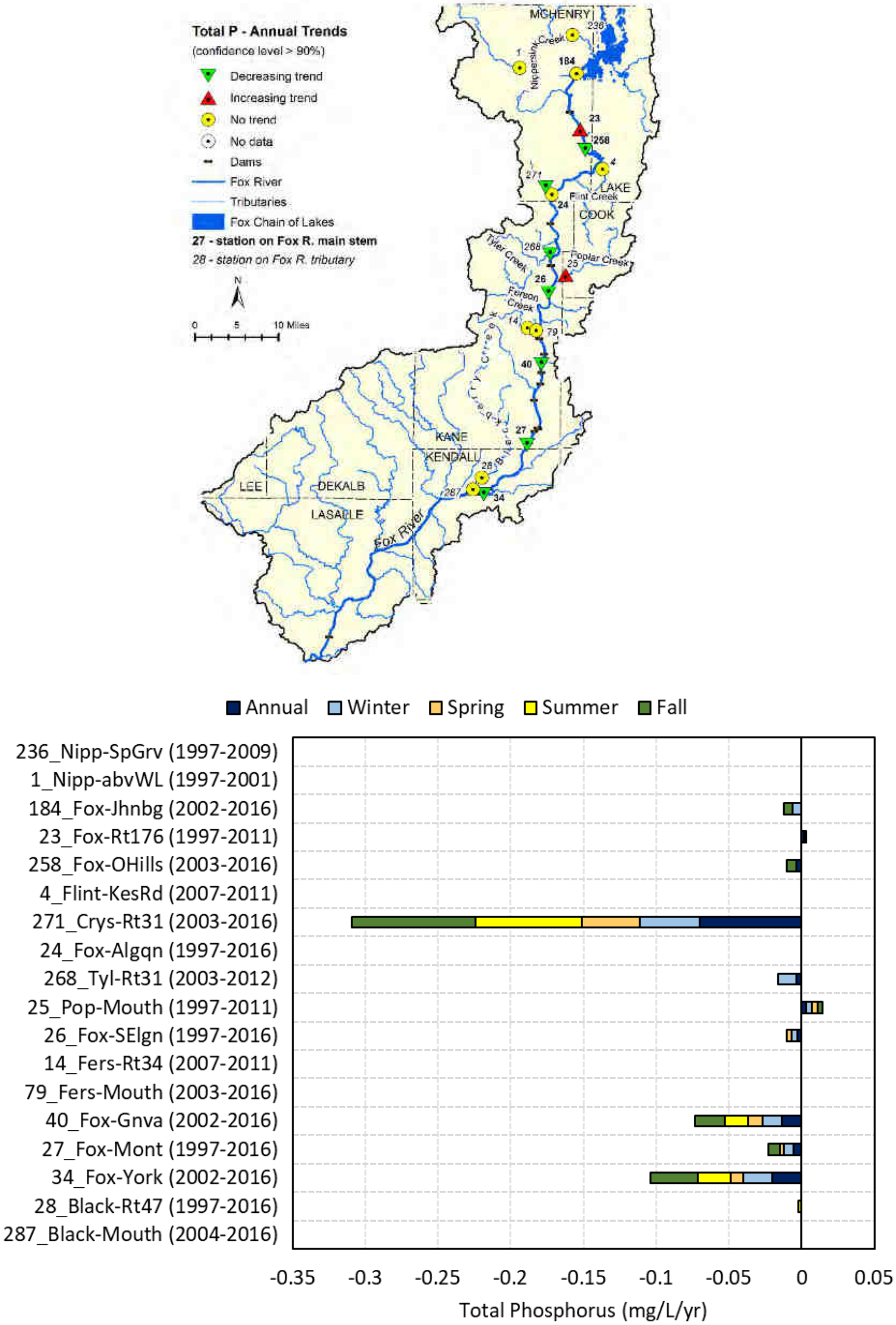


Figure 5. Annual trends of total phosphorus (TP) in the Fox River watershed

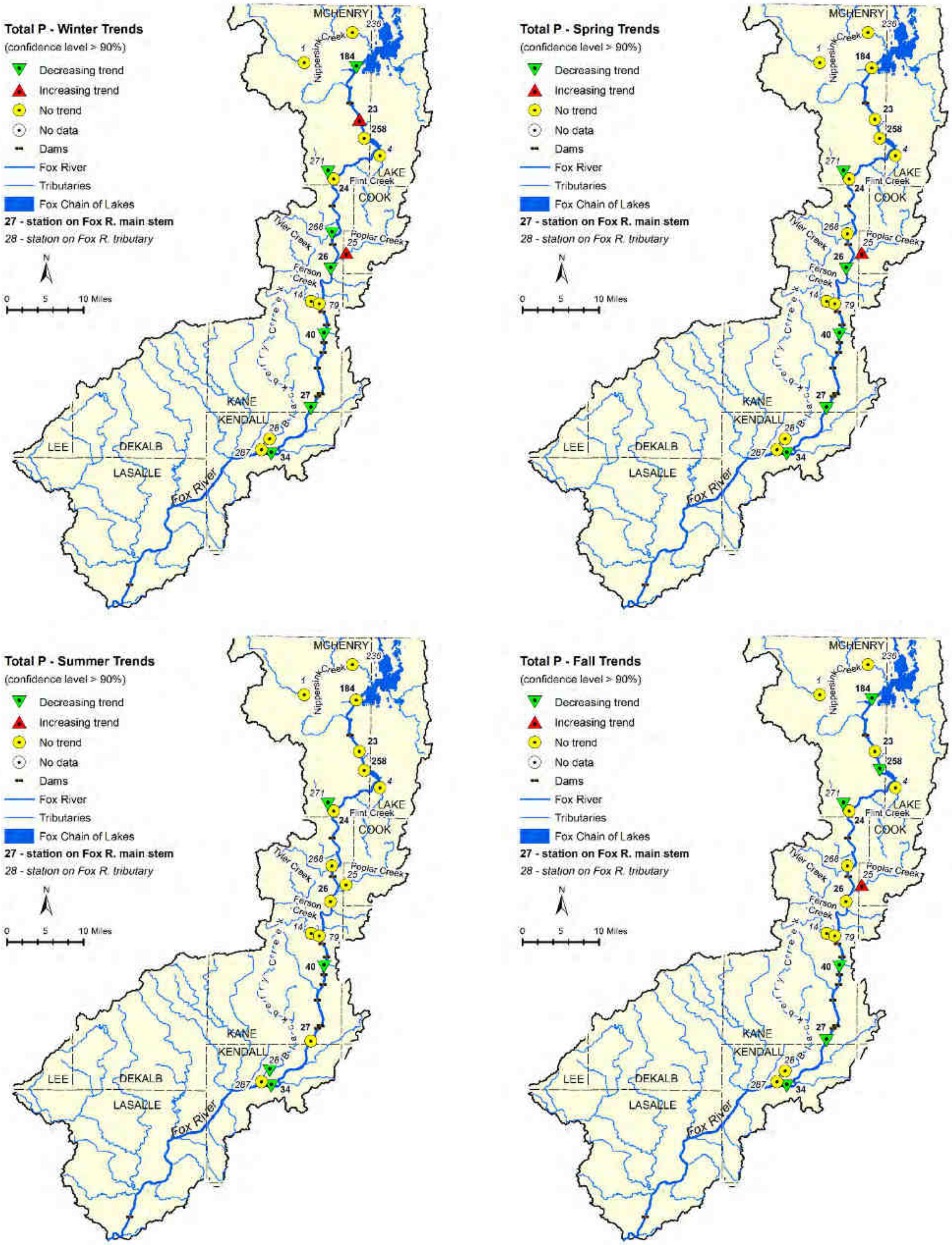


Figure 6. Seasonal trends of total phosphorus (TP) in the Fox River watershed

Organic Nitrogen

The Org-N concentration along the Fox River main stem shows a decreasing annual trend in five of the eight stations with a maximum reduction of 2% per year (0.03 mg/L per year) at the Fox River at Montgomery. In contrast, no trend is detected at the remaining two stations, namely Fox River at Algonquin and Fox River at Oakwood Hills. Similarly, none of the four stations in the Fox River tributaries with Org-N data shows any trend.

The Org-N concentration trends showed seasonal variations. For example, no winter trend was detected for Org-N, with the exception of Tyler Creek at Rt. 31-Elgin, which showed the maximum reduction of 12.5% per year (0.085 mg/L per year) of all seasons. In contrast, this same station exhibited the only increasing trend (i.e., 5.34% per year for the summer Org-N concentration). At Blackberry Creek at Rt. 47, the Org-N showed a decreasing summer trend of 9.8% per year (0.066 mg/L per year), but no annual or other seasonal trend was detected for the same station. For the remaining stations, the fall, spring, and summer trends conform to the annual trends.

Along the Fox River, the annual and seasonal Org-N concentration showed a decreasing trend, with the exception of Fox River at Johnsburg, which showed no spring, summer, or winter trends.

Ammonia Nitrogen

For only two of the eight stations in the Fox River, namely Fox River at Algonquin and Fox River at Rt. 176, no annual trend for the NH_3-N concentration was detected. All the remaining stations showed decreasing annual trends of NH_3-N concentration, with the largest decrease of 5.2% per year (0.002 mg/L) obtained for Fox River at Montgomery. In the tributaries, the NH_3-N concentration showed a decreasing annual trend at only three stations with the rest showing no trend. The largest decrease was 5.3% per year, which was for Blackberry Creek near Mouth. In contrast, no trend was detected for Blackberry Creek at Rt. 47, which is an upstream station on the same creek.

Despite exhibiting an annual trend for Fox River at Johnsburg, no seasonal NH_3-N trend was detected. In all other cases in which annual trends exist, there is at least one or more seasons with a similar trend. For the most part, fall and summer trends conform to annual trends with some exceptions. For example, the fall NH_3-N concentration showed an increasing trend of 4.3% per year for Tyler Creek at Rt. 31-Elgin, while no trend was detected annually or for any other season. The largest increasing trend of 11.8% per year was detected for the spring NH_3-N concentration at Blackberry Creek at Rt. 47. This station also exhibited one of the summer's largest decreasing trends (13.2% per year). In all of the monitoring stations upstream of Fox River at Montgomery, no spring trend was detected, with the exception of Nippersink Creek at Spring Grove, which showed a decreasing trend of 10.4% per year.

NH_3-N concentrations generally showed decreasing annual and seasonal trends along the Fox main stem for at least four of the eight stations. The winter NH_3-N concentration shows larger decreasing trends ranging from 8.3% per year for Fox River at South Elgin to 21% per year for Fox River at Yorkville.

Nitrate Nitrogen

The NO_3-N concentration showed a decreasing trend in six of the eight stations in the Fox River main stem with the maximum NO_3-N reduction of 4.6% (0.028 mg/L per year for Fox River at Oakwood Hills. An increasing or no trend was detected in two of the remaining stations; Fox River at Rt. 176 showed an increasing trend of 5.1% per year (0.047 mg/L of NO_3-N). Only four tributary stations have NO_3-N concentration data, and a decreasing trend of 9.6% per year (0.066 mg/L per year) was estimated for Blackberry Creek near Mouth, which was found to be the largest decrease in NO_3-N concentrations. An increasing trend was obtained for Crystal Creek at Rt. 31 and no trend was detected for the remaining two tributary stations.

Fox River at Rt. 176 showed an increasing NO_3-N trend in fall (6.2% per year), spring (9.2% per year), and winter (67.7% per year), but no trend in summer. Its winter increasing trend amounted to 0.63 mg/L per year. No seasonal trend was obtained for Crystal Creek at Rt. 31, which showed an increasing annual trend of 2.2% (0.075 mg/L per year). All of the remaining stations on the Fox River or its tributaries exhibited either a decreasing or no trend. The largest seasonal decrease of 37.4% per year (0.258 mg/L per year) was estimated for the winter NO_3-N concentration at Blackberry Creek near Mouth. There was no seasonal trend for the most downstream station on the Fox main stem (Fox River at Yorkville), in spite of detecting a decreasing annual trend.

All stations downstream and upstream of Fox River at Rt. 176 except one exhibited decreasing trends of NO_3-N concentrations, indicating that a decreasing longitudinal trend exists. Mostly, the fall and summer longitudinal trends follow the annual trend, whereas most of the spring and winter NO_3-N concentrations showed no trend.

Total Kjeldahl Nitrogen

All eight stations along the Fox River main stem did not show a statistically significant trend in TKN concentrations, whereas five of the nine tributary stations with TKN data exhibited a decreasing annual trend ranging from 0.4% (0.004 mg/L per year) at Nippersink Creek at Spring Grove to 12.6% per year (0.0.15 mg/L per year) at Ferson Creek at Rt. 34. In contrast, an increasing trend of TKN concentrations by 1.8% per year (0.017 mg/L per year) was estimated for Poplar Creek near Mouth-Elgin.

With few exceptions, no seasonal TKN trend was detected for most monitoring stations in the Fox River main stem, largely conforming to that of the annual trend. A decreasing spring trend of 0.82% per year (0.012 mg/L per year of TKN) was estimated for Fox River at Montgomery. In contrast, Fox River at Oakwood Hills showed an increasing winter trend of 2.1% per year (0.036 mg/L of TKN). In the tributaries, the seasonal TKN concentration showed an increasing trend in some stations and a decreasing or no trend in others. For example, Poplar Creek near Mouth-Elgin exhibited an increasing winter trend of TKN (3.8% per year or 0.038 mg/L per year), which is the largest increasing trend estimated for TKN concentrations in the tributaries or the Fox main stem. On the other hand, the largest decreasing trend of TKN concentrations was estimated in winter for Ferson Creek at Rt. 34 at 59.6% per year (0.715 mg/L per year). Fall TKN concentrations in the Fox main stem showed no trend. In contrast, results showed decreasing trends for Flint Creek at Kelsey Rd-Lk Barrington (15.7%) and Nippersink Creek at Spring Grove (0.6%); increasing trends for Blackberry Creek at Rt. 47 (0.7%), Ferson

Creek at Rt. 34 (0.8%), and Poplar Creek near Mouth-Elgin (3.1%); and no trends for the remaining four tributary stations.

In general, no annual or seasonal longitudinal trend was detected along the Fox River. A decreasing spring trend was detected for Fox River at Montgomery, despite no trends in all the stations upstream. An increasing winter trend at Fox River at Oakwood Hills did not translate into any trend downstream.

Dissolved Oxygen

Out of the 18 gaging stations used in the trend analysis, 13 stations have 13 to 20 years of DO concentration and pH data. These include all 8 stations on the Fox River main stem and 5 on the tributaries (see Table 3). The mean DO concentration on the Fox River and its tributaries ranges from 9.2 mg/L at Crystal Creek-Rt. 31 to 11.5 mg/L at Tyler Creek at Rt. 31-Elgin. The minimum and maximum DO levels of 0.82 and 27.6 mg/L were recorded at Nippersink Creek at Spring Grove and Fox River at Johnsburg, respectively. The Fox River and its tributaries have detailed water quality standards that vary by location, season, and number of consecutive days, as presented in Table 2. The DO water quality standards can be compared with the DO time series and monthly boxplots provided for each monitoring station in Appendix A.

Annual, Seasonal, and Longitudinal Trends

The DO concentrations exhibited a decreasing trend for most stations along the Fox River watershed, with the exception of station 258 (Fox River at Oakwood Hills). In contrast, no DO trend was detected for most of the gaging stations in the summer months. However, a decreasing trend was obtained at Tyler Creek-Rt. 31 at Elgin, Blackberry Creek near Mouth, Fox River at Yorkville, and the Algonquin stations.

The annual DO levels along the Fox River main stem showed a decreasing trend in six of the eight stations with the largest decrease of 1.7% per year (0.17 mg/L per year) at the most downstream station in the Fox main stem (Fox River at Yorkville). No trend in DO levels was exhibited at Fox River at Johnsburg, and an increasing trend of 0.7% per year (0.06 mg/L per year) was estimated at Fox River at Oakwood Hills. The annual DO levels in the Fox River tributaries indicate a decreasing trend in four out of seven stations analyzed, with the largest decrease of 1.6% per year (0.15 mg/L per year) at Blackberry Creek near Mouth. However, no statistically significant trend was detected at Blackberry Creek at Rt. 47, which is located a few miles upstream in the same creek.

The DO trends vary from season to season. In summer, the DO levels show a decreasing trend in only 4 out of the 13 stations, namely, Tyler Creek at Rt. 31-Elgin, Blackberry Creek near Mouth, Fox River at Yorkville, and Fox River at Algonquin. At Fox River at Geneva, the DO levels increased by 1.4% per year (0.145 mg/L per year) during the summer. In spring, most of the stations showed a decreasing trend in DO levels. Throughout the watershed, the largest seasonal decrease of 10.2% (0.98 mg/L per year) was calculated for Blackberry Creek near Mouth in winter, whereas the smallest decrease in DO levels was 0.6% (0.05mg/L per year) in the fall for the Fox River at South Elgin. Longitudinally along the Fox River, the annual and seasonal trend results consistently indicate that DO levels are generally declining at varying levels.

pH

All of the stations with DO data also have pH data. The mean and median pH values ranged from 7.8 to 8.5 on both the Fox main stem and tributaries, which is within the pH limit for freshwater (6.5 to 9.0). The minimum and maximum pH values of 6.0 and 13.4 were observed at Fox River at Oakwood Hills and Blackberry Creek near Mouth, respectively. All but two stations showed some violations of the pH limit. These two stations are Fox River at Oakwood Hills and Fox River at Montgomery, both located on the Fox River main stem.

Annual, Seasonal, and Longitudinal Trends

For all monitoring stations, the central tendencies of all pH values, as expressed in their mean and median values, are within the pH limits for freshwater; thus a decreasing or increasing pH trend would indicate a declining water quality. The majority of the stations on the Fox River main stem do not show any trend in pH values, as the values were stable. Decreasing pH trends were seen only at Fox River at Montgomery and Fox River at Yorkville, whereas an increasing pH trend was exhibited at Fox River at Johnsburg. Decreasing pH trends were detected at Crystal Creek-Rt. 31, Blackberry Creek near Mouth, and Blackberry Creek at Rt. 47. In contrast, increasing pH trends were seen at Tyler Creek at Rt. 31-Elgin and Ferson Creek near Mouth-Elgin.

The majority of the stations showed no seasonal trend in pH values, which also indicates stable pH values in all seasons. For the most part, the spring pH trends are in line with the annual decreasing trends. The fall pH values showed no trend for most stations, but the increasing trend in two stations (Ferson Creek near Mouth-Elgin and Fox River at Johnsburg) conforms to the annual pH trends. In summer, there was a decreasing pH trend at Fox River at Yorkville, Poplar Creek near Mouth-Elgin, and Blackberry Creek near Mouth. The winter pH values showed an increasing trend at Ferson Creek near Mouth-Elgin, whereas these values showed decreasing trends at Fox River at Montgomery and Fox River at Yorkville. For either decreasing or increasing pH trends detected, the maximum change per year was less than1%. The pH values showed a decreasing trend downstream of the Fox River at Geneva Park-Fabyan.

Total Suspended Solids

The TSS concentration data are available for only seven stations, of which four are on the Fox main stem and three are on its tributaries. The mean TSS concentrations across these stations vary from 12.2 mg/L for Poplar Creek near Mouth-Elgin to 34.1 mg/L for Fox River at Montgomery. The minimum and maximum TSS concentrations are 1.0 and 203 mg/L, with both recorded at Blackberry Creek at Rt. 47. No water quality standard is currently available for TSS.

Annual, Seasonal, and Longitudinal Trends

Out of the four stations on the Fox River main stem with TSS data, two showed no annual TSS trend, and the remaining two downstream stations exhibited a decreasing TSS trend with a maximum reduction of 0.65 mg/L per year (2% per year) at the Fox River at Montgomery. No annual trend was seen in any of the three stations on Fox tributaries with TSS data.

No TSS trend was detected in the Fox River main stem or tributaries for fall or spring except for Fox River at Montgomery, which showed a decreasing fall trend of 2.67 mg/L per year (8.1% per year). Increasing winter trends were detected for Fox River at Rt. 176 and Poplar Creek near Mouth-Elgin, which were 2.0 and 3.3 mg/L per year, respectively, but neither station showed an annual TSS trend. Poplar Creek near Mouth-Elgin also exhibited a decreasing summer TSS trend of 1.2 mg/L per year. An increasing trend for summer TSS concentrations was detected at Blackberry Creek at Rt. 47, but all remaining stations show no trend for the summer months.

A longitudinal TSS trend seems to appear along the Fox River because both stations downstream of Algonquin showed a reduction in TSS concentrations. The fall TSS trend conforms to the annual trend along the Fox River. No distinct longitudinal trend was observed for other seasons.

Chlorophyll-A

Only 11 out of the 18 stations have CHL-A concentration data, the majority of which are located in the Fox main stem (i.e., seven stations). The mean CHL-A concentration across these stations has a range of 95.6 µg/l with higher and lower concentrations on the Fox main stem and tributaries, respectively. The mean concentration on the main stem ranges from 81.6 µg/l at Fox River at Johnsburg to 105.3 µg/l at Fox River at Geneva. In contrast, the mean CHL-A concentration in the tributaries varies from 9.7 µg/l at Tyler Creek at Rt. 31-Elgin to 29.7 µg/l at Crystal Creek at Rt. 31. The range of CHL-A concentration on the Fox main stem and tributary stations is 478.8 µg/l, with the lowest concentration of 0.63 µg/l observed at Ferson Creek near Mouth-Elgin and Blackberry Creek near Mouth. The maximum CHL-A concentration in the tributaries is 244.4 µg/l for Crystal Creek at Rt. 31. Currently, there is no CHL-A standard for Fox River and its tributaries.

Annual, Seasonal, and Longitudinal Trends

The CHL-A concentration showed a decreasing annual trend in all seven stations with observed data in the Fox River main stem, ranging from 1.37 µg/l per year (1.7% per year) for Fox River at South Elgin to 2.87 µg/l (3.4% per year) for Fox River at Oakwood Hills. In contrast, no annual trend was detected for all four tributary stations with CHL-A records.

No trend was detected for summer CHL-A concentrations. Fall and spring trends conform to annual trends with the maximum decreasing fall trend of 4.8 µg/l per year (6% per year) for Fox River at Yorkville. Despite having no annual CHL-A trend for Ferson Creek near Mouth-Elgin, an increasing winter trend of 5.2% (0.56 µg/l) was detected. Along the Fox River, CHL-A concentrations clearly showed decreasing annual, fall, and spring trends.

Summaries of the annual, winter, spring, summer, and fall trends are presented in Tables 5 through 9, showing increasing, decreasing, no trend, or '-' for no data. Furthermore, insufficient data for conducting the annual or seasonal trend analysis falls under the no data category. Improving, stable, and declining trends are shown in green, yellow, and red colors. In the tables, the stations are listed in upstream (Nippersink Creek at Spring Grove) to downstream (Blackberry Creek near Mouth) order and tributaries (in italics) appear in the order of their confluence with the Fox River (in bold).

Table 5. Annual Water Quality Trends

Station ID	Station Name	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	TSS	CHL-A
236	*Nippersink Cr at Spring Grove*	No Trend	Decreasing	-	Decreasing	-	No Trend	No Trend	No Trend	No Trend	-
1	*Nippersink Cr above Wonder Lake*	No Trend	No Trend	-	-	-	-	-	-	-	-
184	**Fox River at Johnsburg**	No Trend	Increasing	Decreasing	Decreasing	Decreasing	Decreasing	No Trend	Increasing	-	Decreasing
23	**Fox River at Rt 176**	Increasing	Increasing	-	No Trend	Increasing	No Trend	Decreasing	No Trend	No Trend	-
258	**Fox River at Oakwood Hills**	Decreasing	No Trend	No Trend	Decreasing	Decreasing	No Trend	Increasing	No Trend	-	Decreasing
4	*Flint Cr at Kelsey Rd-Lk Barrington*	No Trend	No Trend	-	No Trend	-	No Trend	-	-	-	-
271	*Crystal Cr at Rt 31*	Decreasing	Decreasing	No Trend	No Trend	Increasing	No Trend	Decreasing	Decreasing	-	No Trend
24	**Fox River at Algonquin**	No Trend	Increasing	No Trend	No Trend	Decreasing	No Trend	Decreasing	No Trend	No Trend	Decreasing
268	*Tyler Cr at Rt. 31-Elgin*	Decreasing	Decreasing	No Trend	No Trend	No Trend	No Trend	Decreasing	Increasing	-	No Trend
25	*Poplar Cr near Mouth-Elgin*	Increasing	Increasing	-	No Trend	-	Increasing	No Trend	No Trend	No Trend	-
26	**Fox River at South Elgin**	Decreasing	Decreasing	Decreasing	Decreasing	No Trend	Decreasing	Decreasing	No Trend	Decreasing	Decreasing
14	*Ferson Cr at Rt 34*	No Trend	No Trend	-	No Trend	-	No Trend	-	-	-	-
79	*Ferson Cr near Mouth-Elgin*	No Trend	Increasing	No Trend	Decreasing	Decreasing	No Trend	Decreasing	Increasing	-	No Trend
40	**Fox River at Geneva**	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	No Trend	-	Decreasing
27	**Fox River at Montgomery**	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing
34	**Fox River at Yorkville**	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	-	Decreasing
28	*Blackberry Cr at Rt 47*	No Trend	Decreasing	-	No Trend	-	No Trend	No Trend	Decreasing	No Trend	-
287	*Blackberry Cr near Mouth*	No Trend	No Trend	No Trend	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing	-	No Trend

Note: Color code – “red” declining trend; “green” improving trend; “yellow” stable; “-” no data.

Table 6. Winter Water Quality Trends

Station ID	Station Name	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	TSS	CHL-A
236	*Nippersink Cr at Spring Grove*	No Trend	No Trend	-	No Trend	-	No Trend	No Trend	No Trend	No Trend	-
1	*Nippersink Cr above Wonder Lake*	No Trend	Decreasing	-	-	-	-	-	-	-	-
184	**Fox River at Johnsburg**	Decreasing	No Trend	No Trend	No Trend	No Trend	No Trend	-	No Trend	-	No Trend
23	**Fox River at Rt 176**	Increasing	Increasing	-	No Trend	Increasing	No Trend	No Trend	No Trend	-	-
258	**Fox River at Oakwood Hills**	No Trend	No Trend	No Trend	No Trend	No Trend	No Trend	-	-	-	No Trend
4	*Flint Cr at Kelsey Rd-Lk Barrington*	No Trend	No Trend	-	No Trend	-	No Trend	-	-	-	-
271	*Crystal Cr at Rt 31*	Decreasing	Decreasing	No Trend	No Trend	No Trend	No Trend	No Trend	-	-	No Trend
24	**Fox River at Algonquin**	No Trend	Increasing	No Trend	No Trend	No Trend	No Trend	Decreasing	No Trend	No Trend	Decreasing
268	*Tyler Cr at Rt. 31-Elgin*	Decreasing	Decreasing	Decreasing	No Trend	Decreasing	No Trend	No Trend	-	-	No Trend
25	*Poplar Cr near Mouth-Elgin*	Increasing	No Trend	-	No Trend	-	Increasing	No Trend	No Trend	Increasing	-
26	**Fox River at South Elgin**	Decreasing	Decreasing	No Trend	Decreasing	No Trend	Decreasing	Decreasing	No Trend	No Trend	Decreasing
14	*Ferson Cr at Rt 34*	No Trend	No Trend	-	No Trend	-	No Trend	-	-	-	-
79	*Ferson Cr near Mouth-Elgin*	No Trend	No Trend	No Trend	No Trend	Decreasing	No Trend	Decreasing	Increasing	-	Increasing
40	**Fox River at Geneva**	Decreasing	No Trend	No Trend	Decreasing	No Trend	No Trend	Decreasing	No Trend	-	No Trend
27	**Fox River at Montgomery**	Decreasing	No Trend	No Trend	Decreasing	No Trend	Decreasing	No Trend	Decreasing	No Trend	No Trend
34	**Fox River at Yorkville**	Decreasing	Decreasing	No Trend	Decreasing	No Trend	No Trend	Decreasing	Decreasing	-	Decreasing
28	*Blackberry Cr at Rt 47*	No Trend	Decreasing	-	No Trend	-	No Trend	No Trend	No Trend	No Trend	-
287	*Blackberry Cr near Mouth*	No Trend	No Trend	No Trend	Decreasing	Decreasing	No Trend	Decreasing	-	-	No Trend

Note: Color code – “red” declining trend; “green” improving trend; “yellow” stable; “-” no data.

Table 7. Spring Water Quality Trends

Station ID	Station Name	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	TSS	CHL-A
236	*Nippersink Cr at Spring Grove*	No Trend	Decreasing	-	Decreasing	-	No Trend	No Trend	No Trend	No Trend	-
1	*Nippersink Cr above Wonder Lake*	No Trend	No Trend	-	-	-	-	-	-	-	-
184	**Fox River at Johnsburg**	No Trend	Increasing	No Trend	No Trend	No Trend	Decreasing	No Trend	No Trend	-	Decreasing
23	**Fox River at Rt 176**	No Trend	Increasing	-	No Trend	Increasing	No Trend	No Trend	No Trend	No Trend	-
258	**Fox River at Oakwood Hills**	No Trend	Increasing	No Trend	No Trend	No Trend	No Trend	No Trend	No Trend	-	Decreasing
4	*Flint Cr at Kelsey Rd-Lk Barrington*	No Trend	No Trend	-	No Trend	-	No Trend	-	-	-	-
271	*Crystal Cr at Rt 31*	Decreasing	Decreasing	No Trend	No Trend	No Trend	No Trend	No Trend	No Trend	-	No Trend
24	**Fox River at Algonquin**	No Trend	Increasing	No Trend	No Trend	No Trend	No Trend	Decreasing	No Trend	No Trend	Decreasing
268	*Tyler Cr at Rt. 31-Elgin*	No Trend	No Trend	No Trend	No Trend	Decreasing	No Trend	Decreasing	No Trend	-	No Trend
25	*Poplar Cr near Mouth-Elgin*	Increasing	Increasing	-	No Trend	-	No Trend	No Trend	No Trend	No Trend	-
26	**Fox River at South Elgin**	Decreasing	No Trend	Decreasing	No Trend	No Trend	Decreasing	Decreasing	No Trend	No Trend	Decreasing
14	*Ferson Cr at Rt 34*	No Trend	No Trend	-	No Trend	-	No Trend	-	-	-	-
79	*Ferson Cr near Mouth-Elgin*	No Trend	Increasing	No Trend	No Trend	Decreasing	No Trend	Decreasing	No Trend	-	No Trend
40	**Fox River at Geneva**	Decreasing	Decreasing	Decreasing	No Trend	No Trend	Decreasing	Decreasing	No Trend	-	Decreasing
27	**Fox River at Montgomery**	Decreasing	No Trend	Decreasing	Decreasing	No Trend	No Trend	Decreasing	Decreasing	No Trend	Decreasing
34	**Fox River at Yorkville**	Decreasing	Decreasing	Decreasing	Decreasing	No Trend	Decreasing	Decreasing	Decreasing	-	Decreasing
28	*Blackberry Cr at Rt 47*	No Trend	No Trend	-	Increasing	-	No Trend	No Trend	Decreasing	No Trend	-
287	*Blackberry Cr near Mouth*	No Trend	No Trend	No Trend	No Trend	No Trend	No Trend	Decreasing	Decreasing	-	No Trend

Note: Color code – "red" declining trend; "green" improving trend; "yellow" stable; "-" no data.

Table 8. Summer Water Quality Trends

Station ID	Station Name	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	TSS	CHL-A
236	*Nippersink Cr at Spring Grove*	No Trend	No Trend	-	No Trend	-	No Trend	No Trend	No Trend	No Trend	-
1	*Nippersink Cr above Wonder Lake*	No Trend	No Trend	-	-	-	-	-	-	-	-
184	**Fox River at Johnsburg**	No Trend	Increasing	No Trend	No Trend	Decreasing	No Trend	No Trend	No Trend	-	No Trend
23	**Fox River at Rt 176**	No Trend	Increasing	-	No Trend	No Trend	No Trend	No Trend	No Trend	No Trend	-
258	**Fox River at Oakwood Hills**	No Trend	No Trend	No Trend	No Trend	Decreasing	No Trend	No Trend	No Trend	-	No Trend
4	*Flint Cr at Kelsey Rd-Lk Barrington*	No Trend	No Trend	-	No Trend	-	No Trend	-	-	-	-
271	*Crystal Cr at Rt 31*	Decreasing	Decreasing	No Trend	No Trend	No Trend	No Trend	No Trend	No Trend	-	No Trend
24	**Fox River at Algonquin**	No Trend	Increasing	No Trend	No Trend	Decreasing	No Trend	Decreasing	No Trend	No Trend	No Trend
268	*Tyler Cr at Rt. 31-Elgin*	No Trend	No Trend	Increasing	No Trend	No Trend	Increasing	Decreasing	No Trend	-	No Trend
25	*Poplar Cr near Mouth-Elgin*	No Trend	Increasing	-	No Trend	-	No Trend	No Trend	Decreasing	Decreasing	-
26	**Fox River at South Elgin**	No Trend	No Trend	Decreasing	No Trend	No Trend	Decreasing	No Trend	No Trend	No Trend	No Trend
14	*Ferson Cr at Rt 34*	No Trend	-	-	No Trend	-	No Trend	-	-	-	-
79	*Ferson Cr near Mouth-Elgin*	No Trend	Increasing	No Trend	Decreasing	Decreasing	No Trend	No Trend	No Trend	-	No Trend
40	**Fox River at Geneva**	Decreasing	Decreasing	Decreasing	Decreasing	No Trend	Decreasing	Increasing	No Trend	-	No Trend
27	**Fox River at Montgomery**	No Trend	No Trend	Decreasing	Decreasing	Decreasing	No Trend	No Trend	No Trend	No Trend	No Trend
34	**Fox River at Yorkville**	Decreasing	Decreasing	Decreasing	Decreasing	No Trend	Decreasing	Decreasing	Decreasing	-	No Trend
28	*Blackberry Cr at Rt 47*	Decreasing	No Trend	-	Decreasing	-	No Trend	No Trend	No Trend	Increasing	-
287	*Blackberry Cr near Mouth*	No Trend	No Trend	Decreasing	Decreasing	Increasing	Decreasing	No Trend	No Trend	-	No Trend

Note: Color code – "red" declining trend; "green" improving trend; "yellow" stable; "-" no data.

Table 9. Fall Water Quality Trends

Station ID	Station Name	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	TSS	CHL-A
236	*Nippersink Cr at Spring Grove*	No Trend	No Trend	-	No Trend	-	No Trend	No Trend	No Trend	No Trend	-
1	*Nippersink Cr above Wonder Lake*	No Trend	No Trend	-	-	-	-	-	-	-	-
184	**Fox River at Johnsburg**	Decreasing	No Trend	Decreasing	No Trend	No Trend	Decreasing	No Trend	Increasing	-	Decreasing
23	**Fox River at Rt 176**	No Trend	No Trend	-	No Trend	Increasing	No Trend	No Trend	No Trend	No Trend	-
258	**Fox River at Oakwood Hills**	Decreasing	No Trend	No Trend	Decreasing	Decreasing	No Trend	No Trend	No Trend	-	No Trend
4	*Flint Cr at Kelsey Rd-Lk Barrington*	No Trend	No Trend	-	No Trend	-	No Trend	-	-	-	-
271	*Crystal Cr at Rt 31*	Decreasing	Decreasing	No Trend	No Trend	No Trend	No Trend	Decreasing	No Trend	-	No Trend
24	**Fox River at Algonquin**	No Trend	No Trend	No Trend	Decreasing	Decreasing	No Trend	No Trend	No Trend	No Trend	Decreasing
268	*Tyler Cr at Rt. 31-Elgin*	No Trend	No Trend	No Trend	Increasing	No Trend	No Trend	No Trend	No Trend	-	No Trend
25	*Poplar Cr near Mouth-Elgin*	Increasing	No Trend	-	No Trend	-	Increasing	No Trend	No Trend	No Trend	-
26	**Fox River at South Elgin**	No Trend	Decreasing	Decreasing	Decreasing	No Trend	Decreasing	Decreasing	No Trend	No Trend	No Trend
14	*Ferson Cr at Rt 34*	No Trend	No Trend	-	No Trend	-	No Trend	-	-	-	-
79	*Ferson Cr near Mouth-Elgin*	No Trend	Increasing	No Trend	Decreasing	Decreasing	No Trend	No Trend	Increasing	-	No Trend
40	**Fox River at Geneva**	Decreasing	Decreasing	Decreasing	Decreasing	No Trend	Decreasing	Decreasing	No Trend	-	Decreasing
27	**Fox River at Montgomery**	Decreasing	No Trend	Decreasing	Decreasing	Decreasing	No Trend	No Trend	No Trend	Decreasing	Decreasing
34	**Fox River at Yorkville**	Decreasing	Decreasing	Decreasing	Decreasing	No Trend	Decreasing	Decreasing	Decreasing	-	Decreasing
28	*Blackberry Cr at Rt 47*	No Trend	No Trend	-	No Trend	-	No Trend	No Trend	No Trend	No Trend	-
287	*Blackberry Cr near Mouth*	No Trend	No Trend	No Trend	Decreasing	Decreasing	No Trend	Decreasing	No Trend	-	No Trend

Note: Color code – “red” declining trend; “green” improving trend; “yellow” stable; “-” no data.

3.3 Weighted Regression on Time, Discharge, and Season

The Weighted Regression on Time, Discharge, and Season (WRTDS) is a relatively new emerging method developed to provide a more accurate representation of long-term trends, and seasonal and discharge-related components of long-term water quality datasets. The WRTDS method is designed to provide estimates of actual and flow-normalized water quality concentrations and fluxes (loads). Estimating the actual history of concentrations and fluxes fosters the understanding of changes occurring in the stream or river water quality and related impacts on the aquatic ecosystem. The flow-normalized concentration and flux estimates are obtained by eliminating the influences of streamflow variability on the water quality parameter of interest, and thus the flux estimates are good indicators of water quality trends, measuring progress made toward load reduction affected by management practices implemented in the watershed.

The WRTDS model considers concentration to be a product of four components, including trend, seasonal, discharge, and random components. Therefore, the model divides the water quality datasets into these four components. The trend component is essentially a moving average of the time series data, indicating the gradual change in water quality condition through the years. The seasonal component depicts the annual cycle of water quality variation that is generally consistent but can gradually change from year to year in the WRTDS. The discharge and random components take into account the flow influences on water quality and the unexplained variation in concentration, respectively. Accounting for these components, the WRTDS equation (Hirsch et al., 2010) can be expressed as

$$\ln(c) = \beta_0 + \beta_1 t + \beta_2 \ln(Q) + \beta_3 \sin(2\pi t) + \beta_4 \cos(2\pi t) + \varepsilon$$

where c is the concentration, Q is discharge, t is the time in years, ε is the unexplained variation, and $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4$ are fitted coefficients that vary through the record. Unlike common approaches, this method calibrates the parameters of the equation for every combination of Q and t where estimates are required. It must be noted that the weighted regression estimation system that calculates the expected value of the concentration (c) for a given Q and t is the integral part of the WRTDS method. The relevance of each observation to an estimation point determines its weight in the regression and is defined by a distance between the observation and the estimation point in terms of discharge and time data points. This distance between an observation and estimation point has three dimensions: time distance as measured by the difference in years; seasonal distance as measured by the difference in times of year; and discharge distance as measured by the difference in the natural log of the discharges. Using these distances, corresponding weights are calculated using a Tricube weight function, and the product will be the overall weight for each data point to be used in the weighted regression. The longer the distance of an observation from an estimation point in either time, season, or discharge, the smaller the chance of that observation being a part of the regression or the lesser its importance. Hirsch et al. (2010, 2015) provides a detailed description of the WRTDS method, which is also part of the USGS's R-package, known as Exploration and Graphics for RivEr Trends (EGRET) software. In addition to implementing the WRTDS method, EGRET provides a useful tool for analyzing long-term changes in water quality and streamflow, including a data-retrieval package that is designed to accept USGS data, EPA STORET, and user-specified text files.

3.4 WRTDS Results and Discussion

Although the SKT trend analysis presented earlier provides concentration trends and estimate changes in magnitude, year-to-year variations in hydrologic conditions may have impacted trends in water quality concentrations. Actual concentration and flux histories may suggest a worsening water quality for a pollutant concentration that increases with flow for a year or two near the end of the period of record, making it hard to detect if trends exist. The WRTDS method allows computing flow-normalized concentration and fluxes where flow-driven variability is eliminated, and thus existing trends, if any, can be identified. In addition, it provides histories of both actual and flow-normalized concentrations and fluxes.

Only four stations fulfill the requirement for conducting parametric trend analysis using the WRTDS method. Three of these stations (Fox River at Montgomery, Blackberry Creek at Rt. 47, and Poplar Creek near Mouth-Elgin) have concentration data along with the corresponding flow data that extend to the year 2016. All remaining stations have either no flow data, insufficient observations (<100 samples), or missing (discontinuous) discharge data, which are required to develop a WRTDS model. For nine of the ten nutrient-related water quality parameters, except pH, WRTDS models were developed. Fox River at Montgomery has all nine water quality parameters, whereas Blackberry Creek at Rt. 47 and Polar Creek at Elgin have only five of the nine parameters, excluding Org-N, NO_3-N, TSS, and CHL-A. In total, 19 WRTDS models were developed that account for the highly variable nature of water quality concentrations as a function of time, discharge, and season. The models were used to evaluate both flow-normalized concentrations and flux histories for the 19 water quality parameters obtained across the three stations.

In a WRTDS model, a flow-normalized concentration on a specific day is calculated as an integral part of the fitted estimates of concentration (i.e., a function of discharge and time) multiplied by the probability density function (pdf) of the discharge for that day of the year. When there are long-term data, the historical discharge sample data could be used in place of the pdf, as was the case in this study. For example, Fox River at Montgomery has 20 years of TP concentration data from 1997 to 2016 but has discharge data for only 14 of the 20 years from water year 2003 to 2016. To estimate a flow-normalized TP concentration and flux for any given date, say for January 1, 2003, all 14 of the January 1 discharge values in the dataset are assumed to have likely occurred on the estimation date (January 1, 2003). The WRTDS model then estimates 14 values of TP concentration for January 1, 2003, using each of the 14 January 1 discharge values, but with the time variable set to the estimation date. The mean of these 14 estimated TP concentration values will be the flow-normalized TP concentration. Similarly, the flow-normalized flux is computed as the product of the flow-normalized TP concentration and mean daily flow for the estimation date. Consequently, trends in concentration may not necessarily imply trends in flux because days of high discharges could strongly affect flux trends, but they have little influence on concentration trends. For percentage changes in concentration and flux to be the same, the changes in concentration across all ranges of discharge and for all seasons need to be identical. In WRTDS, trends are not restricted as being linear or monotonic, and thus the trends could be different across seasons and flows.

The 19 WRTDS models developed using concentration-discharge relationships were examined using graphical comparisons and computations of model biases, exploring the performance of the fitted model. For the Fox River at Montgomery, the output of the WRTDS model for TP is presented using eight panel graphics in Figure 7, showing the quality of the fitted

WRTDS model. The first four panels show WRTDS residuals (i.e., observed minus estimated values of concentration in natural log units, $\ln(c)$) as a function of estimated concentrations in natural log units, discharge, date, and months, respectively. For a good quality model, the WRTDS residuals need to be approximately symmetrical around the zero value line; in the case of the boxplot, the zero line is expected to pass through the middle of the boxes. In addition, these residuals should not show any substantial curvature in the first three panels, which would indicate either an over-prediction or under-prediction if the residuals are negative or positive, respectively. In this case, the TP WRTDS model residuals seem to be symmetrical around the value of zero with no apparent curvature. If there were single or multiple events that profoundly affected the TP concentration during the period of analysis, the third panel, which shows residuals versus time, would have shown these events. The fourth panel showing residuals versus the boxplot of concentration by month indicates that the model is accounting for seasonal differences in the TP concentration at Fox River at Montgomery because the boxes are symmetrical around the value of zero for nearly all months. The fifth panel, which shows a figure consisting of three boxplots of concentration based on sample day values, sample day estimates, and all day estimates, indicates a good performing model with nearly identical median and interquartile ranges of concentrations and similar distribution. It must be noted that the width of the boxplots is proportional to the square root of the sample size and thus, a wider boxplot for all of the day estimates is to be expected. The scatter plot of observed versus estimated concentration shown in panel six is clustered and symmetrical around the 1:1 line with no substantial departures from that line, indicating the model's good performance. The seventh panel shows boxplots of discharge values during sampled days and all days, providing insight into the distribution of discharges in the sampled days. In this case, the two boxplots being equivalent indicates that the TP sampling appears to cover ranges of discharges, which is particularly important in the estimation of fluxes and flux trends. The last and eighth panel is a scatter plot of observed versus estimated TP fluxes on all sampled days. Since the dots appear to be symmetrical around the 1:1 line, there is a close match between observed and estimated TP fluxes.

A flux bias statistic, which is defined as the difference between the sums of estimated and observed fluxes on all sampled days divided by the sum of estimated fluxes, is computed for TP at Fox River at Montgomery to be 0.0193 (an average error of 1.93% in flux estimates). The absolute flux bias statistic for all remaining water quality parameters, including DP, Org-N, NH_3-N, NO_3-N, TKN, and TSS at Fox River at Montgomery, is below 0.065, except for CHL-A, which is calculated to be 0.166. For Blackberry Creek at Rt. 47 and Poplar Creek near Mouth-Elgin, the absolute flux bias for TP and TKN was found to be below 0.085, whereas it ranges between 0.2 to 0.4 for DP and NH_3-N fluxes. A significant amount of the DP and NH_3-N concentration data (20 to 35% of the sample data) for these two stations is below the detection limit and thus is incorporated as censored data in the model. As a result, larger biases were obtained and this poor model performance needs to be taken into account when examining DP and NH_3-N concentration and flux estimates and trends in these two stations. Next, the WRTDS analysis results are presented for each monitoring station.

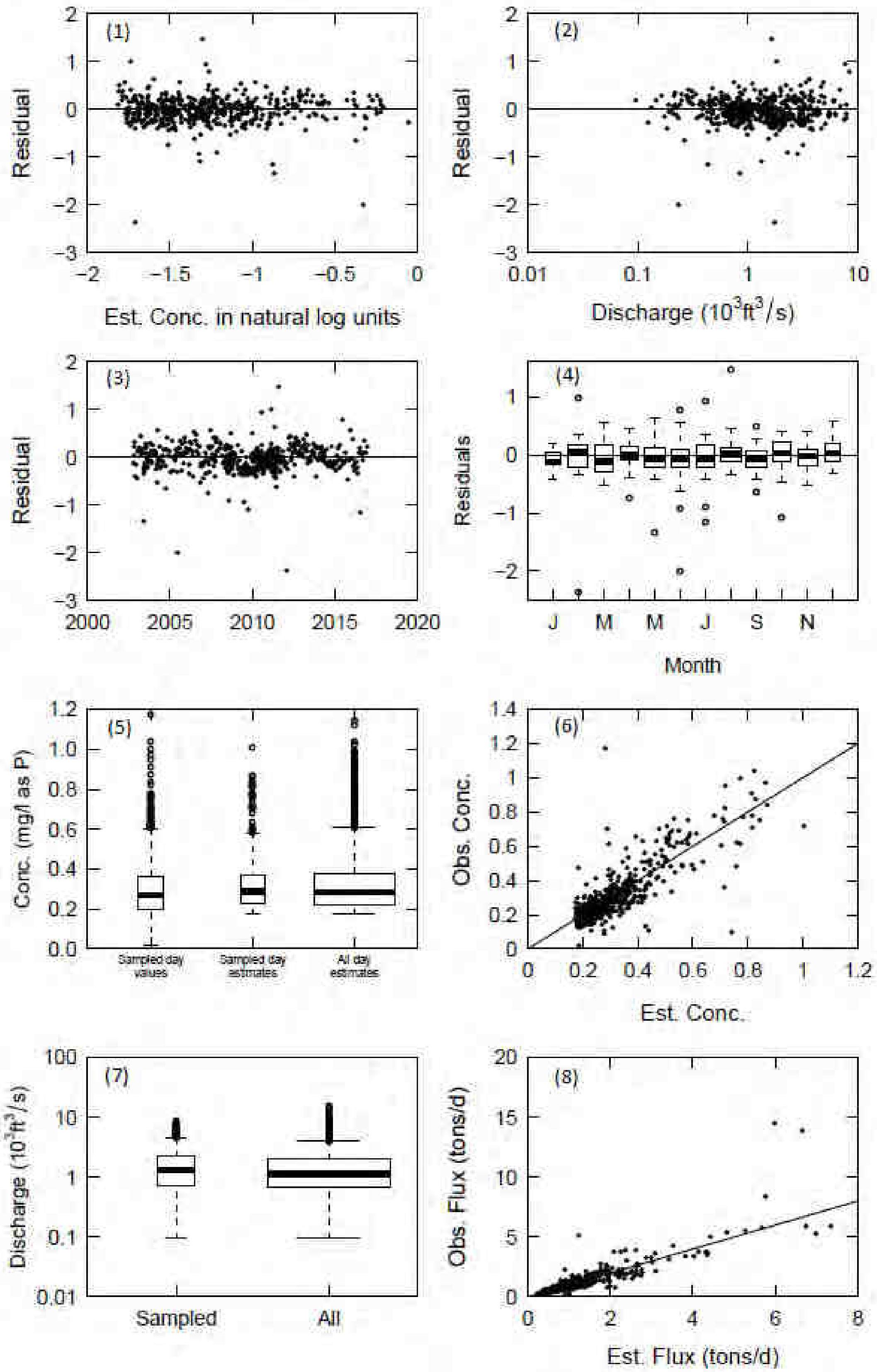


Figure 7. WRTDS model output for total phosphorus (TP) at Fox River at Montgomery

Trends in Flow-normalized Concentration

Annual and seasonal trends in flow-normalized concentration are estimated for Fox River at Montgomery, Blackberry Creek at Rt. 47, and Poplar Creek near Mouth-Elgin between 2006 and 2016. Changes in flow-normalized concentrations in milligrams per liter (mg/L) and percent (%) are presented in Tables 10 and 11, respectively. The annual values are based on a water year, which starts in October and ends in September of the following year, and the four seasons are winter (December to February), spring (March to May), summer (June to August), and fall (September to November).

The result of concentration trend analysis using the WRTDS method indicates that the flow-normalized concentrations of almost all water quality parameters analyzed showed decreasing trends across all seasons from 2006 to 2016 for Fox River at Montgomery, with the exception of spring TSS and summer CHL-A concentrations. Large concentration decreases at this station were obtained in summer for DP, NH_3-N, and NO_3-N; in winter for TP, TSS, and CHL-A; and in spring for DO, Org-N, and TKN. Unlike other water quality parameters, a decreasing DO concentration at Fox River at Montgomery across all seasons is indicative of a declining water quality trend. The changes in annual TP and DP concentrations between 2006 and 2016 are 27% and 28%, respectively, showing the largest decreases as compared to the remaining water quality parameters. In contrast, the decrease in the annual TKN, DO, and TSS concentrations was less than 10%.

For the two tributary monitoring stations (Blackberry Creek at Rt. 47 and Poplar Creek near Mouth-Elgin), NH_3-N concentrations exhibited the largest annual and seasonal increasing trends. TP, DP, and DO concentrations for Blackberry Creek at Rt. 47 showed decreasing annual and seasonal trends, except in fall for DO and in summer for TP and DO. Across all seasons, the TKN concentration at this station increased from 1.7% in winter to 38% in summer with an average annual decrease of 23% between 2006 and 2016. For Poplar Creek near Mouth-Elgin, the DP and DO concentrations show improving water quality trends across all seasons. For all three monitoring stations, the seasonal concentration trends largely conform to the annual trends.

Figure 8 illustrates the annual phosphorus and nitrogen trend results for Fox River at Montgomery, showing average annual and seasonal flow-normalized concentrations. Note that the dots in the figure represent the actual values of annual mean concentration, whereas the flow-normalized concentration is represented by a line. In this figure, although all concentrations show decreasing trends, there are differences between them. For example, the decrease in NO_3-N for the Fox River at Montgomery is more pronounced after 2010, as evidenced by a steeper slope in flow-normalized concentration, and the reverse is true for NH_3-N.

All annual and seasonal trend results for the remaining water quality parameters and the two tributary stations are included in Appendix D.

Table 10. Changes in Flow-normalized Concentrations (mg/L) between 2006 and 2016

Station ID	Station Name		TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	TSS	CHL-A
25	*Poplar Cr near Mouth-Elgin* :	Annual	🟥 1.900	🟩 -0.650	-	🟥 0.081	-	🟥 19.000	🟩 12.000	-	-
		Winter	🟥 0.091	🟩 -0.009	-	🟥 0.084	-	🟥 38.000	🟩 0.570	-	-
		Spring	🟥 0.019	🟩 -0.008	-	🟥 0.051	-	🟥 11.000	🟩 0.800	-	-
		Summer	🟩 -0.005	🟩 -0.013	-	🟥 0.140	-	🟩 -0.007	🟩 0.570	-	-
		Fall	🟥 0.063	🟩 -0.018	-	🟥 0.055	-	🟥 0.810	🟩 0.620	-	-
27	**Fox River at Montgomery**:	Annual	🟩 -0.099	🟩 -0.054	🟩 -0.180	🟩 -0.019	🟩 -0.390	🟩 -0.130	🟥 -1.000	🟩 -3.500	🟩 -0.011
		Winter	🟩 -0.110	🟩 -0.048	🟩 -0.110	🟩 -0.041	🟩 -0.400	🟩 -0.190	🟥 -1.900	🟩 -2.600	🟩 -0.012
		Spring	🟩 -0.059	🟩 -0.024	🟩 -0.260	🟩 -0.003	🟩 -0.290	🟩 -0.140	🟥 -1.100	🟥 1.100	🟩 -0.023
		Summer	🟩 -0.093	🟩 -0.069	🟩 -0.210	🟩 -0.008	🟩 -0.340	🟩 -0.050	🟥 -0.300	🟩 -1.400	🟥 0.008
		Fall	🟩 -0.120	🟩 -0.076	🟩 -0.070	🟩 -0.023	🟩 -0.570	🟩 -0.110	🟥 -0.820	🟩 -9.400	🟩 -0.011
28	*Blackberry Cr at Rt 47:*	Annual	🟥 0.011	🟥 0.017	-	🟥 0.280	-	🟩 -0.200	🟥 -0.088	-	-
		Winter	🟥 0.027	🟥 0.040	-	🟥 0.410	-	🟩 -0.010	🟥 -0.260	-	-
		Spring	🟥 0.024	🟥 0.019	-	🟥 0.400	-	🟩 -0.390	🟥 -0.880	-	-
		Summer	🟩 -0.012	🟥 0.002	-	🟥 0.230	-	🟩 -0.410	🟩 0.014	-	-
		Fall	🟥 0.004	🟥 0.009	-	🟥 0.100	-	🟩 -0.010	🟩 0.840	-	-

Note: “red” declining trend; “green” improving trend; “-” no data

Table 11. Percent Changes in Flow-normalized Concentrations between 2006 and 2016

Station ID	Station Name		TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	TSS	CHL-A
25	*Poplar Cr near Mouth-Elgin* :	Annual	51	-35	-	109	-	52	3.8	-	-
		Winter	168	-60	-	59	-	110	4.1	-	-
		Spring	28	-35	-	99	-	22	7.2	-	-
		Summer	-5.3	-24	-	293	-	-0.73	7.2	-	-
		Fall	82	-65	-	99	-	92	6.3	-	-
27	**Fox River at Montgomery**:	Annual	-27	-28	-11	-23	-20	-7.7	-8.7	-9.6	-10
		Winter	-34	-23	-11	-31	-13	-16	-12	-15	-35
		Spring	-21	-22	-18	-4.3	-14	-9.2	-9.4	3	-28
		Summer	-22	-32	-9.2	-15	-38	-2.2	-3.4	-2.6	4.2
		Fall	-29	-31	-4	-31	-32	-5.9	-7.4	-25	-8.7
28	*Blackberry Cr at Rt 47:*	Annual	12	43	-	405	-	-23	-0.85	-	-
		Winter	42	161	-	382	-	-1.7	-1.9	-	-
		Spring	27	73	-	502	-	-34	-8.1	-	-
		Summer	-9.3	2.1	-	531	-	-38	0.18	-	-
		Fall	5.7	25	-	222	-	-1.6	8.8	-	-

Note: “red” declining trend; “green” improving trend; “-” no data

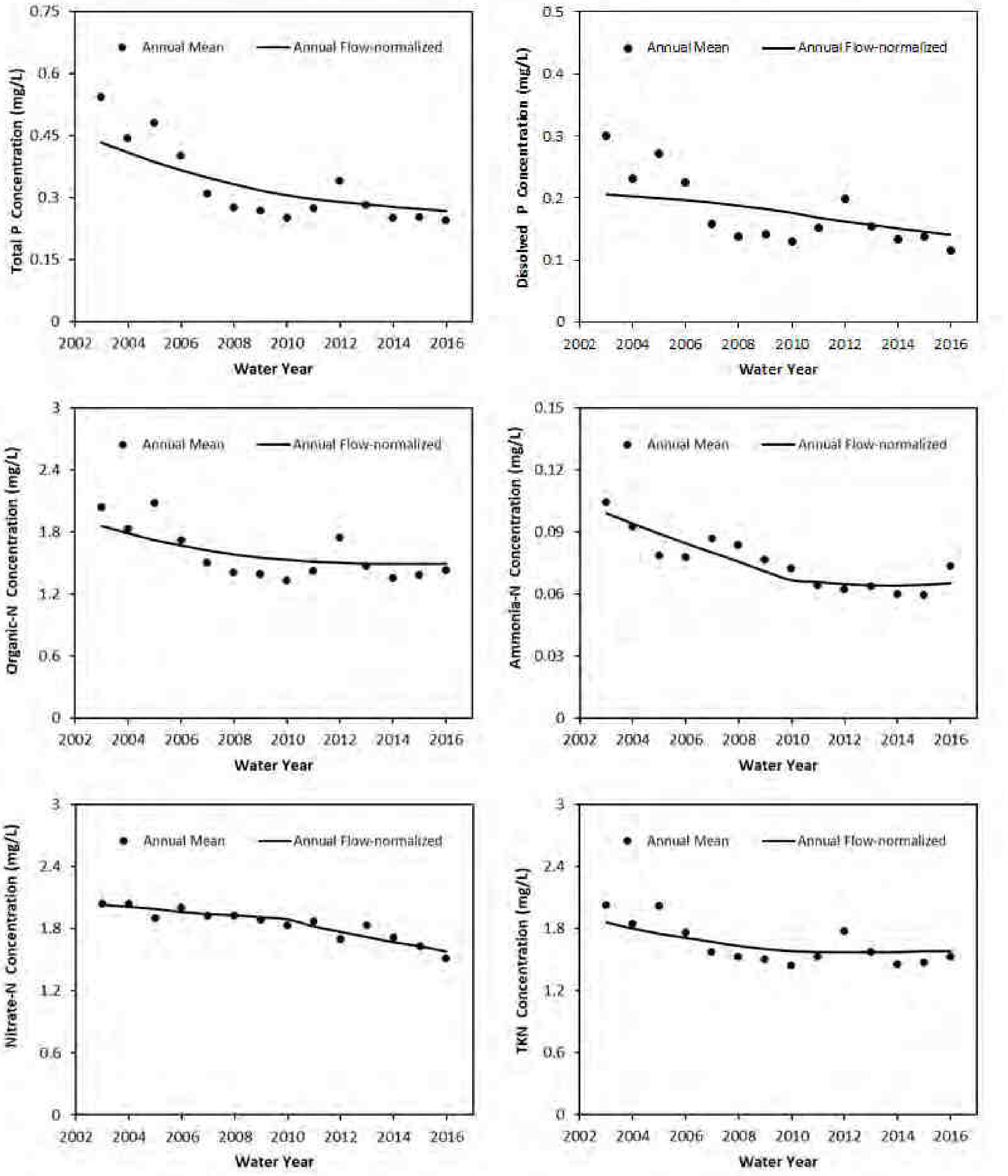


Figure 8. Actual and flow-normalized phosphorus and nitrogen concentrations for Fox River at Montgomery

Trends in Flow-normalized Flux

For the same water quality parameters, with the exception of DO, annual and seasonal trends in flow-normalized fluxes are also estimated for the three monitoring stations between 2006 and 2016. Changes in flow-normalized fluxes in pounds per year (lbs/yr) and percent (%) are presented in Tables 12 and 13, respectively.

Flow-normalized fluxes (loads) of most water quality parameters decreased across all seasons from 2006 to 2016 for the Fox River at Montgomery. An upward trend occurring around 2009-2010 was obtained only for spring fluxes of ammonia nitrogen (NH_3-N) and TSS and summer fluxes of CHL-A during the same period. In comparison with other water quality parameters, flow-normalized fluxes of TP and DP show a larger decrease across all seasons between 2006 and 2016. A similar downward trend of nitrate nitrogen (NO_3-N) fluxes were obtained for Fox River at Montgomery in the summer and fall months. For Fox River at Montgomery, the flow-normalized fluxes show a decreasing annual trend ranging from 6.3% for TSS (a difference of 8.49×10^6 lbs/yr between the 2006 and 2016 fluxes) to 25% (108×10^3 lbs/yr) for DP. From 2006 to 2016, the downward annual trends for TKN, CHL-A, and TSS fluxes were found to be less than 10%. The DP fluxes decreased by 20% to 31% across all seasons and similarly, the TP fluxes consistently reduced across all seasons by 16% to 30% with an average annual decrease of 20% (200.6×10^3 lbs/yr). All nutrient fluxes showed decreasing annual and seasonal trends, with the exception of the NH_3-N flux in spring that seemed to exhibit a slightly increasing trend (0.1% or 400 lbs/yr). A maximum upward trend of 6.7% (24.3×10^3 lbs/yr) from 2006 to 2016 was detected for the CHL-A flux in the summer. The TSS flux also increased by 4.2% (8.2×10^6 lbs/yr) in the spring. The maximum percentage change in flow-normalized fluxes was obtained for NO_3-N in the fall, which was 32% (1.13×10^6 lbs/yr). The 2016 summer NO_3-N flux also showed a large decrease in 2016 of 28% from that of 2006.

Trend analysis results showing actual and flow-normalized phosphorus and nitrogen fluxes for Fox River at Montgomery are illustrated in Figure 9. All annual and seasonal trend results for the remaining water quality parameters and the two tributary stations are included in Appendix D. Although the seasonal trends conform to annual trends in most cases, there are differences in seasonal and annual trends for some of the water quality parameters. For example, the spring NH_3-N flux showed a downward trend until 2009, followed by an upward trend thereafter. However, it exhibited a decreasing trend in summer, fall, and winter seasons that stabilized in the later years, conforming to the annual trend. Similarly, the TSS flux showed a downward trend, followed by an upward trend in spring. Although there is a difference in percentage changes, the flux and concentration trends are largely similar for this station (i.e., they are in the same downward or upward direction). The only difference observed was between spring NH_3-N concentration and flux, which showed opposing trends. The NH_3-N concentration decreased by 4.3% between 2006 and 2016, whereas its fluxes increased by 0.1% during the same time, showing that concentration trends do not necessarily translate into flux trends.

For Blackberry Creek at Rt. 47 and Poplar Creek near Mouth-Elgin, the WRTDS models were developed for five nutrient-related water quality parameters, namely NH_3-N, TKN, TP, and DP. All flow-normalized fluxes with few exceptions show larger upward trends for these two stations. The DP and TKN fluxes exhibited decreasing annual and seasonal trends for Poplar Creek near Mouth-Elgin and Blackberry Creek at Rt. 47, respectively. The NH_3-N, TKN, and TP fluxes for Poplar Creek near Mouth-Elgin showed increasing trends across all seasons from 2006 to 2016, ranging from 11% for summer TKN to 118% for fall TP fluxes. For this same station, large increases of 51% to 118% were obtained for TKN and TP fluxes that are similar across all seasons. For this station, only DP fluxes showed a downward trend across all seasons ranging from 29% in winter to 41% in spring with an annual downward trend of 35% (1.43×10^3 lbs/yr). In contrast, for Blackberry Creek at Rt. 47, flow-normalized fluxes for NH_3-N, TP, and DP showed an upward trend across all seasons from 2006 to 2016. The maximum annual increase of 163% (24.3×10^3 lbs/yr) was obtained for the NH_3-N flux, which is over a 100% increase across all seasons. Unlike Poplar Creek near Mouth-Elgin, both TP and DP showed a similar upward trend across all seasons ranging from 4.8% to 92% for TP and from 13% to 68% for DP fluxes. For this station, decreasing trends of TKN fluxes ranging from 0.04% in winter to 26% in summer were detected, with the exception of fall months that exhibited an upward trend of 2.7% in the TKN flux from 2006 to 2016.

Table 12. Changes in Flow-normalized Fluxes ($\times 10^3$ lbs/yr) between 2006 and 2016

Station ID	Station Name		TP	DP	Org-N	NH_3-N	NO_3-N	TKN	TSS	CHL-A
25	*Poplar Cr near Mouth-Elgin* :	Annual	4.2	-1.4	-	1.5	-	41.9	-	-
		Winter	6.6	-1.0	-	2.9	-	83.8	-	-
		Spring	1.4	-1.8	-	1.1	-	24.3	-	-
		Summer	1.4	-2.1	-	1.4	-	8.6	-	-
		Fall	8.2	-0.9	-	0.6	-	63.9	-	-
27	**Fox River at Montgomery**:	Annual	-200.6	-108.0	-533.5	-39.7	-1009.7	-381.4	-8492.2	-22.0
		Winter	-229.3	-99.2	-231.5	-81.6	-1097.9	-463.0	-7149.6	-18.3
		Spring	-202.8	-88.2	-1051.6	0.4	-1155.2	-463.0	8218.8	-70.5
		Summer	-165.3	-132.3	-619.5	-22.0	-751.8	-229.3	-9352.0	24.3
		Fall	-176.4	-110.2	-103.6	-55.8	-1128.8	-280.0	-21550.2	-16.5
28	*Blackberry Cr at Rt 47:*	Annual	6.6	4.9	-	24.3	-	-19.2	-	-
		Winter	13.4	11.9	-	26.5	-	-0.04	-	-
		Spring	9.3	4.6	-	46.3	-	-44.1	-	-
		Summer	0.8	1.4	-	16.5	-	-35.3	-	-
		Fall	3.3	1.9	-	5.1	-	1.4	-	-

Note: “red” declining trend; “green” improving trend; “-” no data

Table 13. Percent Changes in Flow-normalized Fluxes between 2006 and 2016

Station ID	Station Name		TP	DP	Org-N	NH_3-N	NO_3-N	TKN	TSS	CHL-A
25	*Poplar Cr near Mouth-Elgin* :	Annual	51.0	-35.0	-	21.0	-	52.0	-	-
		Winter	105.0	-29.0	-	22.0	-	110.0	-	-
		Spring	13.0	-41.0	-	12.0	-	22.0	-	-
		Summer	16.0	-36.0	-	46.0	-	11.0	-	-
		Fall	118.0	-30.0	-	19.0	-	99.0	-	-
27	**Fox River at Montgomery**:	Annual	-21.0	-25.0	-11.0	-14.0	-16.0	-7.8	-6.3	-8.8
		Winter	-30.0	-21.0	-8.2	-22.0	-13.0	-14.0	-13.0	-21.0
		Spring	-16.0	-20.0	-15.0	0.1	-11.0	-6.4	4.2	-20.0
		Summer	-16.0	-31.0	-11.0	-12.0	-28.0	-4.0	-4.7	6.7
		Fall	-25.0	-29.0	-3.5	-2.9	-32.0	-8.7	-26.0	-8.7
28	*Blackberry Cr at Rt 47:*	Annual	43.0	46.0	-	163.0	-	-15.0	-	-
		Winter	92.0	68.0	-	108.0	-	-0.04	-	-
		Spring	48.0	57.0	-	190.0	-	-20.0	-	-
		Summer	4.8	13.0	-	277.0	-	-26.0	-	-
		Fall	37.0	32.0	-	198.0	-	2.7	-	-

Note: “red” declining trend; “green” improving trend; “-” no data

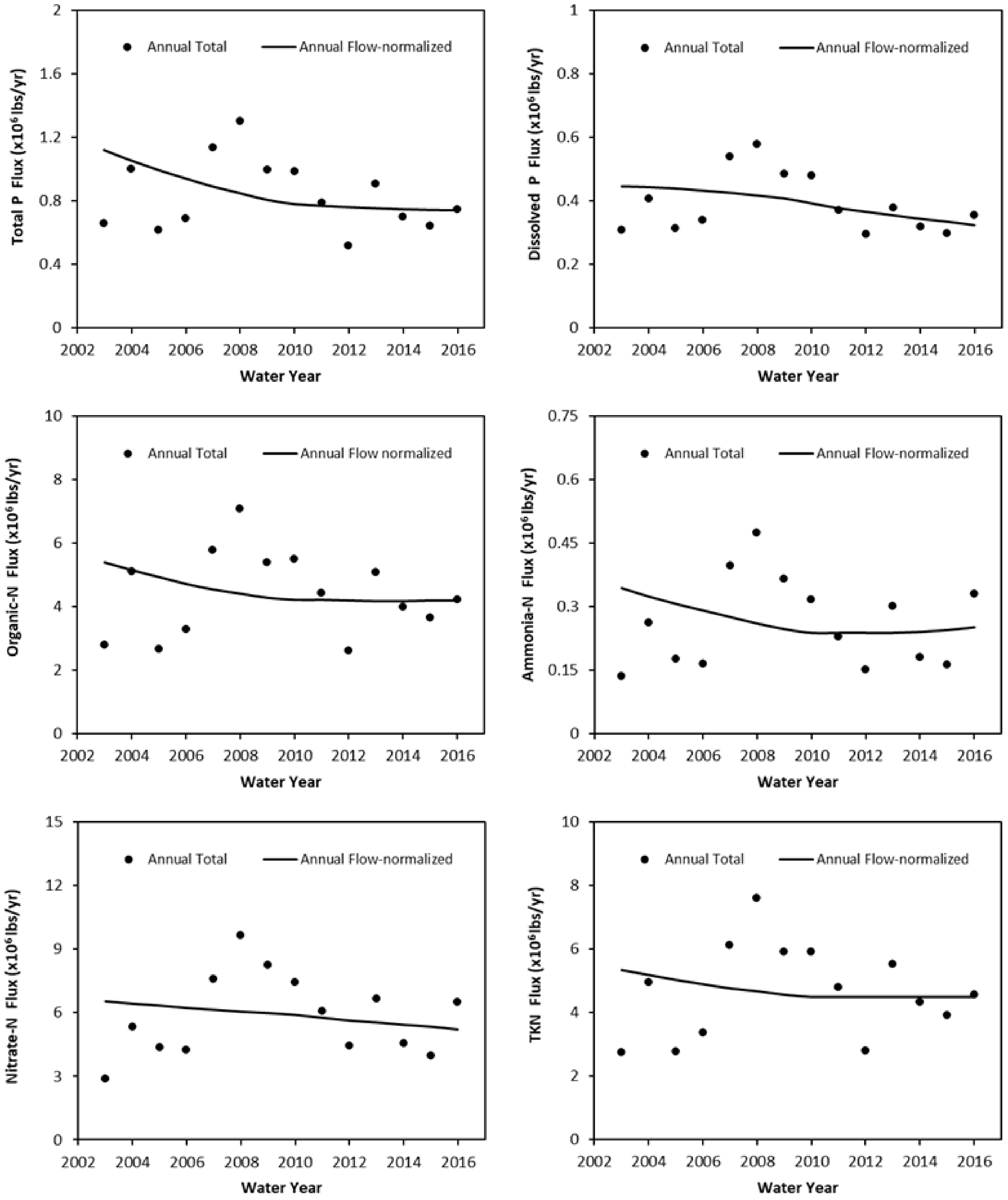


Figure 9. Actual and flow-normalized phosphorus and nitrogen fluxes for Fox River at Montgomery

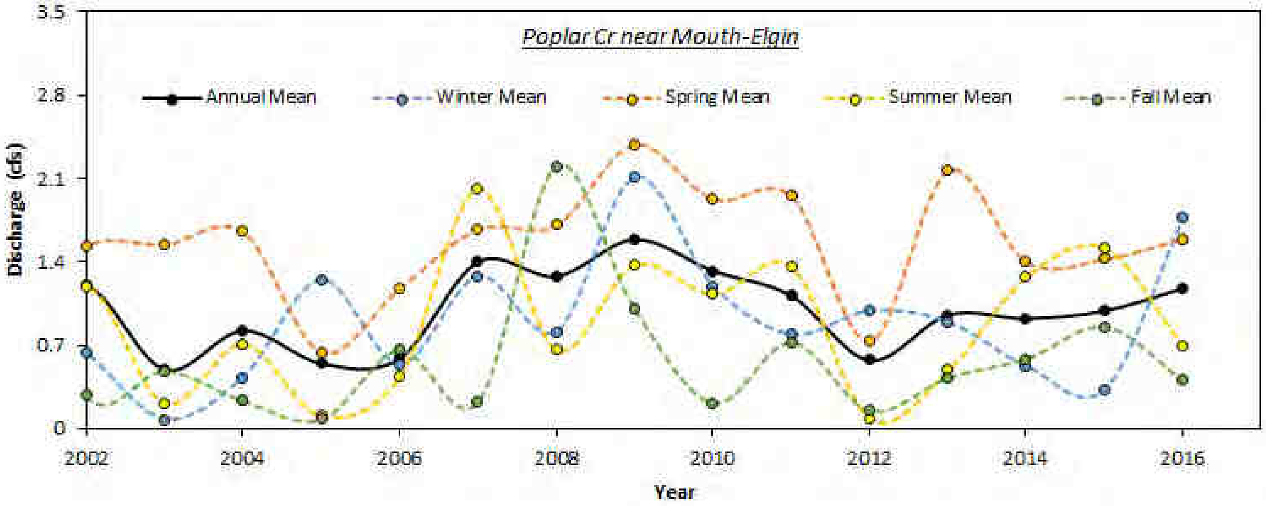
3.5 Streamflow Durations and Trends

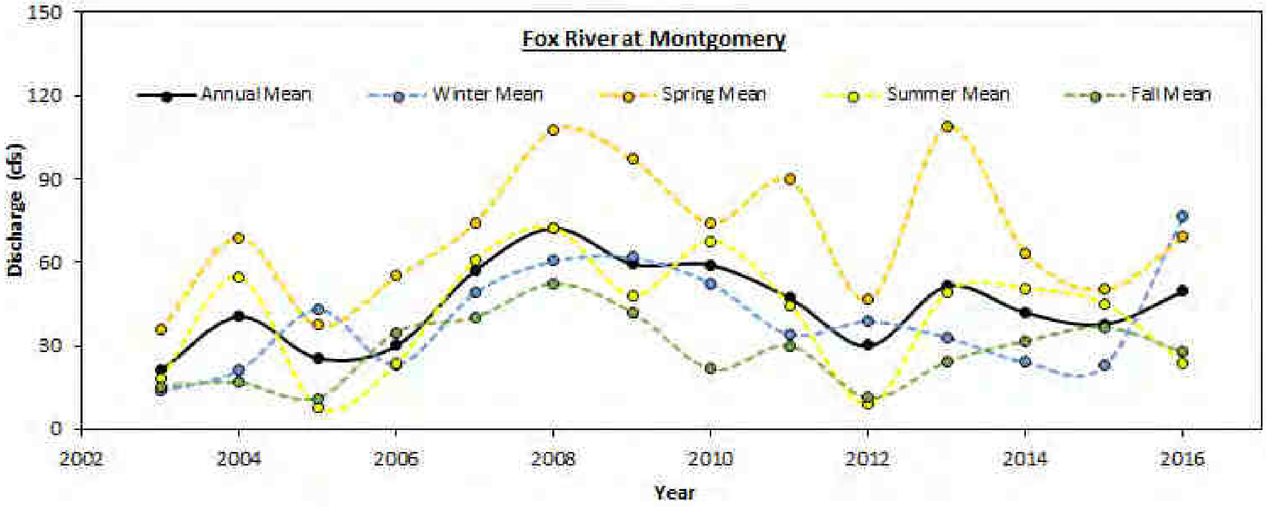
In addition to the water quality trends, selected streamflow statistics were evaluated for the periods of water quality data in an effort to characterize the annual and seasonal flow histories for the three monitoring stations. Figure 10 illustrates the annual and seasonal discharges in cubic feet per second (cfs) for Fox River at Montgomery, Poplar Creek near Mouth-Elgin, and Blackberry Creek at Rt. 47. The mean discharge for Fox River at Montgomery during the 2003-2016 period is 44.61 cfs with the minimum and maximum annual discharges occurring in 2003 and 2008, respectively. For Poplar Creek near Mouth-Elgin and Blackberry Creek at Rt. 47, the mean discharges for the period from 1997 to 2016 were 0.98 and 1.62 cfs, respectively. For both stations, the maximum annual discharges occurred in 2009, whereas the minimum annual discharges were obtained in 2006 for Poplar Creek near Mouth-Elgin and in 2003 for Blackberry Creek at Rt. 47. In all three stations, spring discharges were higher, whereas fall discharges were lower with few exceptions (e.g., 2008 fall discharges in the tributaries shown in green color).

Flow durations and trends (e.g., changes in mean, 7-day minimum, and 1-day maximum flows) were examined using continuous flow records available for periods of analysis. These streamflow statistics help provide insight into multi-year hydrologic variability and its potential influence on increasing or decreasing constituent concentrations and/or fluxes. However, to explicitly attribute the change in water quality trends to changes in hydrologic factors, the extent of other potential factors that affect water quality, such as conservation efforts, land use changes, and so forth, should also be examined.

Annual and seasonal flow durations were calculated as percentiles of flow exceedance for five periods of analysis, which include annual (October to September), fall (September to October), winter (December to February), spring (March to May), and summer (June to August). The 50th percentile flow represents the median flow value for the period of analysis (e.g., summer median flow), and it is the flow value that is exceeded 50% of the time over the period of analysis. Similarly, the 25th and 75th percentile flows are flow values that are less than or equal to the 25% and 75% of flows for each of the five periods of analysis, respectively. The range between the 25th and 75th percentiles, which is also called as interquartile range (IQR), represents 50% of the flow duration and provides insight into the distribution of the flow records, characterizing variations in flow values during the period of analysis. The smaller or larger the IQR is, the smaller or larger the variation in streamflow will be. To compare the IQRs for different periods of analysis, a coefficient of variation (COV) is calculated as a measure of the dispersion in flow values of interest.

Table 14 provides the annual and seasonal streamflow duration and the IQR and COV results for one station in the Fox main stem and two in the tributaries. The annual median flows for Poplar Creek near Mouth-Elgin, Fox River at Montgomery, and Blackberry Creek at Rt. 47 are 15.1, 1150, and 32.7 cfs, respectively. For all three stations, the largest median flow occurred in the spring season, whereas the smallest values were calculated for summer, except for Blackberry Creek at Rt. 47. The IQR is the highest in spring for all stations, indicating the flow variability in that season. However, in comparison to annual and other seasonal values, the spring season shows the smallest flow variations, as indicated in the lowest COV values. The largest flow variation occurred in the summer season for all stations, as evidenced by the largest COV values for each station.





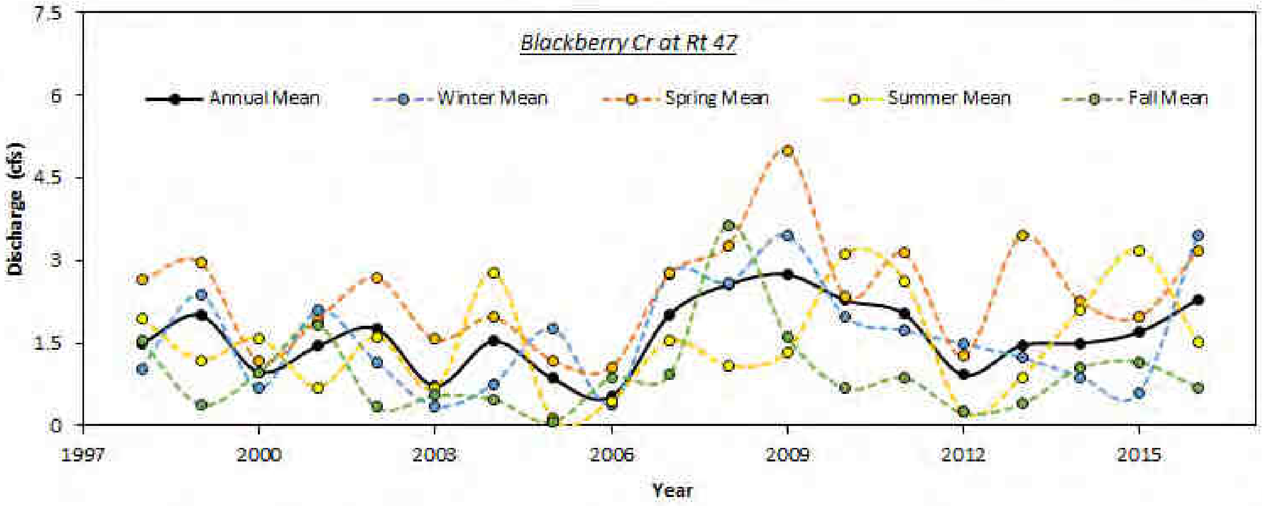


Figure 10. Annual, winter, spring, summer, and fall mean discharges for the three monitoring stations

Annual and seasonal trends of selected streamflow statistics, including mean, 7-day minimum, and 1-day maximum flows, are calculated to evaluate their changes through the years as they relate to water quality. It must be noted that the annual 1-day maximum flow is not identical to the annual peak discharge, which represents the instantaneous maximum discharge value for the year. The difference between the 1-day maximum and annual peak discharges is larger for smaller streams since the discharge could change from a very low to an annual maximum value in a given day. The mean provides the central tendency of the multi-year hydrologic variability. The minimum and maximum flow trends may help explain part of the increase or decrease in constituent concentration and fluxes.

Table 14. Annual and Seasonal Flow Durations (cubic-feet per second, cfs)

Station ID	Station Name	min	5%	10%	25%	50%	75%	90%	95%	max	IQR	COV
25	*Poplar Cr near Mouth-Elgin:*	Period of analysis (1997-2016)										
	Annual	0.51	1.63	2.6	5.99	15.1	33.1	78.1	134	1400	27.11	1.8
	Winter	0.58	2.4	3.46	7.2	14.7	31.6	74	127	928	24.4	1.7
	Spring	0.7	7.4	11.7	19	29.9	55.1	123	176	1050	36.1	1.2
	Summer	0.56	1.29	1.79	3.88	9.31	24.4	60.5	111	1020	20.52	2.2
	Fall	0.51	1.3	1.85	3.64	8.07	18.5	39.6	78.6	1400	14.86	1.8
27	**Fox River at Montgomery:**	Period of analysis (2002-2016)										
	Annual	95.8	258	430	666	1150	2040	3280	4120	15500	1374	1.2
	Winter	243	440	500	707	1100	1770	2760	3310	8940	1063	1.0
	Spring	248	704	908	1430	2190	3210	4260	5260	14600	1780	0.8
	Summer	95.8	209	287	544	917	1850	3310	4550	13200	1306	1.4
	Fall	99.6	209	245	538	800	1230	1760	2170	15500	692	0.9
28	*Blackberry Cr at Rt 47:*	Period of analysis (1997-2016)										
	Annual	0.32	5.8	9.3	16.8	32.7	64.1	118	178	1970	47.3	1.4
	Winter	3.23	10.2	12	17.4	31.5	60.2	127	202	1600	42.8	1.4
	Spring	8.18	17.3	23.8	39	60.7	96.9	157	225	1530	57.9	1.0
	Summer	0.73	4.4	7.01	14.1	28	57	109	161	1030	42.9	1.5
	Fall	0.32	3.23	5.43	10.8	19.5	33.8	58.8	88.2	1970	23	1.2

For all five periods of analysis, changes in mean, 7-day minimum, and 1-day maximum flows between 2006 and 2016 in percent and cubic-feet per day are presented in Tables 15 and 16, respectively. The results presented in the figures and tables indicate that the mean and 7-day minimum flows exhibit an increasing trend with varying magnitudes across all seasons except for the spring 7-day minimum flow, which showed a 1.5% decrease between 2006 and 2016. Generally, the annual and seasonal 7-day minimum flows seem to show larger changes during the period of analysis, ranging from 32% for Blackberry Creek at Rt. 47 in winter to at least 108% for the Fox River at Montgomery and Poplar Creek near Mouth-Elgin in a climate year. The annual and seasonal 1-day maximum flows show increasing trends for Blackberry Creek at Rt. 47. In contrast, for Poplar Creek near Mouth-Elgin, the 1-day maximum flow exhibits a decreasing trend in winter, spring, and fall seasons, whereas its annual and summer values have increased.

Table 15. Changes in Selected Streamflow Statistics (cfs) between 2006 and 2016

Station ID	Station Name		7-day minimum	Mean	1-day Maximum
25	*Poplar Cr near Mouth-Elgin* :	Annual	0.0015	0.005	0.035
		Winter	0.0032	0.0059	-0.012
		Spring	0.0015	0.0054	-0.0097
		Summer	0.0018	0.0078	0.071
		Fall	0.002	0.00094	-0.0076
27	**Fox River at Montgomery**:	Annual	0.25	0.47	1.1
		Winter	0.4	0.5	0.43
		Spring	0.56	0.59	0.54
		Summer	0.22	0.34	1.6
		Fall	0.27	0.29	-0.045
28	*Blackberry Cr at Rt 47:*	Annual	0.0032	0.012	0.22
		Winter	0.0049	0.011	0.022
		Spring	-0.00039	0.014	0.096
		Summer	0.0049	0.013	0.034
		Fall	0.0056	0.0045	0.011

Note: "blue" increasing flow trend; "orange" decreasing flow trend

Table 16. Percent Changes in Selected Streamflow Statistics between 2006 and 2016

Station ID	Station Name		7-day minimum	Mean	1-day Maximum
25	*Poplar Cr near Mouth-Elgin* :	Annual	109	16	6.5
		Winter	87	23	-6.2
		Spring	18	11	-3
		Summer	84	37	39
		Fall	86	5.9	-5.8
27	**Fox River at Montgomery**:	Annual	108	35	16
		Winter	79	45	15
		Spring	80	28	11
		Summer	65	32	49
		Fall	98	37	-1.7
28	*Blackberry Cr at Rt 47:*	Annual	53	24	39
		Winter	32	25	9.5
		Spring	-1.5	18	25
		Summer	52	34	16
		Fall	75	19	10

Note: "blue" increasing flow trend; "orange" decreasing flow trend

In Figures 11, 12, and 13, the streamflow statistics including 7-day minimum, mean, and 1-day maximum flow are plotted for Poplar Creek near Mouth-Elgin, Fox River at Montgomery, and Blackberry Creek at Rt. 47, respectively. The streamflow statistics are calculated as water depths over the drainage area of the monitoring stations and are expressed in units of millimeters per day (mm/d) for plotting purposes. This value can be converted to inches per day by dividing the values by 25.4 (1 inch = 25.4 mm). The circles and lines in the figures represent the streamflow statistics and their smoothed version (i.e., the locally weighted streamflow statistics). The smoothed version provides insight into streamflow trends by focusing on multi-year variability and changes in its central tendencies of these three streamflow statistics. It must be noted that the annual 7-day minimum is computed for a climate year (April to March), whereas the mean and 1-day maximum flow statistics are calculated for a water year (October to September). Using a climate year for low flow statistics avoids counting individual drought events twice in consecutive water years since a water year is bounded by typically low-flow months. The drainage areas of the monitoring stations in square miles are 1,732 for Fox River at Montgomery, 35.2 for Poplar Creek near Mouth-Elgin, and 70.2 for Blackberry Creek at Rt. 47.

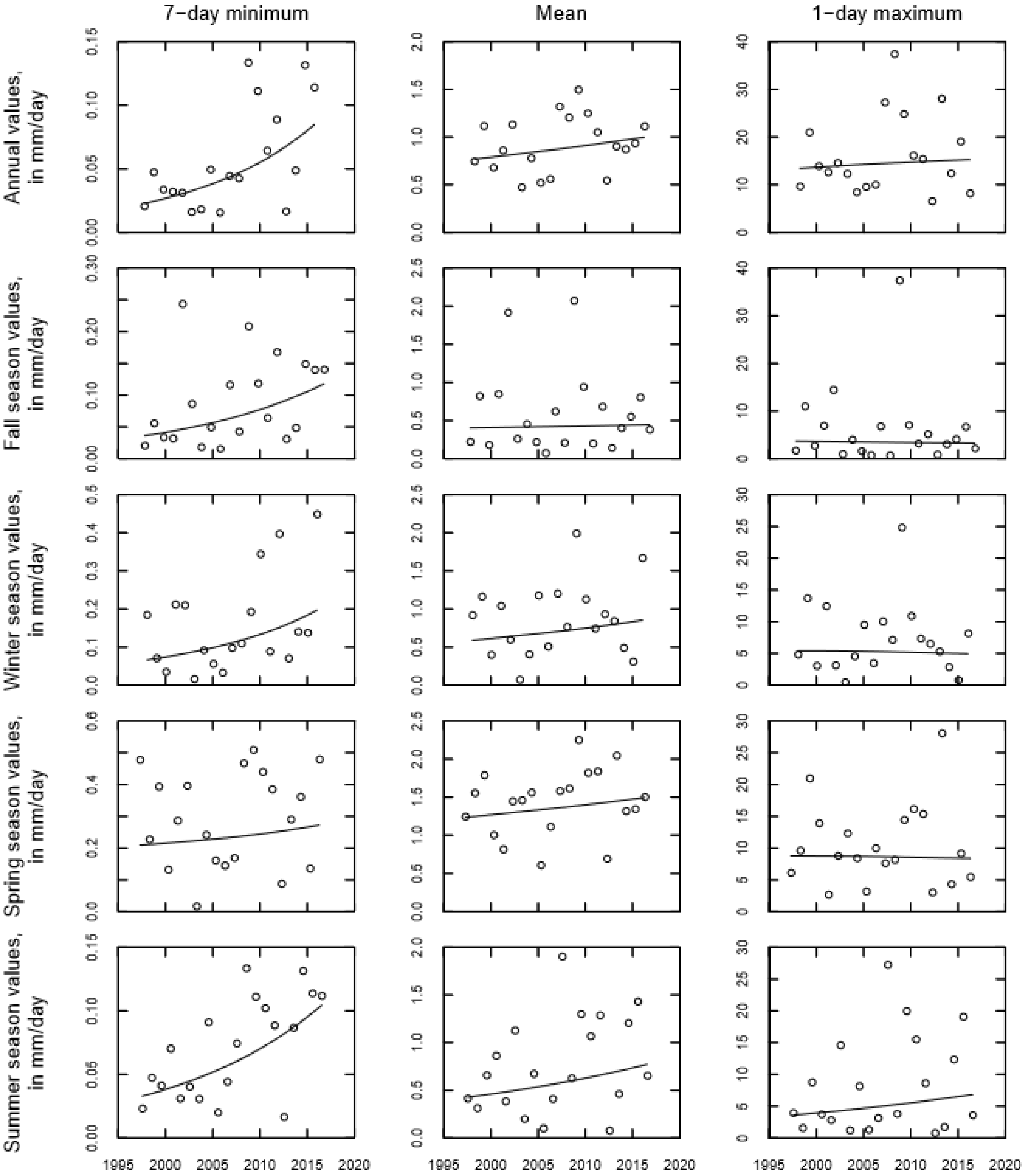


Figure 11. Annual and seasonal flow statistics for Poplar Creek near Mouth-Elgin

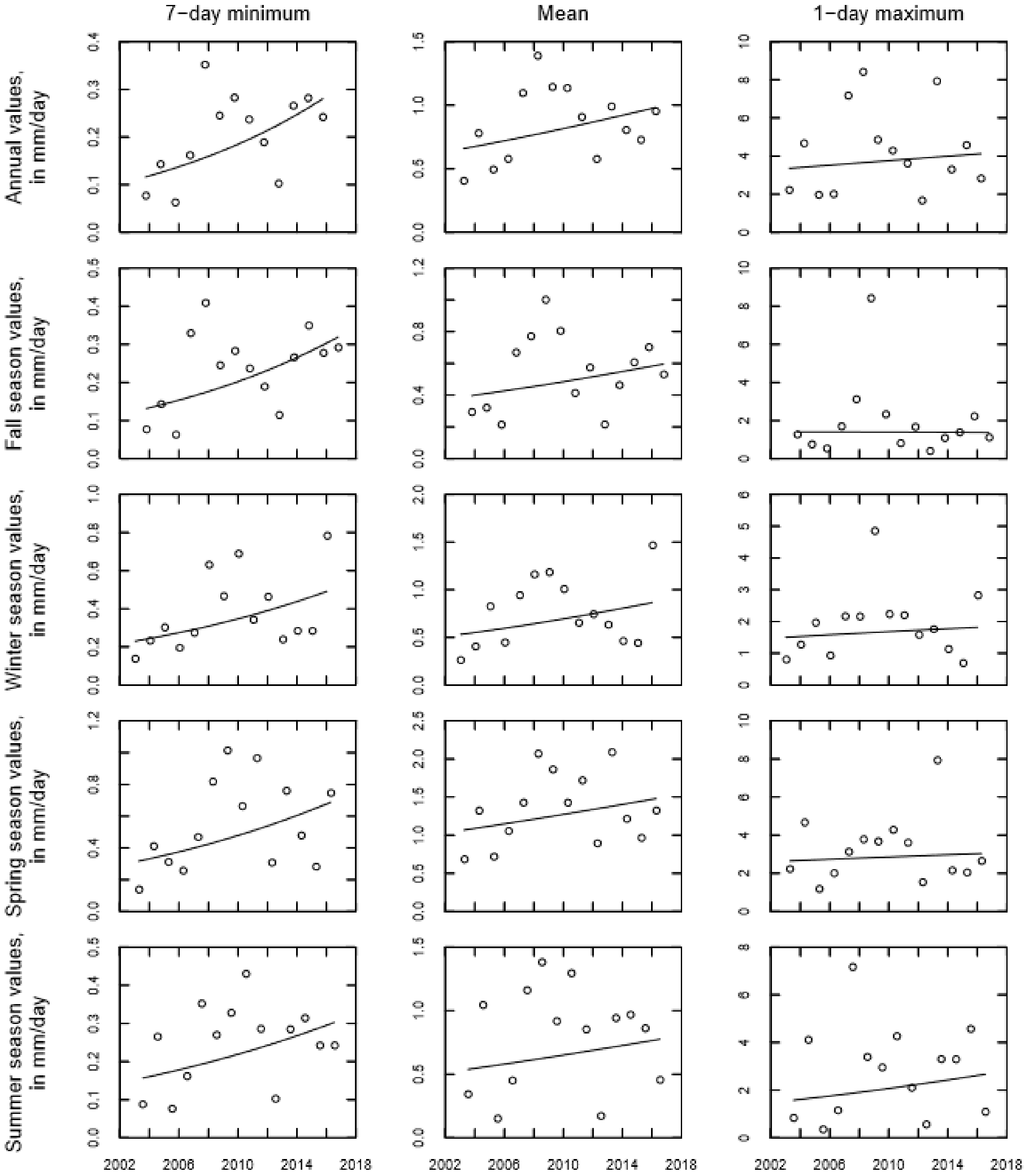


Figure 12. Annual and seasonal flow statistics for Fox River at Montgomery

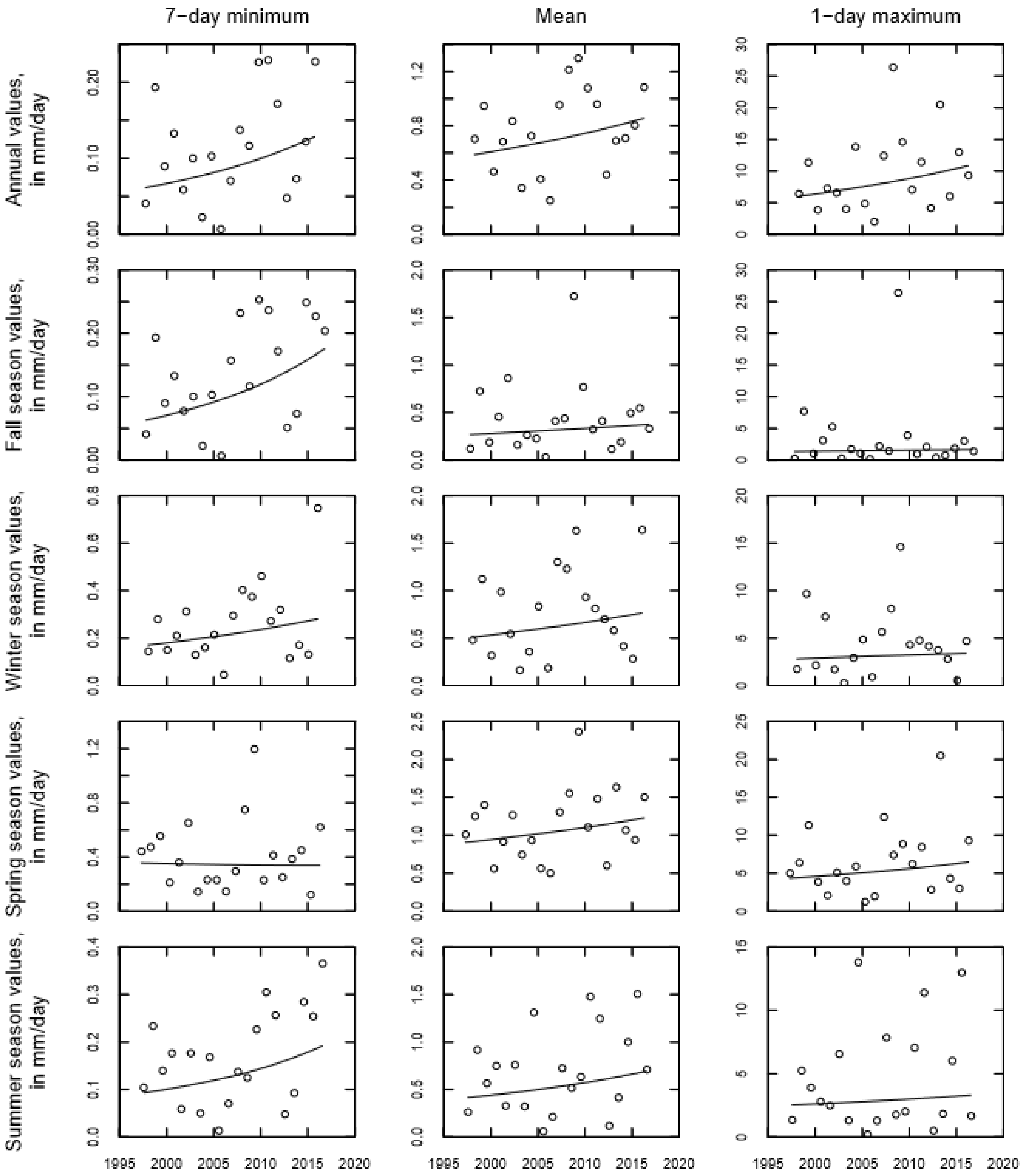


Figure 13. Annual and seasonal flow statistics for Blackberry Creek at Rt. 47

4. Summary

In this study, a trend analysis was conducted for nutrient-related water quality parameters obtained from 18 monitoring stations located in the Fox River main stem and tributaries. Exploratory data analysis (EDA) was performed for a total of 141 water quality parameters across the 18 monitoring stations to better understand the underlying characteristics of the water quality data. Based on the EDA analysis, the core method of analysis selected was the Seasonal Kendall Test (SKT) for trends. The EnvStats software R-package, which includes the SKT method as one of its algorithms, was used to perform the trend analysis based on data of water quality concentrations at each of the monitoring stations. A trend analysis for pH was also conducted. The trend analysis involved preparing computer codes using the R program with the EnvStats library of codes. Using the codes, selected water quality data were directly extracted from the FoxDB, which is the database containing all water quality and related data obtained from various agencies. In addition to the trend analysis for concentrations and pH using the SKT method, a trend analysis of water quality concentrations and fluxes (loads) using a parametric model was conducted for three stations (one Fox River main stem and two tributary stations), which have not only the long-term concentration data, but also the corresponding continuous daily discharge data. The analysis was performed using the Weighted Regression on Time, Discharge, and Season (WRTDS) method, and a total of 19 WRTDS models were developed using concentration and flow data across the three stations.

For all monitoring stations, the SKT trend analysis generally showed that most of the nutrient-related water quality parameters exhibit either a decreasing or no trend across all seasons. No upward annual trend was exhibited for organic nitrogen (Org-N), ammonia nitrogen, total suspended solids (TSS), or chlorophyll-A (CHL-A) at any of the monitoring stations. At the most downstream station on the main stem (Fox River at Yorkville), no increasing trend was detected, with most of the water quality parameters showing a decreasing trend across all seasons. Most of the upward trend was detected for dissolved phosphorus (DP), particularly in spring and summer months. In contrast, total phosphorus (TP) showed an increasing annual trend only for the Poplar Creek near Mouth-Elgin station. For more than half of the stations, the pH showed an upward or no trend. All water quality parameters exhibited a decreasing longitudinal trend downstream of the Fox River at Algonquin.

The results of the trend analysis conducted using the WRTDS method generally indicate that flow-normalized concentration and fluxes (loads) of most water quality parameters decreased across all seasons from 2006 to 2016 for the Fox River at Montgomery. A few exceptions were the concentration and fluxes of TSS in spring and CHL-A in summer, which showed increasing trends. Although there is a difference in the percentage changes, the flux and concentration trends are largely similar for this station (i.e., they are in the same downward or upward direction). The only difference observed was between the spring NH3-N concentration and its corresponding flux, which showed opposing trends, indicating that concentration trends are not necessarily informative of flux trends. Large decreases in summer DP, NH3-N, and NO3-N; winter TP, TSS, and CHL-A; and spring for DO, Org-N, and TKN concentrations were obtained for the Fox River at Montgomery station. A decreasing trend in concentration across all seasons, unlike for DO, is indicative of an improving water quality trend. In comparison with other water quality parameters, flow-normalized fluxes of TP and DP also showed larger decreases across all seasons between 2006 and 2016. A similar downward trend of nitrate nitrogen (NO3-N) fluxes were obtained in the summer and fall.

For the two tributaries (Blackberry Creek at Rt. 47 and Poplar Creek near Mouth-Elgin) most of the water quality concentrations and fluxes showed larger upward trends with a few exceptions. NH3-N concentrations exhibited the largest annual and seasonal increasing trends at both stations. Concentrations of TP, DP, and DO showed decreasing annual and seasonal trends for Blackberry Creek at Rt. 47, except in fall for DO and in summer for TP and DO concentrations. For Poplar Creek near Mouth-Elgin, the DP and DO concentrations showed improving water quality trends across all seasons. The flow-normalized DP and TKN fluxes exhibited decreasing annual and seasonal trends for Poplar Creek near Mouth-Elgin and Blackberry Creek at Rt. 47, respectively. The seasonal concentration trends largely conform to the annual trends for all three monitoring stations.

In addition to water quality trends, flow durations and trends of selected streamflow statistics, including mean, 7-day minimum, and 1-day maximum flows, were calculated to evaluate their changes through the years as they relate to water quality. The flow durations allow characterizing the ranges of flows in the river that are common or extreme during an entire year or season. The results indicate that the highest and lowest flow variability occurred in summer and spring, respectively. The mean flow provides information about the central tendency of the multi-year hydrologic variability, whereas the minimum and maximum flow trends may explain part of the increase or decrease in constituent concentration and fluxes. However, to explicitly attribute the change in water quality trends to some changes in hydrologic factors, the extent of other potential factors influencing water quality, such as conservation efforts, land use changes, etc., also need to be examined. For all three stations, low flow appears to be increasing. Between 2006 and 2016, the mean and 7-day minimum flows exhibited an increasing trend with varying magnitudes across all seasons except for the spring 7-day minimum flow. Generally, the annual and seasonal 7-day minimum flows seemed to show large increases during the period of analysis. The annual and seasonal 1-day maximum flows showed increasing trends for Blackberry Creek at Rt. 47. In contrast, for Poplar Creek near Mouth-Elgin, the 1-day maximum flow exhibited a decreasing trend in winter, spring, and fall seasons, whereas its annual and summer values had increased.

5. Recommendations for Future Work

The majority of the water quality monitoring stations do not have corresponding flow data and, as a result, WRTDS models based on concentration and discharge relationships were developed only for water quality parameters in the three stations. However, flow estimates for most of these stations can be generated using the current Fox River watershed modeling efforts using (Hydrologic Simulation Program – Fortran (HSPF). A similar watershed model was previously developed by ISWS for the entire Fox River watershed including the Wisconsin portion. The hydrologic model was developed using Soil and Water Assessment Tool (SWAT), which is a physically-based, basin-scale model, to assess the impacts of potential climate change on water supply availability in the Fox River watershed (Bekele (Getahun) and Knapp, 2010; Bekele (Getahun) and Knapp, 2009). With additional modeling efforts, the SWAT-based Fox River watershed model can also be used to generate flow estimates for the water quality monitoring stations. A comparison between flow estimates of HSPF and SWAT could help in understanding the uncertainties in the estimates, thereby selecting the best flow estimates for use in WRTDS model development. The development of WRTDS models for those stations with longer water quality data allows estimating flow-normalized concentration and flux trends, complementing the current trend analysis. The additional modeling efforts for the SWAT-based Fox River watershed model can be further leveraged to include water quality components that would allow an evaluation of best management practices (e.g., scenarios proposed in the Illinois Nutrient Loss Reduction Strategy) in reducing nonpoint source pollution. Finally, by updating the FoxDB at least every three years, a meaningful trend analysis can be conducted that will provide insight into the water quality status of the Fox River and its tributaries.

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Appendices

This report includes four appendices that are compiled as a separate document. The appendices are:

Appendix A – Selected Outputs of Exploratory Data Analysis

Appendix B – Summary Statistics of the Water Quality Parameters

Appendix C – Water Quality Trend Maps

Appendix D – Annual and Seasonal Trends of Flow-normalized Concentration and Fluxes

Appendix A - Selected Outputs of the Exploratory Data Analysis

Table A.1 Water Quality Parameters Analyzed by Monitoring Stations

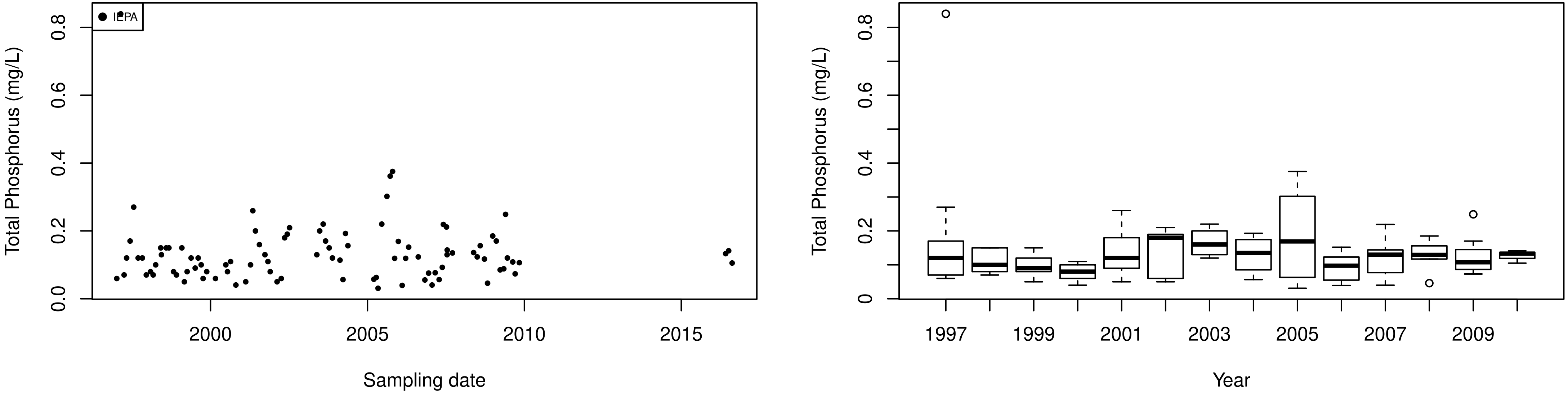
Station ID	Station name	Water quality parameters by Station									
236	*Nippersink Cr at Spring Grove*	TP	DP	-	NH_3-N	-	TKN	DO	pH	TSS	-
1	*Nippersink Cr above Wonder Lake*	TP	DP	-	-	-	-	-	-	-	-
184	**Fox River at Johnsburg**	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	-	CHL-A
23	**Fox River at Rt 176**	TP	DP	-	NH_3-N	NO_3-N	TKN	DO	pH	TSS	-
258	**Fox River at Oakwood Hills**	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	-	CHL-A
4	*Flint Cr at Kelsey Rd-Lk Barrington*	TP	DP	-	NH_3-N	-	TKN	-	-	-	-
271	*Crystal Cr at Rt 31*	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	-	CHL-A
24	**Fox River at Algonquin**	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	TSS	CHL-A
268	*Tyler Cr at Rt. 31-Elgin*	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	-	CHL-A
25	*Poplar Cr near Mouth-Elgin*	TP	DP	-	NH_3-N	-	TKN	DO	pH	TSS	-
26	**Fox River at South Elgin**	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	TSS	CHL-A
14	*Ferson Cr at Rt 34*	TP	DP	-	NH_3-N	-	TKN	-	-	-	-
79	*Ferson Cr near Mouth-Elgin*	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	-	CHL-A
40	**Fox River at Geneva**	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	-	CHL-A
27	**Fox River at Montgomery**	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	TSS	CHL-A
34	**Fox River at Yorkville**	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	-	CHL-A
28	*Blackberry Cr at Rt 47*	TP	DP	-	NH_3-N	-	TKN	DO	pH	TSS	-
287	*Blackberry Cr near Mouth*	TP	DP	Org-N	NH_3-N	NO_3-N	TKN	DO	pH	-	CHL-A

Note: Stations are in upstream-to-downstream order, and are in bold for Fox River main stem and in italics for tributaries.

Table A.2 Fox River Water Quality Standards

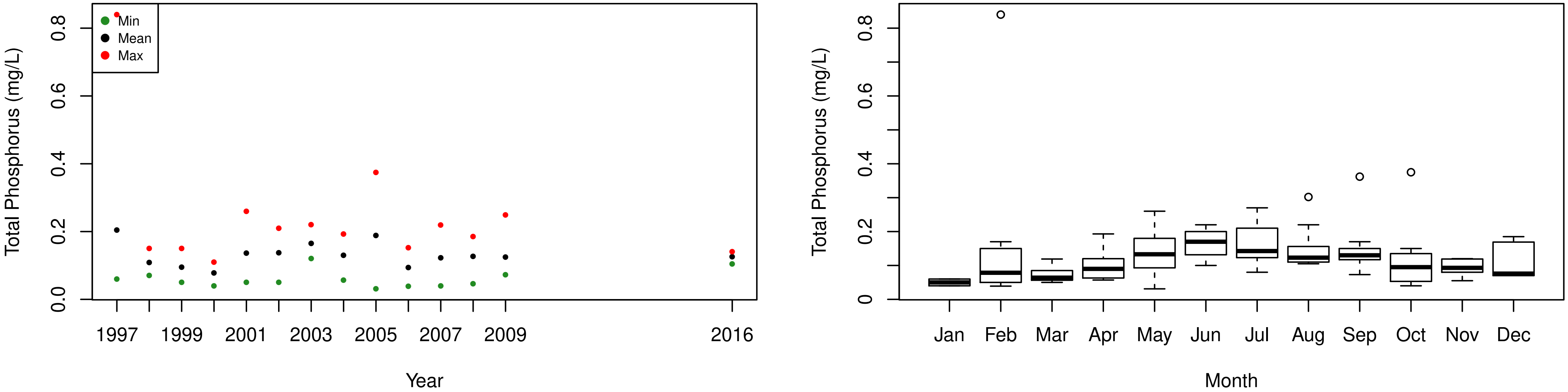
Water Quality Parameter	Existing Water Quality Standards for Fox River and its tributaries in Illinois	Other Water Quality Standards & Criteria
Total P (TP)	None	• Illinois lakes > 20 acres, including the Chain O'Lakes and other lakes within the Fox River watershed shall not exceed 0.05 mg/L (see Part 302.205) • The Wisconsin portion of the Fox River has a phosphorus standard of 0.1 mg/L. (available at https://dnr.wi.gov/topic/SurfaceWater/phosphorus.html) • Ecoregional criterium for Region VI Corn Belt and N Great Plains: 0.07625 mg/L. (https://www.epa.gov/nutrient-policy-data/ecoregional-criteria)
Dissolved P (DP)	None	
Organic-N (Org-N)	None	
Ammonia N (NH_3-N)	• Total NH3-N must in no case exceed 15 mg/L. • Acute standard is dependent on pH. Mean pH values in the Fox River range from 7.85 to 8.48. The acute standard at pH 8.2 is 5.73 mg/L. • Chronic standard differs for periods when Early Life Stage is present (March-October) and absent. It is dependent on temperature and pH. For pH 8.2, the Early Life Stage present value at 24C is 0.97 mg/L. For pH 8.2, the Early Life Stage absent value at 10C is 2.40 mg/L. The 30-day average concentration must not exceed the chronic standard except in those waters in which mixing is allowed.	• The most recent 2013 USEPA criterion document recognizes the sensitivity of freshwater mussels to ammonia levels. These new standards have not yet been adopted in Illinois. For pH 8.2 and 24C, the acute criterion is 1.9 mg/L (1-hour average). For pH 8.2 and 24C, the chronic criterion is 0.44 mg/L (30-day rolling average). Not to be exceeded more than 1 in 3 years on average. (https://www.epa.gov/wqc/aquatic-life-criteria-ammonia)
Nitrate N (NO_3-N)	• Public and food processing water supply standard. Waters of the State are generally designated for public and food processing use: 10 mg/L	
TKN	None	
Total N (= TKN+NO_3-N)	None	• USEPA recommends 2-6 mg/L of Total N. (https://www.epa.gov/sites/production/files/2015-09/documents/totalnitrogen.pdf) • Ecoregional criterium for Region VI Corn Belt and N Great Plains: 2.18 mg/L. (See https://www.epa.gov/nutrient-policy-data/ecoregional-criteria)
Dissolved Oxygen (DO)	• All waters except enhanced DO stretch below: Mar-July: not less than 5.0 mg/L at any time, 6.0 as daily mean avg'd over 7 days. Aug-Feb: not less than 3.5 mg/L at any time, 4.0 as daily minimum avg'd over 7 days, 5.5 as daily mean avg'd over 30 days. • Enhanced DO stretch (LAT/LONG): 41° 37' 3.7194"/-88° 33' 21.0162" to 41° 45' 59.5296"/-88° 18' 36.0858" Mar-July: not less than 5.0 mg/L at any time, 6.25 as daily mean avg'd over 7 days. Aug-Feb: not less than 4.0 mg/L at any time, 4.5 as daily minimum avg'd over 7 days, 6.0 as daily mean avg'd over 30 days.	
pH	6.5 to 9.0	
TSS	None	
Cholorophyll-A (CHL-A)	None	• Ecoregional criterium for Region VI Corn Belt and N Great Plains: 2.70 µg/L. (https://www.epa.gov/nutrient-policy-data/ecoregional-criteria)

Nippersink Cr at Spring Grove (236): Total Phosphorus (mg/L)



(a) Observation data

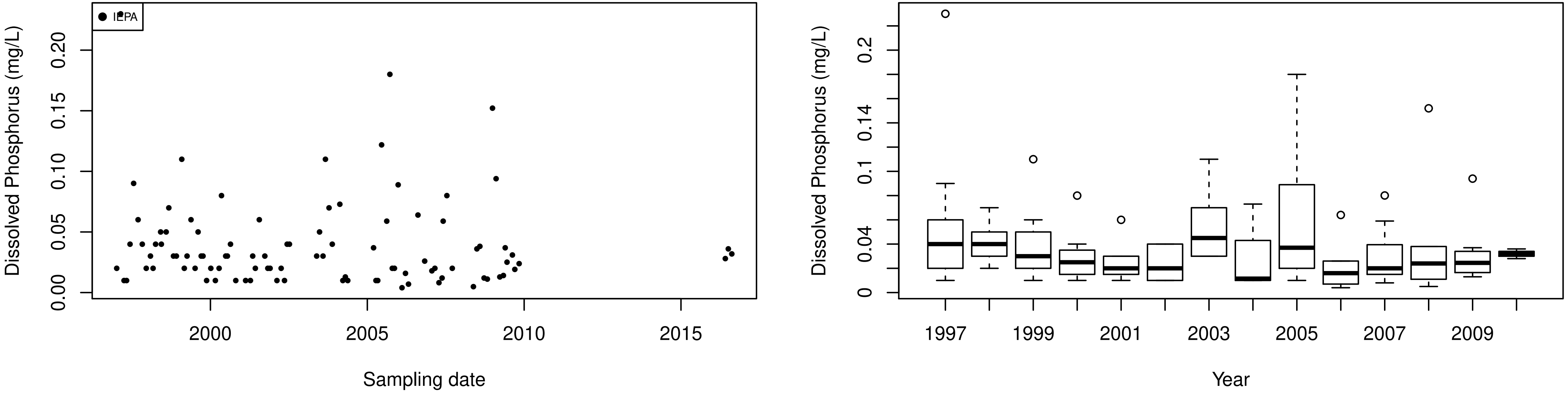
(b) Boxplot by year



(c) Annual values

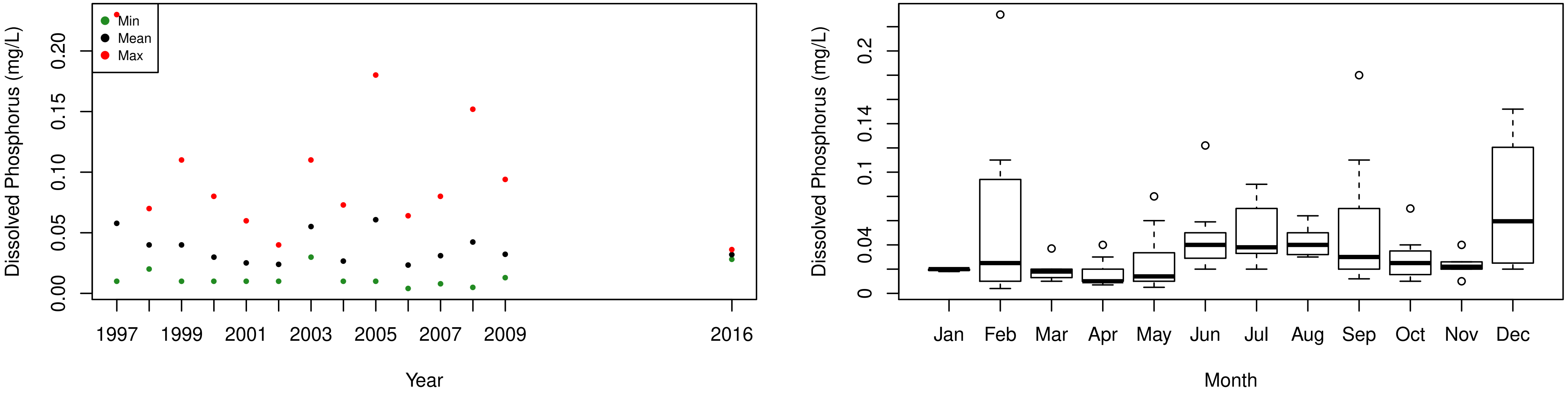
(d) Boxplot by month

Nippersink Cr at Spring Grove (236): Dissolved Phosphorus (mg/L)



(a) Observation data

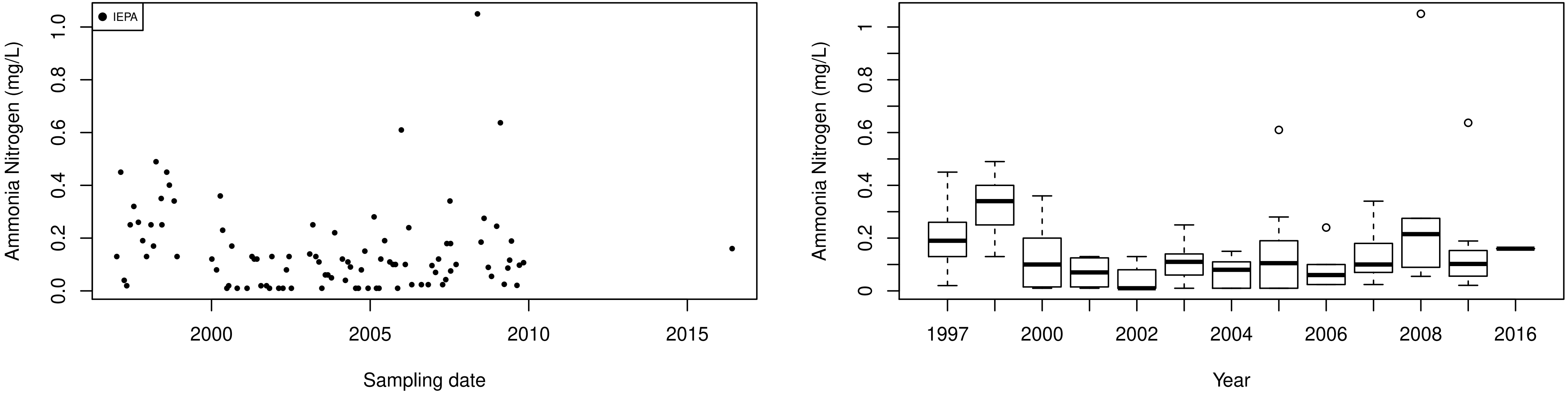
(b) Boxplot by year



(c) Annual values

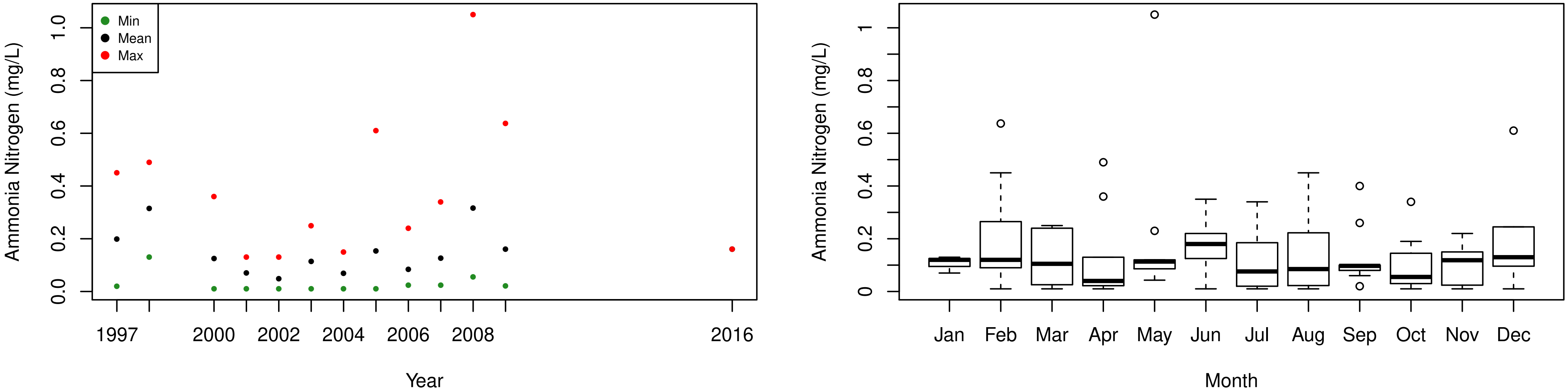
(d) Boxplot by month

Nippersink Cr at Spring Grove (236): Ammonia Nitrogen (mg/L)



(a) Observation data

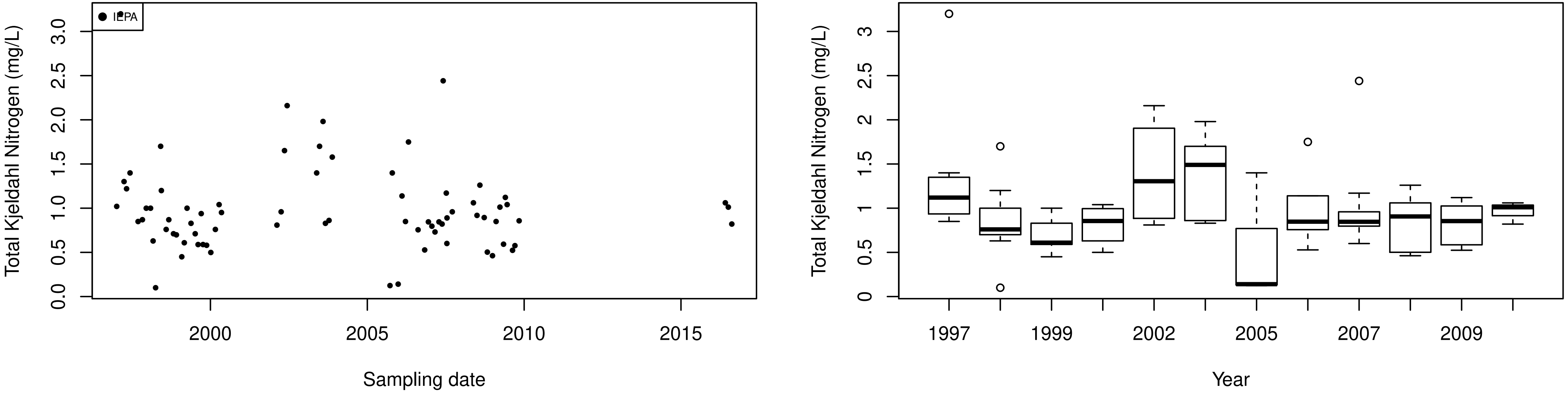
(b) Boxplot by year



(c) Annual values

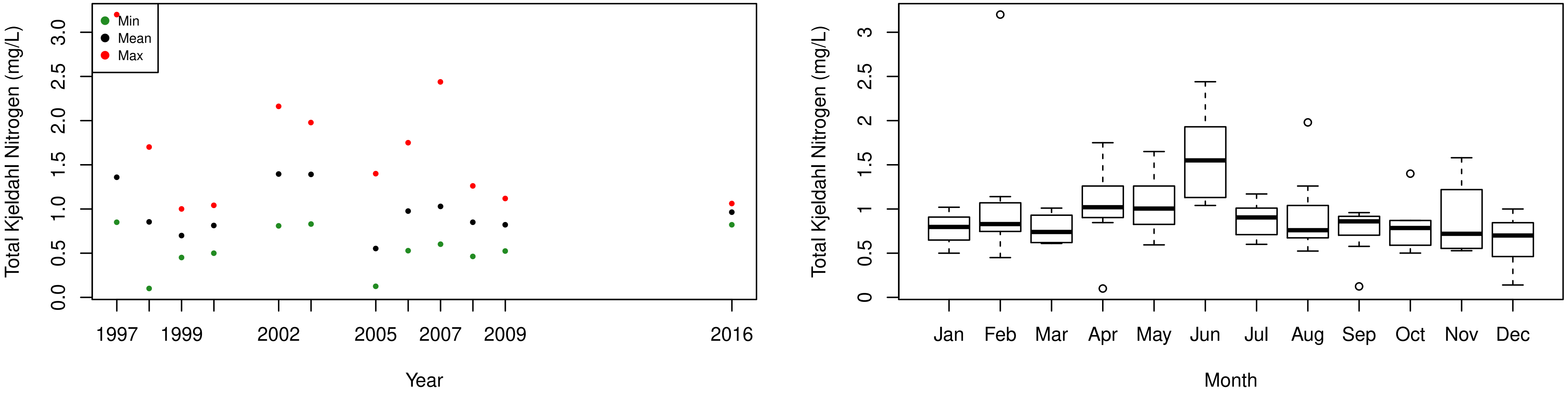
(d) Boxplot by month

Nippersink Cr at Spring Grove (236): Total Kjeldahl Nitrogen (mg/L)



(a) Observation data

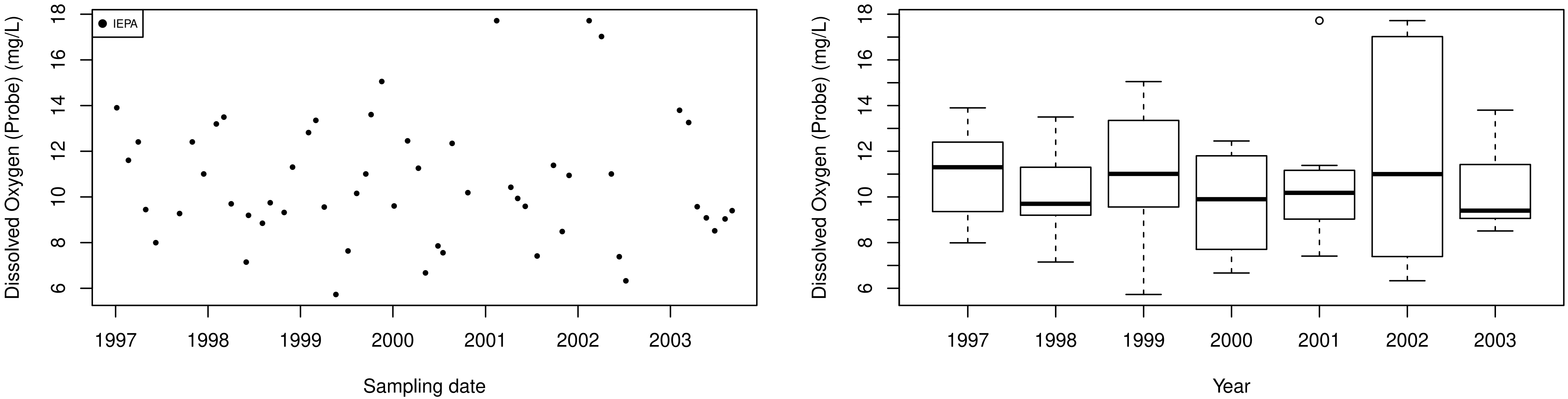
(b) Boxplot by year



(c) Annual values

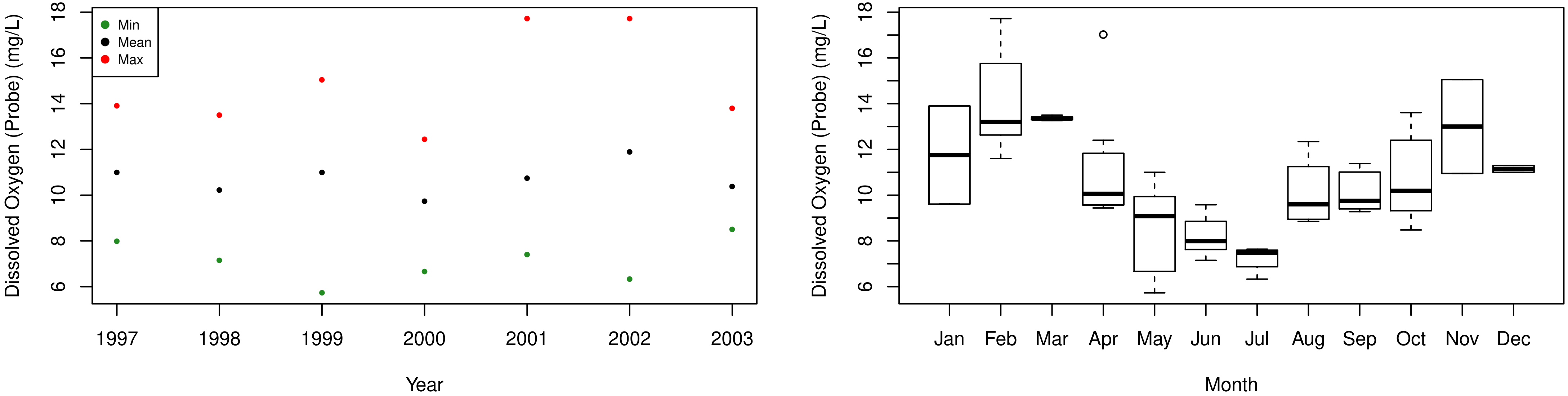
(d) Boxplot by month

Nippersink Cr at Spring Grove (236): Dissolved Oxygen (Probe) (mg/L)



(a) Observation data

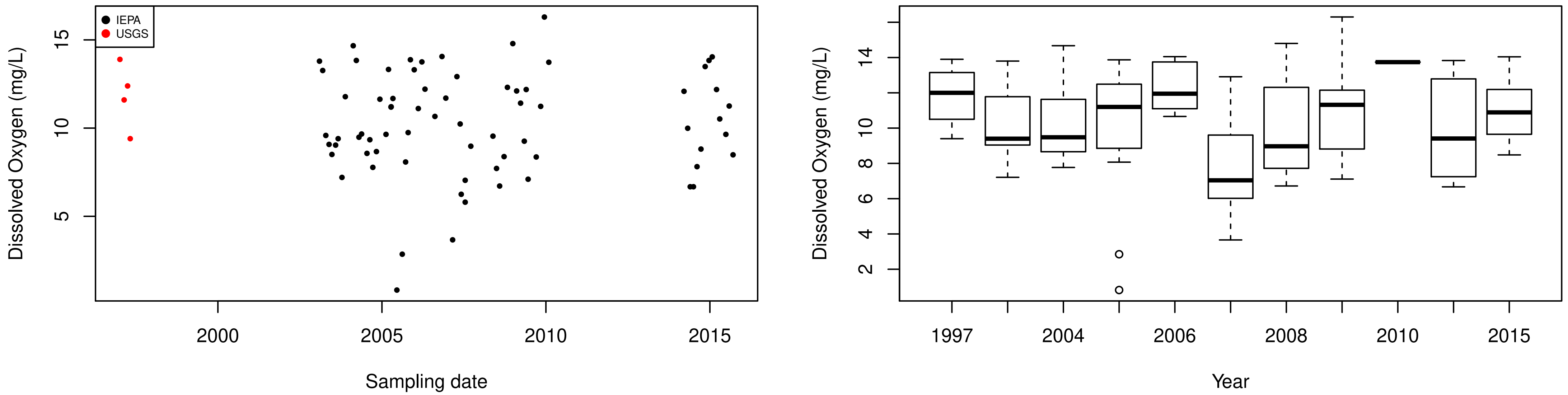
(b) Boxplot by year



(c) Annual values

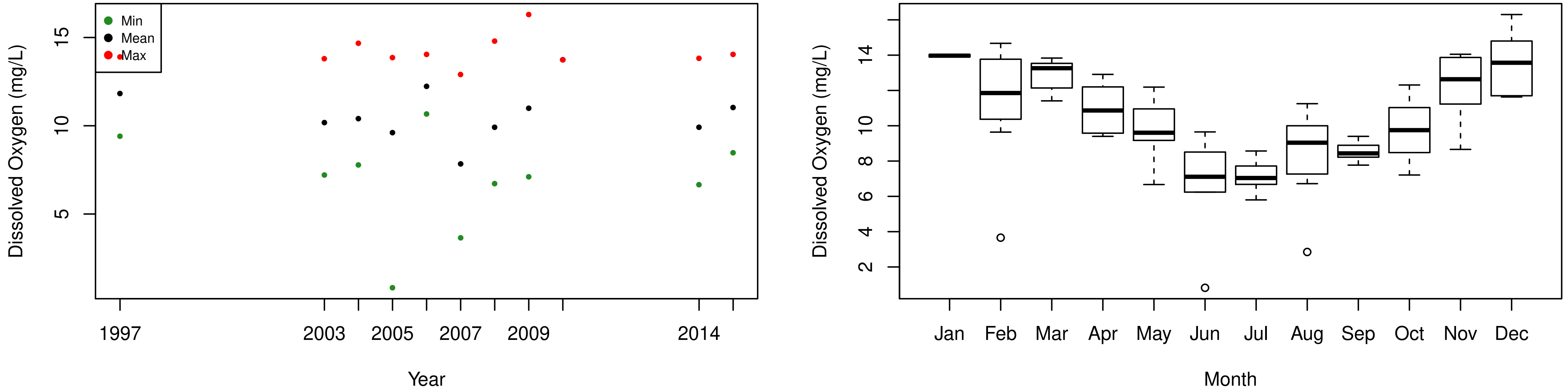
(d) Boxplot by month

Nippersink Cr at Spring Grove (236): Dissolved Oxygen (mg/L)



(a) Observation data

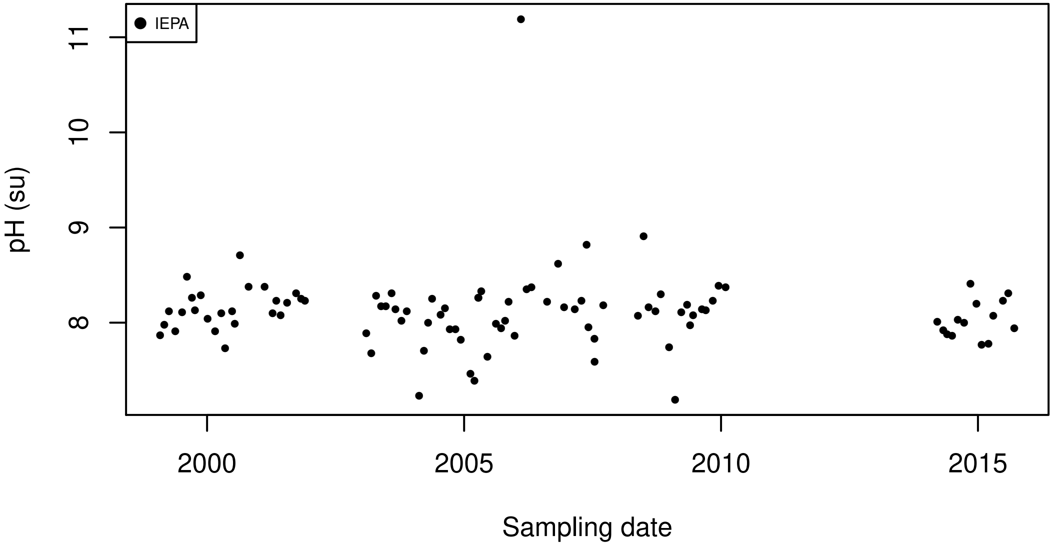
(b) Boxplot by year



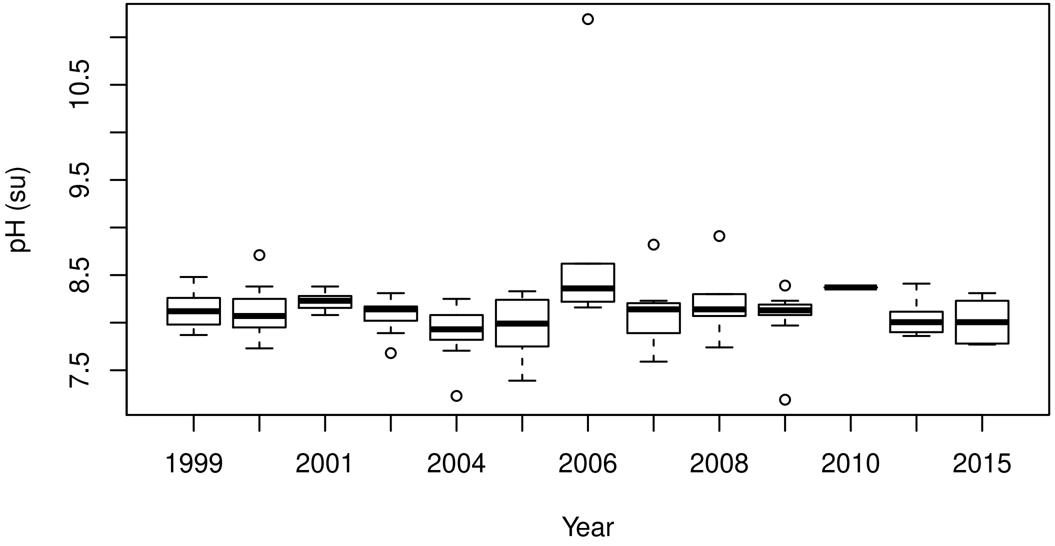
(c) Annual values

(d) Boxplot by month

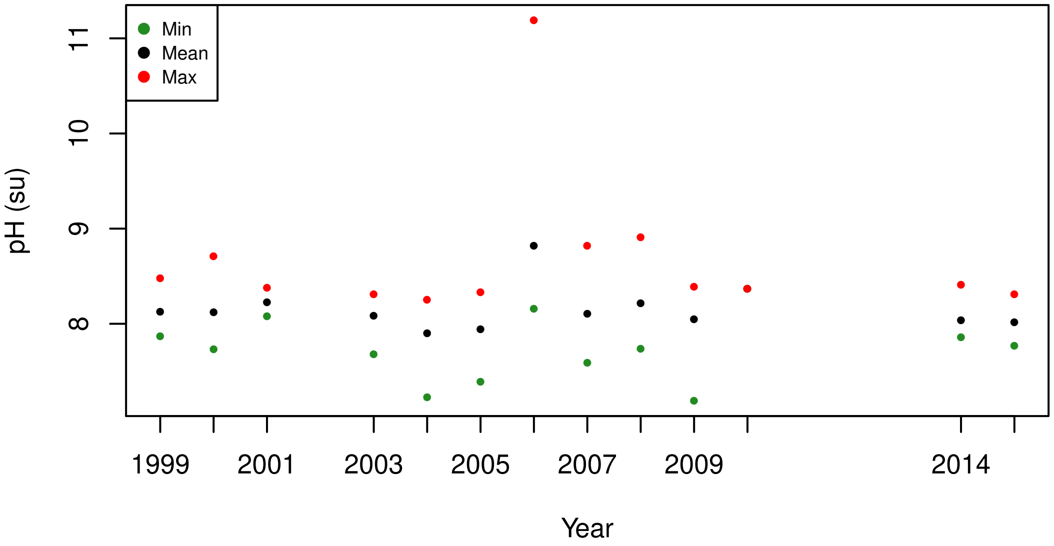
Nippersink Cr at Spring Grove (236): pH (su)



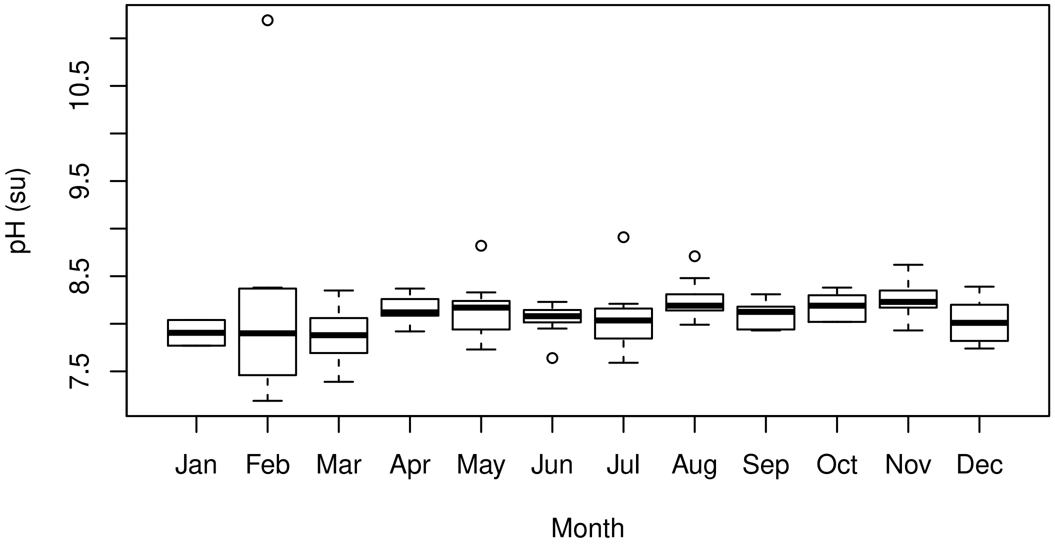
(a) Observation data



(b) Boxplot by year

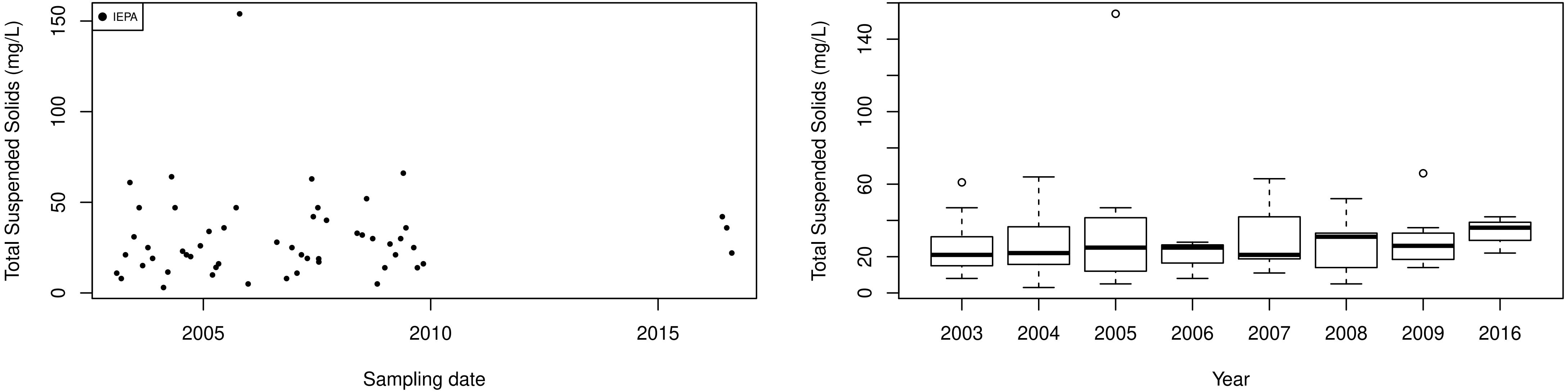


(c) Annual values



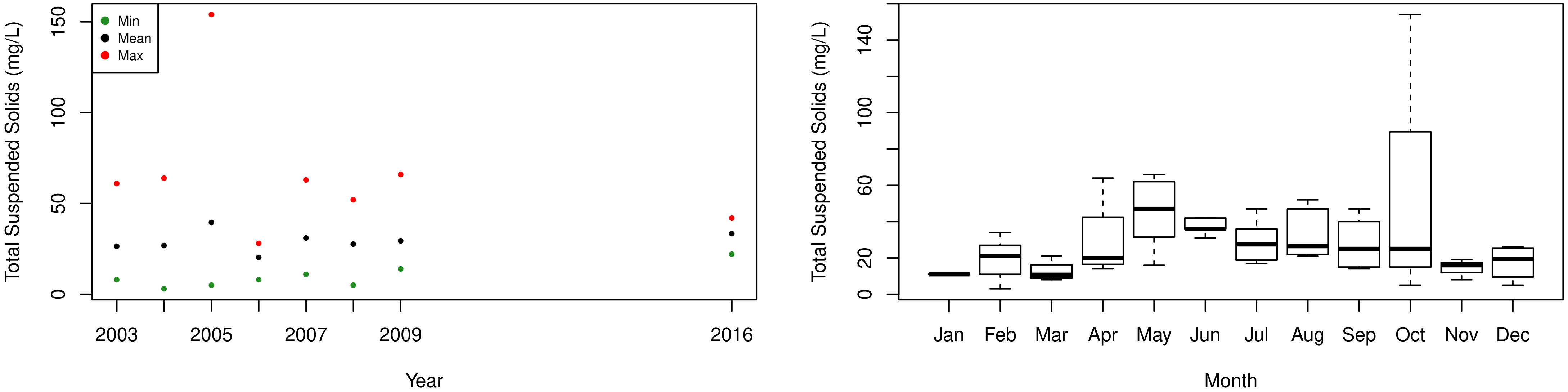
(d) Boxplot by month

Nippersink Cr at Spring Grove (236): Total Suspended Solids (mg/L)



(a) Observation data

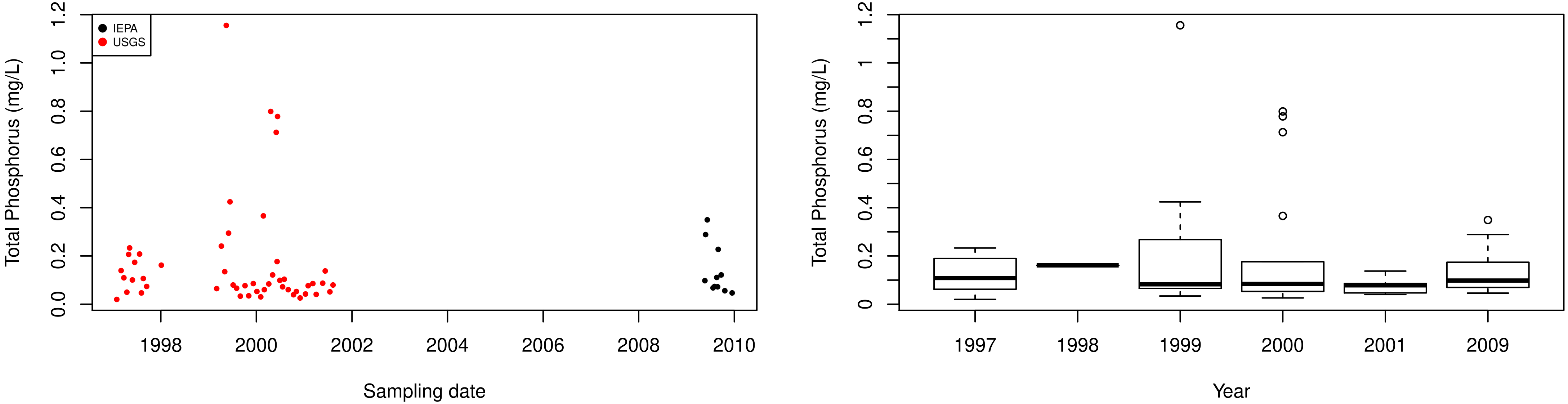
(b) Boxplot by year



(c) Annual values

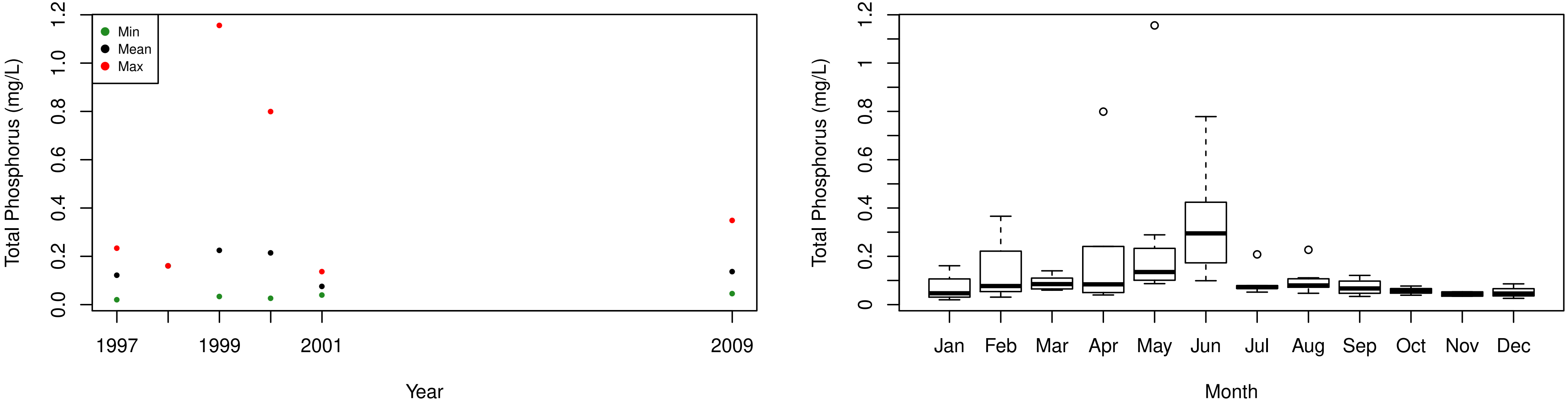
(d) Boxplot by month

Nippersink Cr above Wonder Lake (1): Total Phosphorus (mg/L)



(a) Observation data

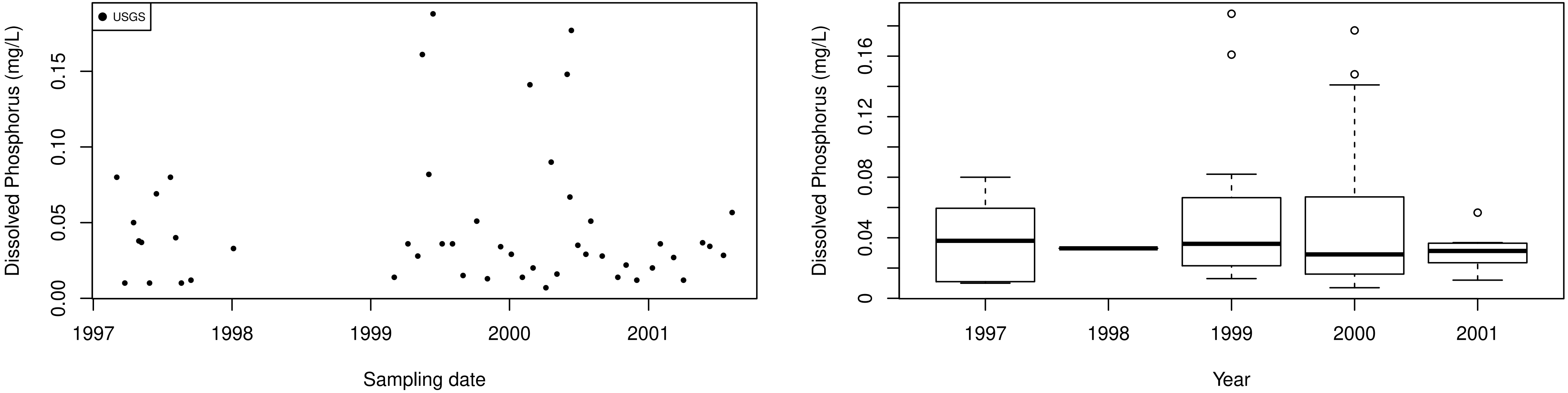
(b) Boxplot by year



(c) Annual values

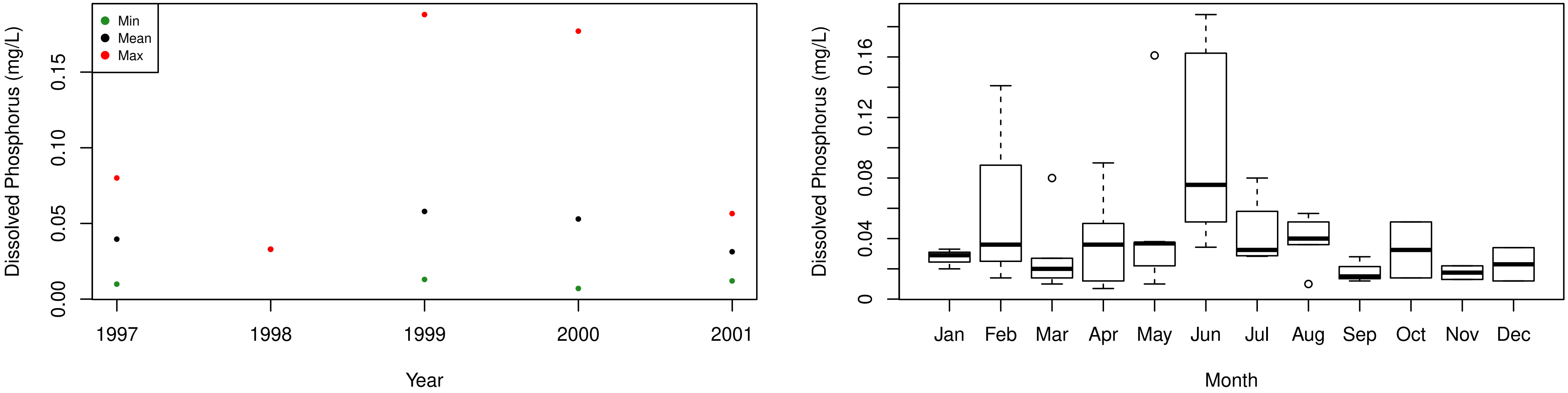
(d) Boxplot by month

Nippersink Cr above Wonder Lake (1): Dissolved Phosphorus (mg/L)



(a) Observation data

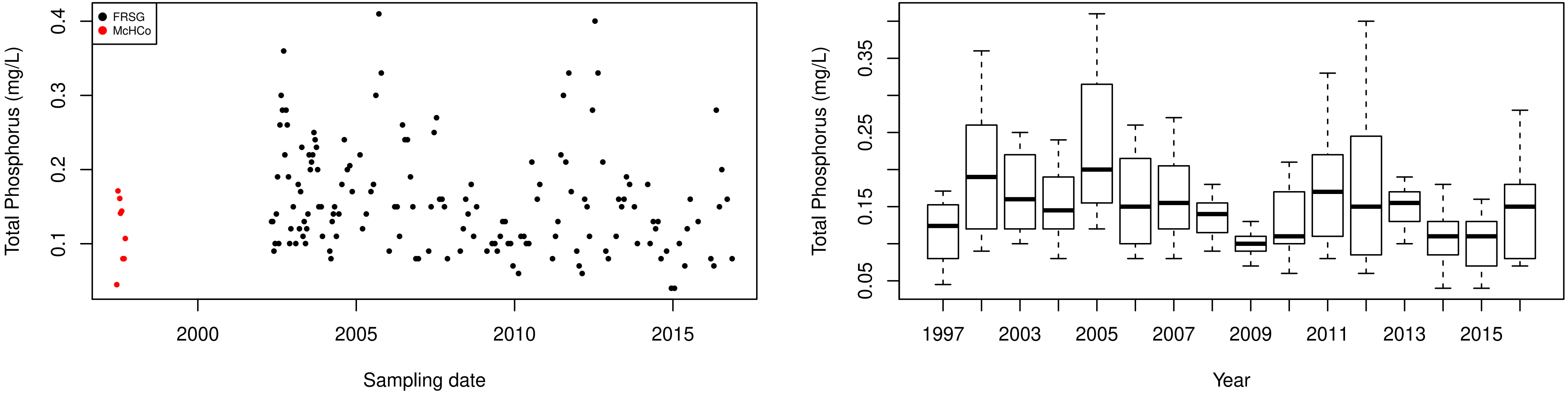
(b) Boxplot by year



(c) Annual values

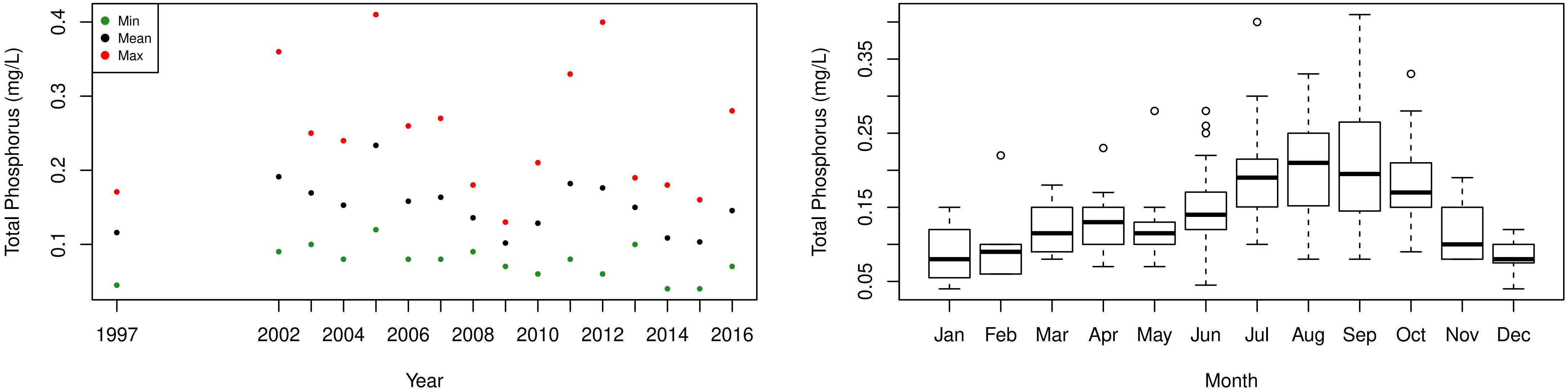
(d) Boxplot by month

Fox River at Johnsburg (184): Total Phosphorus (mg/L)



(a) Observation data

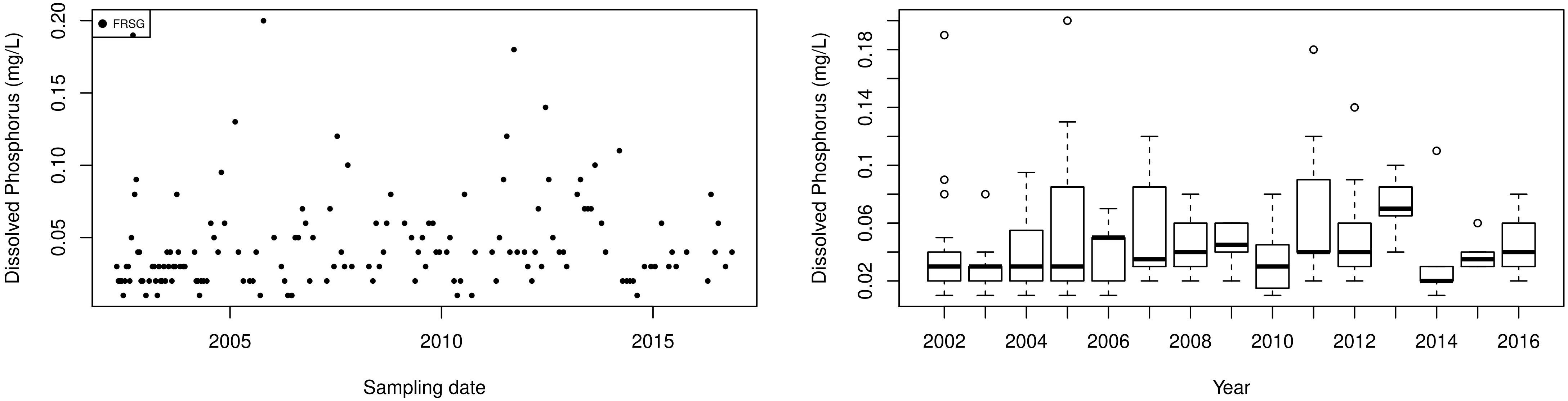
(b) Boxplot by year



(c) Annual values

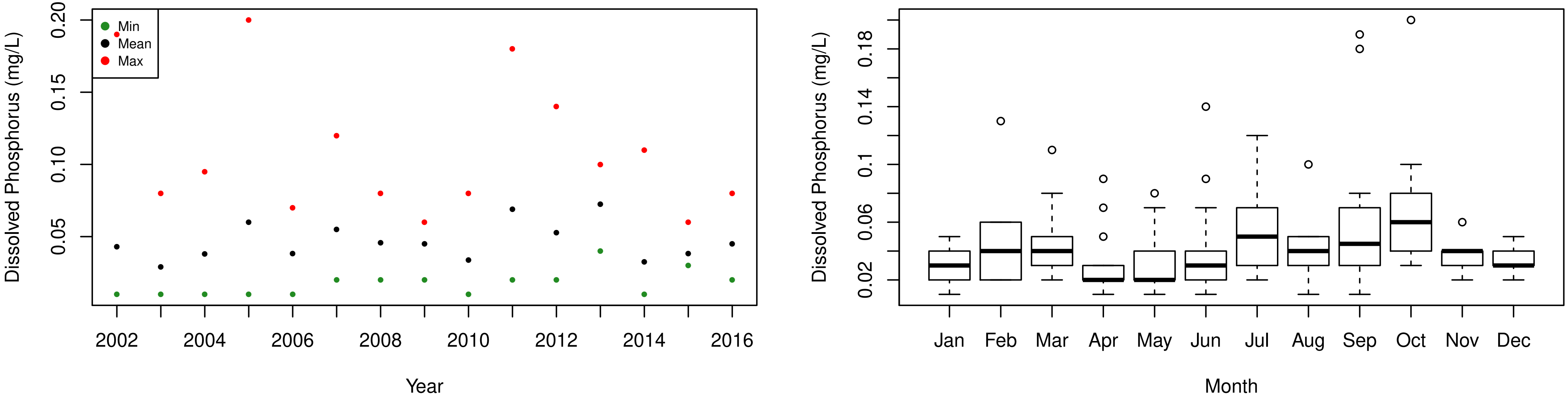
(d) Boxplot by month

Fox River at Johnsburg (184): Dissolved Phosphorus (mg/L)



(a) Observation data

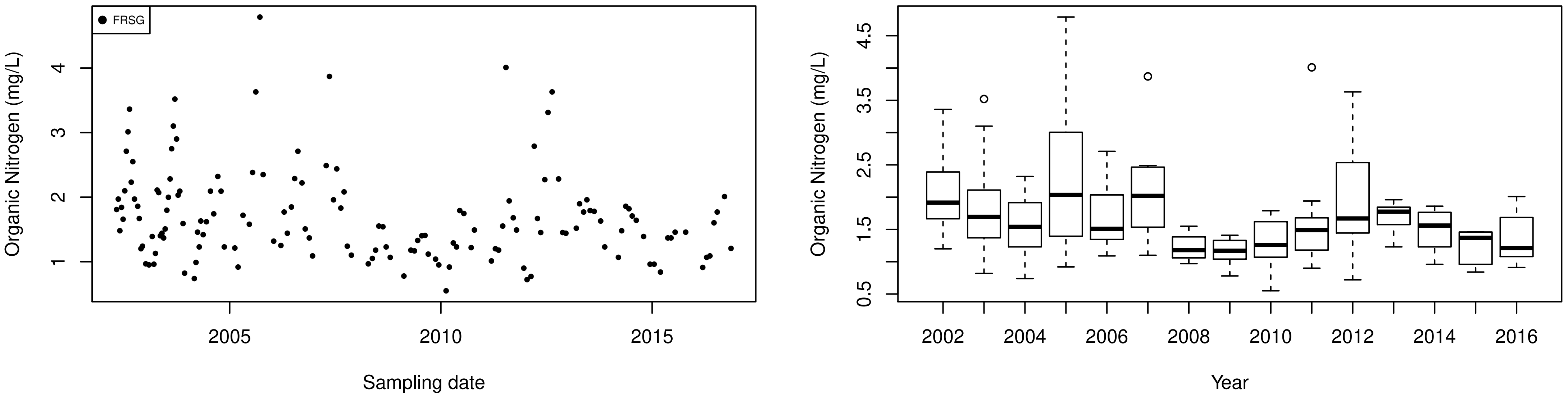
(b) Boxplot by year



(c) Annual values

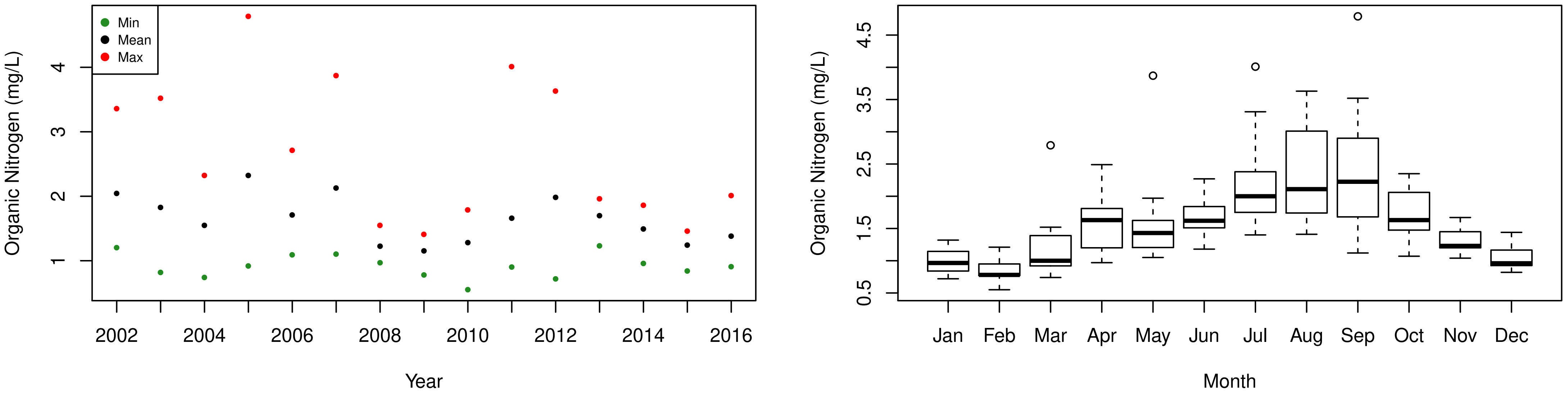
(d) Boxplot by month

Fox River at Johnsburg (184): Organic Nitrogen (mg/L)



(a) Observation data

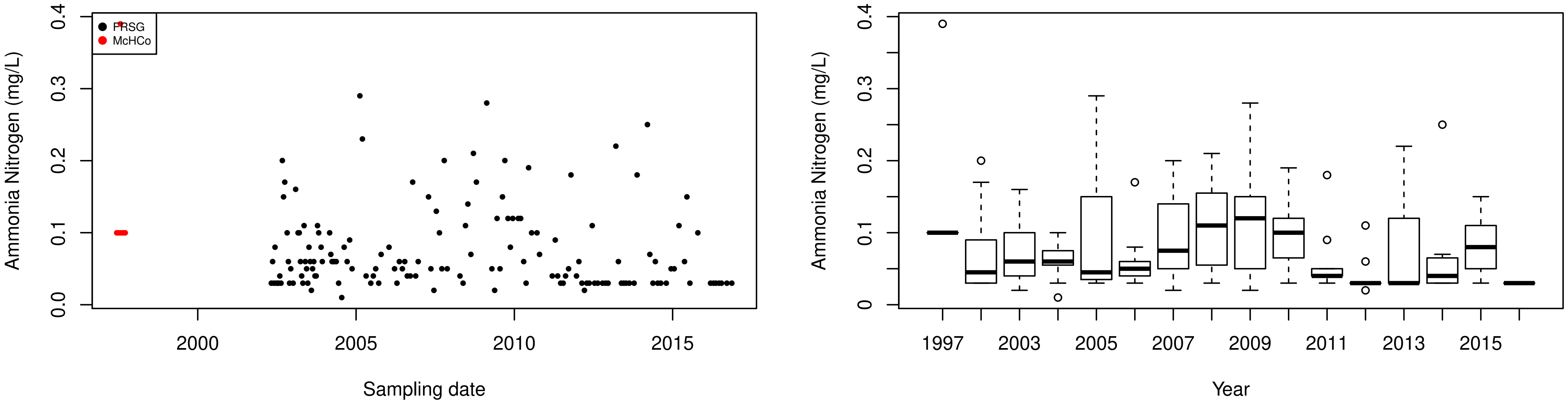
(b) Boxplot by year



(c) Annual values

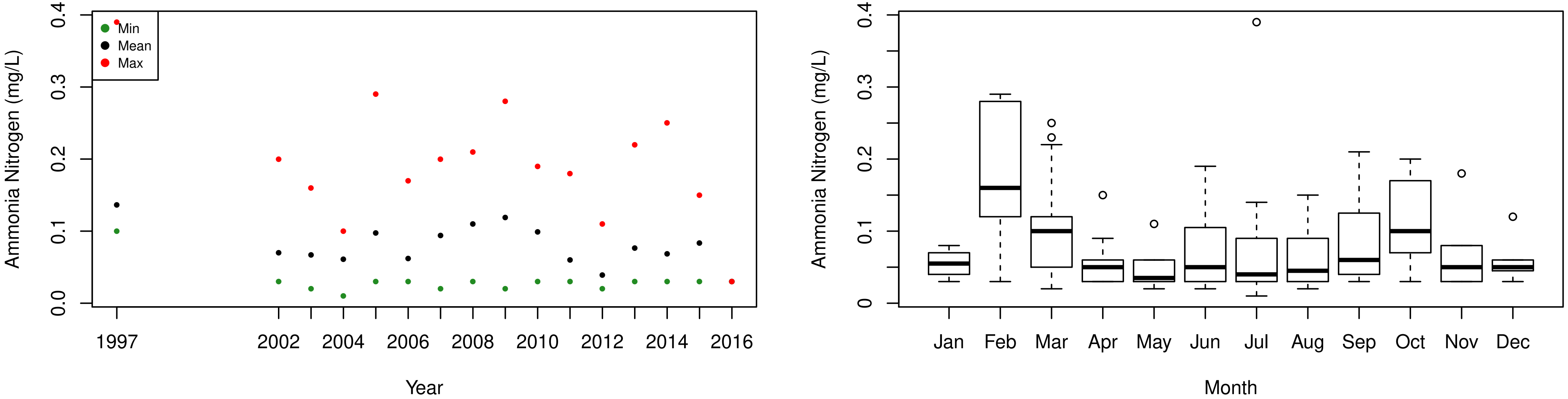
(d) Boxplot by month

Fox River at Johnsburg (184): Ammonia Nitrogen (mg/L)



(a) Observation data

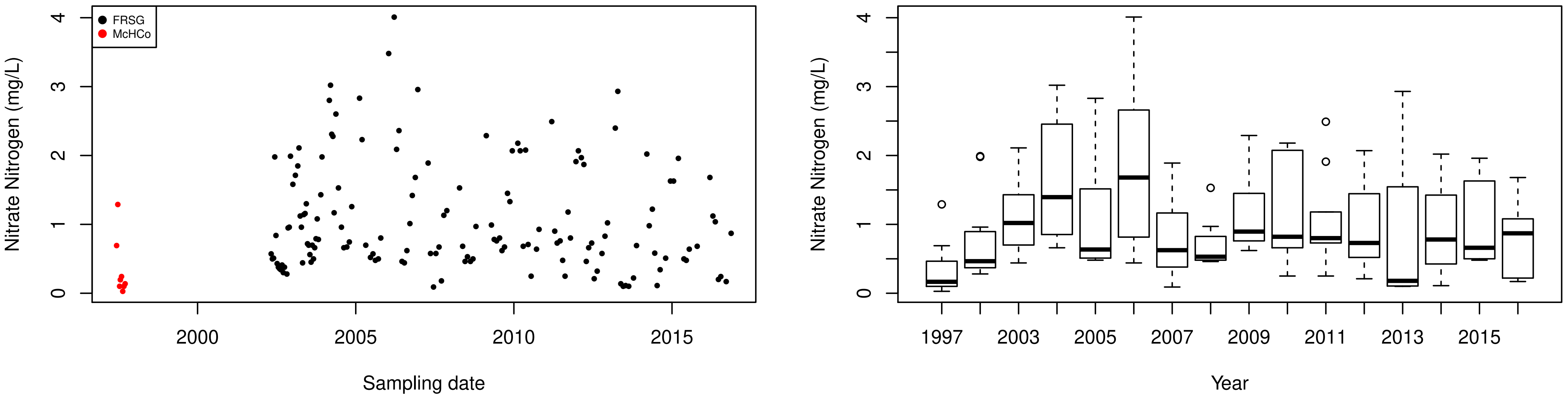
(b) Boxplot by year



(c) Annual values

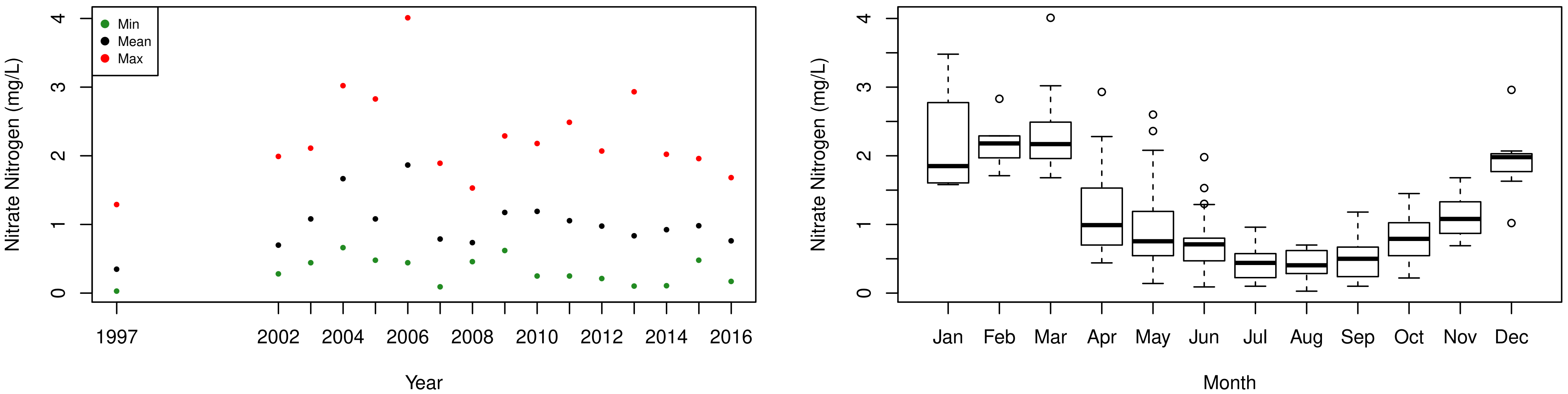
(d) Boxplot by month

Fox River at Johnsburg (184): Nitrate Nitrogen (mg/L)



(a) Observation data

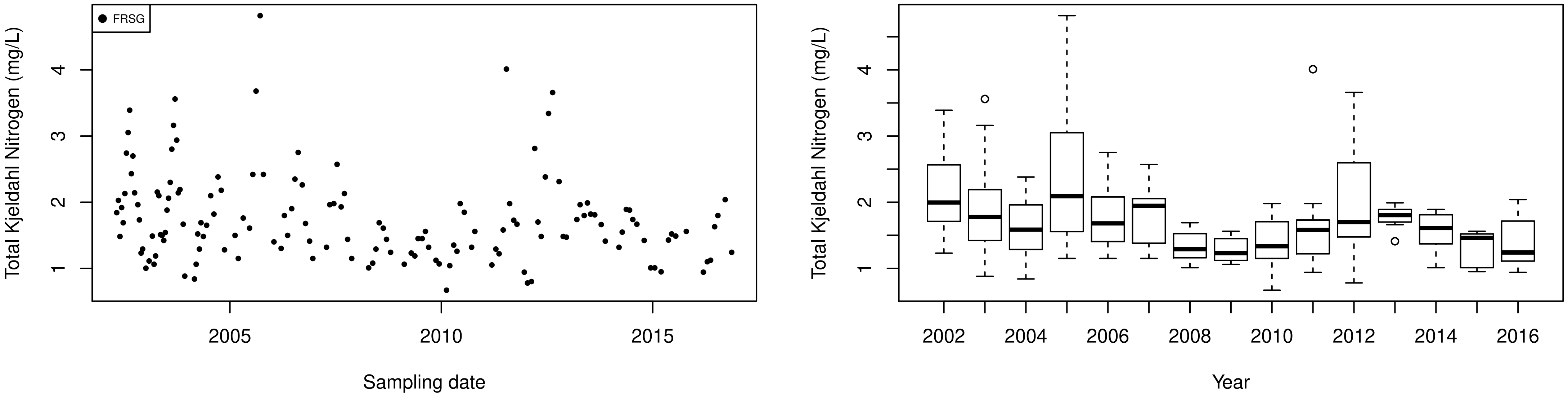
(b) Boxplot by year



(c) Annual values

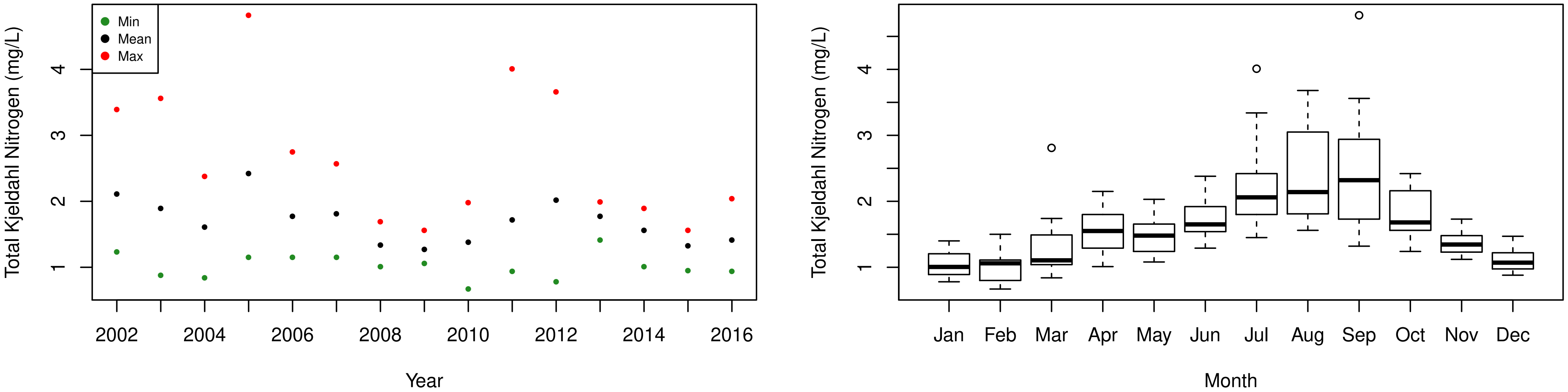
(d) Boxplot by month

Fox River at Johnsburg (184): Total Kjeldahl Nitrogen (mg/L)



(a) Observation data

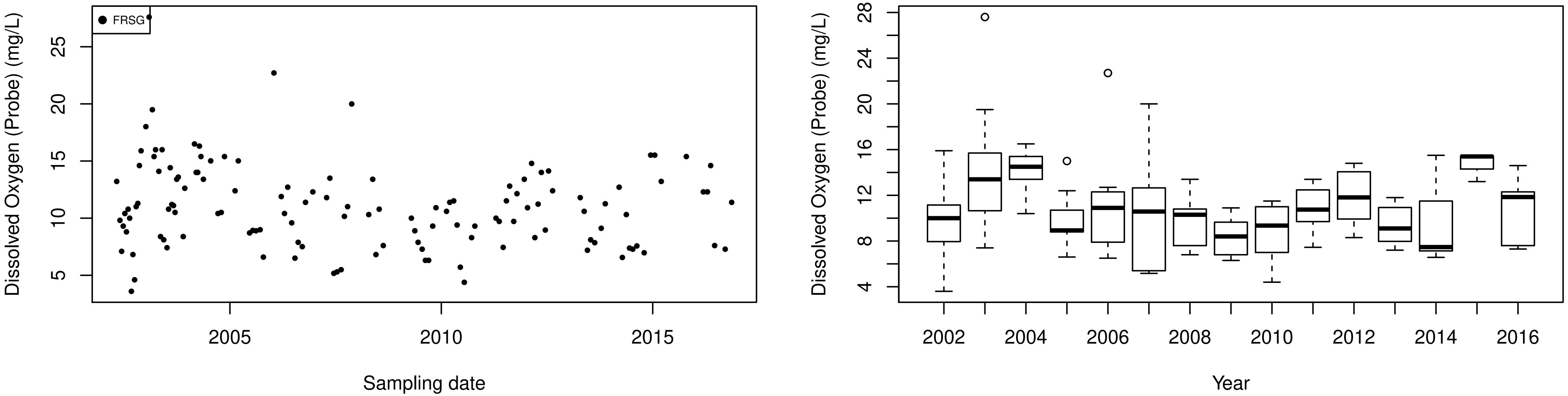
(b) Boxplot by year



(c) Annual values

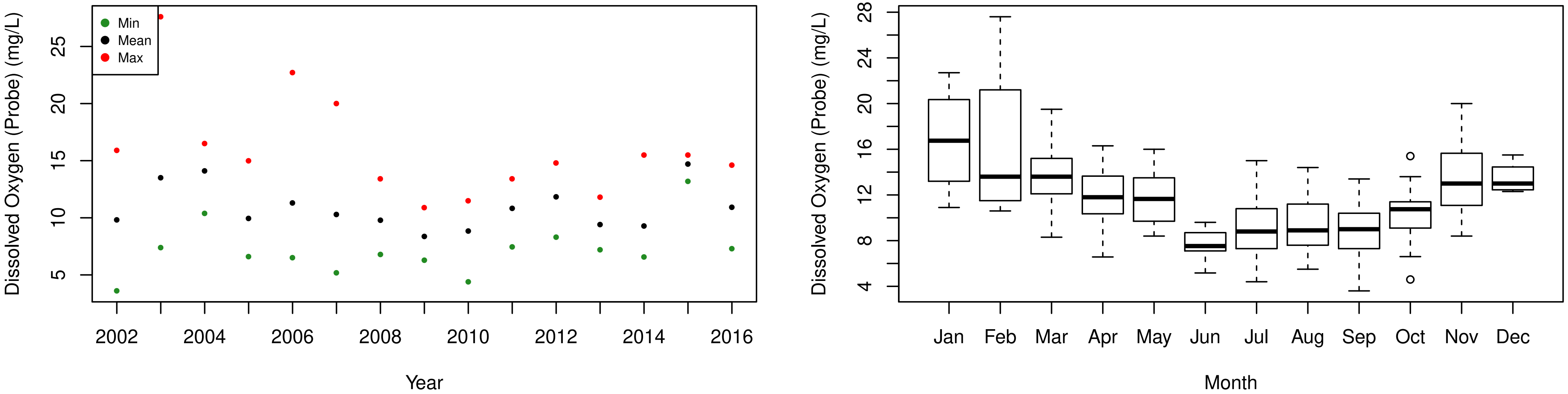
(d) Boxplot by month

Fox River at Johnsburg (184): Dissolved Oxygen (Probe) (mg/L)



(a) Observation data

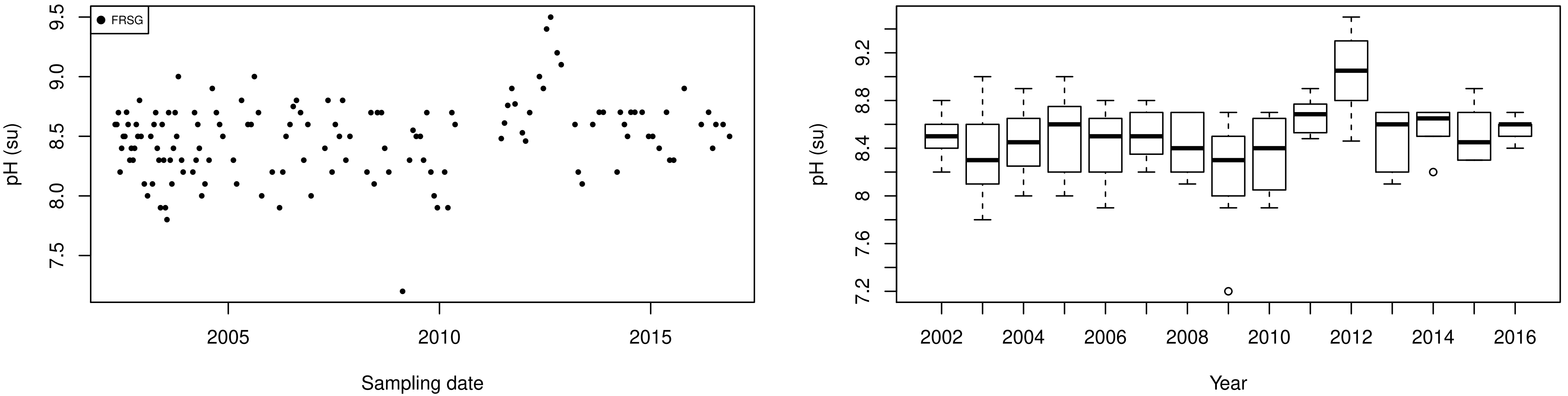
(b) Boxplot by year



(c) Annual values

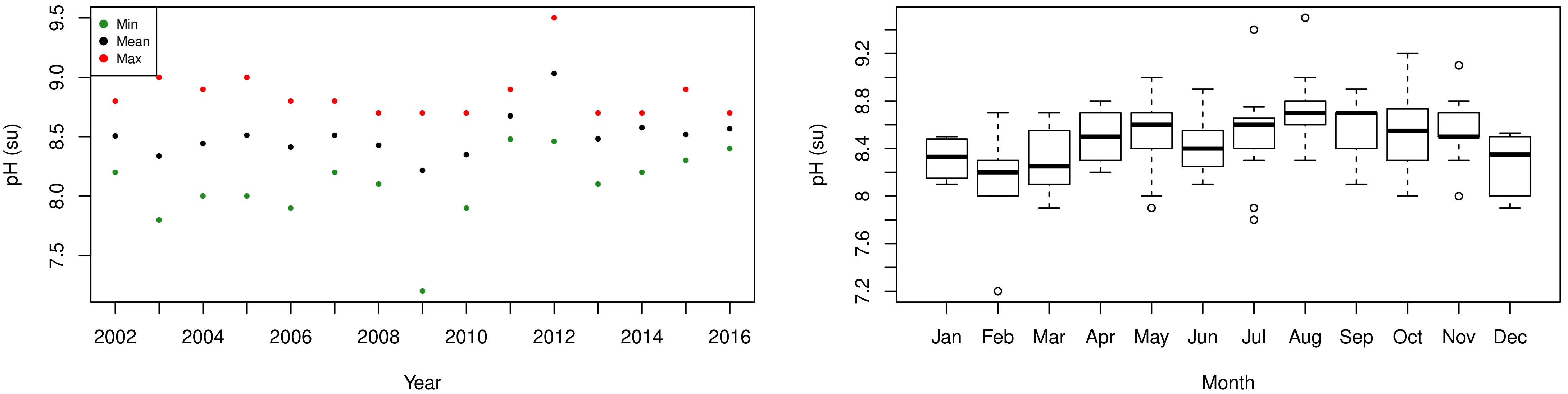
(d) Boxplot by month

Fox River at Johnsburg (184): pH (su)



(a) Observation data

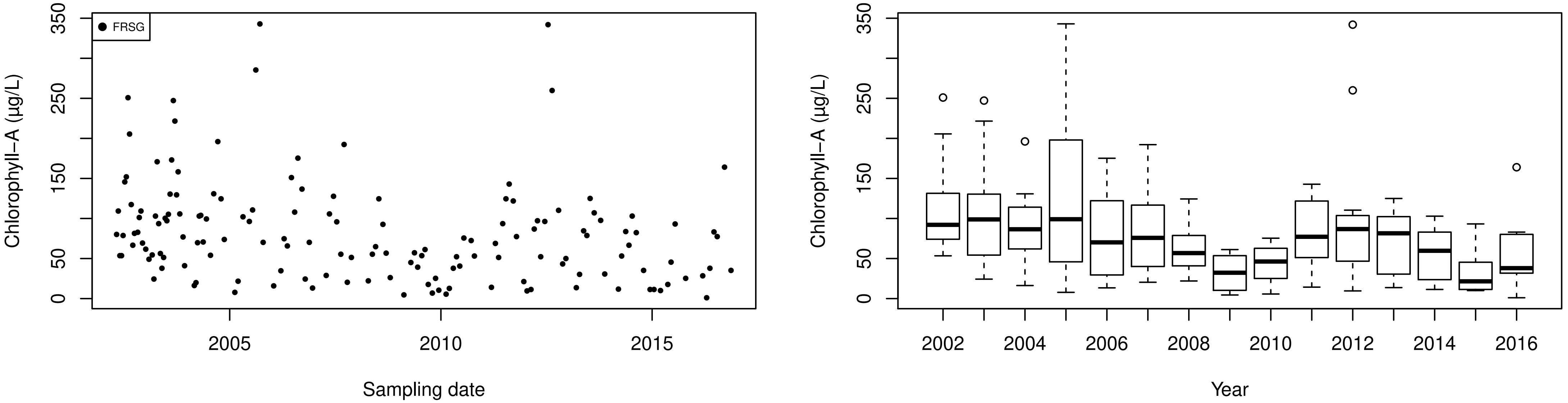
(b) Boxplot by year



(c) Annual values

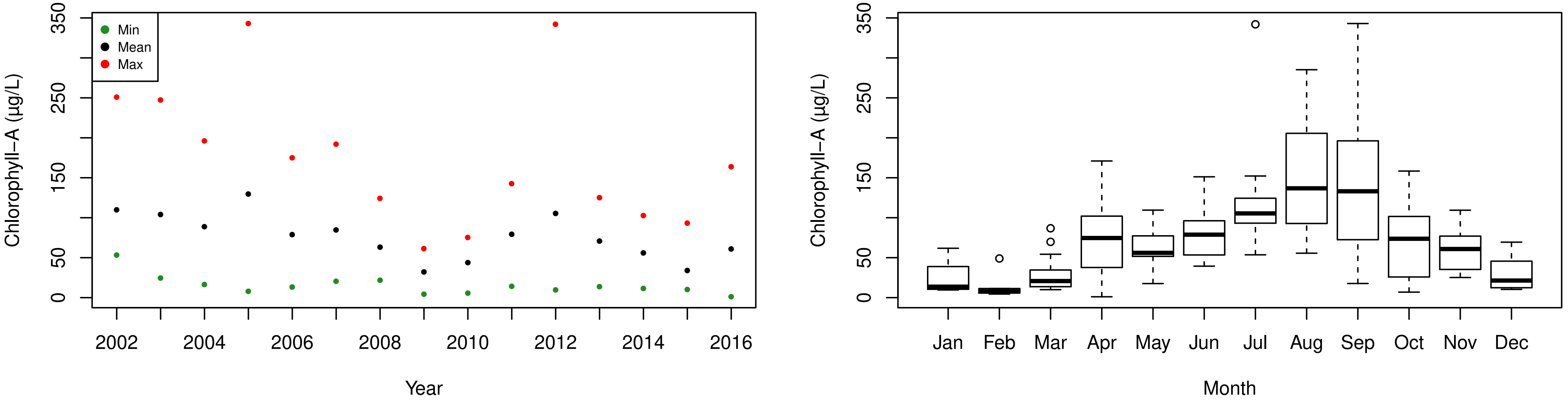
(d) Boxplot by month

Fox River at Johnsburg (184): Chlorophyll–A (µg/L)



(a) Observation data

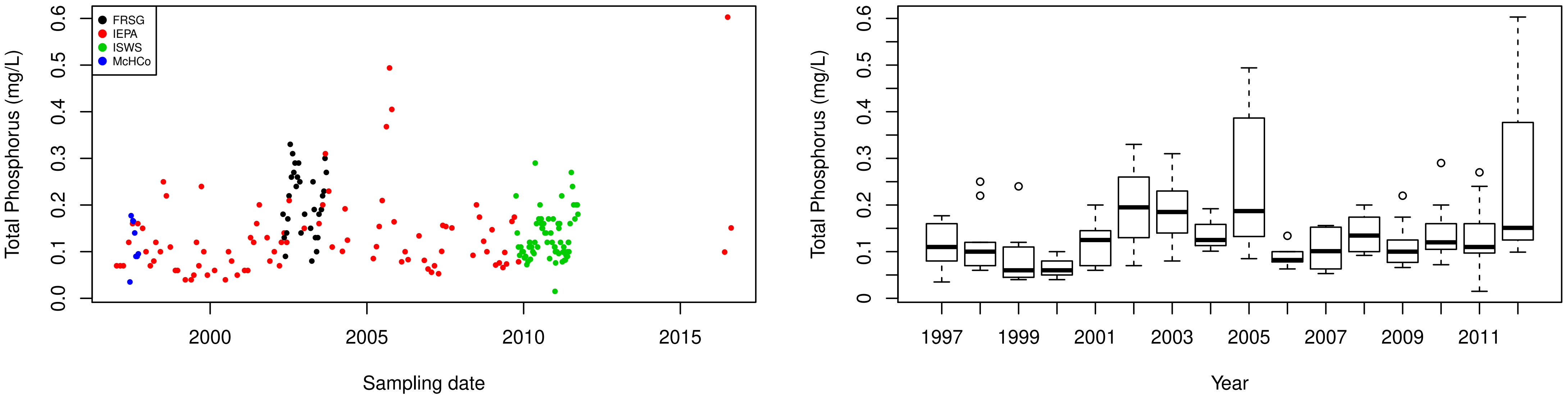
(b) Boxplot by year



(c) Annual values

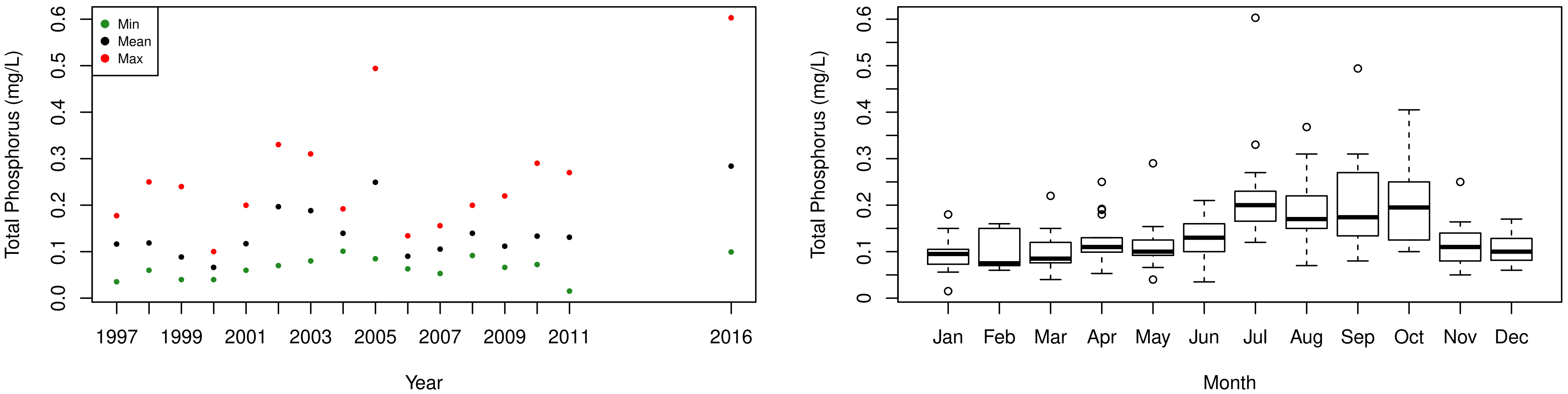
(d) Boxplot by month

Fox River at Rt 176 (23): Total Phosphorus (mg/L)



(a) Observation data

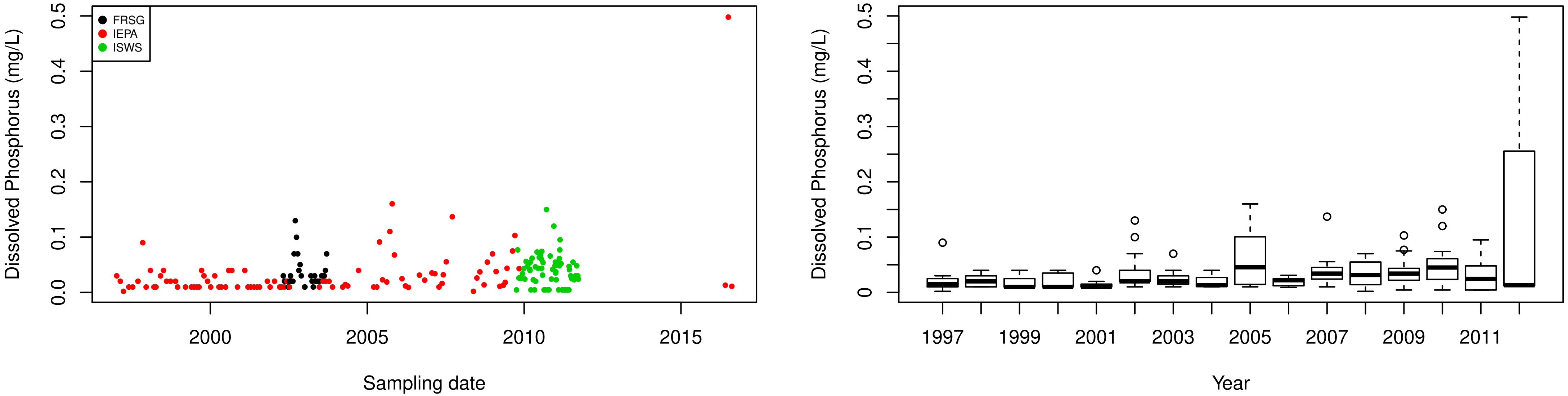
(b) Boxplot by year



(c) Annual values

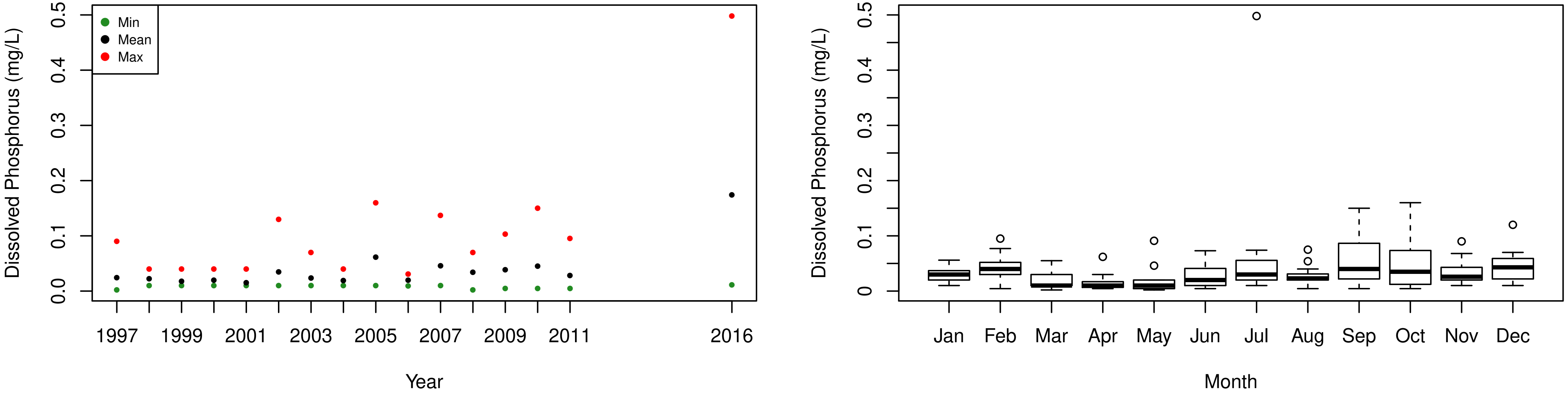
(d) Boxplot by month

Fox River at Rt 176 (23): Dissolved Phosphorus (mg/L)



(a) Observation data

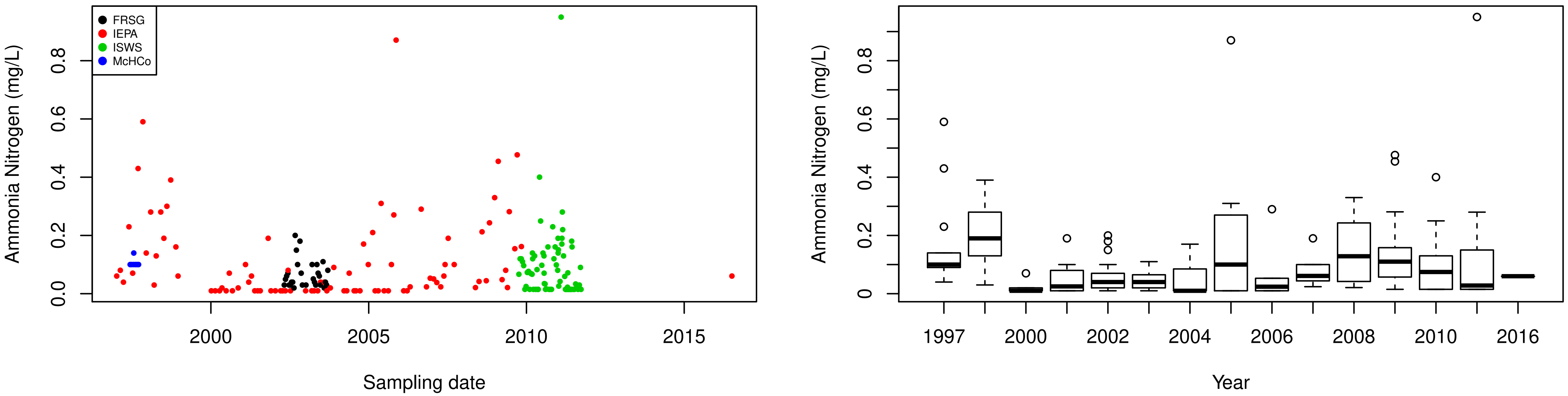
(b) Boxplot by year



(c) Annual values

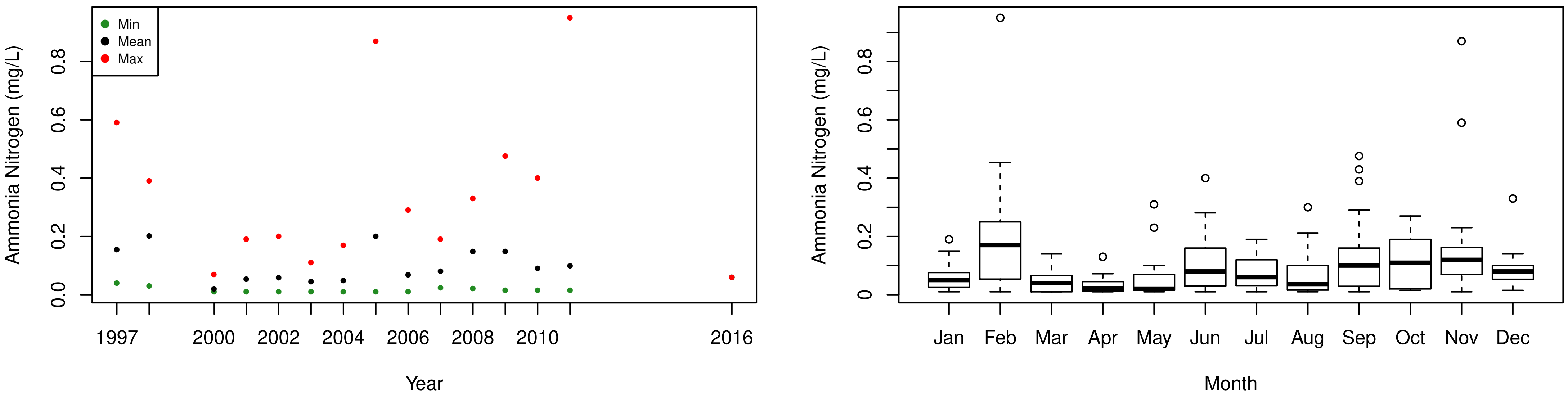
(d) Boxplot by month

Fox River at Rt 176 (23): Ammonia Nitrogen (mg/L)



(a) Observation data

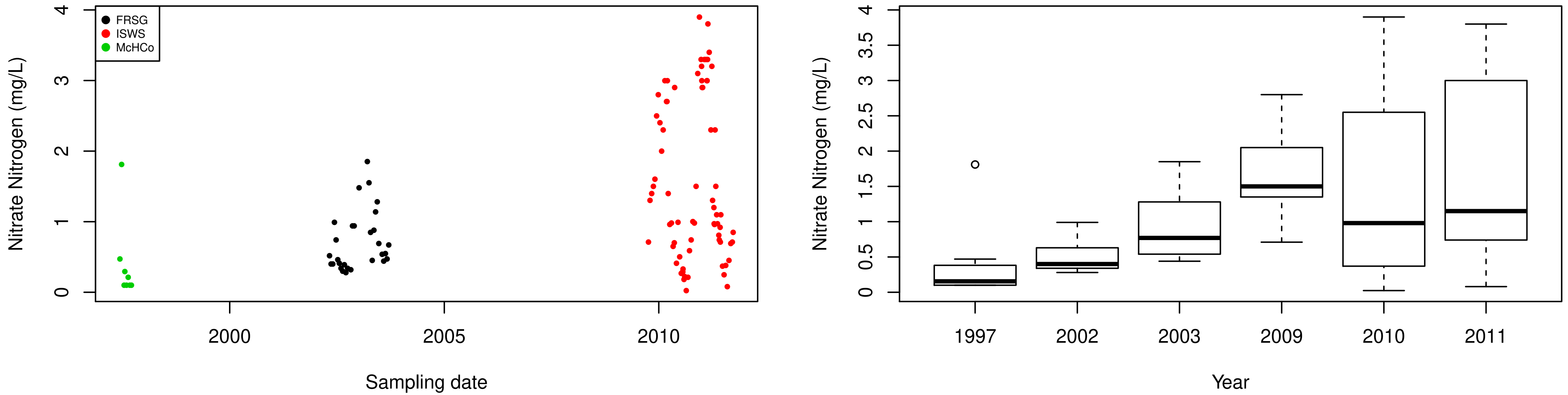
(b) Boxplot by year



(c) Annual values

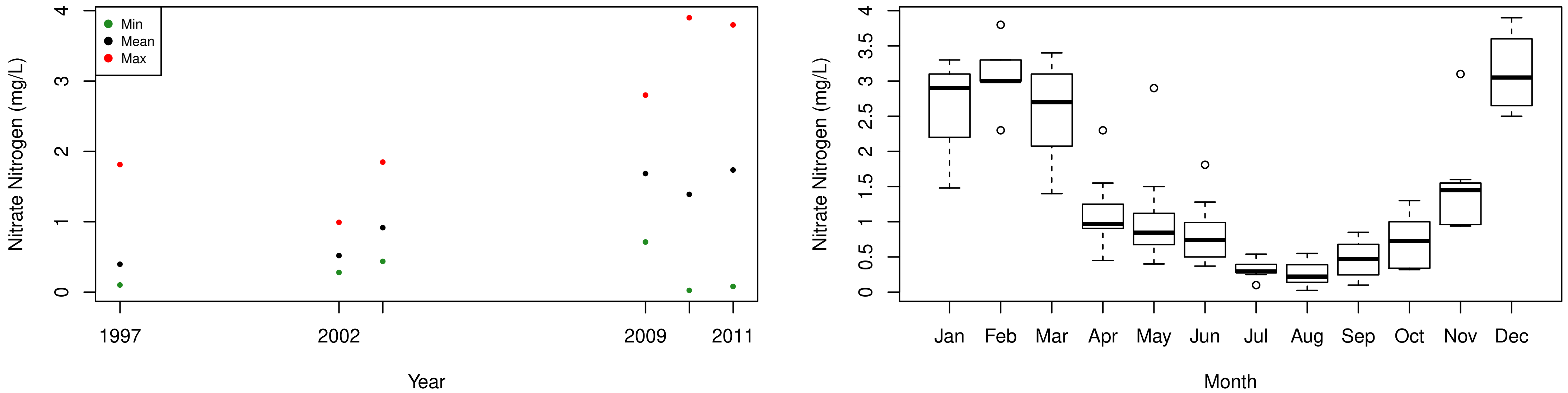
(d) Boxplot by month

Fox River at Rt 176 (23): Nitrate Nitrogen (mg/L)



(a) Observation data

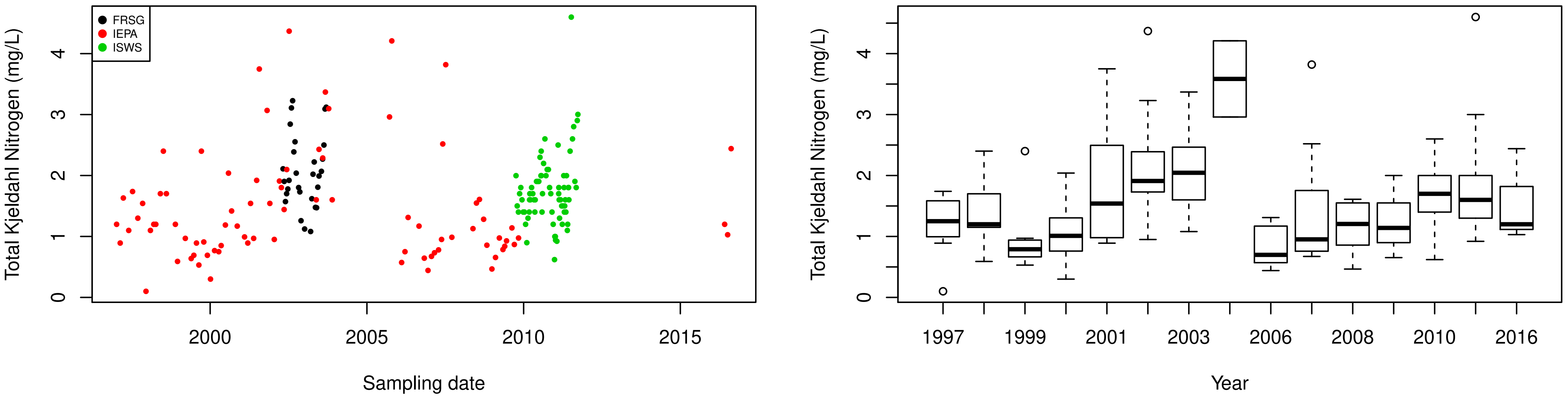
(b) Boxplot by year



(c) Annual values

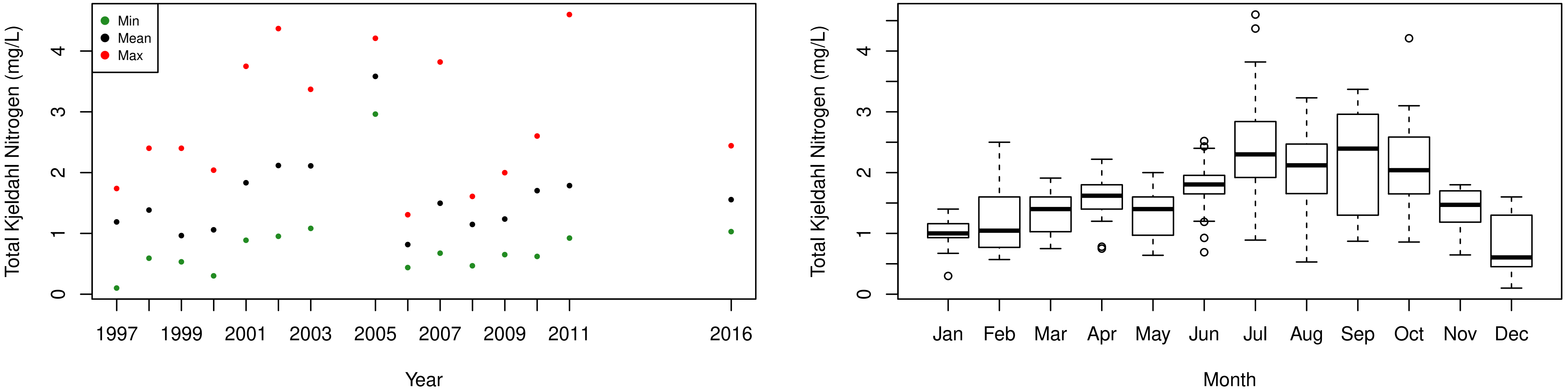
(d) Boxplot by month

Fox River at Rt 176 (23): Total Kjeldahl Nitrogen (mg/L)



(a) Observation data

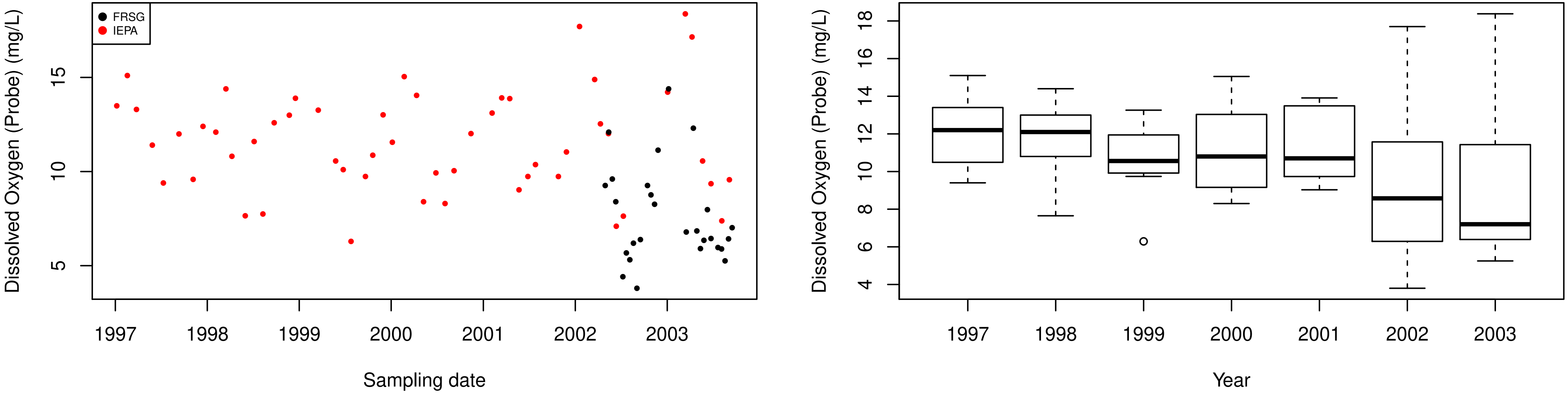
(b) Boxplot by year



(c) Annual values

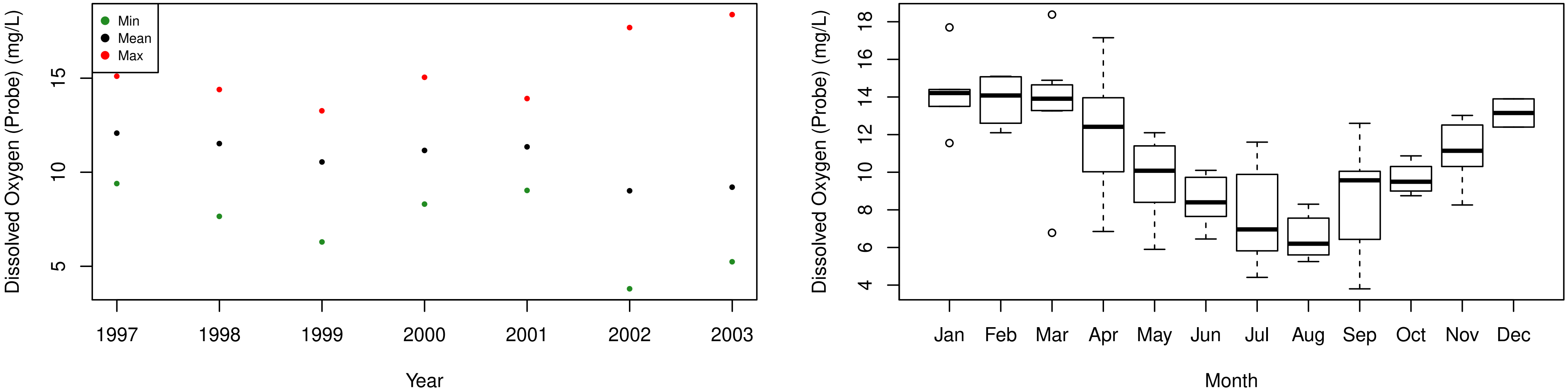
(d) Boxplot by month

Fox River at Rt 176 (23): Dissolved Oxygen (Probe) (mg/L)



(a) Observation data

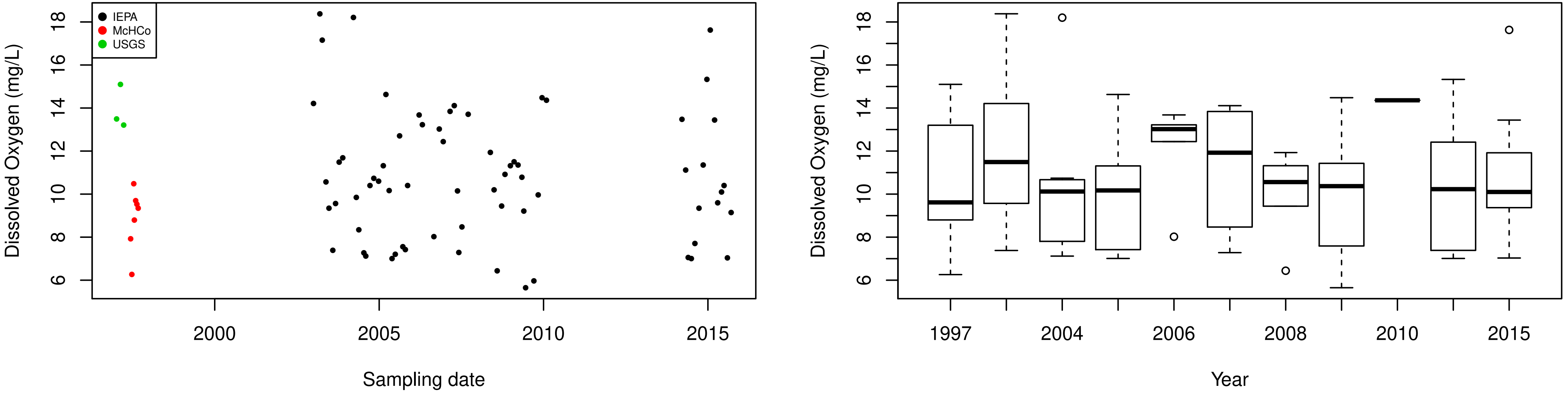
(b) Boxplot by year



(c) Annual values

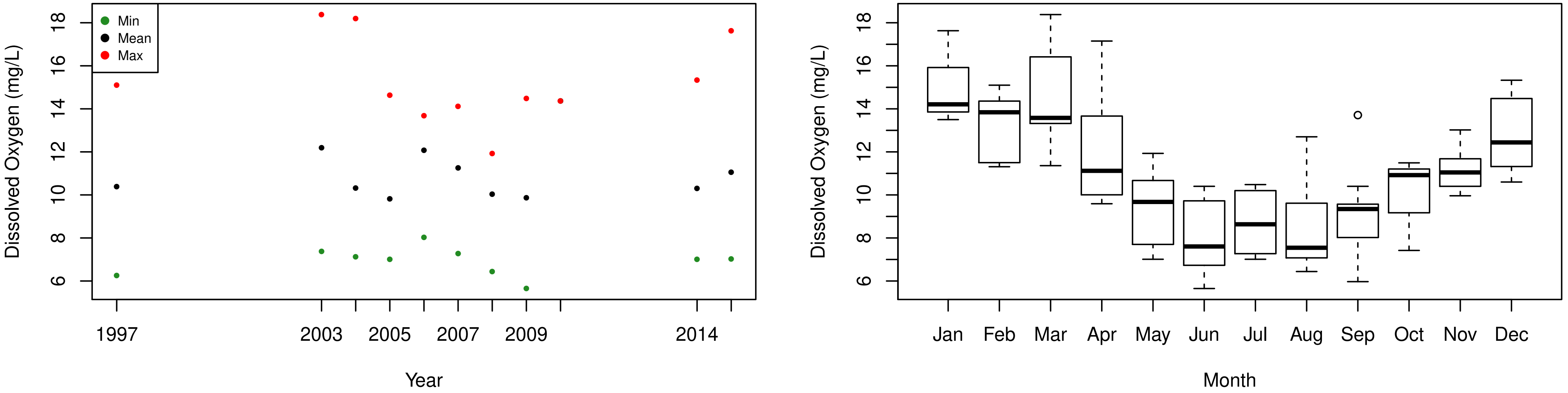
(d) Boxplot by month

Fox River at Rt 176 (23): Dissolved Oxygen (mg/L)



(a) Observation data

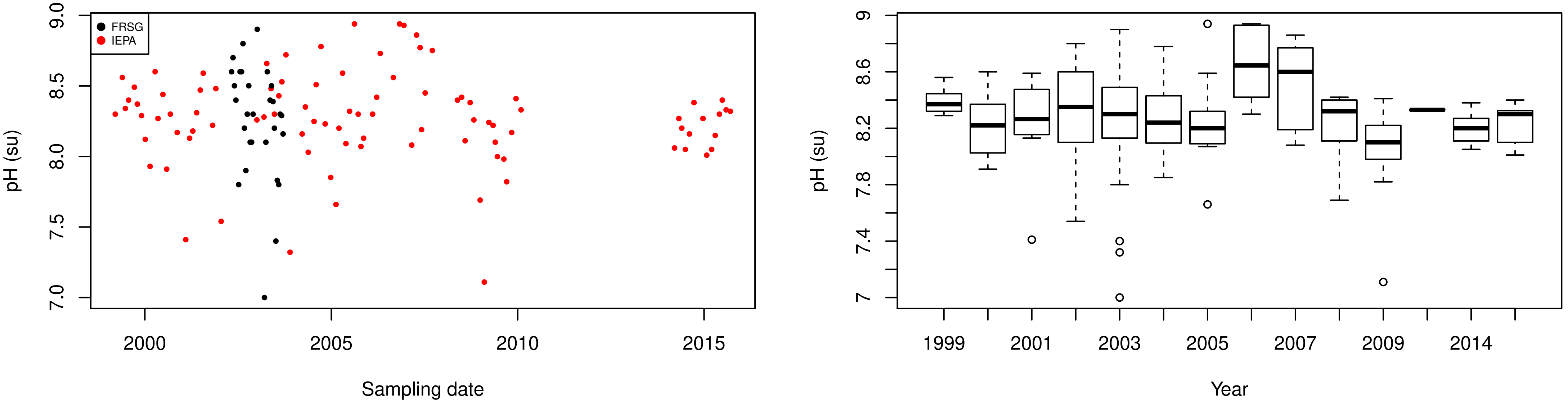
(b) Boxplot by year



(c) Annual values

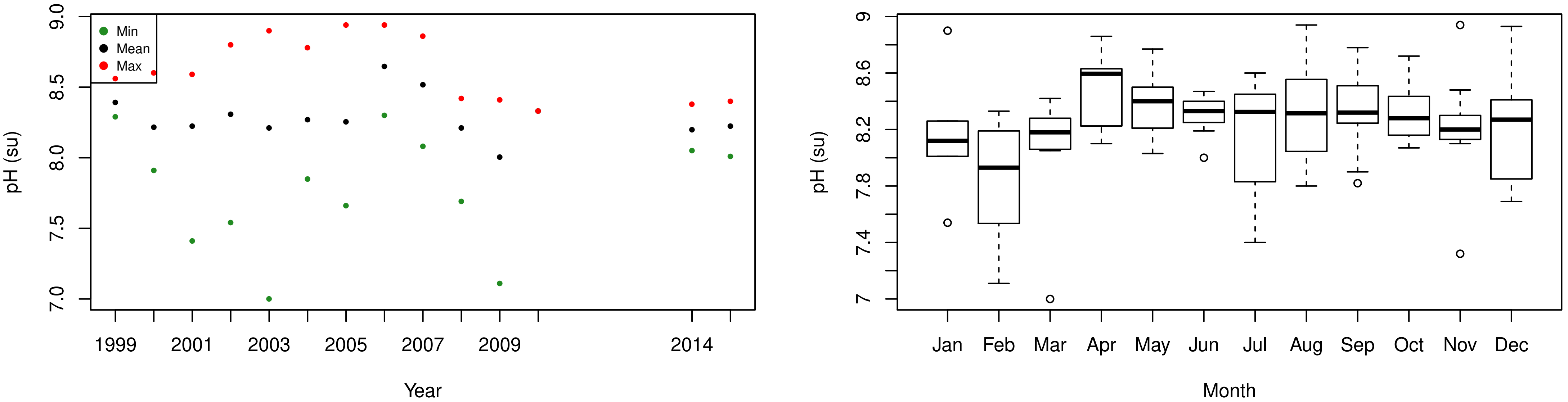
(d) Boxplot by month

Fox River at Rt 176 (23): pH (su)



(a) Observation data

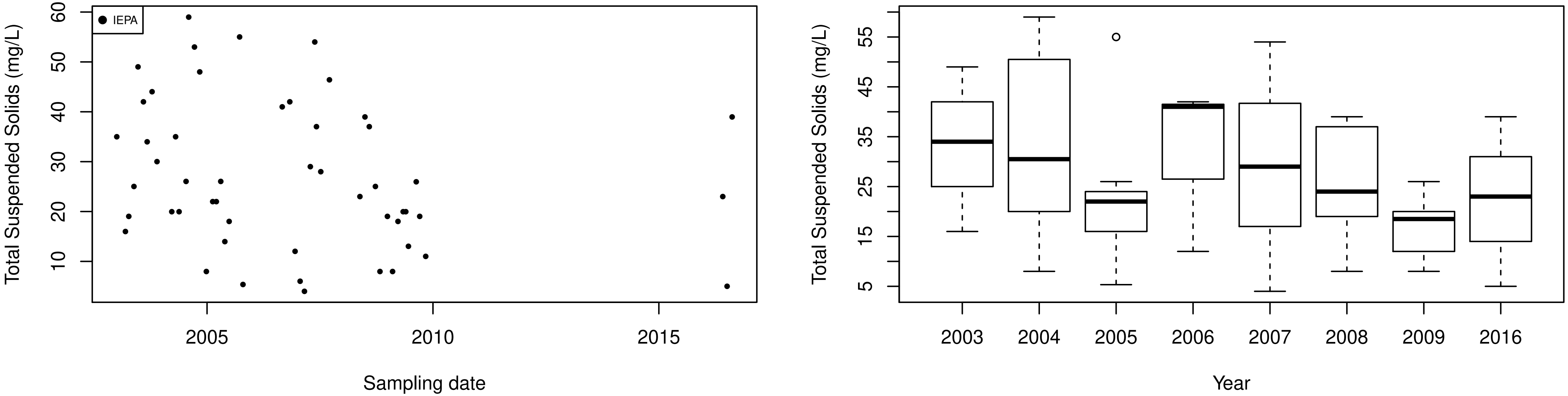
(b) Boxplot by year



(c) Annual values

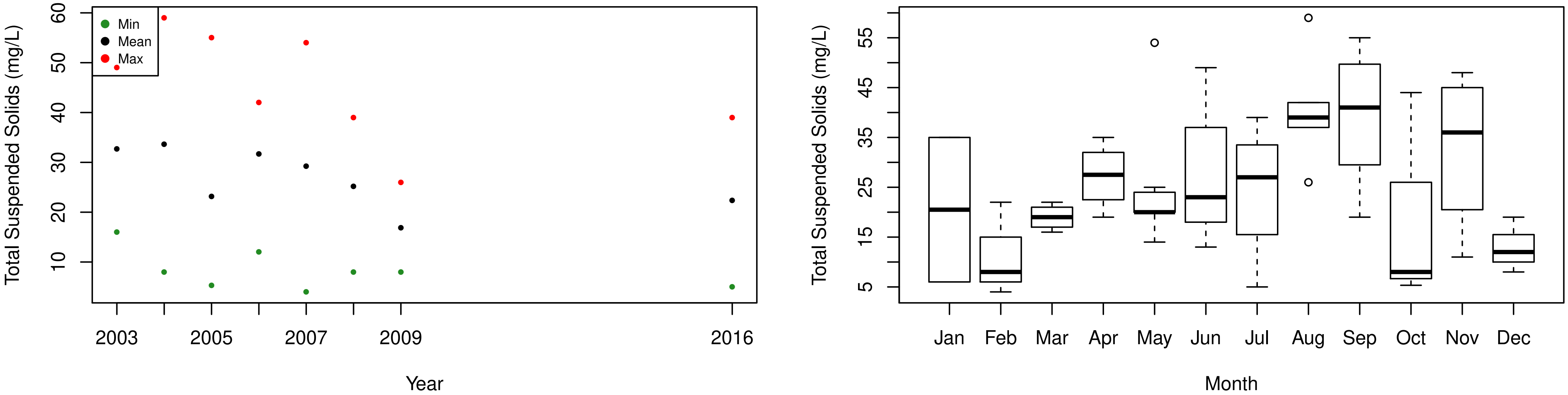
(d) Boxplot by month

Fox River at Rt 176 (23): Total Suspended Solids (mg/L)



(a) Observation data

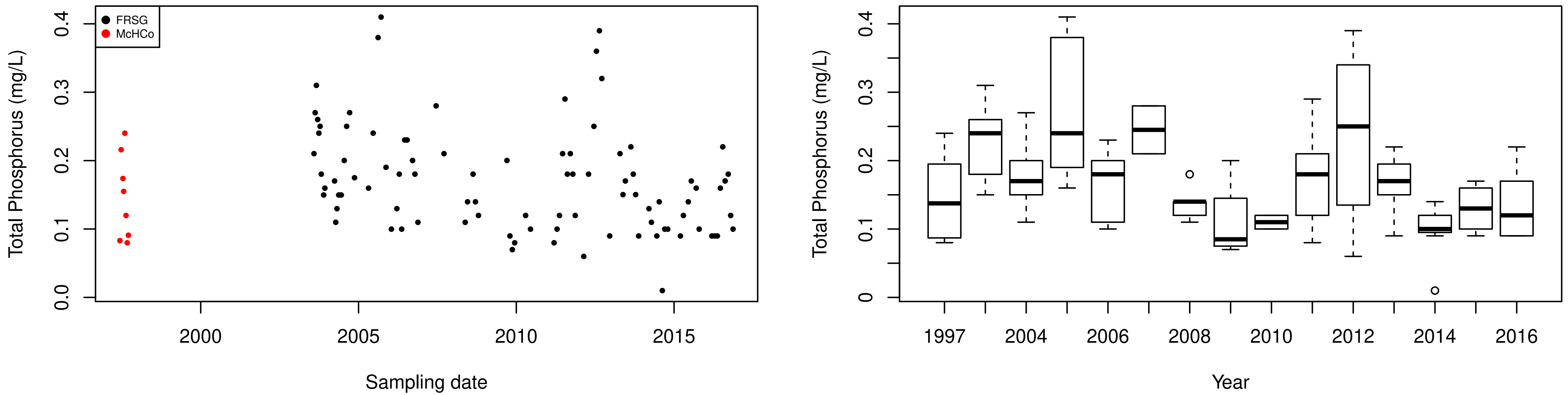
(b) Boxplot by year



(c) Annual values

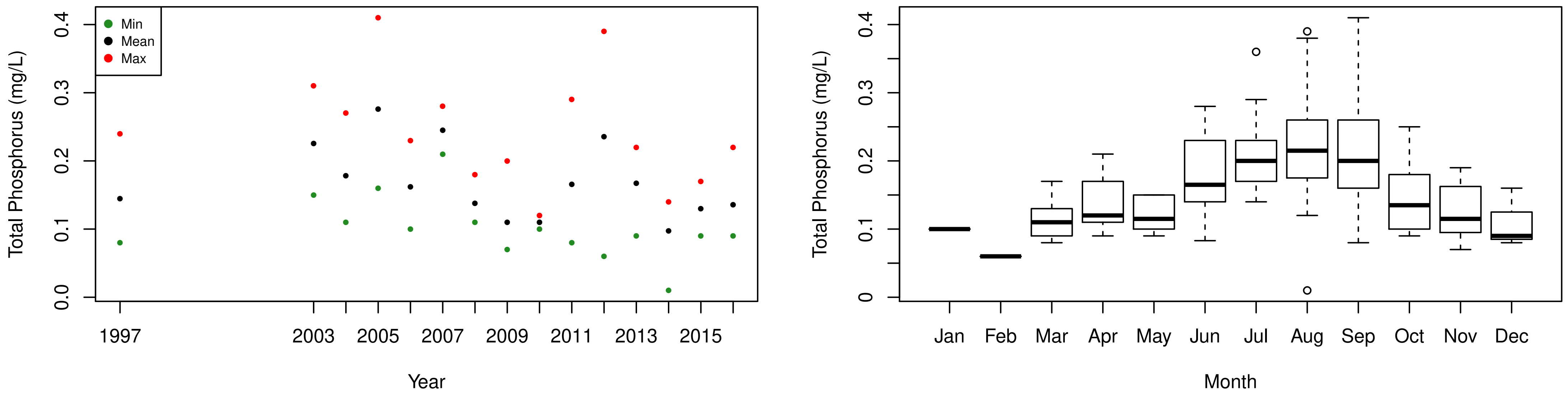
(d) Boxplot by month

Fox River at Oakwood Hills (258): Total Phosphorus (mg/L)



(a) Observation data

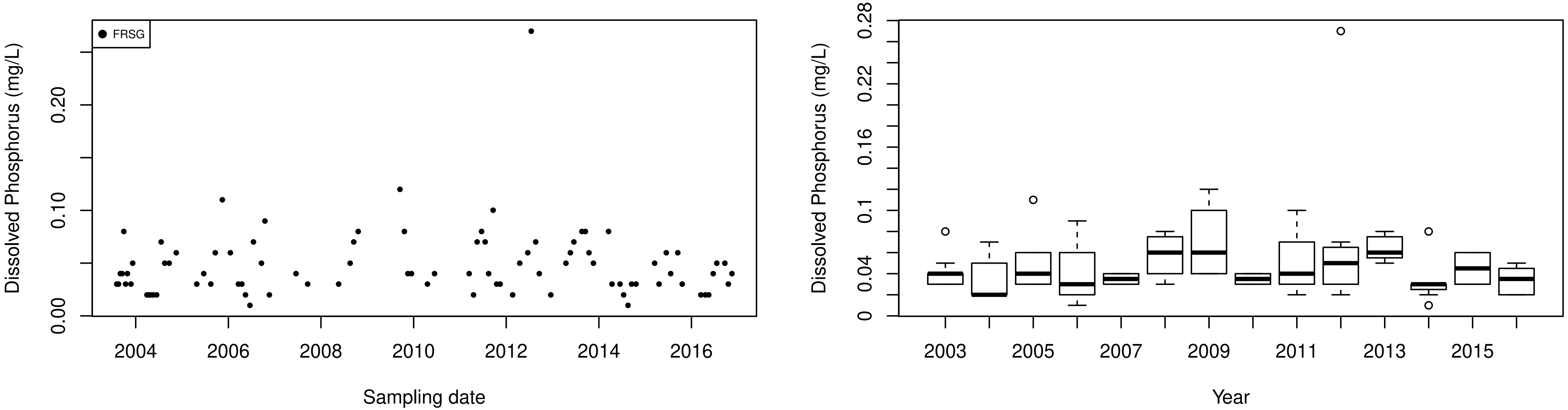
(b) Boxplot by year



(c) Annual values

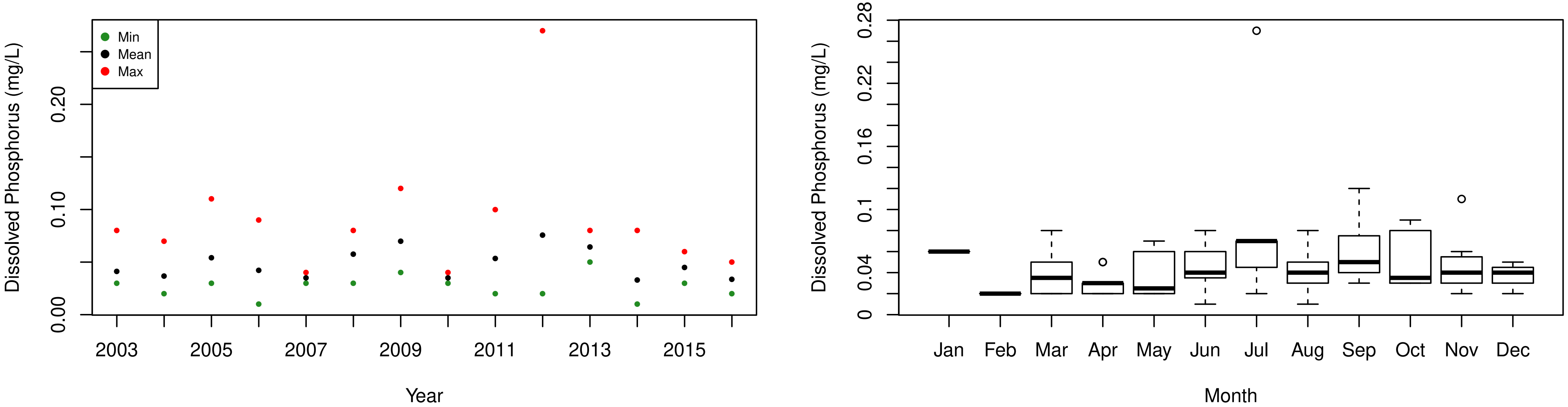
(d) Boxplot by month

Fox River at Oakwood Hills (258): Dissolved Phosphorus (mg/L)



(a) Observation data

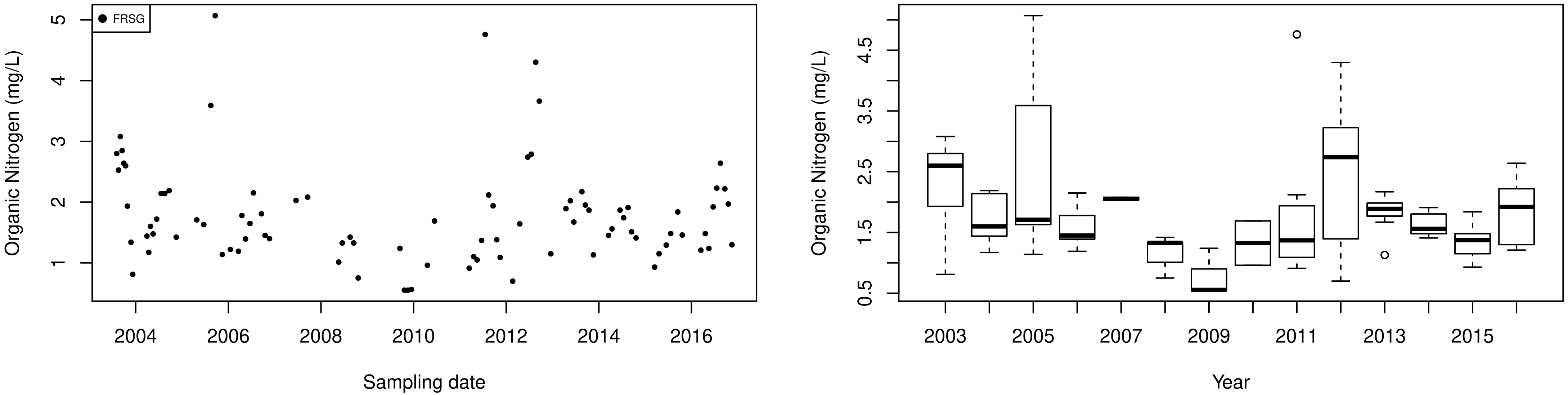
(b) Boxplot by year



(c) Annual values

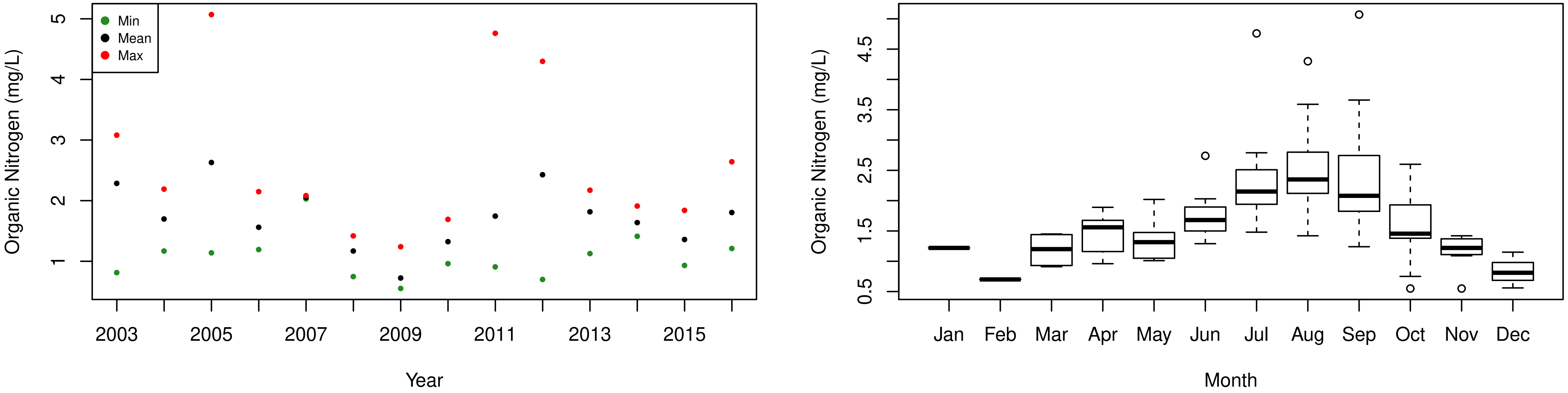
(d) Boxplot by month

Fox River at Oakwood Hills (258): Organic Nitrogen (mg/L)



(a) Observation data

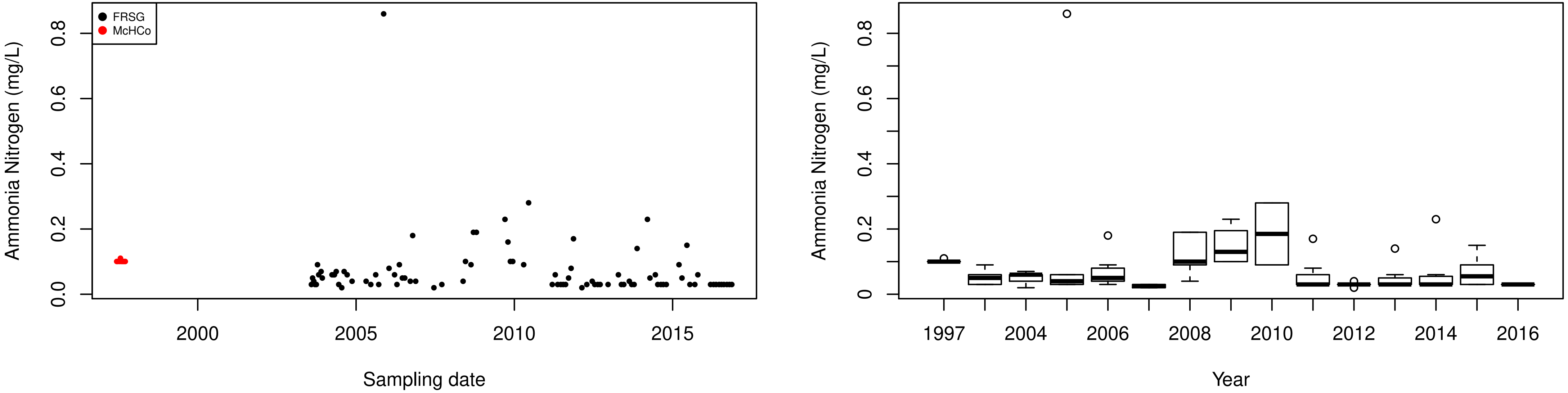
(b) Boxplot by year



(c) Annual values

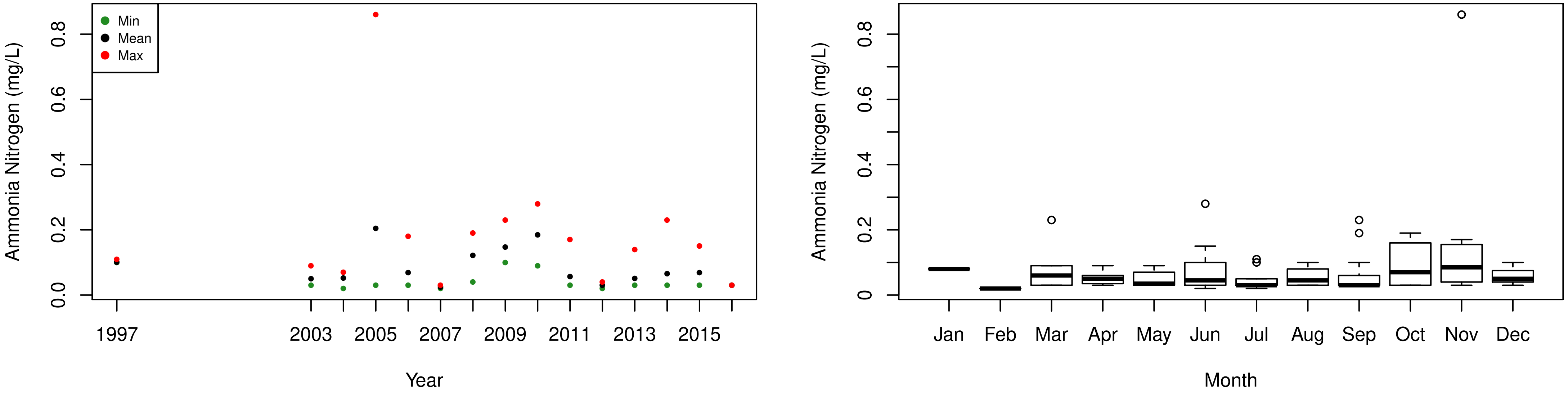
(d) Boxplot by month

Fox River at Oakwood Hills (258): Ammonia Nitrogen (mg/L)



(a) Observation data

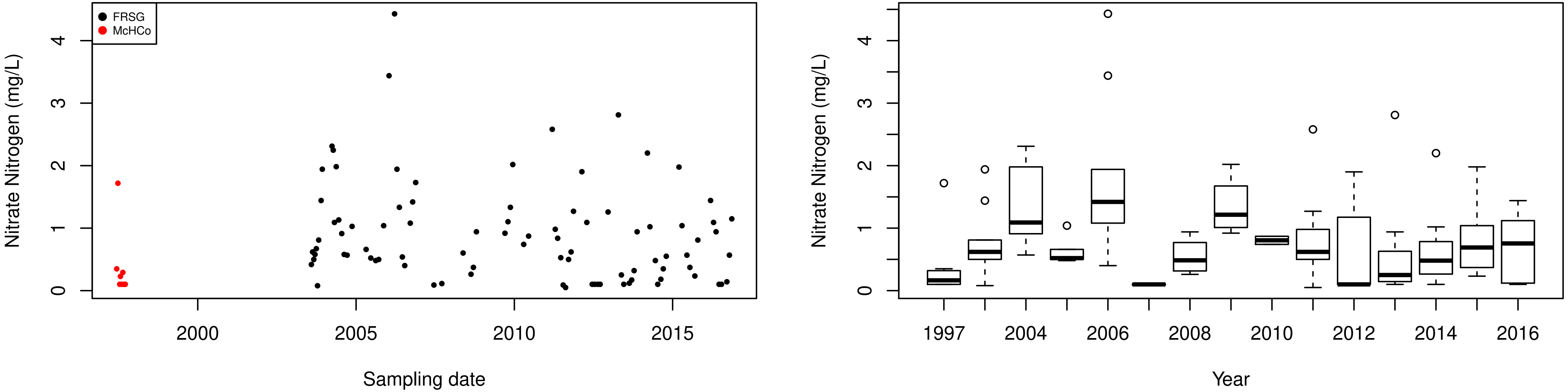
(b) Boxplot by year



(c) Annual values

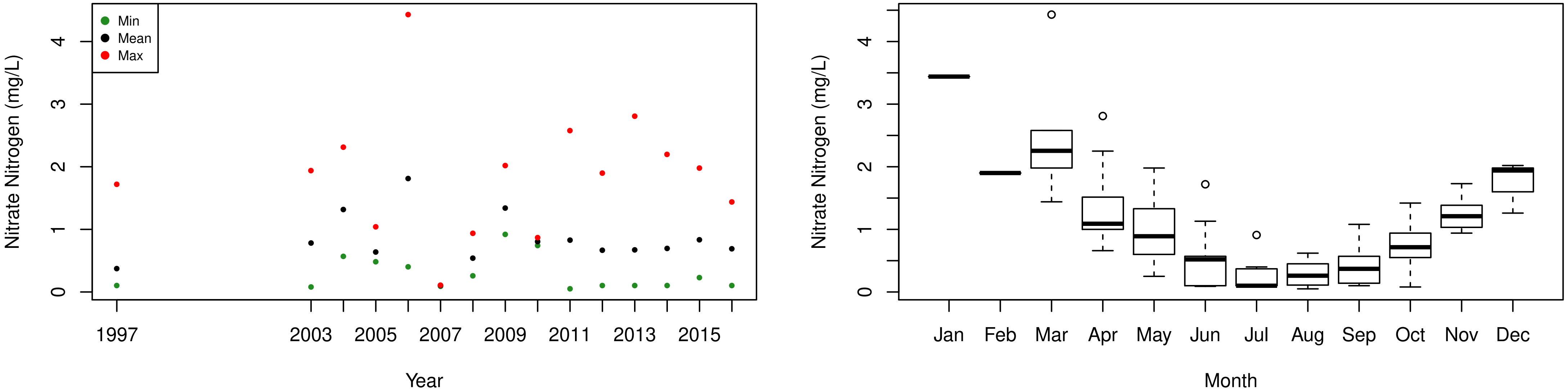
(d) Boxplot by month

Fox River at Oakwood Hills (258): Nitrate Nitrogen (mg/L)



(a) Observation data

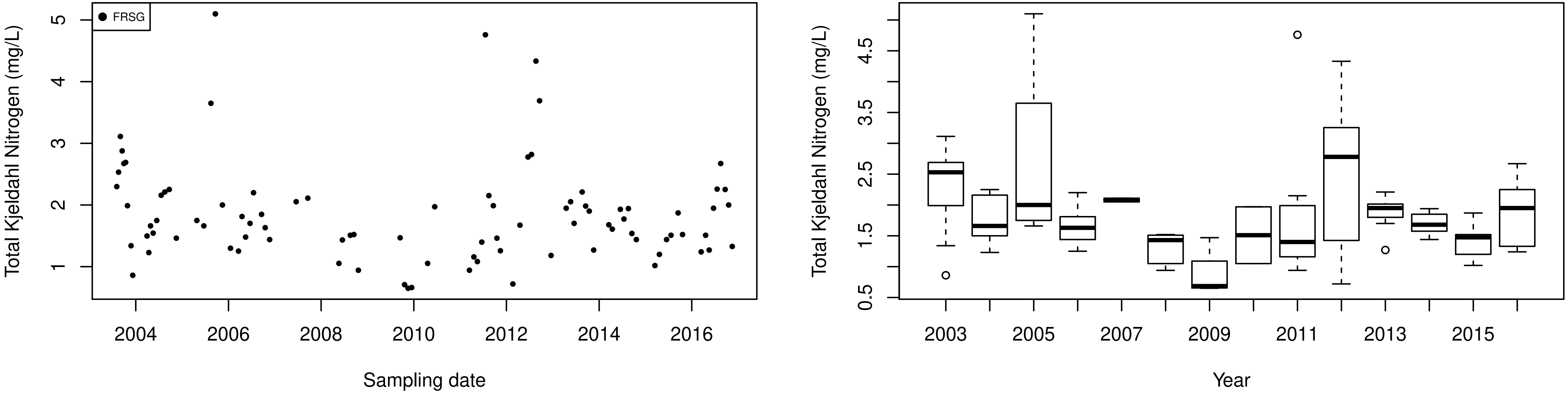
(b) Boxplot by year



(c) Annual values

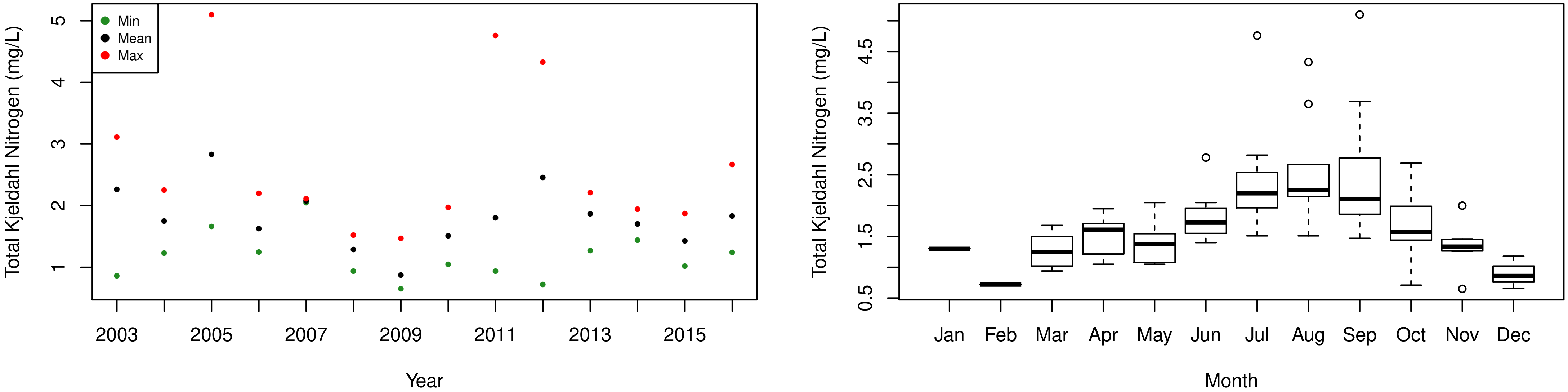
(d) Boxplot by month

Fox River at Oakwood Hills (258): Total Kjeldahl Nitrogen (mg/L)



(a) Observation data

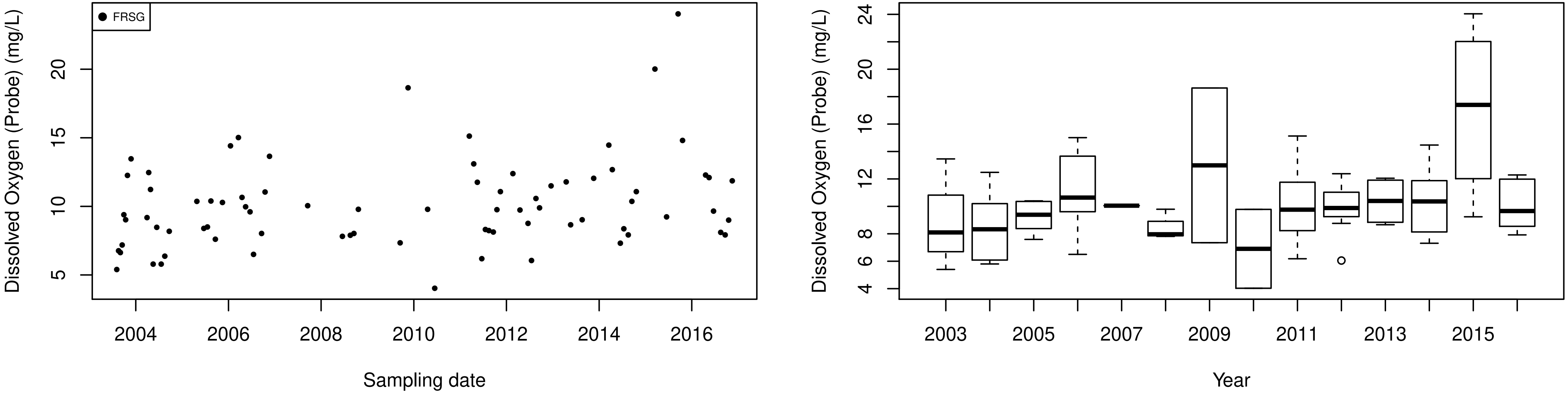
(b) Boxplot by year



(c) Annual values

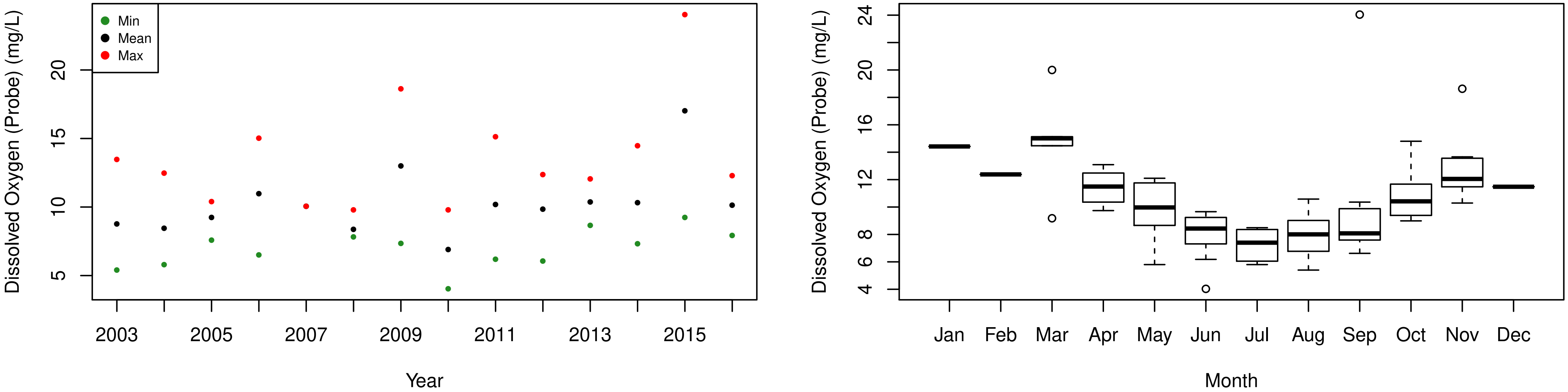
(d) Boxplot by month

Fox River at Oakwood Hills (258): Dissolved Oxygen (Probe) (mg/L)



(a) Observation data

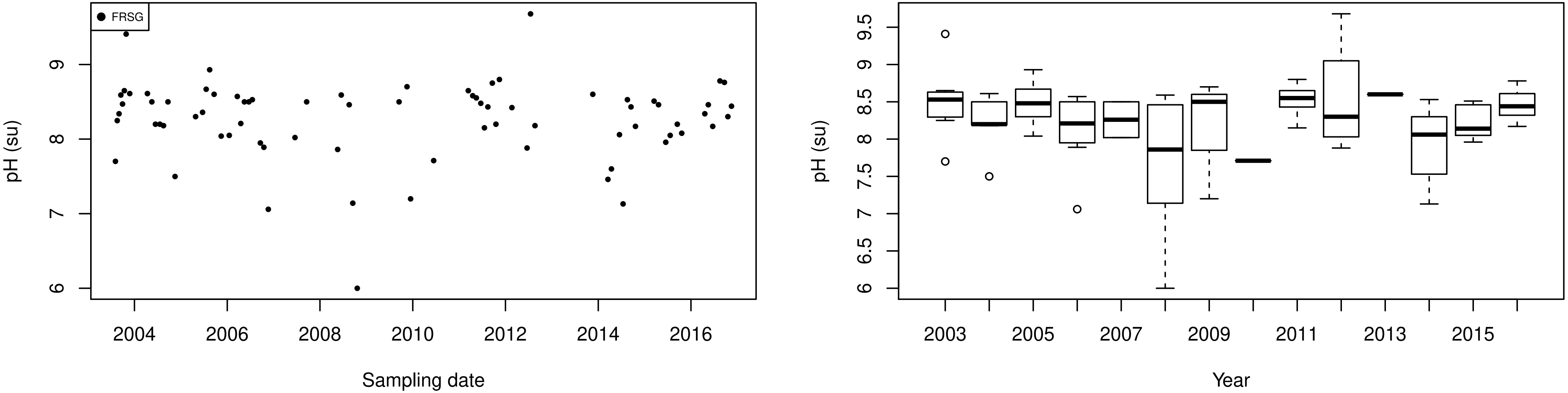
(b) Boxplot by year



(c) Annual values

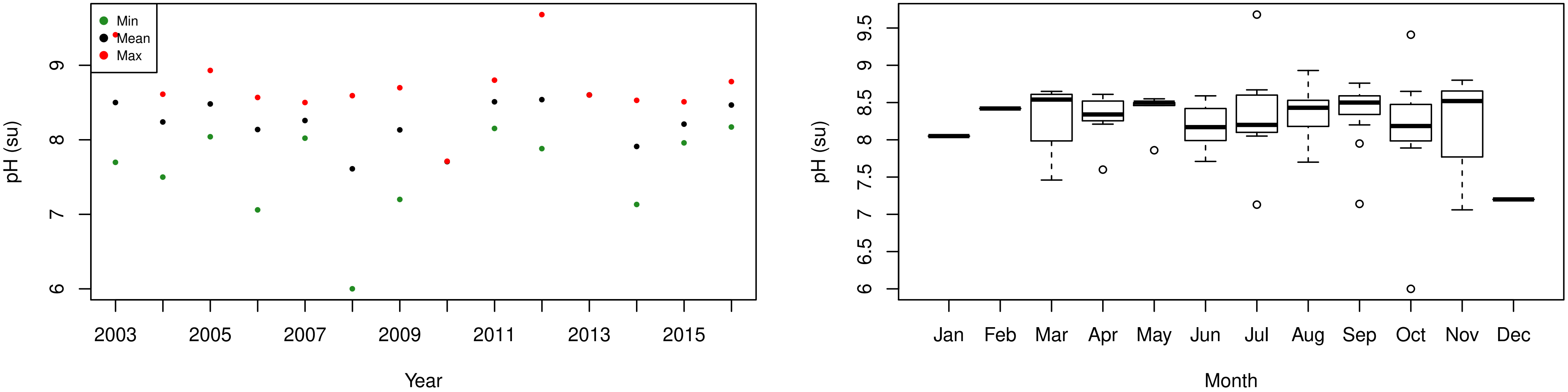
(d) Boxplot by month

Fox River at Oakwood Hills (258): pH (su)



(a) Observation data

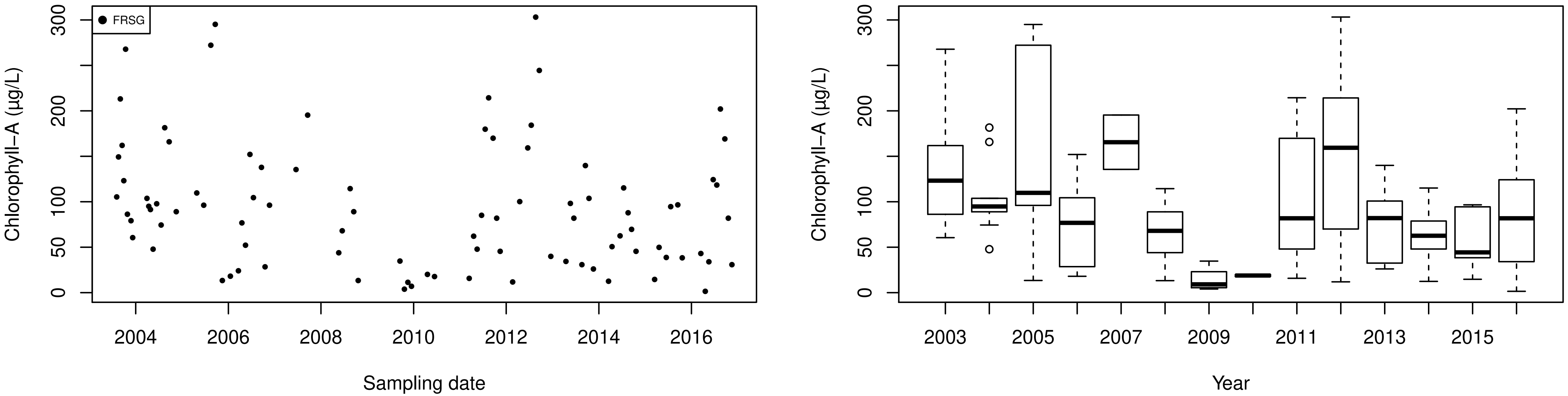
(b) Boxplot by year



(c) Annual values

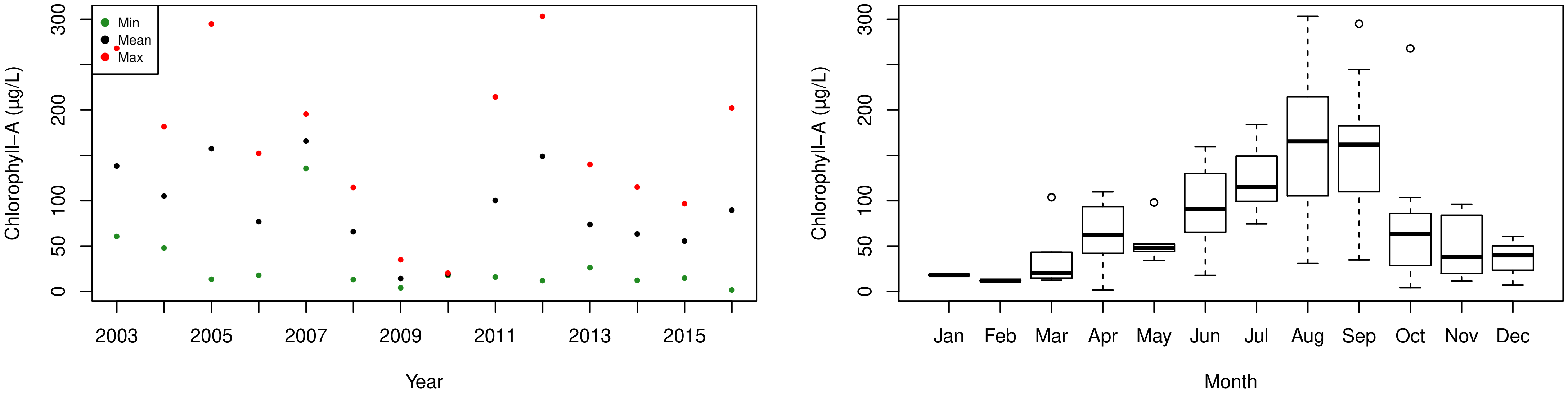
(d) Boxplot by month

Fox River at Oakwood Hills (258): Chlorophyll−A (µg/L)



(a) Observation data

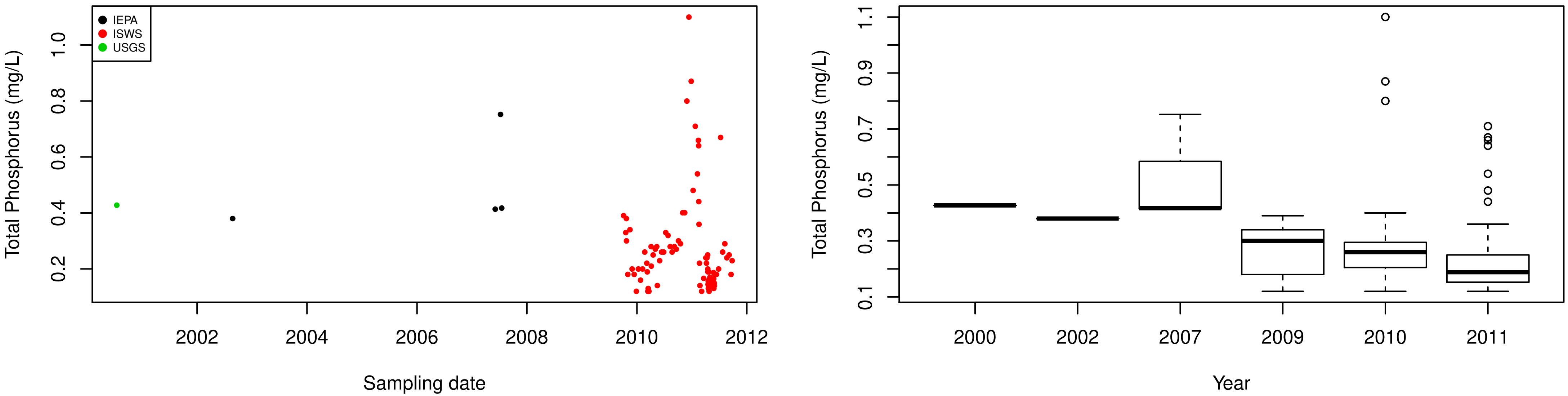
(b) Boxplot by year



(c) Annual values

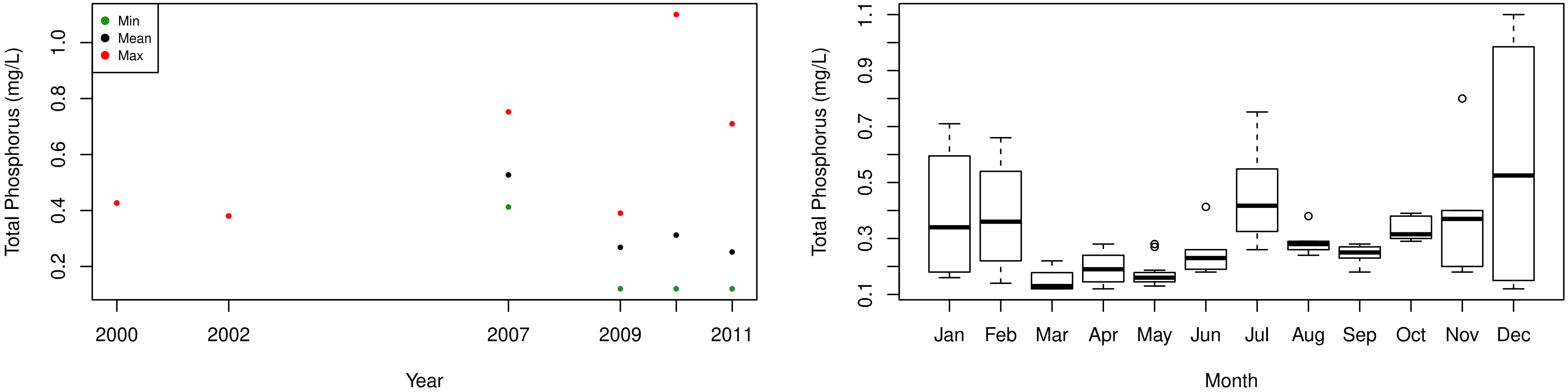
(d) Boxplot by month

Flint Cr at Kelsey Rd–Lk Barrington (4): Total Phosphorus (mg/L)



(a) Observation data

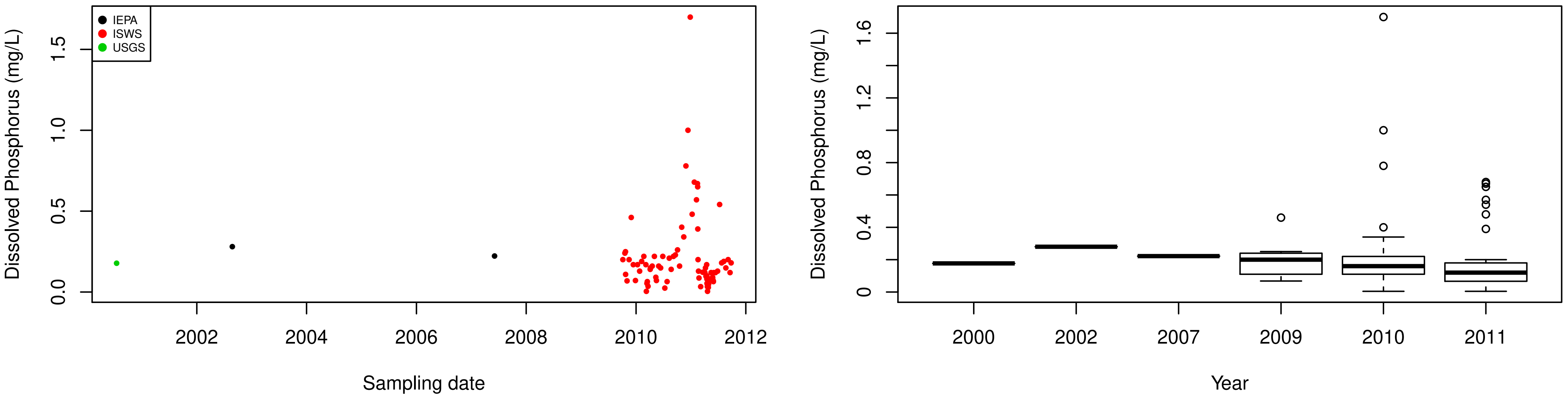
(b) Boxplot by year



(c) Annual values

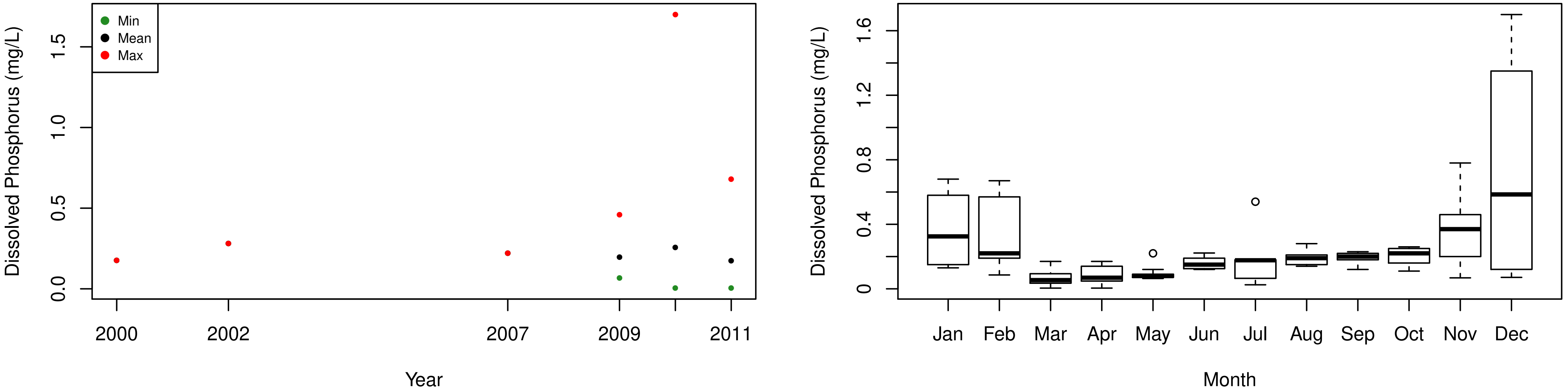
(d) Boxplot by month

Flint Cr at Kelsey Rd–Lk Barrington (4): Dissolved Phosphorus (mg/L)



(a) Observation data

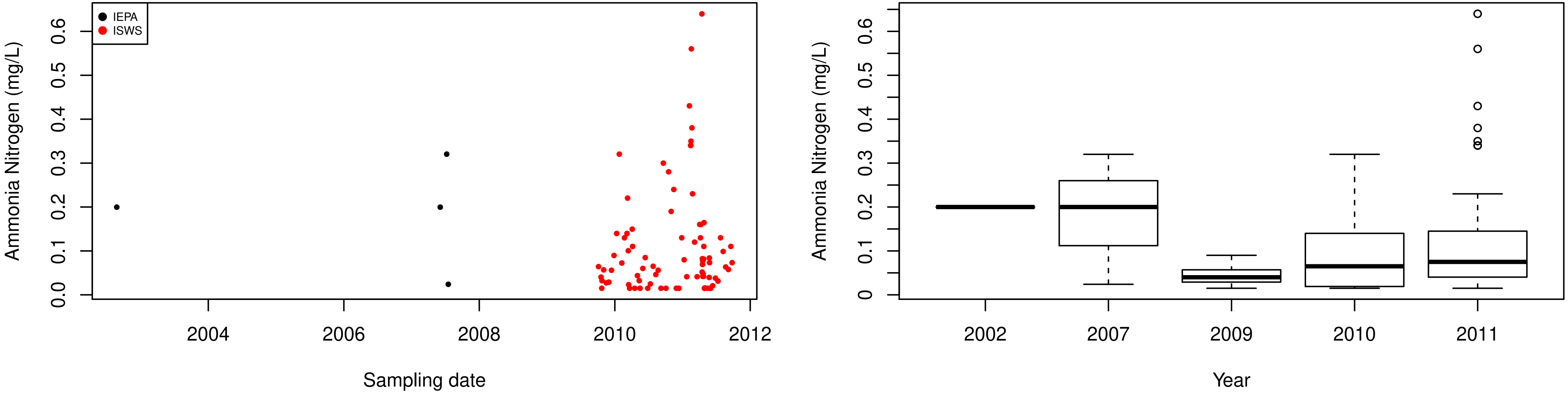
(b) Boxplot by year



(c) Annual values

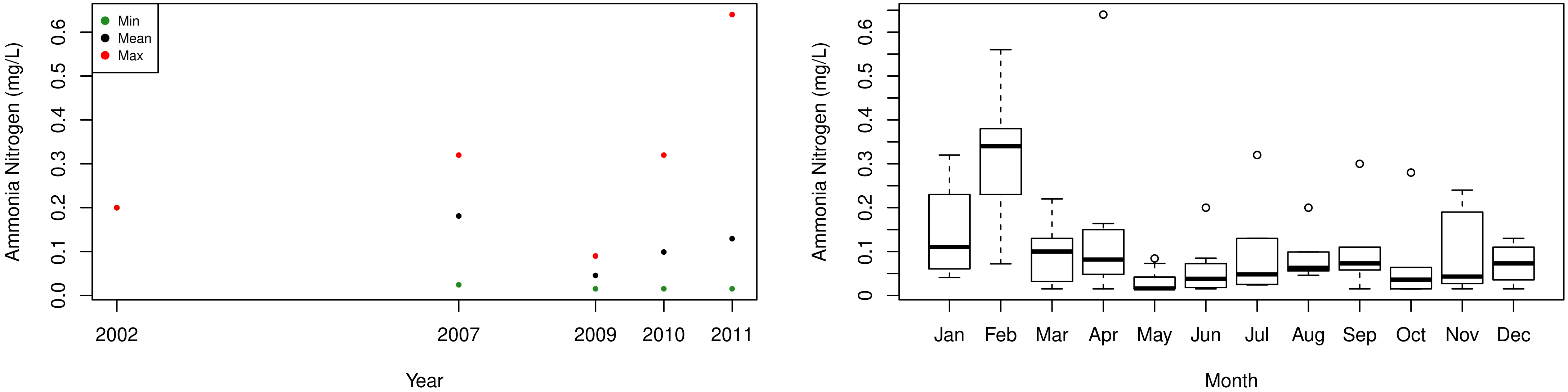
(d) Boxplot by month

Flint Cr at Kelsey Rd–Lk Barrington (4): Ammonia Nitrogen (mg/L)



(a) Observation data

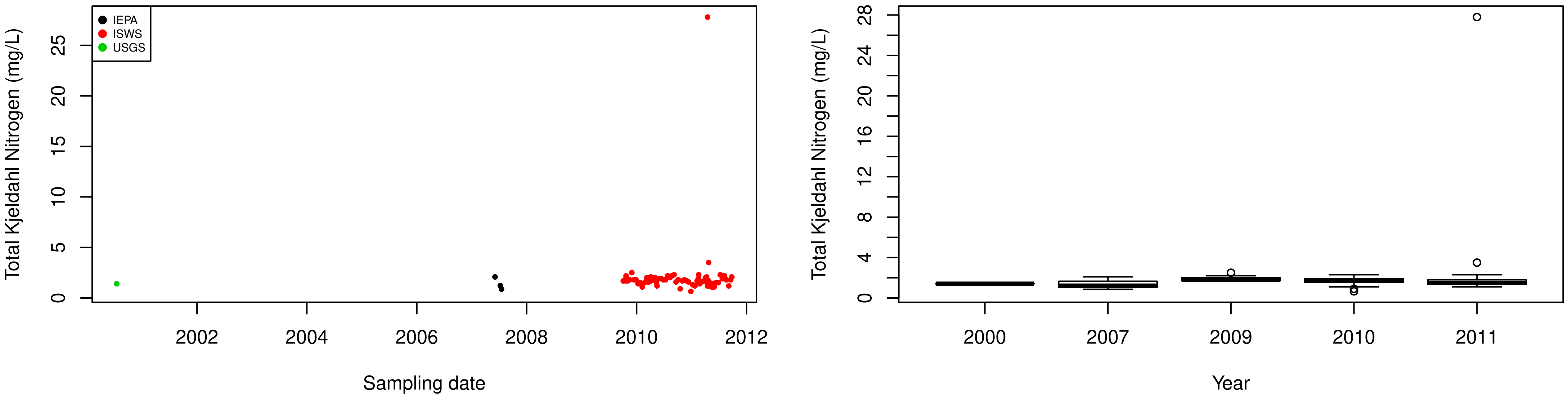
(b) Boxplot by year



(c) Annual values

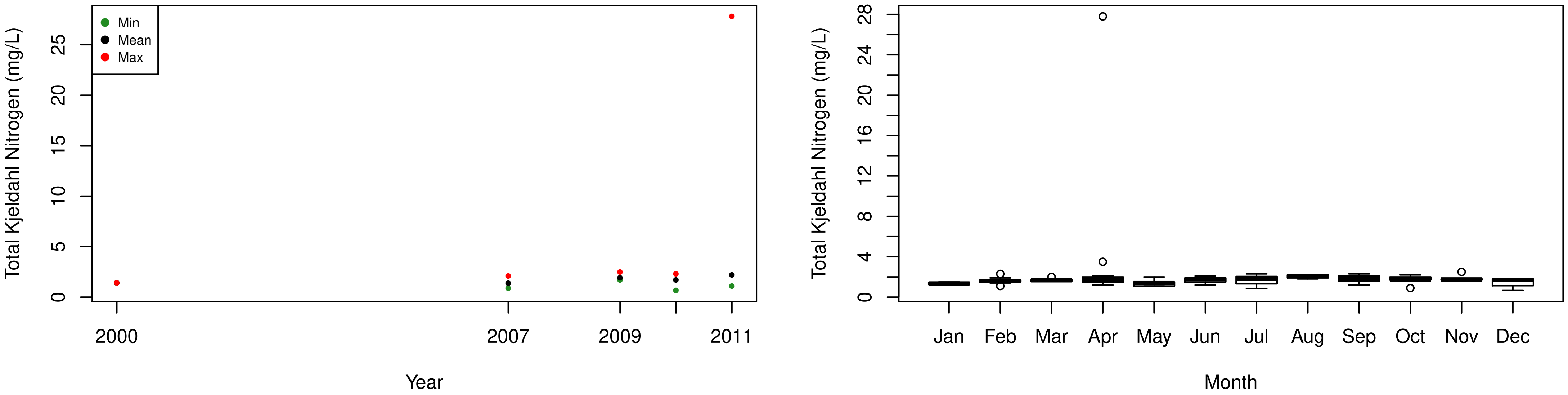
(d) Boxplot by month

Flint Cr at Kelsey Rd–Lk Barrington (4): Total Kjeldahl Nitrogen (mg/L)



(a) Observation data

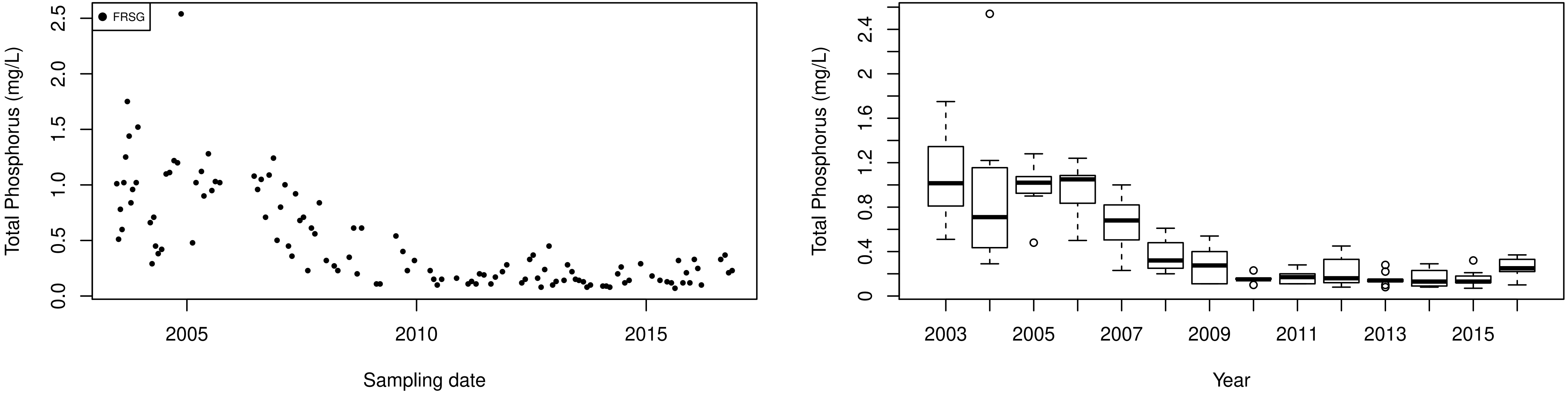
(b) Boxplot by year



(c) Annual values

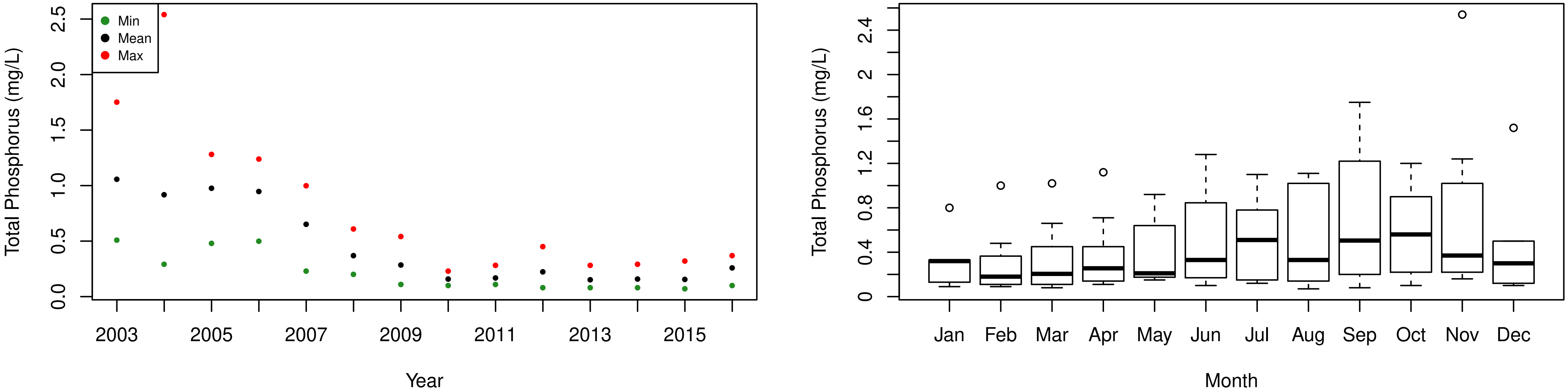
(d) Boxplot by month

Crystal Cr at Rt 31 (271): Total Phosphorus (mg/L)



(a) Observation data

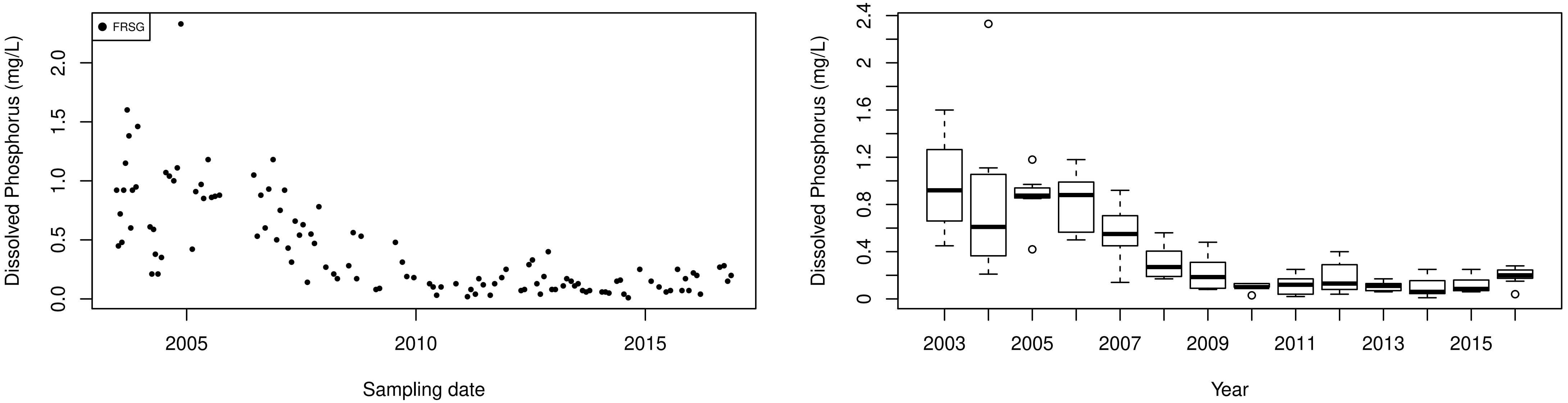
(b) Boxplot by year



(c) Annual values

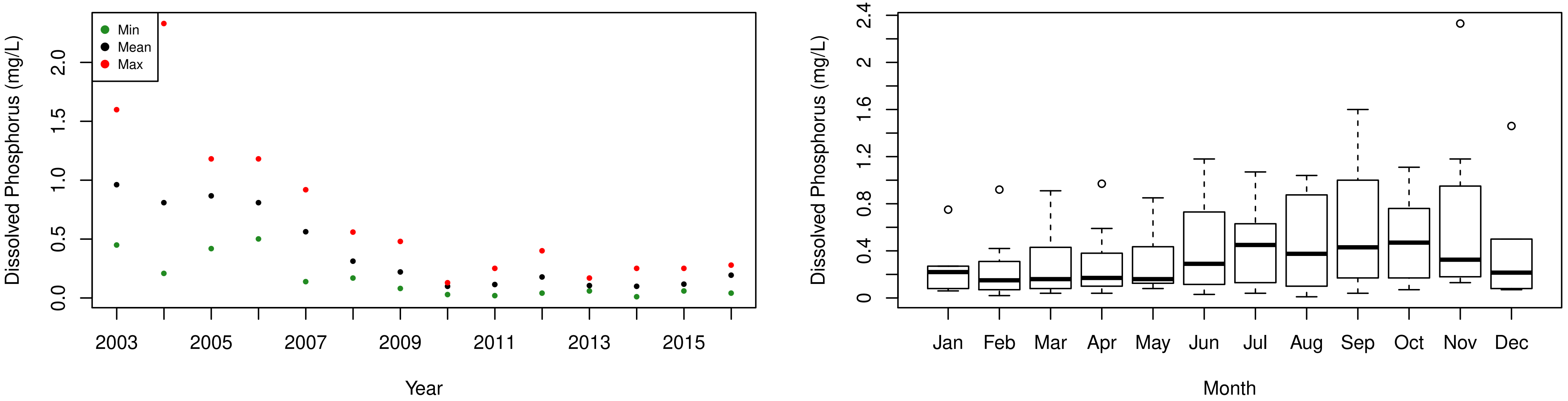
(d) Boxplot by month

Crystal Cr at Rt 31 (271): Dissolved Phosphorus (mg/L)



(a) Observation data

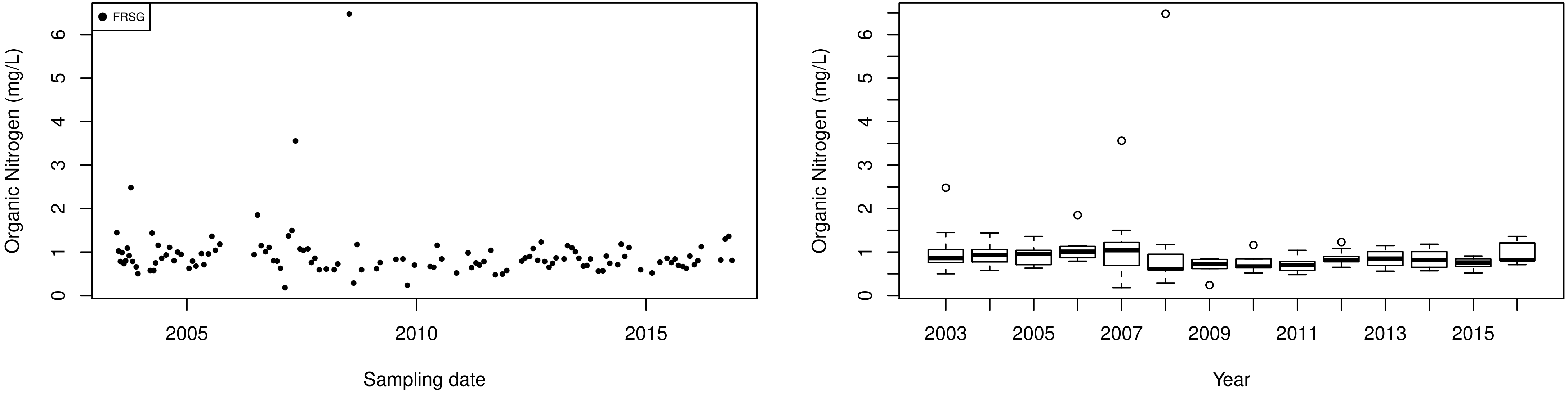
(b) Boxplot by year



(c) Annual values

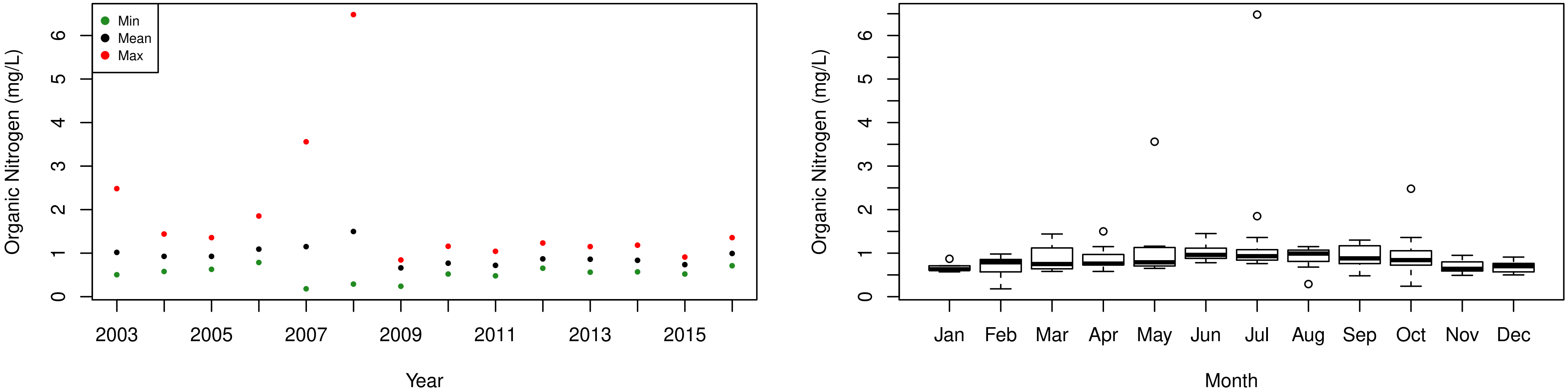
(d) Boxplot by month

Crystal Cr at Rt 31 (271): Organic Nitrogen (mg/L)



(a) Observation data

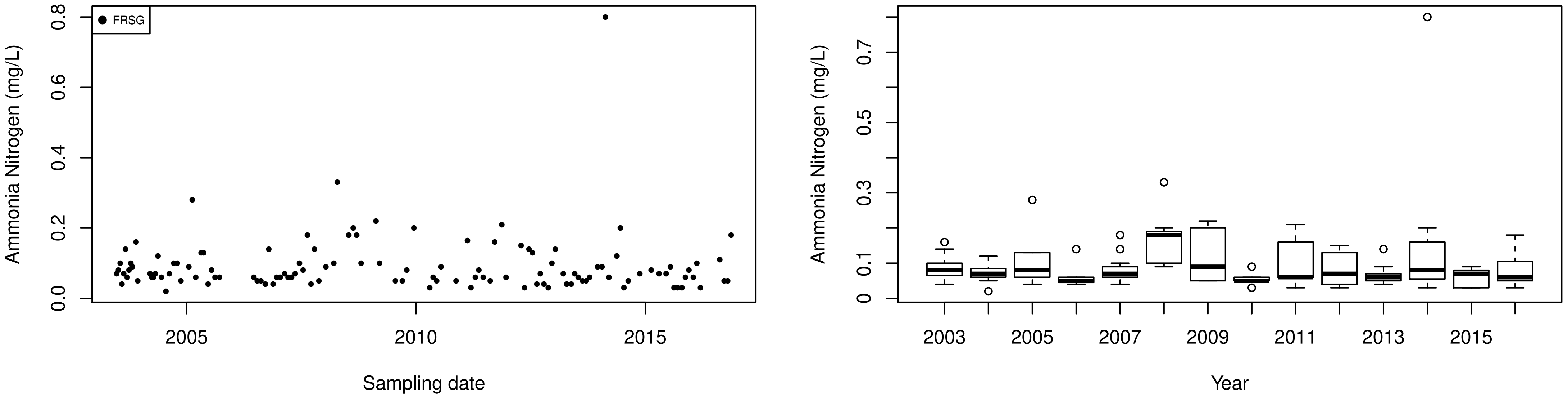
(b) Boxplot by year



(c) Annual values

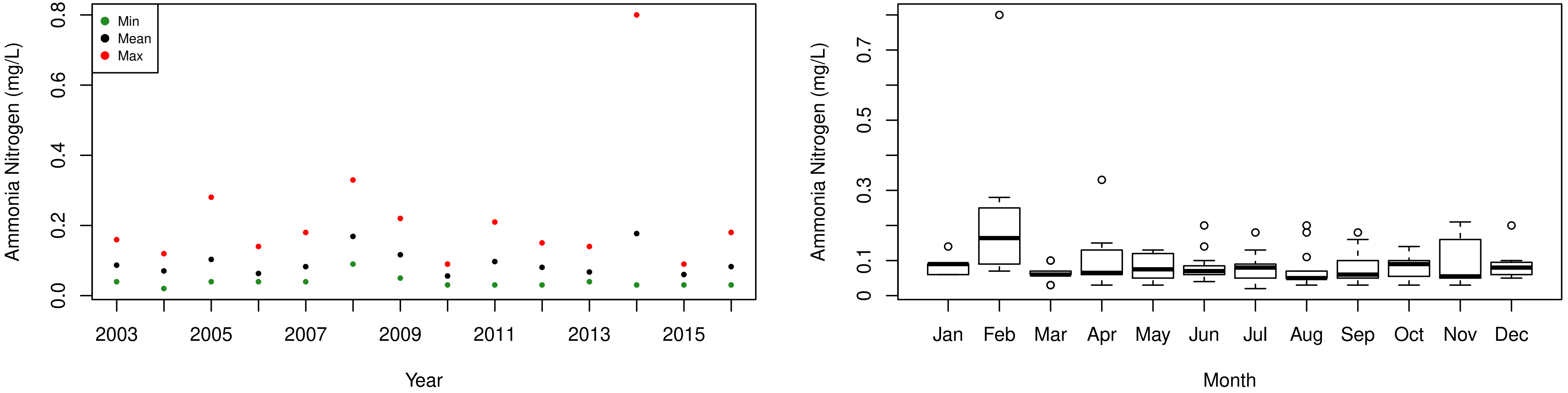
(d) Boxplot by month

Crystal Cr at Rt 31 (271): Ammonia Nitrogen (mg/L)



(a) Observation data

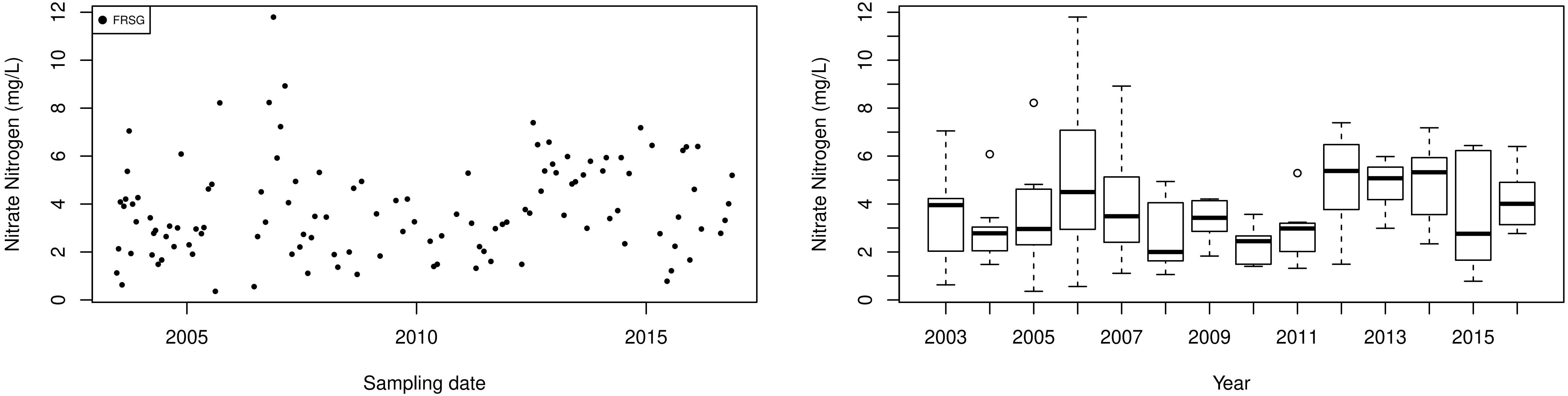
(b) Boxplot by year



(c) Annual values

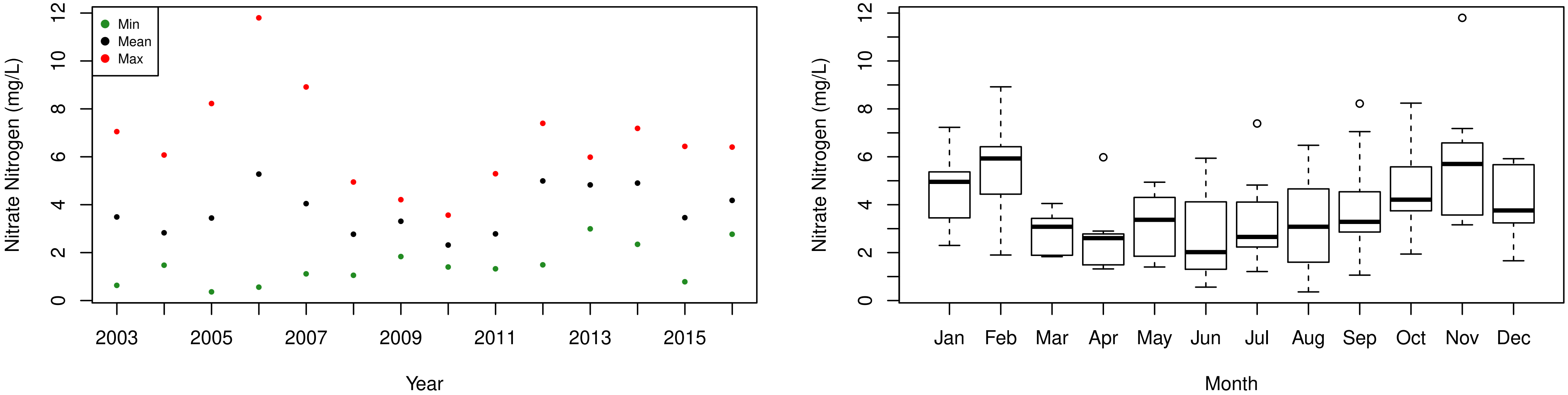
(d) Boxplot by month

Crystal Cr at Rt 31 (271): Nitrate Nitrogen (mg/L)



(a) Observation data

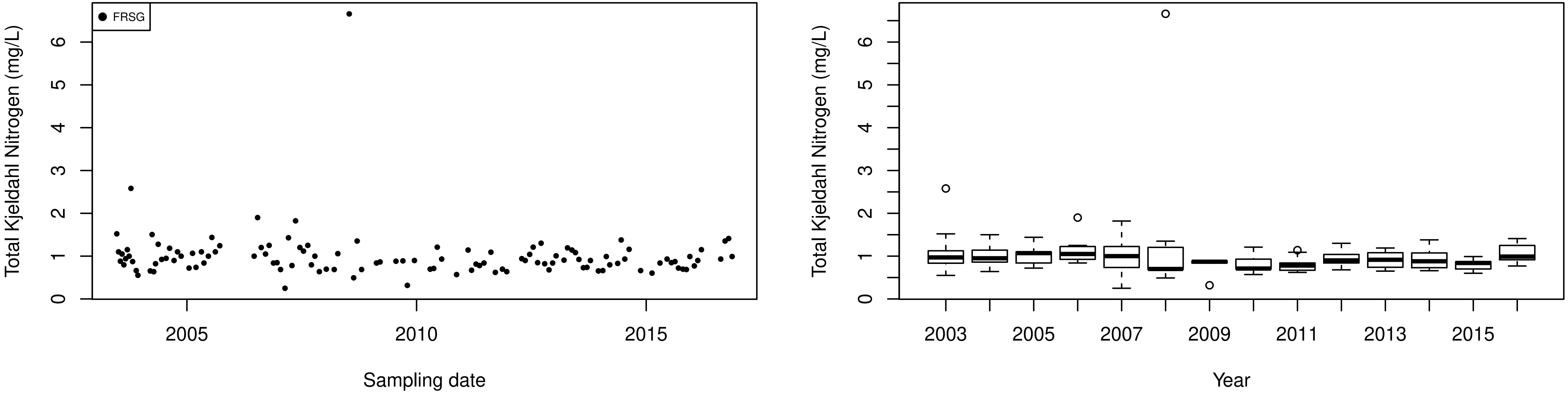
(b) Boxplot by year



(c) Annual values

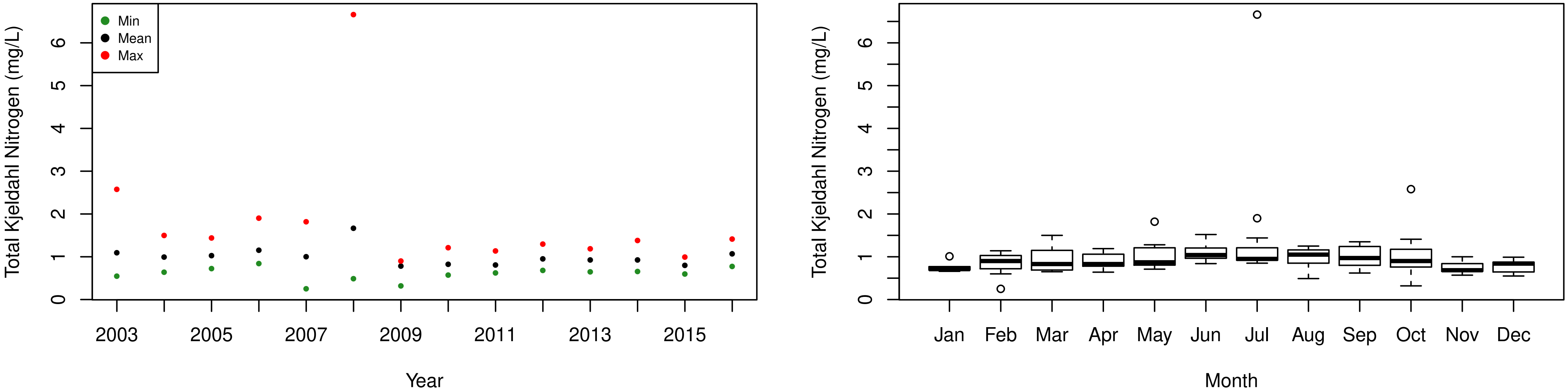
(d) Boxplot by month

Crystal Cr at Rt 31 (271): Total Kjeldahl Nitrogen (mg/L)



(a) Observation data

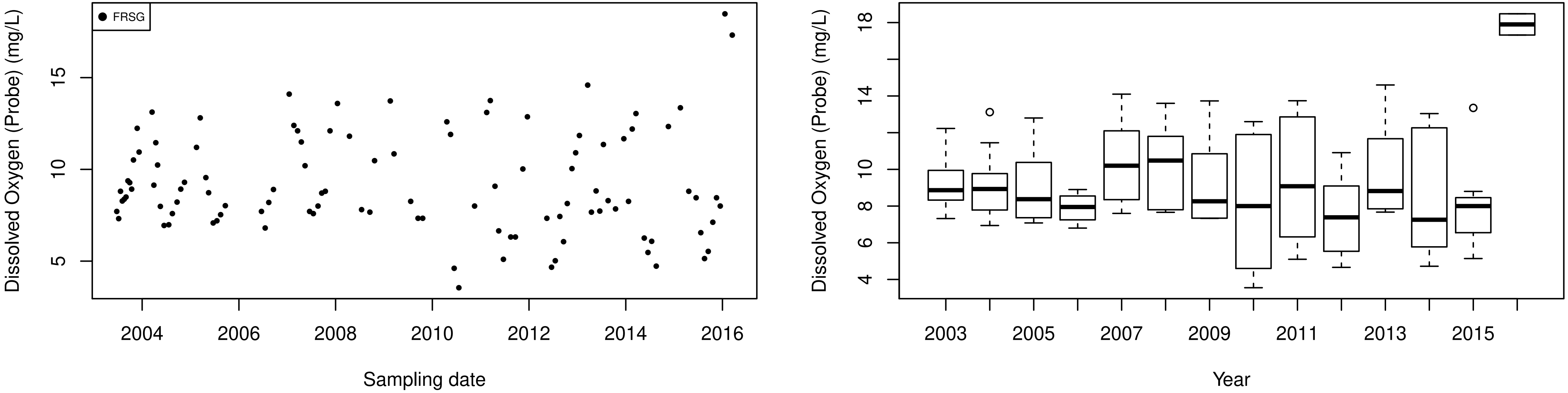
(b) Boxplot by year



(c) Annual values

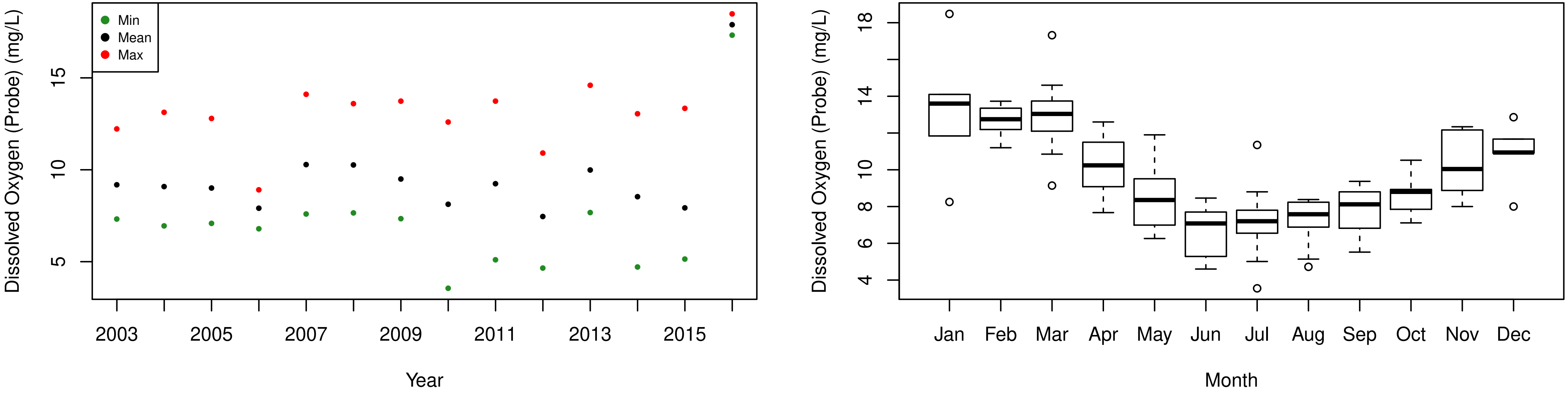
(d) Boxplot by month

Crystal Cr at Rt 31 (271): Dissolved Oxygen (Probe) (mg/L)



(a) Observation data

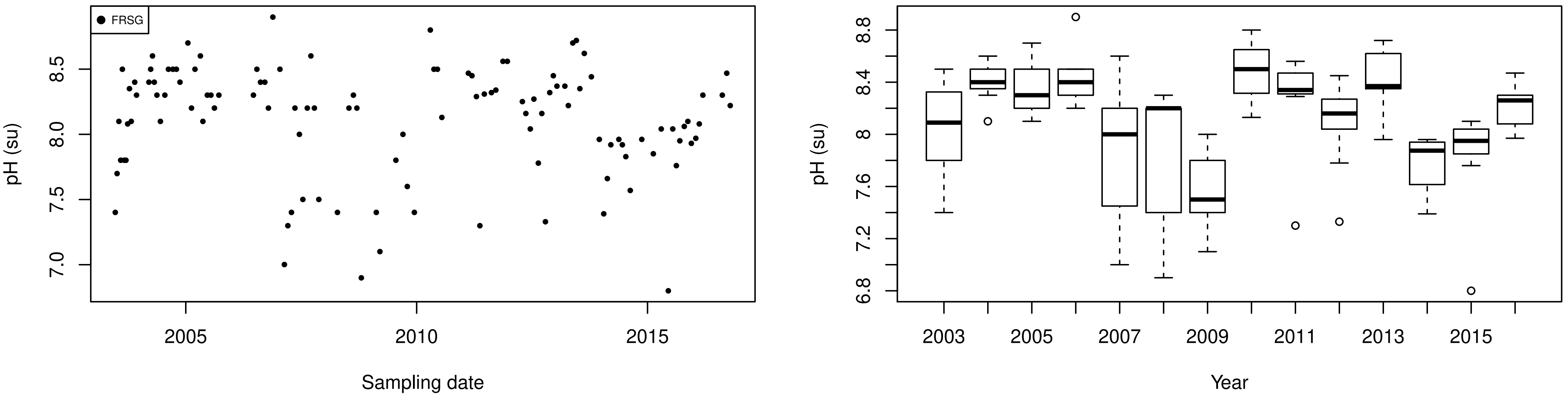
(b) Boxplot by year



(c) Annual values

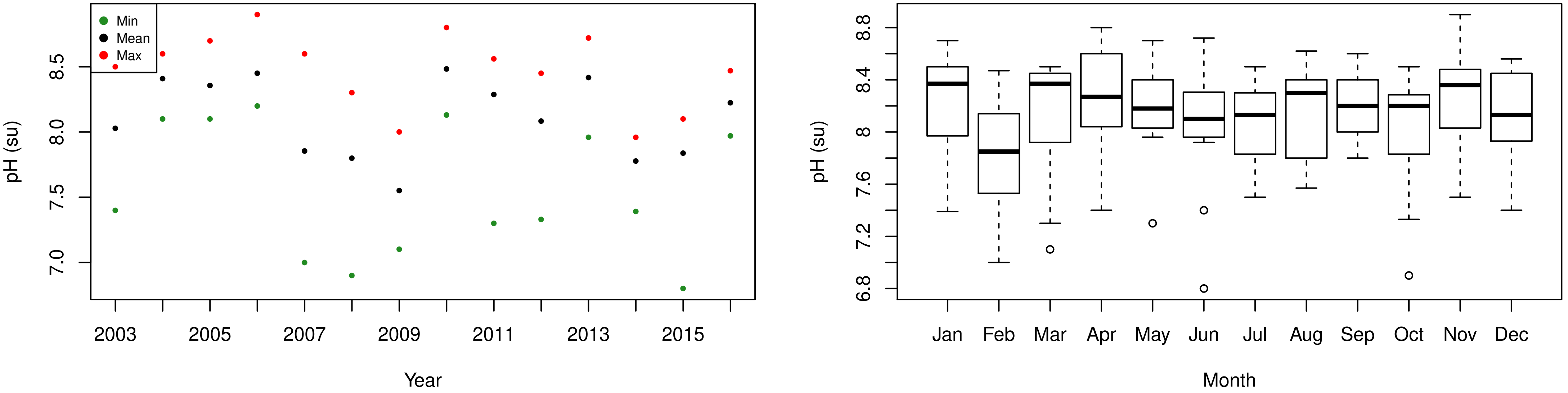
(d) Boxplot by month

Crystal Cr at Rt 31 (271): pH (su)



(a) Observation data

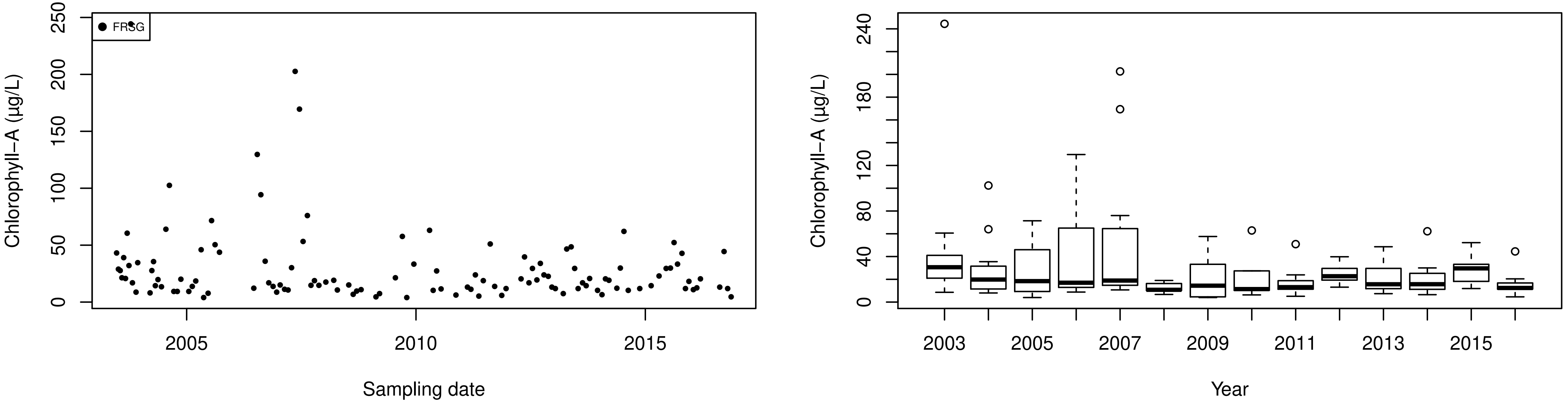
(b) Boxplot by year



(c) Annual values

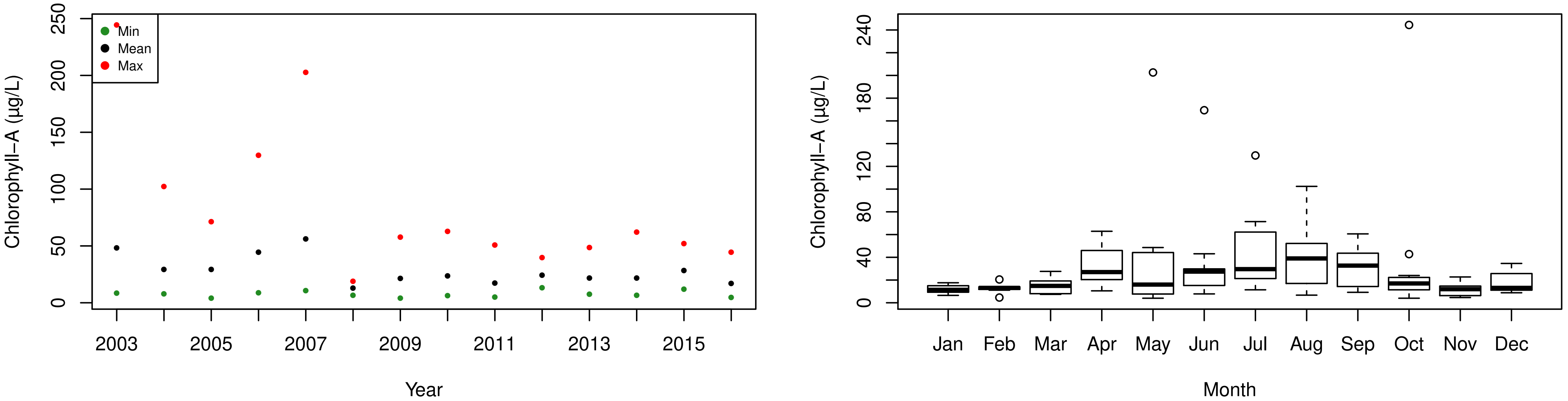
(d) Boxplot by month

Crystal Cr at Rt 31 (271): Chlorophyll–A (µg/L)



(a) Observation data

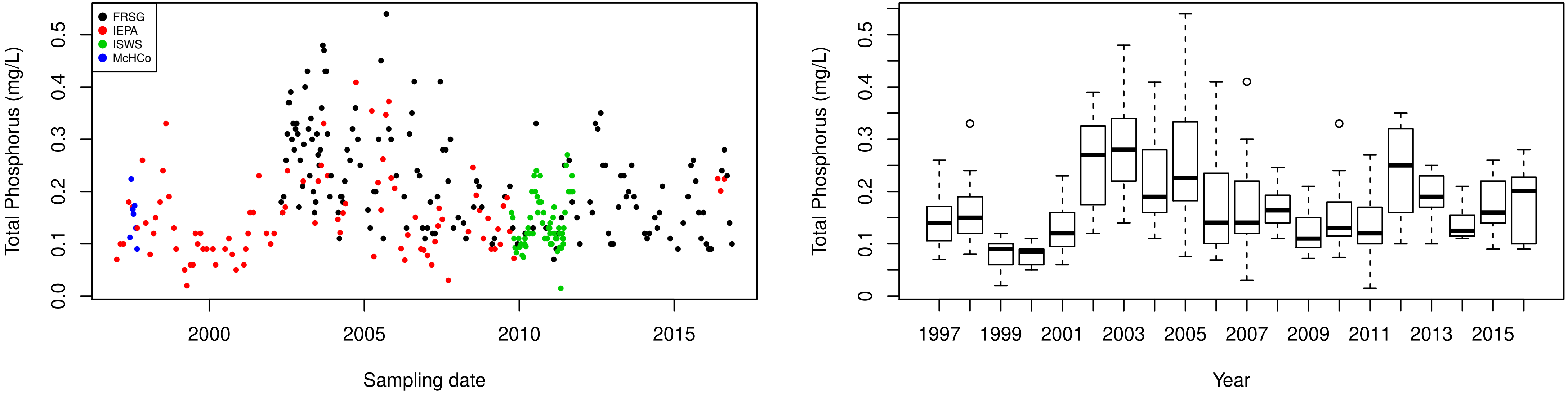
(b) Boxplot by year



(c) Annual values

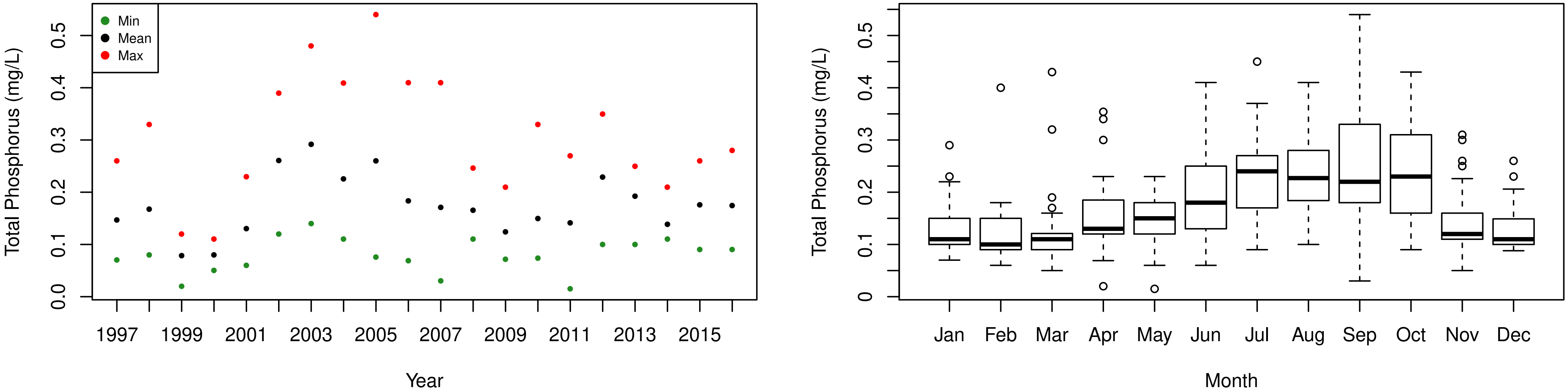
(d) Boxplot by month

Fox River at Algonquin (24): Total Phosphorus (mg/L)



(a) Observation data

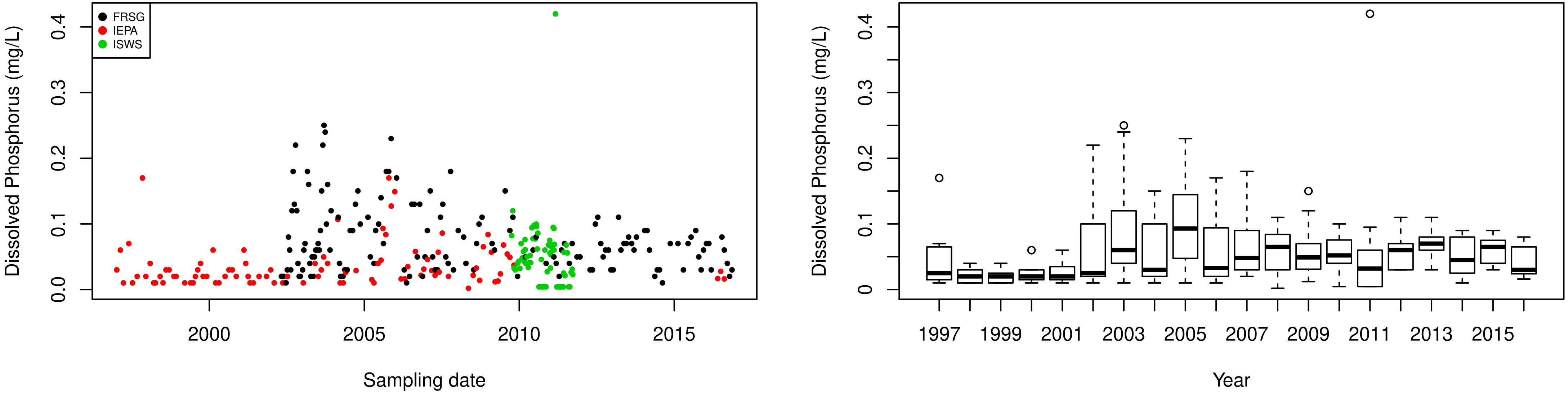
(b) Boxplot by year



(c) Annual values

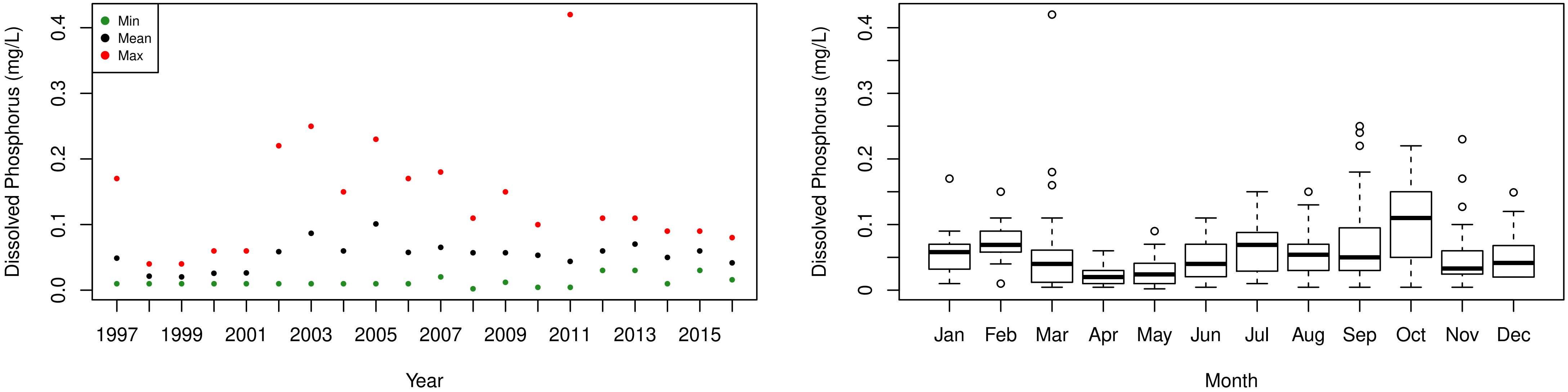
(d) Boxplot by month

Fox River at Algonquin (24): Dissolved Phosphorus (mg/L)



(a) Observation data

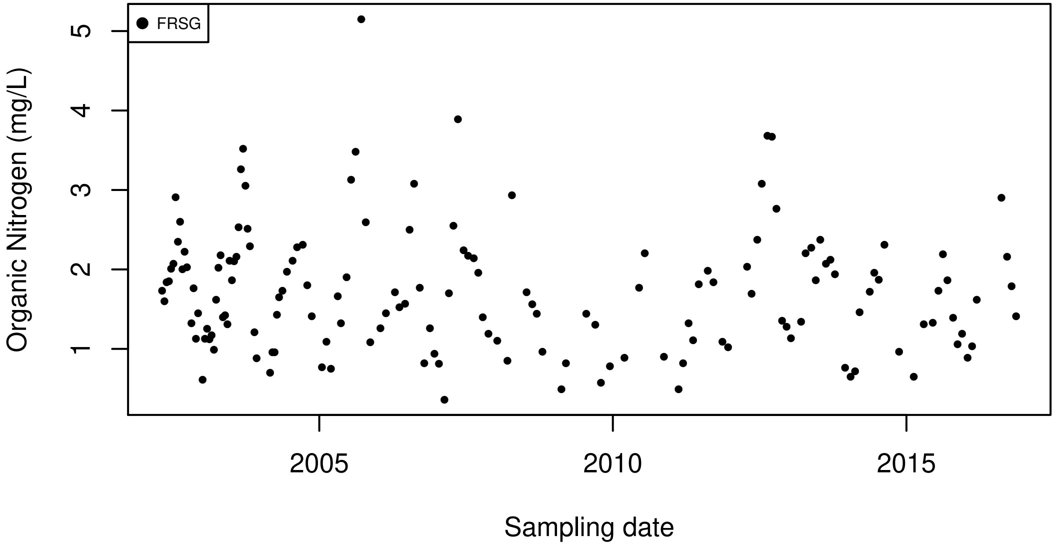
(b) Boxplot by year



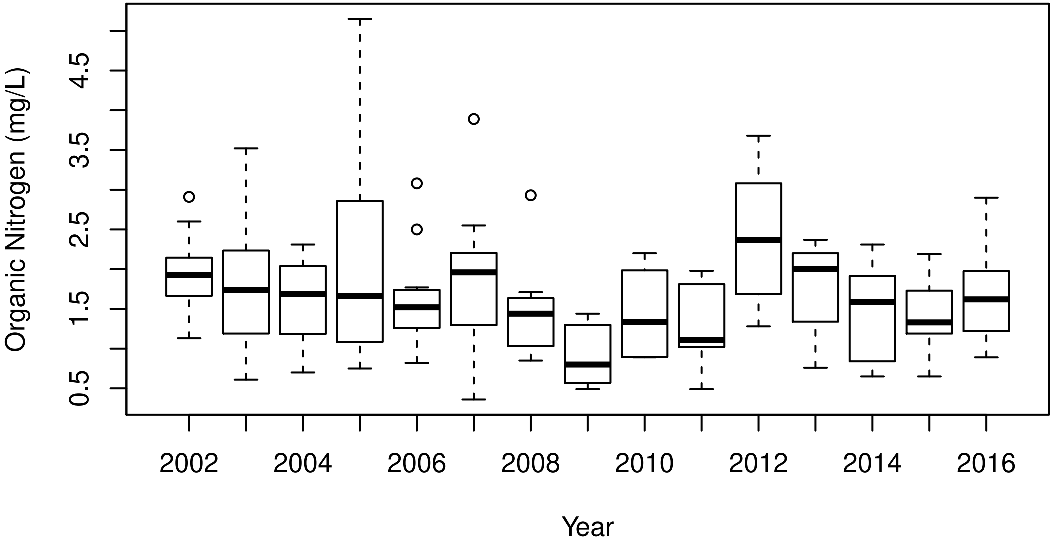
(c) Annual values

(d) Boxplot by month

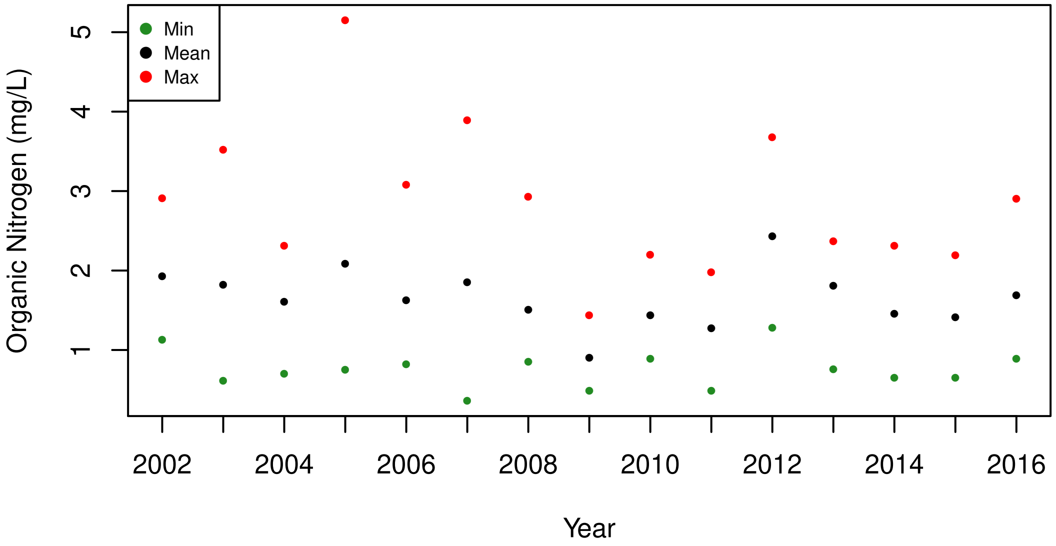
Fox River at Algonquin (24): Organic Nitrogen (mg/L)



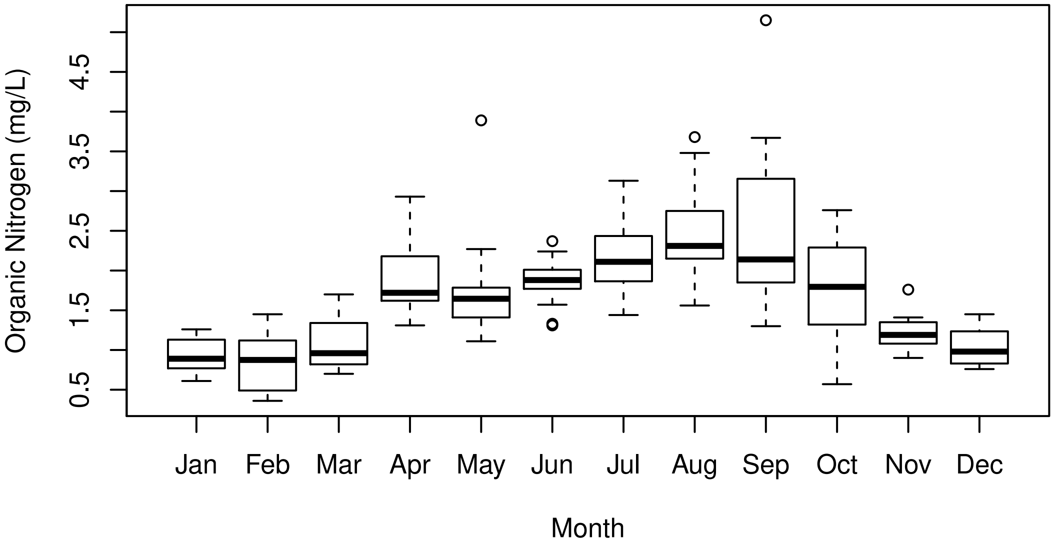
(a) Observation data



(b) Boxplot by year

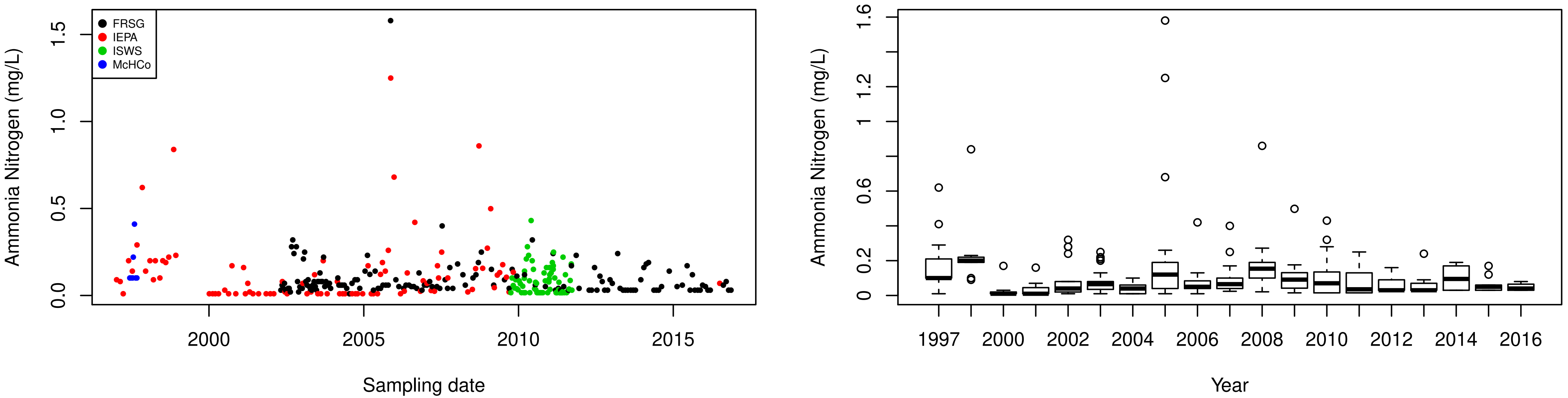


(c) Annual values



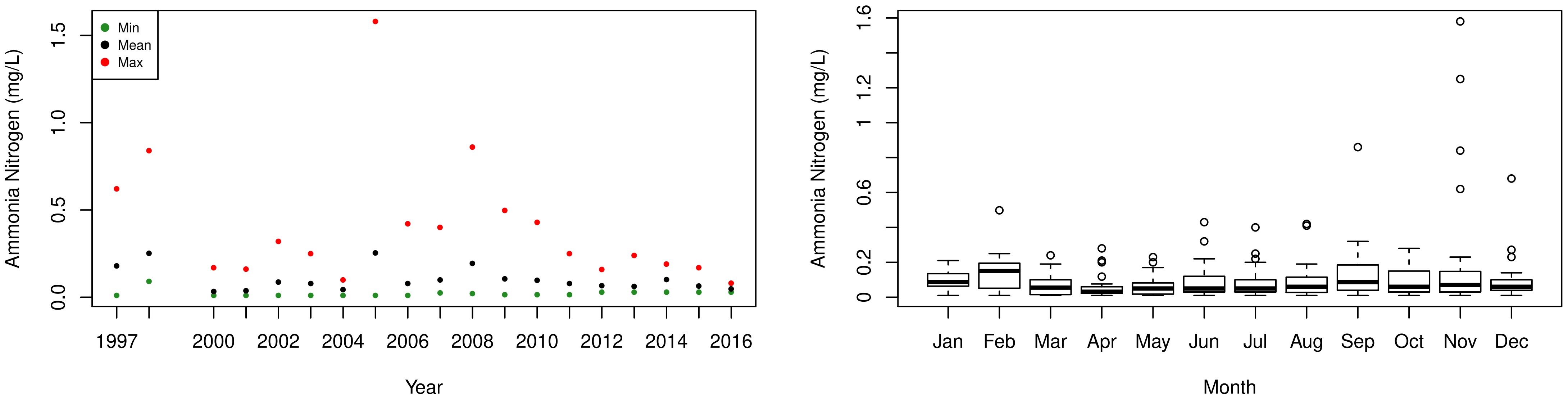
(d) Boxplot by month

Fox River at Algonquin (24): Ammonia Nitrogen (mg/L)



(a) Observation data

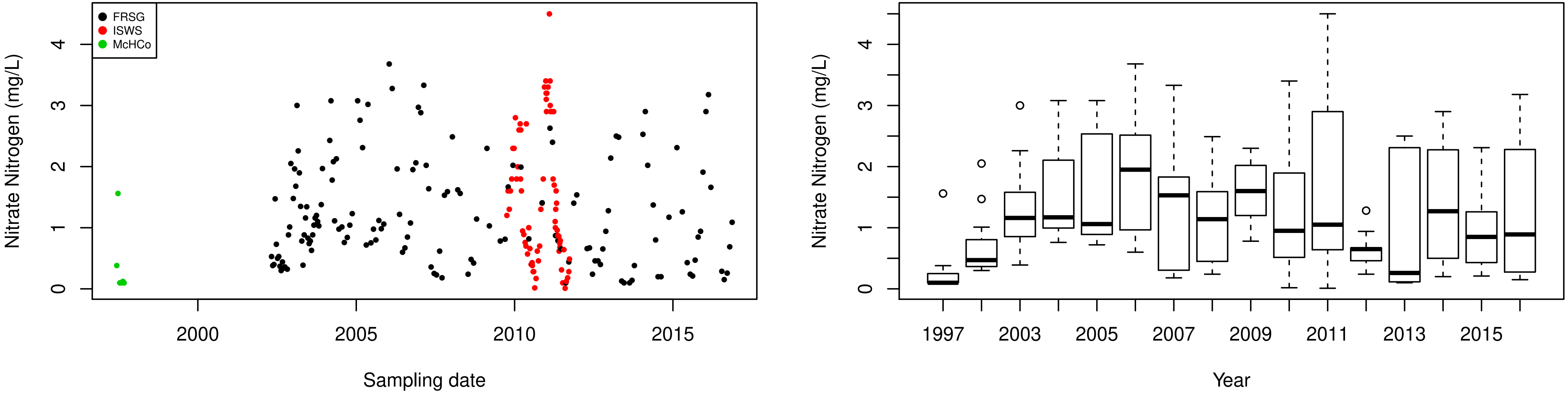
(b) Boxplot by year



(c) Annual values

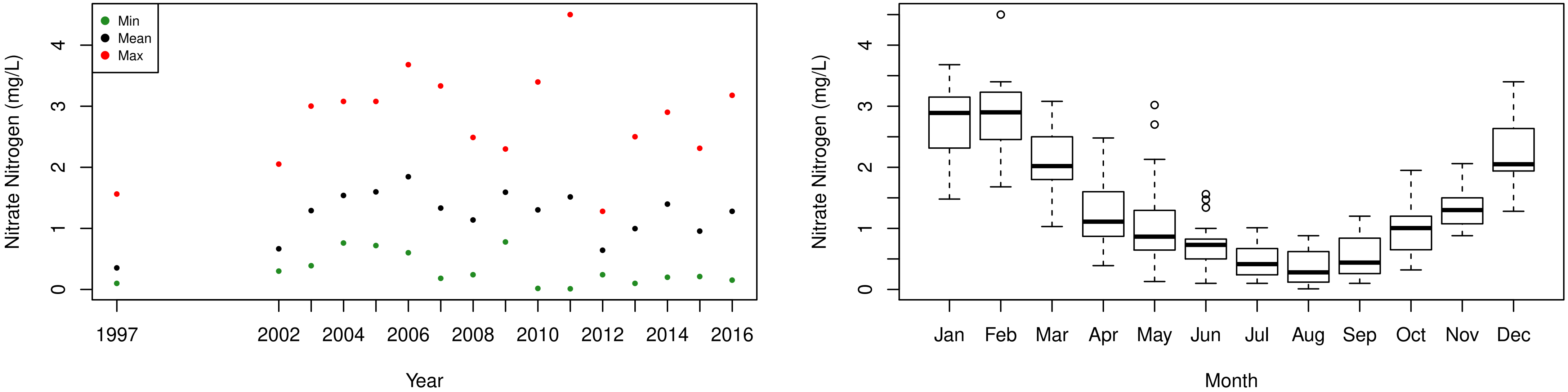
(d) Boxplot by month

Fox River at Algonquin (24): Nitrate Nitrogen (mg/L)



(a) Observation data

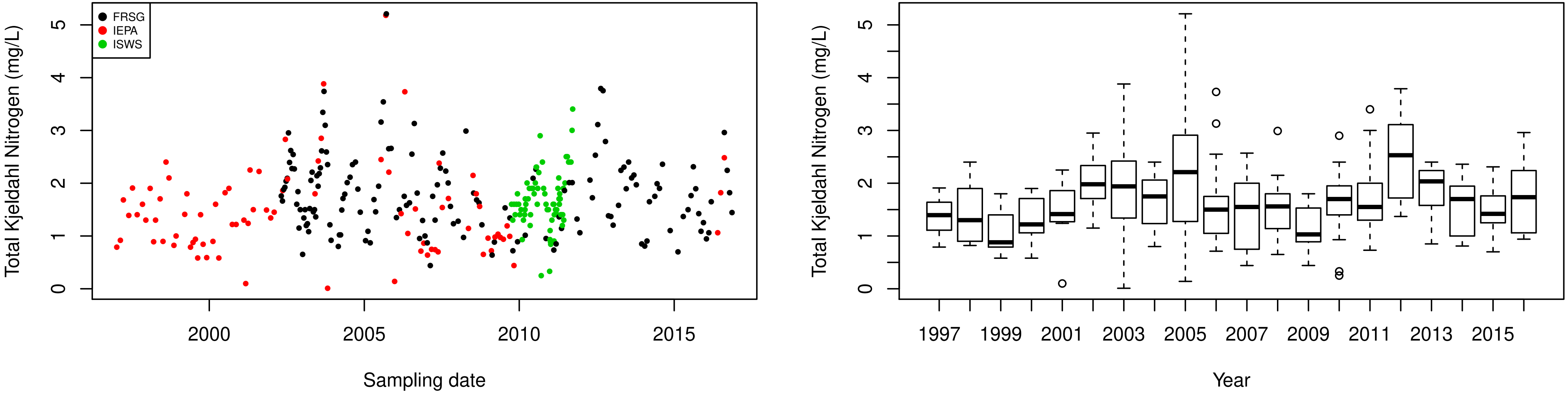
(b) Boxplot by year



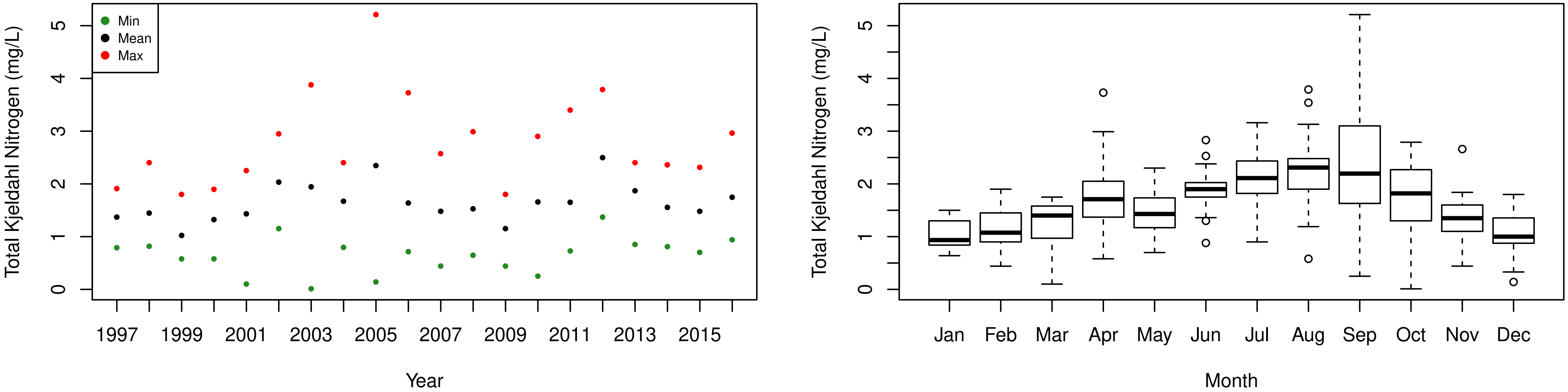
(c) Annual values

(d) Boxplot by month

Fox River at Algonquin (24): Total Kjeldahl Nitrogen (mg/L)

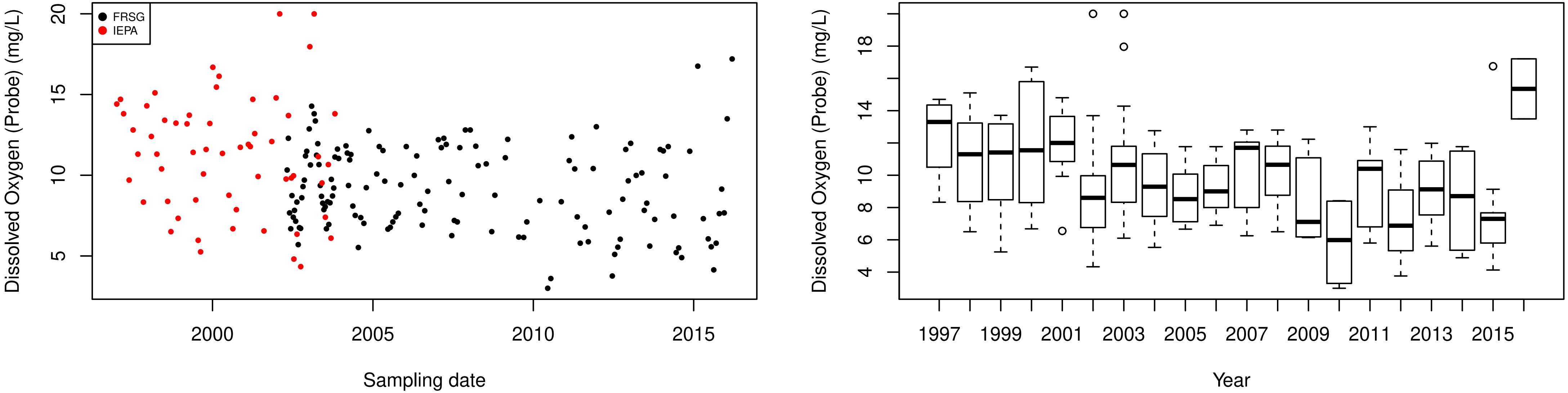


(a) Observation data (b) Boxplot by year



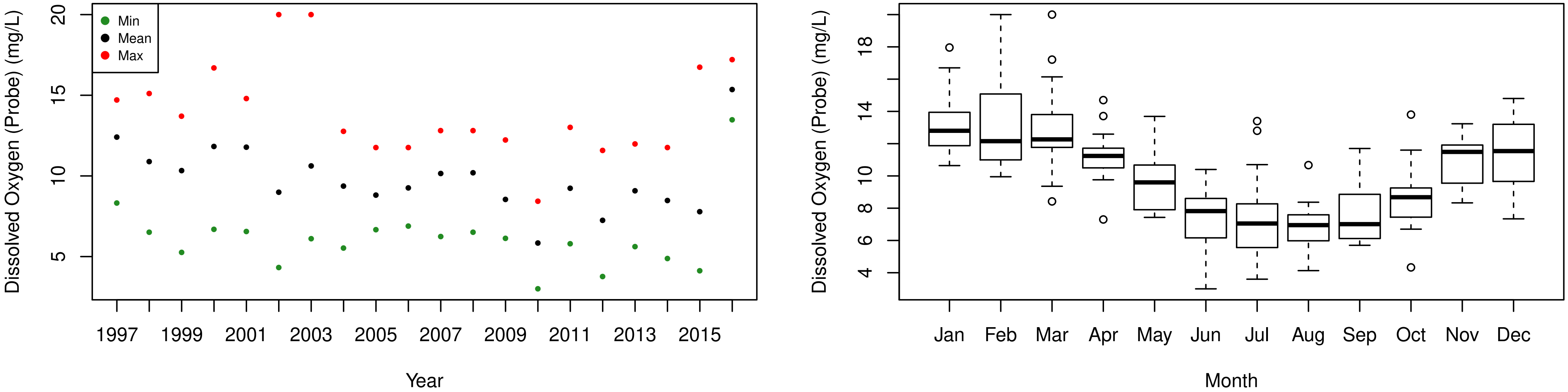
(c) Annual values (d) Boxplot by month

Fox River at Algonquin (24): Dissolved Oxygen (Probe) (mg/L)



(a) Observation data

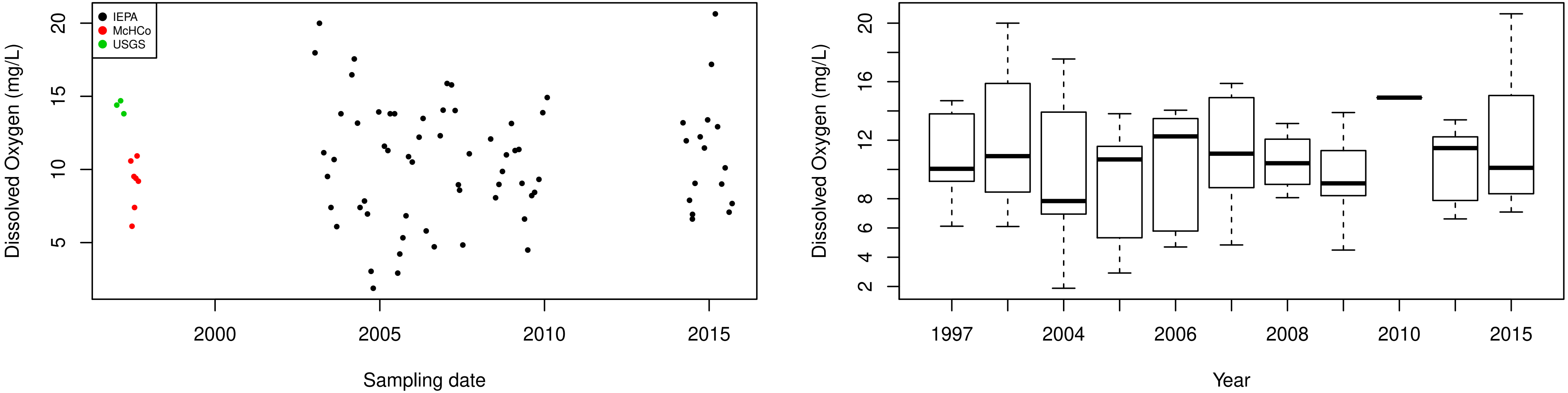
(b) Boxplot by year



(c) Annual values

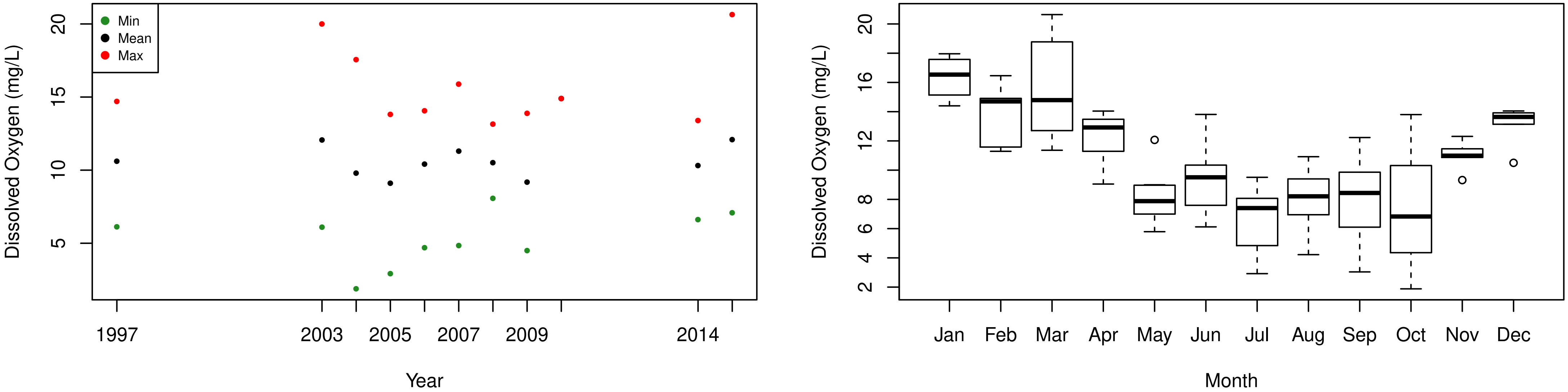
(d) Boxplot by month

Fox River at Algonquin (24): Dissolved Oxygen (mg/L)



(a) Observation data

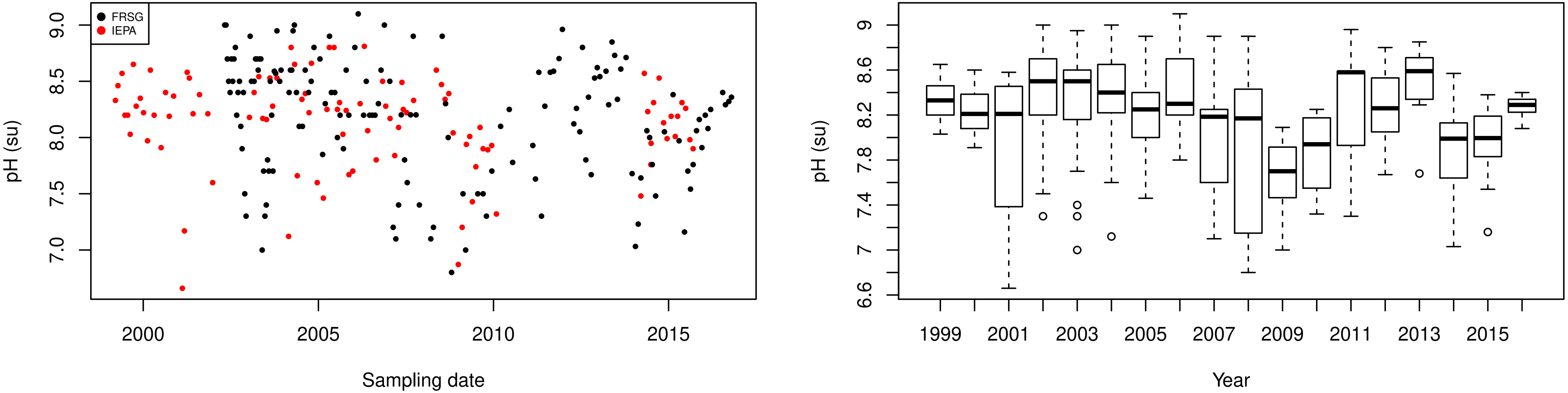
(b) Boxplot by year



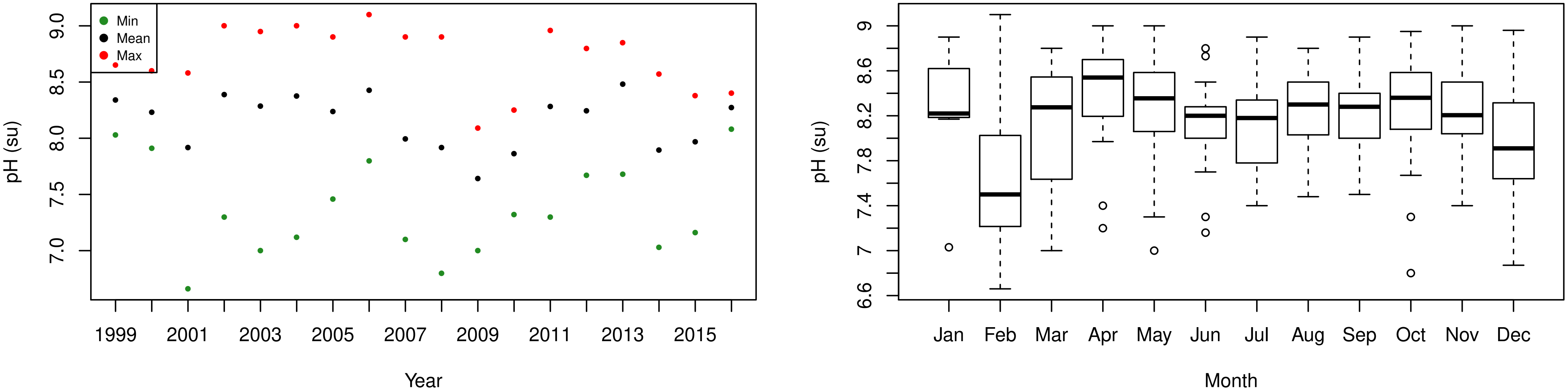
(c) Annual values

(d) Boxplot by month

Fox River at Algonquin (24): pH (su)

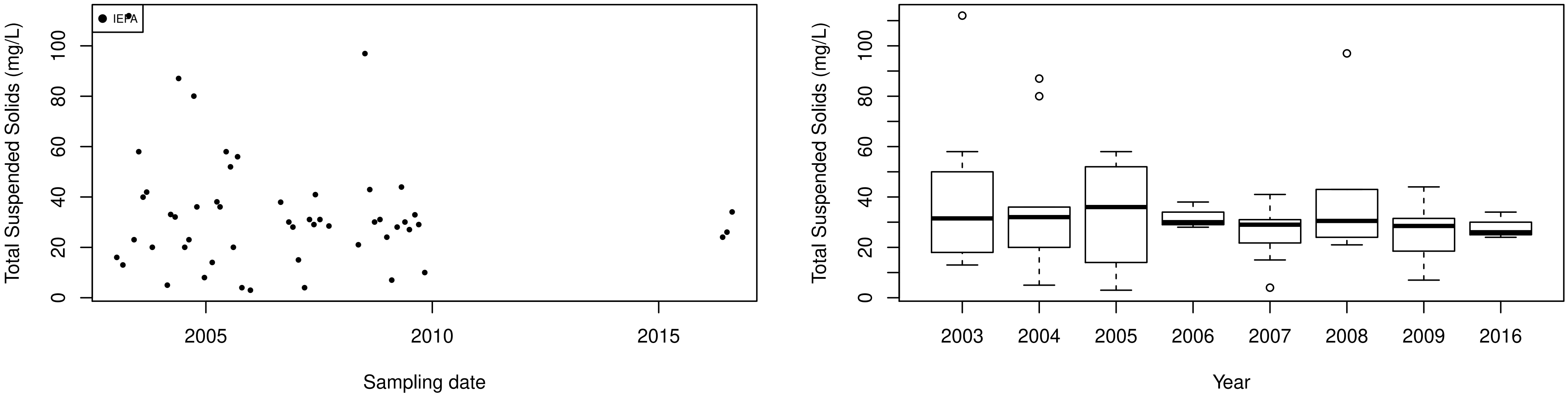


(a) Observation data (b) Boxplot by year



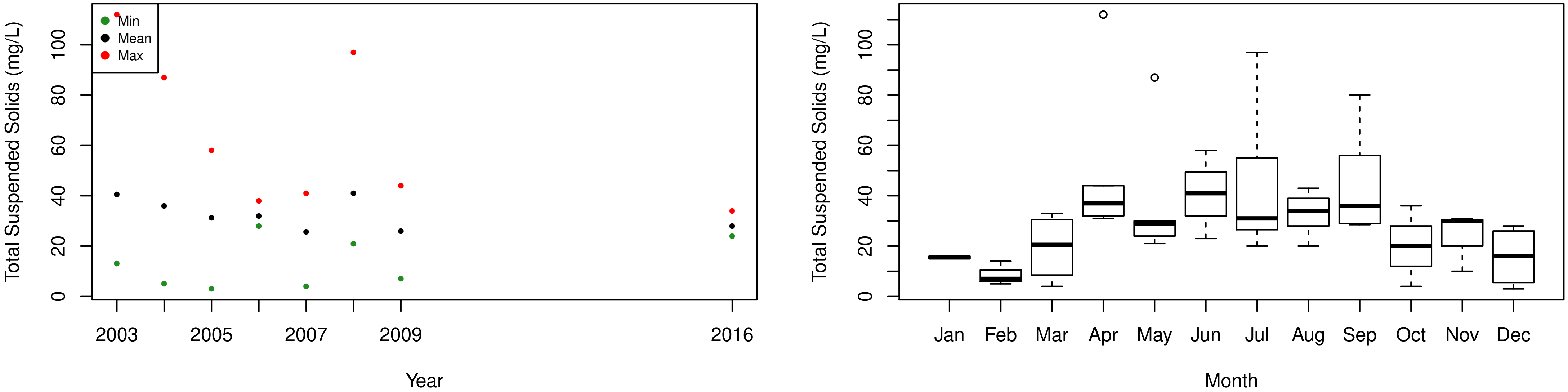
(c) Annual values (d) Boxplot by month

Fox River at Algonquin (24): Total Suspended Solids (mg/L)



(a) Observation data

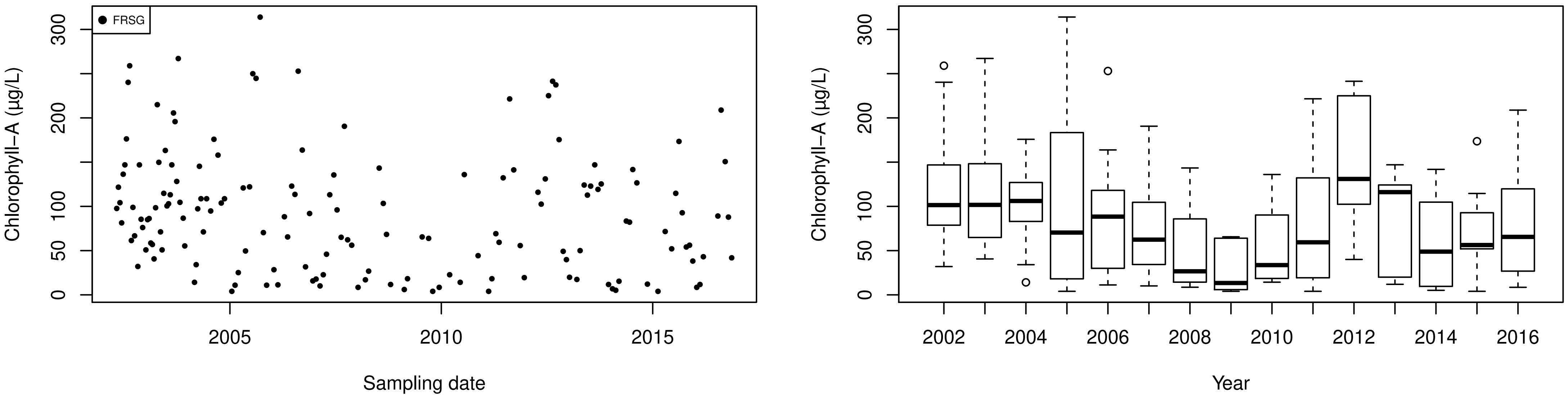
(b) Boxplot by year



(c) Annual values

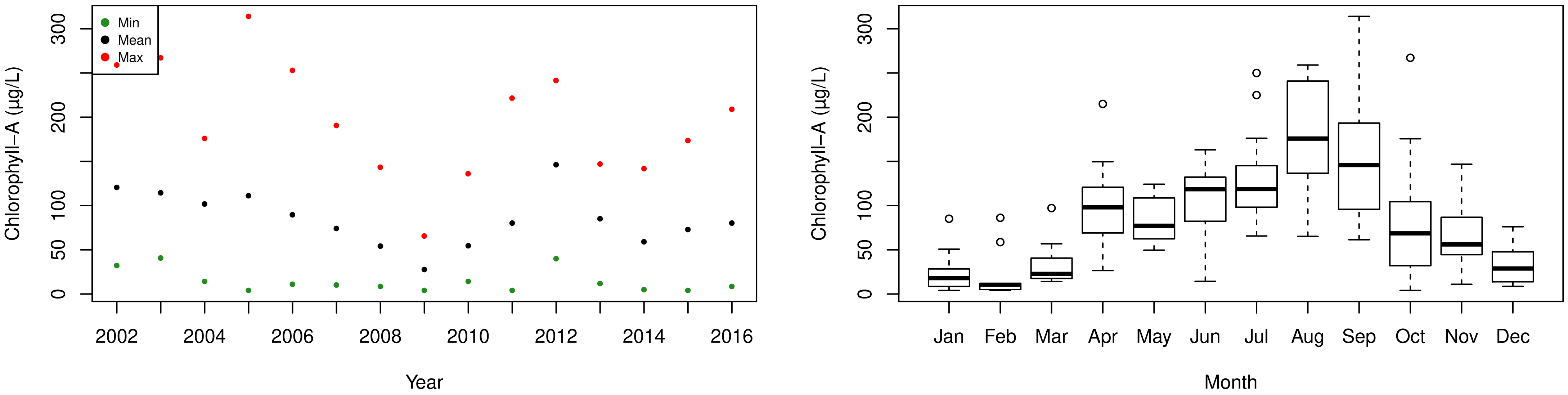
(d) Boxplot by month

Fox River at Algonquin (24): Chlorophyll−A (µg/L)



(a) Observation data

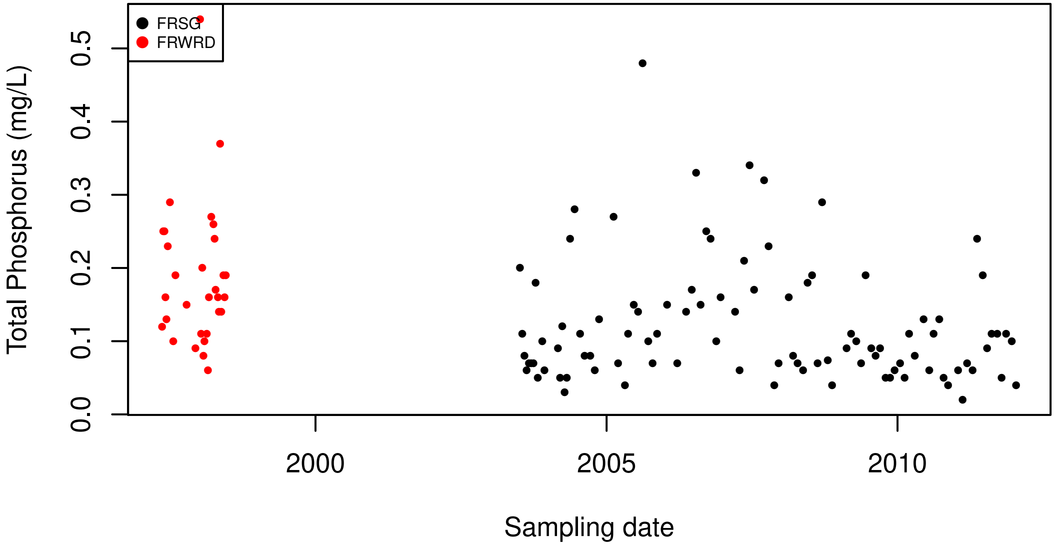
(b) Boxplot by year



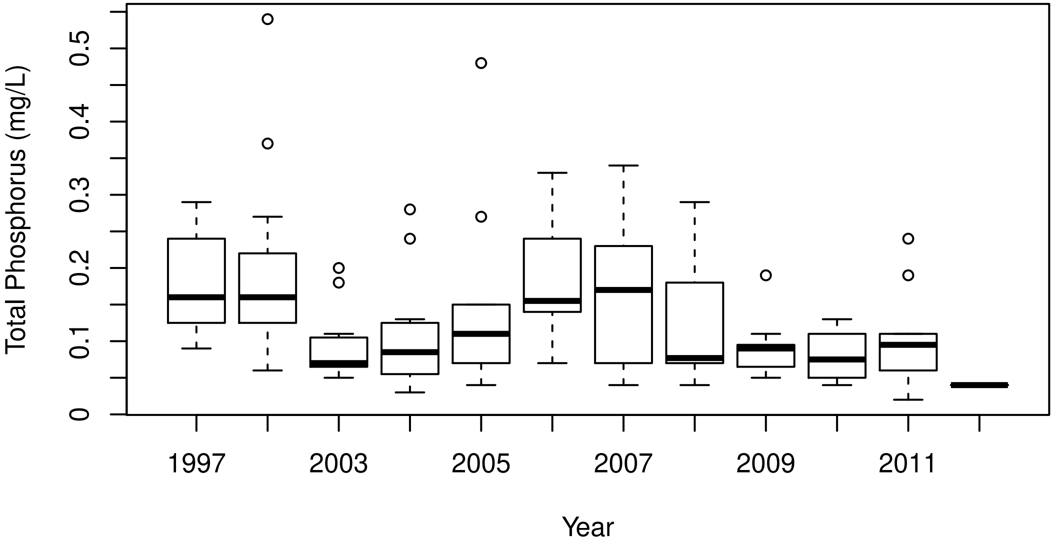
(c) Annual values

(d) Boxplot by month

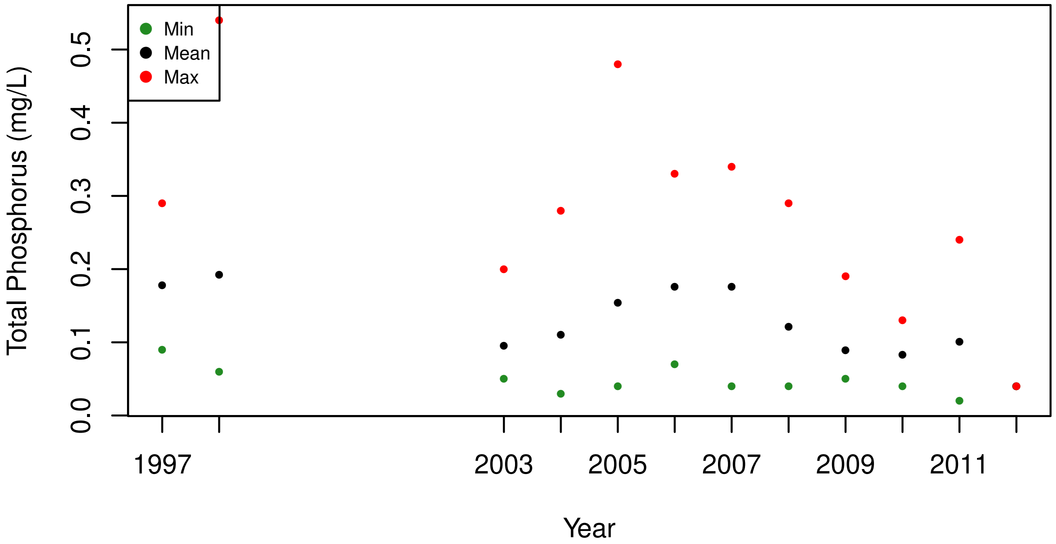
Tyler Cr at Rt. 31–Elgin (268): Total Phosphorus (mg/L)



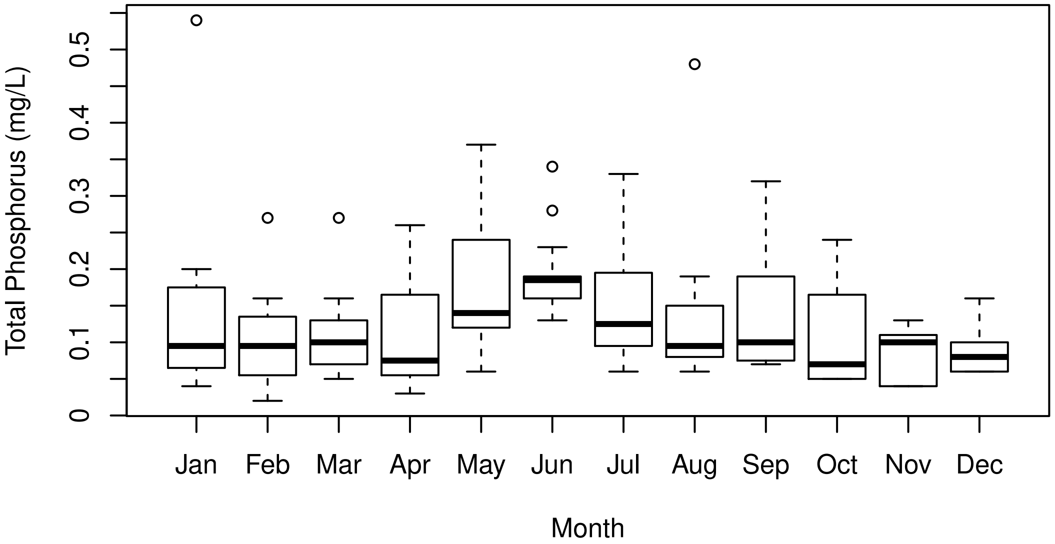
(a) Observation data



(b) Boxplot by year

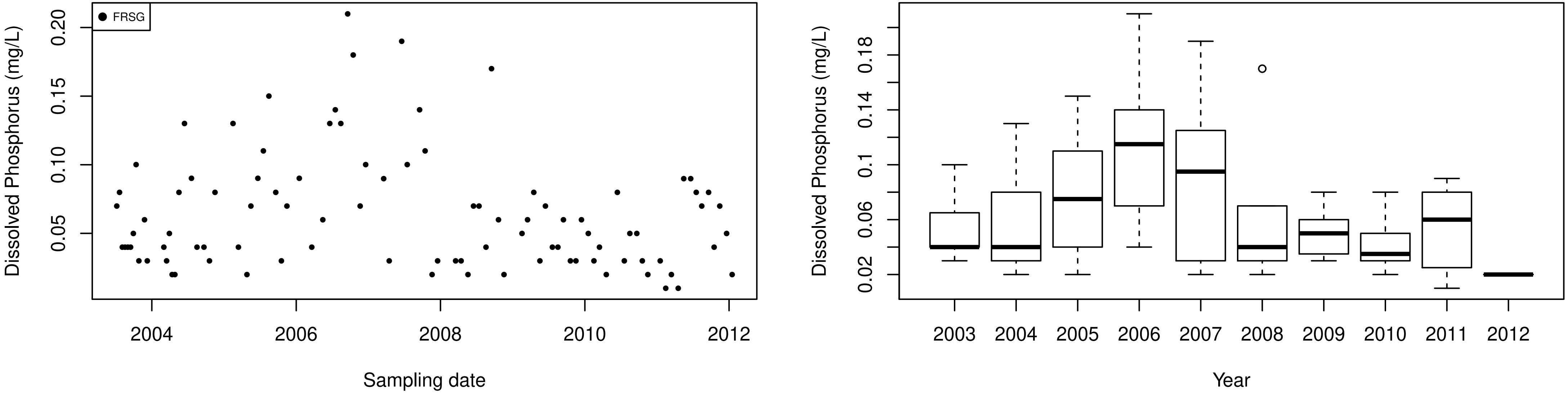


(c) Annual values



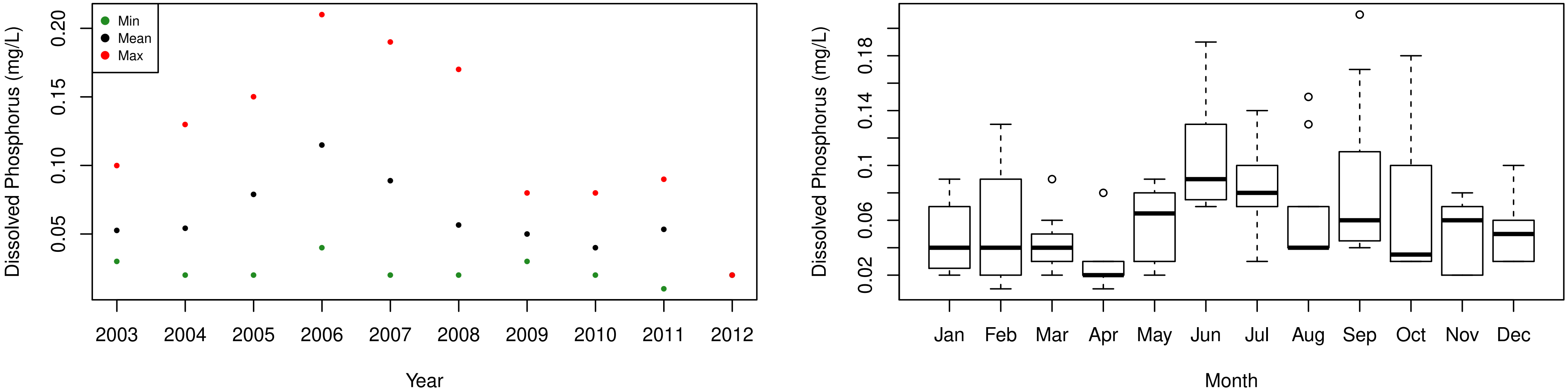
(d) Boxplot by month

Tyler Cr at Rt. 31−Elgin (268): Dissolved Phosphorus (mg/L)



(a) Observation data

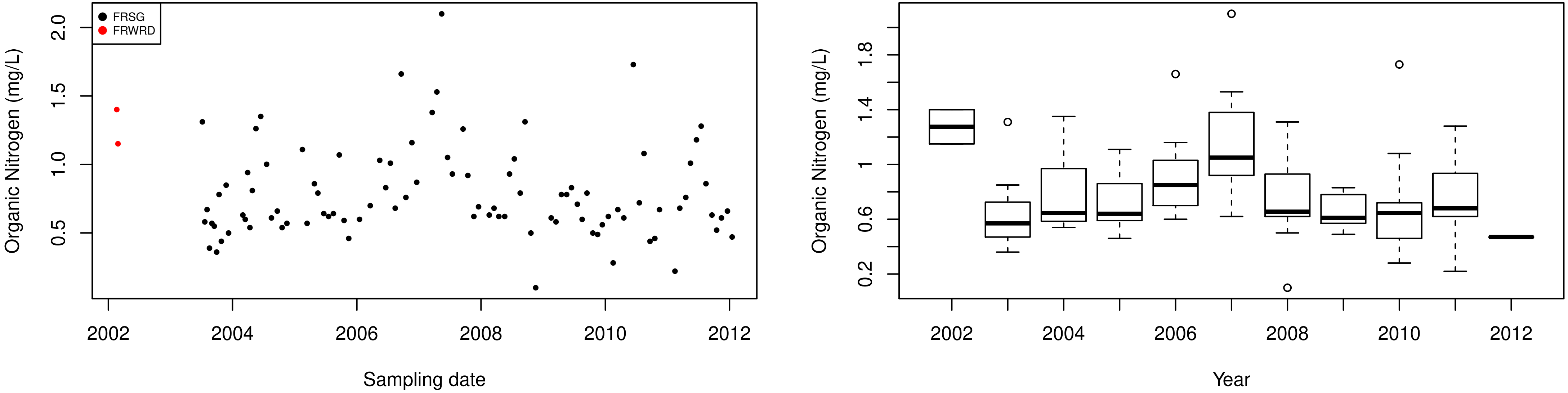
(b) Boxplot by year



(c) Annual values

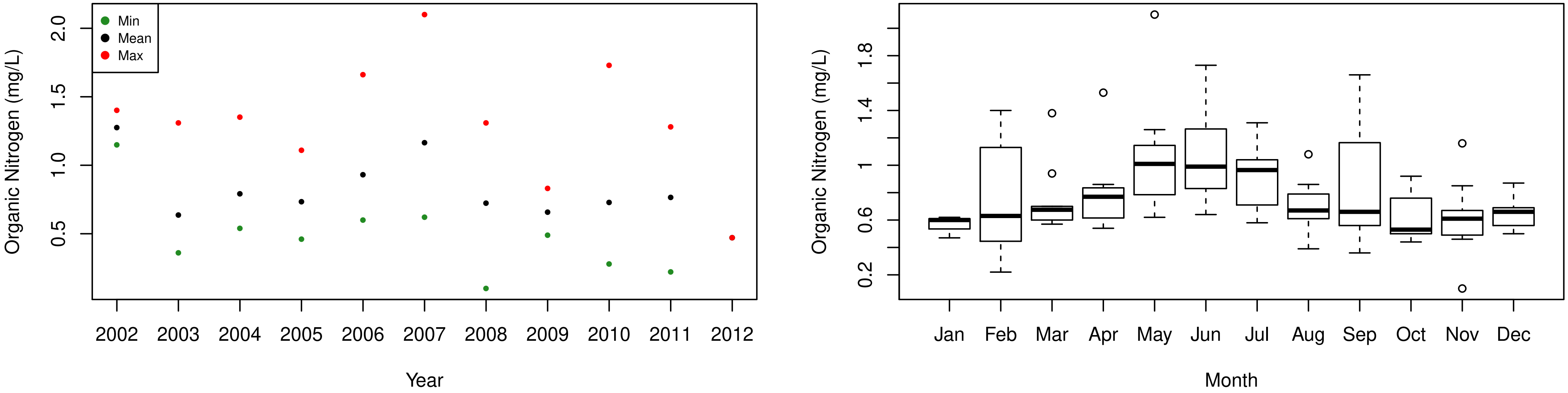
(d) Boxplot by month

Tyler Cr at Rt. 31−Elgin (268): Organic Nitrogen (mg/L)



(a) Observation data

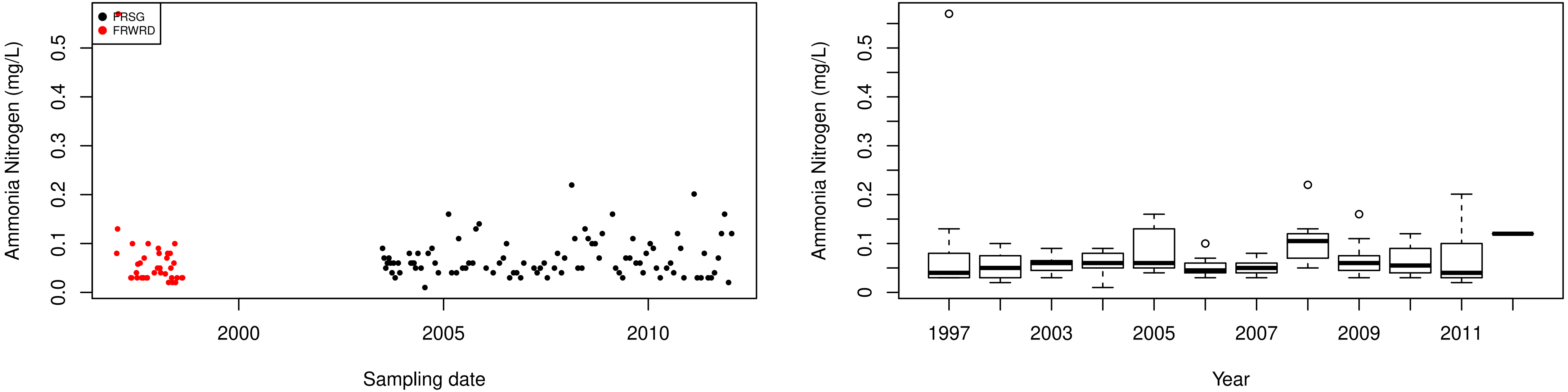
(b) Boxplot by year



(c) Annual values

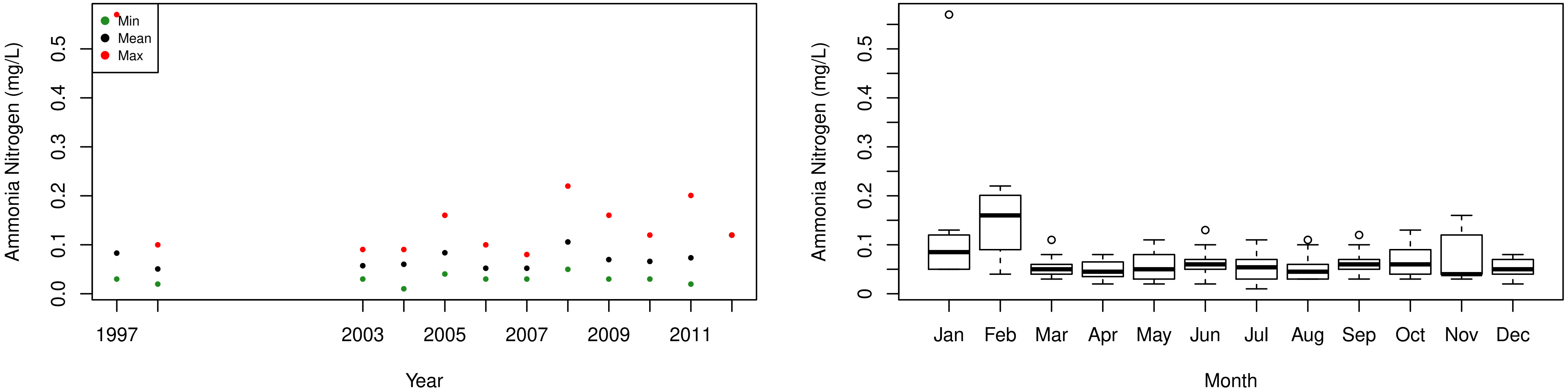
(d) Boxplot by month

Tyler Cr at Rt. 31−Elgin (268): Ammonia Nitrogen (mg/L)



(a) Observation data

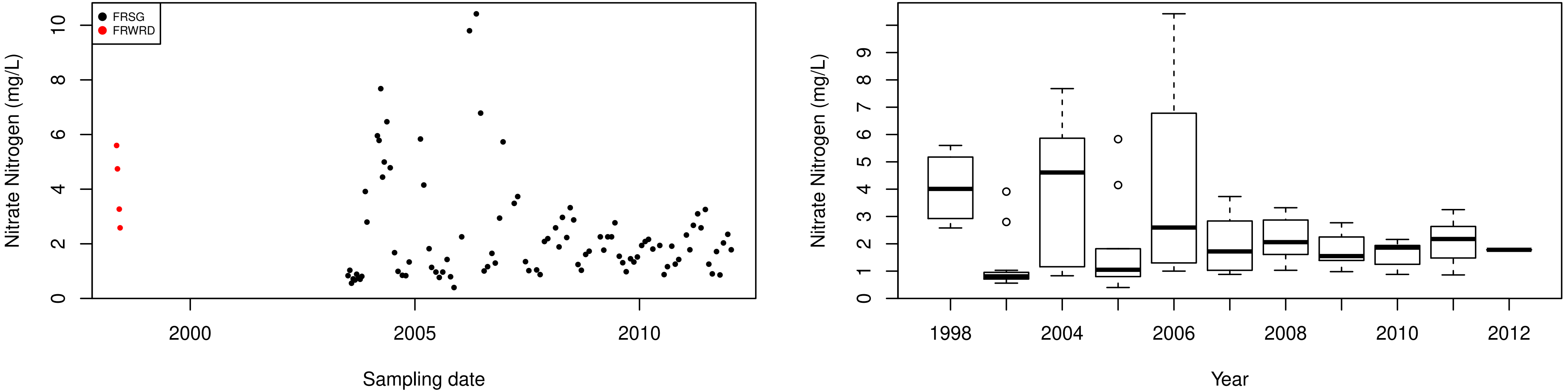
(b) Boxplot by year



(c) Annual values

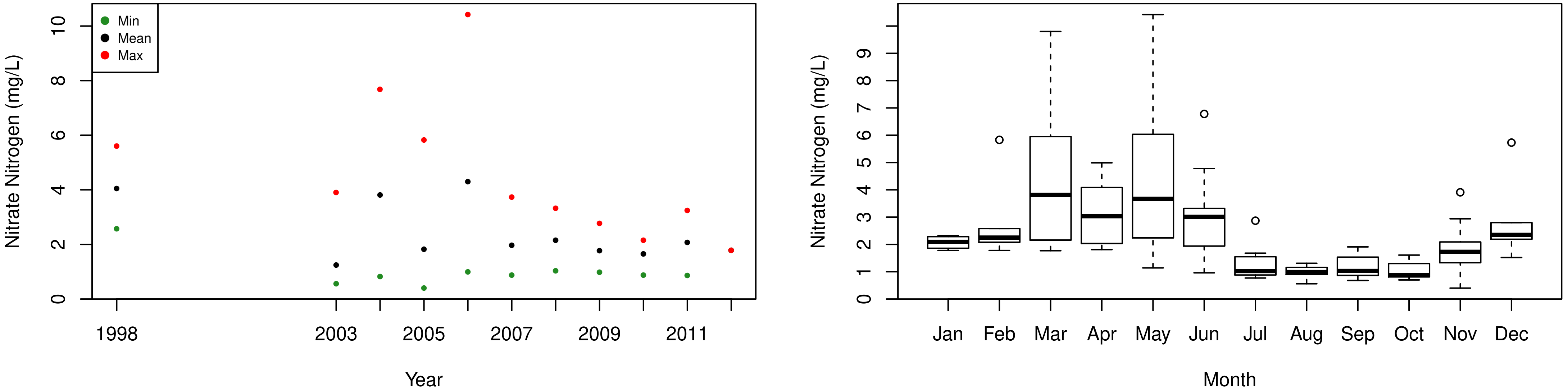
(d) Boxplot by month

Tyler Cr at Rt. 31–Elgin (268): Nitrate Nitrogen (mg/L)



(a) Observation data

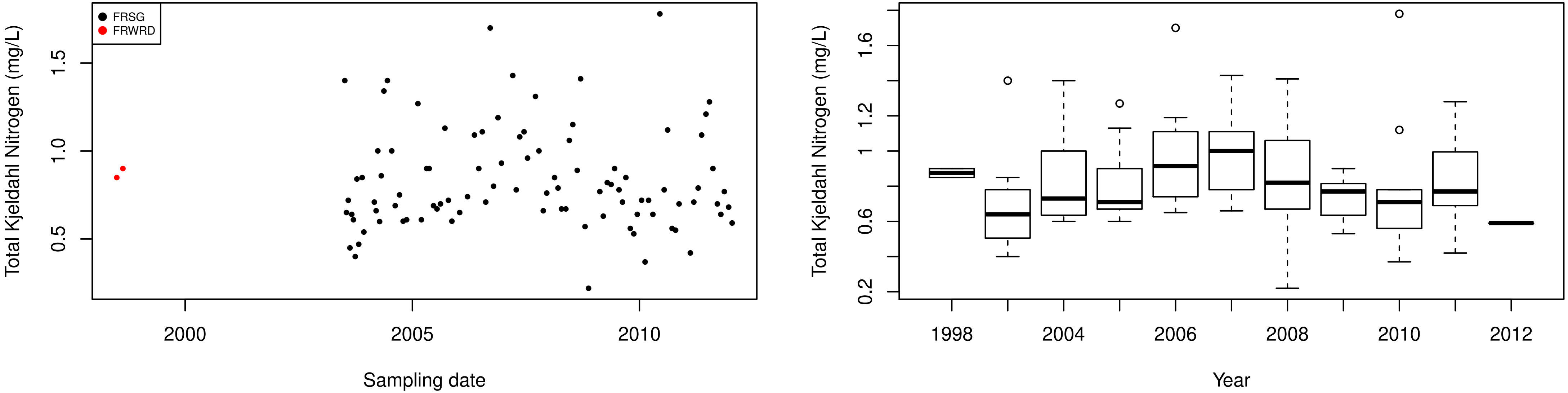
(b) Boxplot by year



(c) Annual values

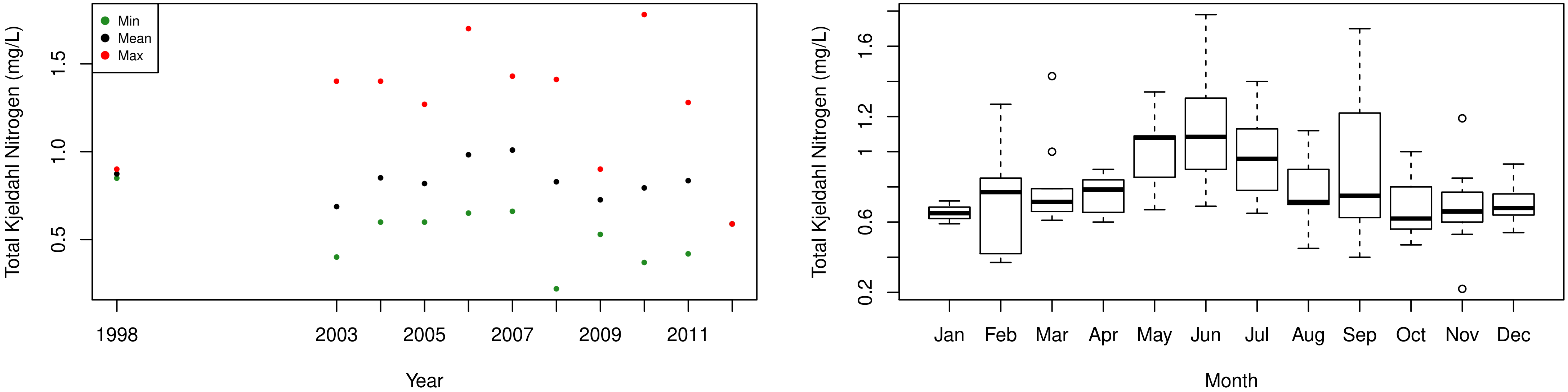
(d) Boxplot by month

Tyler Cr at Rt. 31–Elgin (268): Total Kjeldahl Nitrogen (mg/L)



(a) Observation data

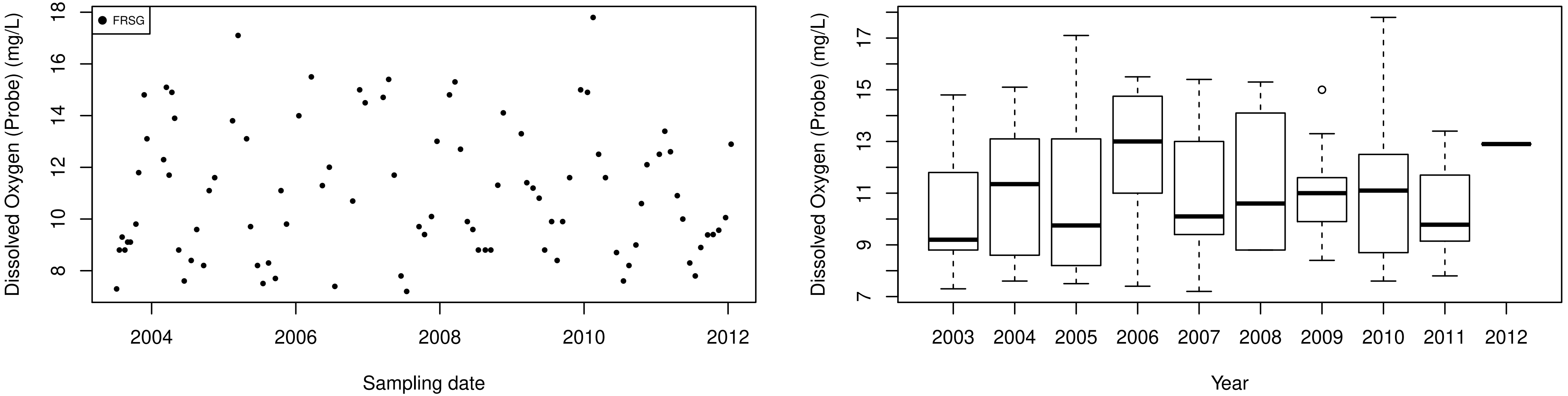
(b) Boxplot by year



(c) Annual values

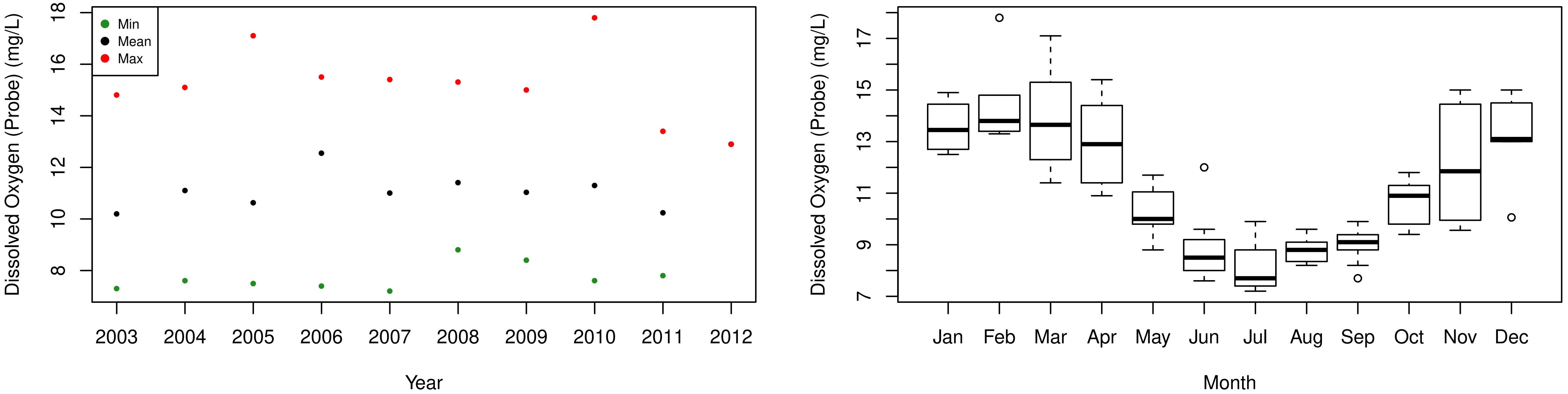
(d) Boxplot by month

Tyler Cr at Rt. 31–Elgin (268): Dissolved Oxygen (Probe) (mg/L)



(a) Observation data

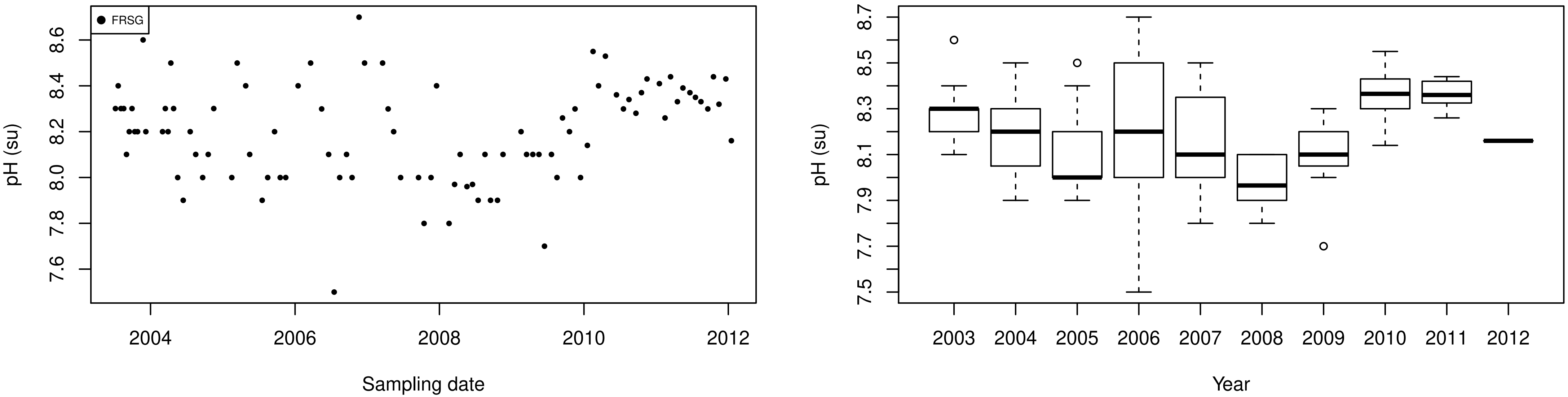
(b) Boxplot by year



(c) Annual values

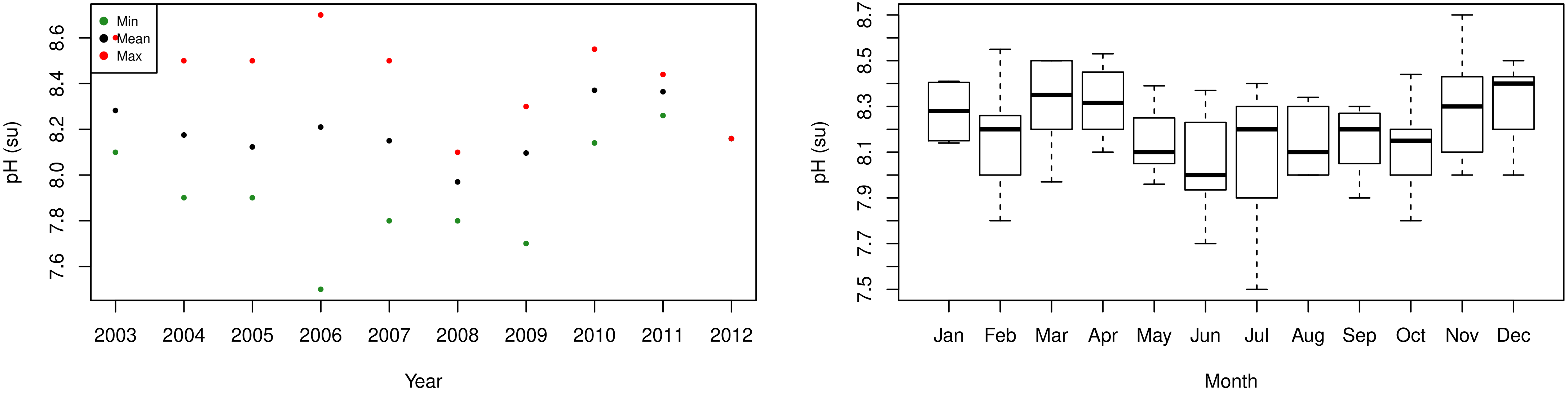
(d) Boxplot by month

Tyler Cr at Rt. 31–Elgin (268): pH (su)



(a) Observation data

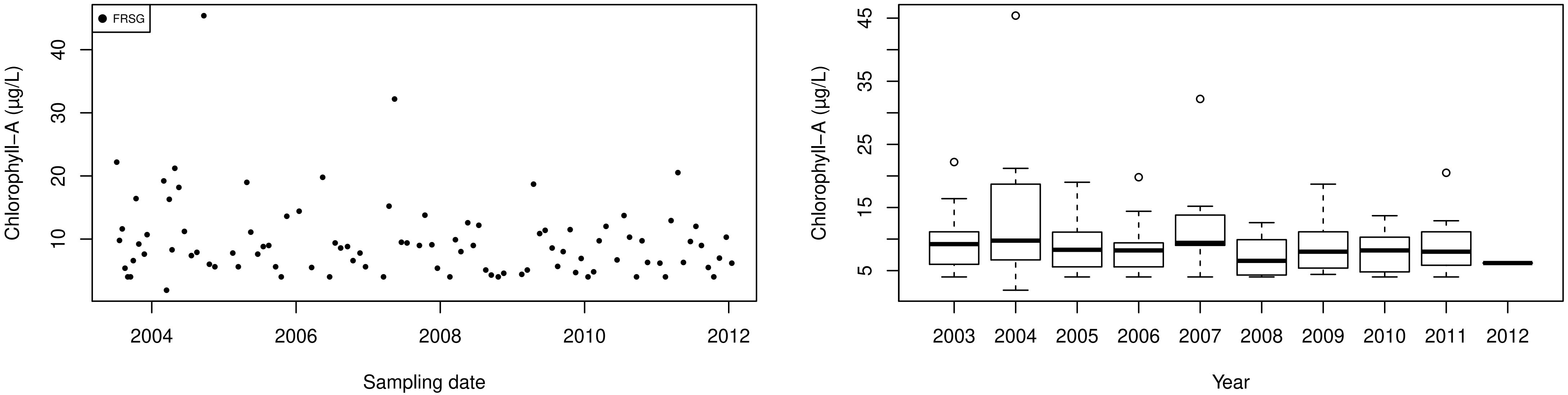
(b) Boxplot by year



(c) Annual values

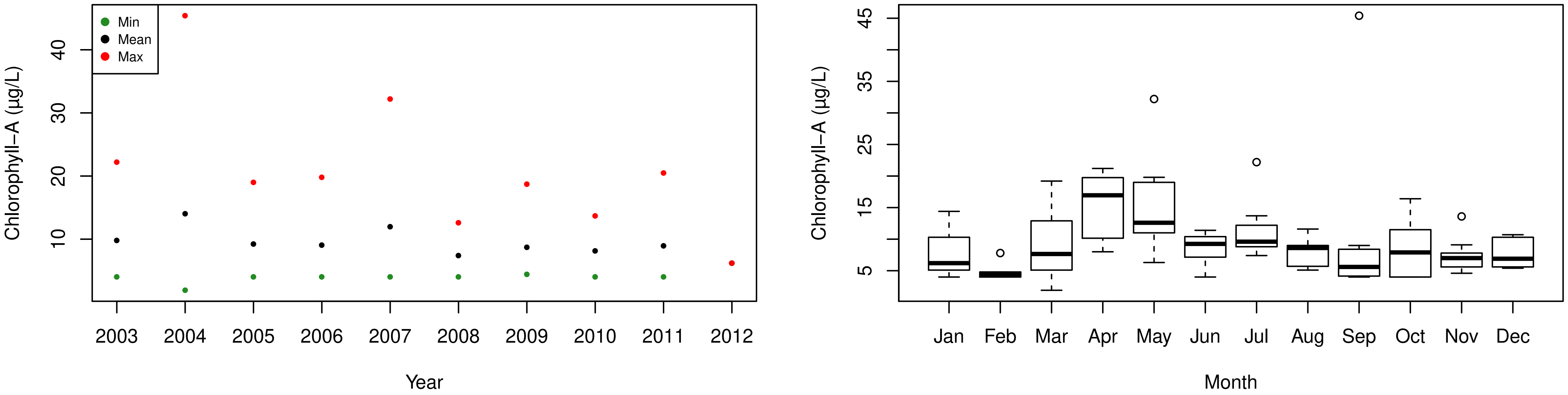
(d) Boxplot by month

Tyler Cr at Rt. 31−Elgin (268): Chlorophyll−A (µg/L)



(a) Observation data

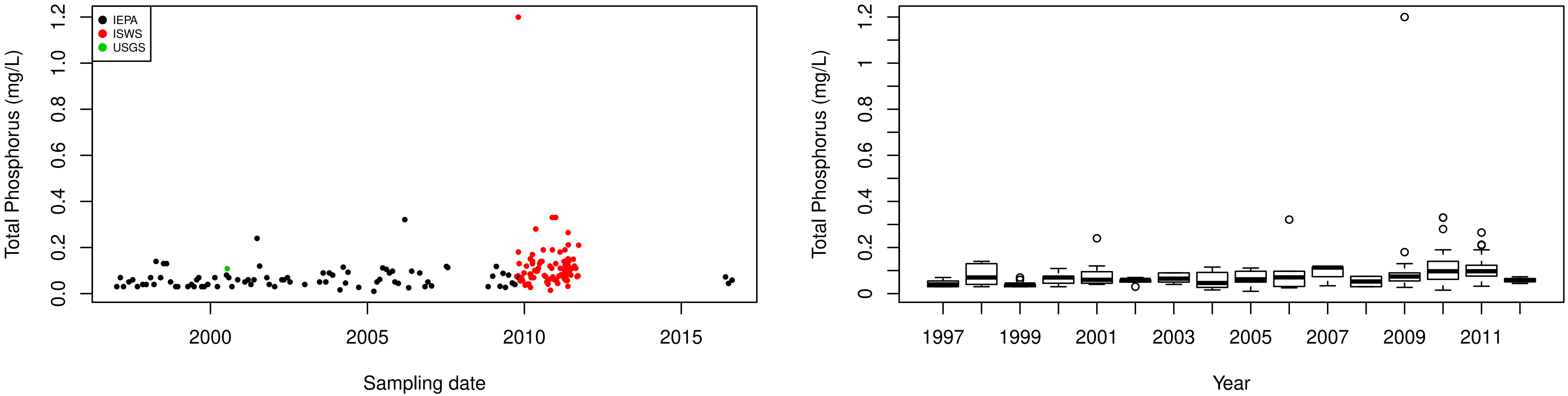
(b) Boxplot by year



(c) Annual values

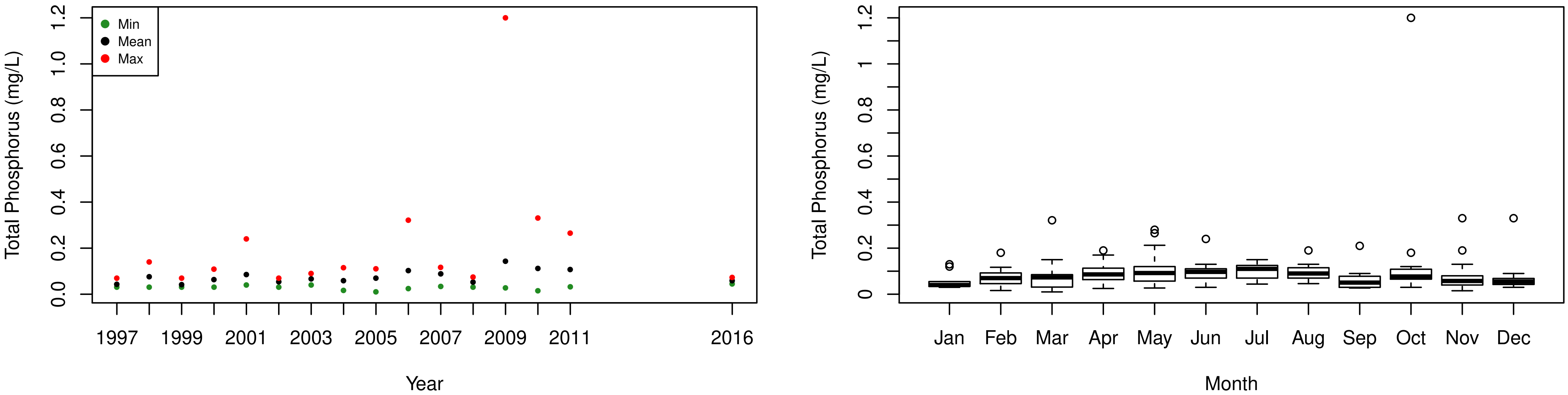
(d) Boxplot by month

Poplar Cr near Mouth–Elgin (25): Total Phosphorus (mg/L)



(a) Observation data

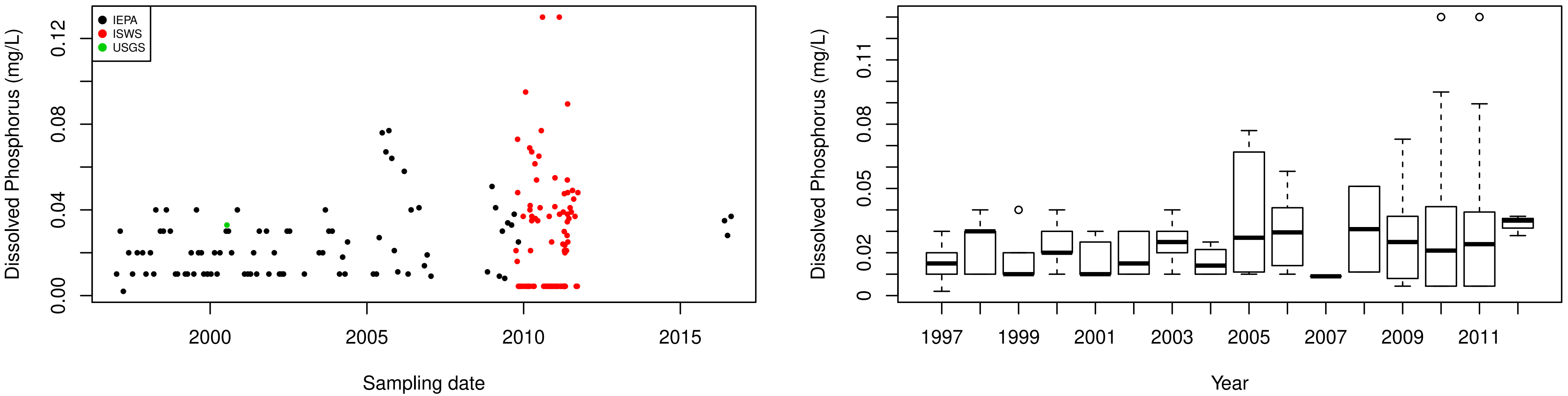
(b) Boxplot by year



(c) Annual values

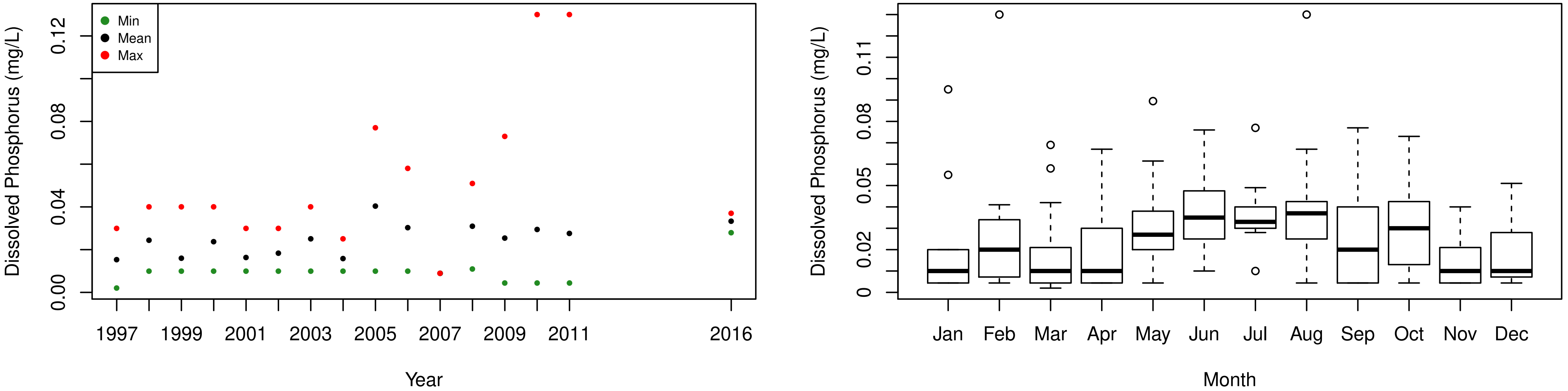
(d) Boxplot by month

Poplar Cr near Mouth–Elgin (25): Dissolved Phosphorus (mg/L)



(a) Observation data

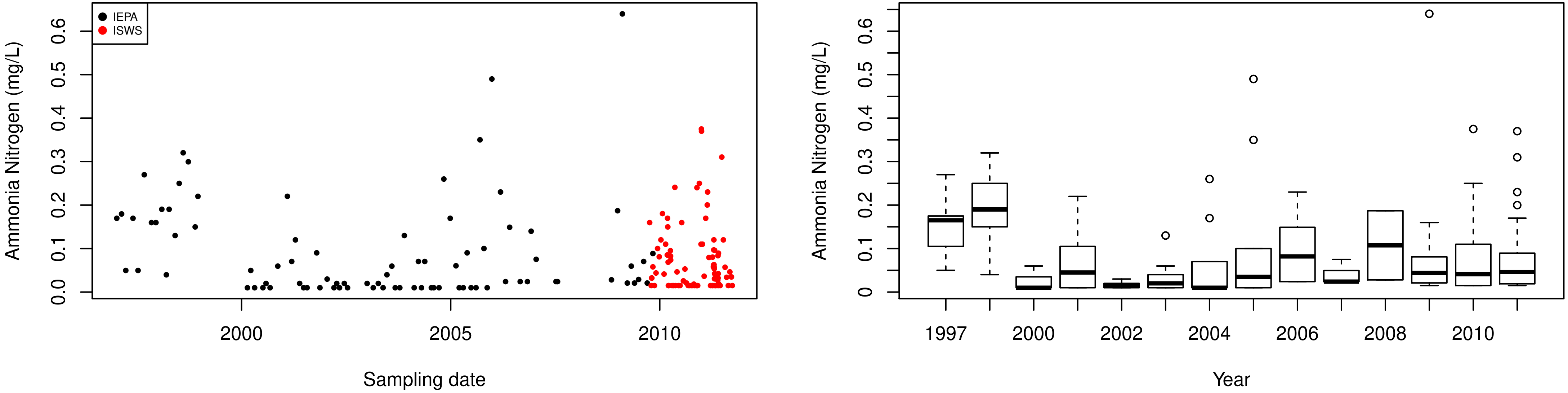
(b) Boxplot by year



(c) Annual values

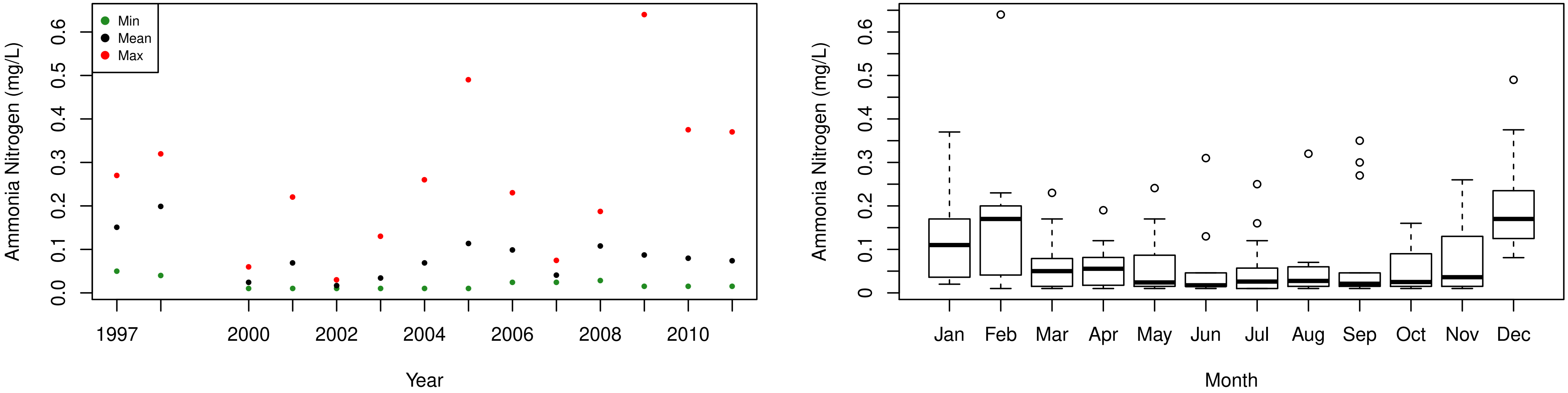
(d) Boxplot by month

Poplar Cr near Mouth–Elgin (25): Ammonia Nitrogen (mg/L)



(a) Observation data

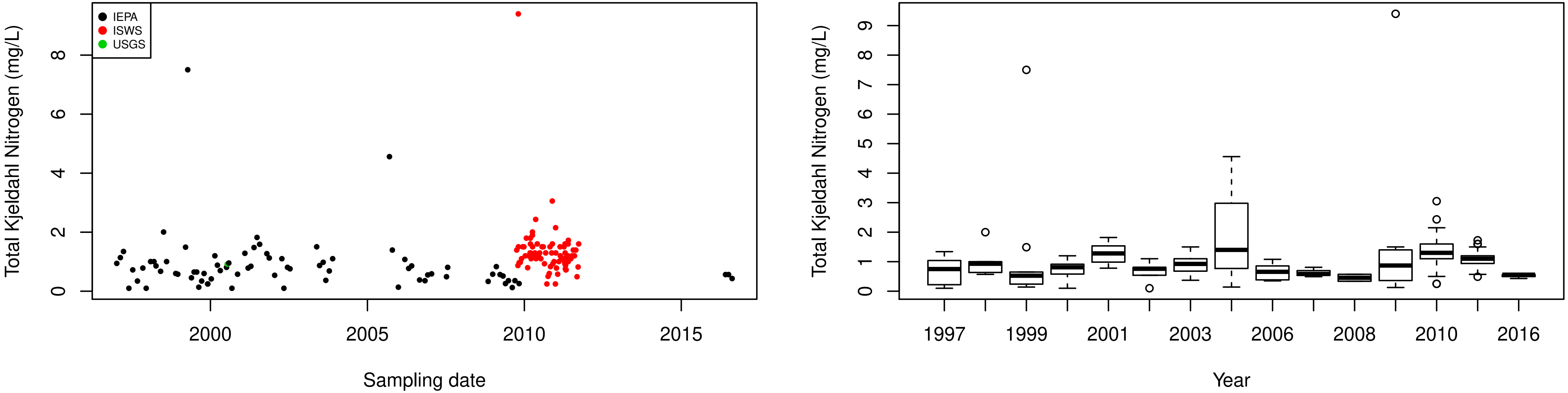
(b) Boxplot by year



(c) Annual values

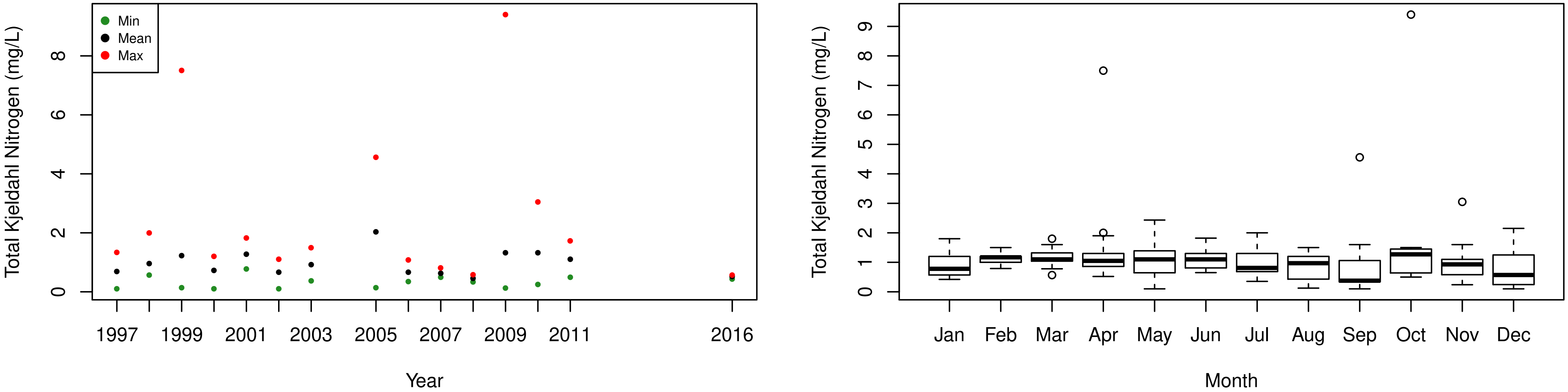
(d) Boxplot by month

Poplar Cr near Mouth–Elgin (25): Total Kjeldahl Nitrogen (mg/L)



(a) Observation data

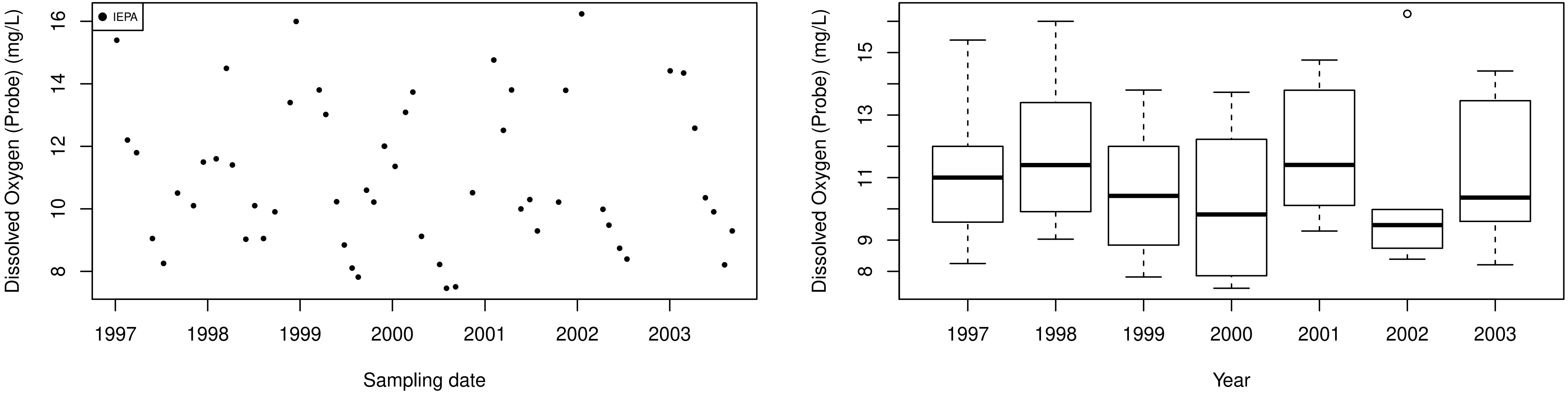
(b) Boxplot by year



(c) Annual values

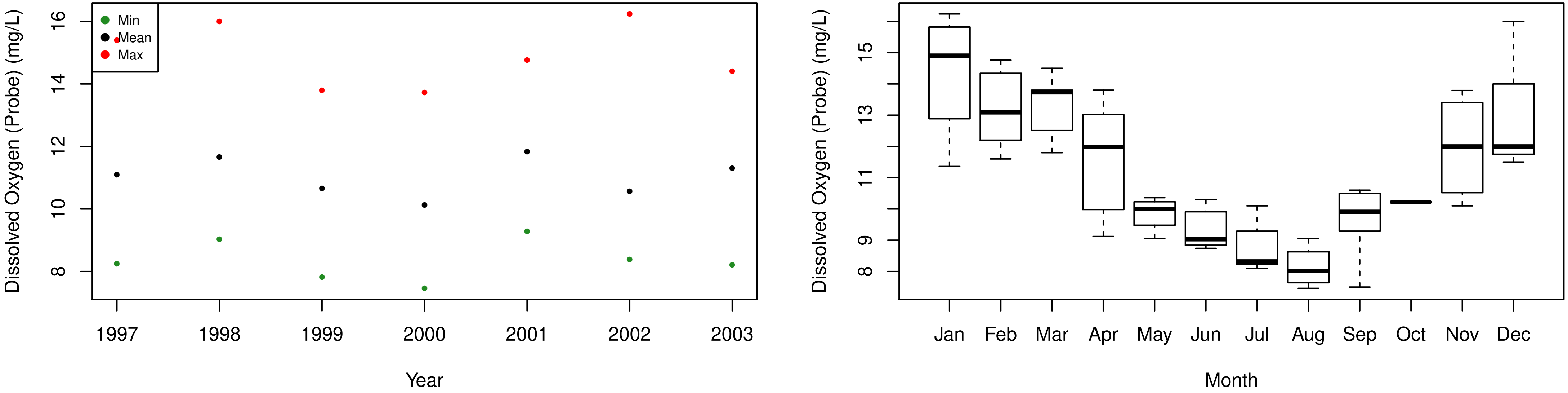
(d) Boxplot by month

Poplar Cr near Mouth–Elgin (25): Dissolved Oxygen (Probe) (mg/L)



(a) Observation data

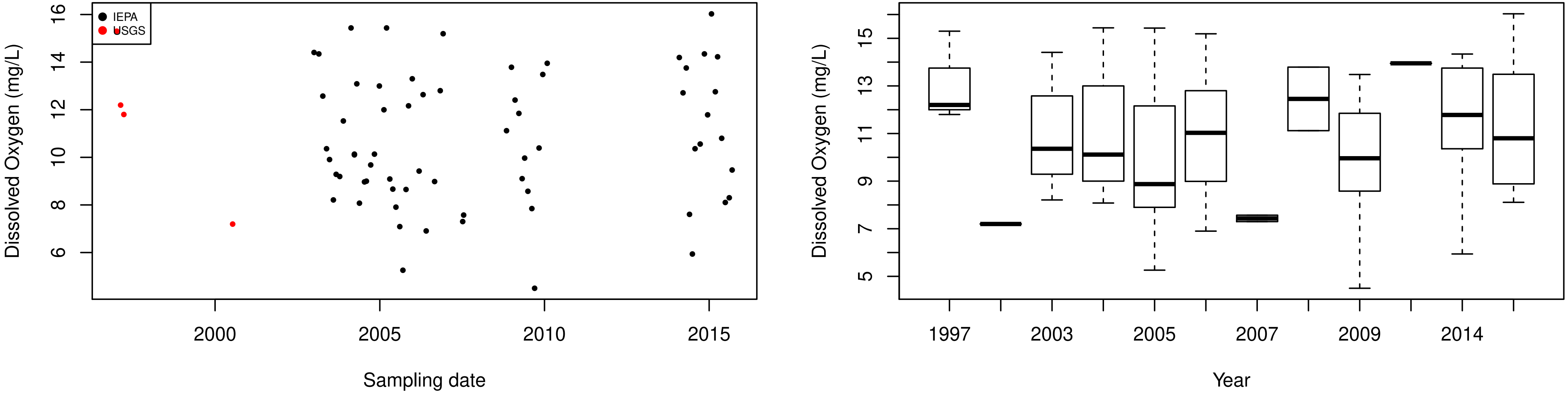
(b) Boxplot by year



(c) Annual values

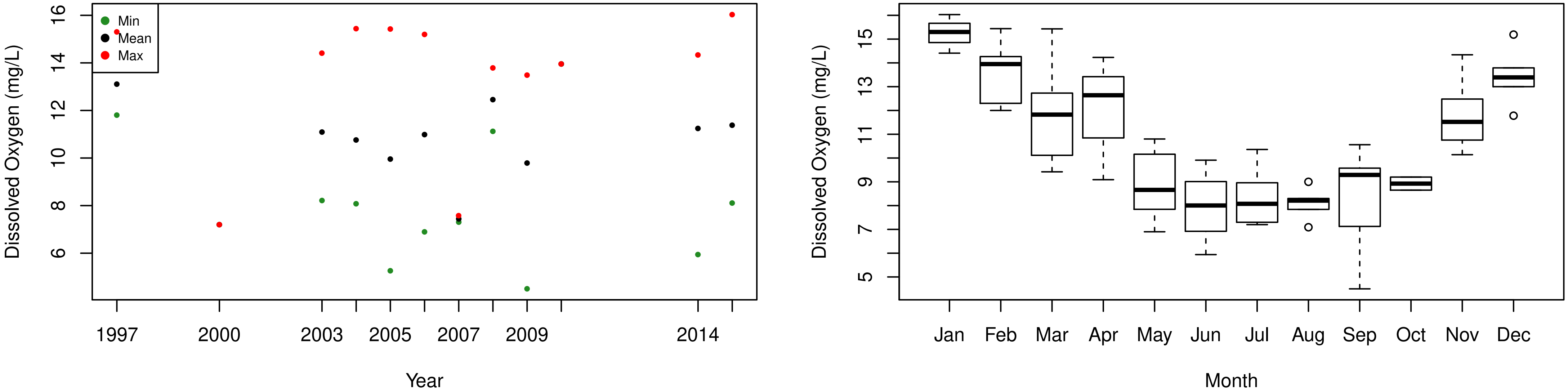
(d) Boxplot by month

Poplar Cr near Mouth–Elgin (25): Dissolved Oxygen (mg/L)



(a) Observation data

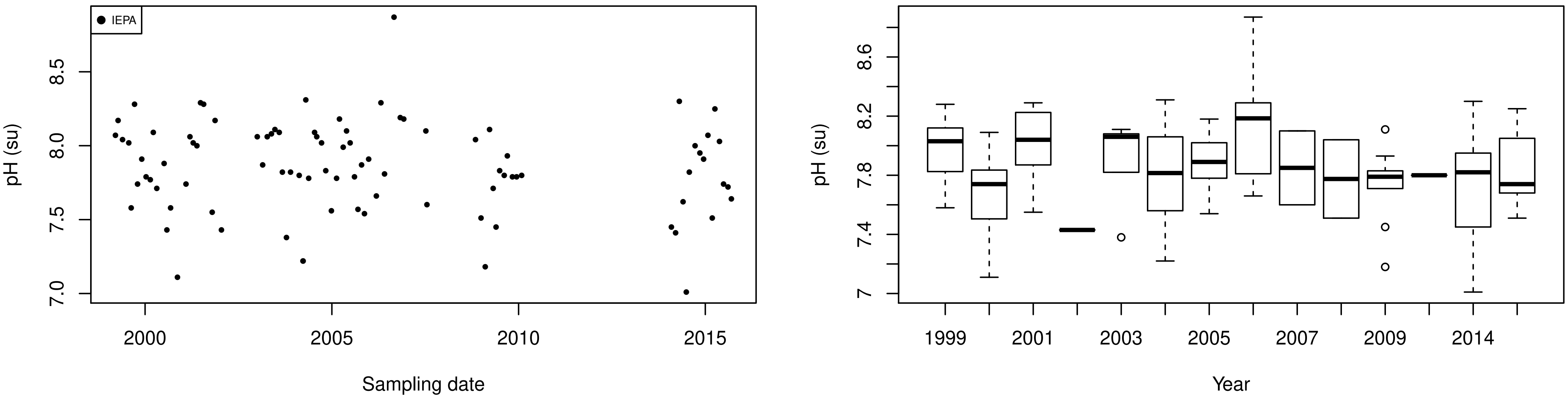
(b) Boxplot by year



(c) Annual values

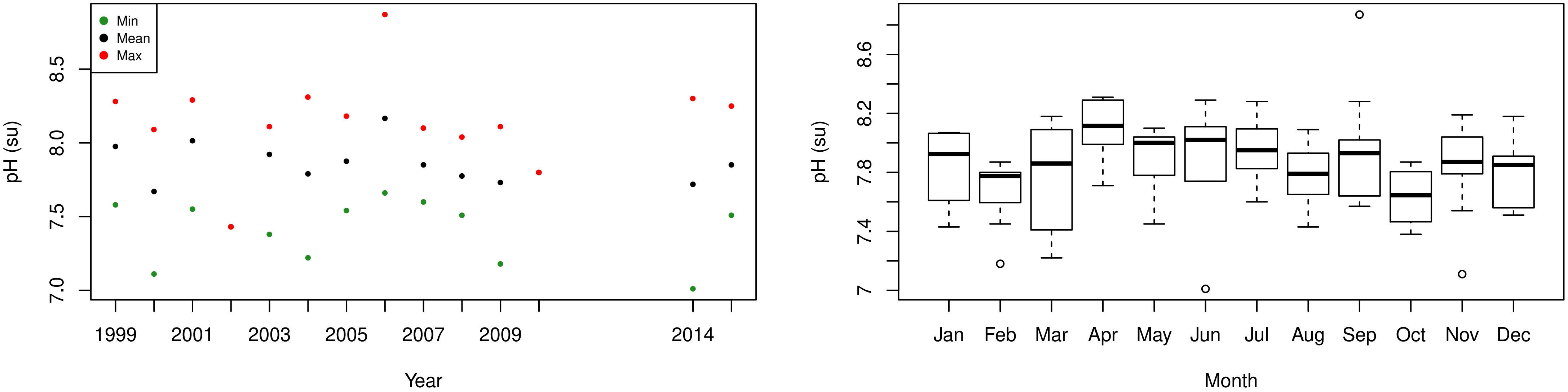
(d) Boxplot by month

Poplar Cr near Mouth–Elgin (25): pH (su)



(a) Observation data

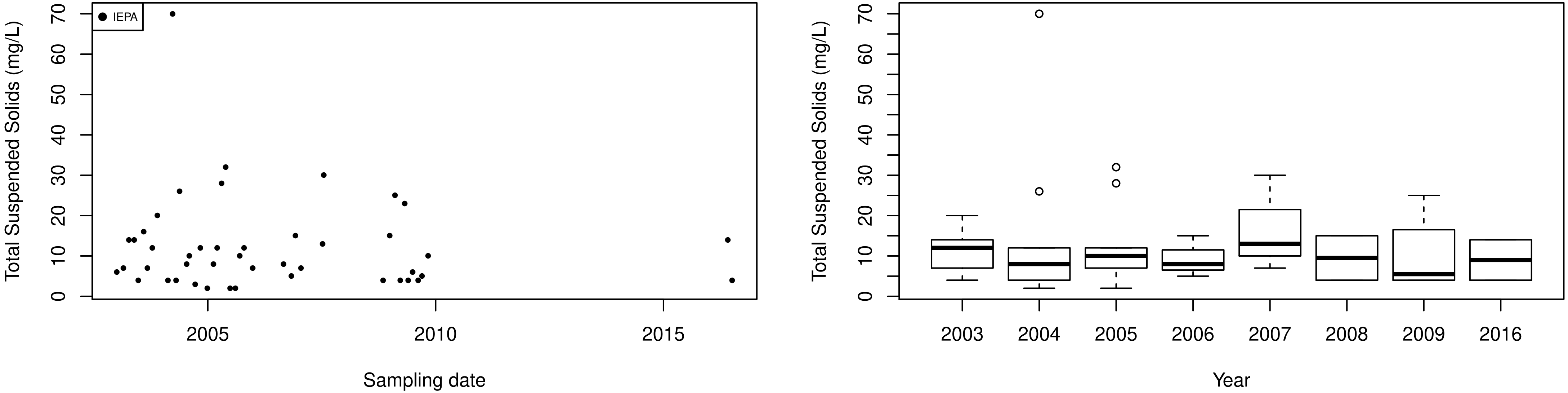
(b) Boxplot by year



(c) Annual values

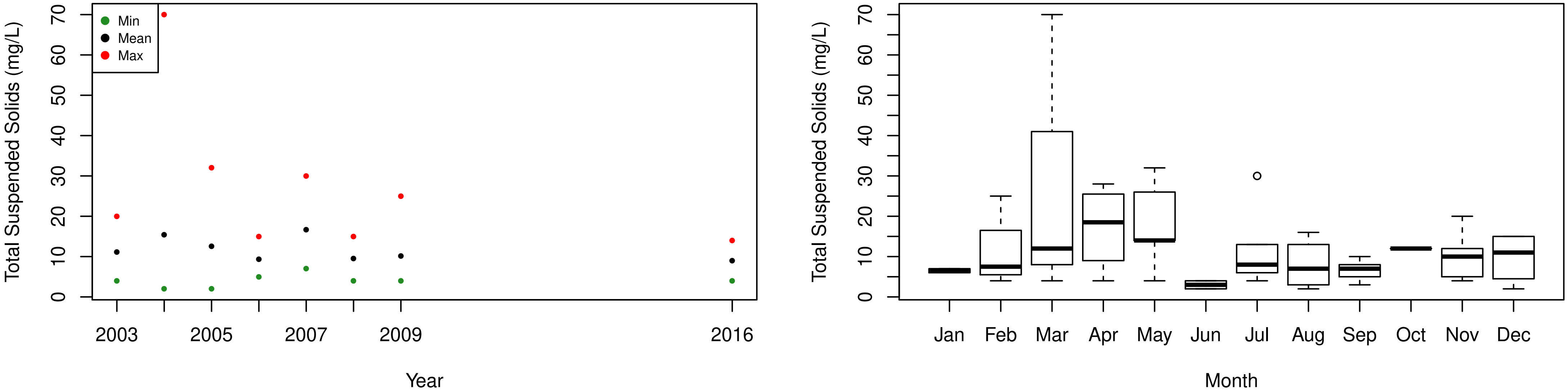
(d) Boxplot by month

Poplar Cr near Mouth–Elgin (25): Total Suspended Solids (mg/L)



(a) Observation data

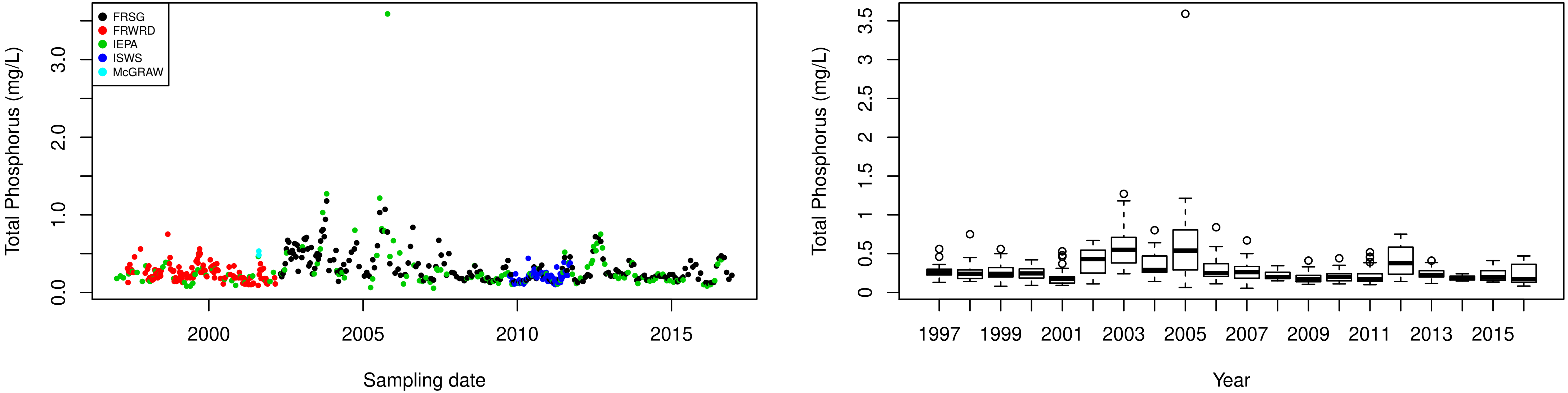
(b) Boxplot by year



(c) Annual values

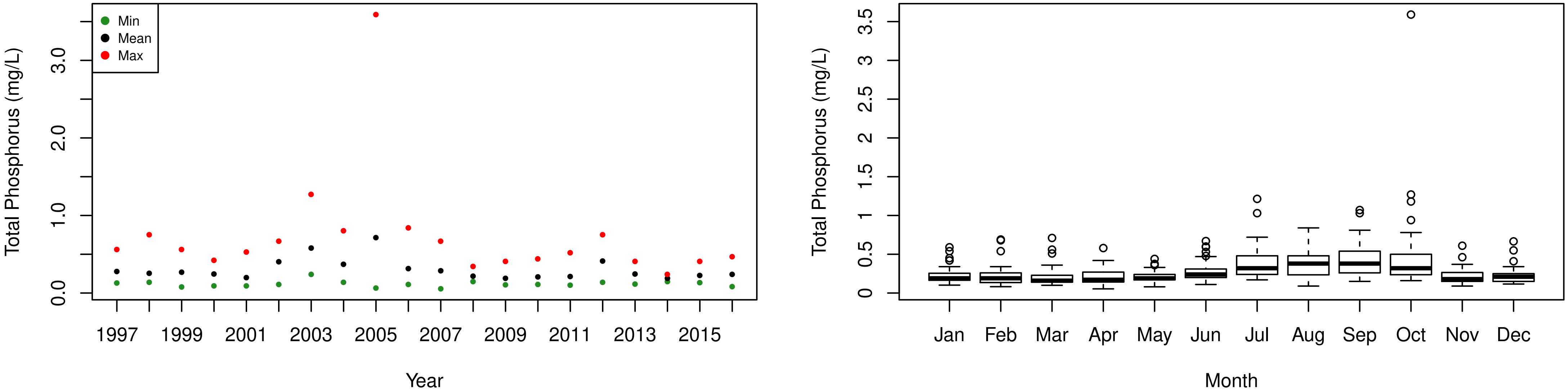
(d) Boxplot by month

Fox River at South Elgin (26): Total Phosphorus (mg/L)



(a) Observation data

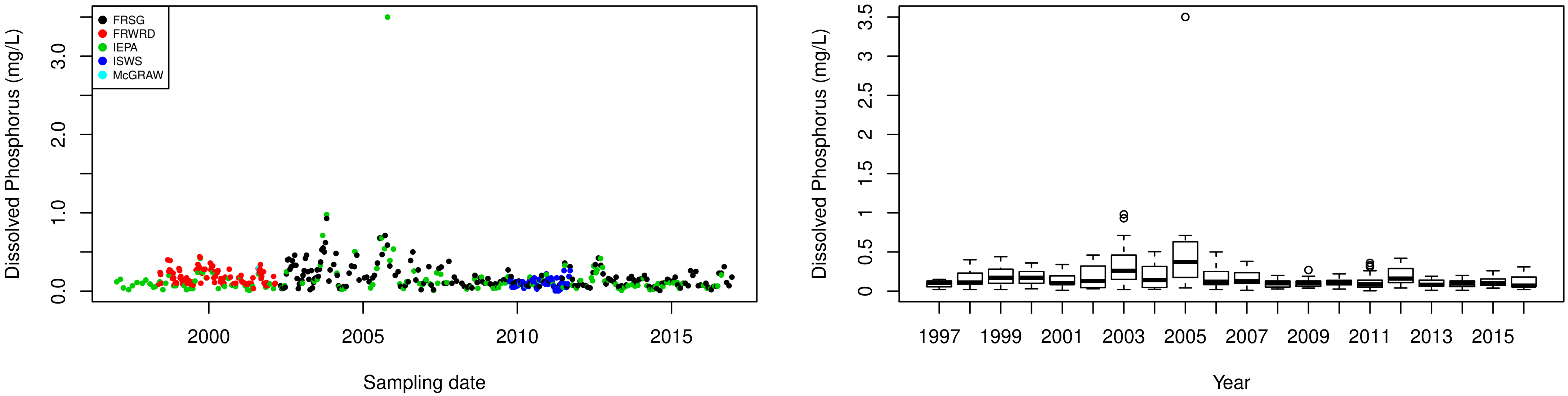
(b) Boxplot by year



(c) Annual values

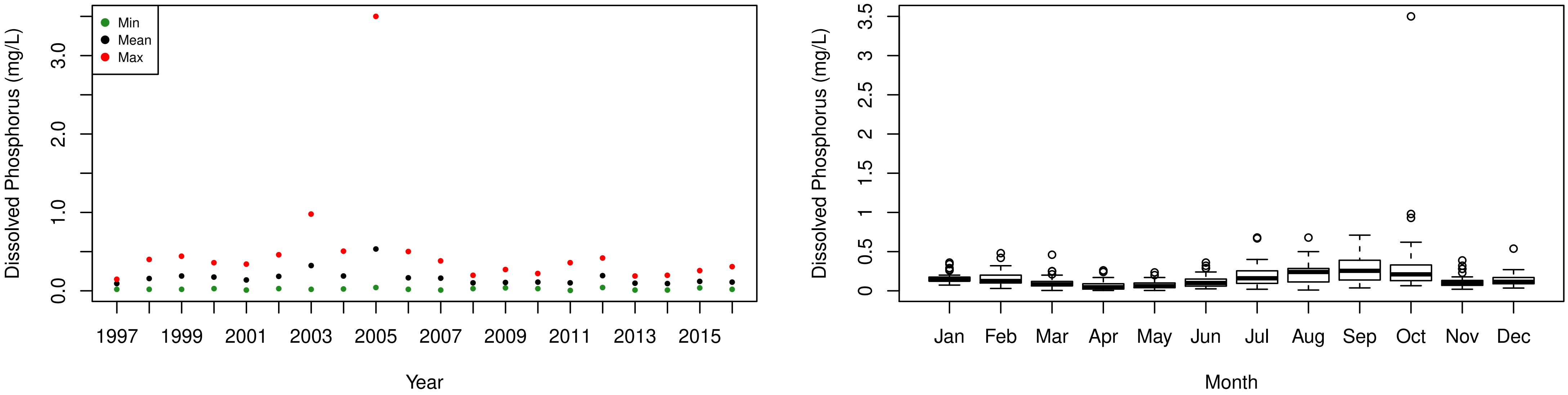
(d) Boxplot by month

Fox River at South Elgin (26): Dissolved Phosphorus (mg/L)



(a) Observation data

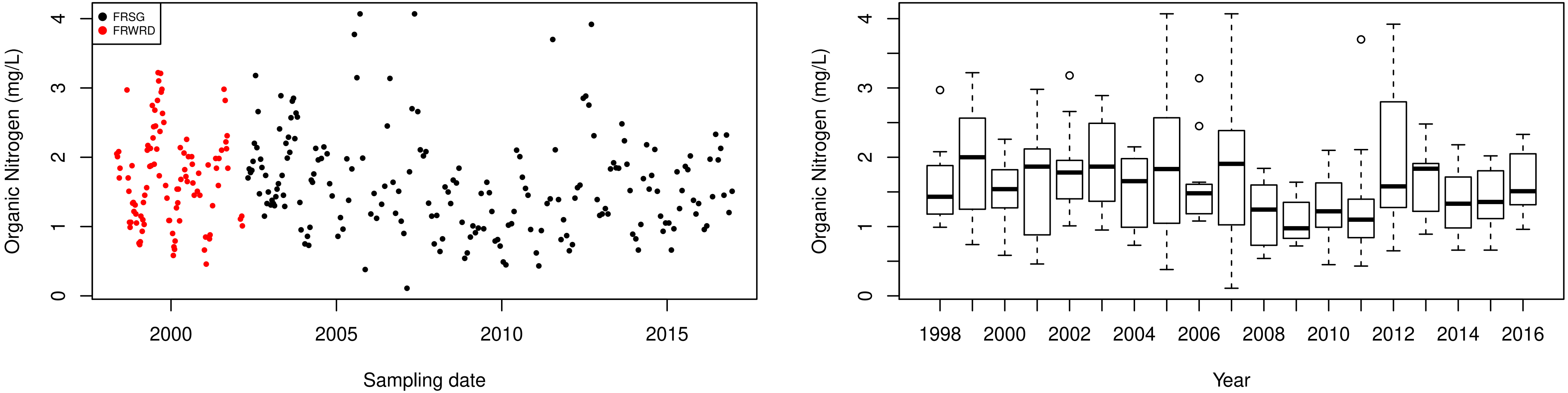
(b) Boxplot by year



(c) Annual values

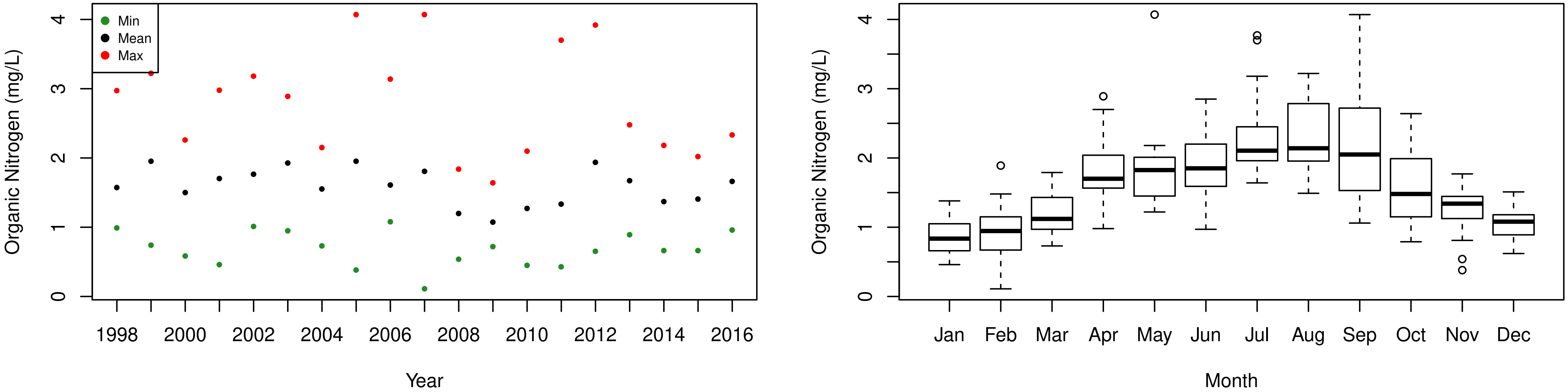
(d) Boxplot by month

Fox River at South Elgin (26): Organic Nitrogen (mg/L)



(a) Observation data

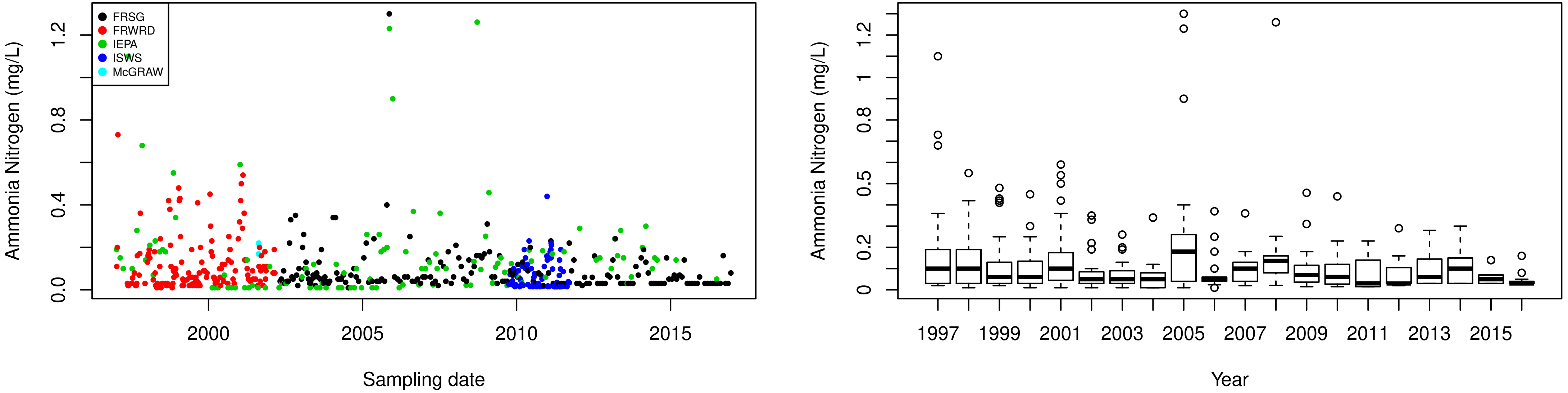
(b) Boxplot by year



(c) Annual values

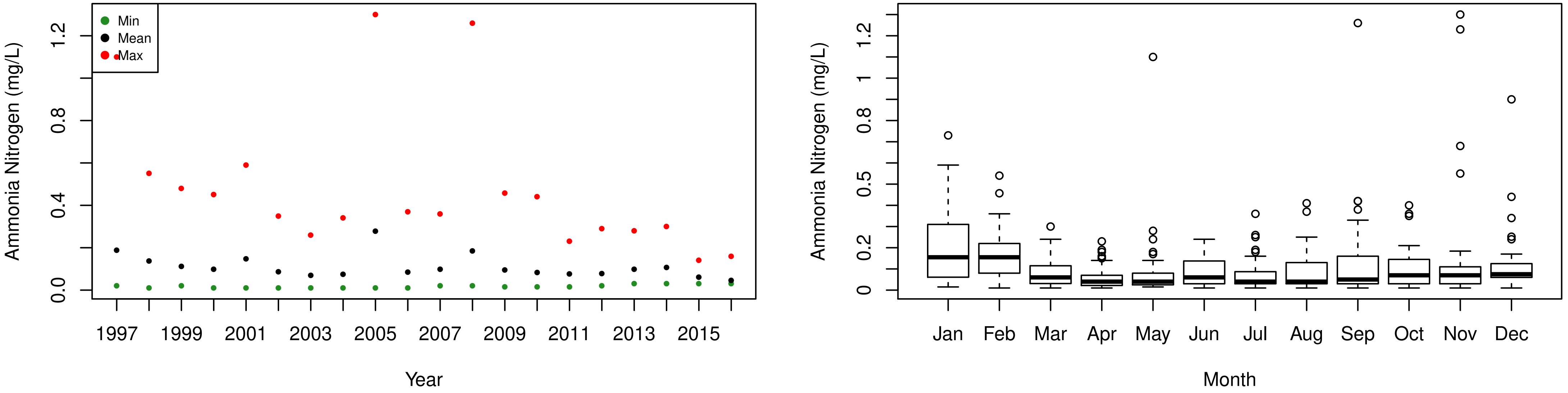
(d) Boxplot by month

Fox River at South Elgin (26): Ammonia Nitrogen (mg/L)



(a) Observation data

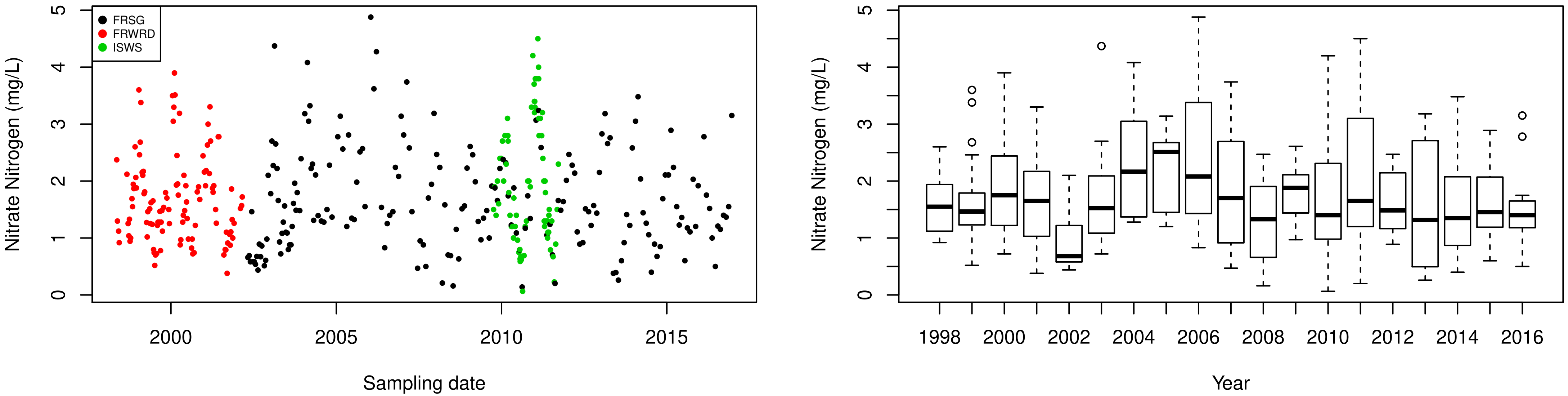
(b) Boxplot by year



(c) Annual values

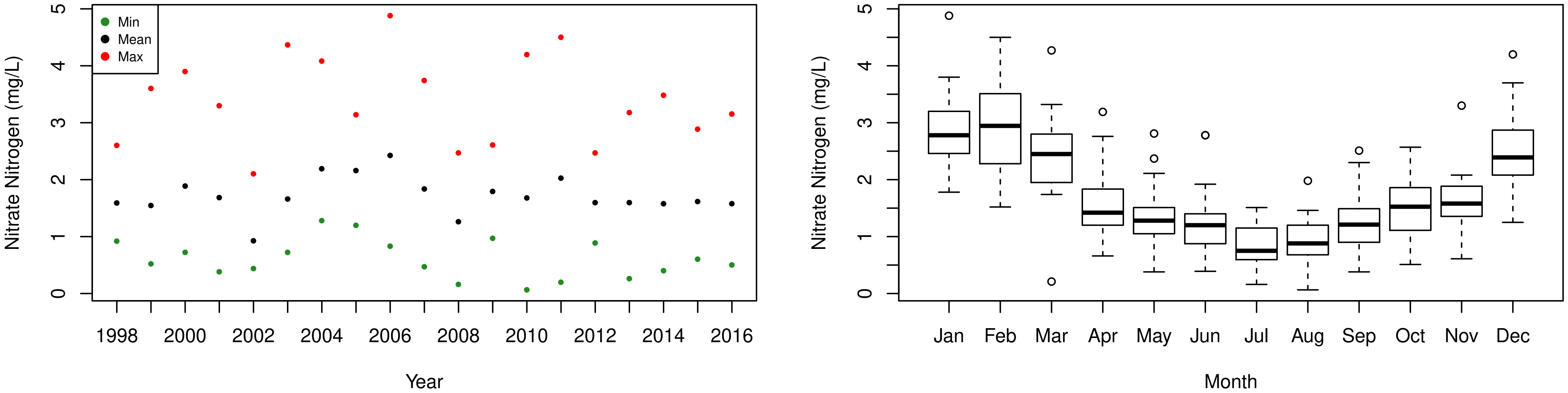
(d) Boxplot by month

Fox River at South Elgin (26): Nitrate Nitrogen (mg/L)



(a) Observation data

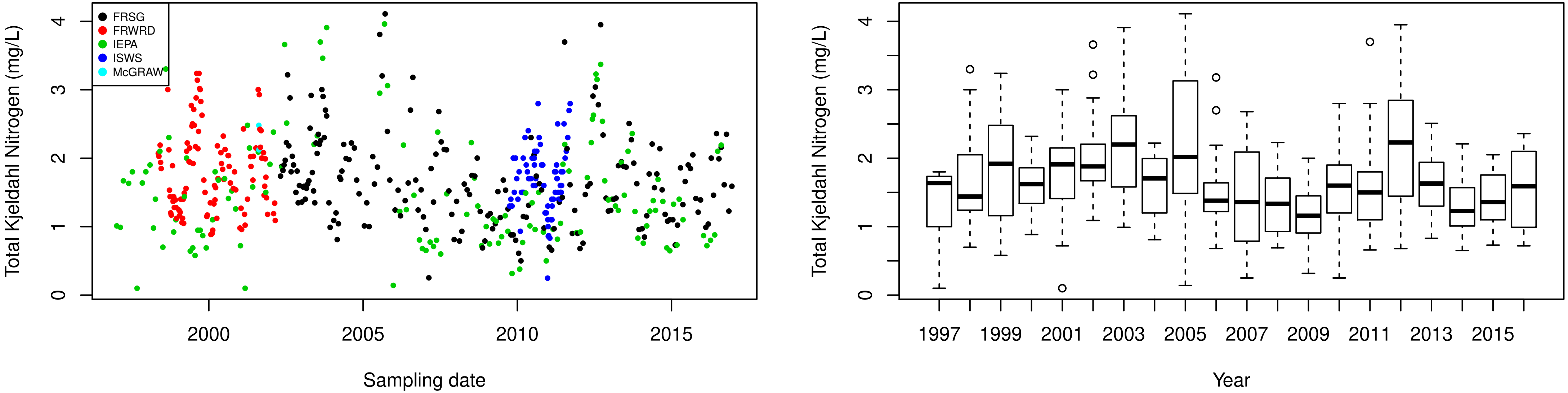
(b) Boxplot by year



(c) Annual values

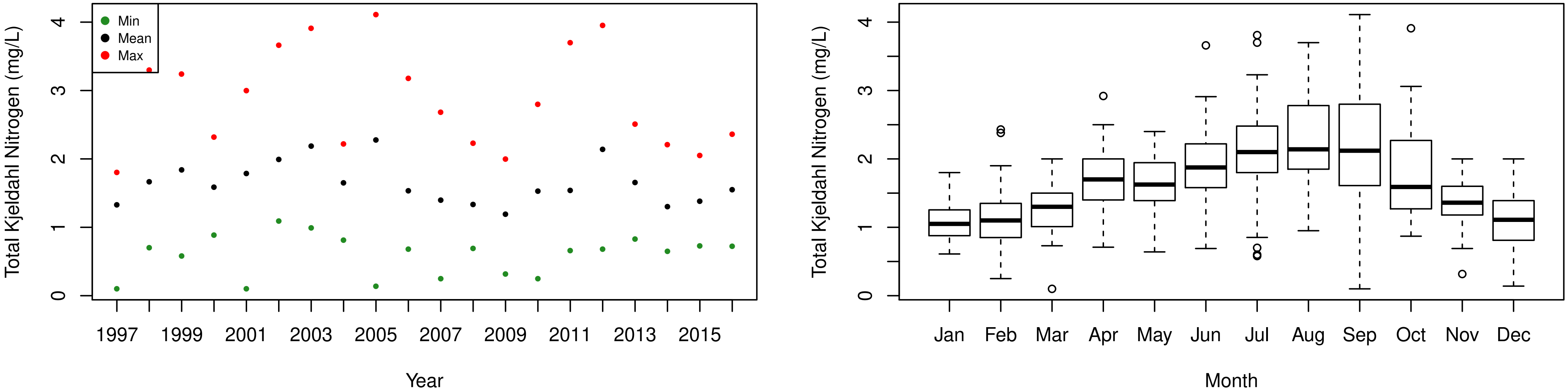
(d) Boxplot by month

Fox River at South Elgin (26): Total Kjeldahl Nitrogen (mg/L)



(a) Observation data

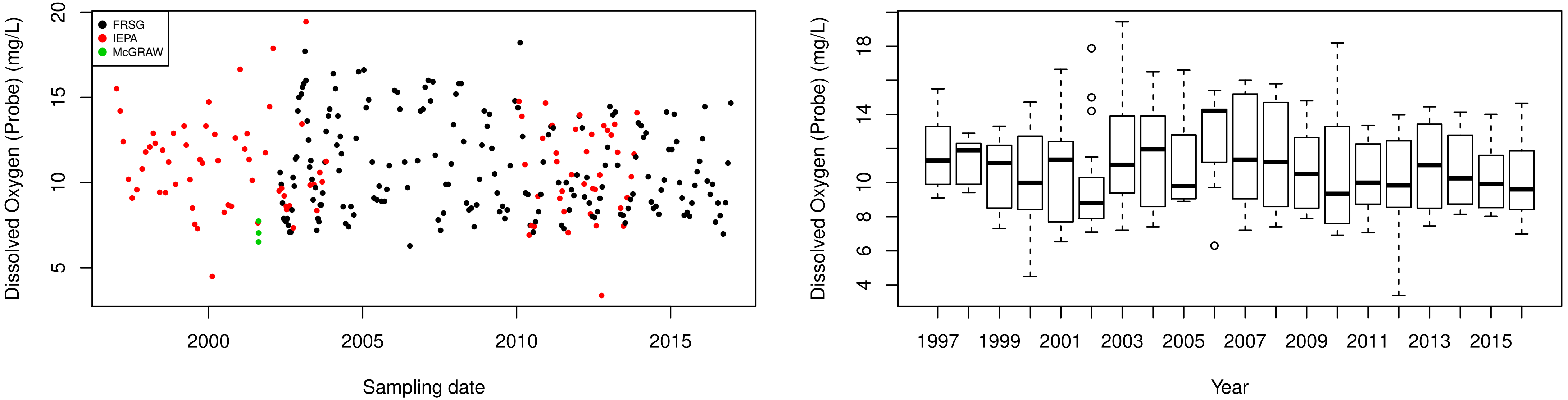
(b) Boxplot by year



(c) Annual values

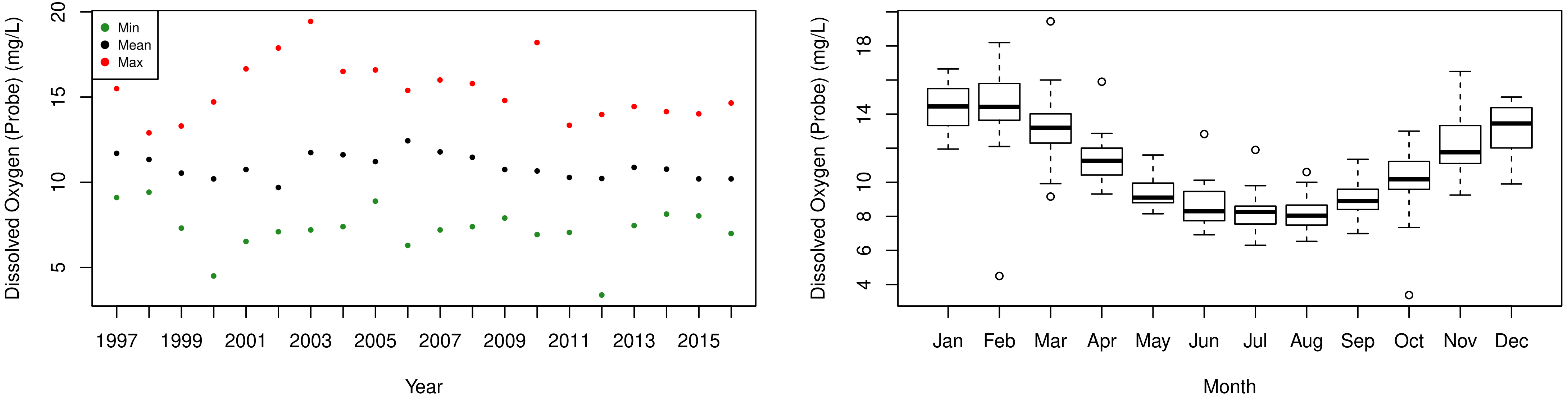
(d) Boxplot by month

Fox River at South Elgin (26): Dissolved Oxygen (Probe) (mg/L)



(a) Observation data

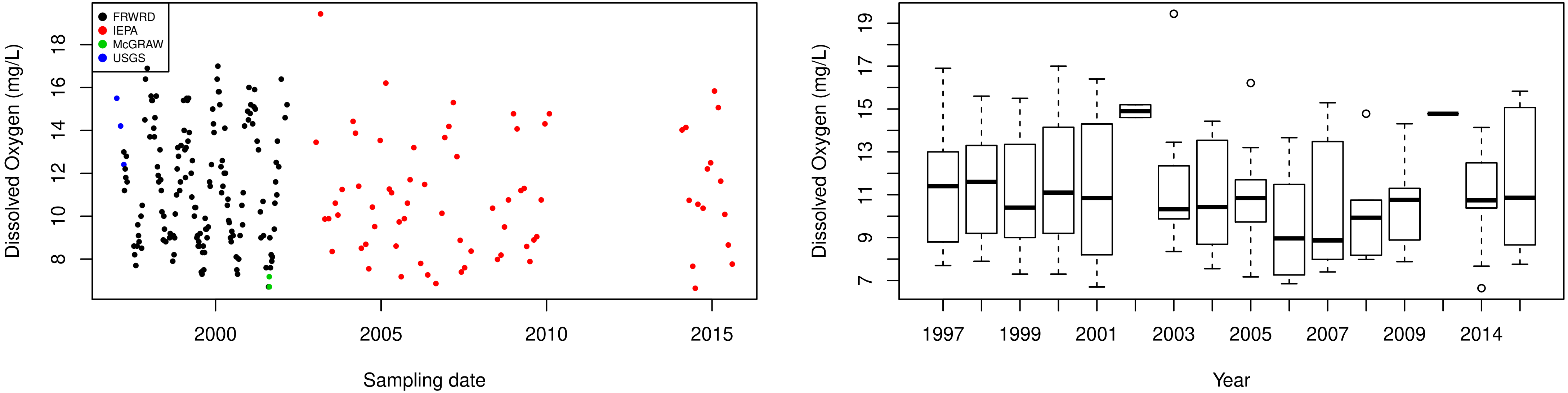
(b) Boxplot by year



(c) Annual values

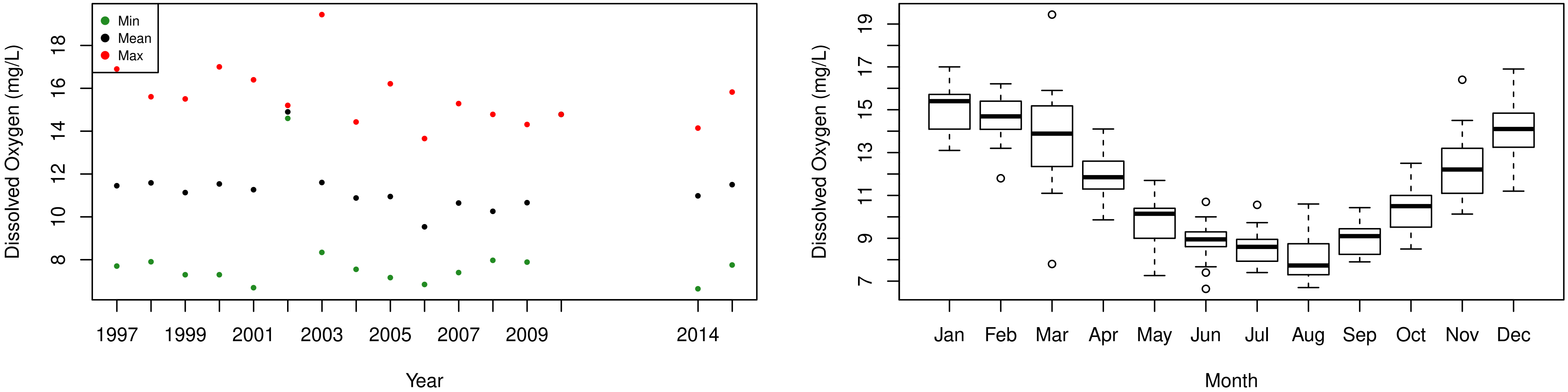
(d) Boxplot by month

Fox River at South Elgin (26): Dissolved Oxygen (mg/L)



(a) Observation data

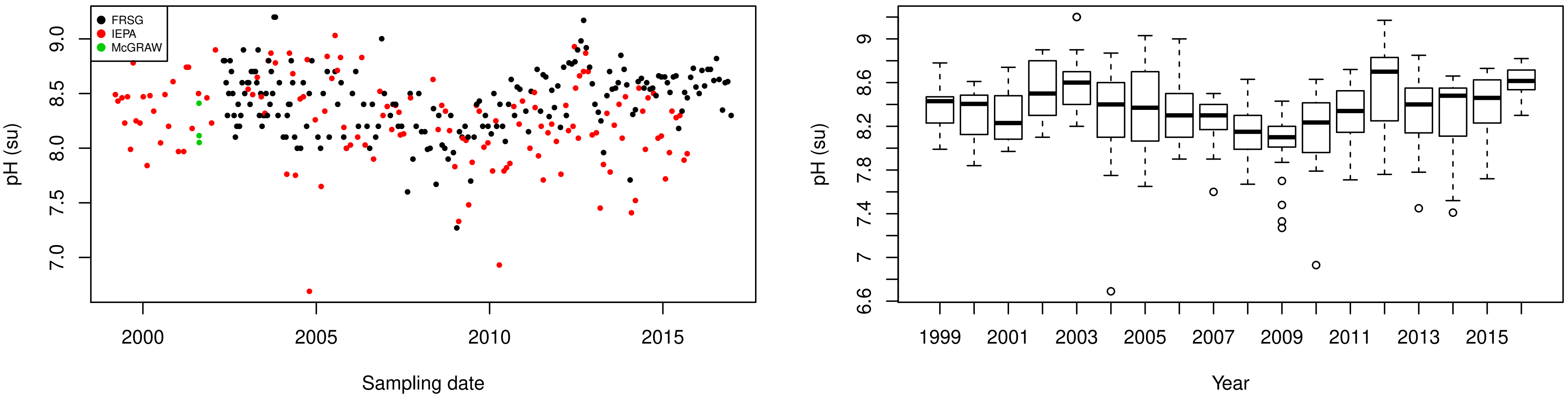
(b) Boxplot by year



(c) Annual values

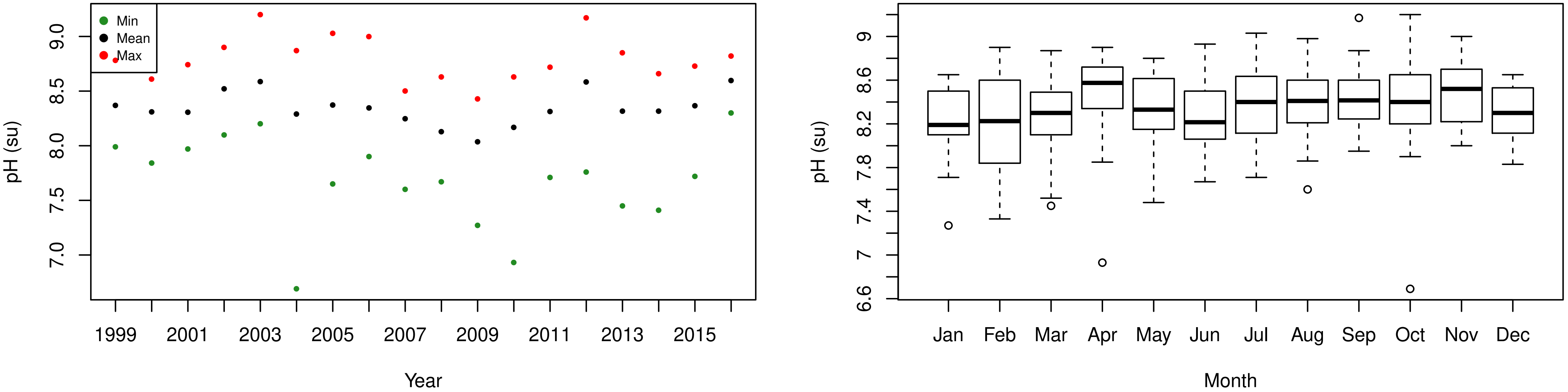
(d) Boxplot by month

Fox River at South Elgin (26): pH (su)



(a) Observation data

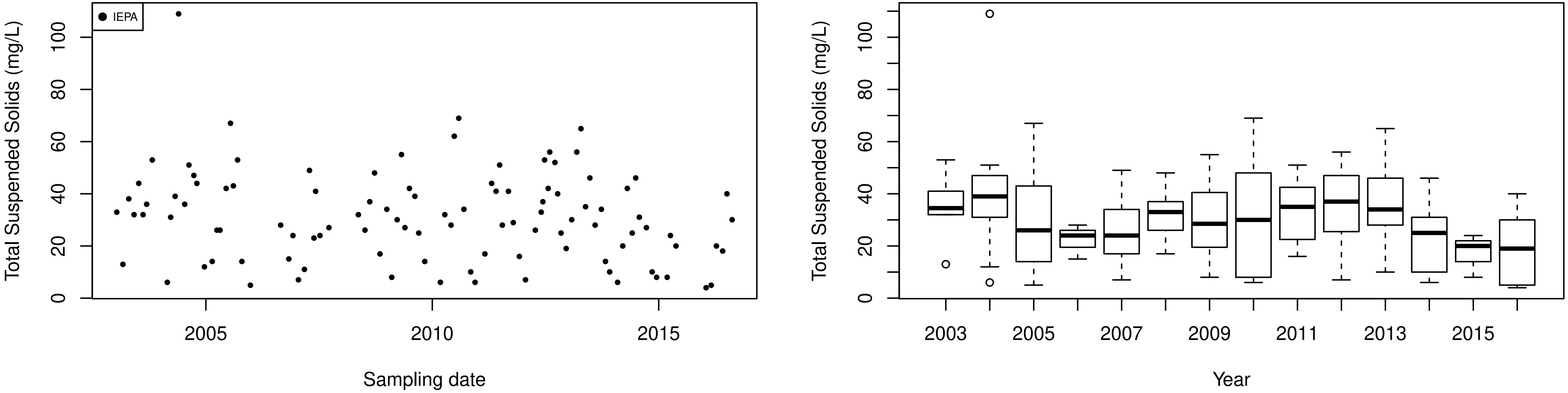
(b) Boxplot by year



(c) Annual values

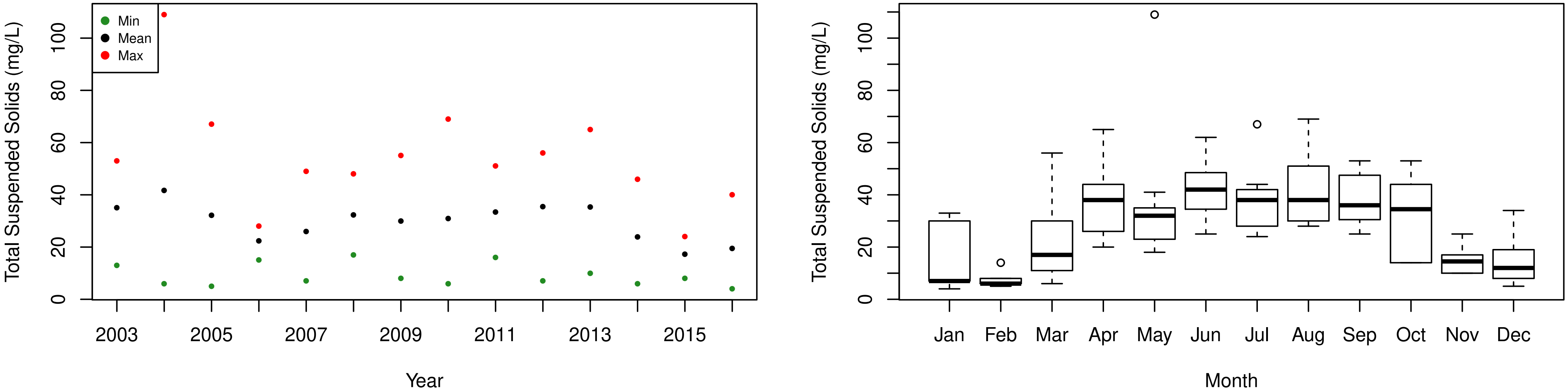
(d) Boxplot by month

Fox River at South Elgin (26): Total Suspended Solids (mg/L)



(a) Observation data

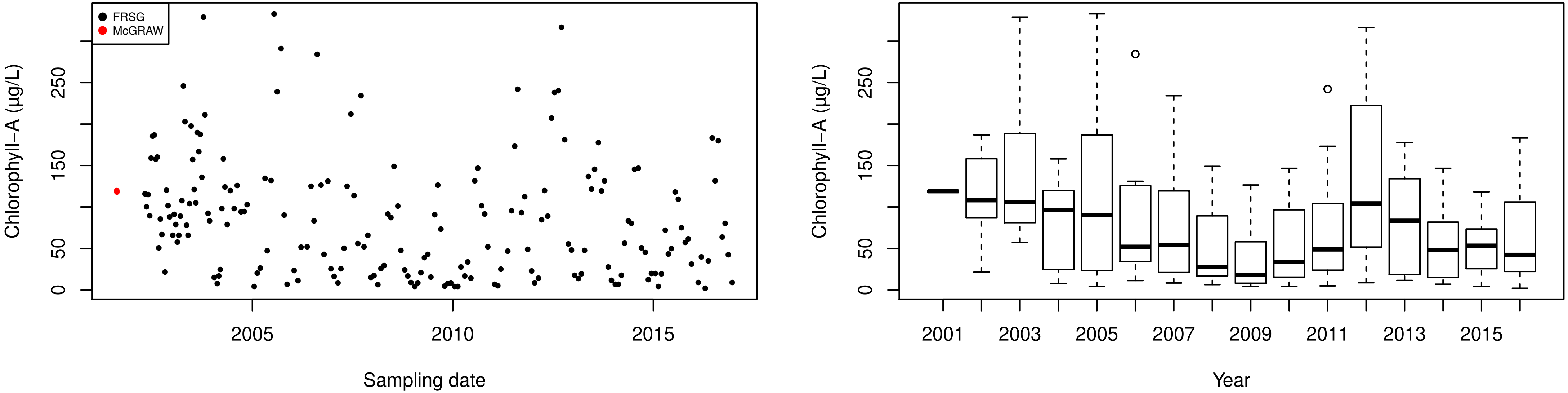
(b) Boxplot by year



(c) Annual values

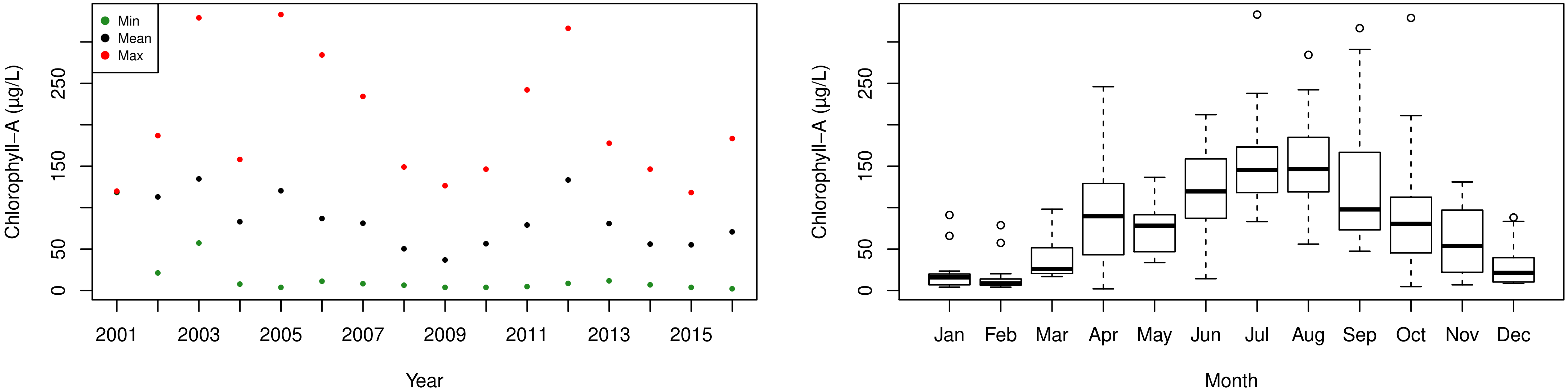
(d) Boxplot by month

Fox River at South Elgin (26): Chlorophyll–A (µg/L)



(a) Observation data

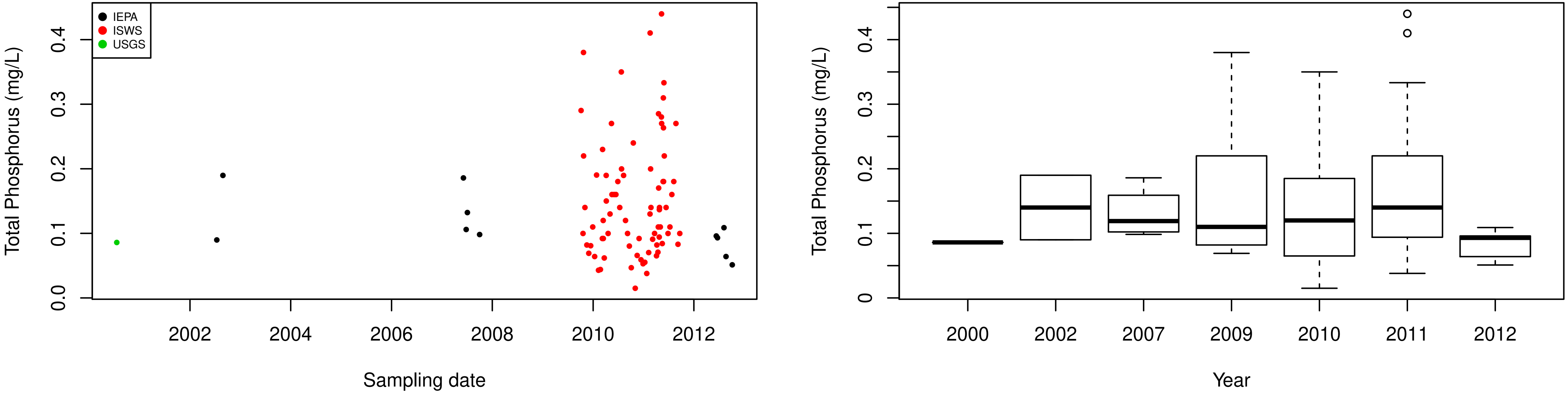
(b) Boxplot by year



(c) Annual values

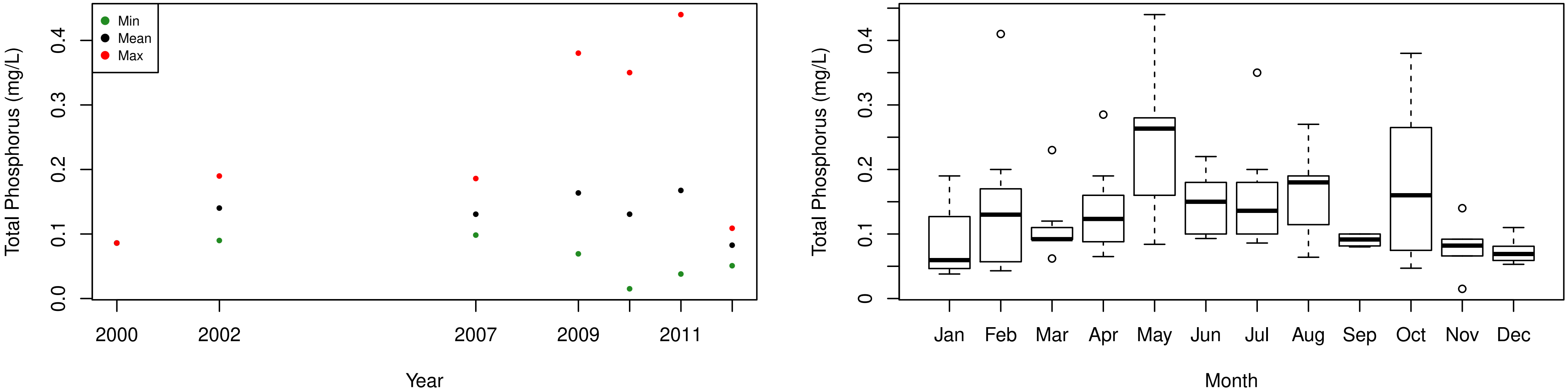
(d) Boxplot by month

Ferson Cr at Rt 34 (14): Total Phosphorus (mg/L)



(a) Observation data

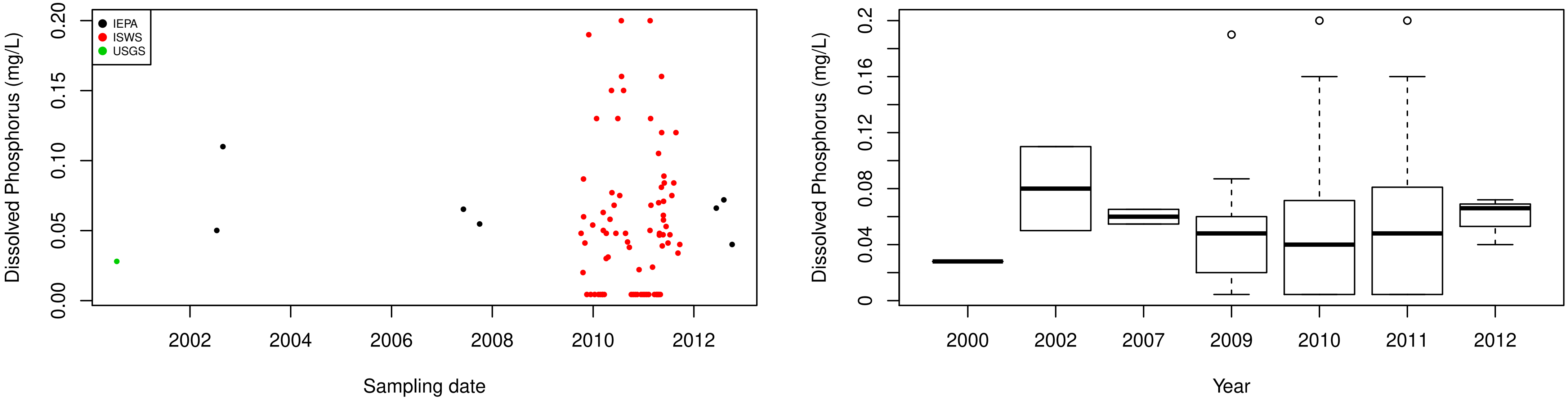
(b) Boxplot by year



(c) Annual values

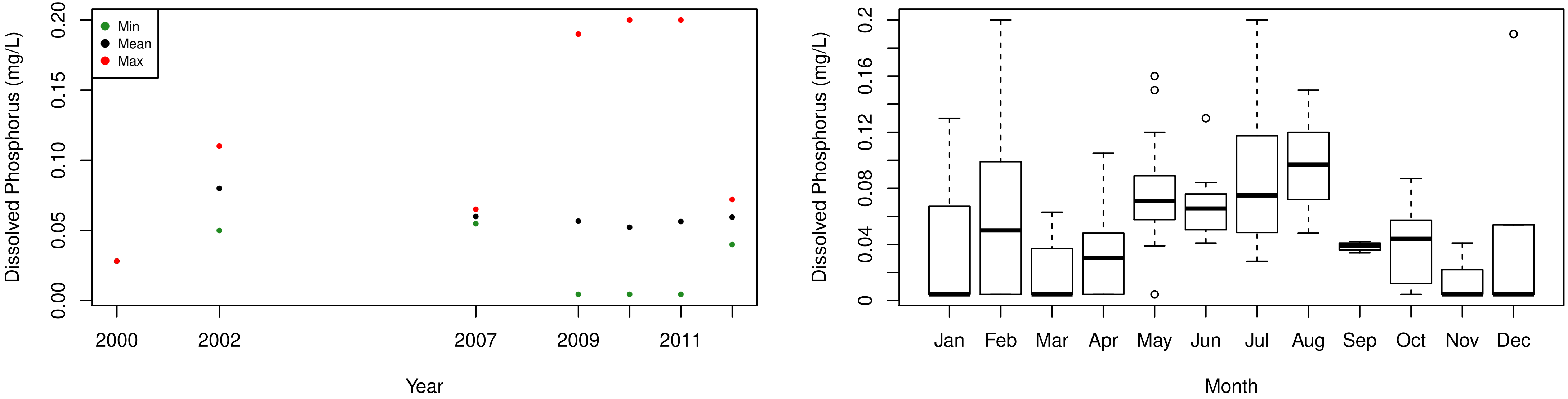
(d) Boxplot by month

Ferson Cr at Rt 34 (14): Dissolved Phosphorus (mg/L)



(a) Observation data

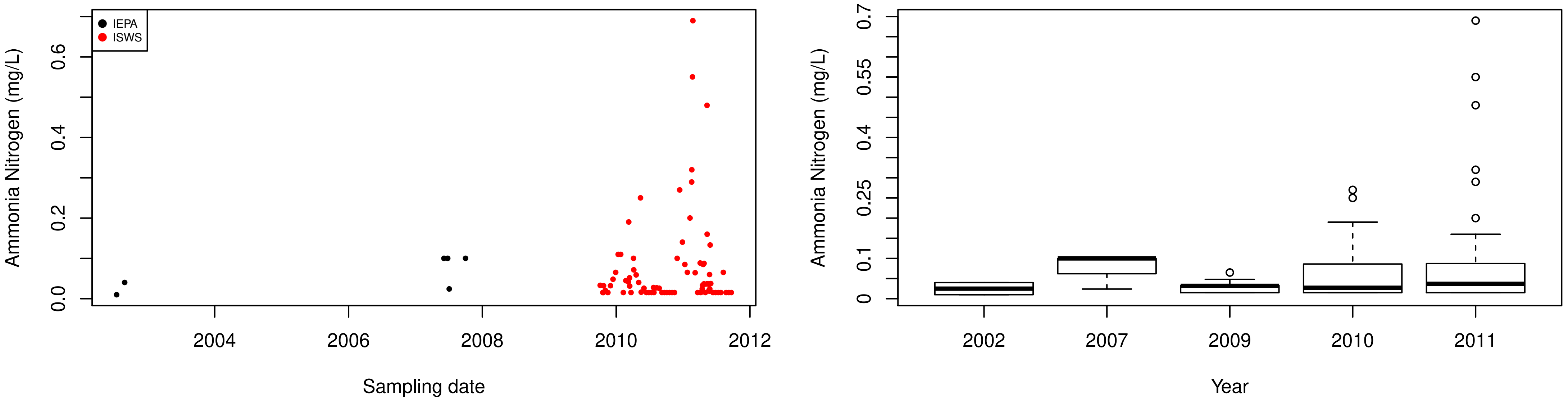
(b) Boxplot by year



(c) Annual values

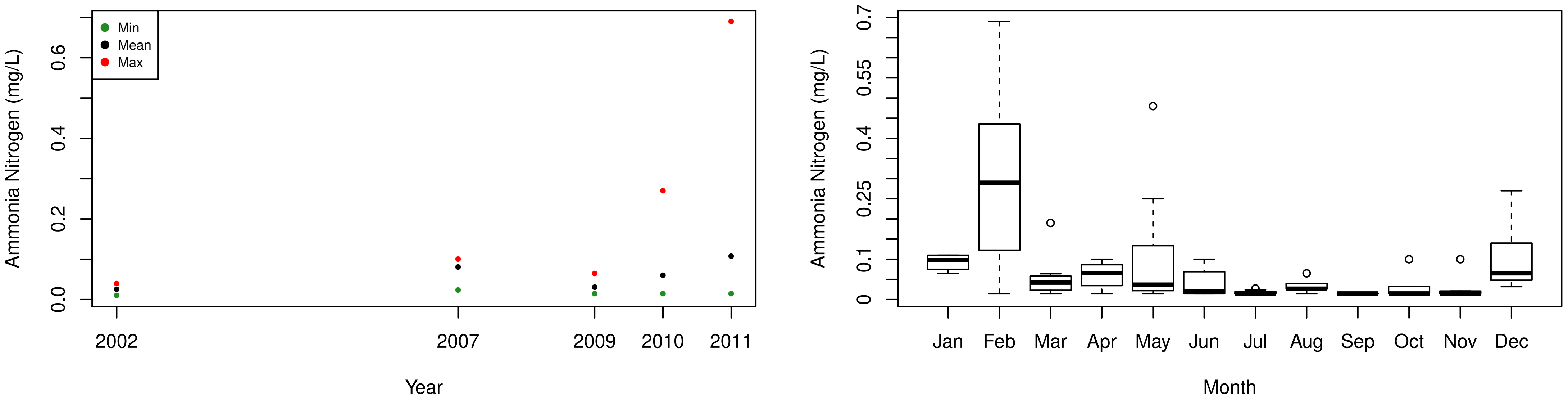
(d) Boxplot by month

Ferson Cr at Rt 34 (14): Ammonia Nitrogen (mg/L)



(a) Observation data

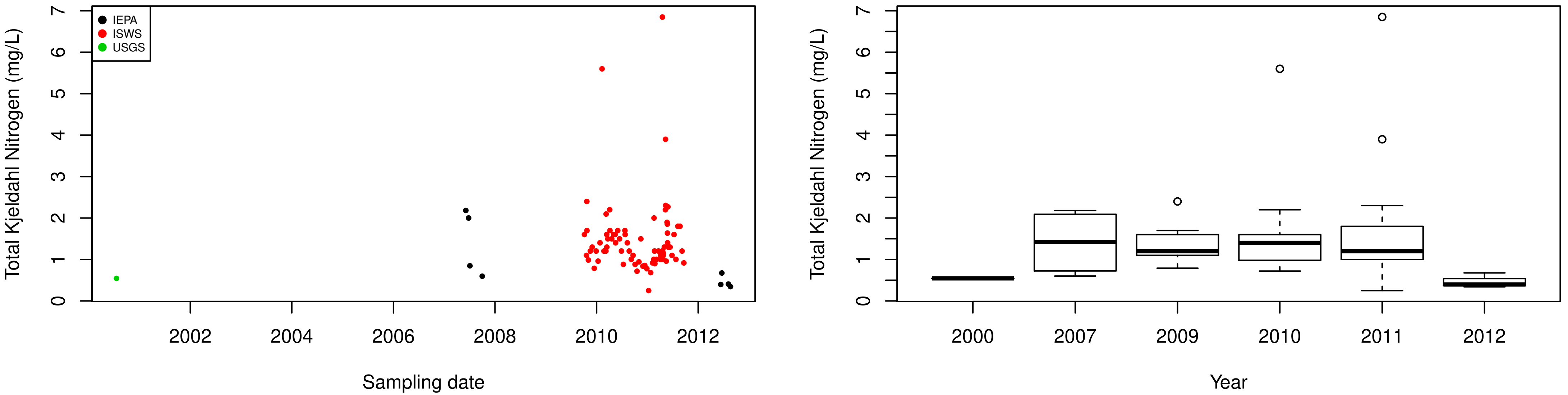
(b) Boxplot by year



(c) Annual values

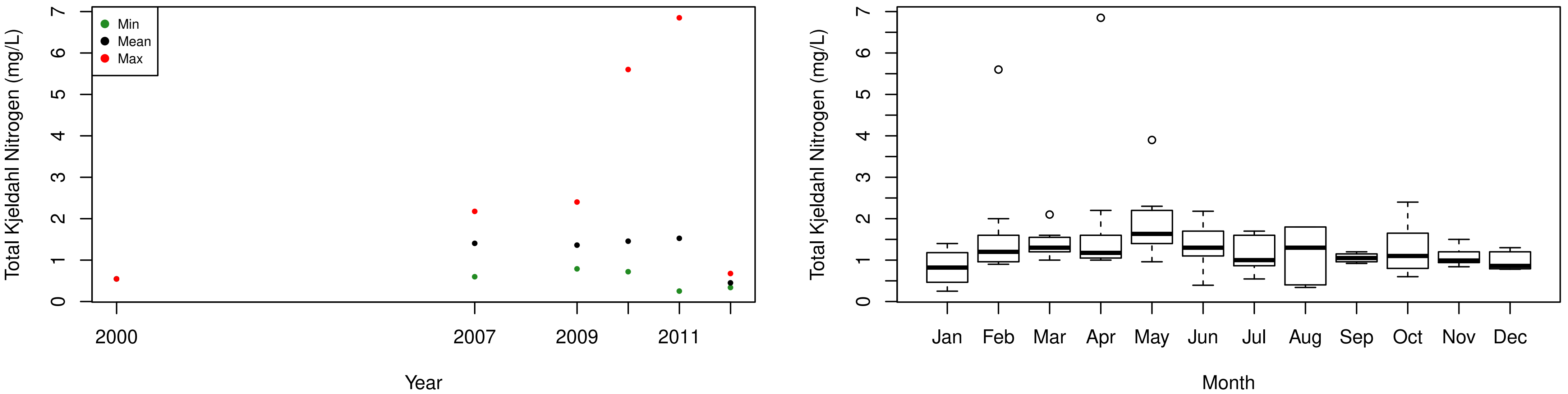
(d) Boxplot by month

Ferson Cr at Rt 34 (14): Total Kjeldahl Nitrogen (mg/L)



(a) Observation data

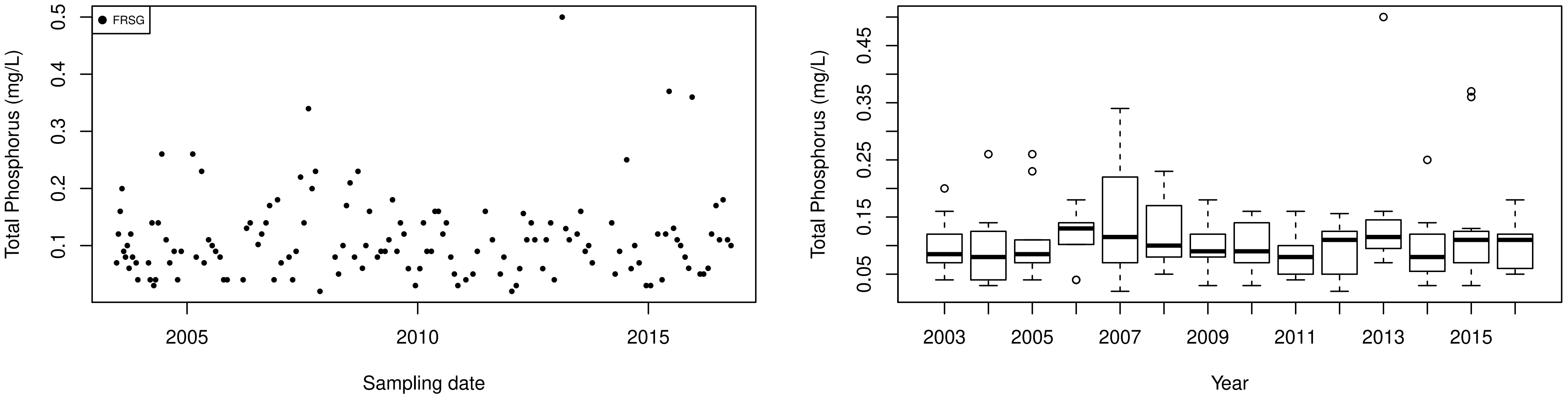
(b) Boxplot by year



(c) Annual values

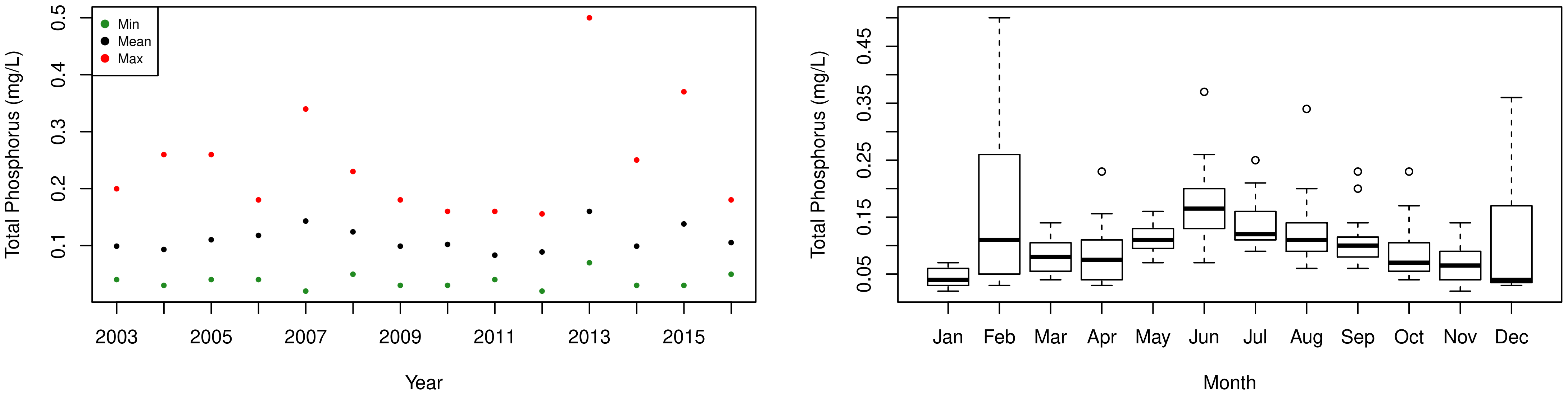
(d) Boxplot by month

Ferson Cr near Mouth−Elgin (79): Total Phosphorus (mg/L)



(a) Observation data

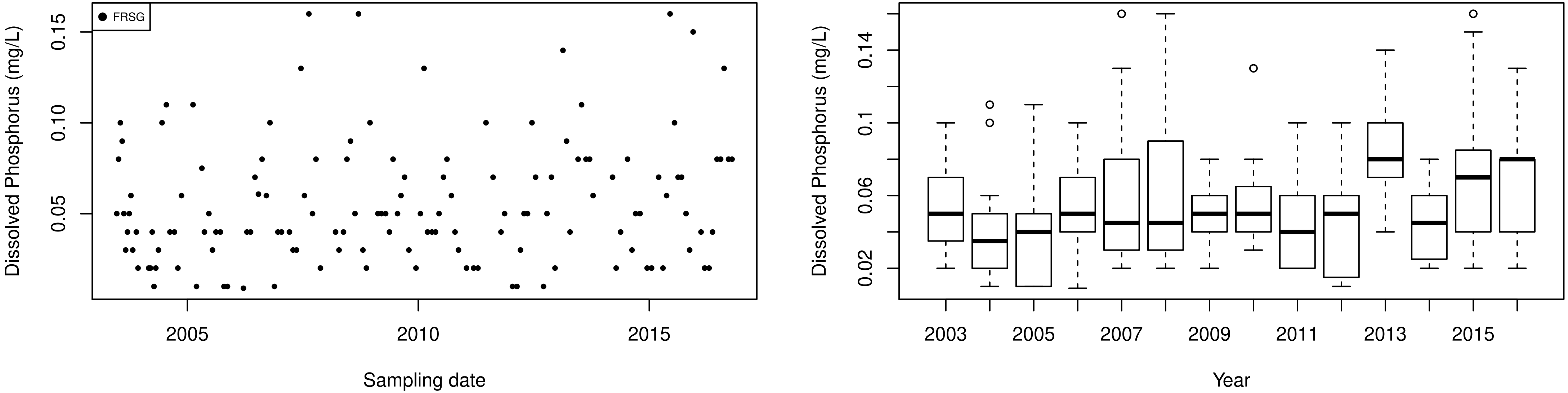
(b) Boxplot by year



(c) Annual values

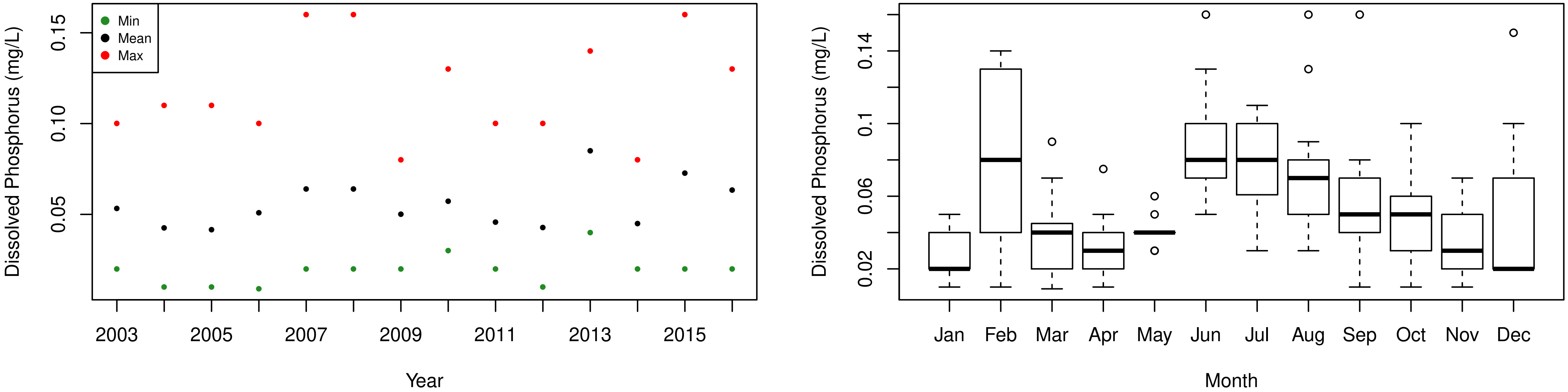
(d) Boxplot by month

Ferson Cr near Mouth−Elgin (79): Dissolved Phosphorus (mg/L)



(a) Observation data

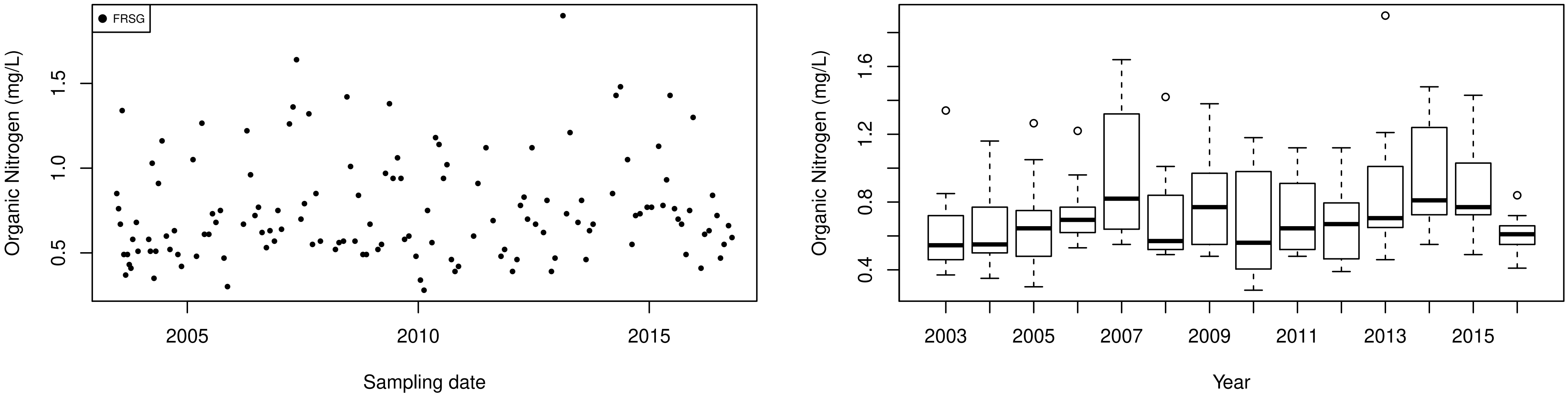
(b) Boxplot by year



(c) Annual values

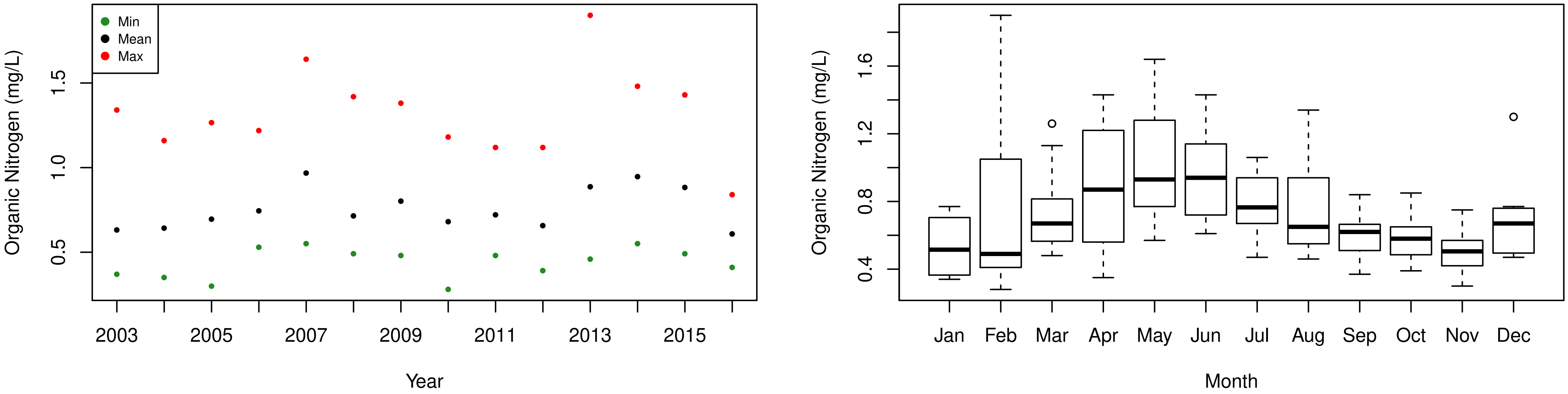
(d) Boxplot by month

Ferson Cr near Mouth–Elgin (79): Organic Nitrogen (mg/L)



(a) Observation data

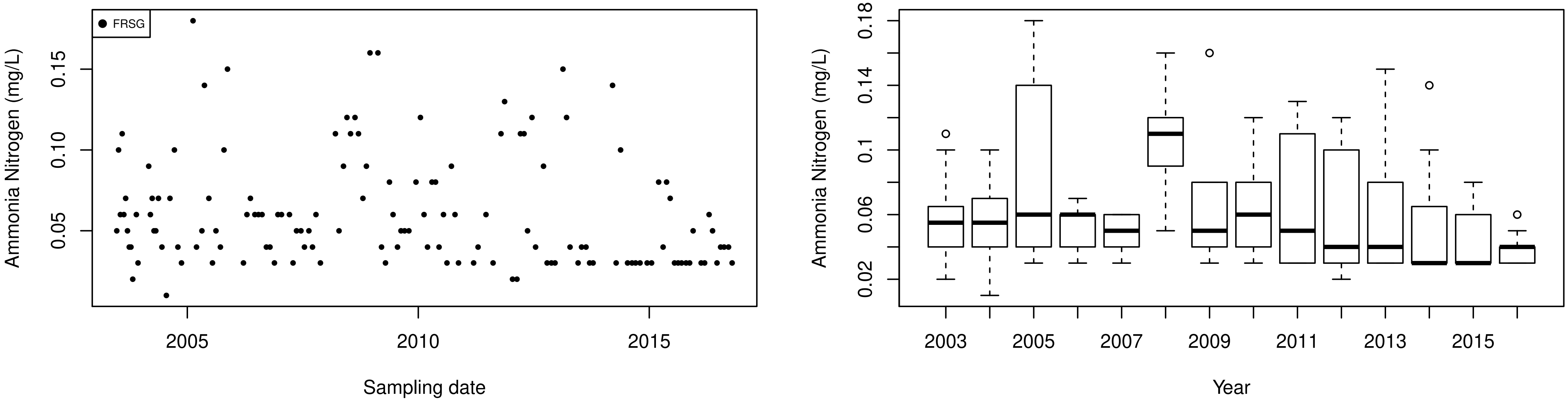
(b) Boxplot by year



(c) Annual values

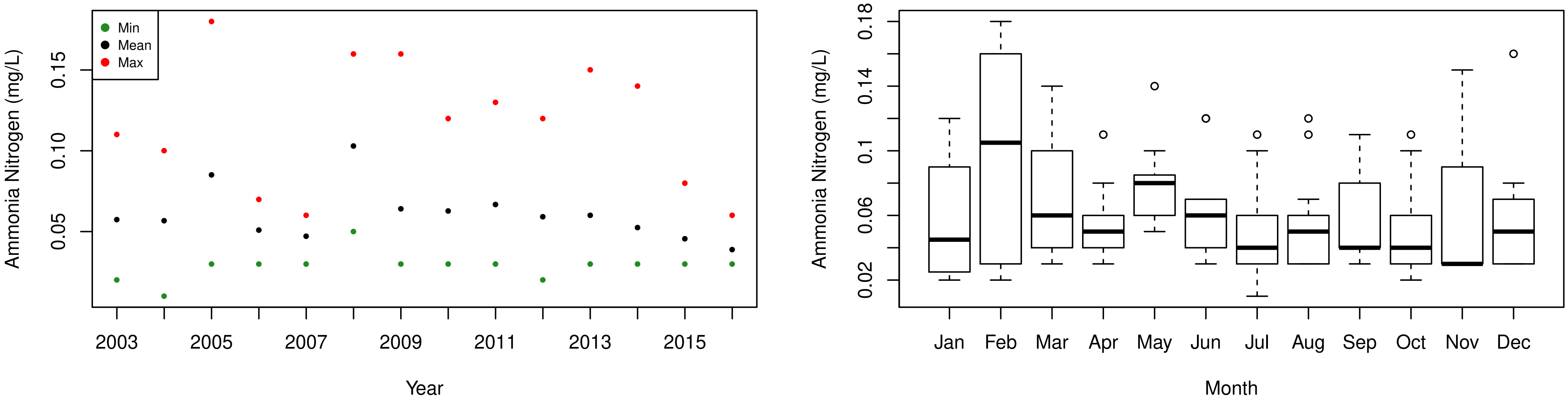
(d) Boxplot by month

Ferson Cr near Mouth–Elgin (79): Ammonia Nitrogen (mg/L)



(a) Observation data

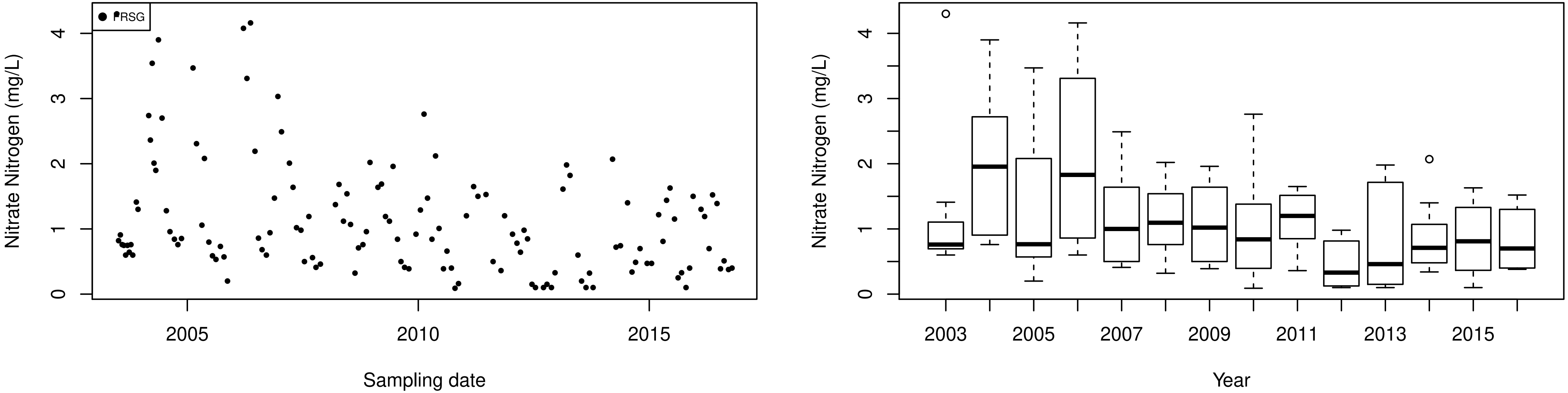
(b) Boxplot by year



(c) Annual values

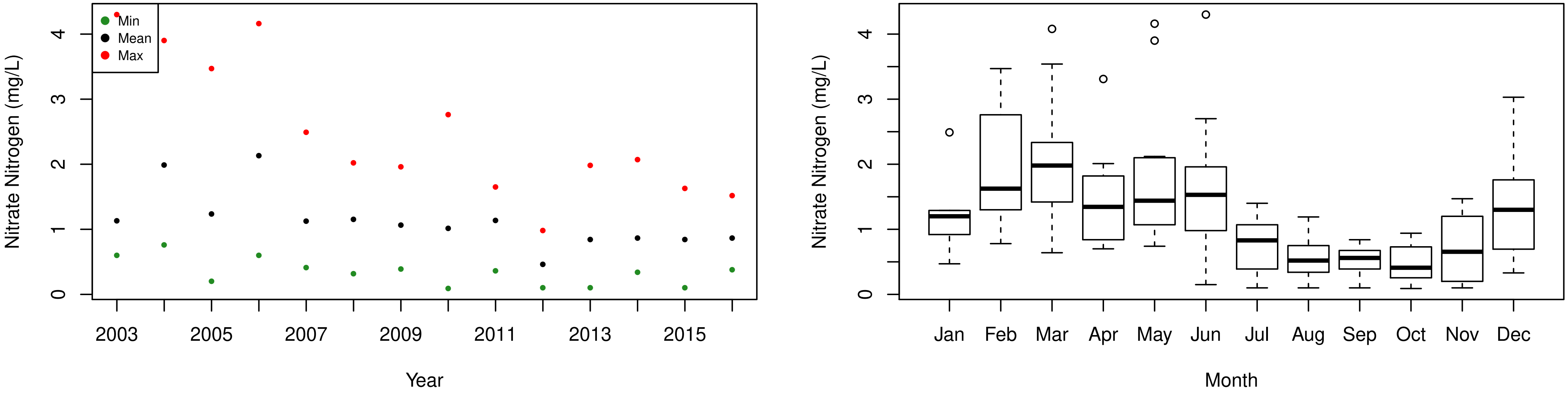
(d) Boxplot by month

Ferson Cr near Mouth–Elgin (79): Nitrate Nitrogen (mg/L)



(a) Observation data

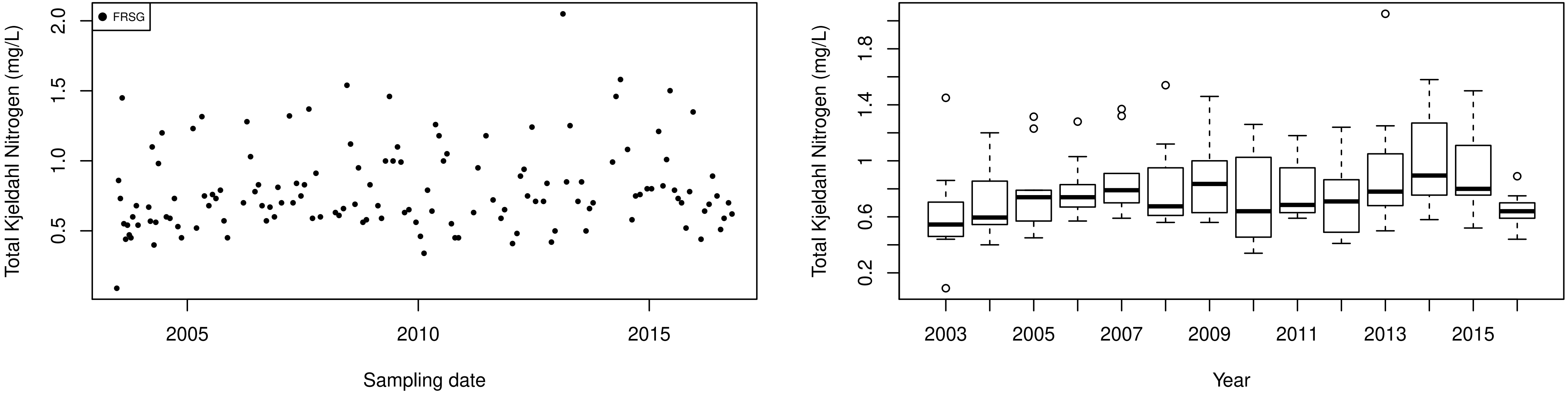
(b) Boxplot by year



(c) Annual values

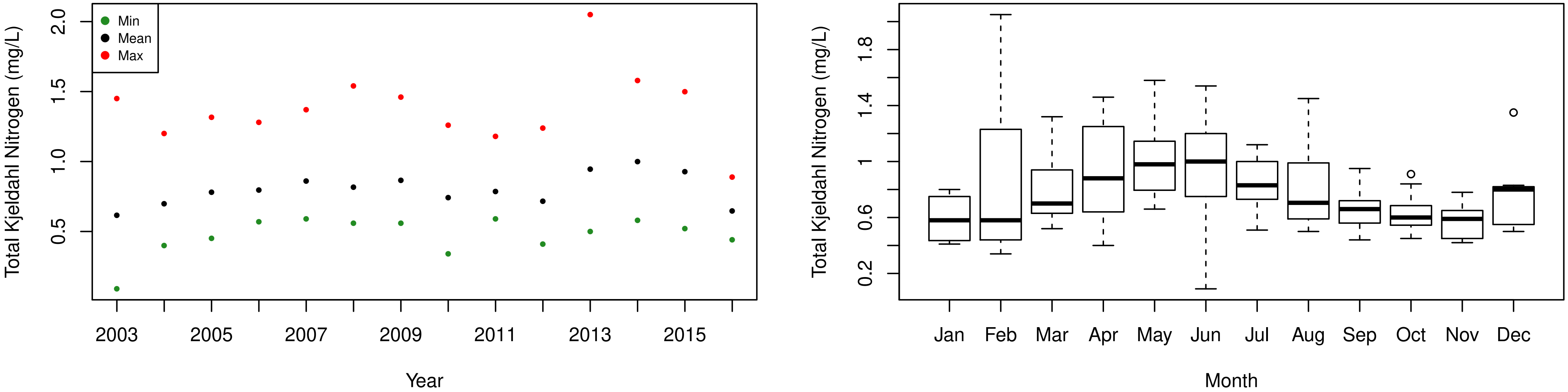
(d) Boxplot by month

Ferson Cr near Mouth–Elgin (79): Total Kjeldahl Nitrogen (mg/L)



(a) Observation data

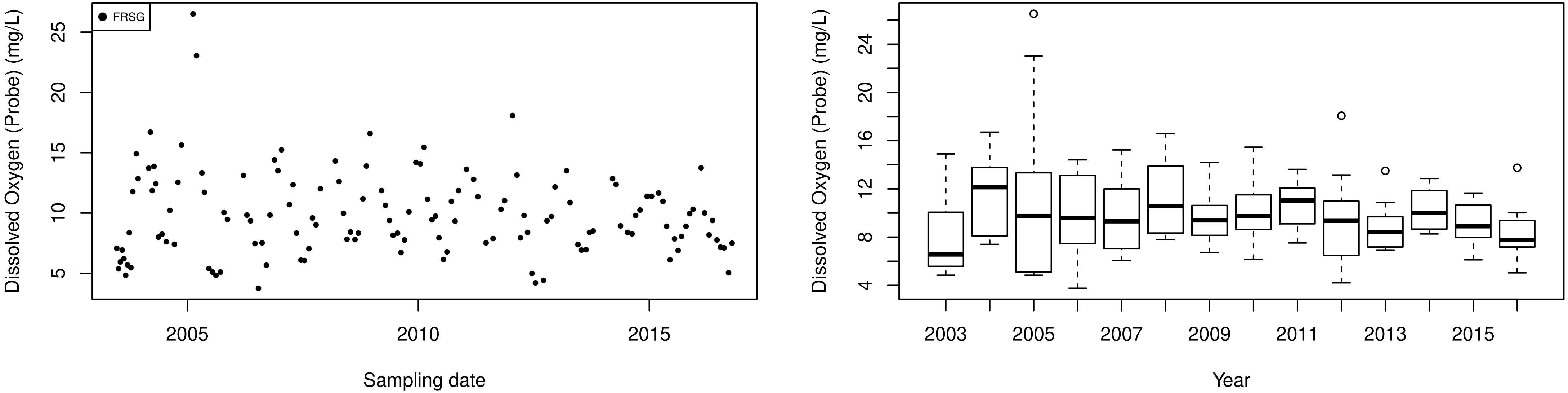
(b) Boxplot by year



(c) Annual values

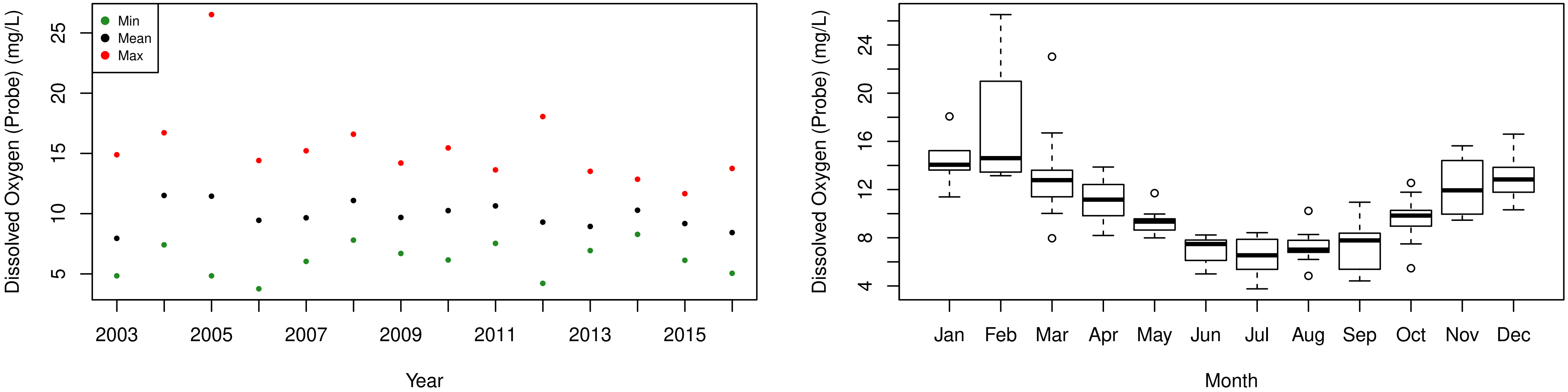
(d) Boxplot by month

Ferson Cr near Mouth–Elgin (79): Dissolved Oxygen (Probe) (mg/L)



(a) Observation data

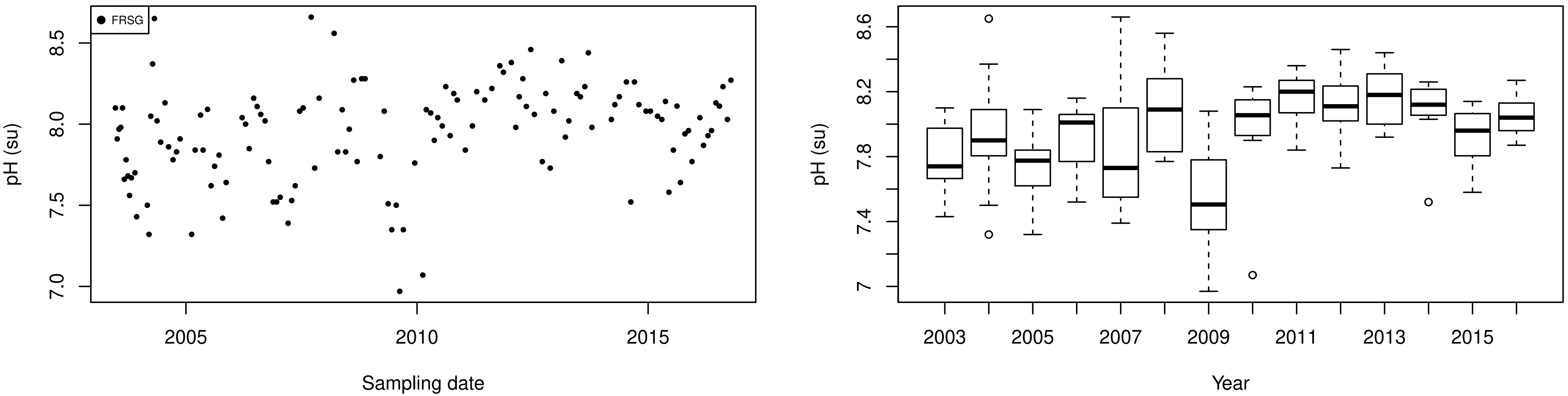
(b) Boxplot by year



(c) Annual values

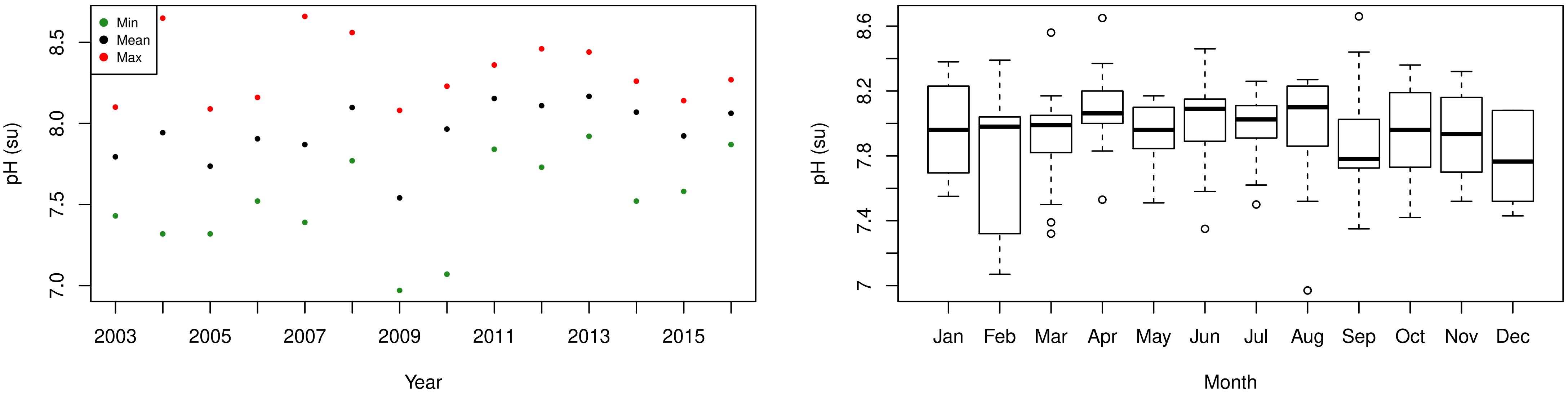
(d) Boxplot by month

Ferson Cr near Mouth−Elgin (79): pH (su)



(a) Observation data

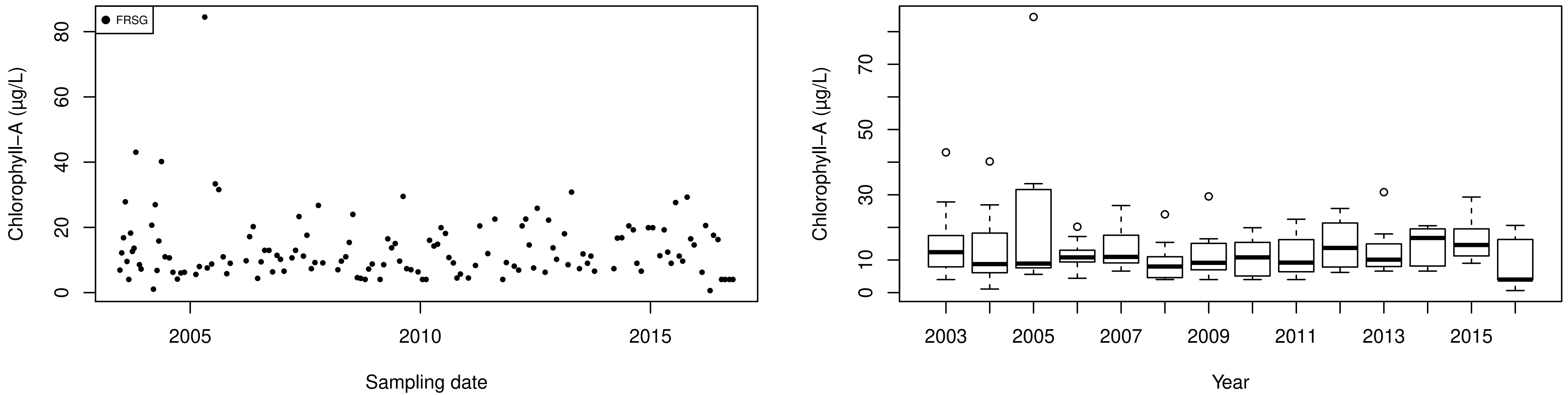
(b) Boxplot by year



(c) Annual values

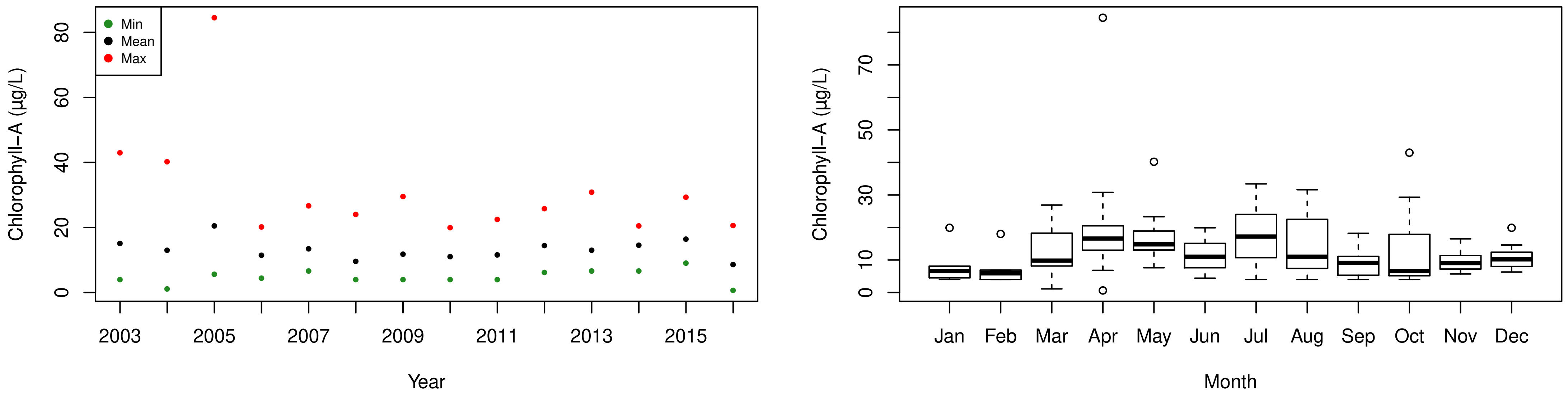
(d) Boxplot by month

Ferson Cr near Mouth–Elgin (79): Chlorophyll–A (µg/L)



(a) Observation data

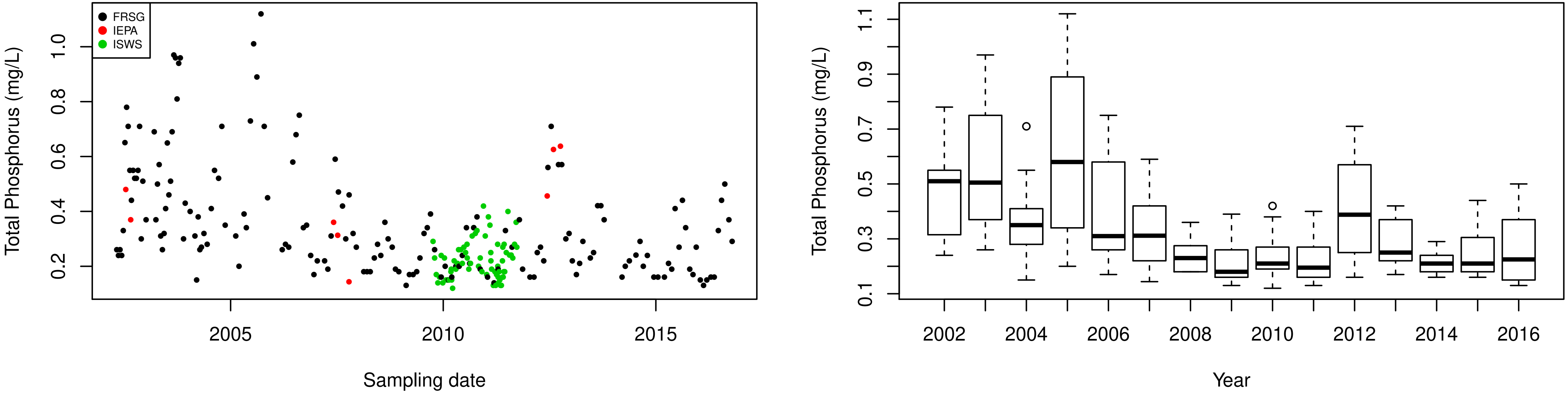
(b) Boxplot by year



(c) Annual values

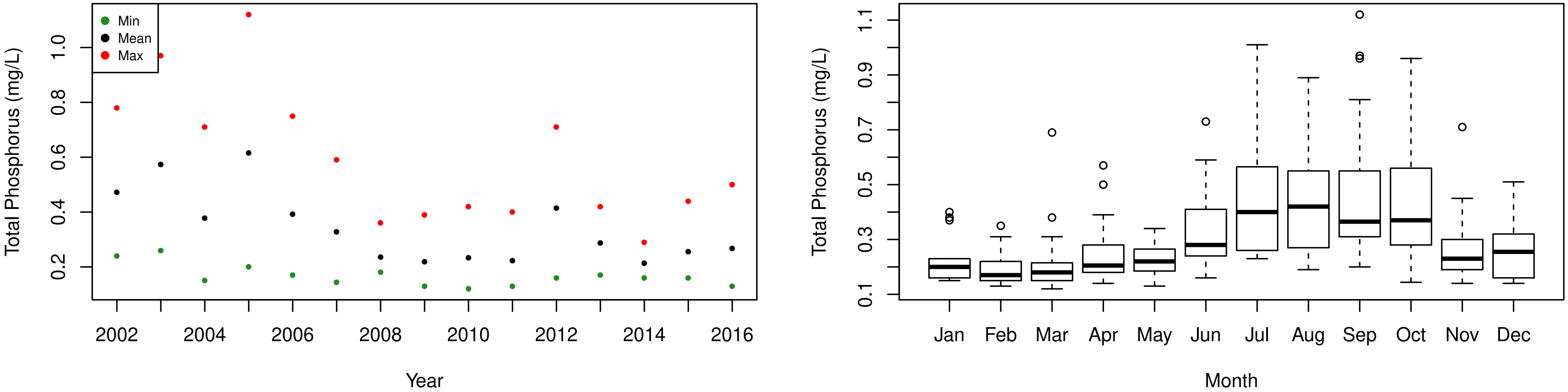
(d) Boxplot by month

Fox River at Geneva (40): Total Phosphorus (mg/L)



(a) Observation data

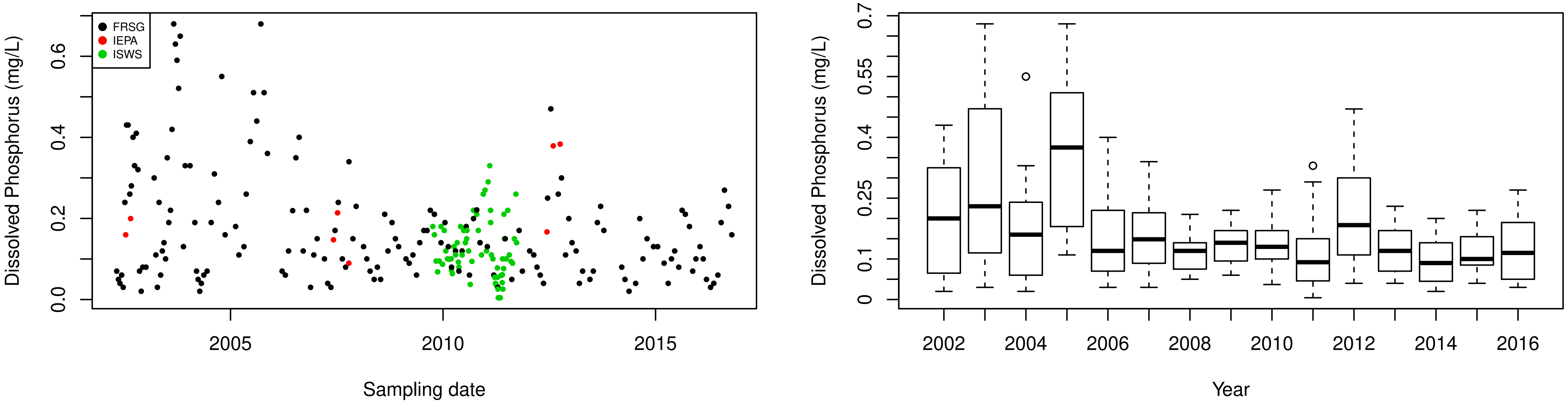
(b) Boxplot by year



(c) Annual values

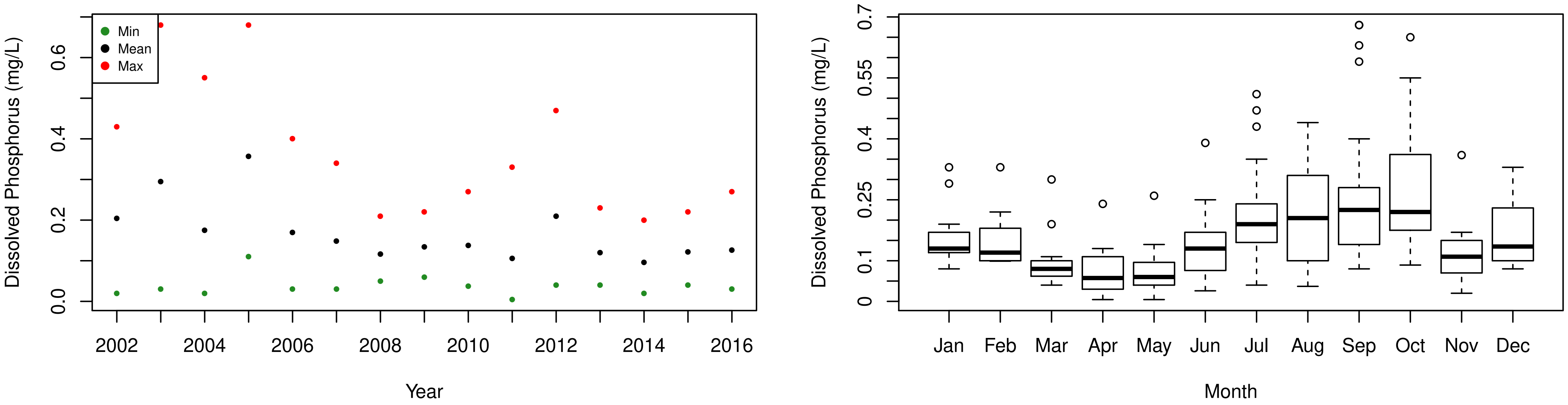
(d) Boxplot by month

Fox River at Geneva (40): Dissolved Phosphorus (mg/L)



(a) Observation data

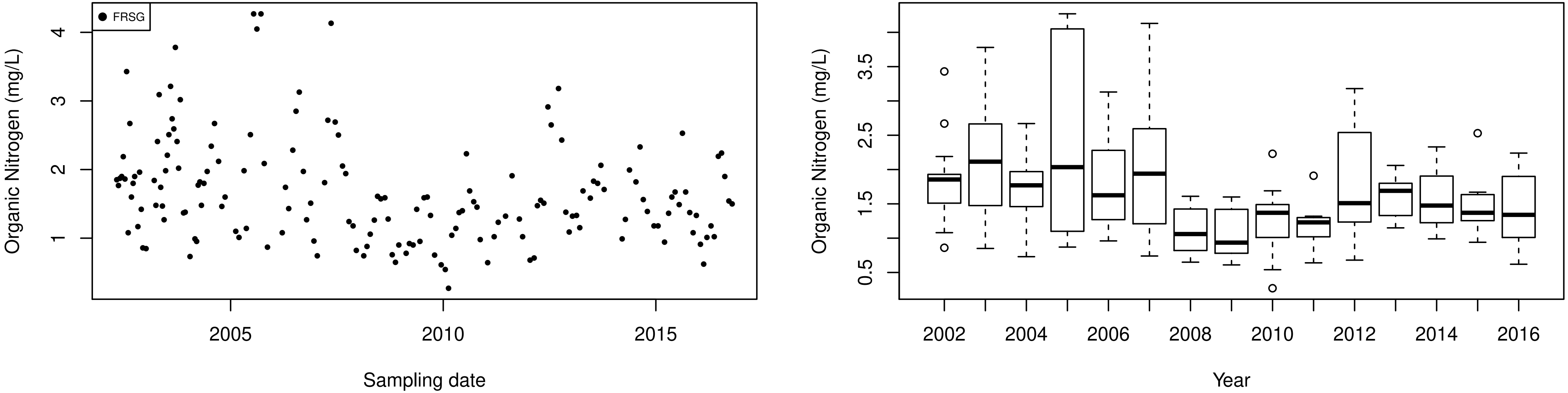
(b) Boxplot by year



(c) Annual values

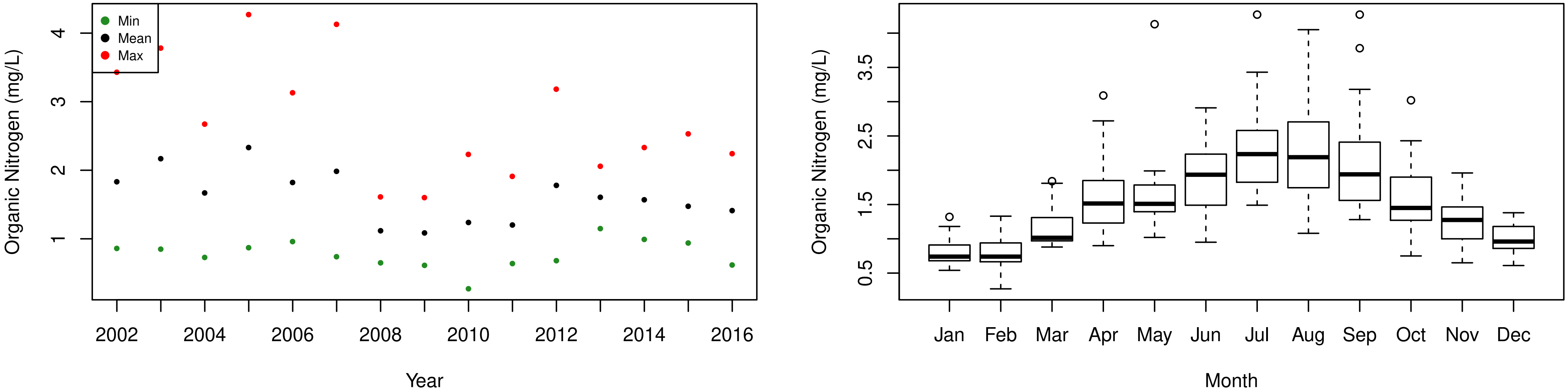
(d) Boxplot by month

Fox River at Geneva (40): Organic Nitrogen (mg/L)



(a) Observation data

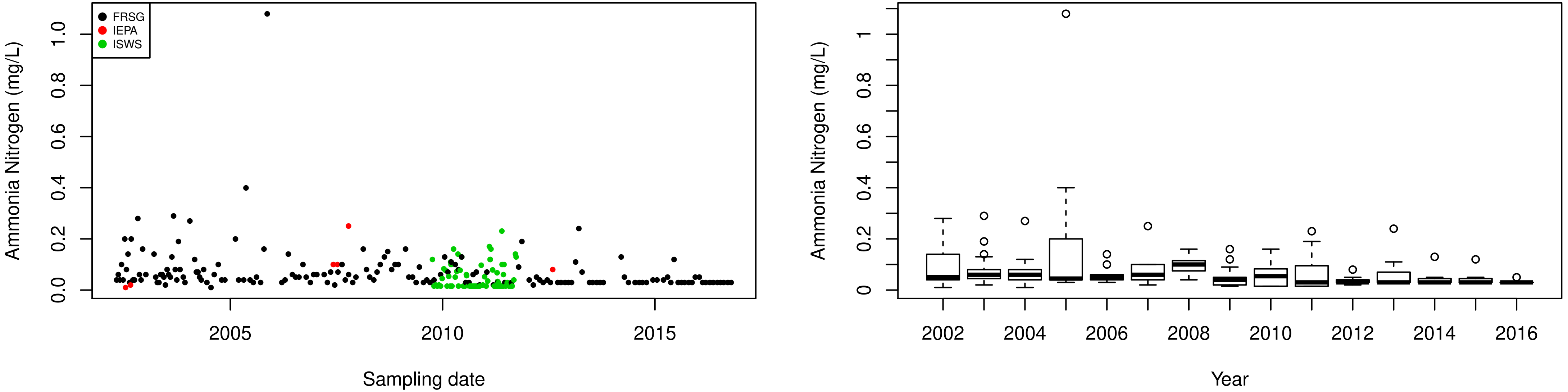
(b) Boxplot by year



(c) Annual values

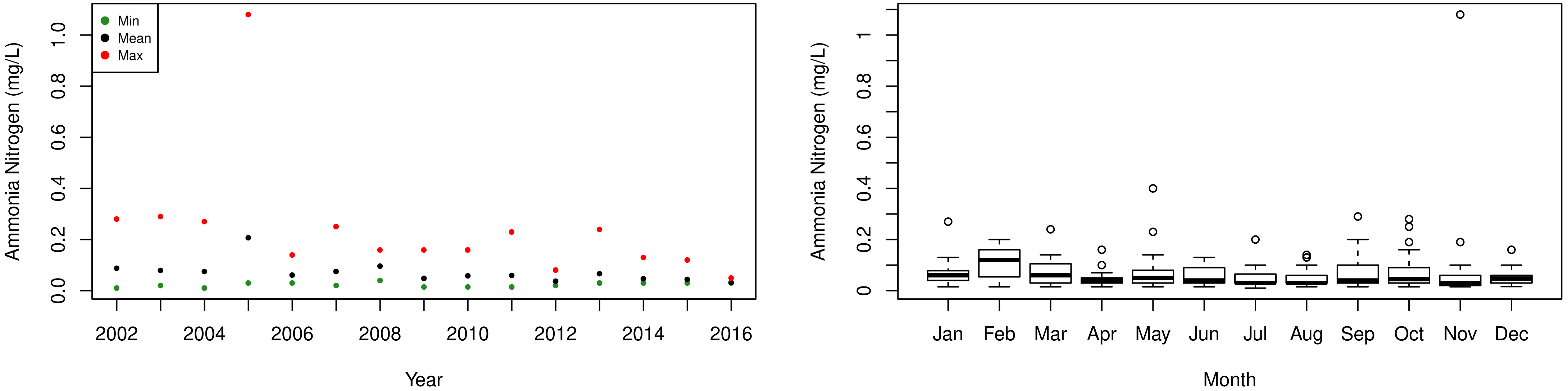
(d) Boxplot by month

Fox River at Geneva (40): Ammonia Nitrogen (mg/L)



(a) Observation data

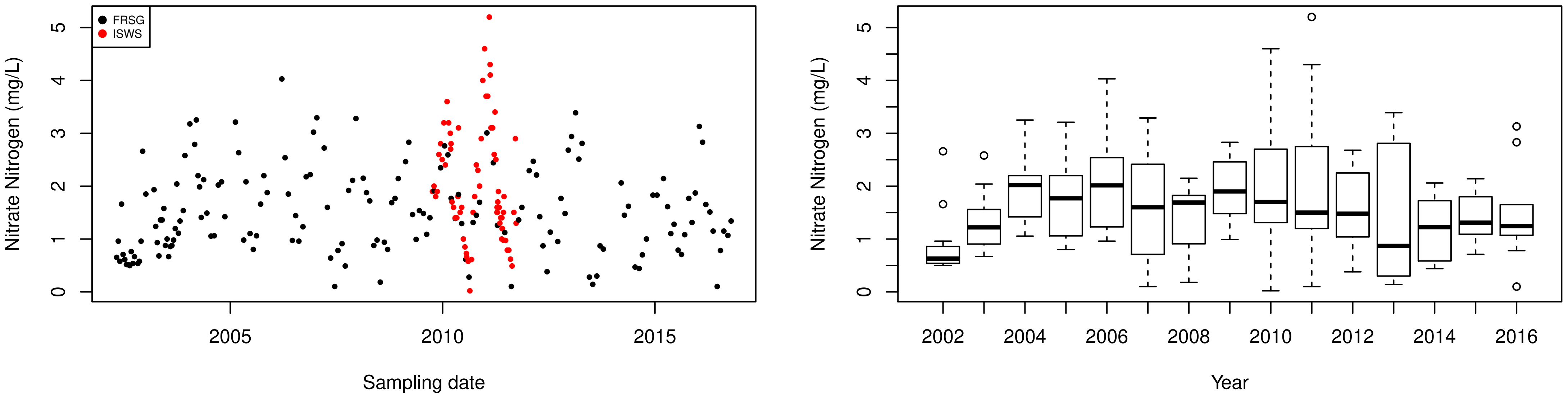
(b) Boxplot by year



(c) Annual values

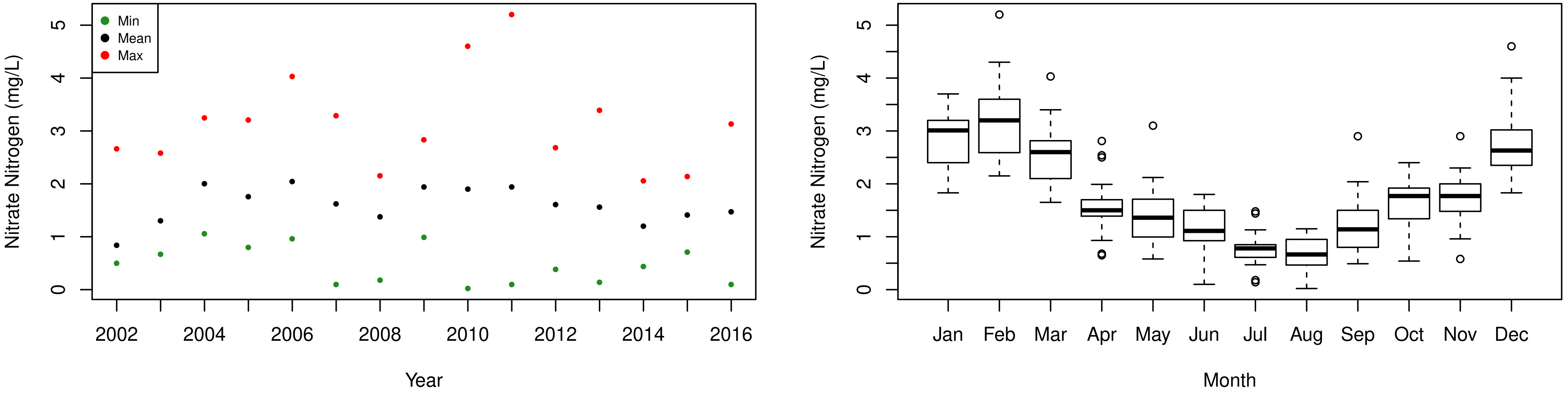
(d) Boxplot by month

Fox River at Geneva (40): Nitrate Nitrogen (mg/L)



(a) Observation data

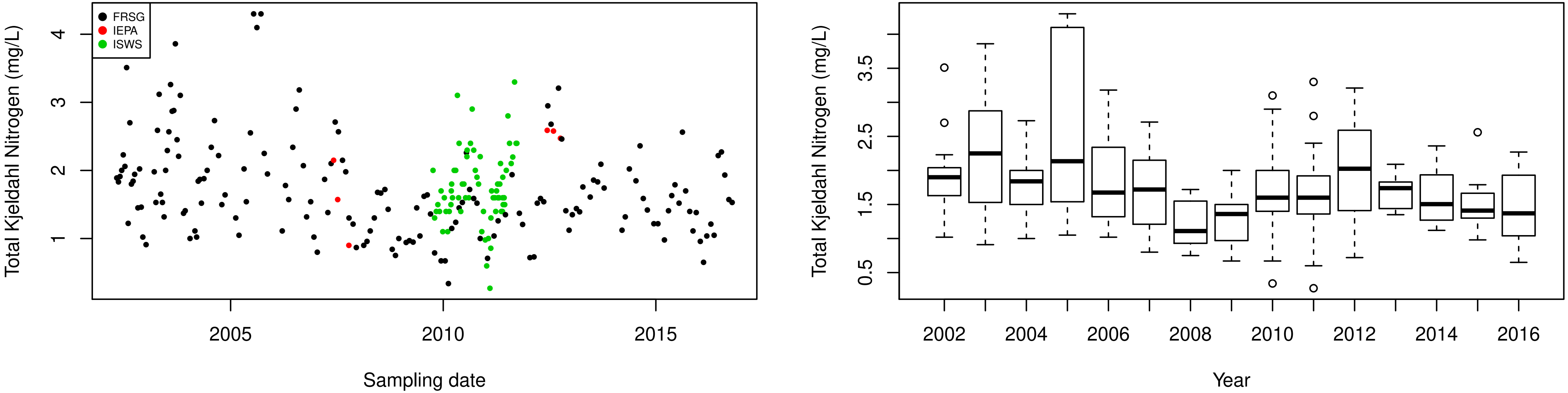
(b) Boxplot by year



(c) Annual values

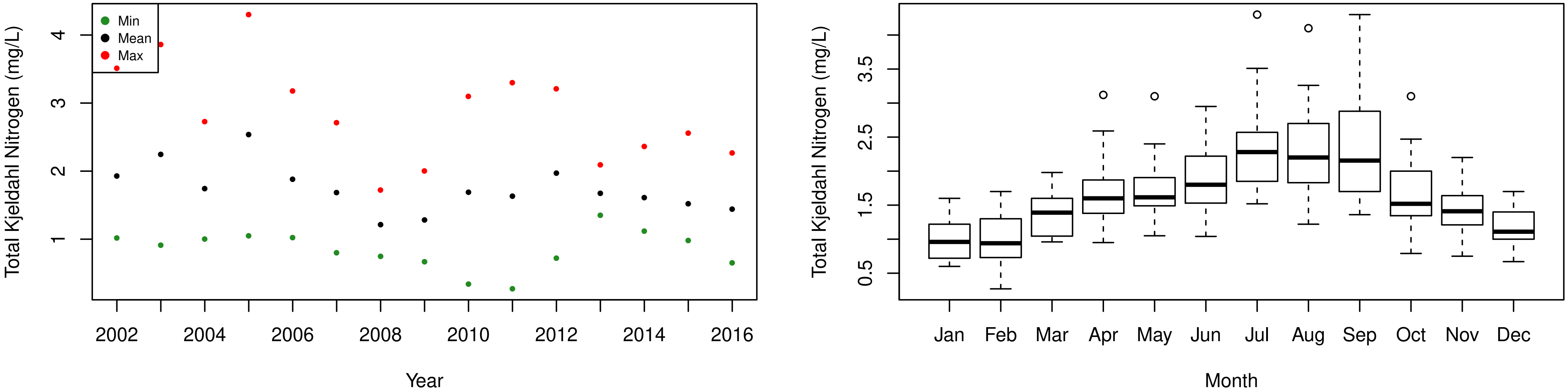
(d) Boxplot by month

Fox River at Geneva (40): Total Kjeldahl Nitrogen (mg/L)



(a) Observation data

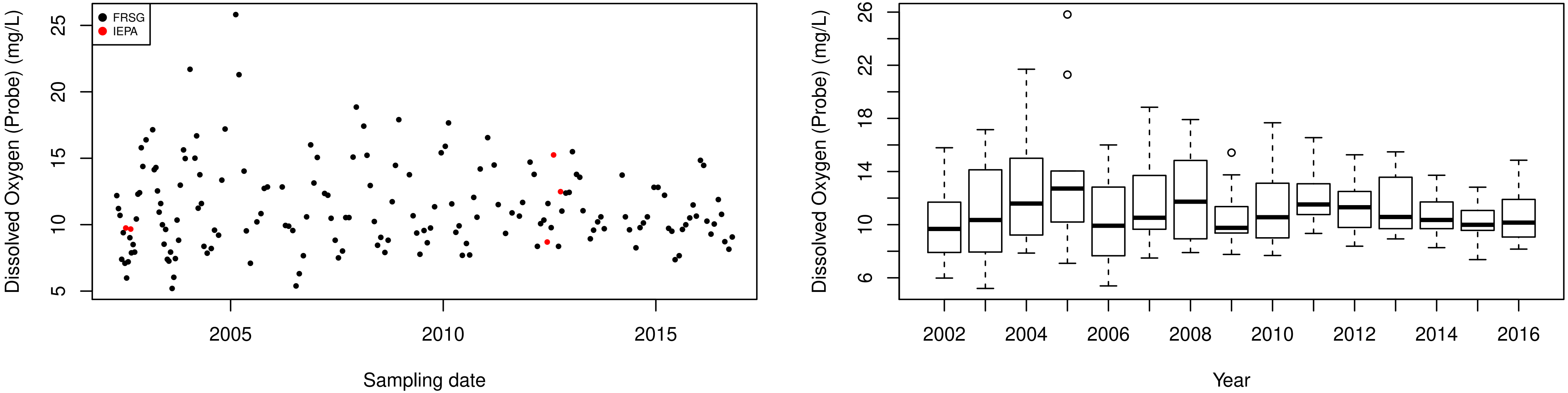
(b) Boxplot by year



(c) Annual values

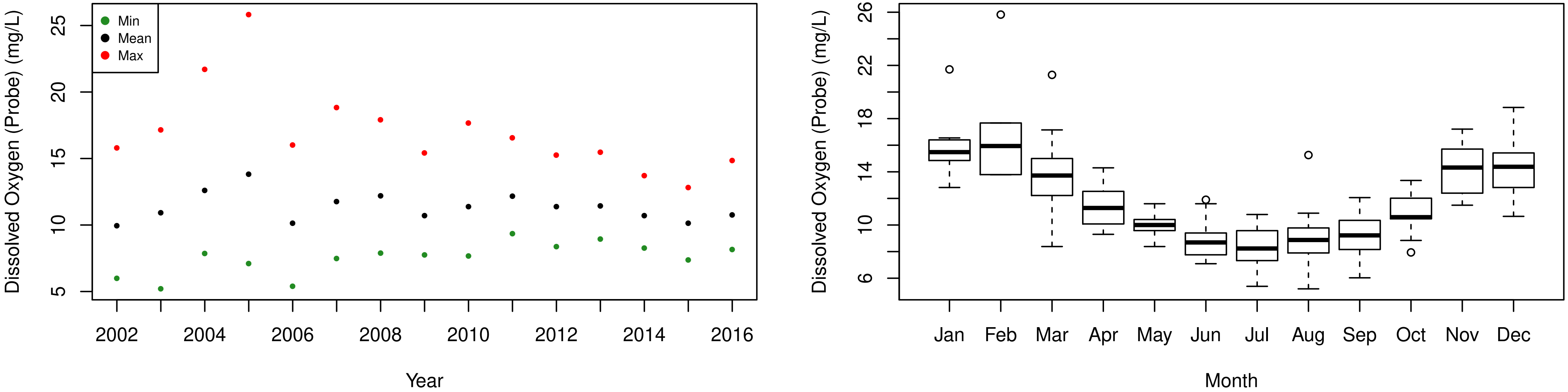
(d) Boxplot by month

Fox River at Geneva (40): Dissolved Oxygen (Probe) (mg/L)



(a) Observation data

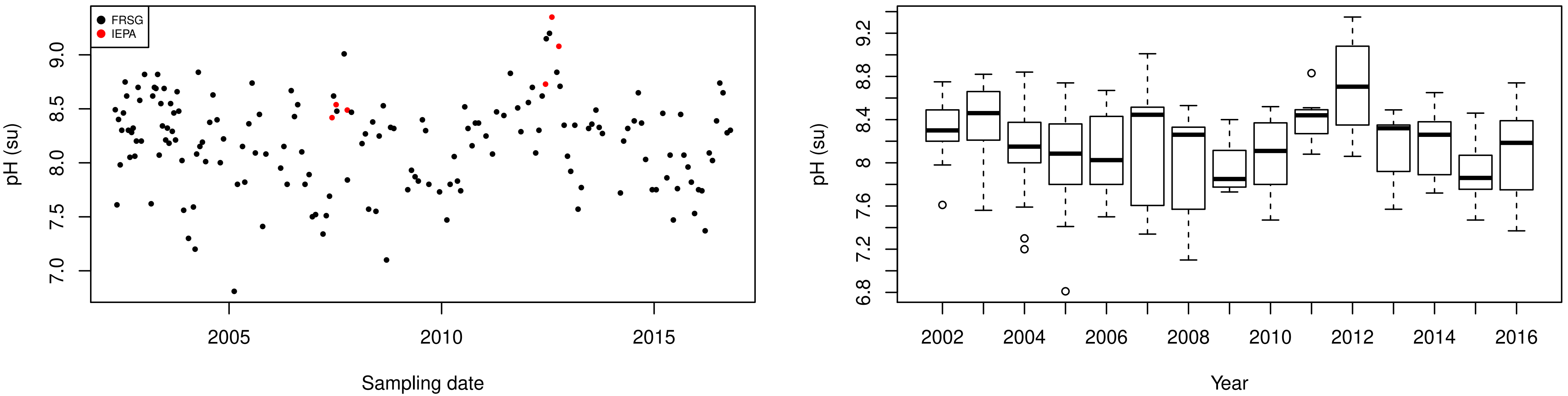
(b) Boxplot by year



(c) Annual values

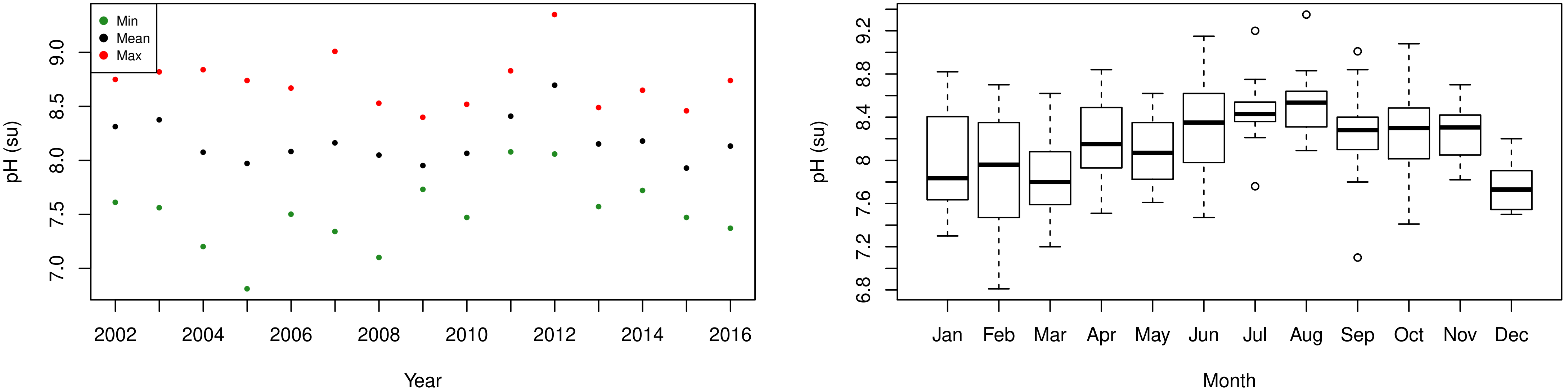
(d) Boxplot by month

Fox River at Geneva (40): pH (su)



(a) Observation data

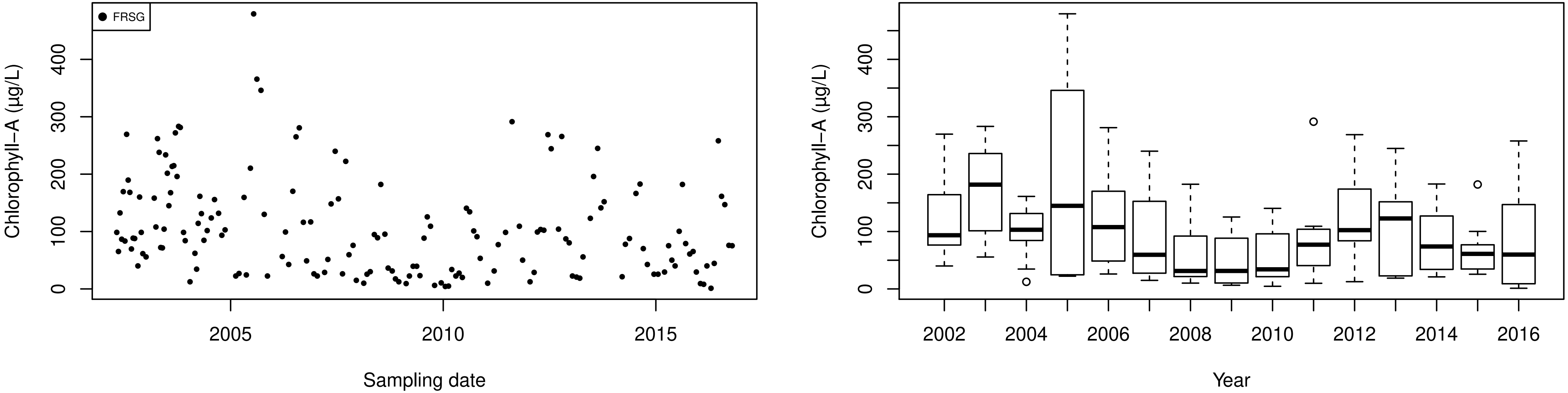
(b) Boxplot by year



(c) Annual values

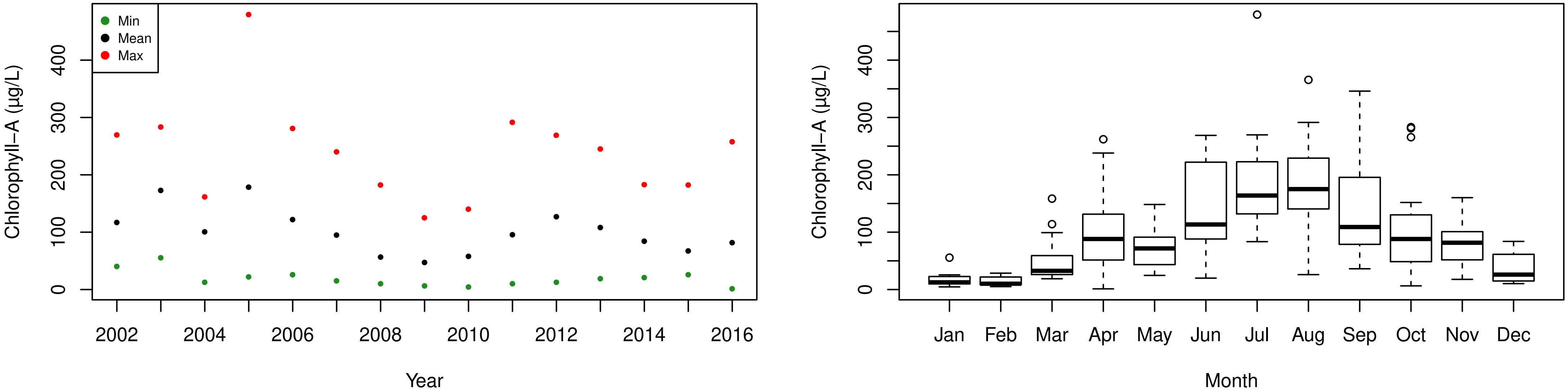
(d) Boxplot by month

Fox River at Geneva (40): Chlorophyll–A (μg/L)



(a) Observation data

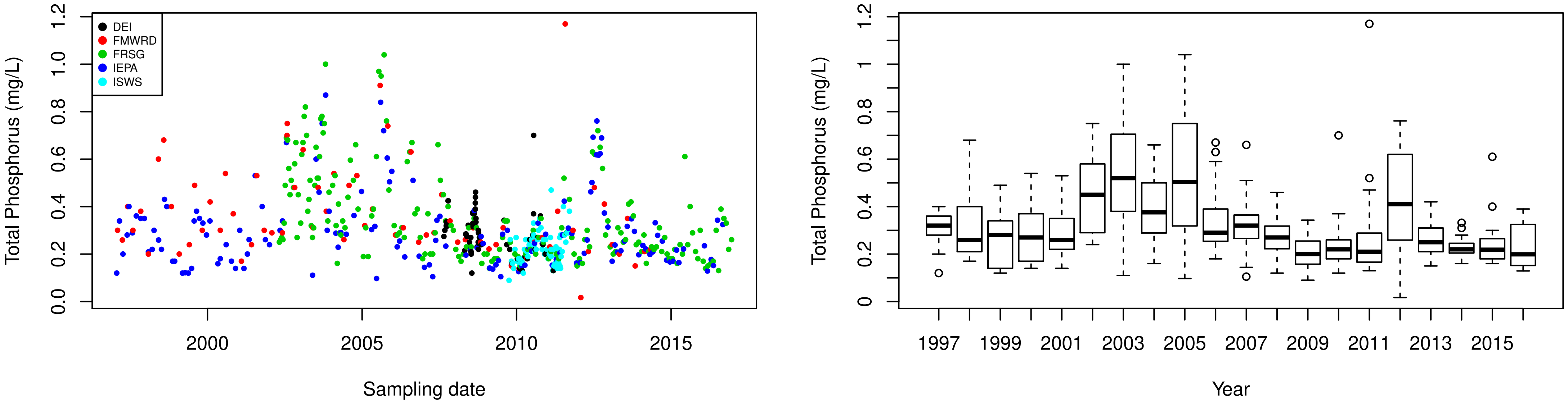
(b) Boxplot by year



(c) Annual values

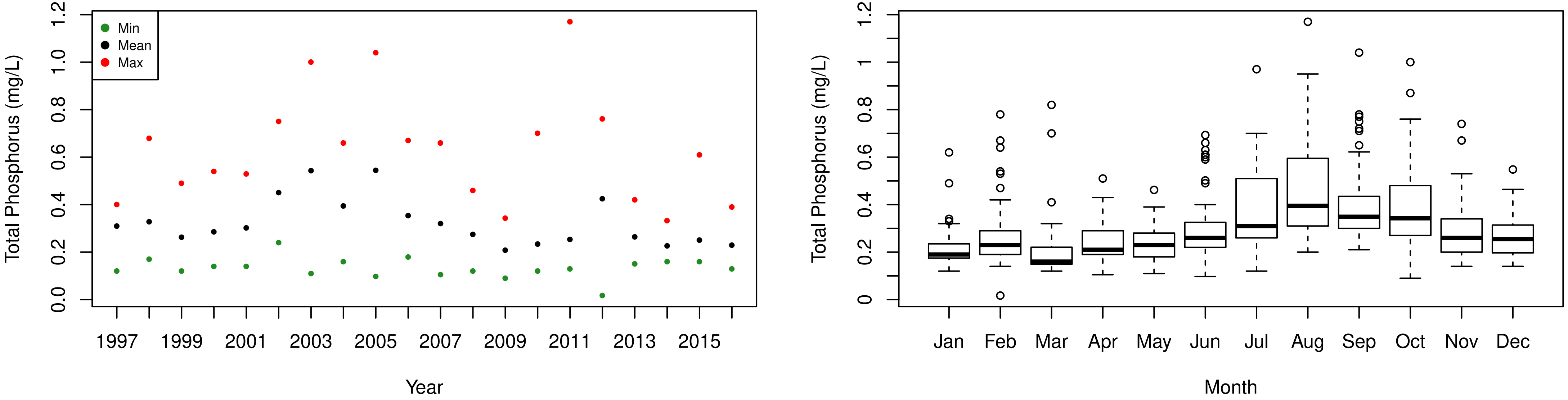
(d) Boxplot by month

Fox River at Montgomery (27): Total Phosphorus (mg/L)



(a) Observation data

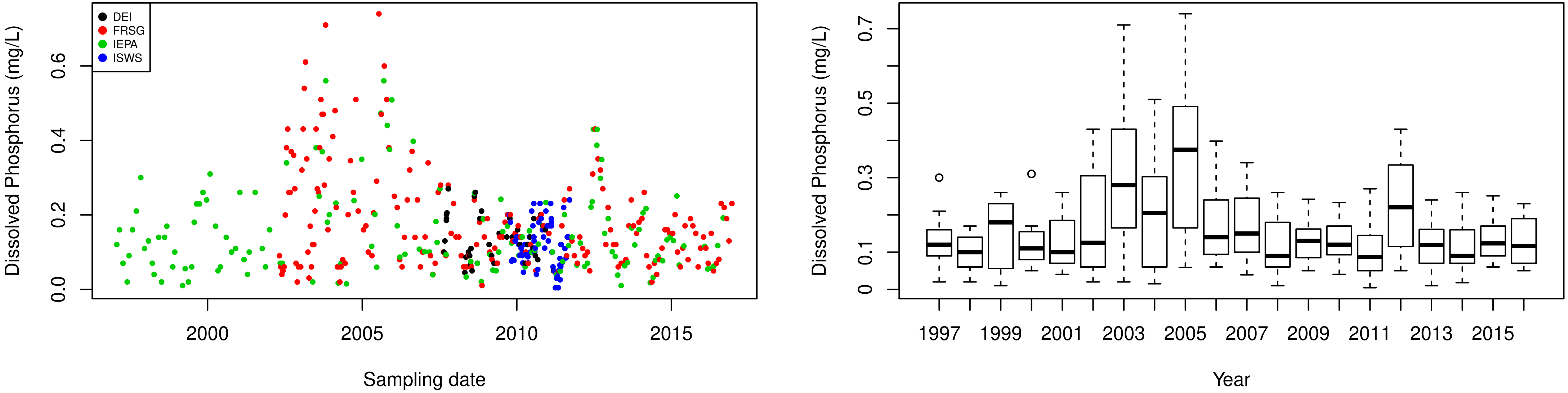
(b) Boxplot by year



(c) Annual values

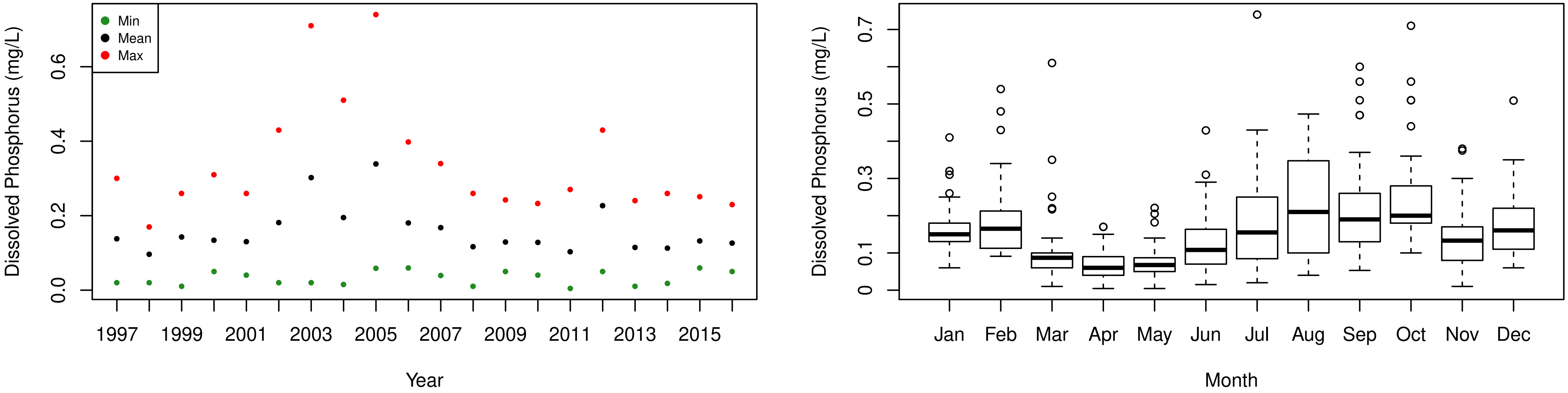
(d) Boxplot by month

Fox River at Montgomery (27): Dissolved Phosphorus (mg/L)



(a) Observation data

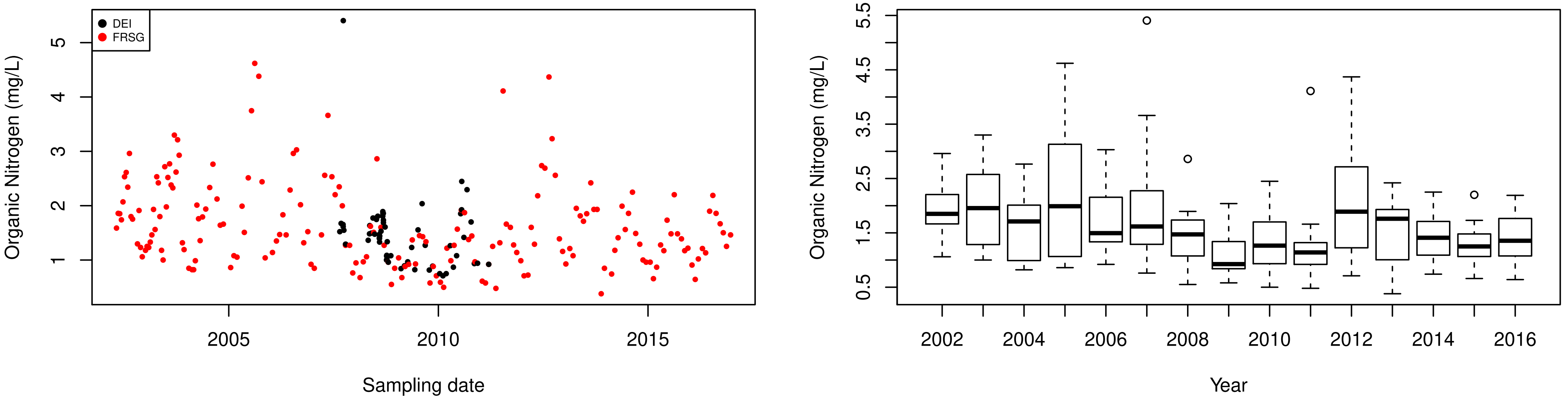
(b) Boxplot by year



(c) Annual values

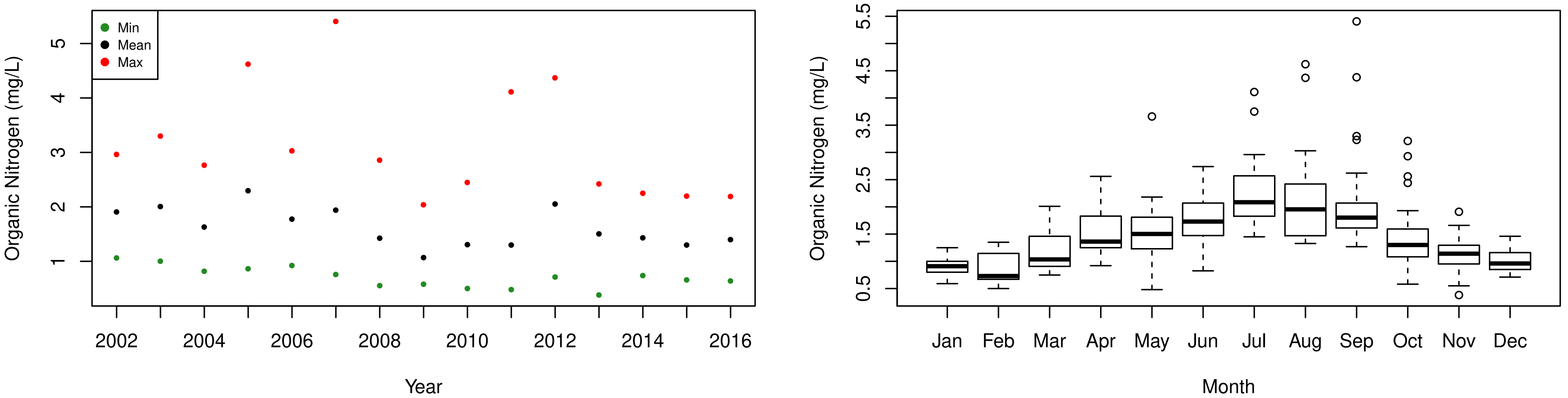
(d) Boxplot by month

Fox River at Montgomery (27): Organic Nitrogen (mg/L)



(a) Observation data

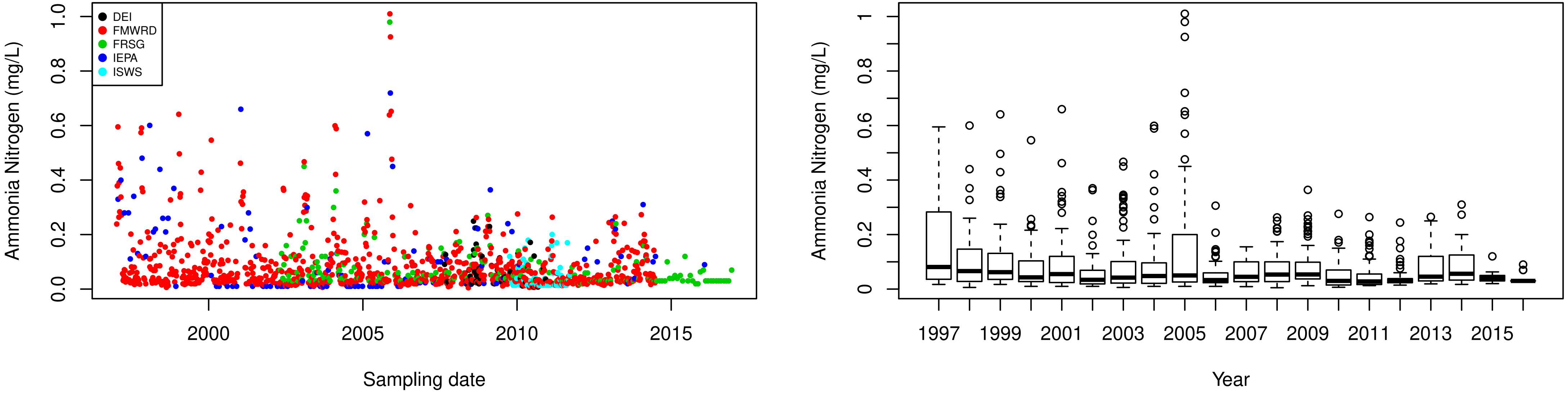
(b) Boxplot by year



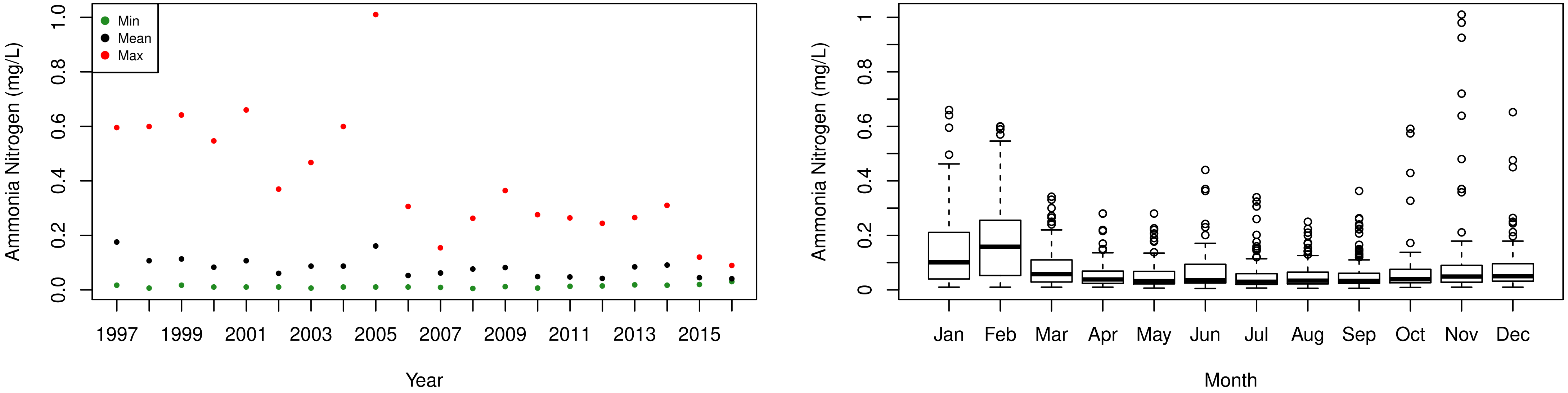
(c) Annual values

(d) Boxplot by month

Fox River at Montgomery (27): Ammonia Nitrogen (mg/L)

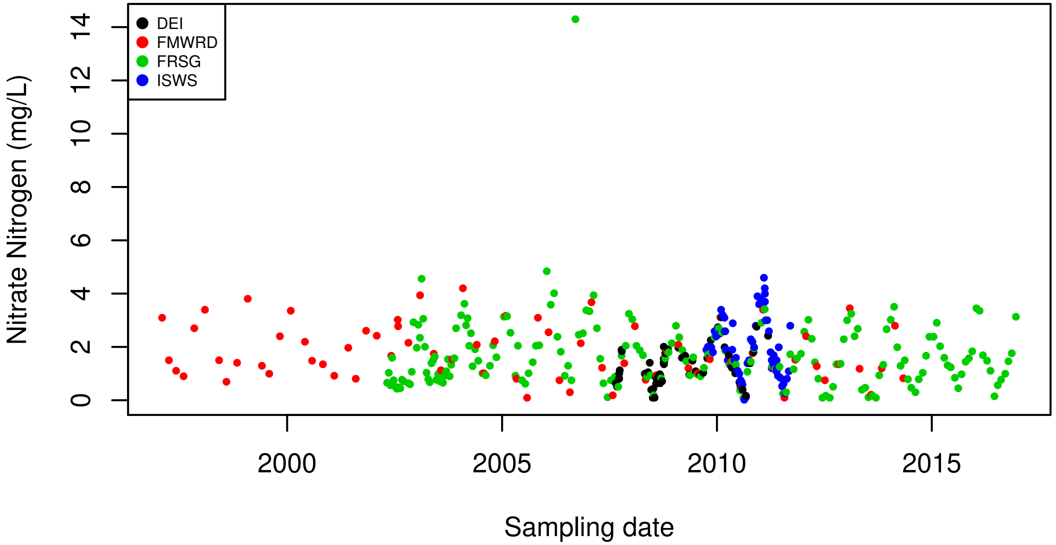


(a) Observation data (b) Boxplot by year

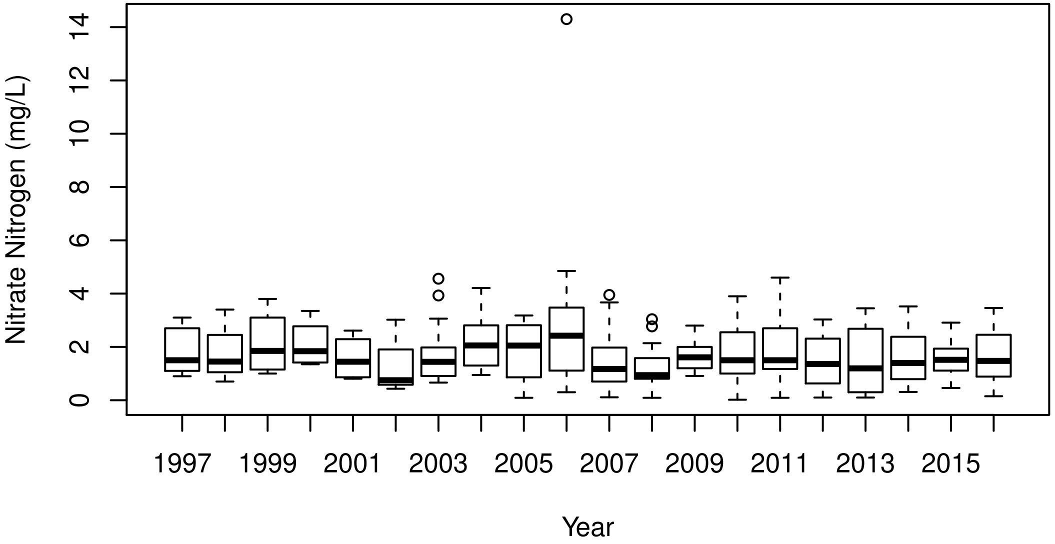


(c) Annual values (d) Boxplot by month

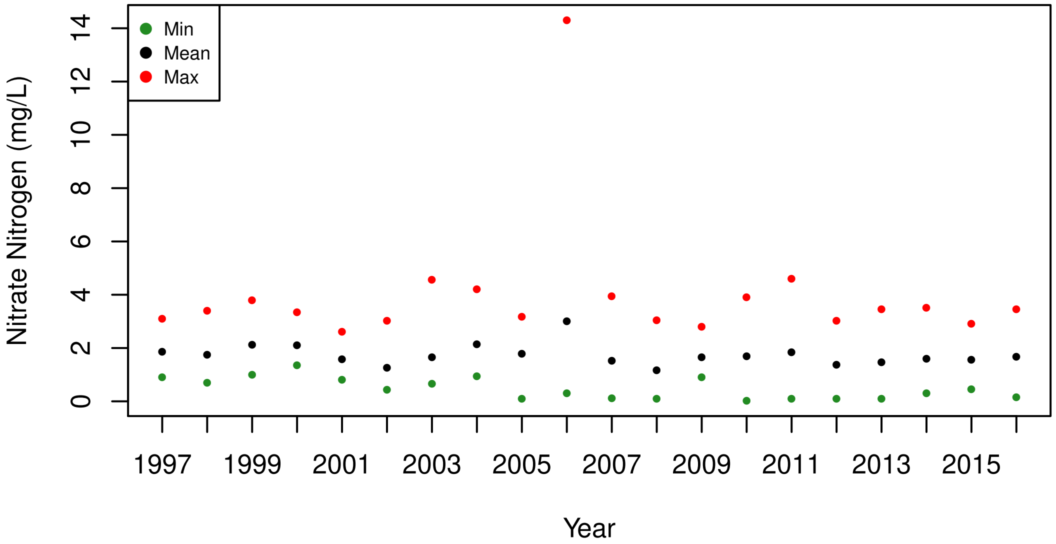
Fox River at Montgomery (27): Nitrate Nitrogen (mg/L)



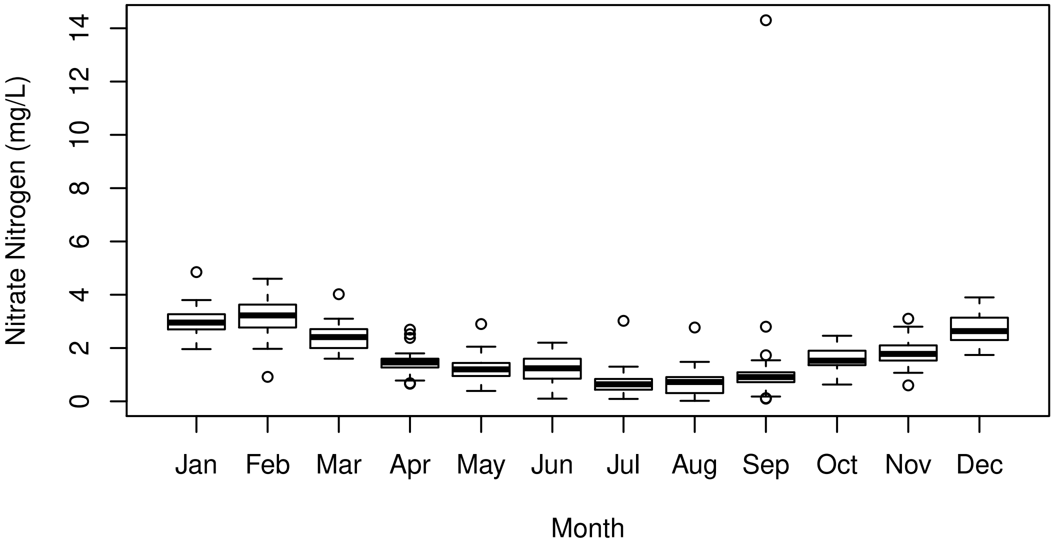
(a) Observation data



(b) Boxplot by year

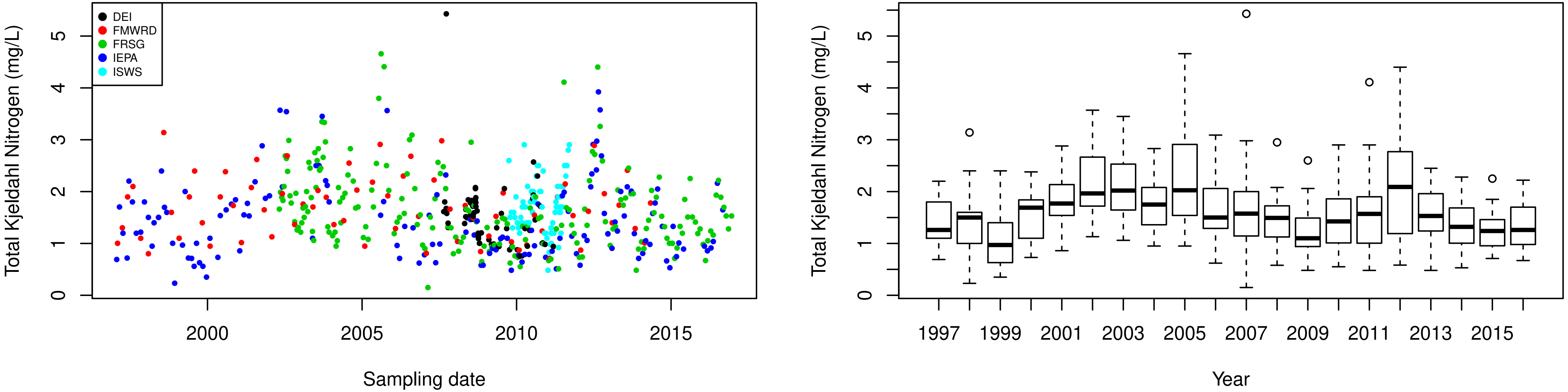


(c) Annual values



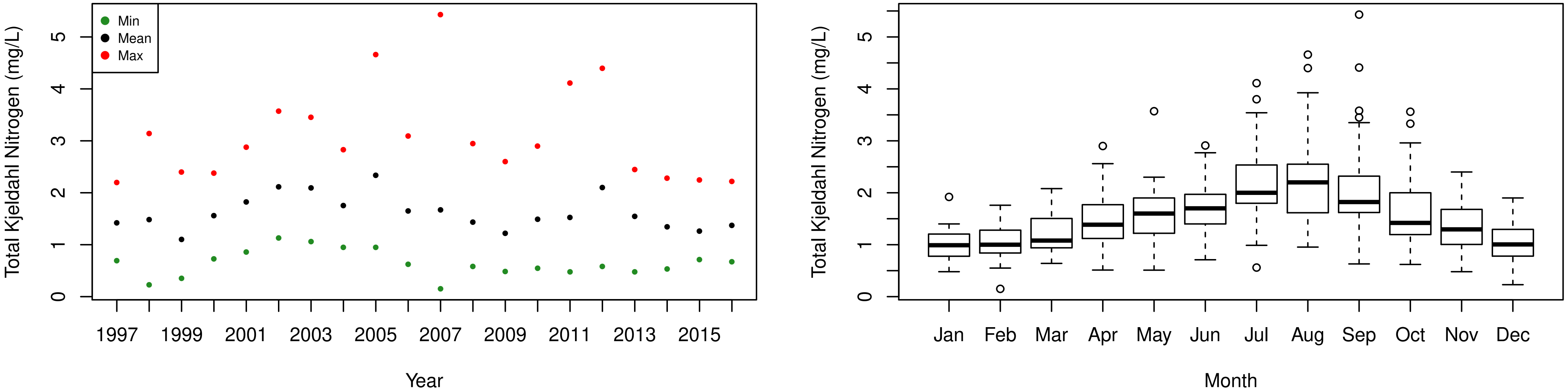
(d) Boxplot by month

Fox River at Montgomery (27): Total Kjeldahl Nitrogen (mg/L)



(a) Observation data

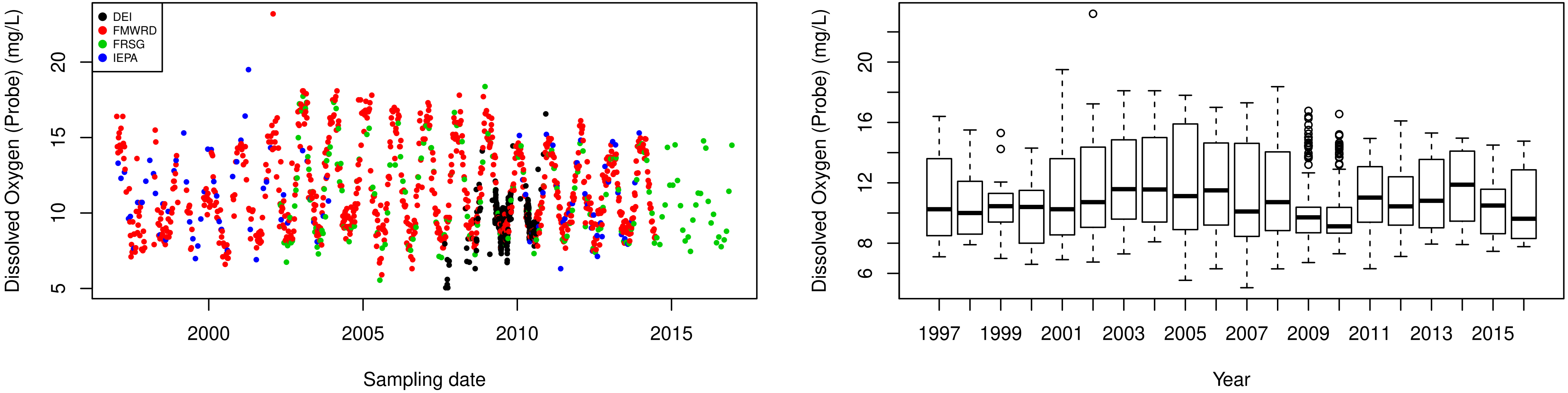
(b) Boxplot by year



(c) Annual values

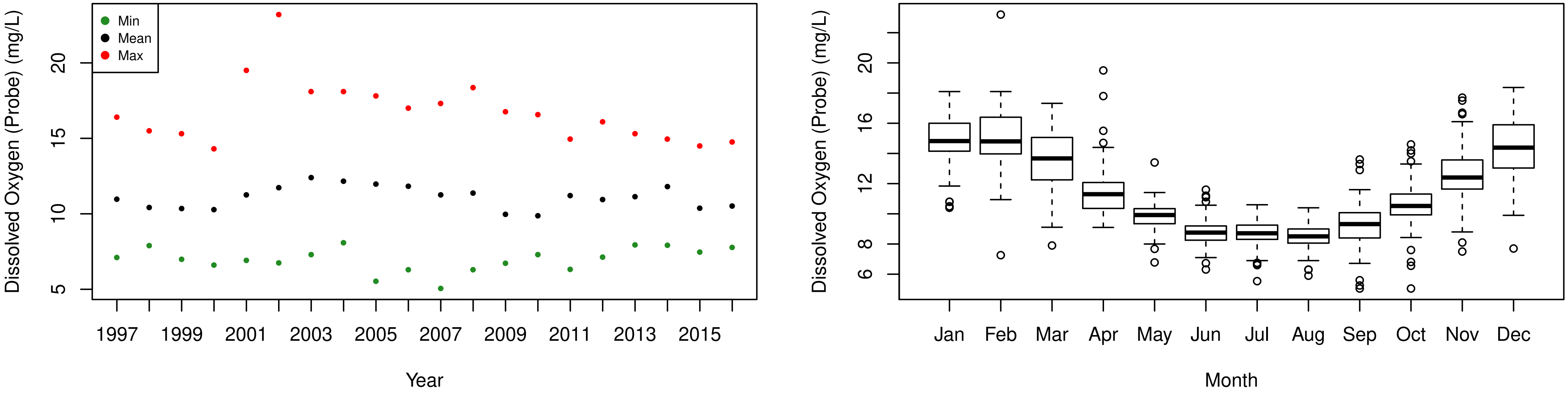
(d) Boxplot by month

Fox River at Montgomery (27): Dissolved Oxygen (Probe) (mg/L)



(a) Observation data

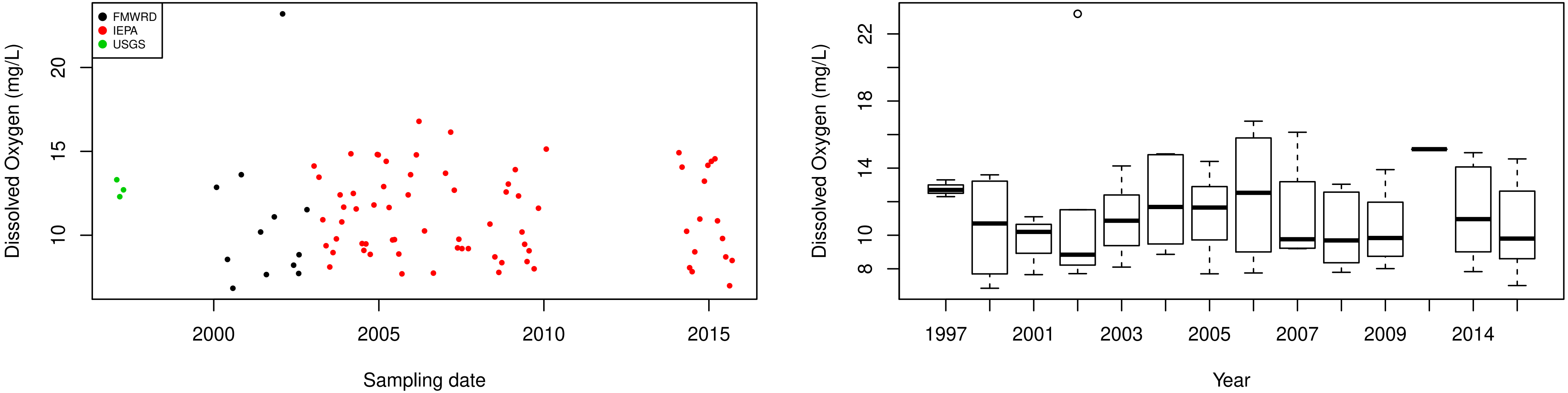
(b) Boxplot by year



(c) Annual values

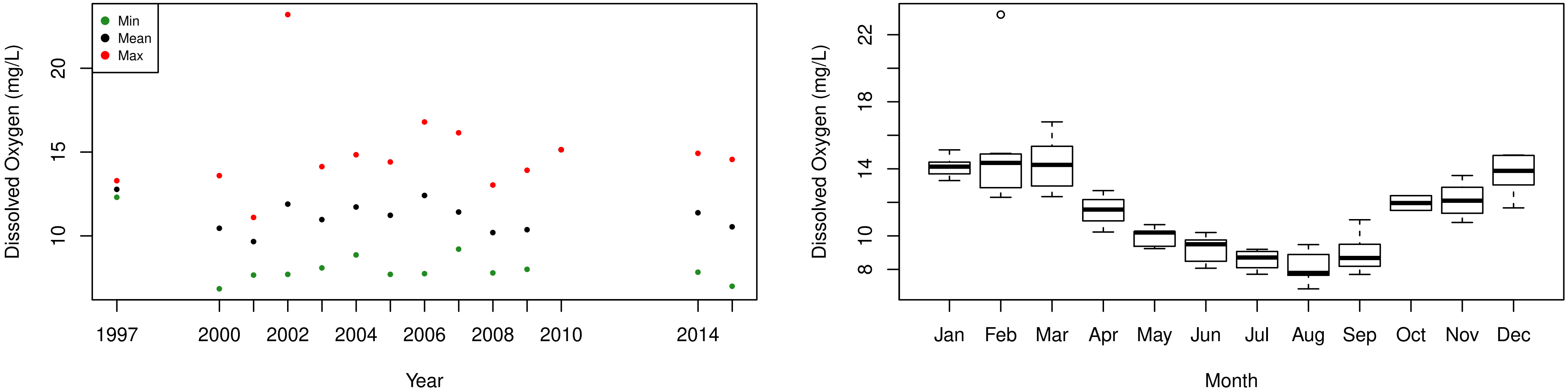
(d) Boxplot by month

Fox River at Montgomery (27): Dissolved Oxygen (mg/L)



(a) Observation data

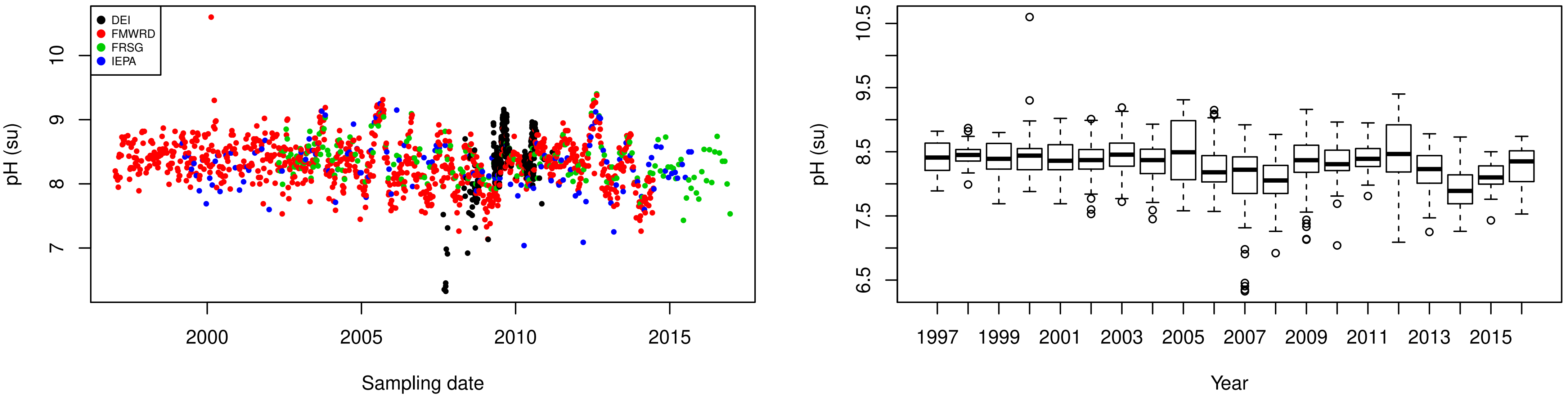
(b) Boxplot by year



(c) Annual values

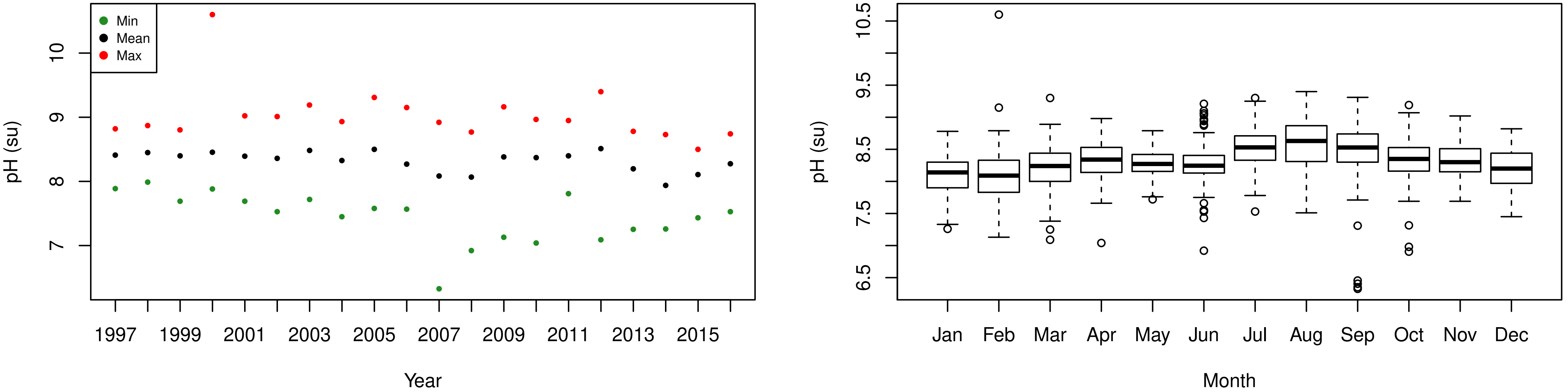
(d) Boxplot by month

Fox River at Montgomery (27): pH (su)



(a) Observation data

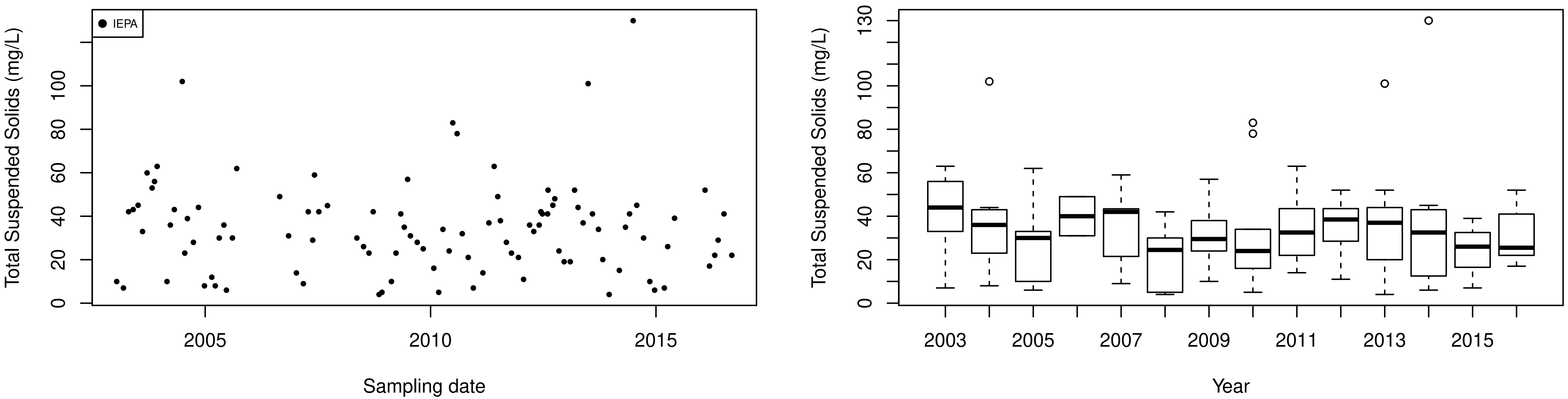
(b) Boxplot by year



(c) Annual values

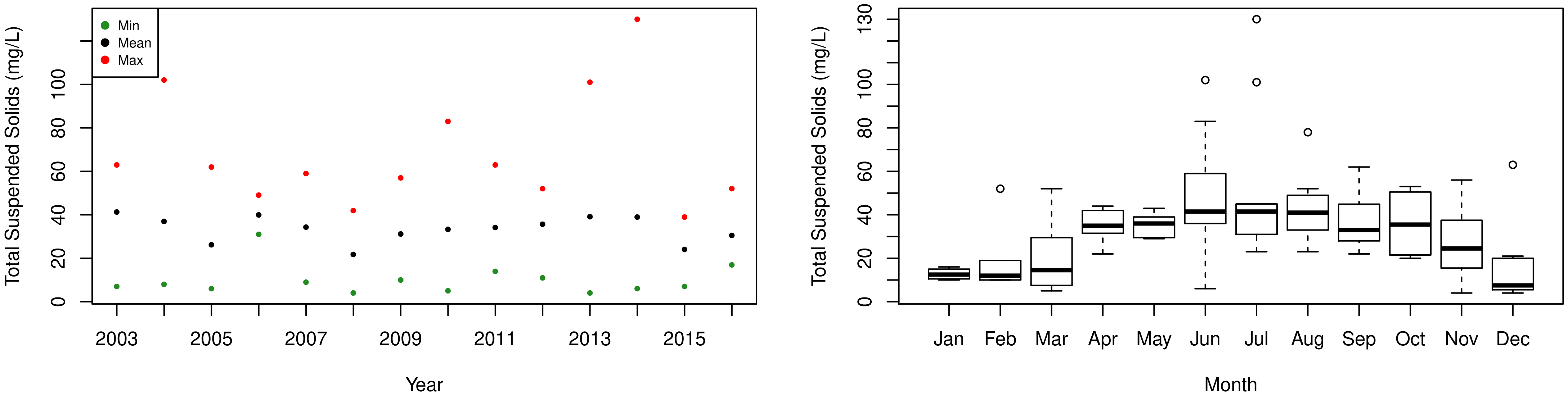
(d) Boxplot by month

Fox River at Montgomery (27): Total Suspended Solids (mg/L)



(a) Observation data

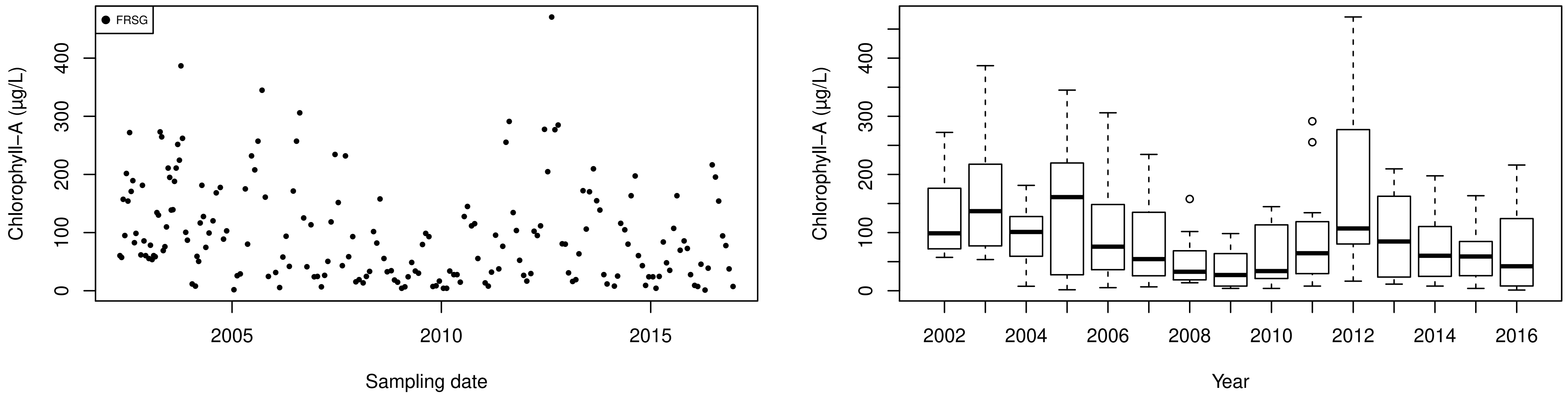
(b) Boxplot by year



(c) Annual values

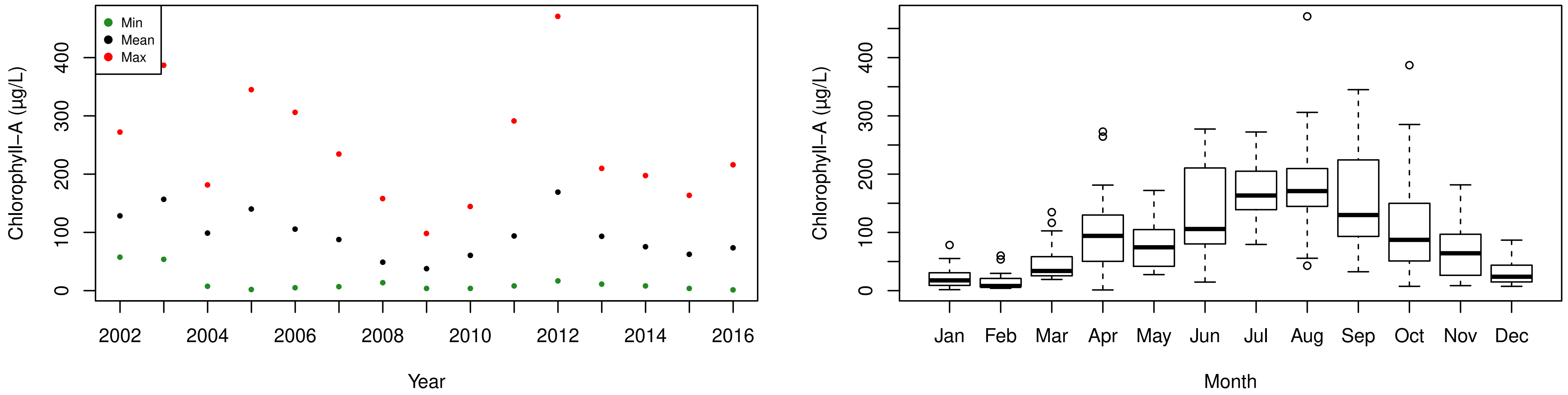
(d) Boxplot by month

Fox River at Montgomery (27): Chlorophyll−A (µg/L)



(a) Observation data

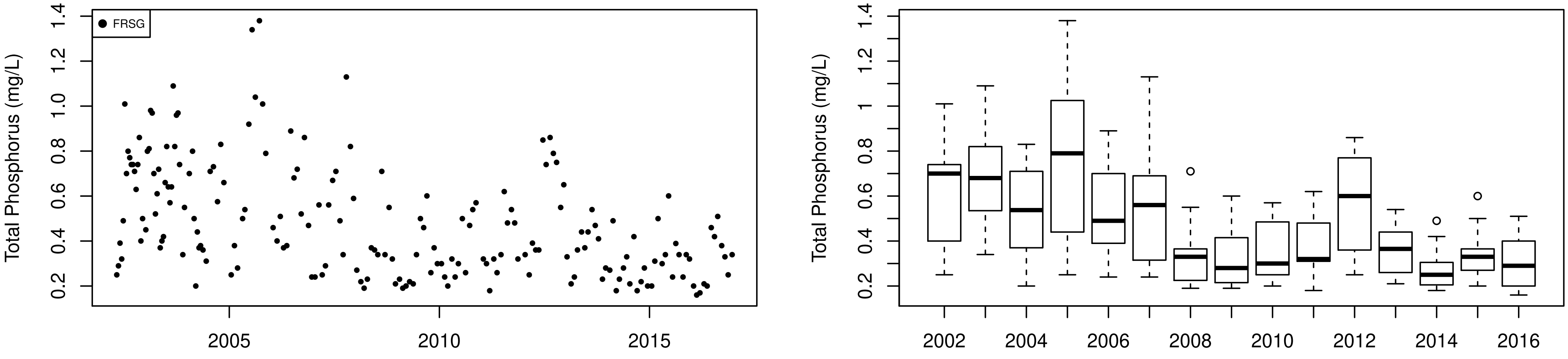
(b) Boxplot by year



(c) Annual values

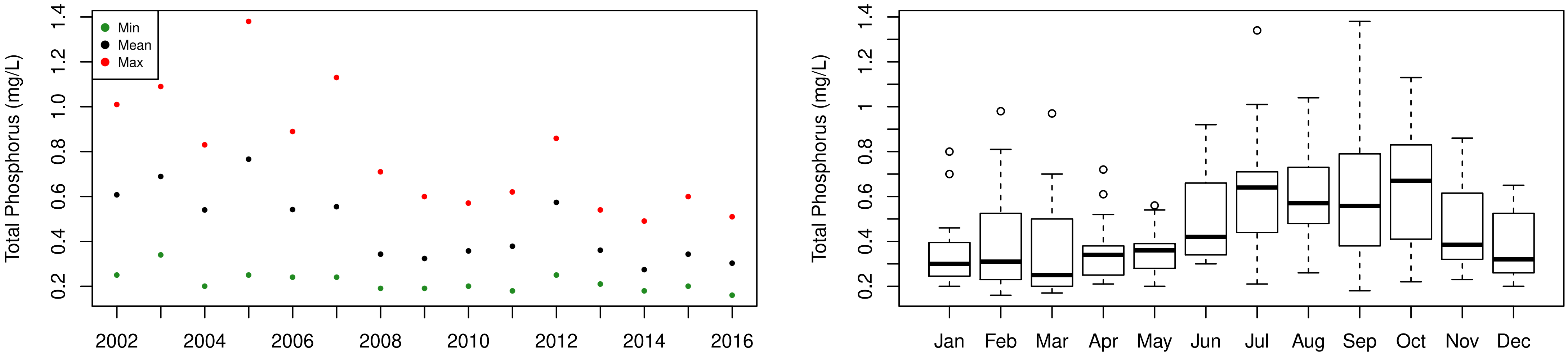
(d) Boxplot by month

Fox River at Yorkville (34): Total Phosphorus (mg/L)



(a) Observation data

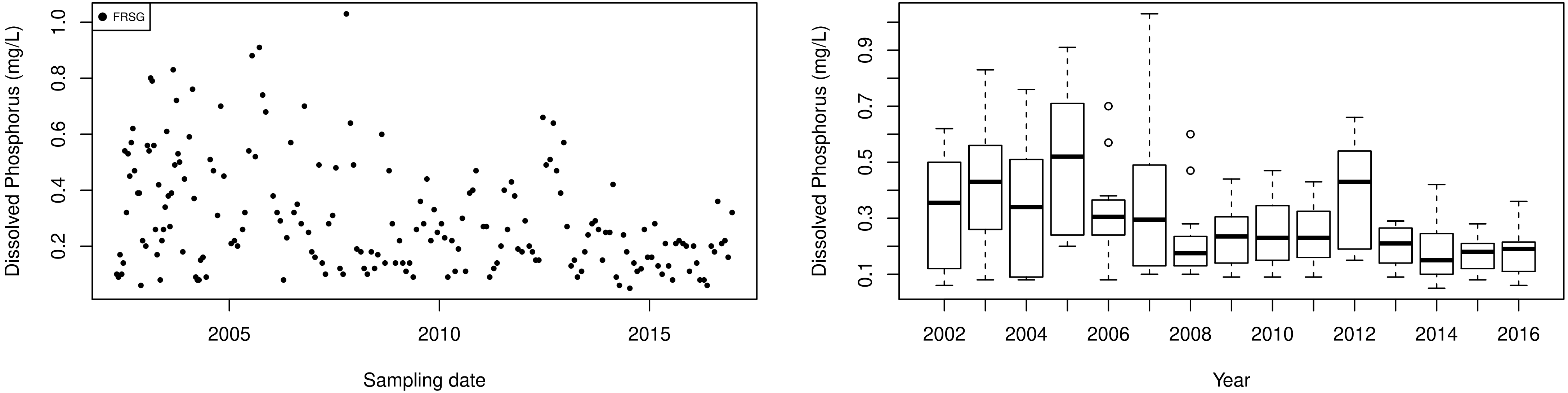
(b) Boxplot by year



(c) Annual values

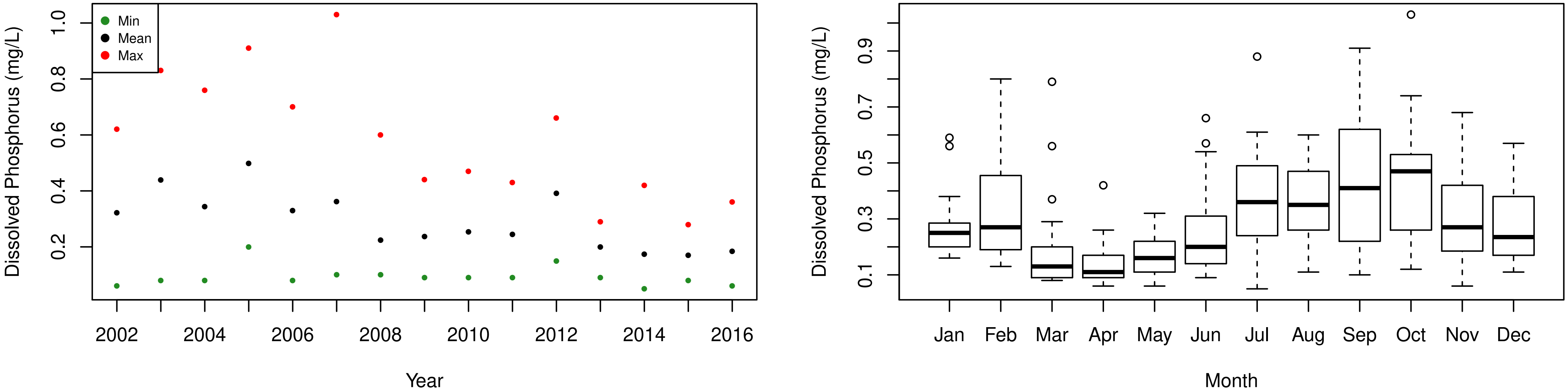
(d) Boxplot by month

Fox River at Yorkville (34): Dissolved Phosphorus (mg/L)



(a) Observation data

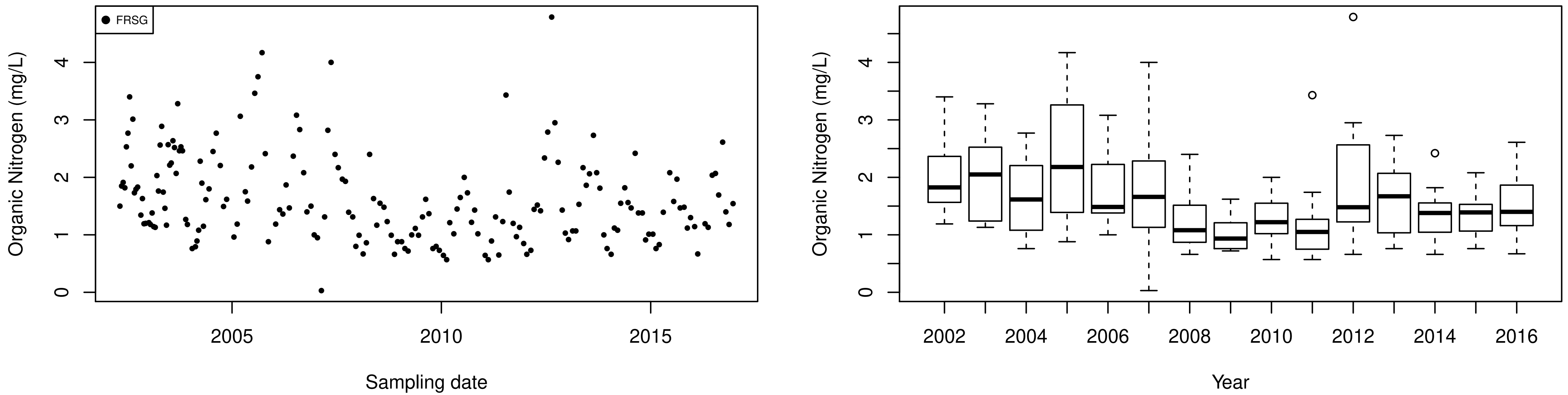
(b) Boxplot by year



(c) Annual values

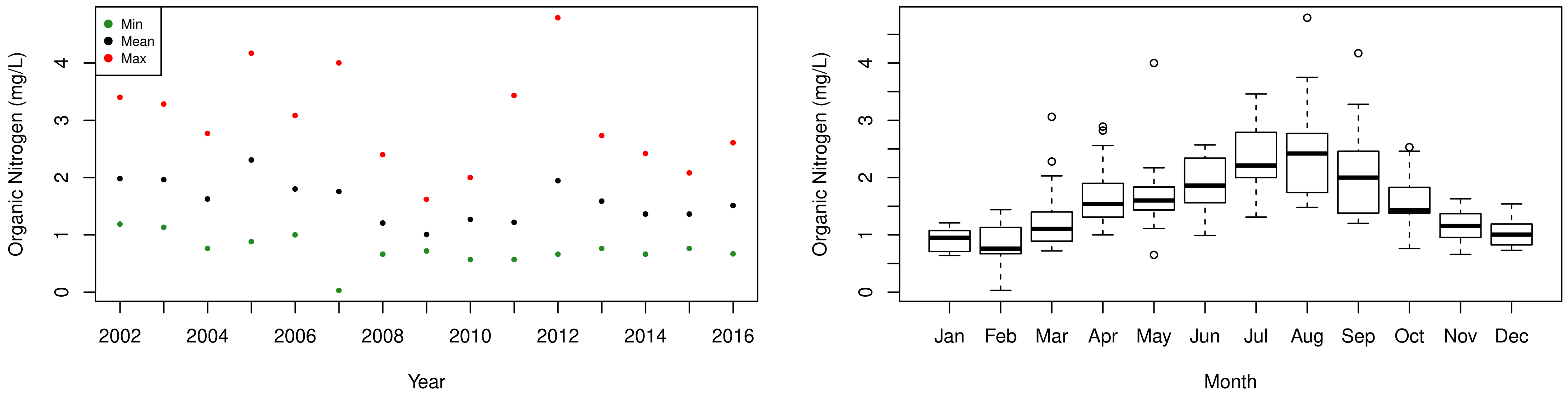
(d) Boxplot by month

Fox River at Yorkville (34): Organic Nitrogen (mg/L)



(a) Observation data

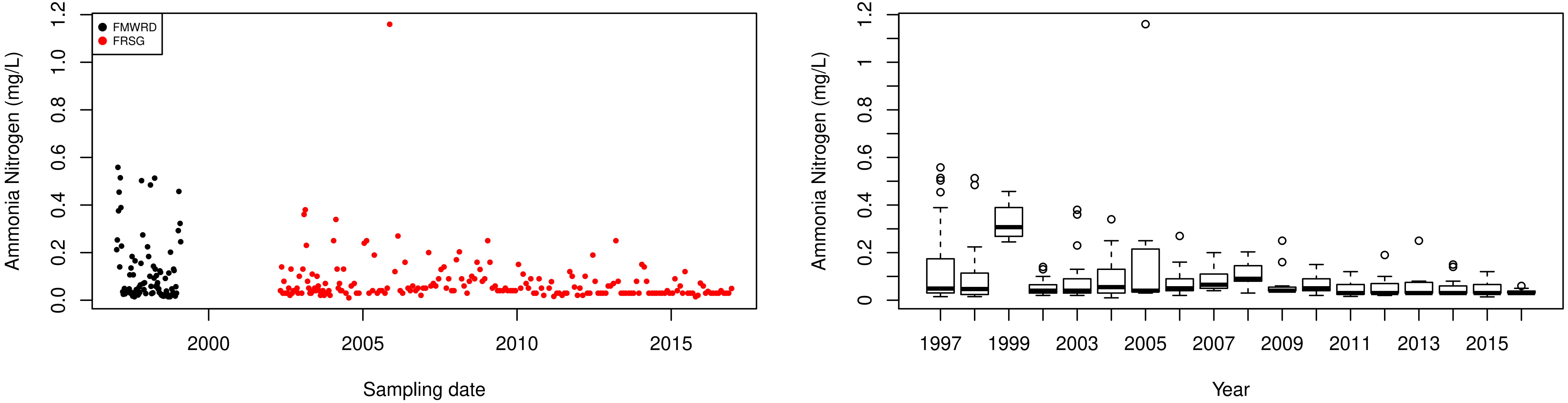
(b) Boxplot by year



(c) Annual values

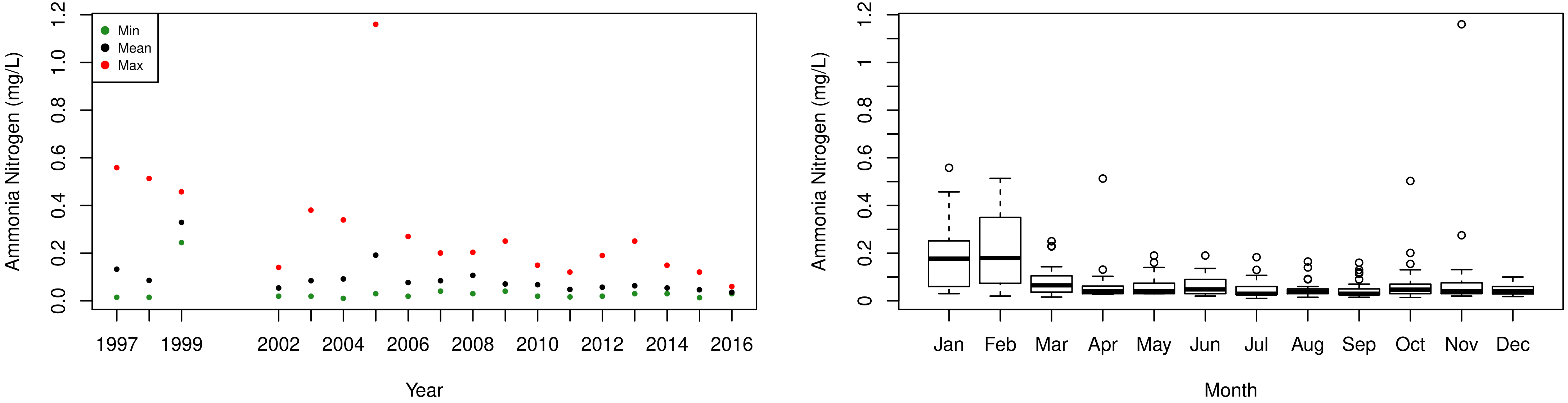
(d) Boxplot by month

Fox River at Yorkville (34): Ammonia Nitrogen (mg/L)



(a) Observation data

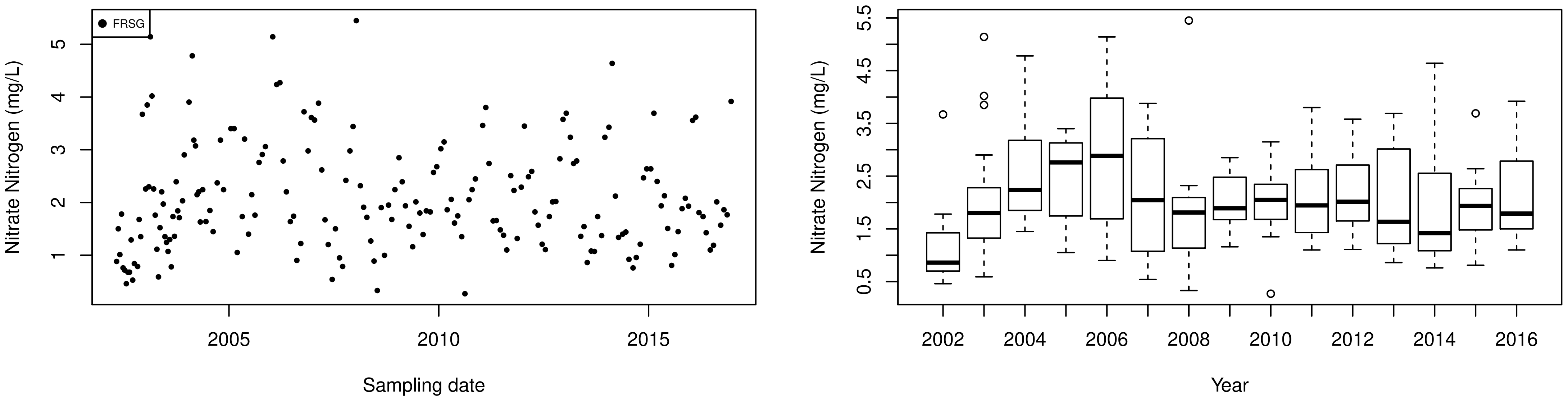
(b) Boxplot by year



(c) Annual values

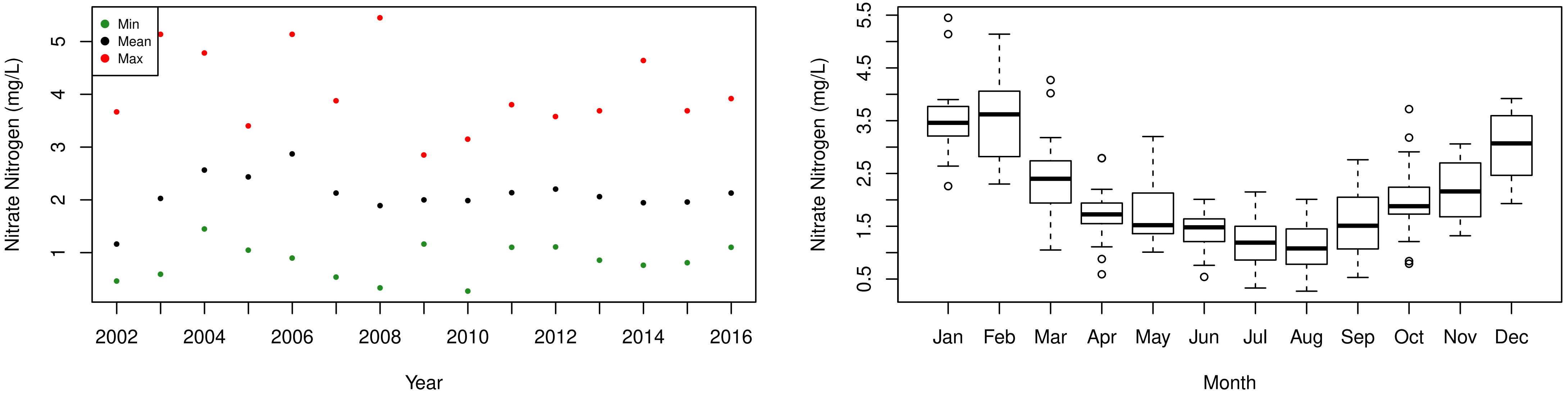
(d) Boxplot by month

Fox River at Yorkville (34): Nitrate Nitrogen (mg/L)



(a) Observation data

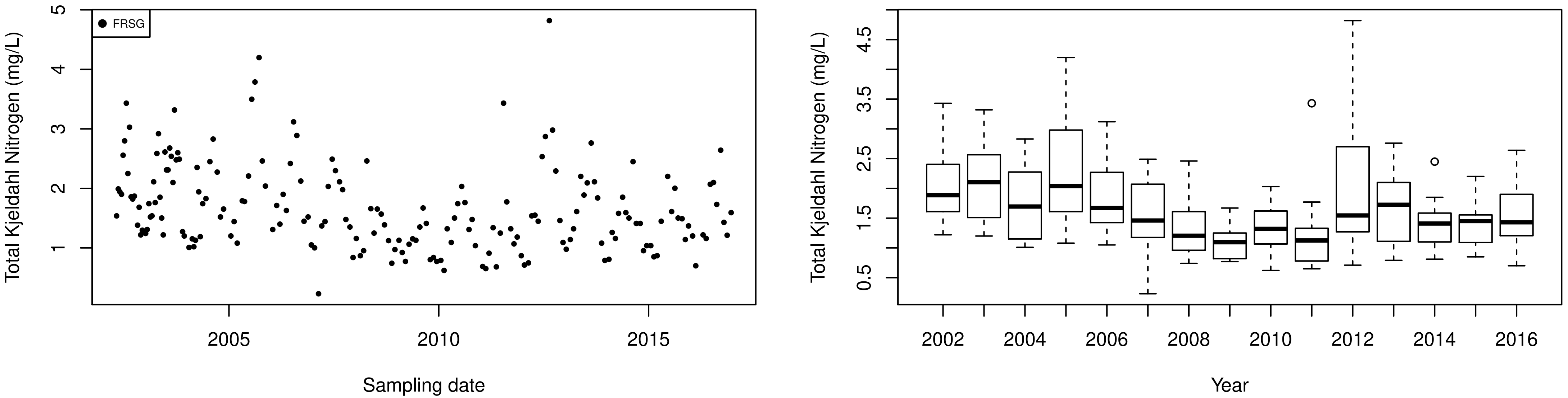
(b) Boxplot by year



(c) Annual values

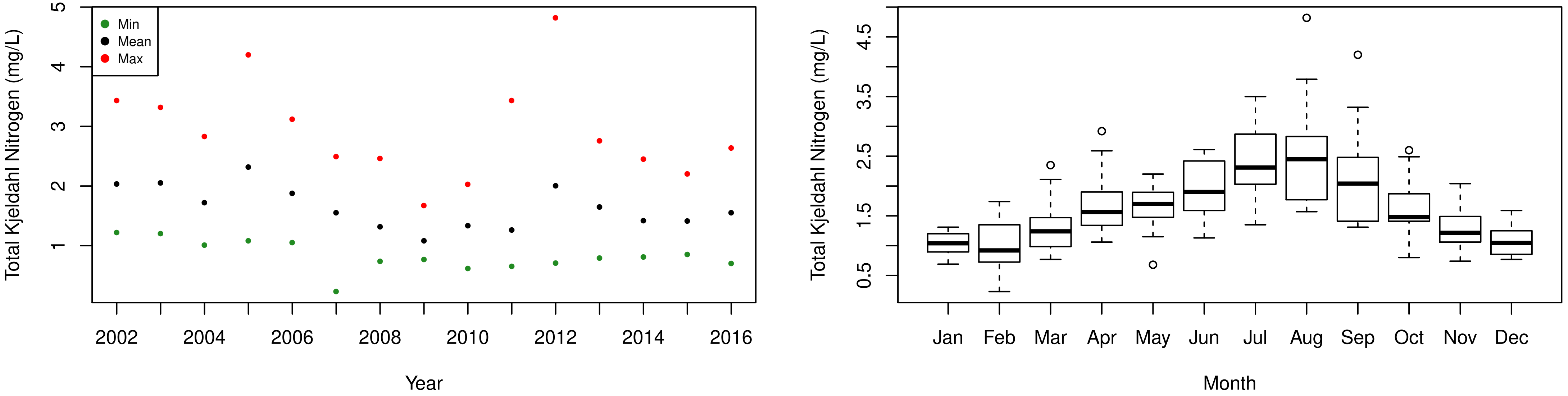
(d) Boxplot by month

Fox River at Yorkville (34): Total Kjeldahl Nitrogen (mg/L)



(a) Observation data

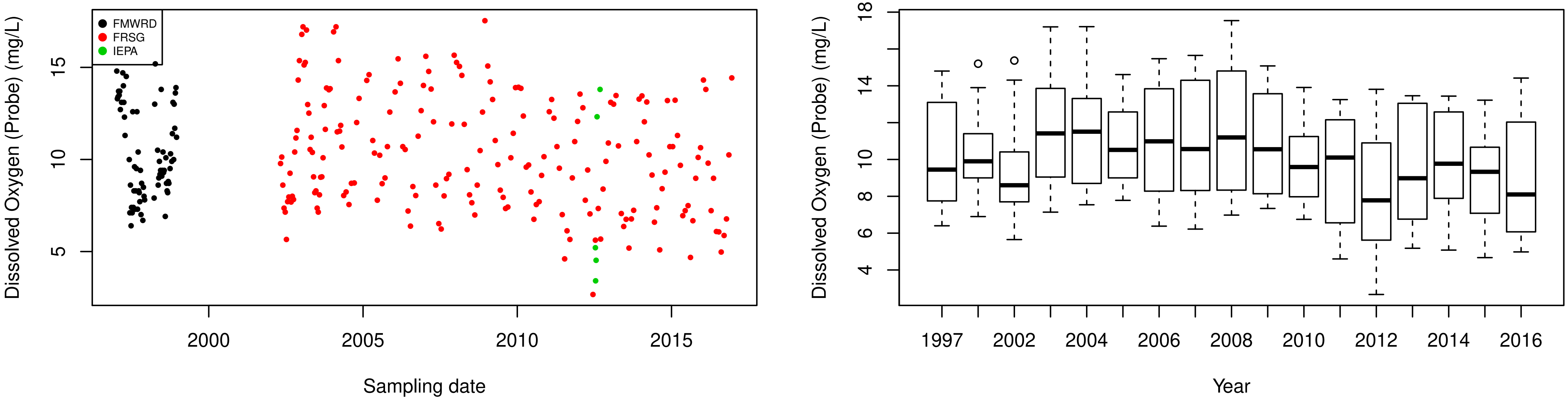
(b) Boxplot by year



(c) Annual values

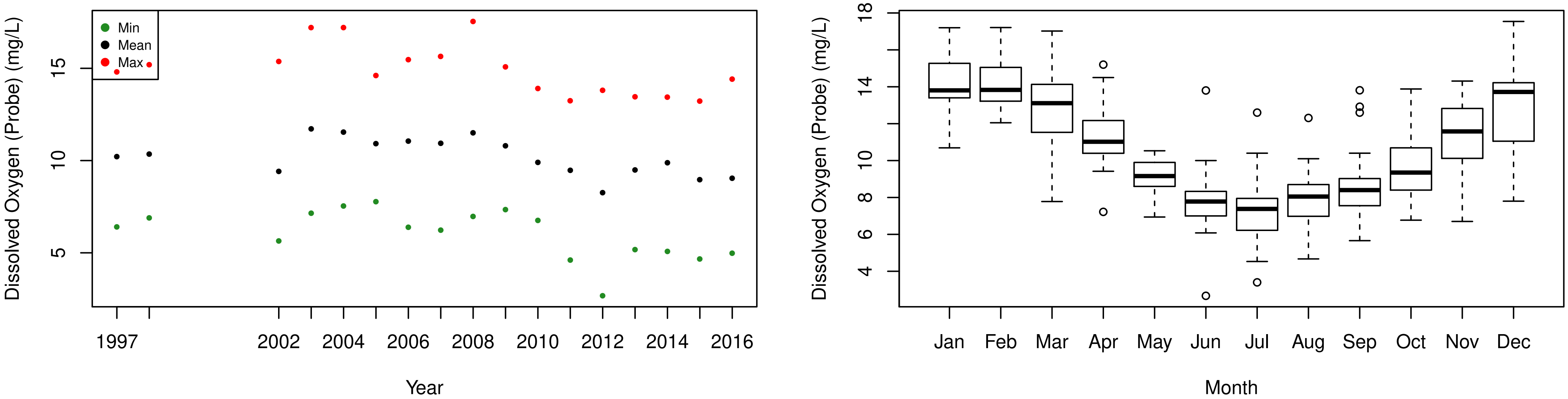
(d) Boxplot by month

Fox River at Yorkville (34): Dissolved Oxygen (Probe) (mg/L)



(a) Observation data

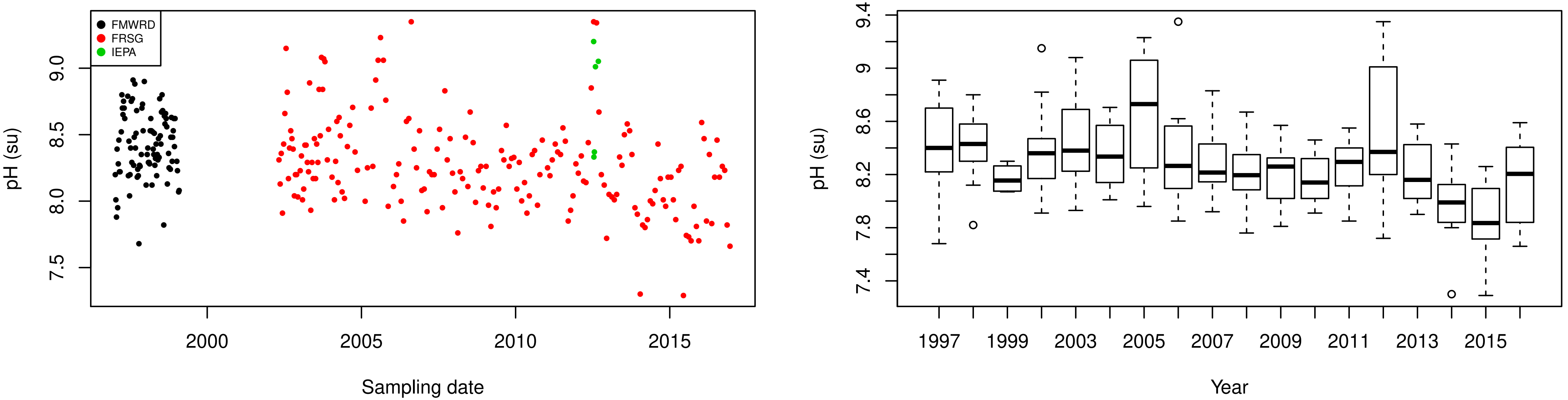
(b) Boxplot by year



(c) Annual values

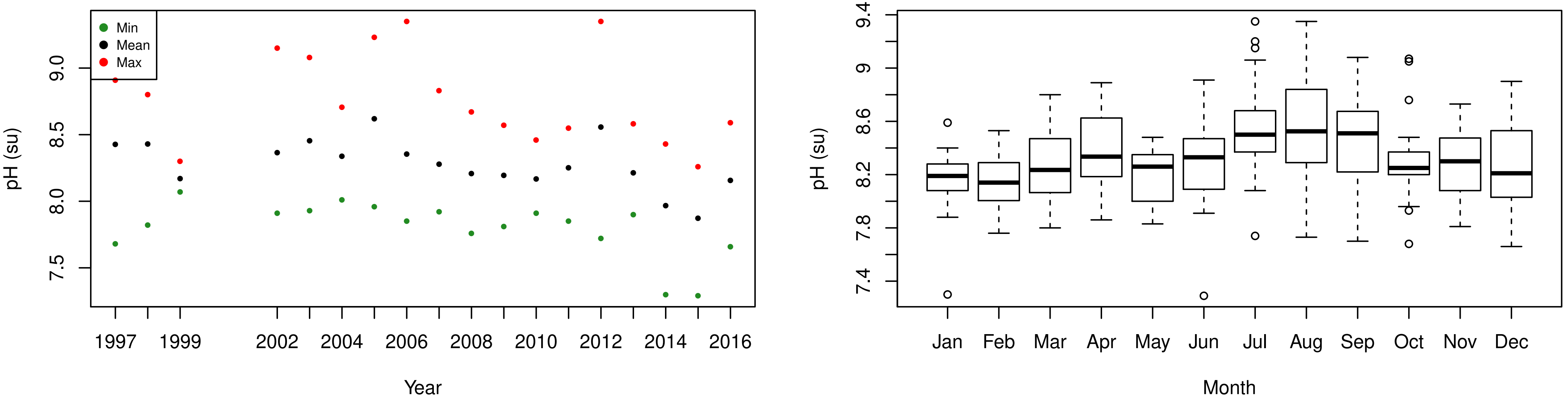
(d) Boxplot by month

Fox River at Yorkville (34): pH (su)



(a) Observation data

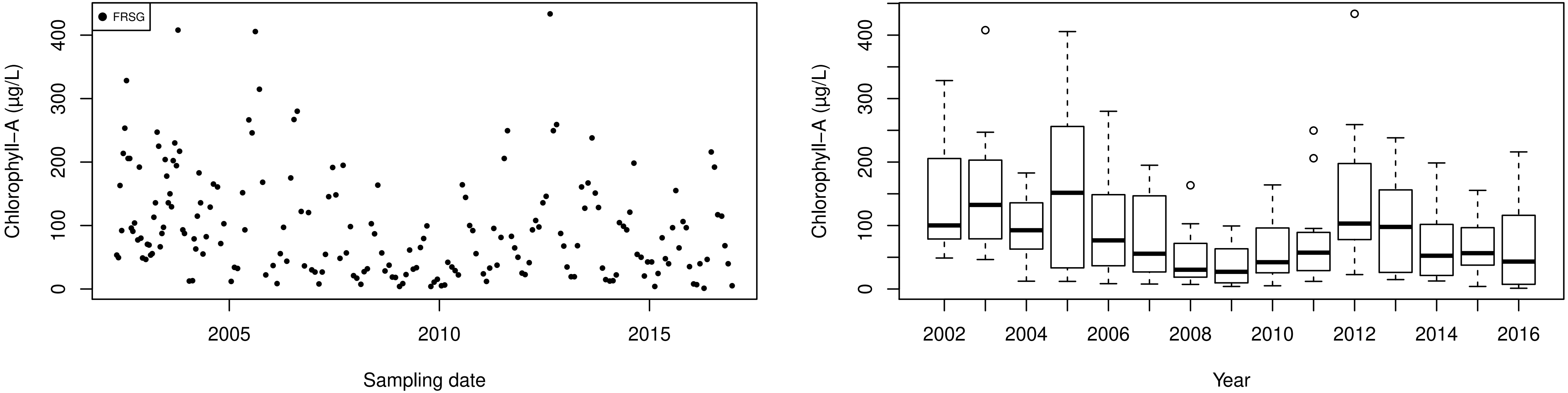
(b) Boxplot by year



(c) Annual values

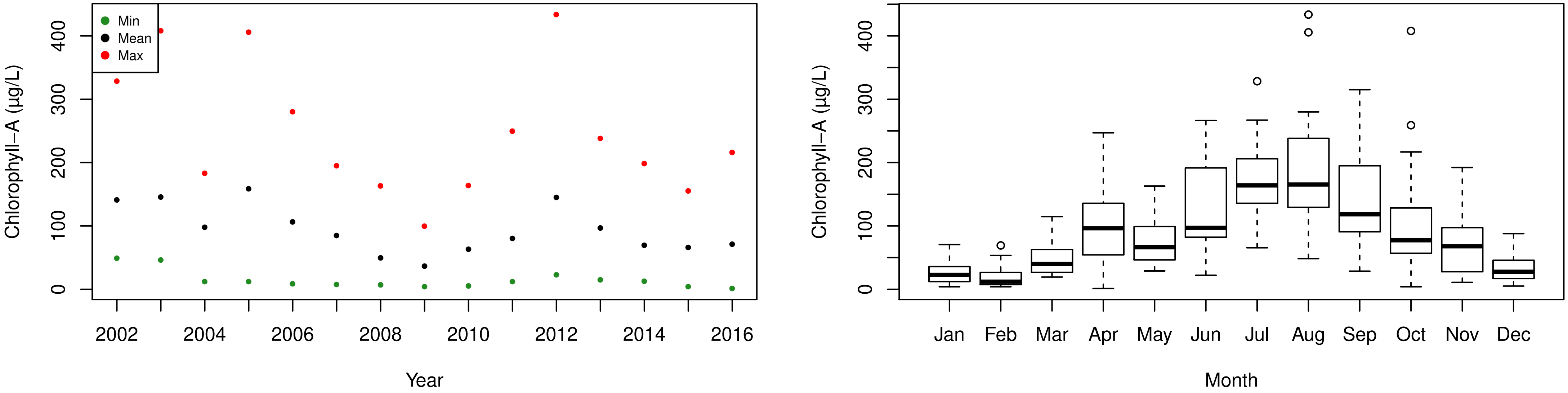
(d) Boxplot by month

Fox River at Yorkville (34): Chlorophyll–A (μg/L)



(a) Observation data

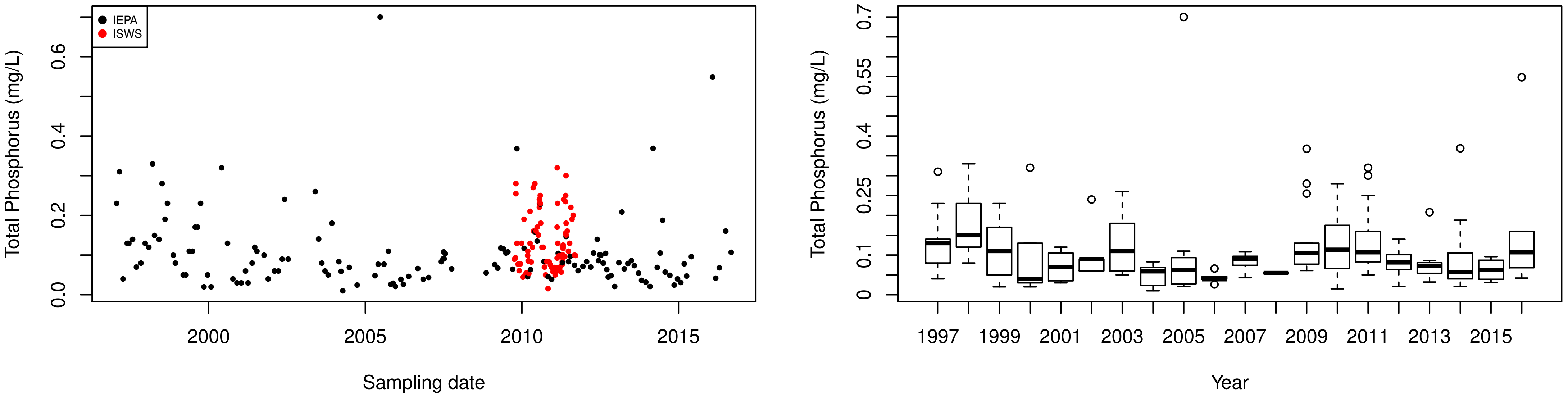
(b) Boxplot by year



(c) Annual values

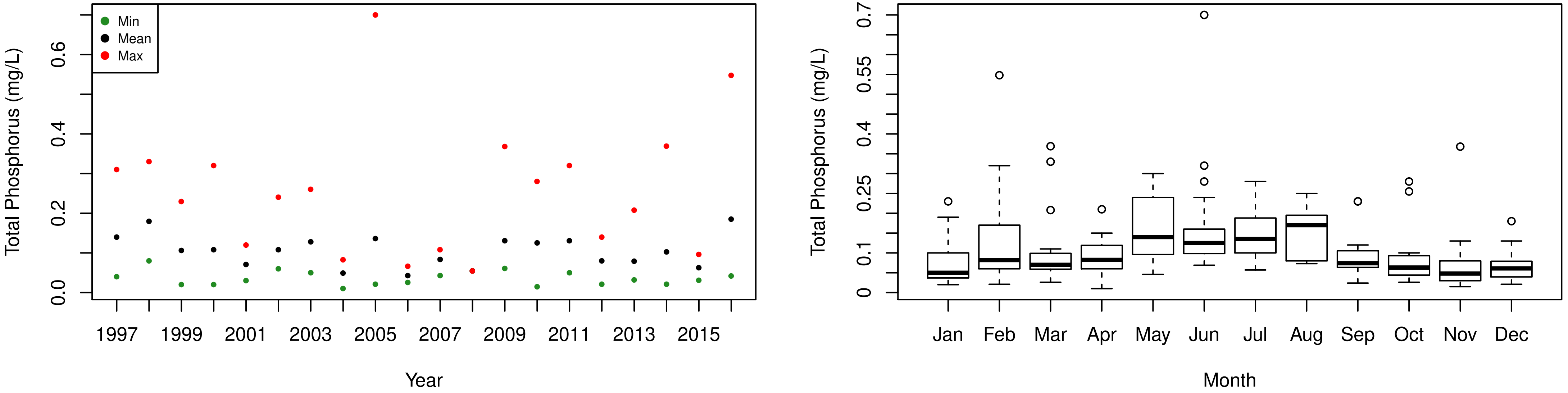
(d) Boxplot by month

Blackberry Cr at Rt 47 (28): Total Phosphorus (mg/L)



(a) Observation data

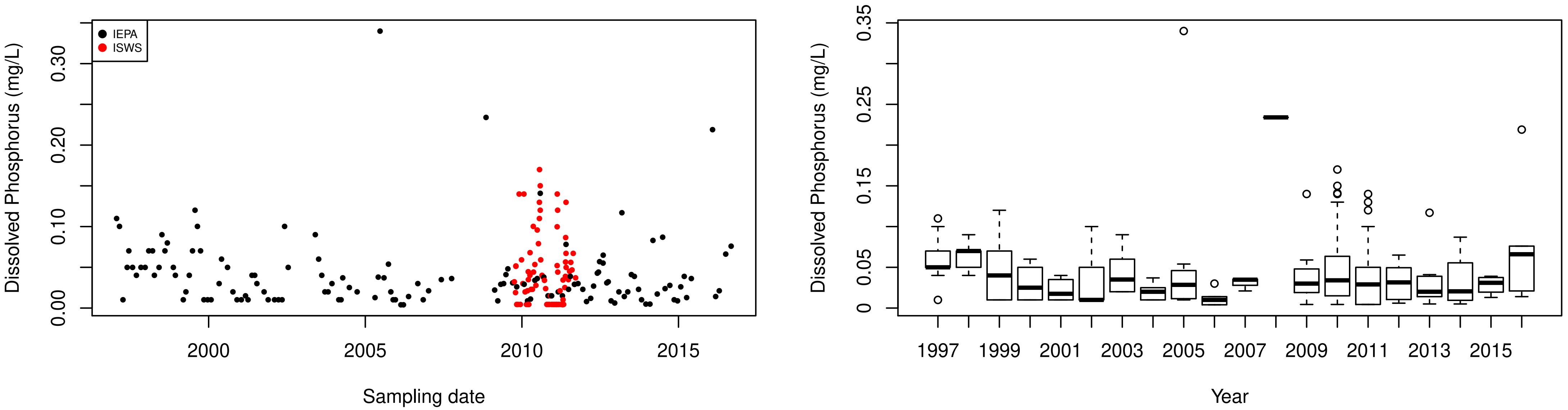
(b) Boxplot by year



(c) Annual values

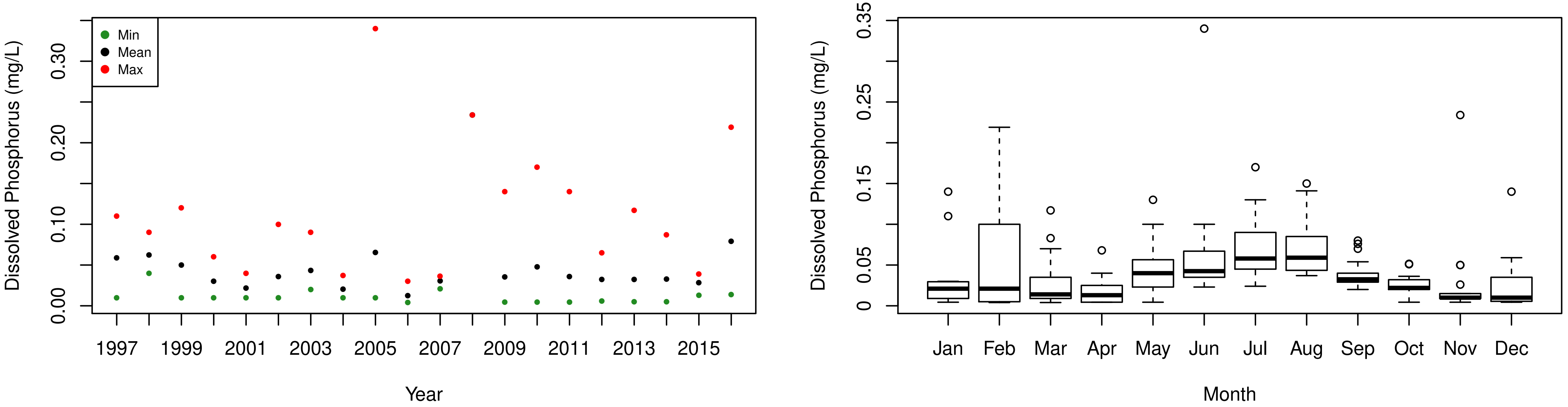
(d) Boxplot by month

Blackberry Cr at Rt 47 (28): Dissolved Phosphorus (mg/L)



(a) Observation data

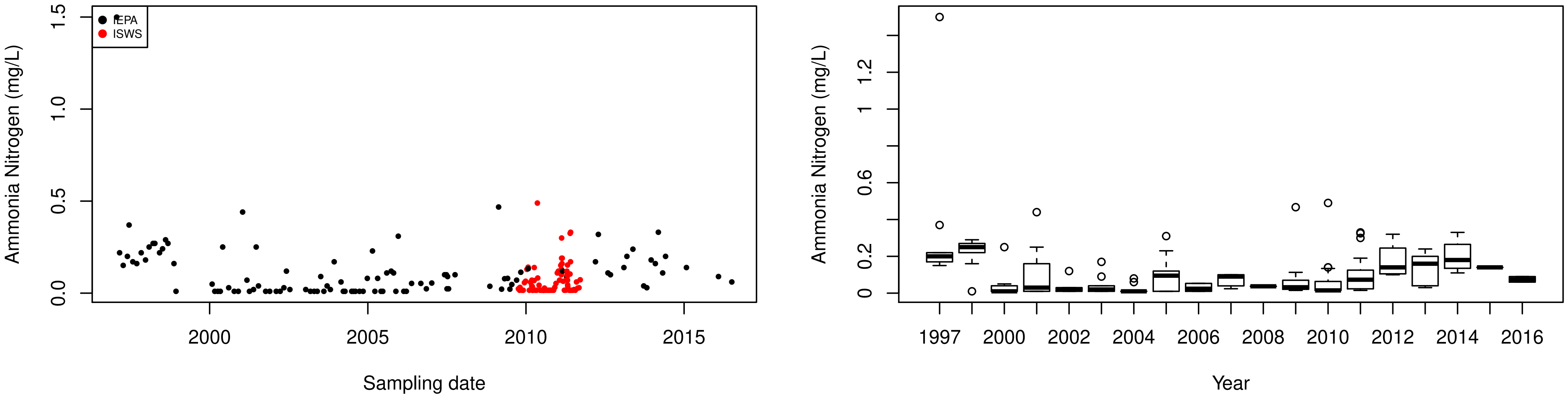
(b) Boxplot by year



(c) Annual values

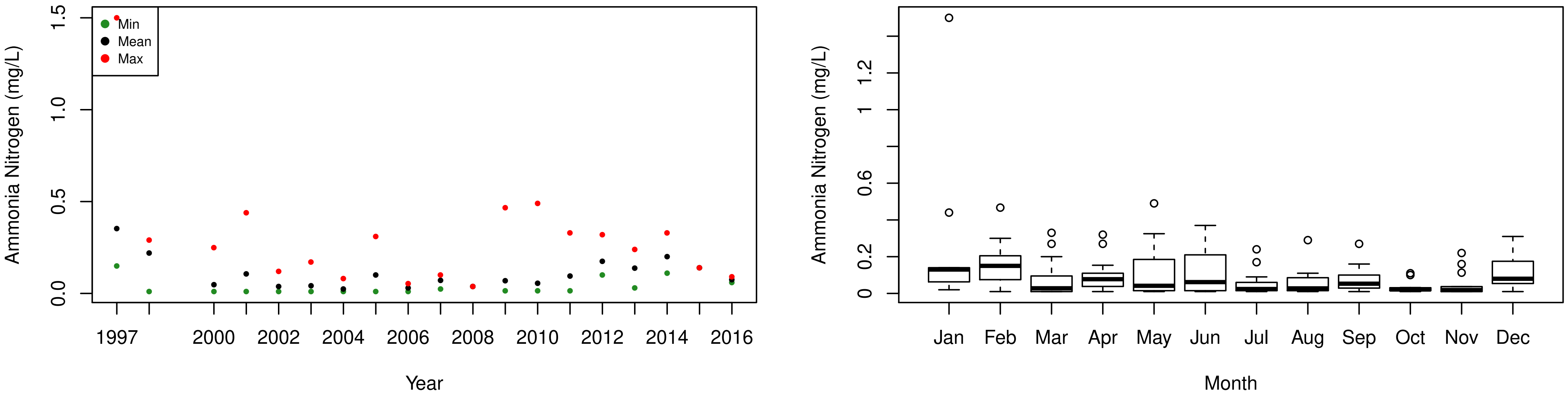
(d) Boxplot by month

Blackberry Cr at Rt 47 (28): Ammonia Nitrogen (mg/L)



(a) Observation data

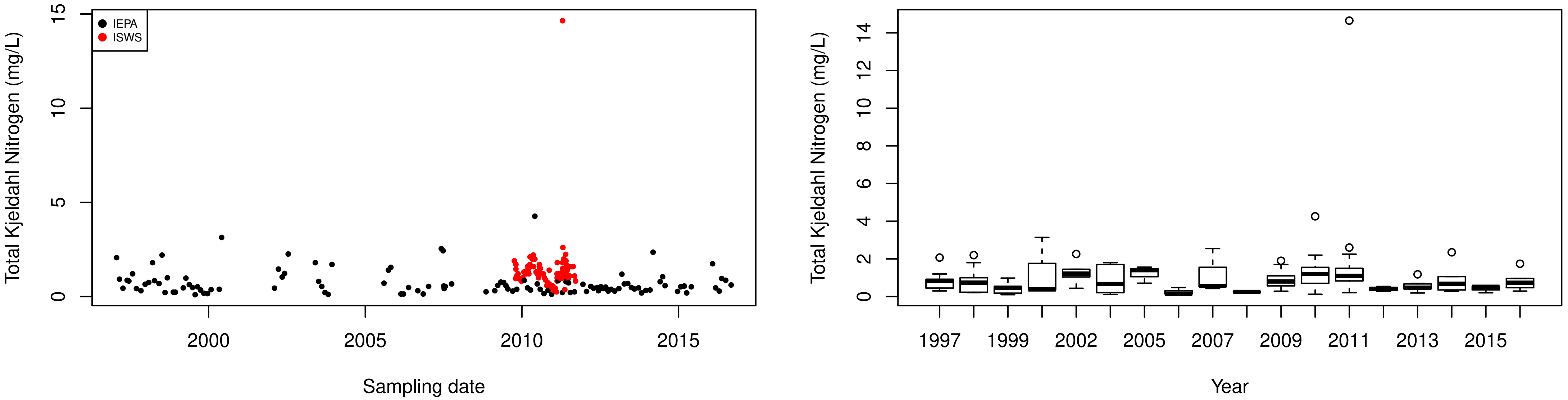
(b) Boxplot by year



(c) Annual values

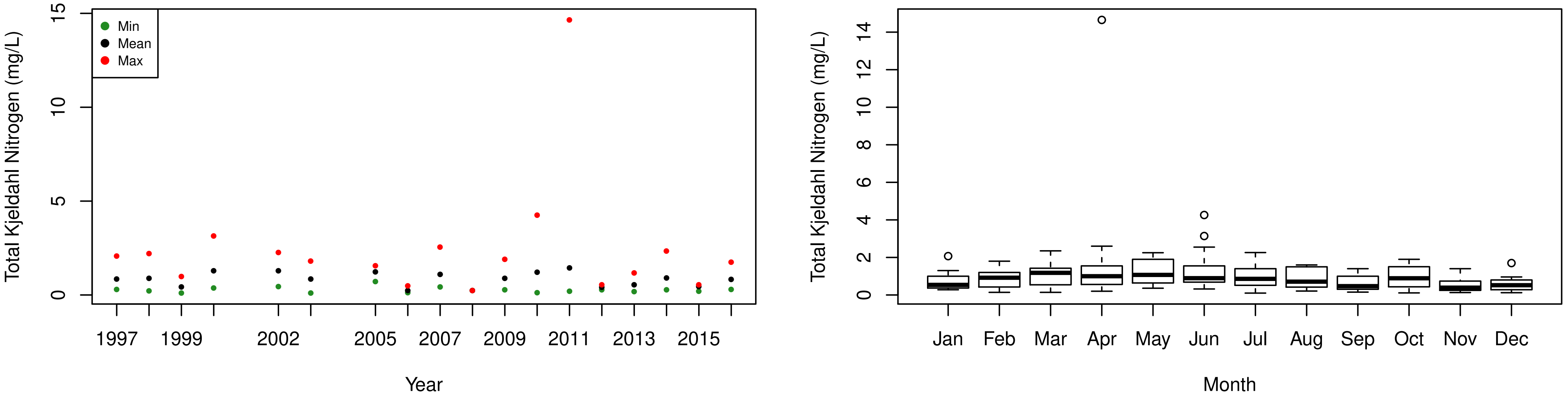
(d) Boxplot by month

Blackberry Cr at Rt 47 (28): Total Kjeldahl Nitrogen (mg/L)



(a) Observation data

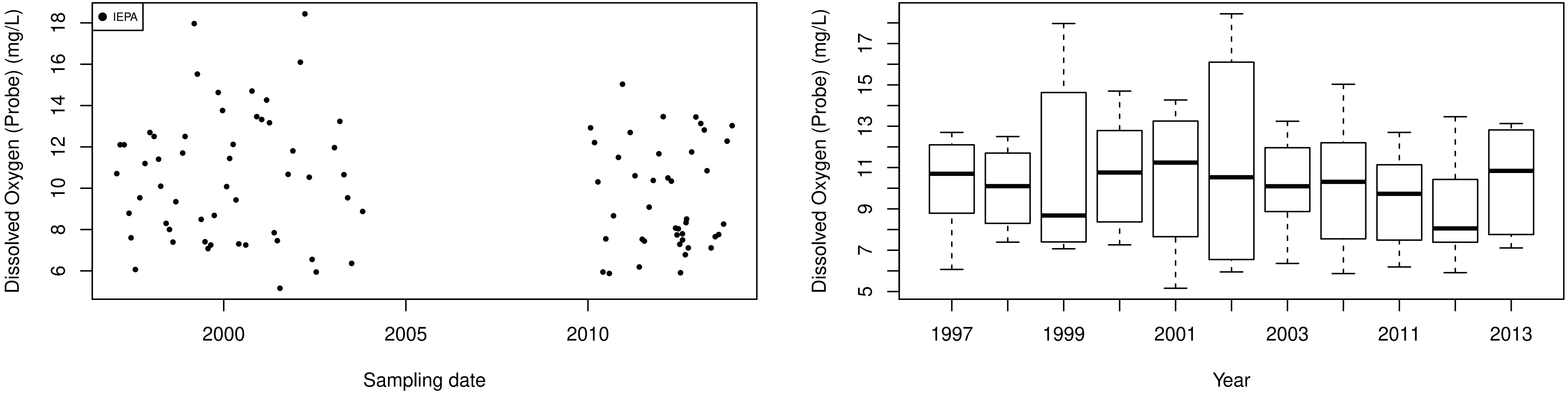
(b) Boxplot by year



(c) Annual values

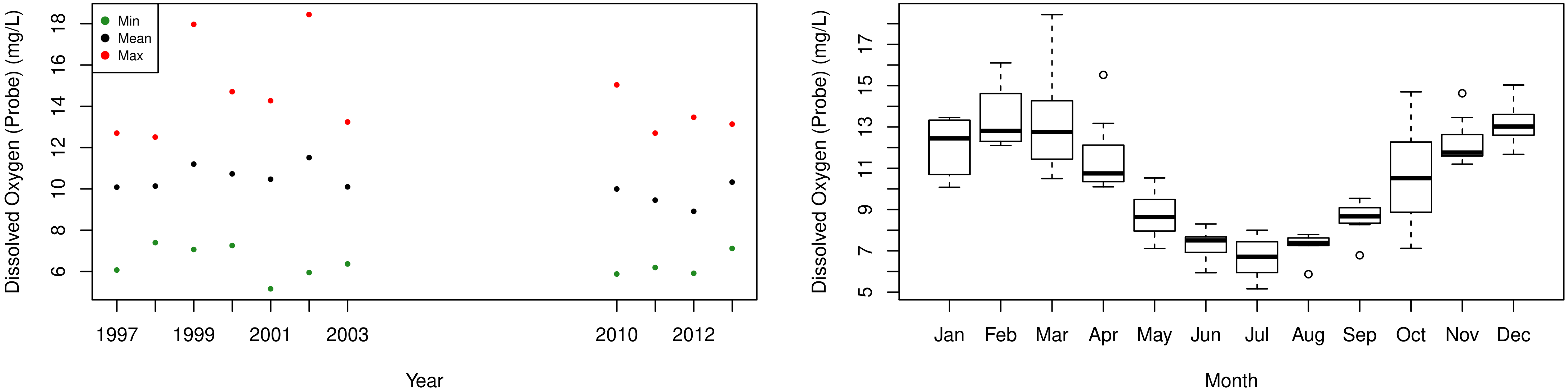
(d) Boxplot by month

Blackberry Cr at Rt 47 (28): Dissolved Oxygen (Probe) (mg/L)



(a) Observation data

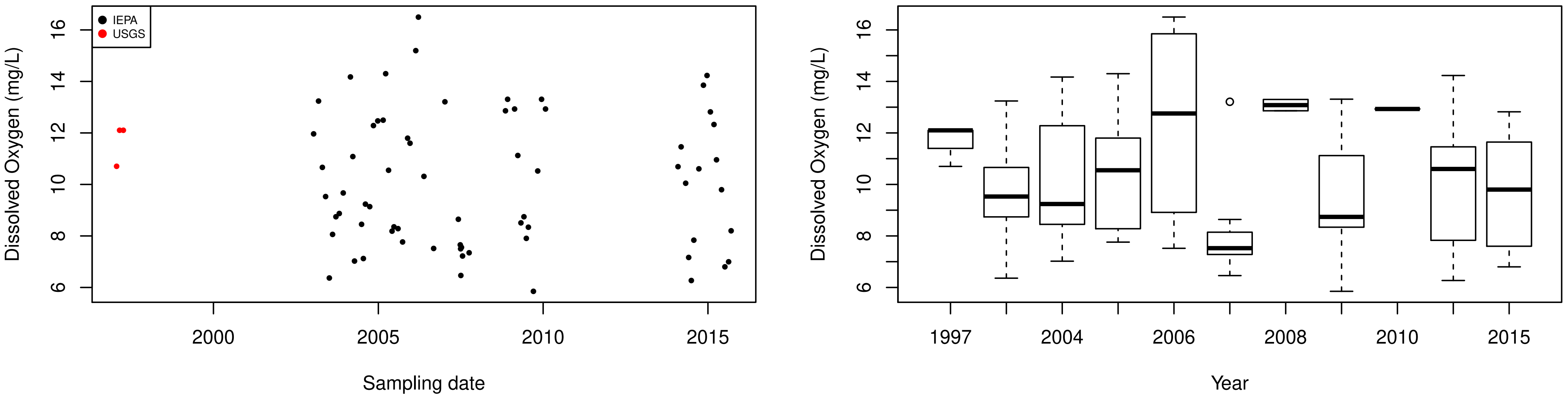
(b) Boxplot by year



(c) Annual values

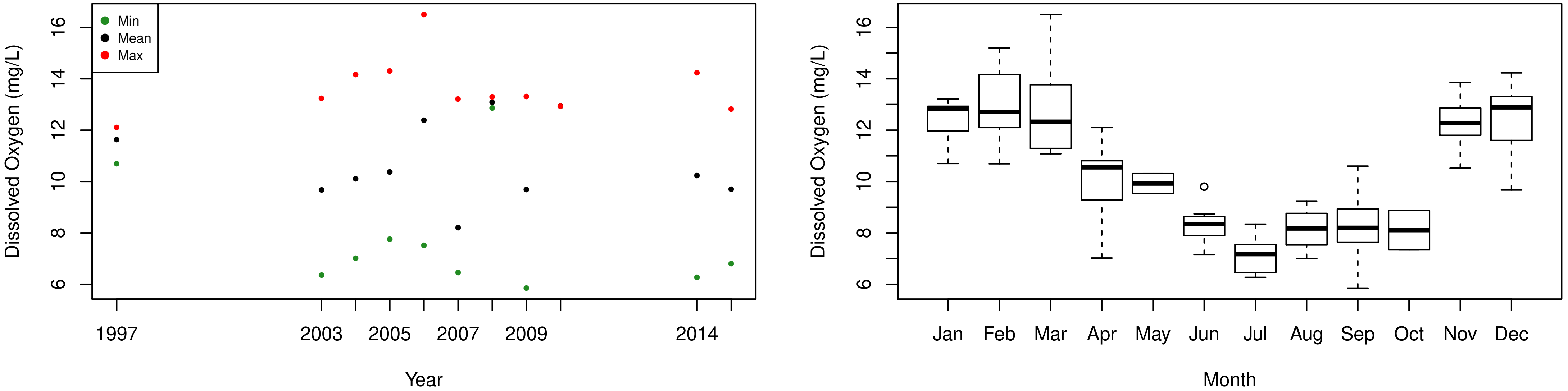
(d) Boxplot by month

Blackberry Cr at Rt 47 (28): Dissolved Oxygen (mg/L)



(a) Observation data

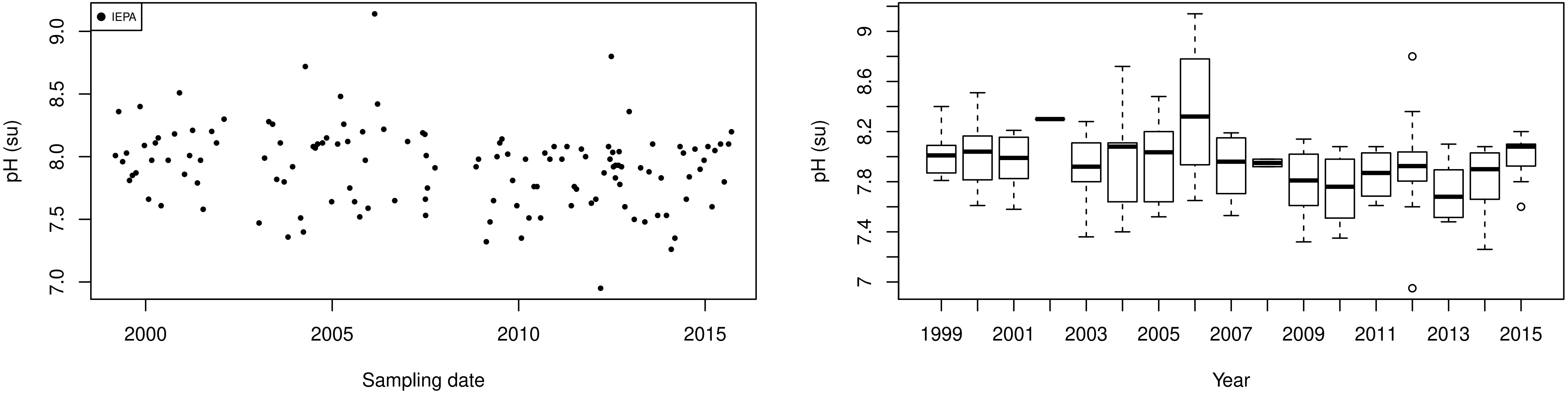
(b) Boxplot by year



(c) Annual values

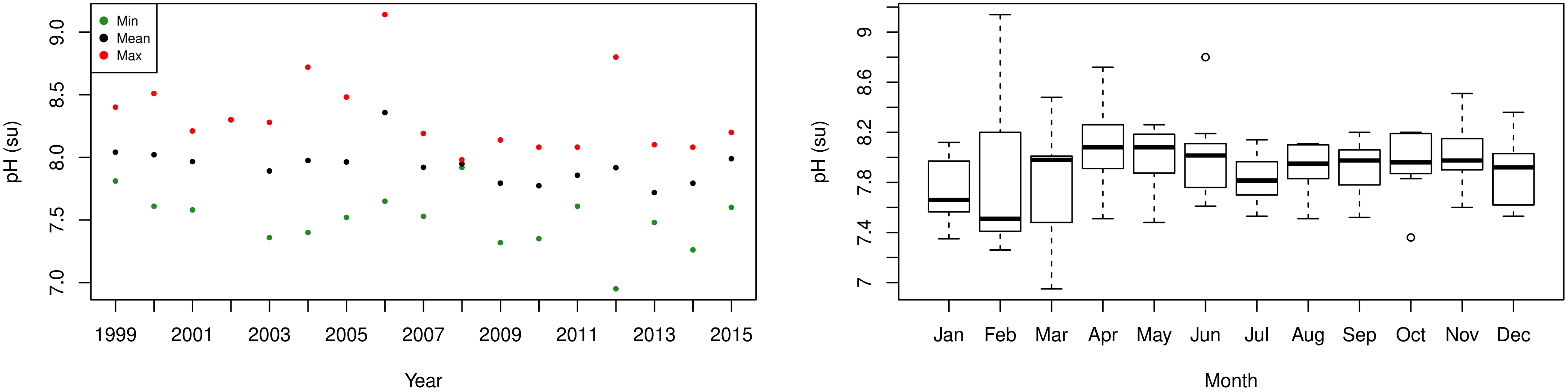
(d) Boxplot by month

Blackberry Cr at Rt 47 (28): pH (su)



(a) Observation data

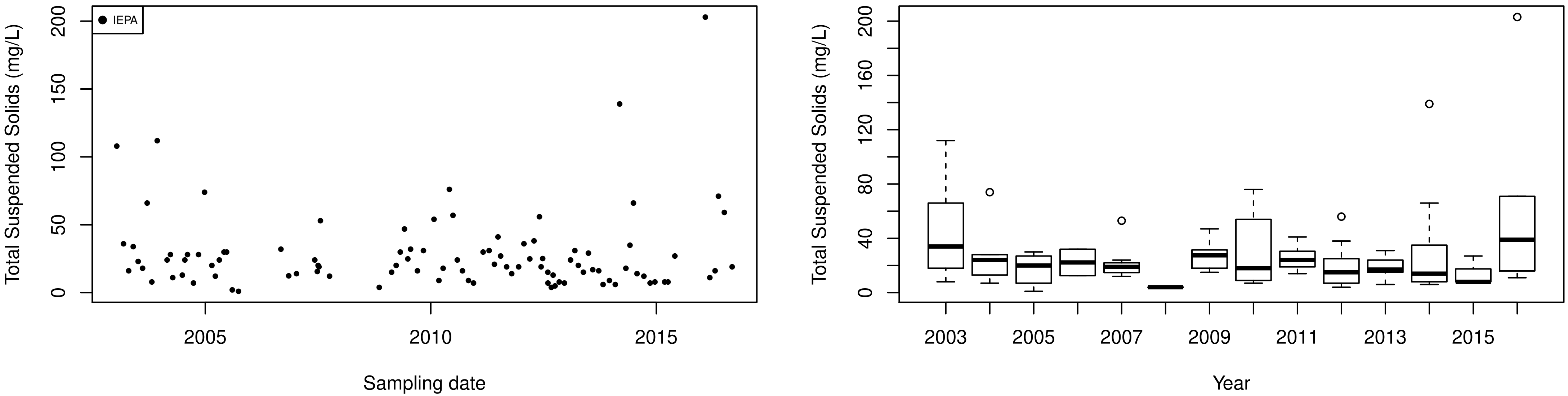
(b) Boxplot by year



(c) Annual values

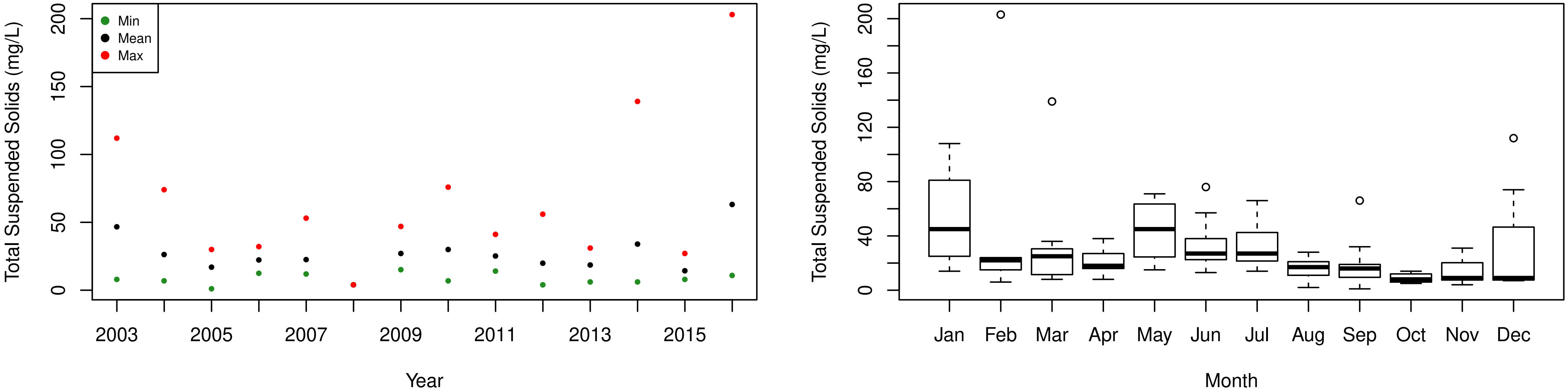
(d) Boxplot by month

Blackberry Cr at Rt 47 (28): Total Suspended Solids (mg/L)



(a) Observation data

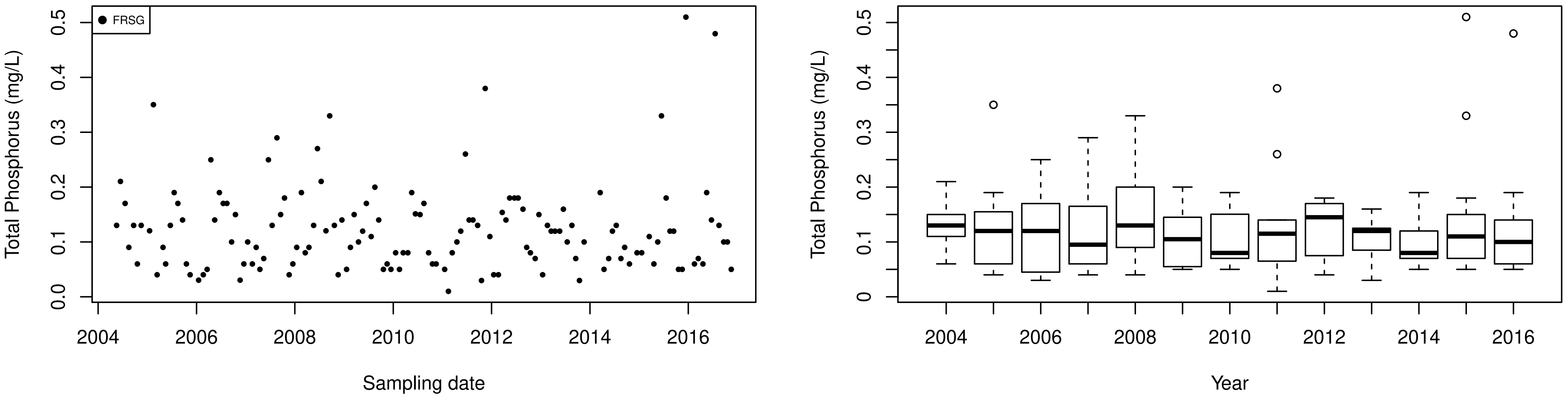
(b) Boxplot by year



(c) Annual values

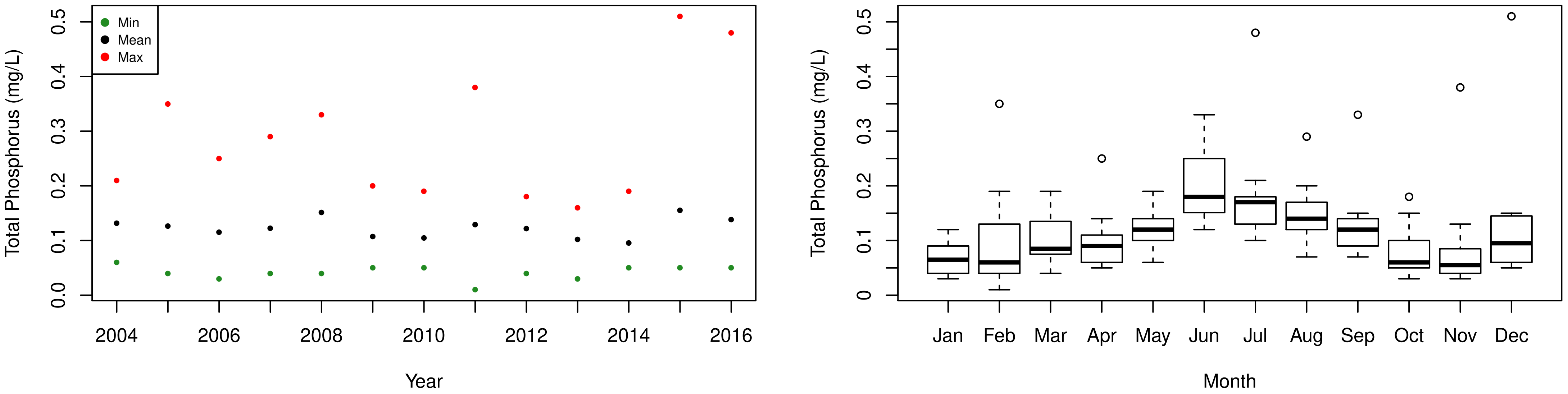
(d) Boxplot by month

Blackberry Cr near Mouth (287): Total Phosphorus (mg/L)



(a) Observation data

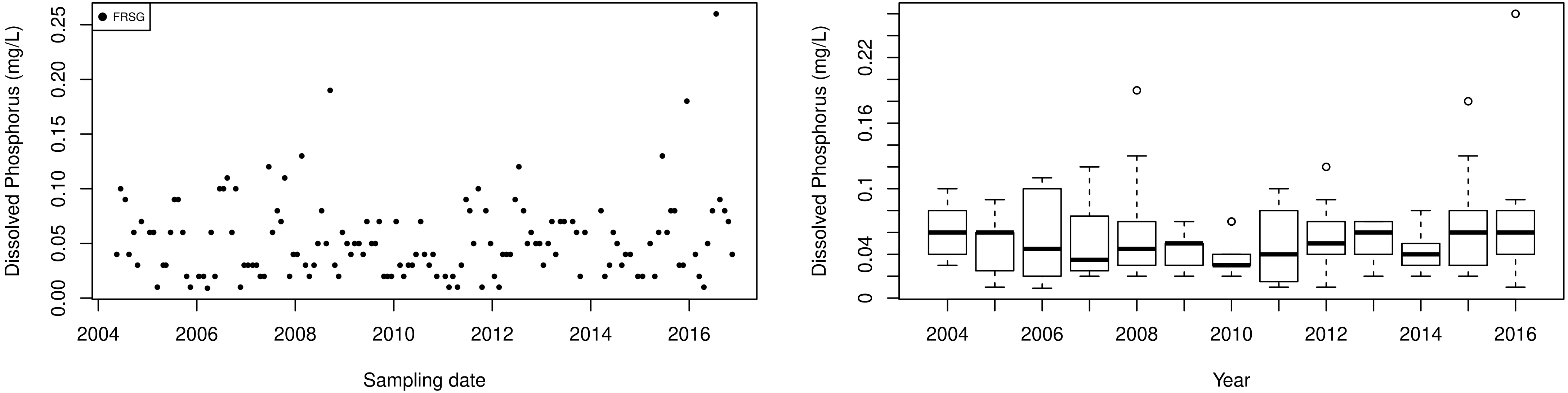
(b) Boxplot by year



(c) Annual values

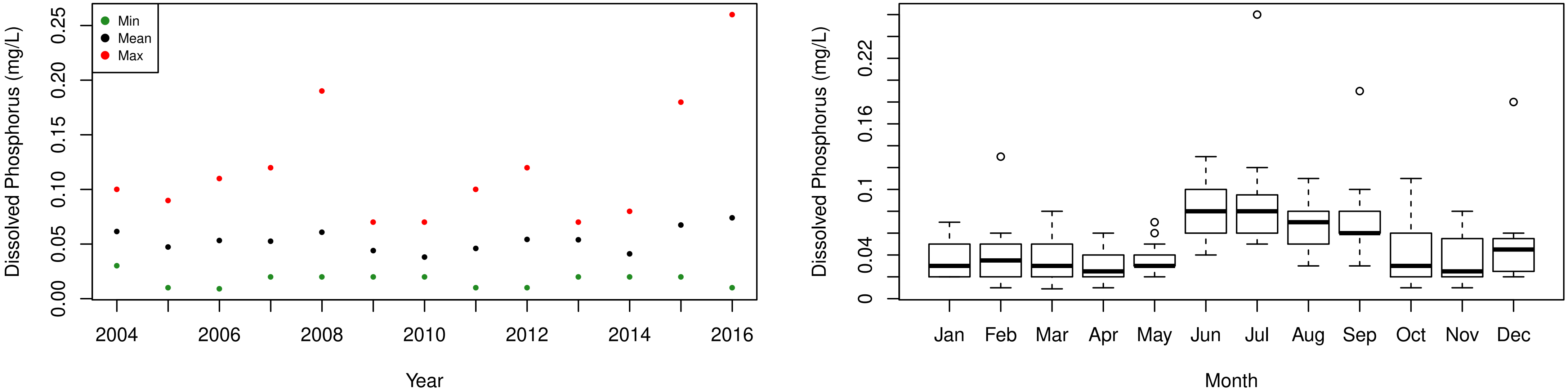
(d) Boxplot by month

Blackberry Cr near Mouth (287): Dissolved Phosphorus (mg/L)



(a) Observation data

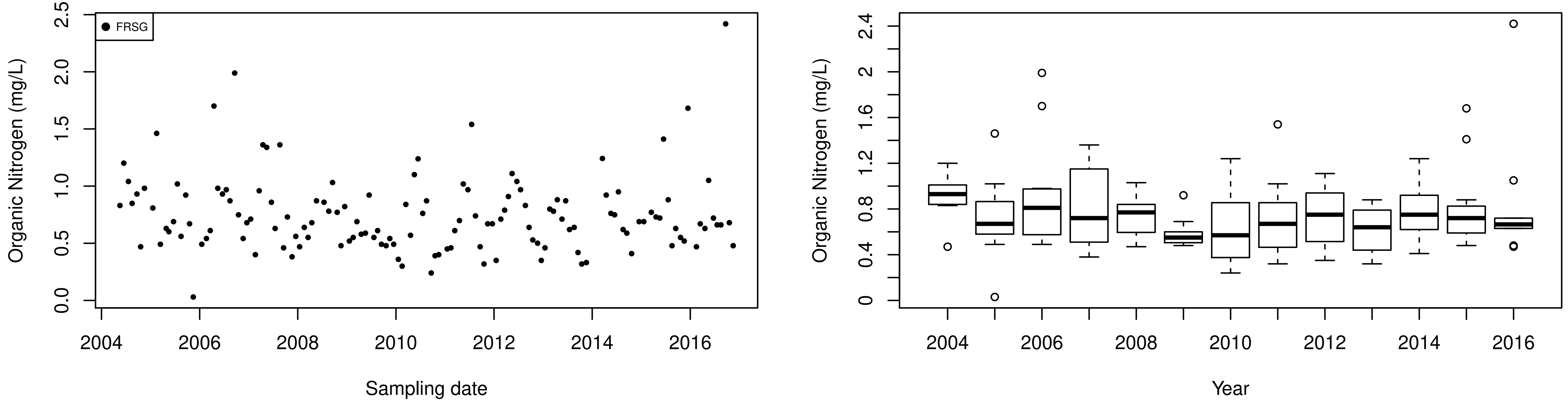
(b) Boxplot by year



(c) Annual values

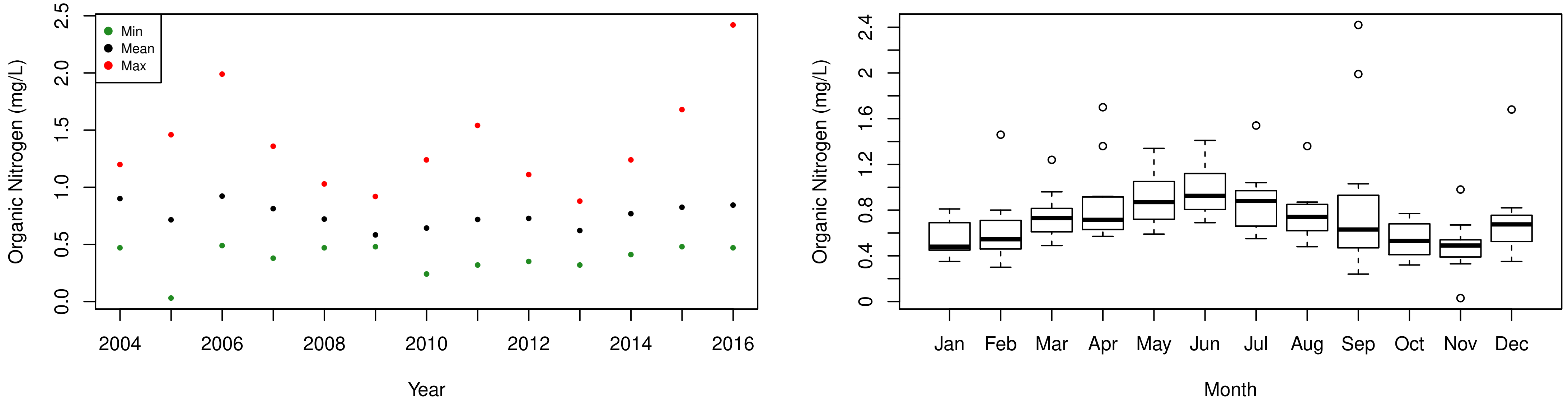
(d) Boxplot by month

Blackberry Cr near Mouth (287): Organic Nitrogen (mg/L)



(a) Observation data

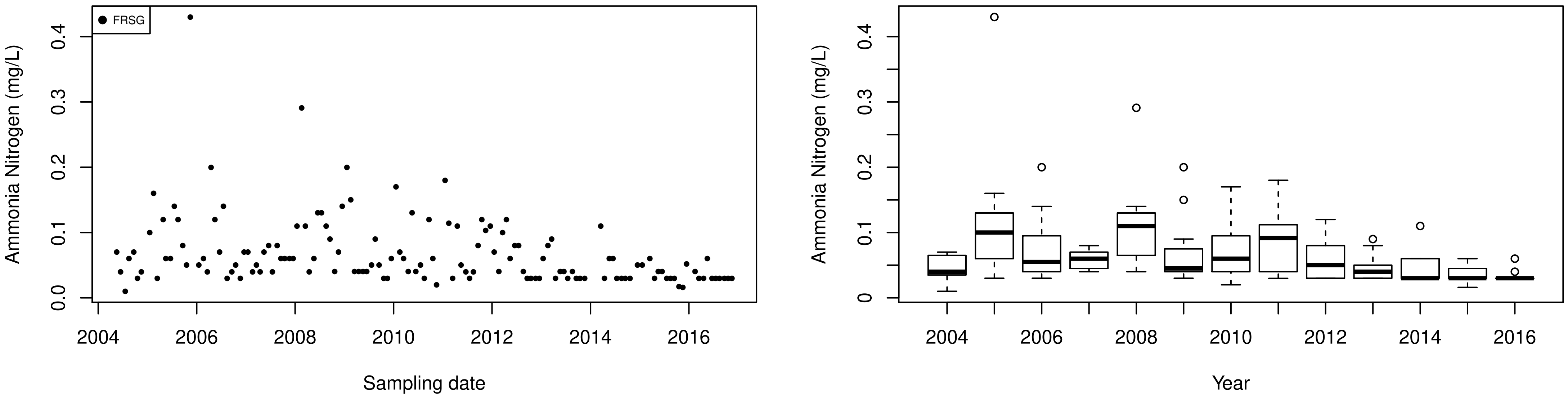
(b) Boxplot by year



(c) Annual values

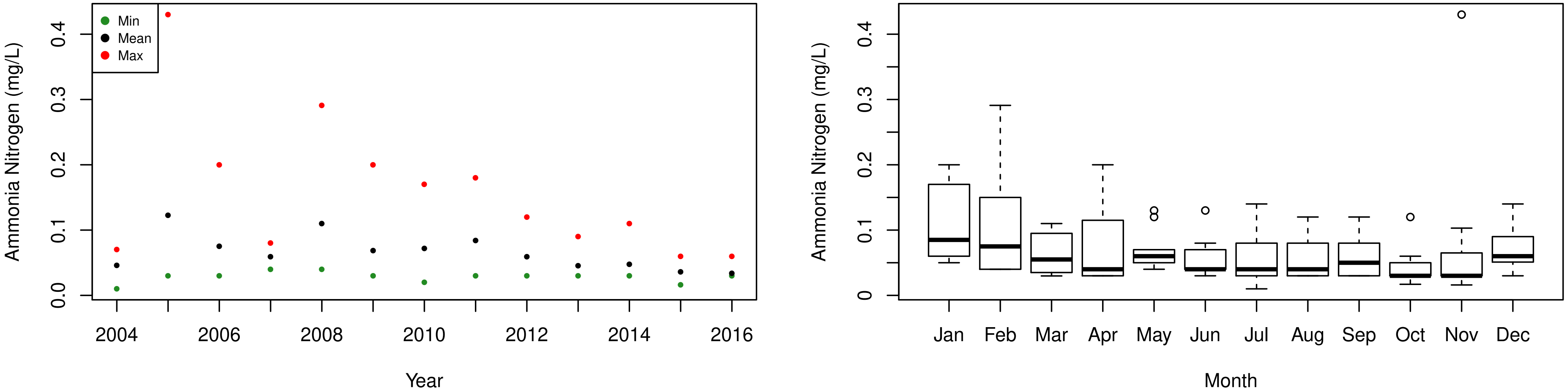
(d) Boxplot by month

Blackberry Cr near Mouth (287): Ammonia Nitrogen (mg/L)



(a) Observation data

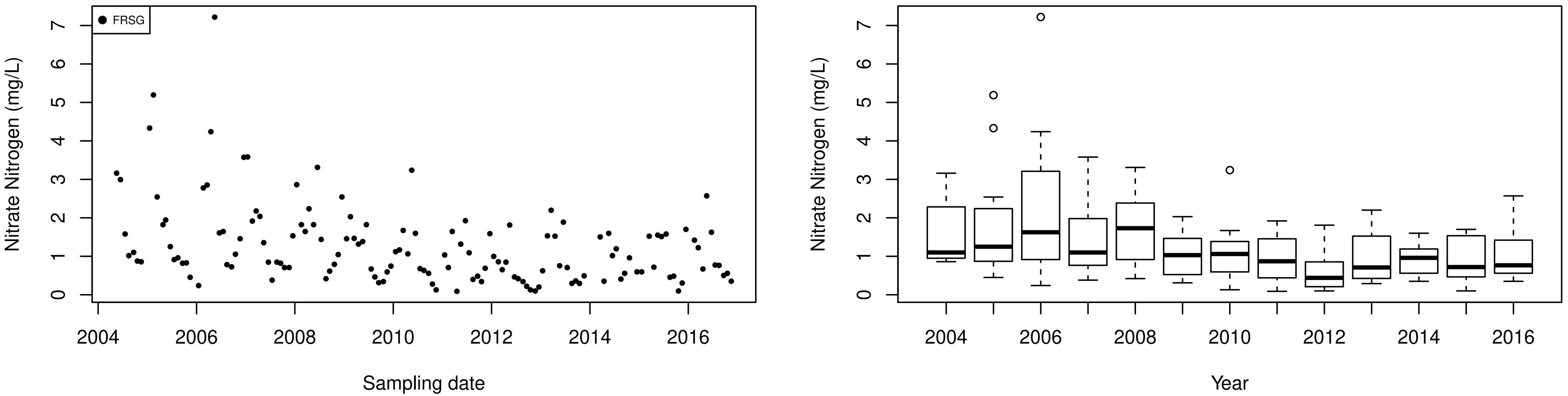
(b) Boxplot by year



(c) Annual values

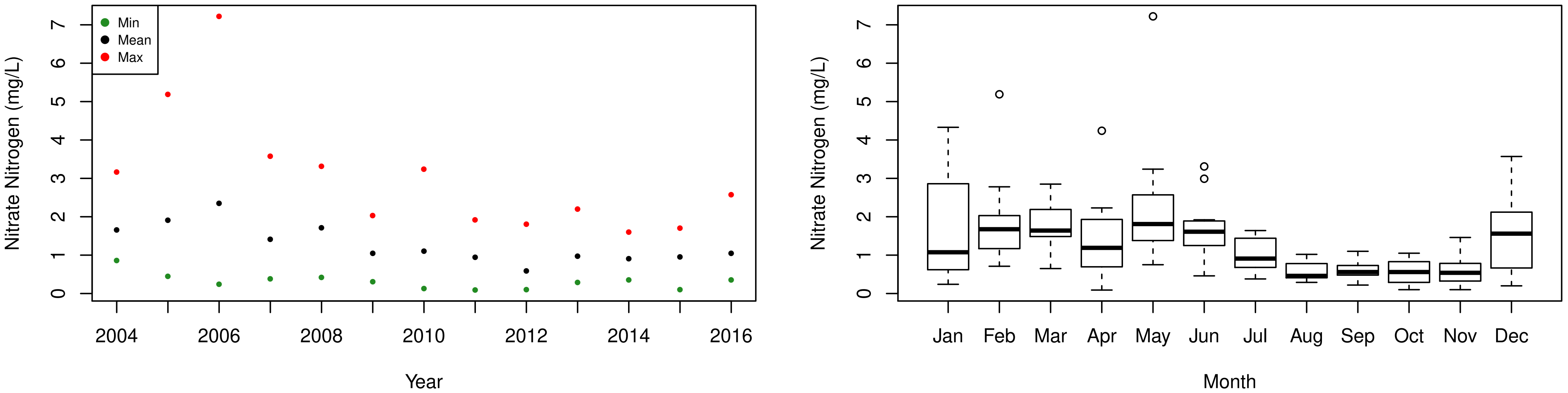
(d) Boxplot by month

Blackberry Cr near Mouth (287): Nitrate Nitrogen (mg/L)



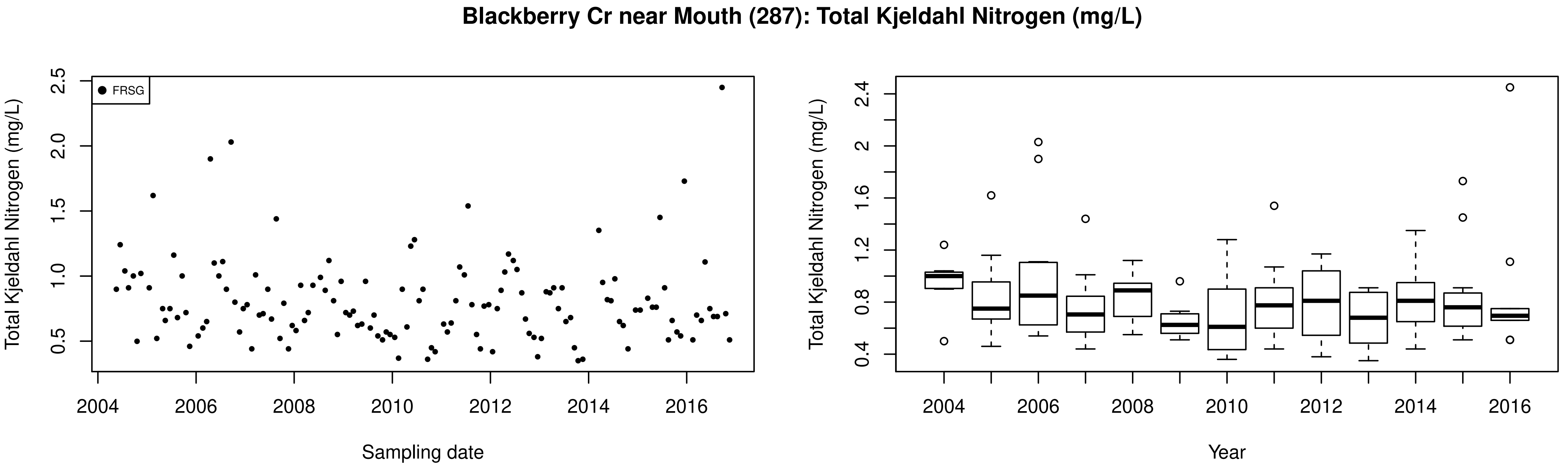
(a) Observation data

(b) Boxplot by year



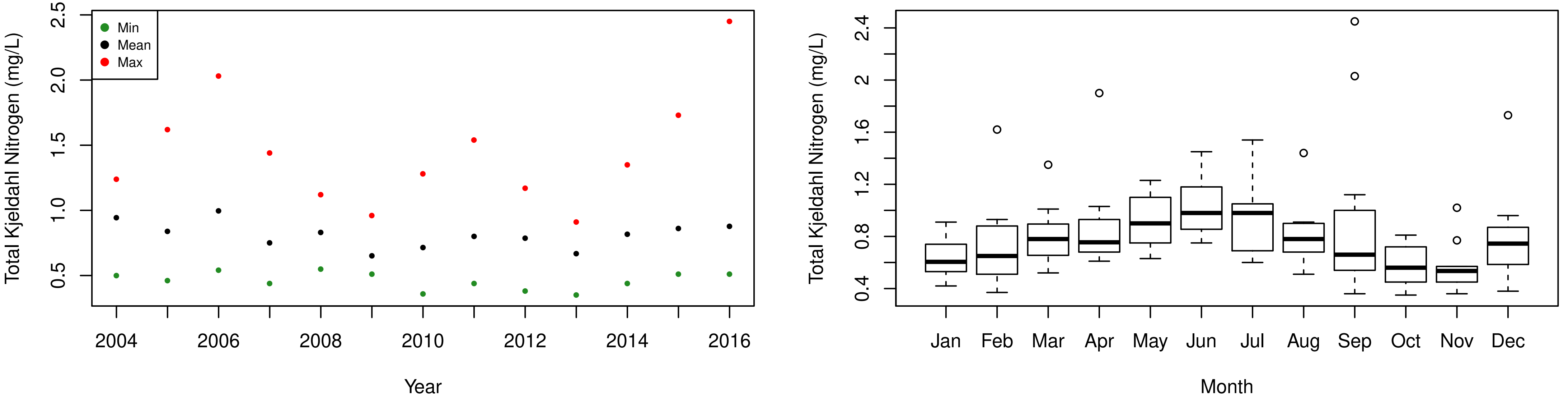
(c) Annual values

(d) Boxplot by month



(a) Observation data

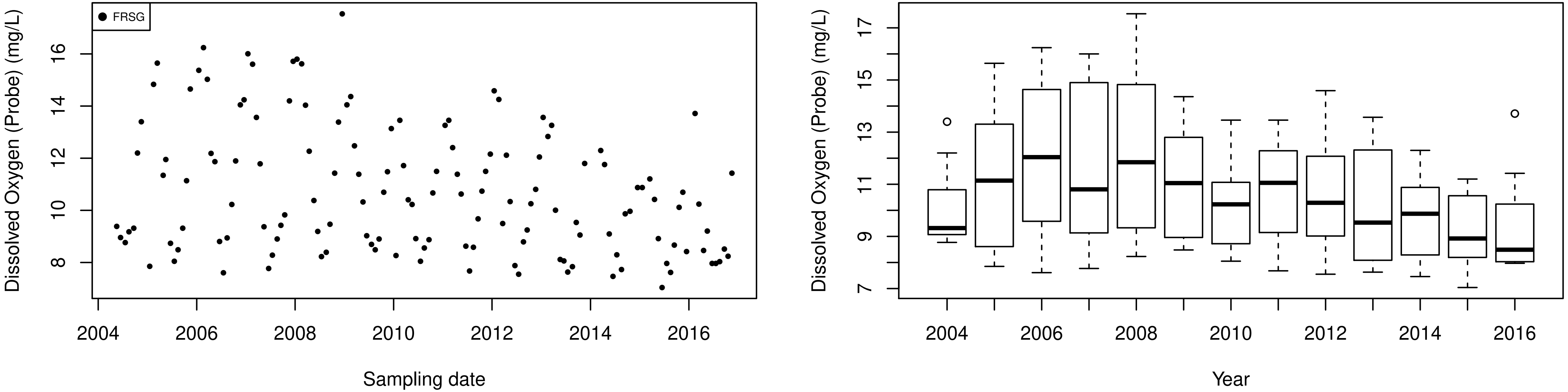
(b) Boxplot by year



(c) Annual values

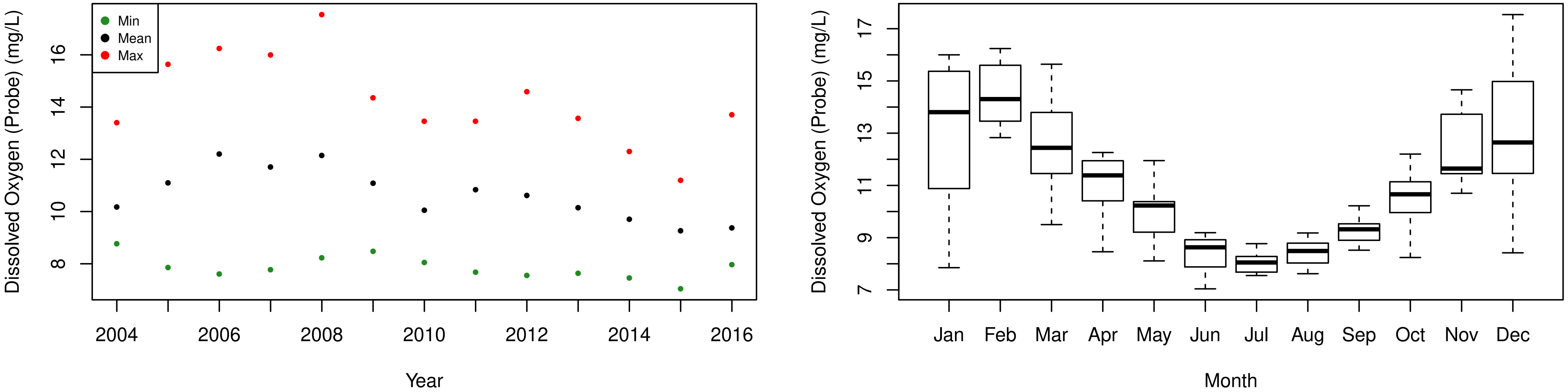
(d) Boxplot by month

Blackberry Cr near Mouth (287): Dissolved Oxygen (Probe) (mg/L)



(a) Observation data

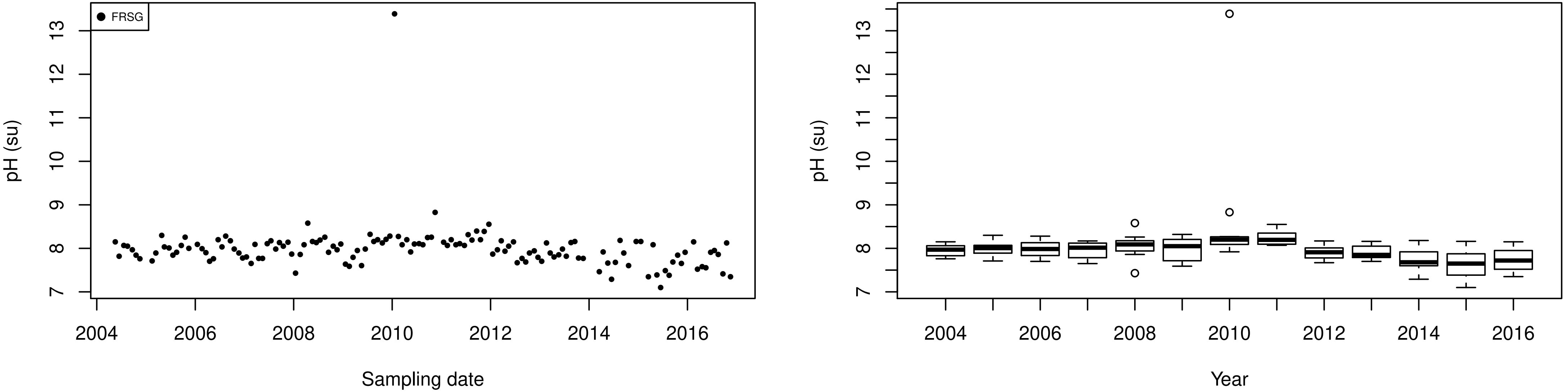
(b) Boxplot by year



(c) Annual values

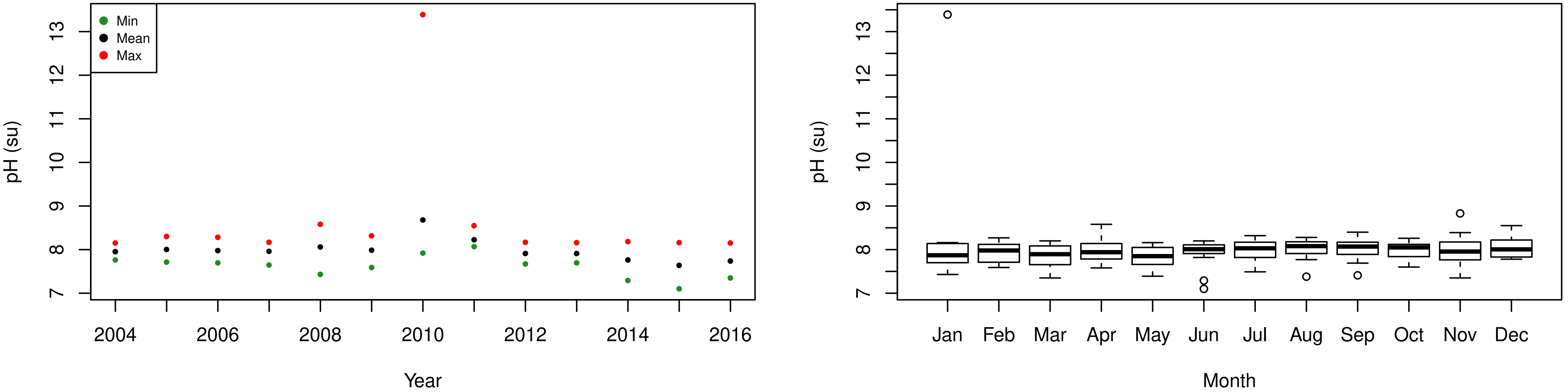
(d) Boxplot by month

Blackberry Cr near Mouth (287): pH (su)



(a) Observation data

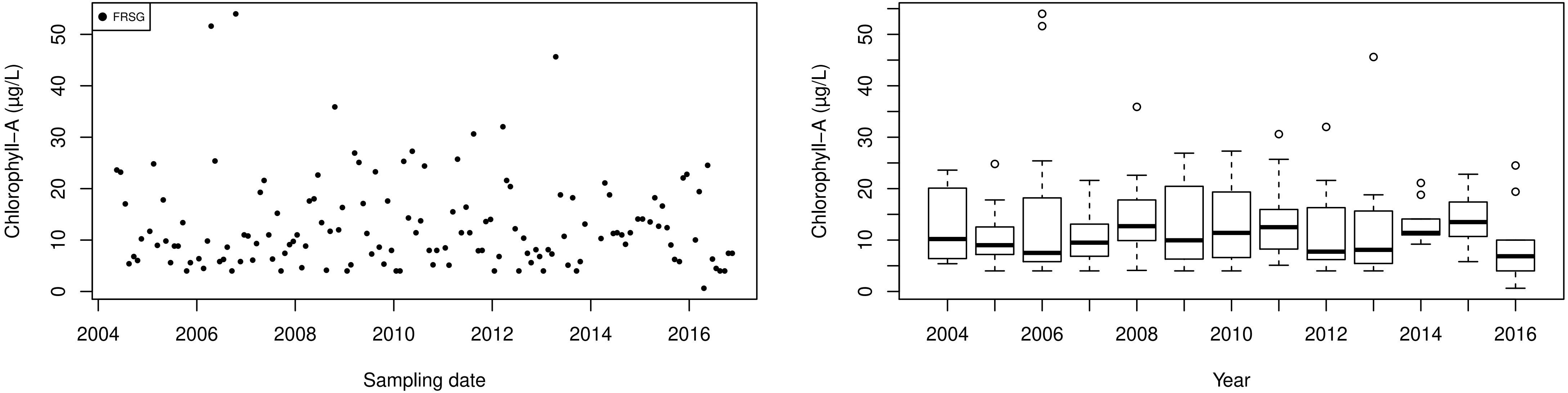
(b) Boxplot by year



(c) Annual values

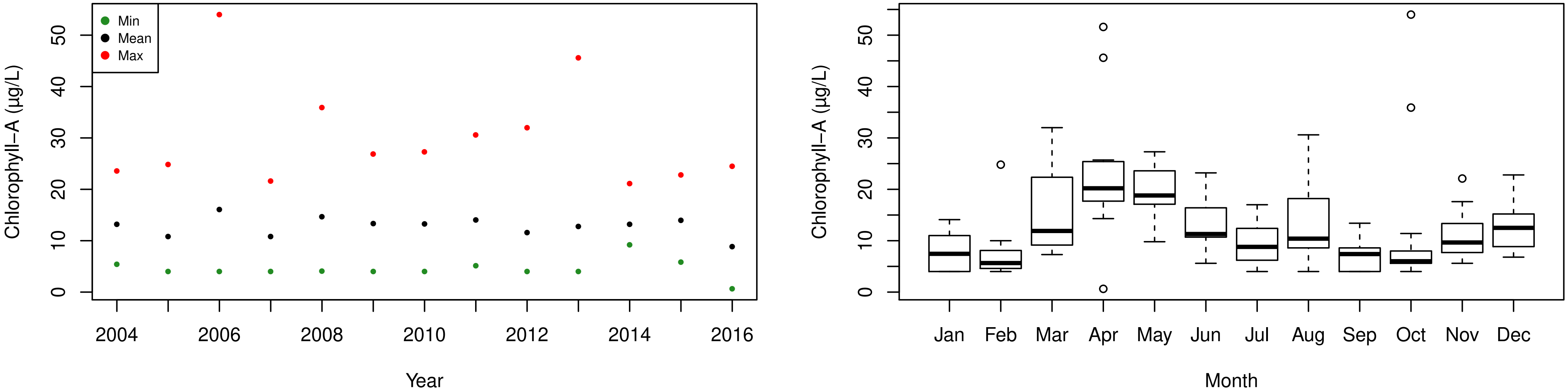
(d) Boxplot by month

Blackberry Cr near Mouth (287): Chlorophyll–A (µg/L)



(a) Observation data

(b) Boxplot by year



(c) Annual values

(d) Boxplot by month

Appendix B - Summary Statistics of the Water Quality Parameters

List of Tables

Table B.1 Summary statistics of Total Phosphorus (TP) concentration (mg/L)

Station ID	Station Name	N	Mean	Median	Skewness	Minimum	Maximum	1st Quartile	3rd Quartile	StdDev
236	*Nipp-SpGrv*	96	0.039	0.030	2.611	0.004	0.230	0.018	0.043	0.037
1	*Nipp-abvWL*	49	0.047	0.034	1.884	0.007	0.188	0.016	0.051	0.045
184	**Fox-Jhnbg**	151	0.045	0.040	2.183	0.010	0.200	0.020	0.060	0.033
23	**Fox-Rt176**	197	0.034	0.023	6.566	0.002	0.498	0.010	0.043	0.044
258	**Fox-OHills**	88	0.049	0.040	3.616	0.010	0.270	0.030	0.060	0.033
4	*Flint-KesRd*	87	0.208	0.150	3.557	0.004	1.700	0.074	0.220	0.244
271	*Crys-Rt31*	117	0.427	0.250	1.517	0.010	2.330	0.110	0.630	0.418
24	**Fox-Algqn**	315	0.057	0.043	2.294	0.002	0.420	0.020	0.073	0.051
268	*Tyl-Rt31*	94	0.064	0.050	1.322	0.010	0.210	0.030	0.080	0.042
25	*Pop-Mouth*	176	0.026	0.020	1.732	0.002	0.130	0.010	0.037	0.023
26	**Fox-SElgn**	513	0.165	0.120	9.902	0.004	3.500	0.070	0.200	0.199
14	*Fers-Rt34*	86	0.055	0.048	1.136	0.004	0.200	0.004	0.074	0.049
79	*Fers-Mouth*	139	0.056	0.050	1.066	0.009	0.160	0.030	0.078	0.034
40	**Fox-Gnva**	247	0.163	0.130	1.741	0.004	0.680	0.077	0.210	0.128
27	**Fox-Mont**	458	0.159	0.130	1.693	0.004	0.740	0.074	0.200	0.118
34	**Fox-York**	196	0.302	0.250	1.136	0.050	1.030	0.150	0.420	0.198
28	*Black-Rt47*	219	0.042	0.030	2.767	0.004	0.340	0.010	0.051	0.044
287	*Black-Mouth*	142	0.123	0.110	2.018	0.010	0.510	0.060	0.150	0.081

Table B.2 Summary statistics of Dissolved Phosphorus (DP) concentration (mg/L)

Station ID	Station Name	N	Mean	Median	Skewness	Minimum	Maximum	1st Quartile	3rd Quartile	StdDev
236	*Nipp-SpGrv*	96	0.134	0.120	4.234	0.031	0.840	0.079	0.156	0.099
1	*Nipp-abvWL*	61	0.165	0.086	2.992	0.020	1.156	0.060	0.173	0.210
184	**Fox-Jhnbg**	159	0.157	0.144	1.099	0.040	0.410	0.100	0.190	0.072
23	**Fox-Rt176**	202	0.143	0.120	2.046	0.015	0.603	0.092	0.170	0.079
258	**Fox-OHills**	97	0.169	0.160	0.968	0.010	0.410	0.110	0.210	0.076
4	*Flint-KesRd*	89	0.287	0.240	2.123	0.120	1.100	0.166	0.330	0.184
271	*Crys-Rt31*	118	0.499	0.320	1.488	0.070	2.540	0.150	0.795	0.443
24	**Fox-Algqn**	323	0.182	0.160	1.057	0.015	0.540	0.110	0.230	0.091
268	*Tyl-Rt31*	126	0.136	0.110	1.669	0.020	0.540	0.070	0.178	0.090
25	*Pop-Mouth*	175	0.093	0.074	7.795	0.010	1.200	0.050	0.110	0.102
26	**Fox-SElgn**	543	0.290	0.230	6.646	0.054	3.590	0.170	0.335	0.227
14	*Fers-Rt34*	90	0.146	0.115	1.254	0.015	0.440	0.085	0.189	0.089
79	*Fers-Mouth*	137	0.112	0.100	2.128	0.020	0.500	0.060	0.140	0.073
40	**Fox-Gnva**	246	0.326	0.270	1.694	0.120	1.120	0.190	0.380	0.189
27	**Fox-Mont**	546	0.317	0.270	1.657	0.017	1.170	0.200	0.370	0.169
34	**Fox-York**	195	0.483	0.410	1.004	0.160	1.380	0.300	0.645	0.245
28	*Black-Rt47*	225	0.116	0.091	2.517	0.010	0.700	0.061	0.140	0.088
287	*Black-Mouth*	141	0.053	0.050	2.095	0.009	0.260	0.030	0.070	0.037

Table B.3 Summary statistics of Organic Nitrogen (Org-N) concentration (mg/L)

Station ID	Station Name	N	Mean	Median	Skewness	Minimum	Maximum	1st Quartile	3rd Quartile	StdDev
236	*Nipp-SpGrv*	-	-	-	-	-	-	-	-	-
1	*Nipp-abvWL*	-	-	-	-	-	-	-	-	-
184	**Fox-Jhnbg**	150	1.689	1.530	1.402	0.100	4.790	1.212	1.970	0.724
23	**Fox-Rt176**	-	-	-	-	-	-	-	-	-
258	**Fox-OHills**	90	1.760	1.615	1.568	0.100	5.070	1.240	2.068	0.850
4	*Flint-KesRd*	-	-	-	-	-	-	-	-	-
271	*Crys-Rt31*	120	0.937	0.815	6.215	0.180	6.480	0.688	1.040	0.641
24	**Fox-Algqn**	154	1.717	1.675	1.057	0.360	5.150	1.130	2.135	0.774
268	*Tyl-Rt31*	97	0.792	0.680	1.211	0.100	2.100	0.590	0.940	0.336
25	*Pop-Mouth*	-	-	-	-	-	-	-	-	-
26	**Fox-SElgn**	293	1.632	1.540	0.749	0.110	4.070	1.100	2.020	0.703
14	*Fers-Rt34*	-	-	-	-	-	-	-	-	-
79	*Fers-Mouth*	138	0.748	0.670	1.151	0.280	1.900	0.520	0.895	0.305
40	**Fox-Gnva**	168	1.660	1.520	1.126	0.250	4.270	1.098	1.980	0.766
27	**Fox-Mont**	256	1.585	1.460	1.603	0.240	5.406	1.048	1.876	0.759
34	**Fox-York**	194	1.619	1.455	1.073	0.030	4.790	1.072	2.068	0.776
28	*Black-Rt47*	-	-	-	-	-	-	-	-	-
287	*Black-Mouth*	141	0.749	0.690	1.715	0.030	2.420	0.540	0.880	0.336

Table B.4 Summary statistics of Ammonia Nitrogen (NH_3-N) concentration (mg/L)

Station ID	Station Name	N	Mean	Median	Skewness	Minimum	Maximum	1st Quartile	3rd Quartile	StdDev
236	*Nipp-SpGrv*	97	0.150	0.110	2.592	0.010	1.050	0.040	0.190	0.161
1	*Nipp-abvWL*	-	-	-	-	-	-	-	-	-
184	**Fox-Jhnbg**	159	0.077	0.060	2.014	0.010	0.390	0.030	0.100	0.061
23	**Fox-Rt176**	203	0.097	0.060	3.410	0.010	0.950	0.015	0.125	0.128
258	**Fox-OHills**	98	0.074	0.050	6.170	0.020	0.860	0.030	0.090	0.095
4	*Flint-KesRd*	88	0.113	0.067	2.052	0.015	0.640	0.031	0.140	0.124
271	*Crys-Rt31*	120	0.092	0.070	5.436	0.020	0.800	0.050	0.100	0.084
24	**Fox-Algqn**	324	0.104	0.060	5.393	0.010	1.580	0.030	0.130	0.152
268	*Tyl-Rt31*	132	0.069	0.060	5.502	0.010	0.570	0.040	0.080	0.057
25	*Pop-Mouth*	172	0.083	0.043	2.312	0.010	0.640	0.015	0.113	0.098
26	**Fox-SElgn**	531	0.111	0.060	4.313	0.010	1.300	0.030	0.140	0.148
14	*Fers-Rt34*	84	0.078	0.035	3.309	0.010	0.690	0.015	0.086	0.117
79	*Fers-Mouth*	138	0.061	0.050	1.263	0.010	0.180	0.030	0.078	0.035
40	**Fox-Gnva**	244	0.068	0.040	7.195	0.010	1.080	0.030	0.080	0.087
27	**Fox-Mont**	1335	0.082	0.041	3.560	0.005	1.010	0.026	0.100	0.105
34	**Fox-York**	288	0.089	0.048	4.257	0.010	1.160	0.030	0.100	0.116
28	*Black-Rt47*	190	0.097	0.054	5.721	0.010	1.500	0.015	0.130	0.141
287	*Black-Mouth*	142	0.068	0.050	3.208	0.010	0.430	0.030	0.080	0.053

Table B.5 Summary statistics of Nitrate Nitrogen (NO_3-N) concentration (mg/L)

Station ID	Station Name	N	Mean	Median	Skewness	Minimum	Maximum	1st Quartile	3rd Quartile	StdDev
236	*Nipp-SpGrv*	-	-	-	-	-	-	-	-	-
1	*Nipp-abvWL*	-	-	-	-	-	-	-	-	-
184	**Fox-Jhnbg**	159	1.038	0.760	1.167	0.028	4.010	0.490	1.490	0.786
23	**Fox-Rt176**	110	1.264	0.930	0.925	0.024	3.900	0.418	1.840	1.062
258	**Fox-OHills**	96	0.864	0.610	1.725	0.050	4.430	0.258	1.108	0.797
4	*Flint-KesRd*	-	-	-	-	-	-	-	-	-
271	*Crys-Rt31*	118	3.766	3.415	0.901	0.360	11.800	2.255	5.135	1.991
24	**Fox-Algqn**	231	1.285	1.010	0.804	0.010	4.500	0.495	1.930	0.952
268	*Tyl-Rt31*	99	2.391	1.780	2.004	0.400	10.420	1.035	2.835	1.922
25	*Pop-Mouth*	-	-	-	-	-	-	-	-	-
26	**Fox-SElgn**	380	1.720	1.505	0.797	0.064	4.880	1.098	2.232	0.898
14	*Fers-Rt34*	-	-	-	-	-	-	-	-	-
79	*Fers-Mouth*	139	1.148	0.860	1.511	0.090	4.300	0.505	1.510	0.897
40	**Fox-Gnva**	238	1.666	1.500	0.811	0.021	5.200	0.970	2.195	0.936
27	**Fox-Mont**	400	1.666	1.462	3.520	0.018	14.300	0.900	2.305	1.172
34	**Fox-York**	196	2.080	1.855	0.828	0.270	5.450	1.358	2.650	1.018
28	*Black-Rt47*	-	-	-	-	-	-	-	-	-
287	*Black-Mouth*	142	1.275	1.010	2.255	0.090	7.220	0.590	1.618	1.052

Table B.6 Summary statistics of Total Kjeldahl Nitrogen (TKN) (mg/L)

Station ID	Station Name	N	Mean	Median	Skewness	Minimum	Maximum	1st Quartile	3rd Quartile	StdDev
236	*Nipp-SpGrv*	75	0.978	0.870	1.753	0.100	3.200	0.710	1.090	0.498
1	*Nipp-abvWL*	-	-	-	-	-	-	-	-	-
184	**Fox-Jhnbg**	150	1.747	1.610	1.547	0.670	4.820	1.290	1.987	0.677
23	**Fox-Rt176**	186	1.645	1.600	1.085	0.100	4.600	1.100	2.000	0.771
258	**Fox-OHills**	90	1.839	1.675	1.777	0.650	5.100	1.355	2.095	0.807
4	*Flint-KesRd*	88	1.959	1.700	9.082	0.660	27.800	1.422	1.900	2.816
271	*Crys-Rt31*	120	1.000	0.900	7.180	0.250	6.660	0.740	1.100	0.604
24	**Fox-Algqn**	309	1.671	1.600	1.101	0.010	5.210	1.200	2.050	0.743
268	*Tyl-Rt31*	97	0.831	0.770	0.993	0.220	1.780	0.650	0.960	0.283
25	*Pop-Mouth*	167	1.096	1.000	5.489	0.100	9.400	0.625	1.300	0.991
26	**Fox-SElgn**	513	1.656	1.580	0.731	0.100	4.110	1.170	2.050	0.681
14	*Fers-Rt34*	87	1.418	1.200	3.638	0.250	6.850	0.975	1.600	0.927
79	*Fers-Mouth*	138	0.792	0.710	1.151	0.090	2.050	0.590	0.948	0.304
40	**Fox-Gnva**	244	1.732	1.600	1.009	0.270	4.300	1.320	2.030	0.671
27	**Fox-Mont**	538	1.604	1.520	1.231	0.150	5.430	1.100	1.938	0.702
34	**Fox-York**	194	1.673	1.510	1.145	0.230	4.820	1.160	2.085	0.721
28	*Black-Rt47*	201	1.013	0.830	8.309	0.100	14.650	0.440	1.300	1.163
287	*Black-Mouth*	141	0.806	0.750	1.887	0.350	2.450	0.580	0.930	0.329

Table B.7 Summary statistics of Dissolved Oxygen (DO) concentration (mg/L)

Station ID	Station Name	N	Mean	Median	Skewness	Minimum	Maximum	1st Quartile	3rd Quartile	StdDev
236	*Nipp-SpGrv*	130	10.480	10.180	-0.146	0.820	17.720	8.700	12.400	2.839
1	*Nipp-abvWL*	-	-	-	-	-	-	-	-	-
184	**Fox-Jhnbg**	138	10.840	10.500	1.075	3.600	27.600	8.150	13.100	3.655
23	**Fox-Rt176**	157	10.480	10.200	0.340	3.800	18.380	7.980	12.700	3.114
258	**Fox-OHills**	85	9.998	9.610	1.584	4.030	24.040	8.100	11.480	3.189
4	*Flint-KesRd*	-	-	-	-	-	-	-	-	-
271	*Crys-Rt31*	106	9.195	8.480	0.683	3.550	18.480	7.462	11.310	2.764
24	**Fox-Algqn**	295	10.050	9.930	0.446	1.880	20.640	7.405	12.140	3.416
268	*Tyl-Rt31*	132	11.490	11.150	0.382	7.200	17.800	9.200	13.580	2.649
25	*Pop-Mouth*	126	10.830	10.360	0.138	4.500	16.240	8.992	12.790	2.575
26	**Fox-SElgn**	664	10.220	9.630	0.547	3.380	19.440	7.698	12.490	2.974
14	*Fers-Rt34*	-	-	-	-	-	-	-	-	-
79	*Fers-Mouth*	139	9.928	9.430	1.242	3.760	26.520	7.530	11.930	3.564
40	**Fox-Gnva**	178	11.240	10.580	1.118	5.200	25.820	9.055	12.920	3.201
27	**Fox-Mont**	16450	9.449	9.290	1.599	4.800	23.200	8.470	10.190	1.440
34	**Fox-York**	276	10.240	9.895	0.221	2.670	17.540	7.990	12.830	2.966
28	*Black-Rt47*	170	10.030	9.735	0.458	5.160	18.440	7.620	12.180	2.777
287	*Black-Mouth*	142	10.720	10.240	0.663	7.040	17.540	8.708	12.200	2.441

Table B.8 Summary statistics of pH (su)

Station ID	Station Name	N	Mean	Median	Skewness	Minimum	Maximum	1st Quartile	3rd Quartile	StdDev
236	*Nipp-SpGrv*	97	8.117	8.120	3.872	7.190	11.190	7.940	8.250	0.423
1	*Nipp-abvWL*	-	-	-	-	-	-	-	-	-
184	**Fox-Jhnbg**	139	8.481	8.500	-0.242	7.200	9.500	8.300	8.700	0.318
23	**Fox-Rt176**	121	8.265	8.300	-0.919	7.000	8.940	8.110	8.470	0.346
258	**Fox-OHills**	75	8.264	8.420	-1.247	6.000	9.680	8.055	8.560	0.530
4	*Flint-KesRd*	-	-	-	-	-	-	-	-	-
271	*Crys-Rt31*	114	8.110	8.200	-0.956	6.800	8.900	7.922	8.400	0.423
24	**Fox-Algqn**	246	8.166	8.225	-0.673	6.660	9.100	7.900	8.522	0.486
268	*Tyl-Rt31*	94	8.198	8.200	-0.349	7.500	8.700	8.000	8.348	0.213
25	*Pop-Mouth*	90	7.852	7.850	-0.211	7.010	8.870	7.672	8.068	0.311
26	**Fox-SElgn**	330	8.349	8.385	-0.769	6.690	9.200	8.140	8.600	0.350
14	*Fers-Rt34*	-	-	-	-	-	-	-	-	-
79	*Fers-Mouth*	134	7.947	8.010	-0.530	6.970	8.660	7.770	8.130	0.301
40	**Fox-Gnva**	170	8.196	8.275	-0.298	6.810	9.350	7.875	8.478	0.430
27	**Fox-Mont**	1570	8.335	8.330	-0.346	6.325	10.600	8.130	8.550	0.372
34	**Fox-York**	294	8.327	8.295	0.366	7.290	9.350	8.120	8.518	0.332
28	*Black-Rt47*	134	7.919	7.970	0.251	6.950	9.140	7.680	8.100	0.314
287	*Black-Mouth*	141	7.992	7.980	7.436	7.100	13.390	7.790	8.150	0.533

Table B.9 Summary statistics of Total Suspended Solids (TSS) concentration (mg/L)

Station ID	Station Name	N	Mean	Median	Skewness	Minimum	Maximum	1st Quartile	3rd Quartile	StdDev
236	*Nipp-SpGrv*	54	29.820	25.000	3.023	3.000	154.000	16.000	36.000	23.400
1	*Nipp-abvWL*	-	-	-	-	-	-	-	-	-
184	**Fox-Jhnbg**	-	-	-	-	-	-	-	-	-
23	**Fox-Rt176**	51	27.010	25.000	0.388	4.000	59.000	18.000	38.000	14.660
258	**Fox-OHills**	-	-	-	-	-	-	-	-	-
4	*Flint-KesRd*	-	-	-	-	-	-	-	-	-
271	*Crys-Rt31*	-	-	-	-	-	-	-	-	-
24	**Fox-Algqn**	53	32.880	30.000	1.616	3.000	112.000	20.000	38.000	22.320
268	*Tyl-Rt31*	-	-	-	-	-	-	-	-	-
25	*Pop-Mouth*	45	12.180	8.000	2.971	2.000	70.000	4.000	14.000	11.830
26	**Fox-SElgn**	104	31.110	30.000	0.929	4.000	109.000	17.750	42.000	17.540
14	*Fers-Rt34*	-	-	-	-	-	-	-	-	-
79	*Fers-Mouth*	-	-	-	-	-	-	-	-	-
40	**Fox-Gnva**	-	-	-	-	-	-	-	-	-
27	**Fox-Mont**	104	34.120	33.000	1.454	4.000	130.000	20.750	43.000	21.520
34	**Fox-York**	-	-	-	-	-	-	-	-	-
28	*Black-Rt47*	100	28.230	20.000	3.285	1.000	203.000	12.380	31.000	29.300
287	*Black-Mouth*	-	-	-	-	-	-	-	-	-

Table B.10 Summary statistics of Chlorophyll A (CHL-A) concentration (µg/L)

Station ID	Station Name	N	Mean	Median	Skewness	Minimum	Maximum	1st Quartile	3rd Quartile	StdDev
236	*Nipp-SpGrv*	-	-	-	-	-	-	-	-	-
1	*Nipp-abvWL*	-	-	-	-	-	-	-	-	-
184	**Fox-Jhnbg**	151	81.630	70.200	1.637	1.070	343.000	37.800	105.500	63.230
23	**Fox-Rt176**	-	-	-	-	-	-	-	-	-
258	**Fox-OHills**	90	94.060	85.650	1.031	1.480	303.200	39.050	124.000	70.170
4	*Flint-KesRd*	-	-	-	-	-	-	-	-	-
271	*Crys-Rt31*	120	29.740	18.850	3.704	4.000	244.400	11.880	33.400	35.510
24	**Fox-Algqn**	155	92.560	86.200	0.827	4.000	314.000	40.300	127.300	67.780
268	*Tyl-Rt31*	96	9.694	8.600	2.706	1.900	45.400	5.600	11.420	6.284
25	*Pop-Mouth*	-	-	-	-	-	-	-	-	-
26	**Fox-SElgn**	195	86.680	78.800	1.094	1.970	333.000	24.650	124.500	71.510
14	*Fers-Rt34*	-	-	-	-	-	-	-	-	-
79	*Fers-Mouth*	139	13.260	10.700	3.229	0.630	84.500	7.000	17.000	9.946
40	**Fox-Gnva**	168	105.300	87.950	1.248	1.180	479.400	34.480	152.800	85.490
27	**Fox-Mont**	194	99.880	80.050	1.223	1.210	470.800	29.800	153.400	85.930
34	**Fox-York**	196	98.150	80.000	1.362	1.190	433.600	33.900	144.800	83.400
28	*Black-Rt47*	-	-	-	-	-	-	-	-	-
287	*Black-Mouth*	142	12.840	10.550	1.936	0.630	54.000	6.325	17.080	8.966

Appendix C – Annual and Seasonal Water Quality Trend Maps

List of Figures

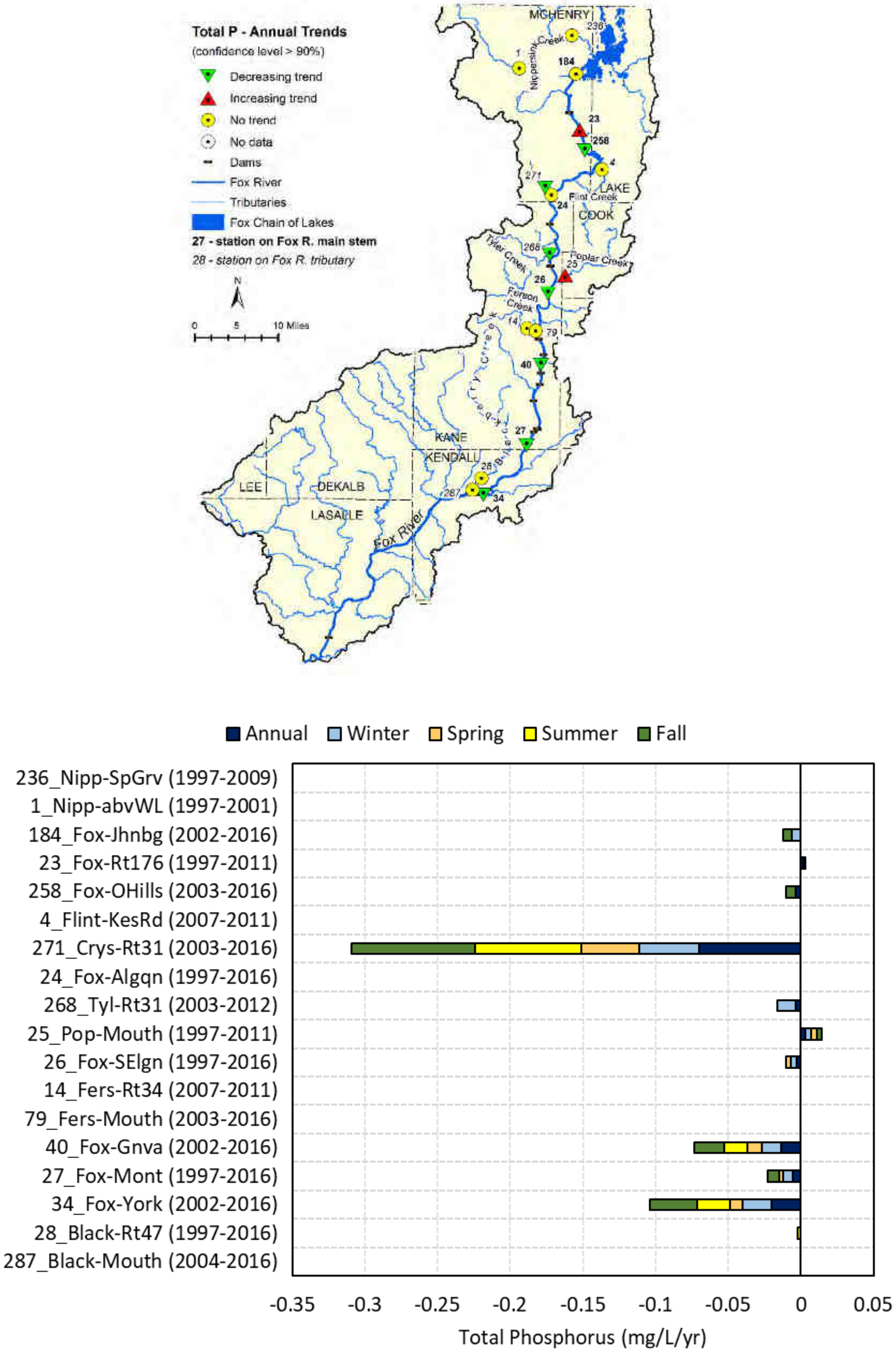


Figure C.1 Annual trends of total phosphorus (TP) in the Fox River watershed

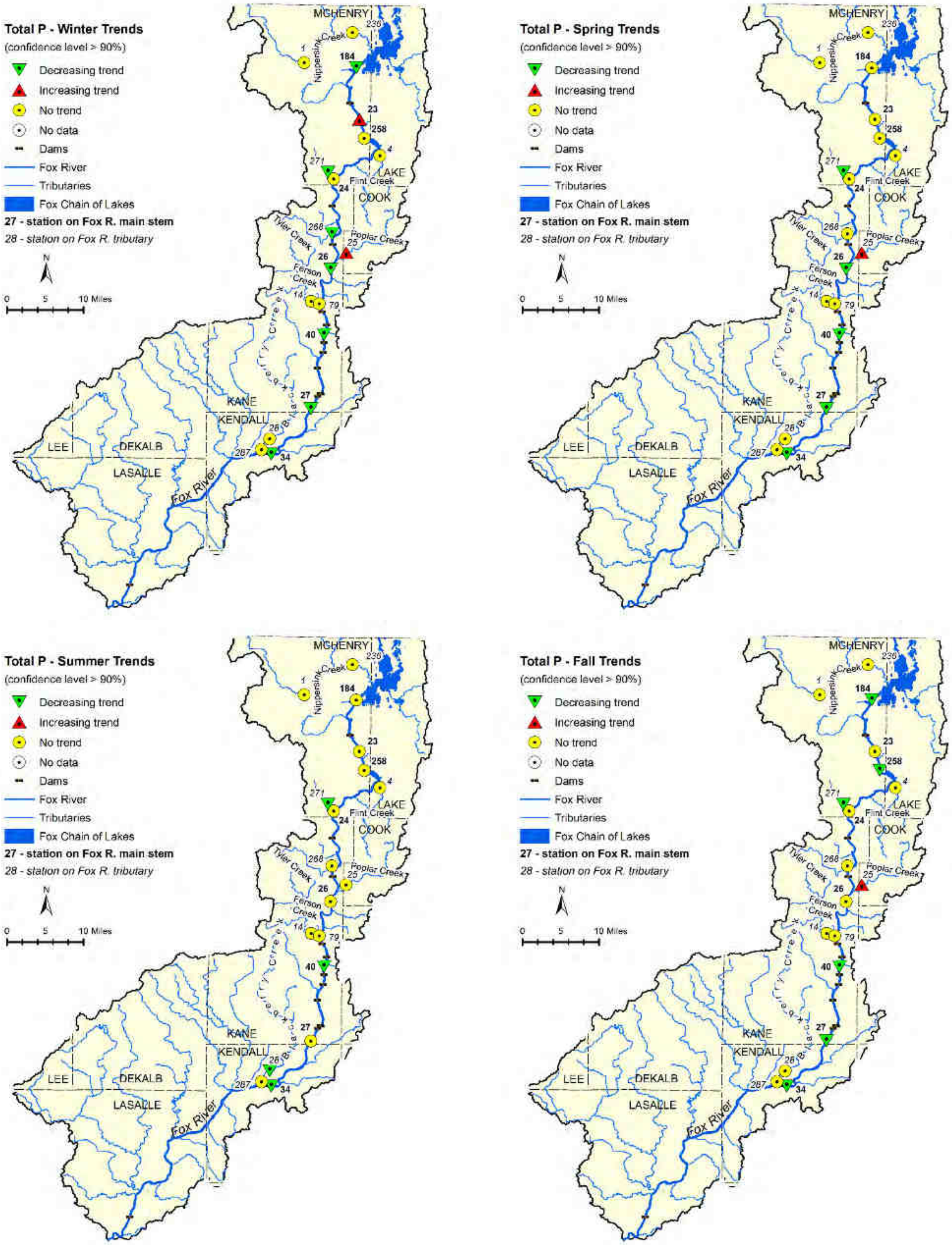


Figure C.2 Seasonal trends of total phosphorus (TP) in the Fox River watershed

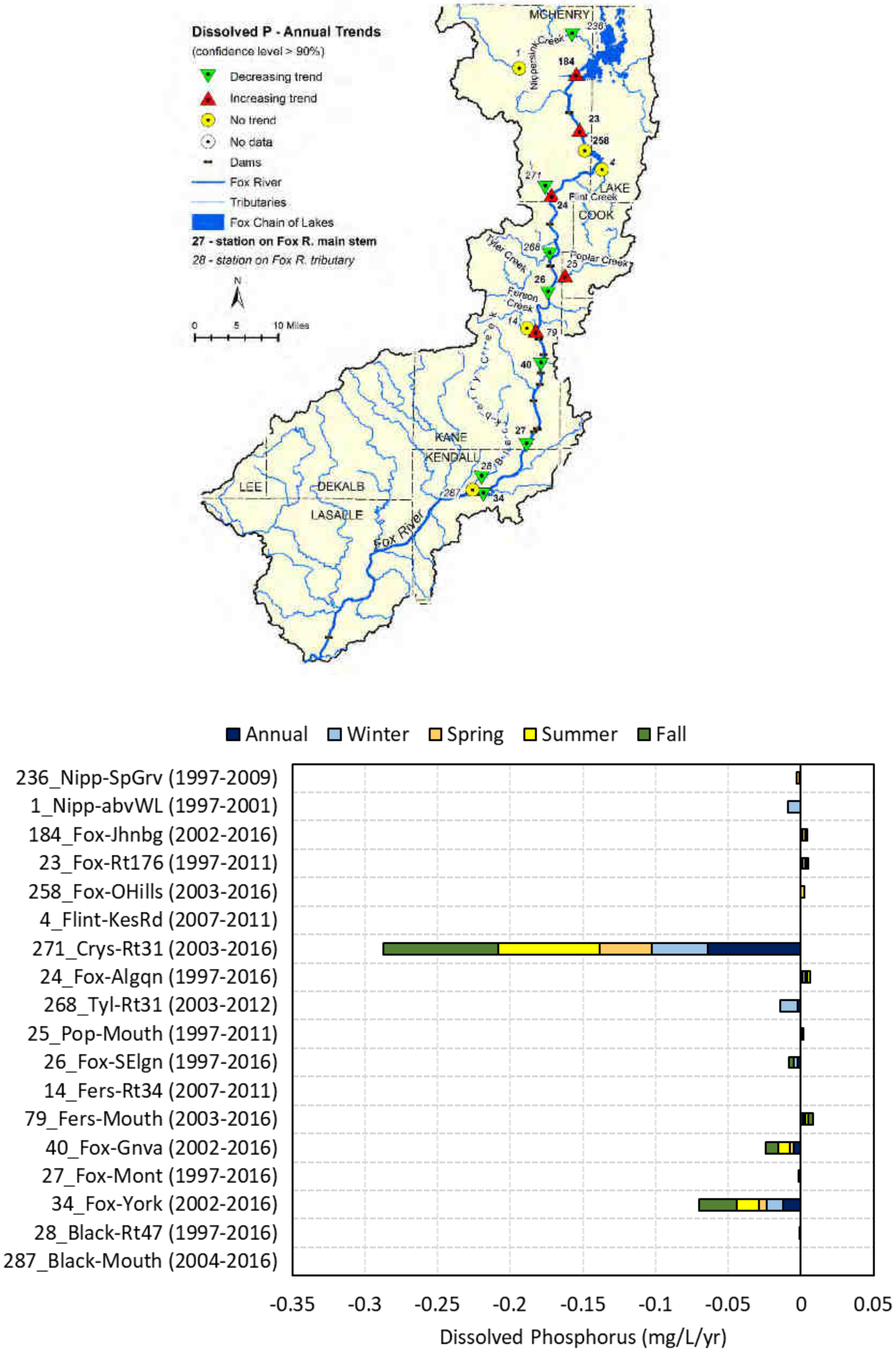


Figure C.3 Annual trends of dissolved phosphorus (DP) in the Fox River watershed

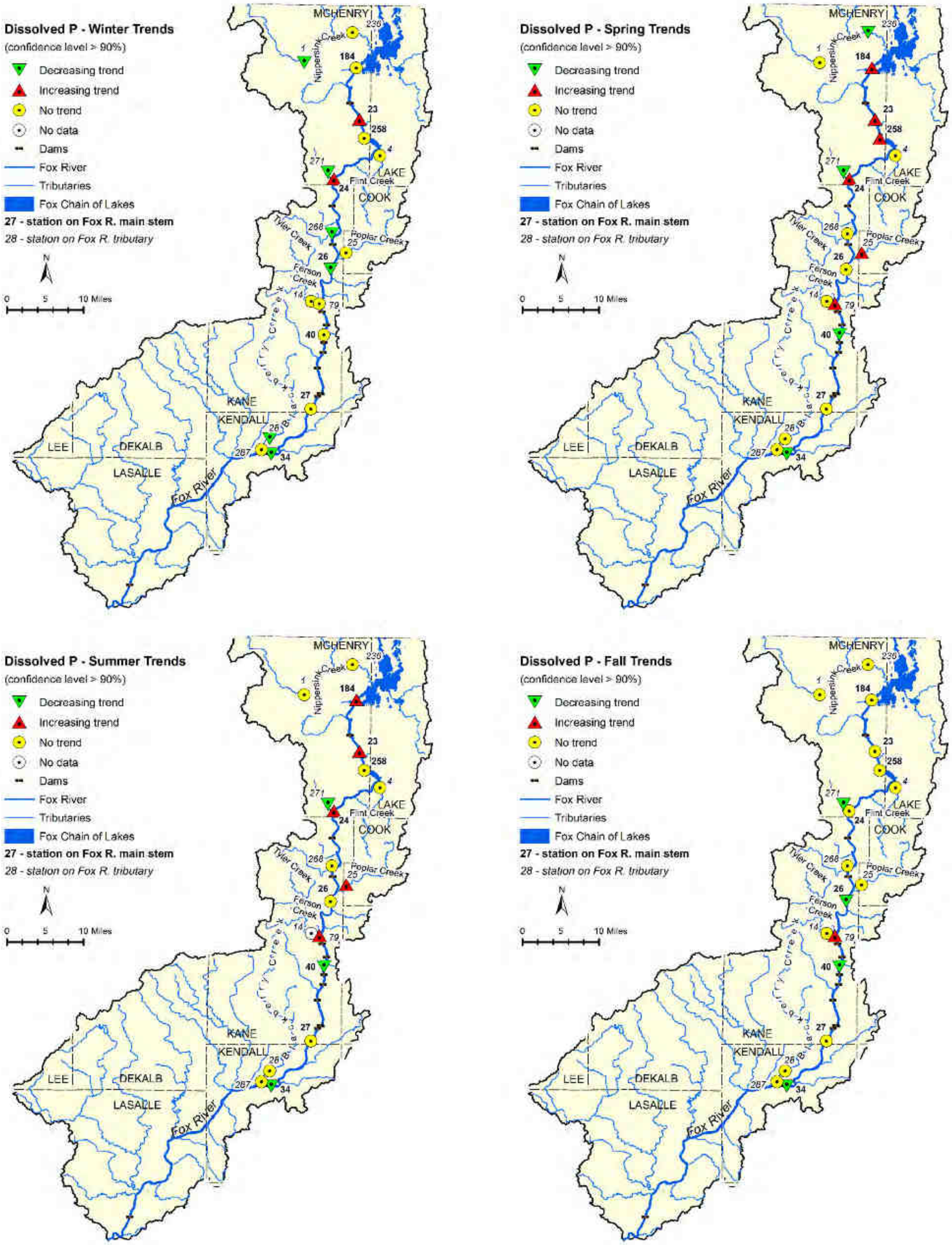


Figure C.4 Seasonal trends of dissolved phosphorus (DP) in the Fox River watershed

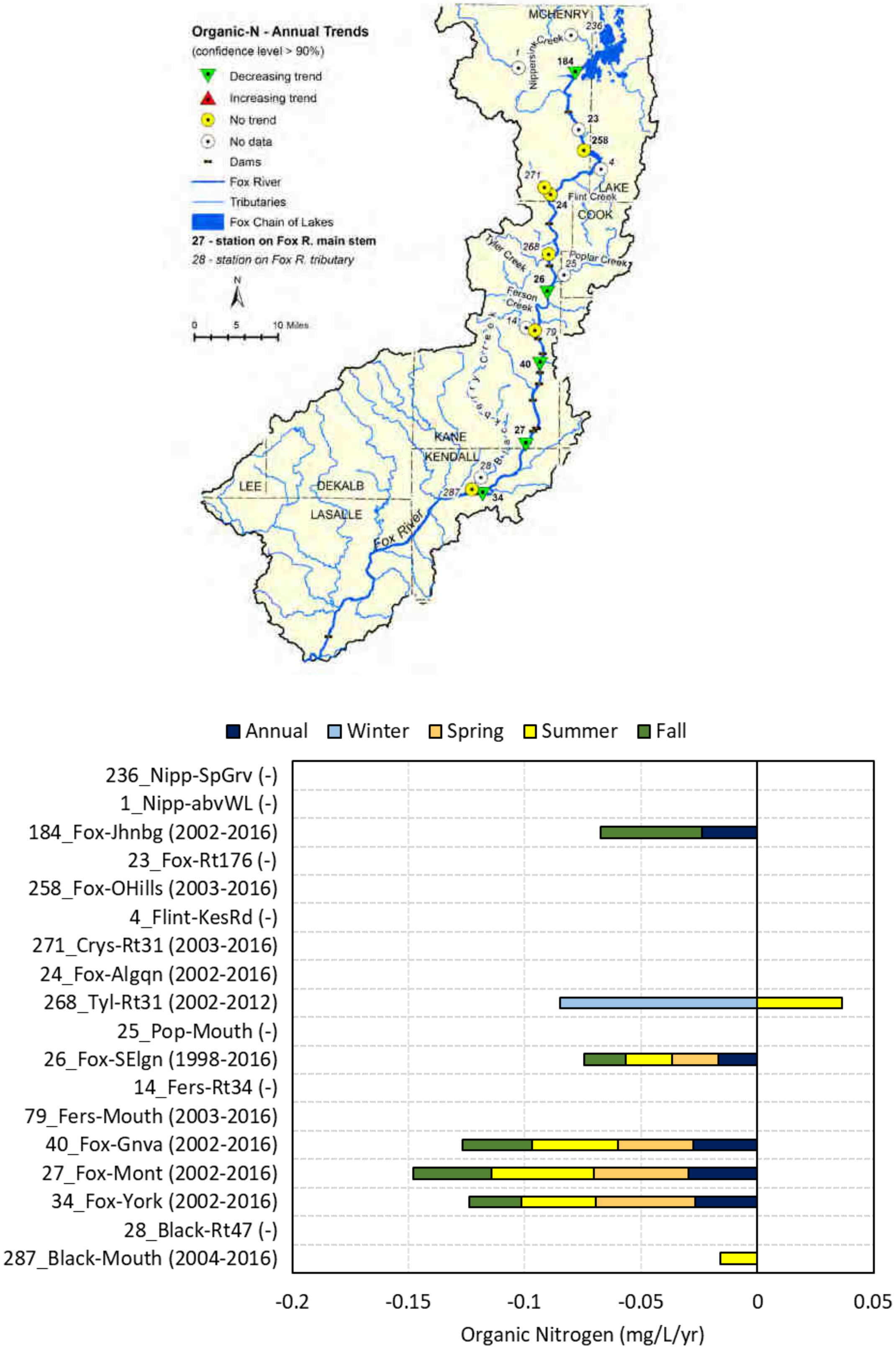


Figure C.5 Annual trends of organic nitrogen (Org-N) in the Fox River watershed

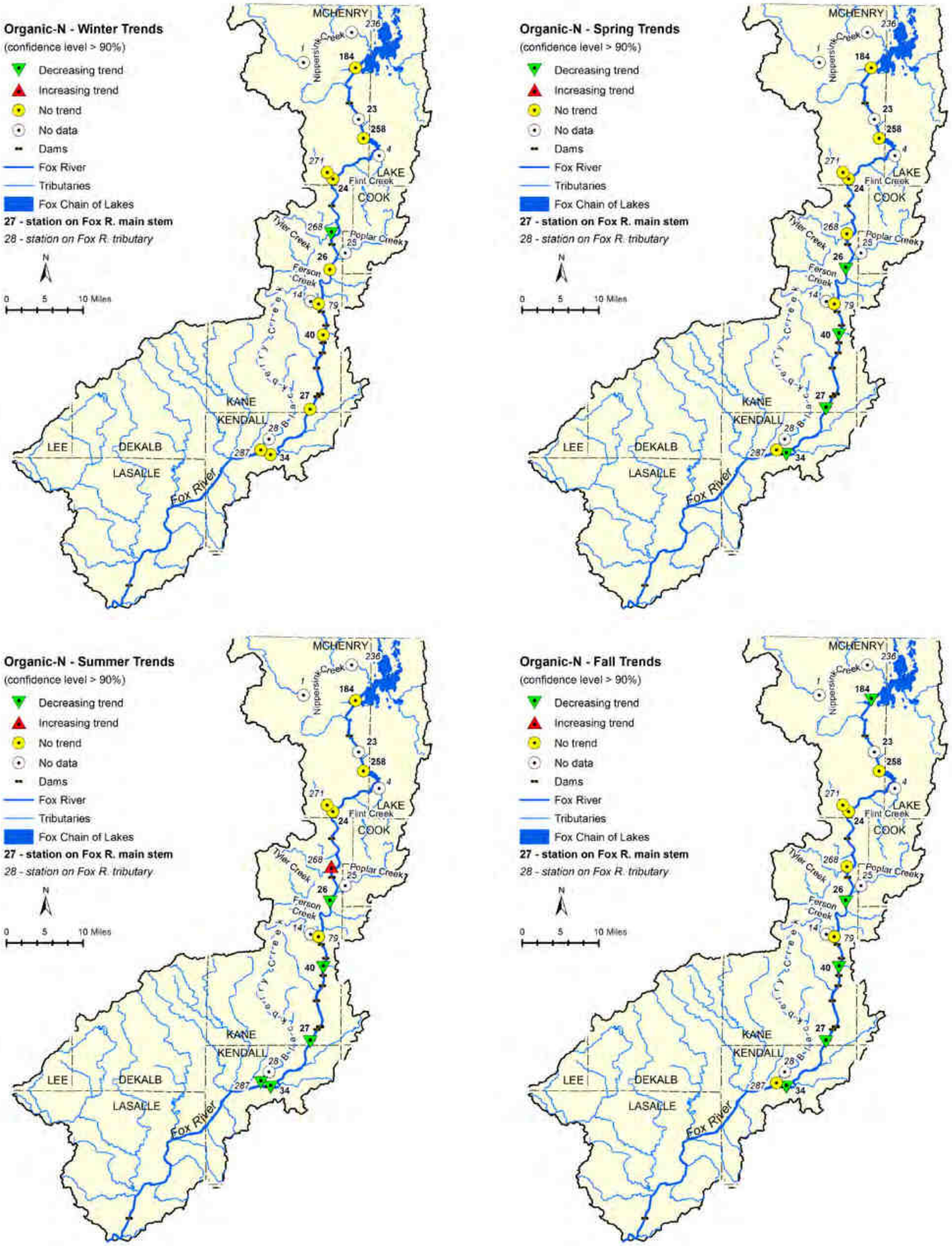
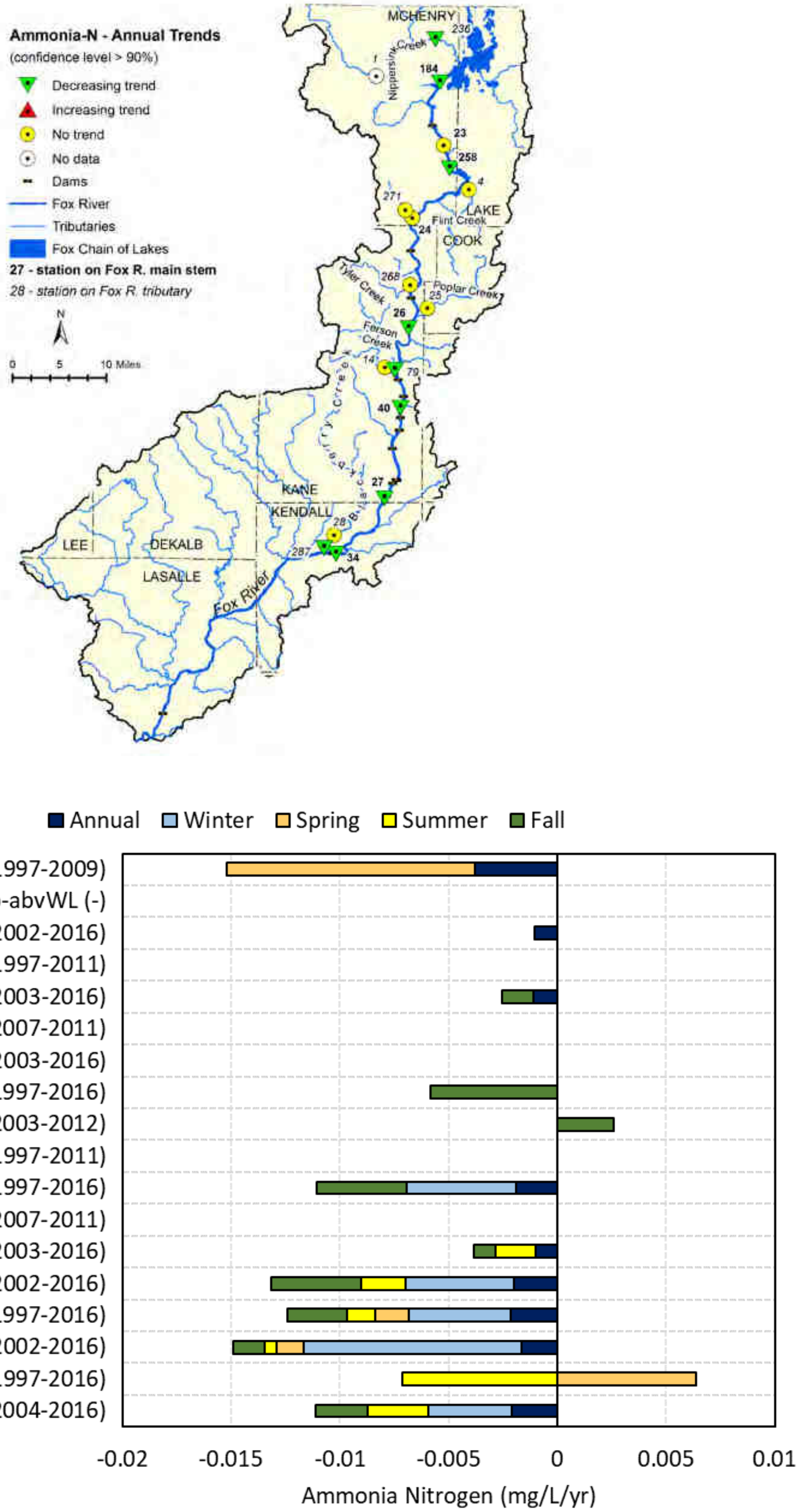


Figure C.6 Seasonal trends of organic nitrogen (Org-N) in the Fox River watershed



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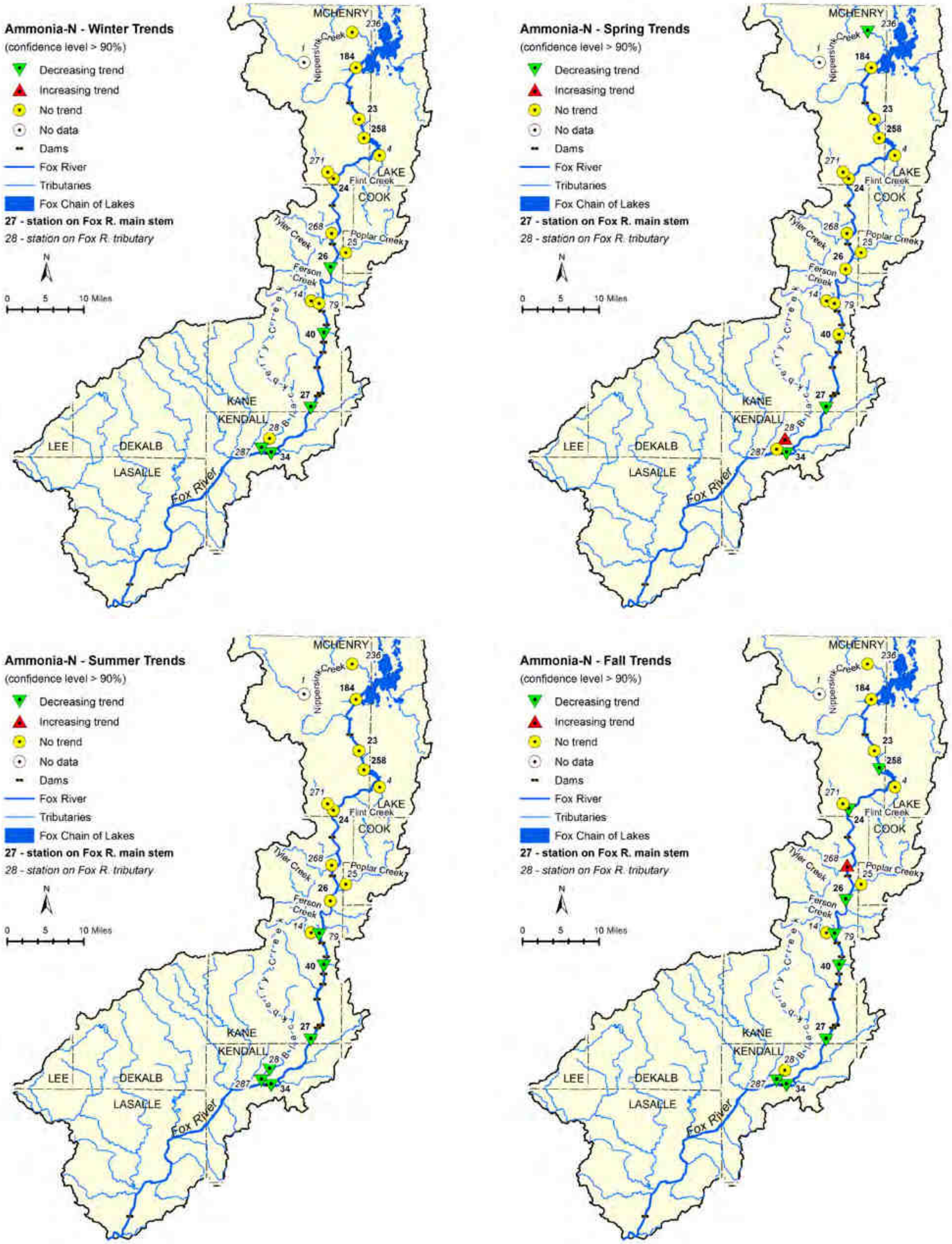

Ammonia-N - Winter Trends

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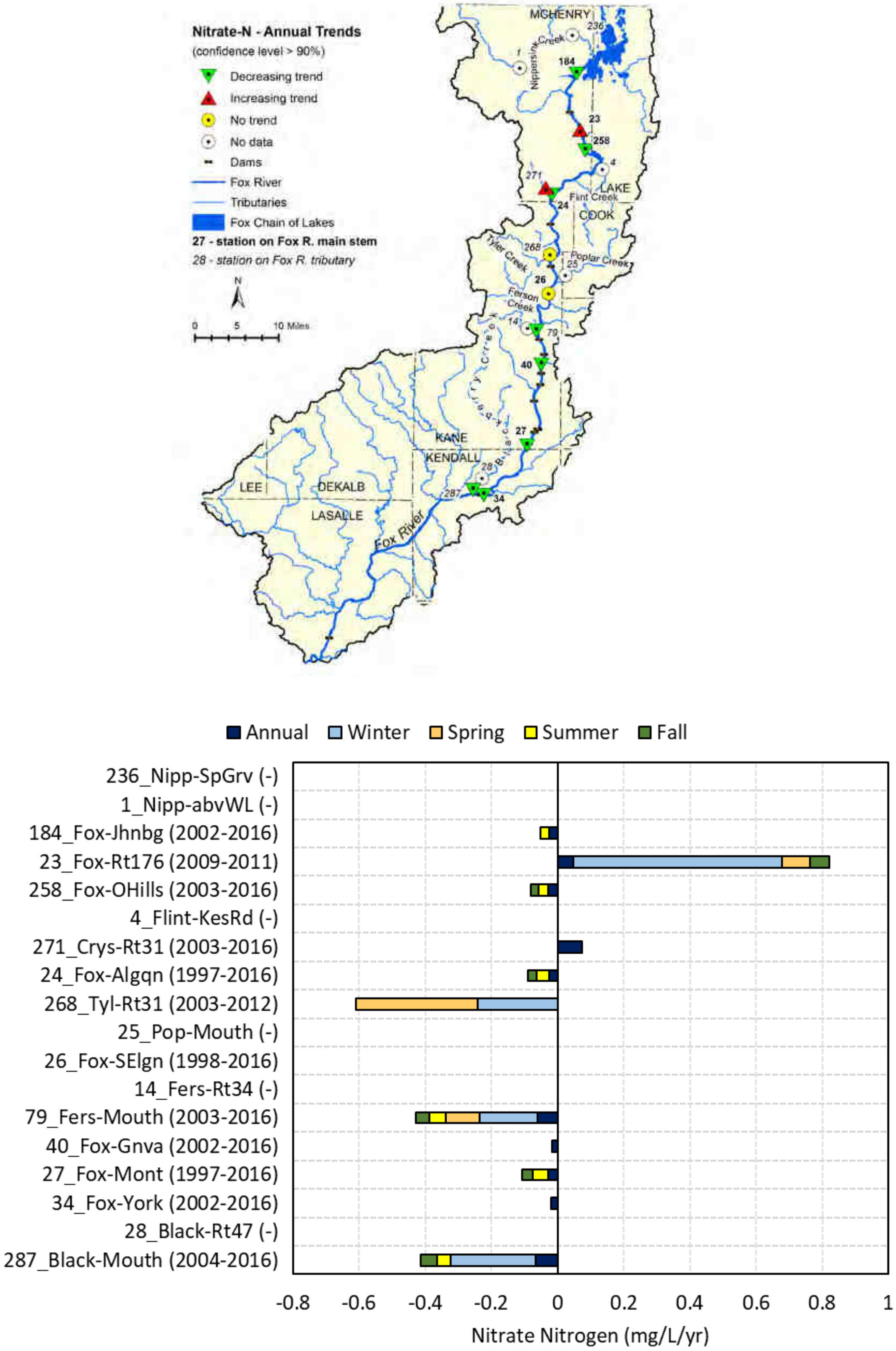

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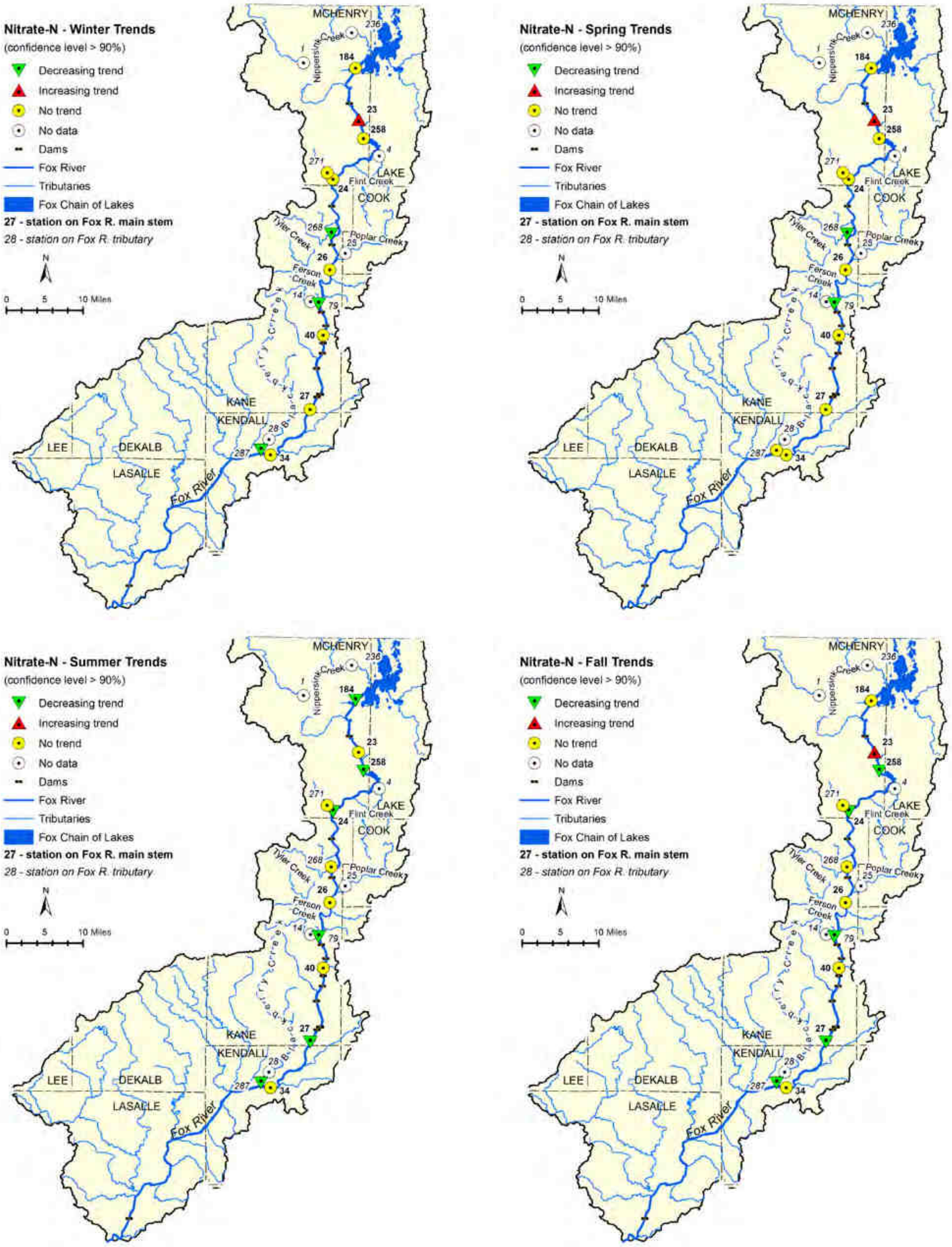

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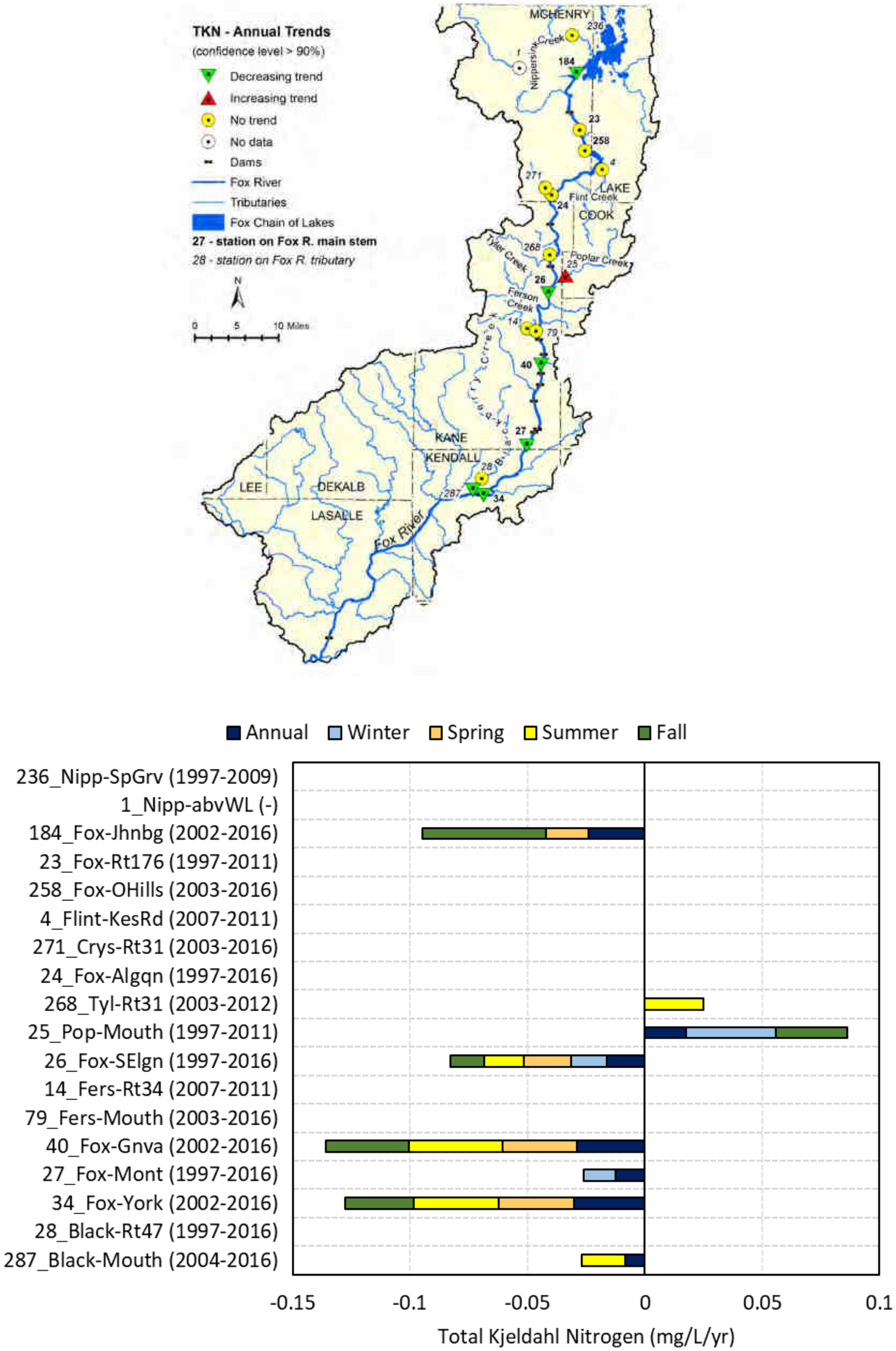

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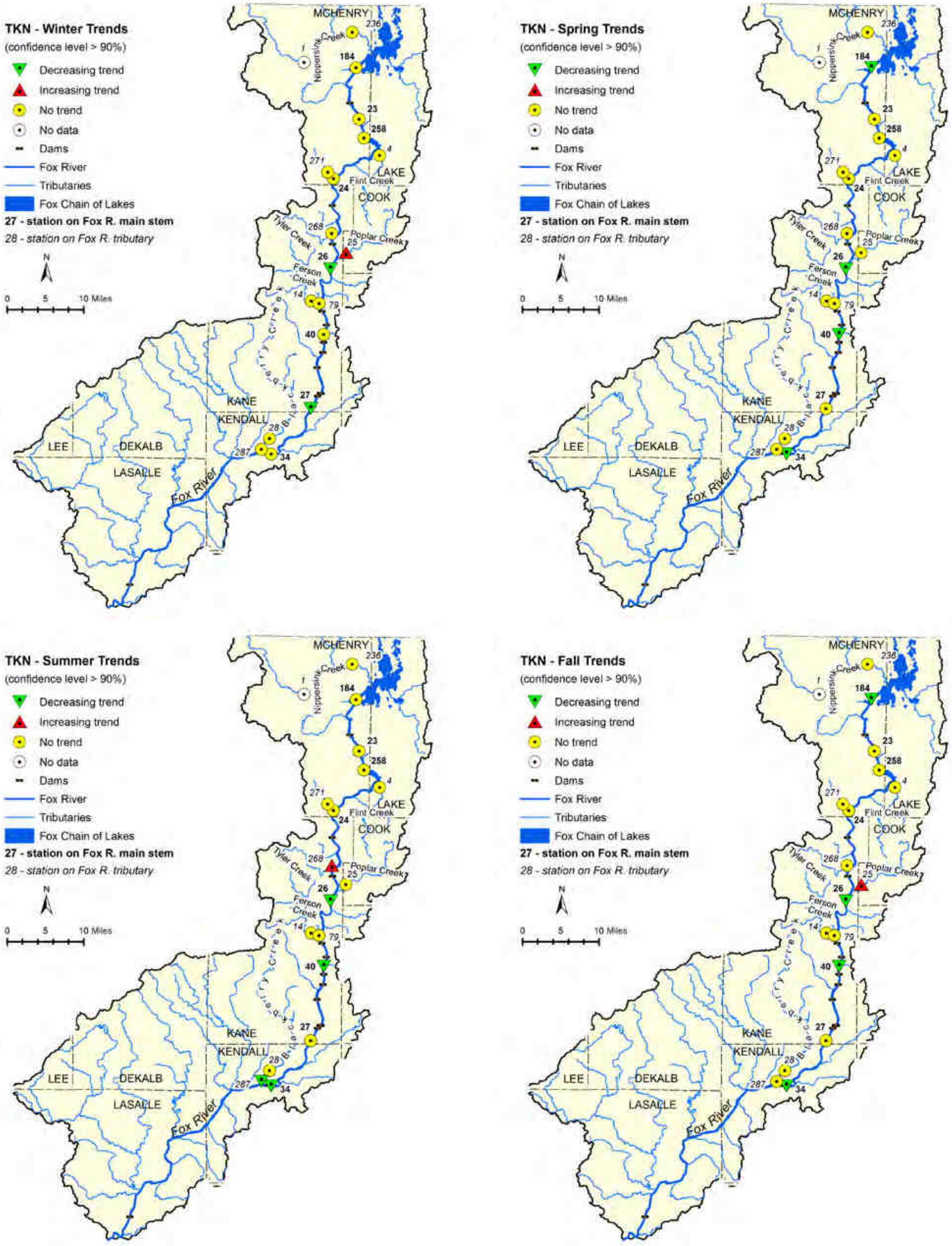

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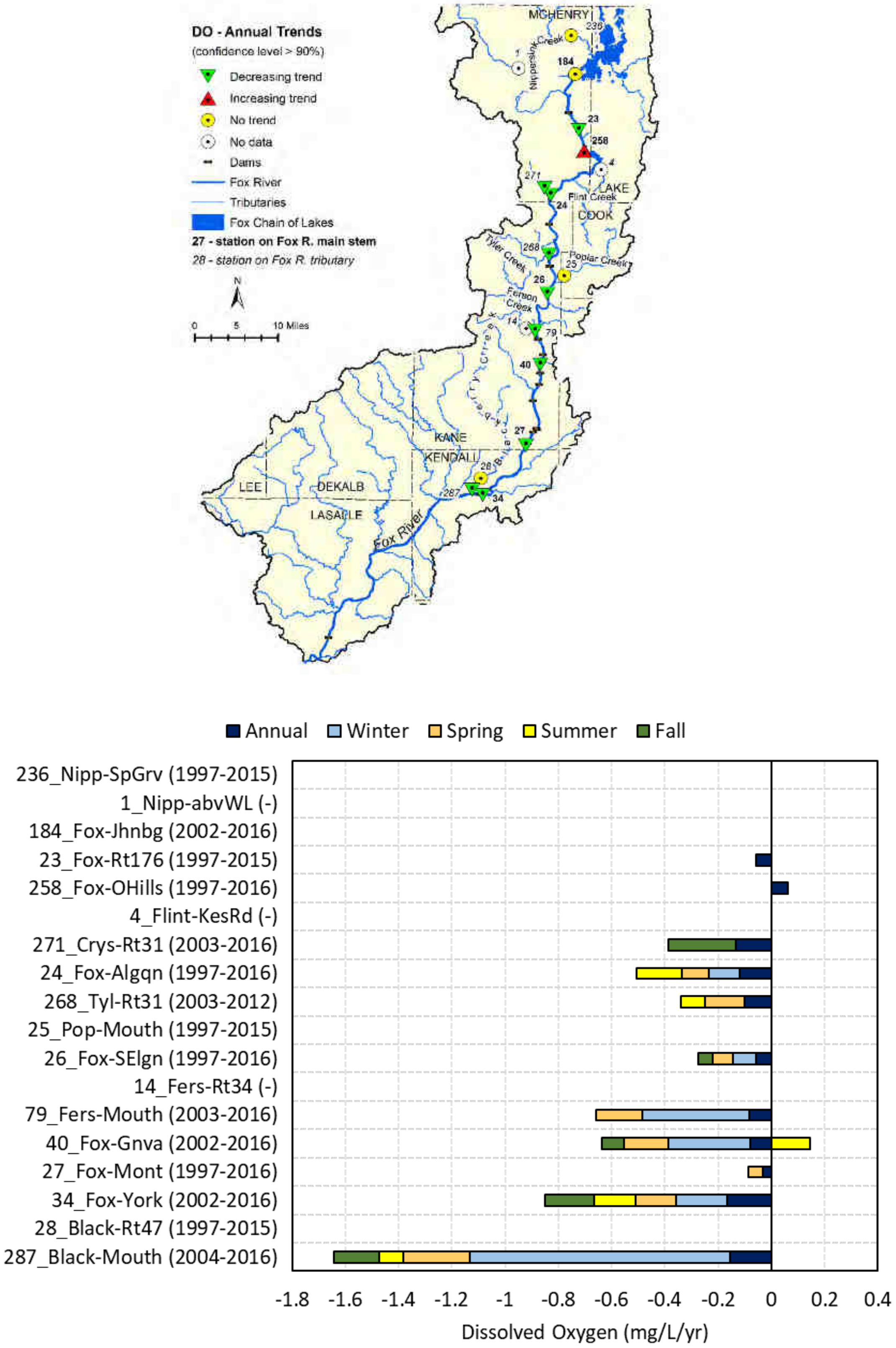

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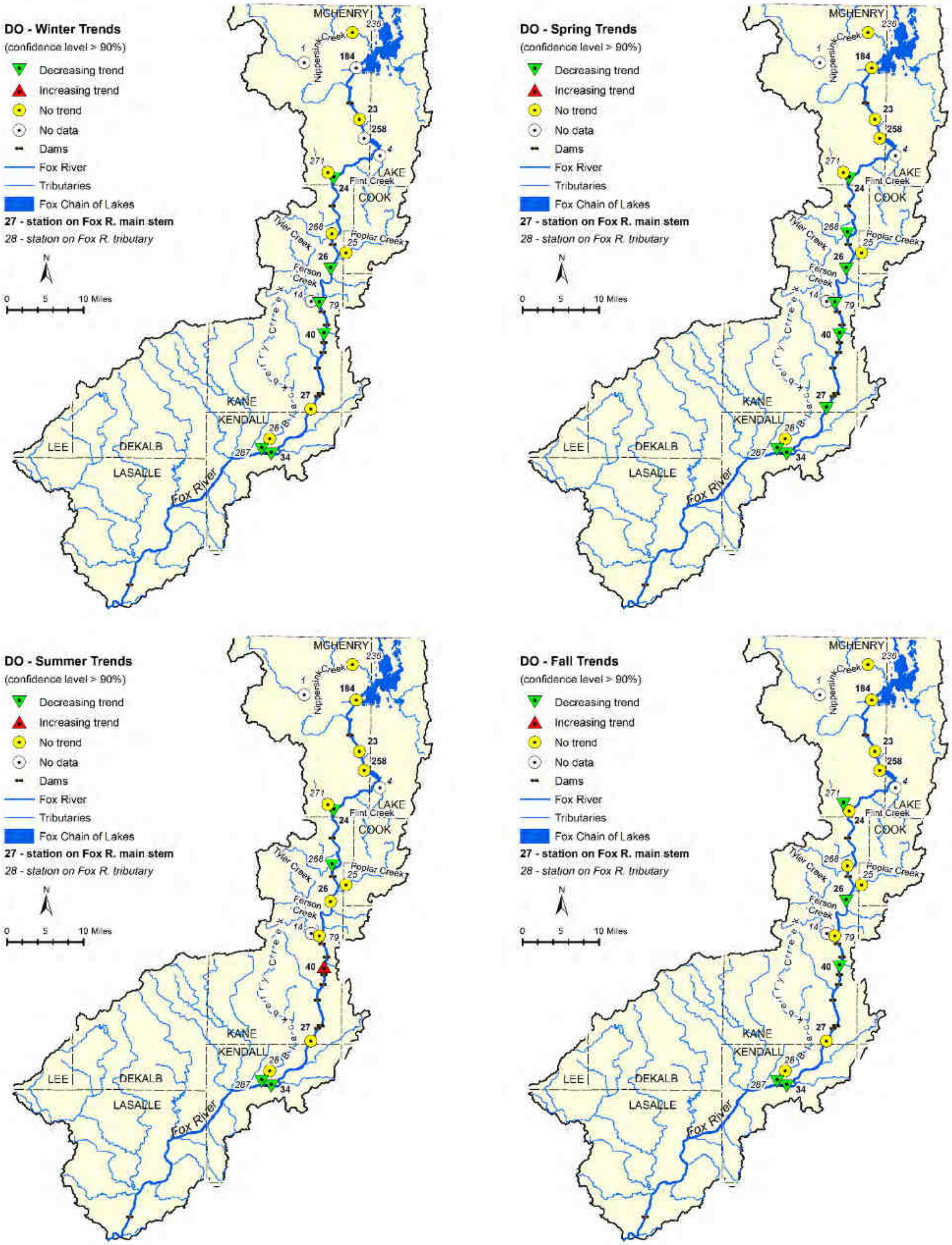

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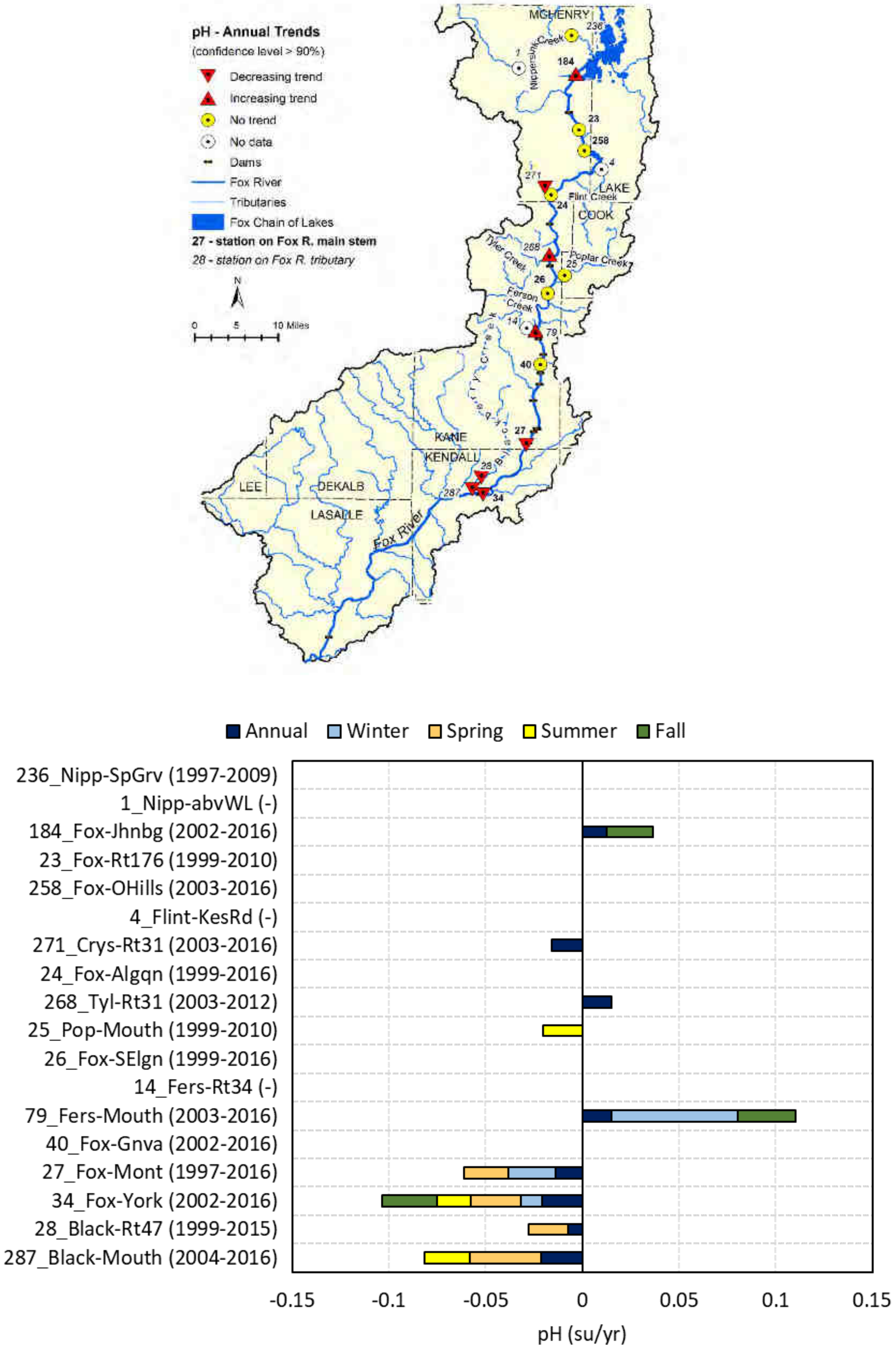

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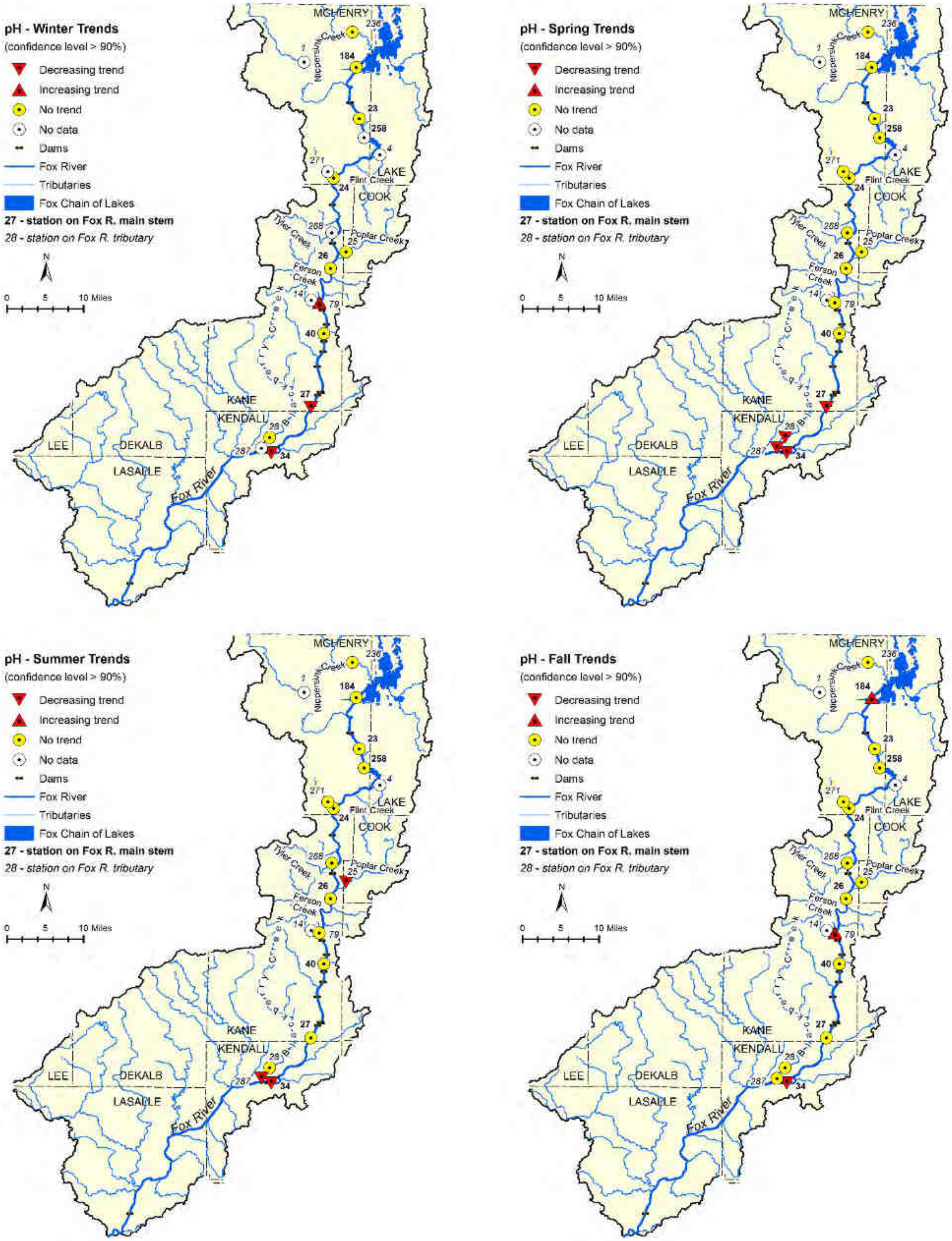

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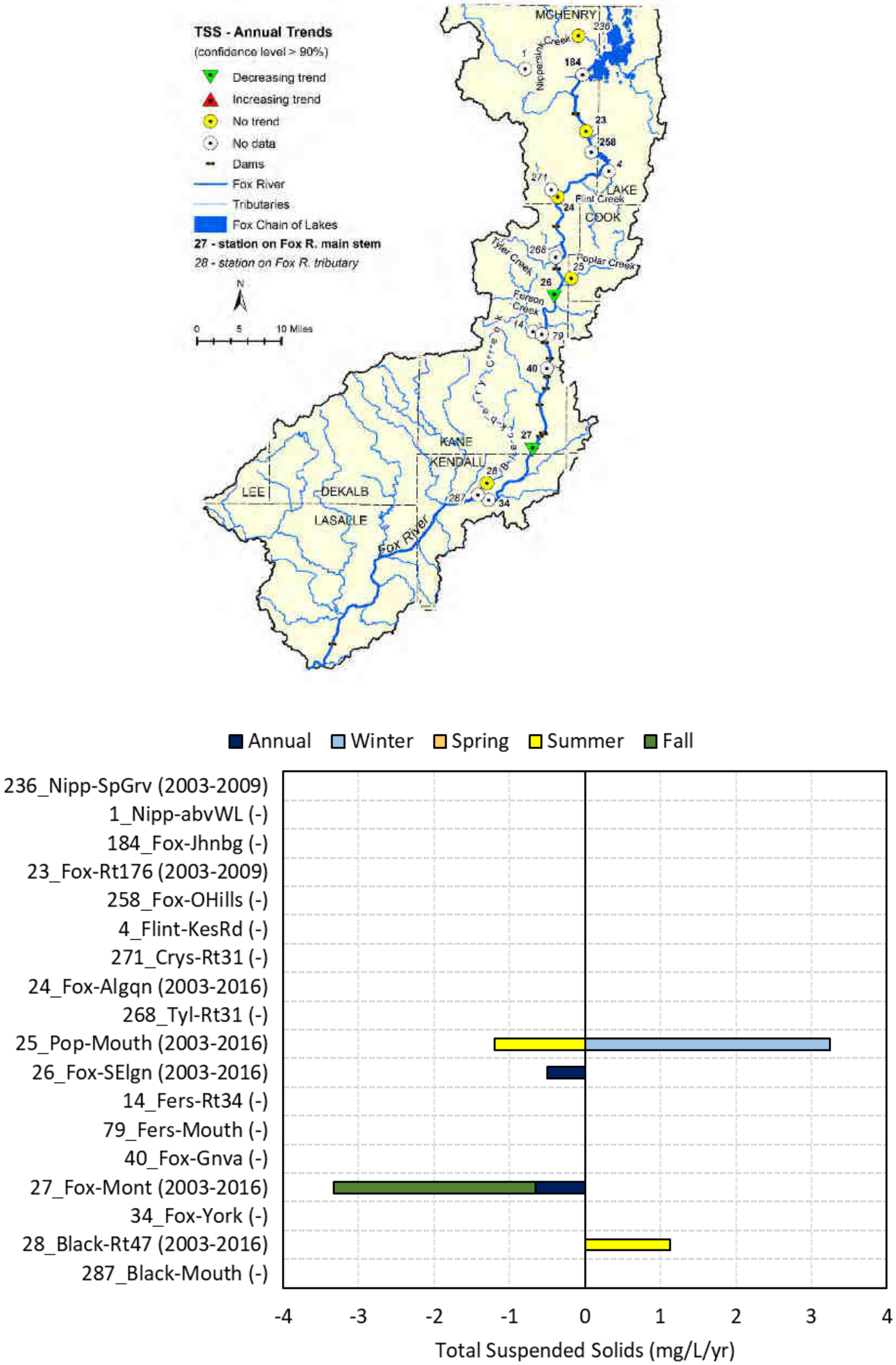

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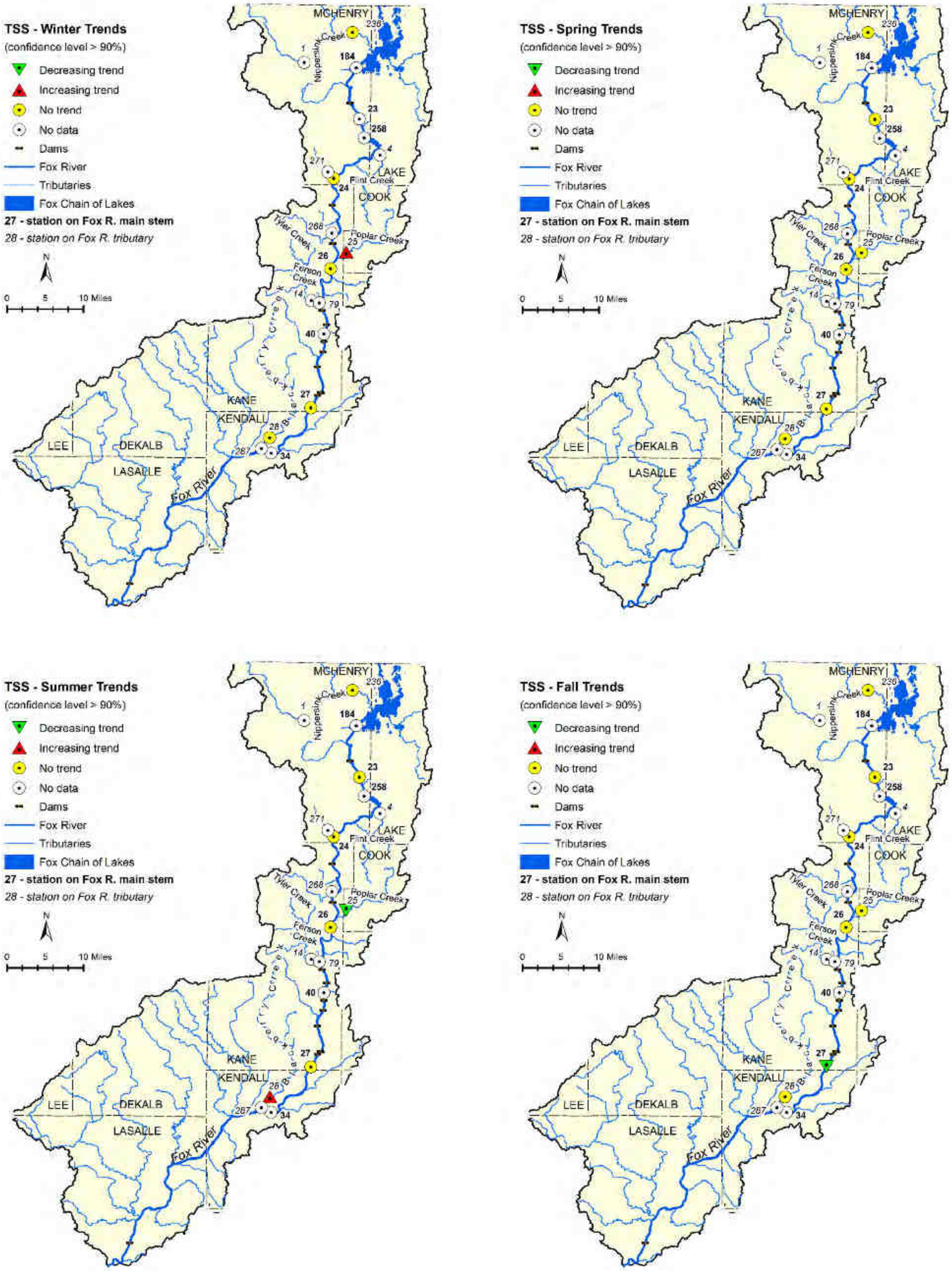

TSS - Winter Trends

(confidence level > 90%)

TSS - Spring Trends

(confidence level > 90%)

TSS - Summer Trends

(confidence level > 90%)

TSS - Fall Trends

(confidence level > 90%)

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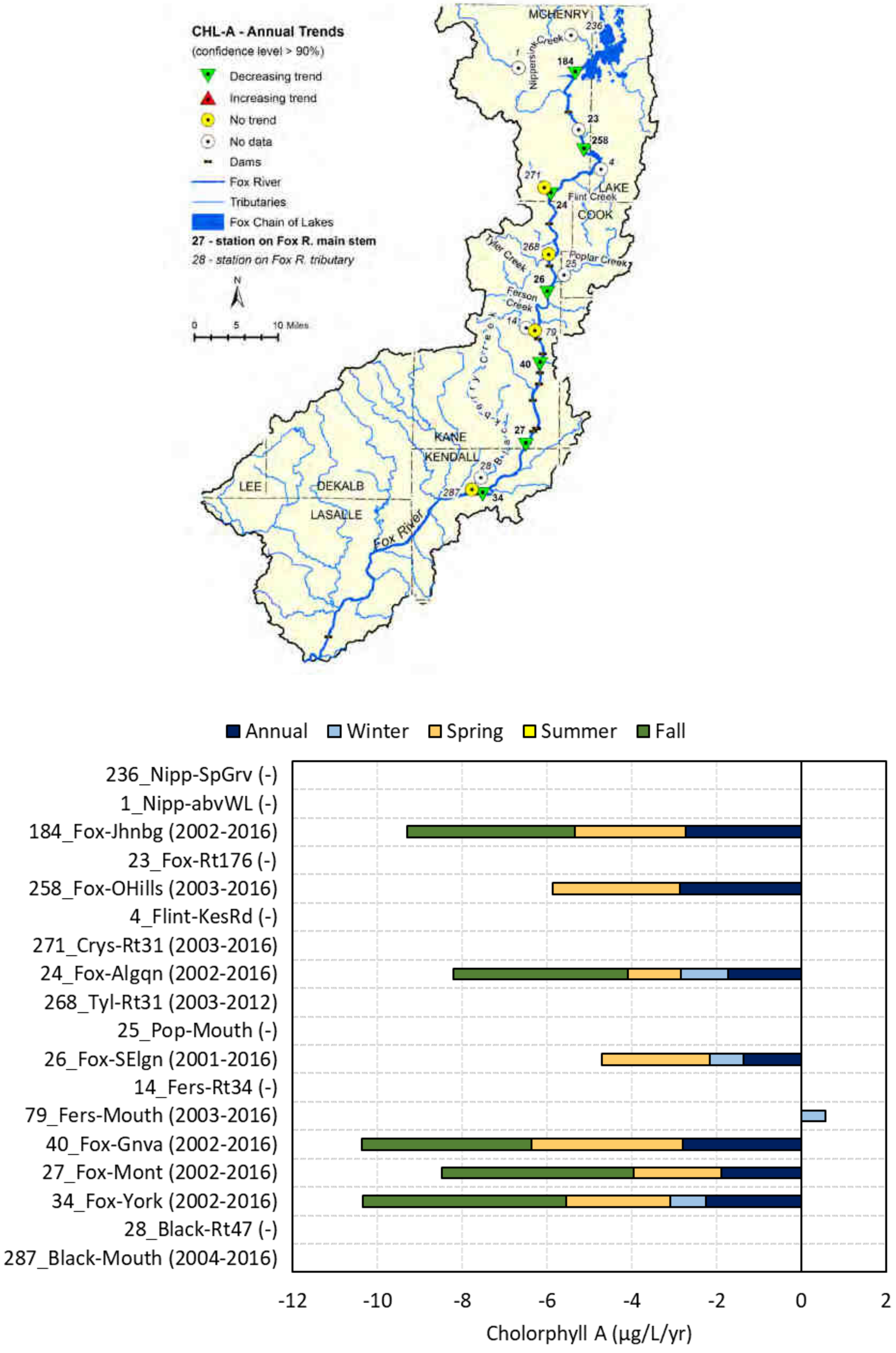

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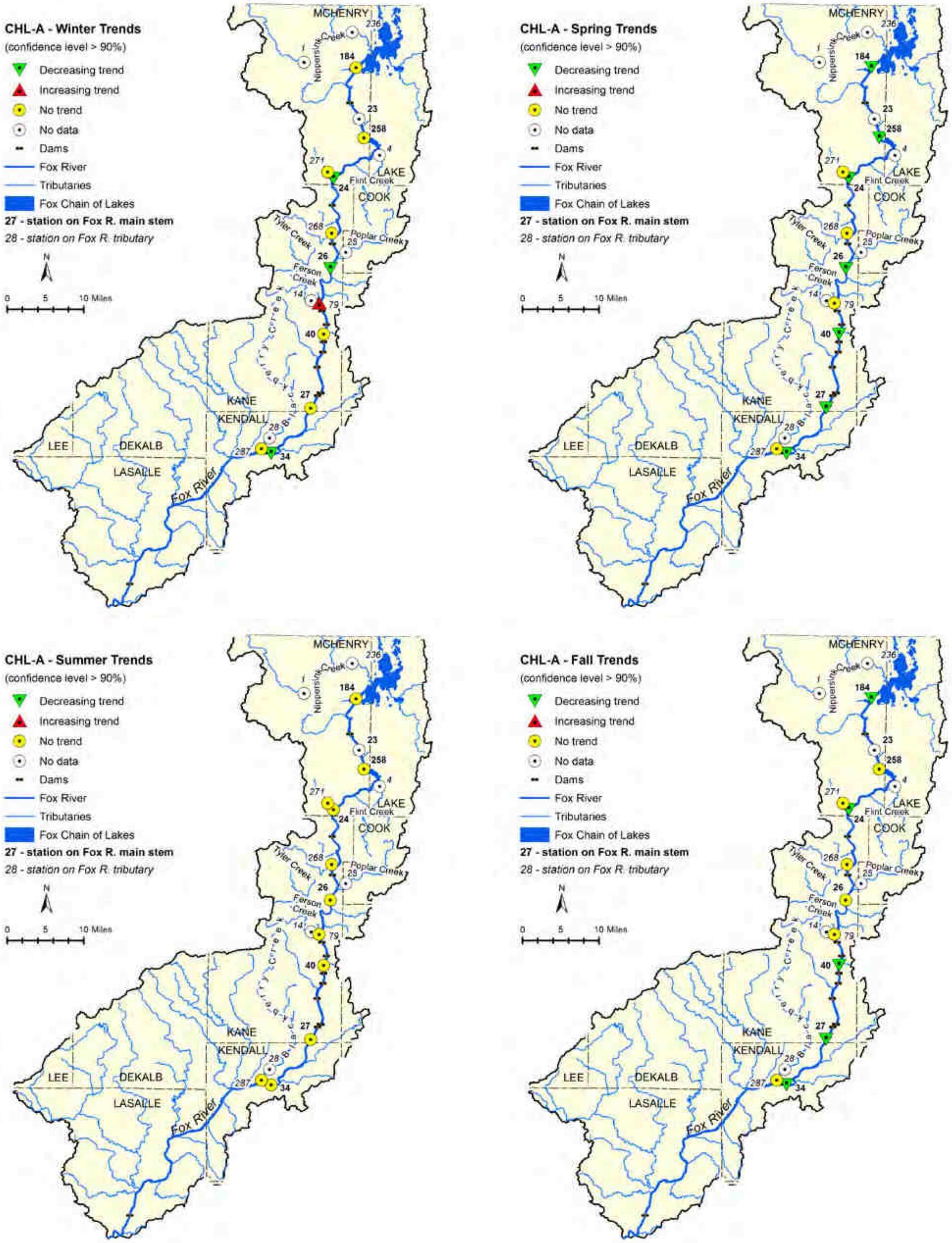

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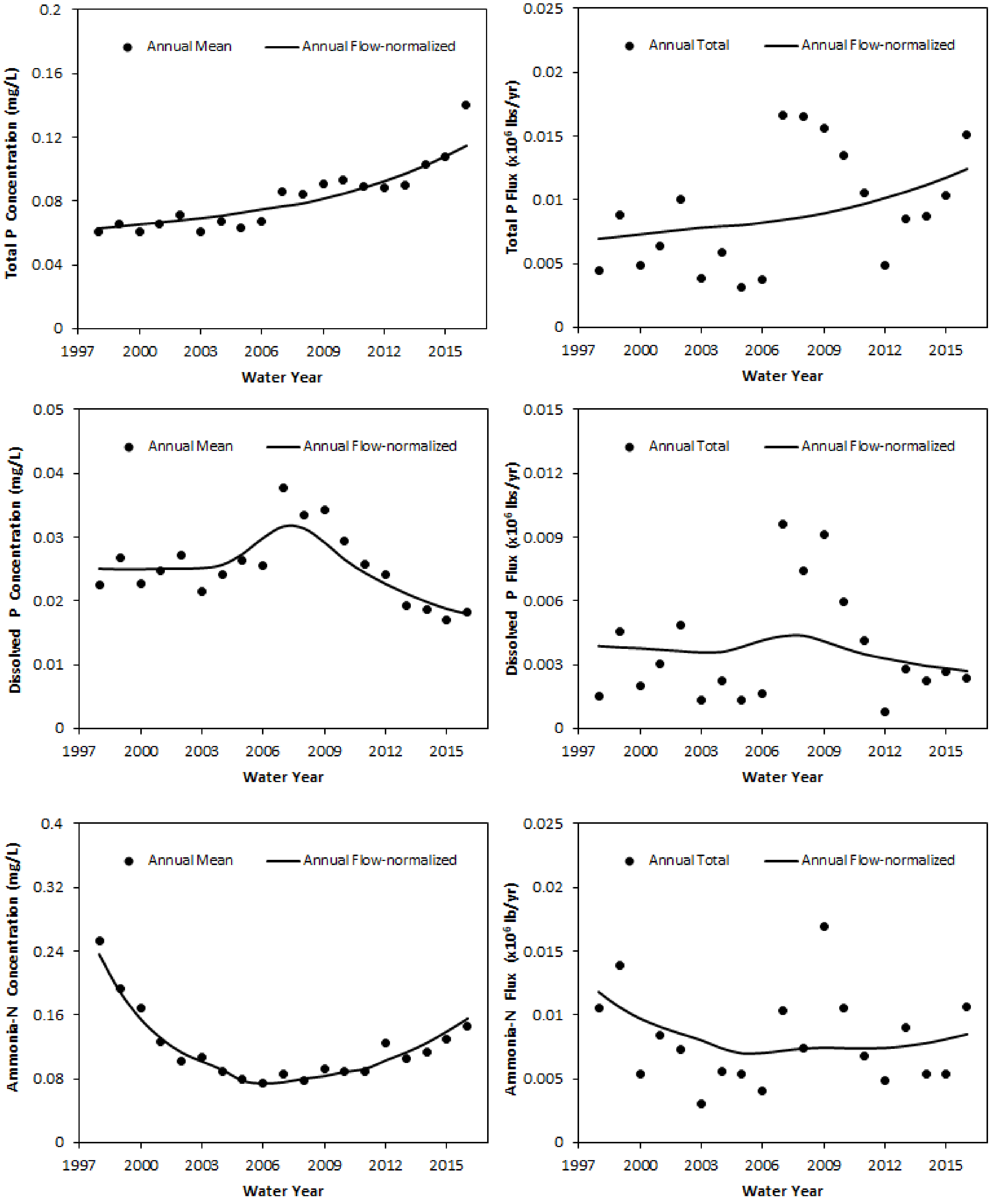

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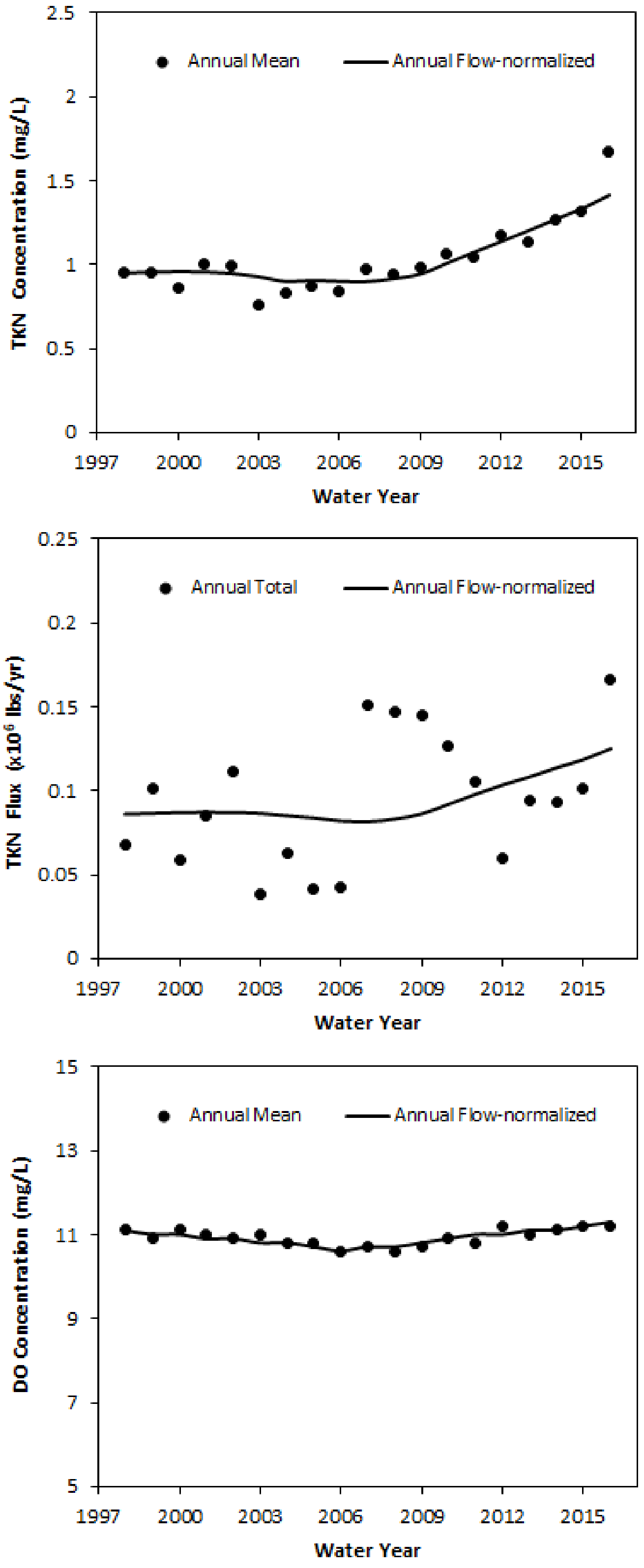

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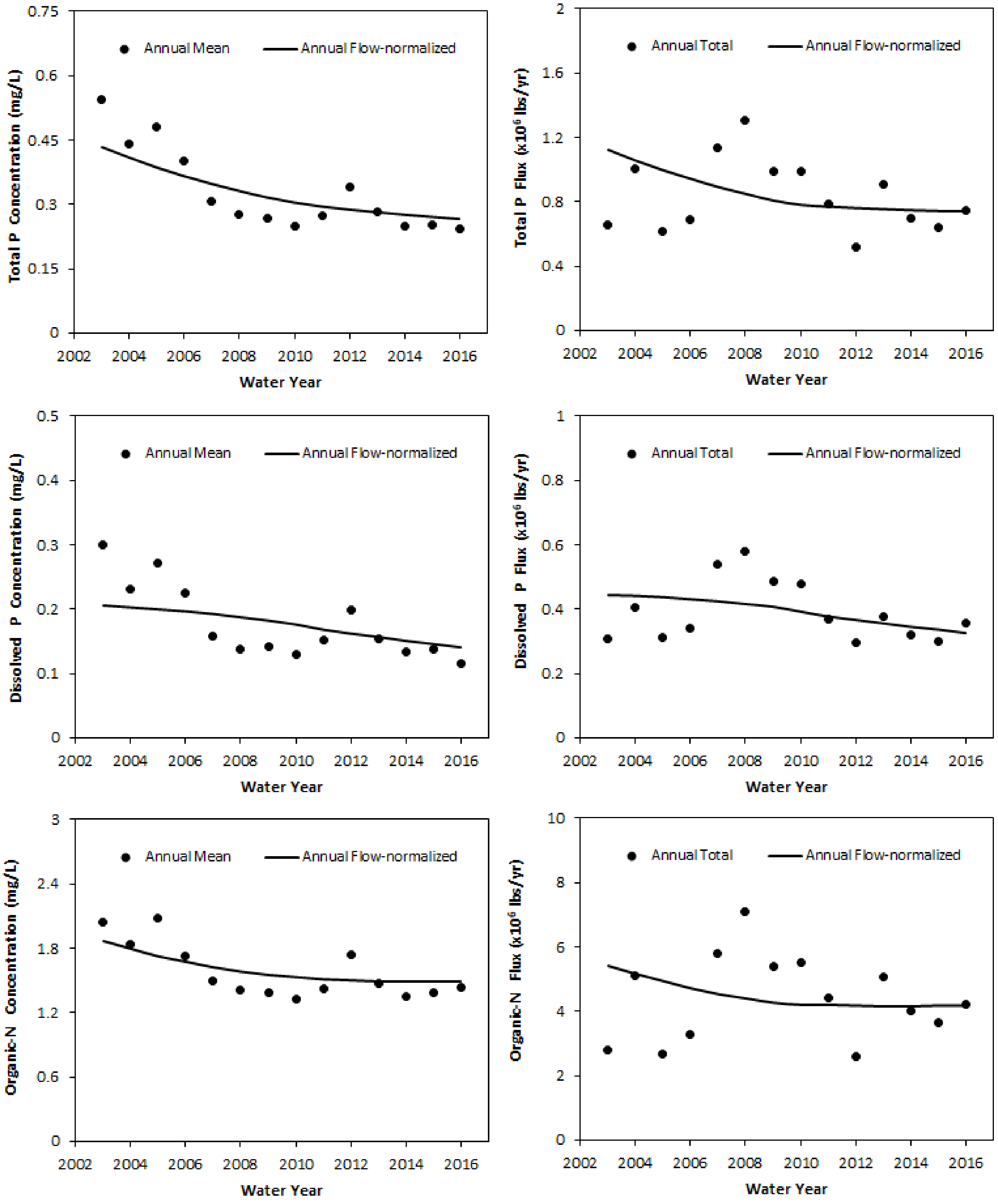

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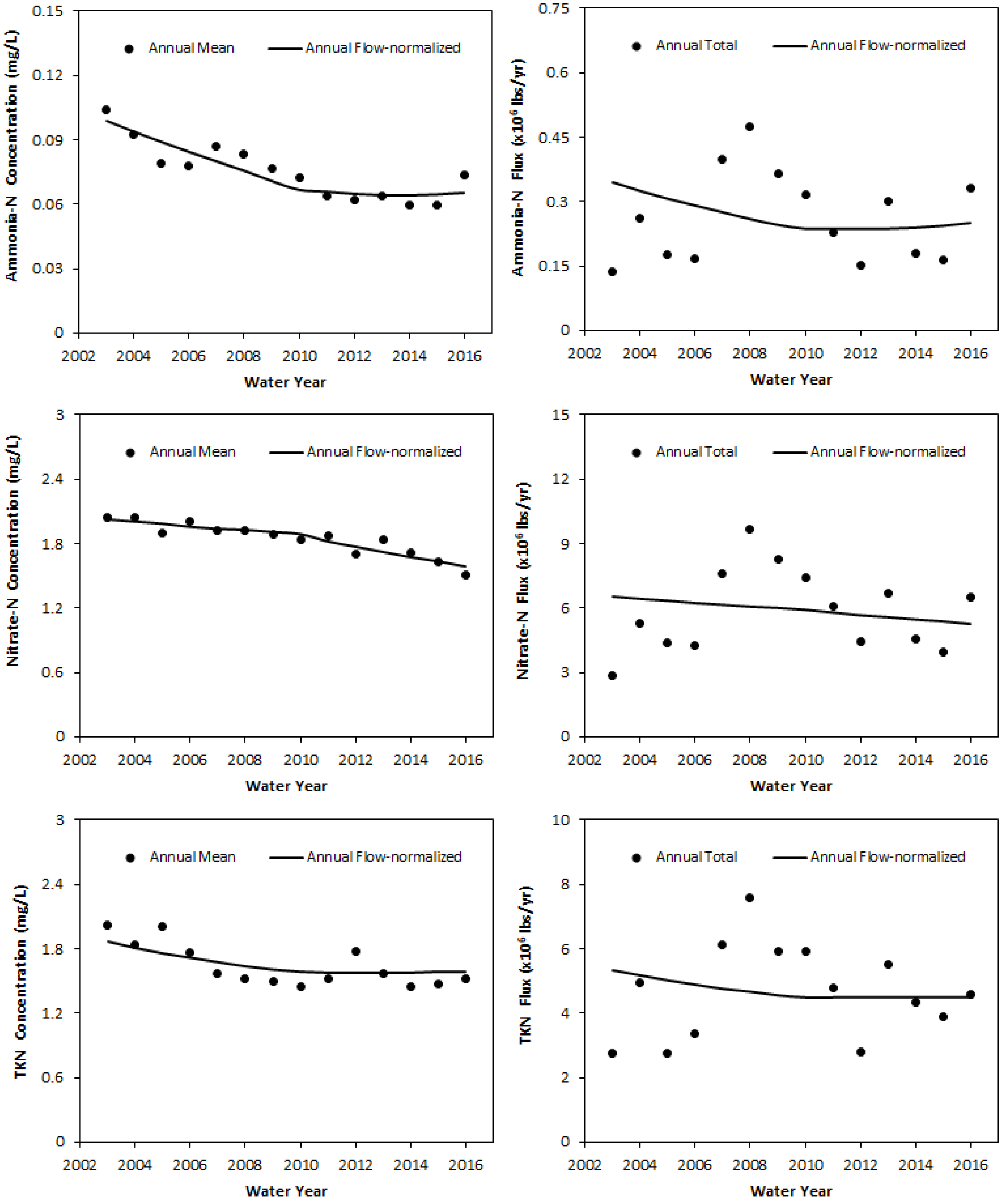

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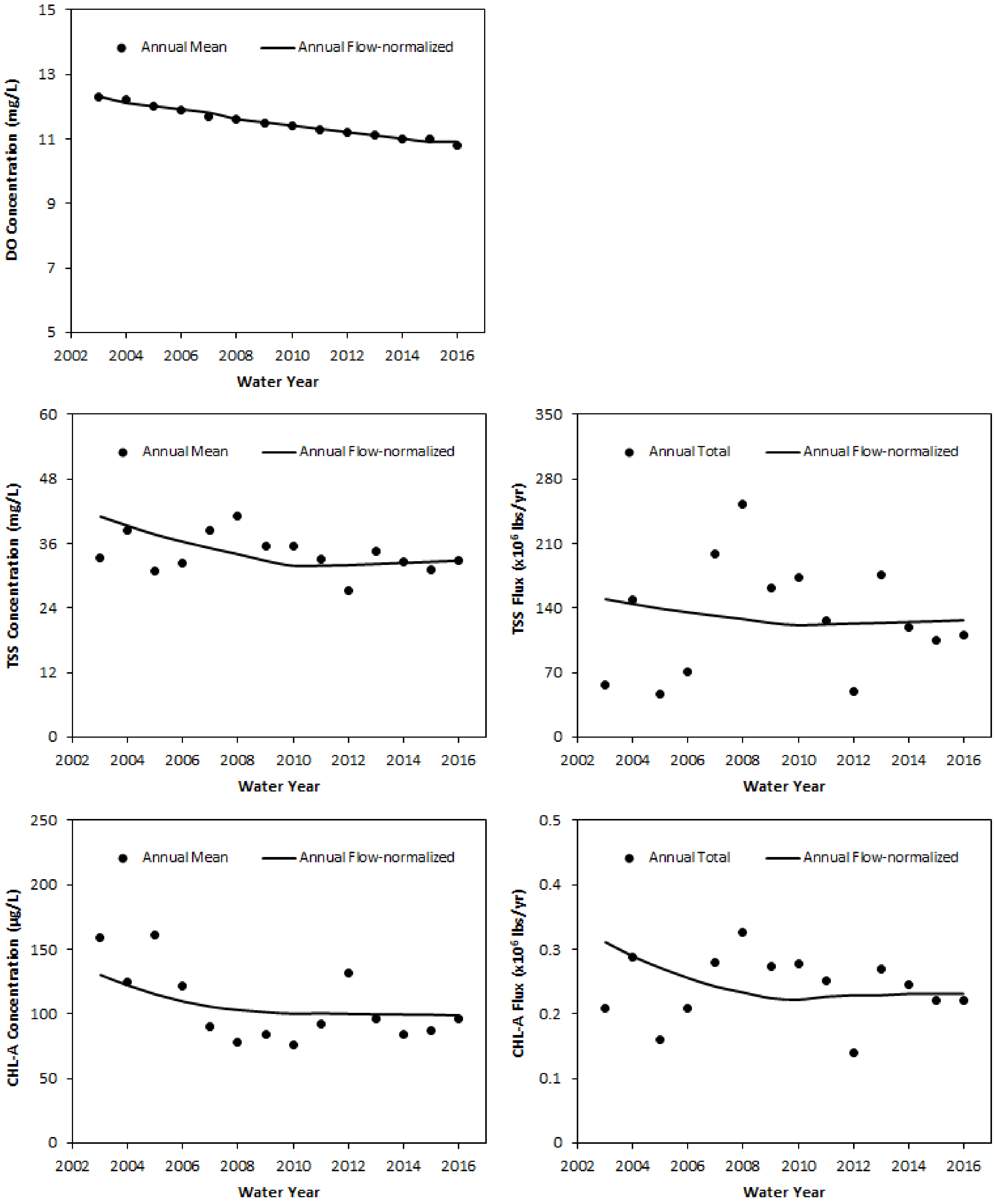

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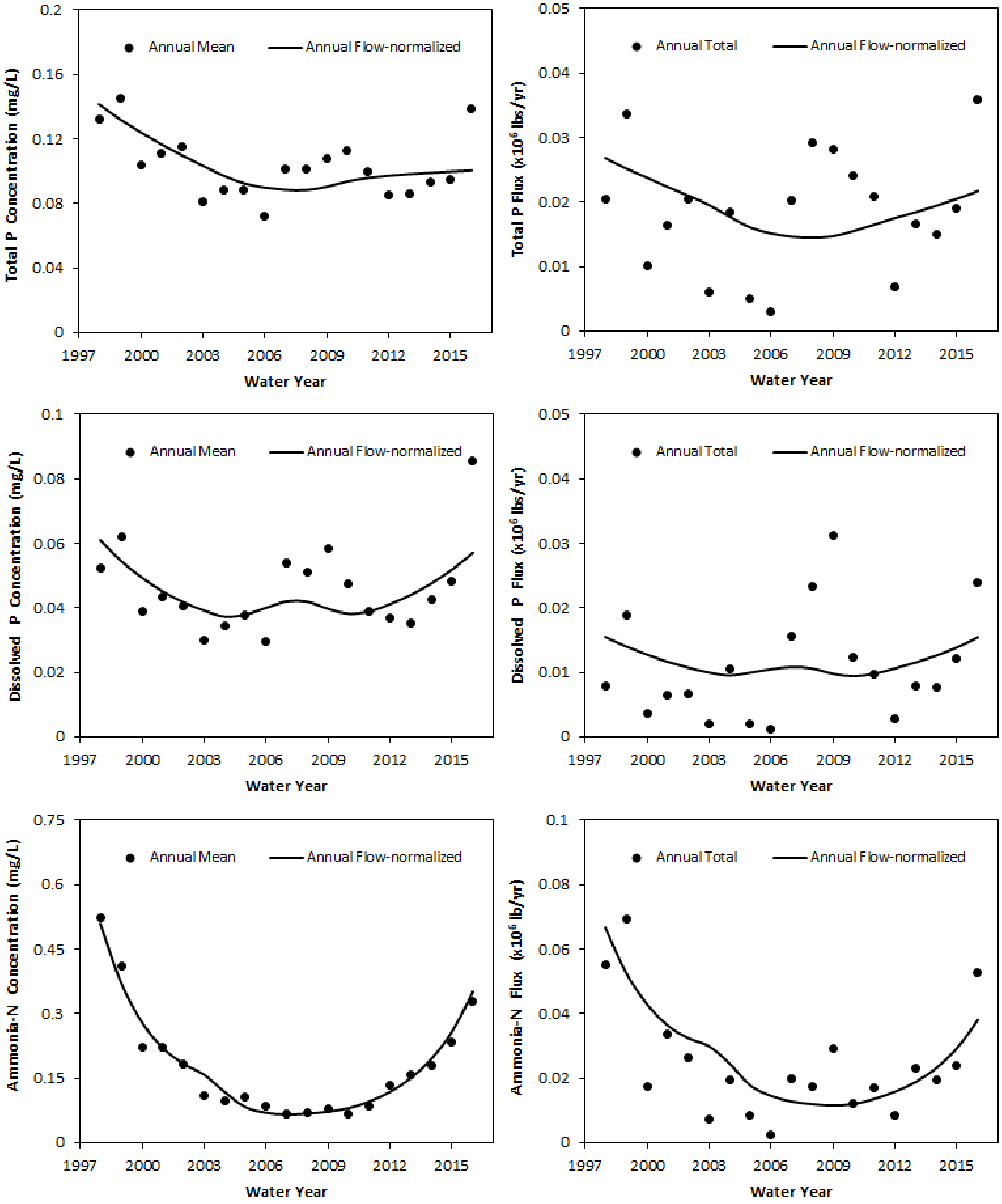

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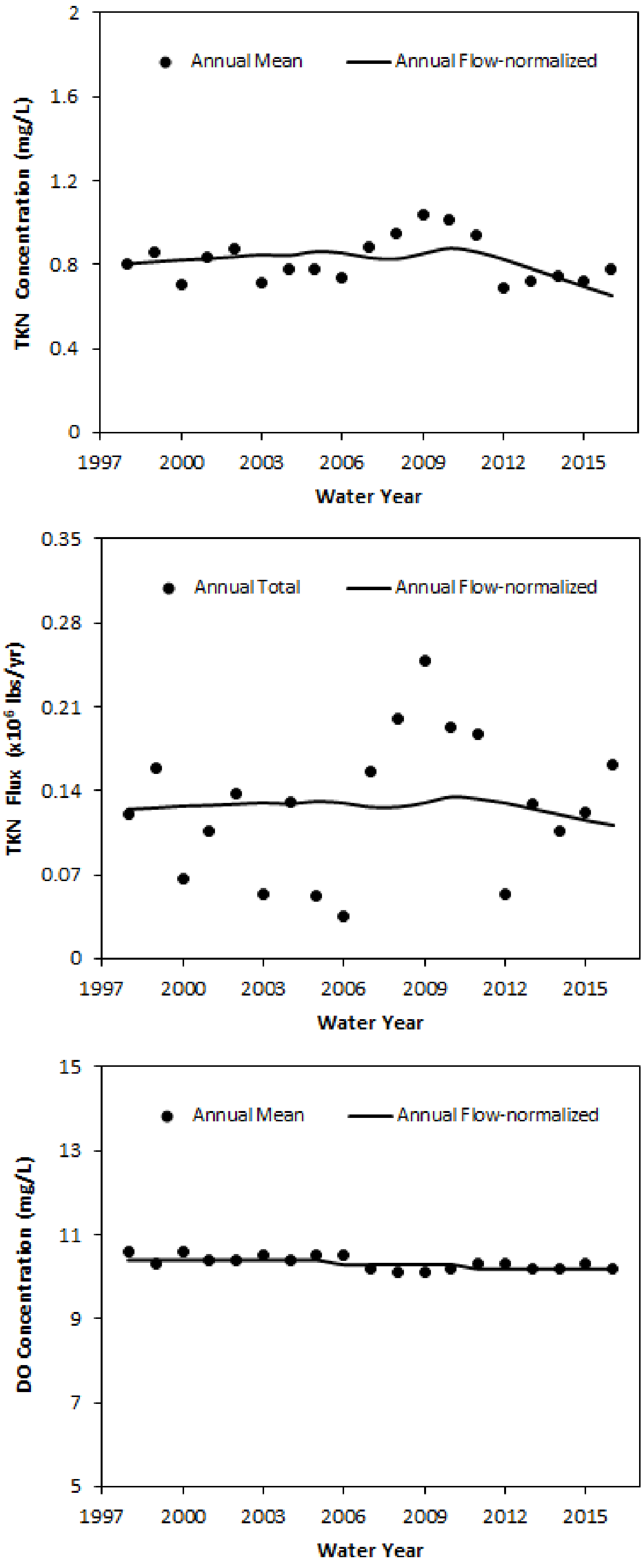

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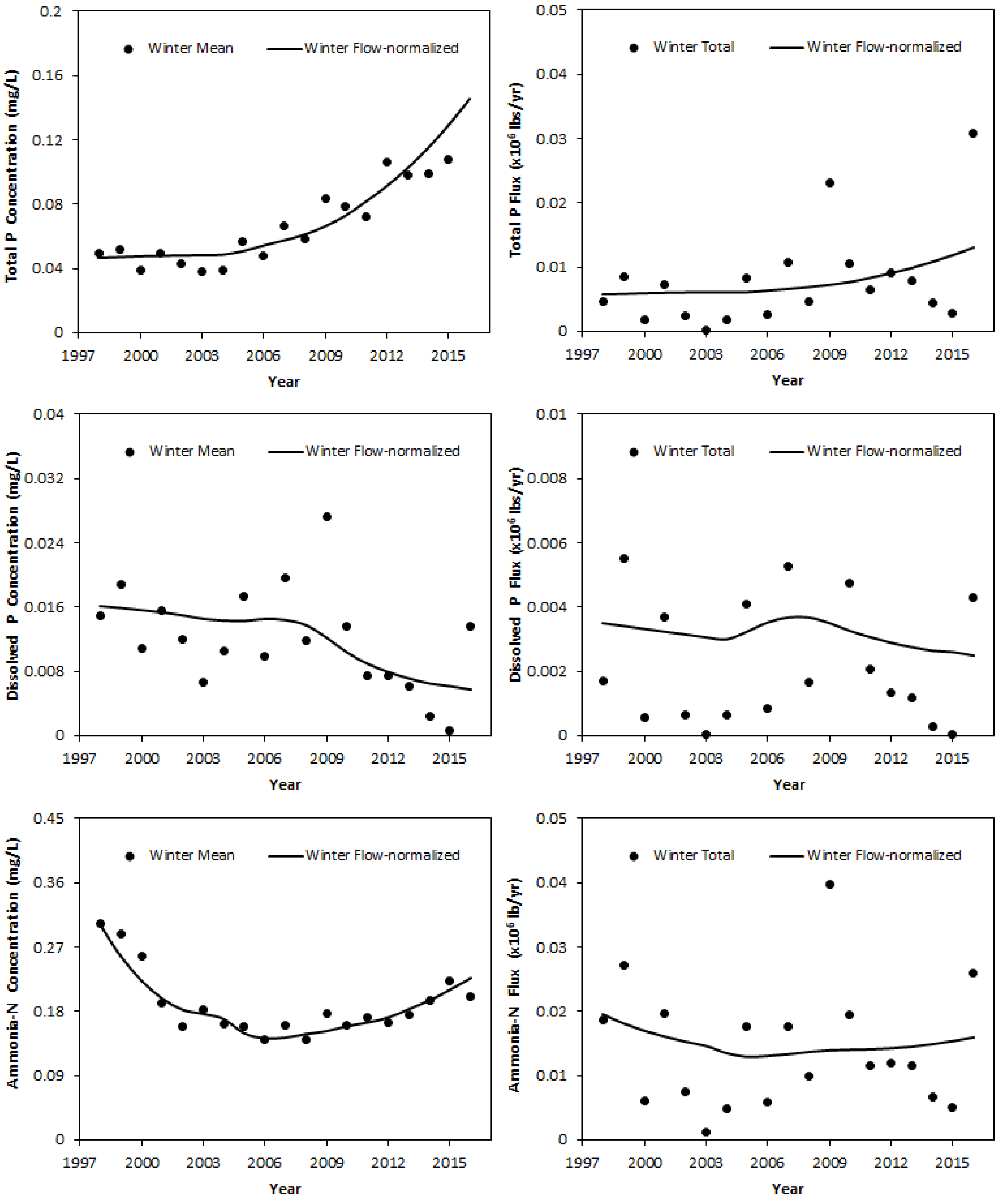

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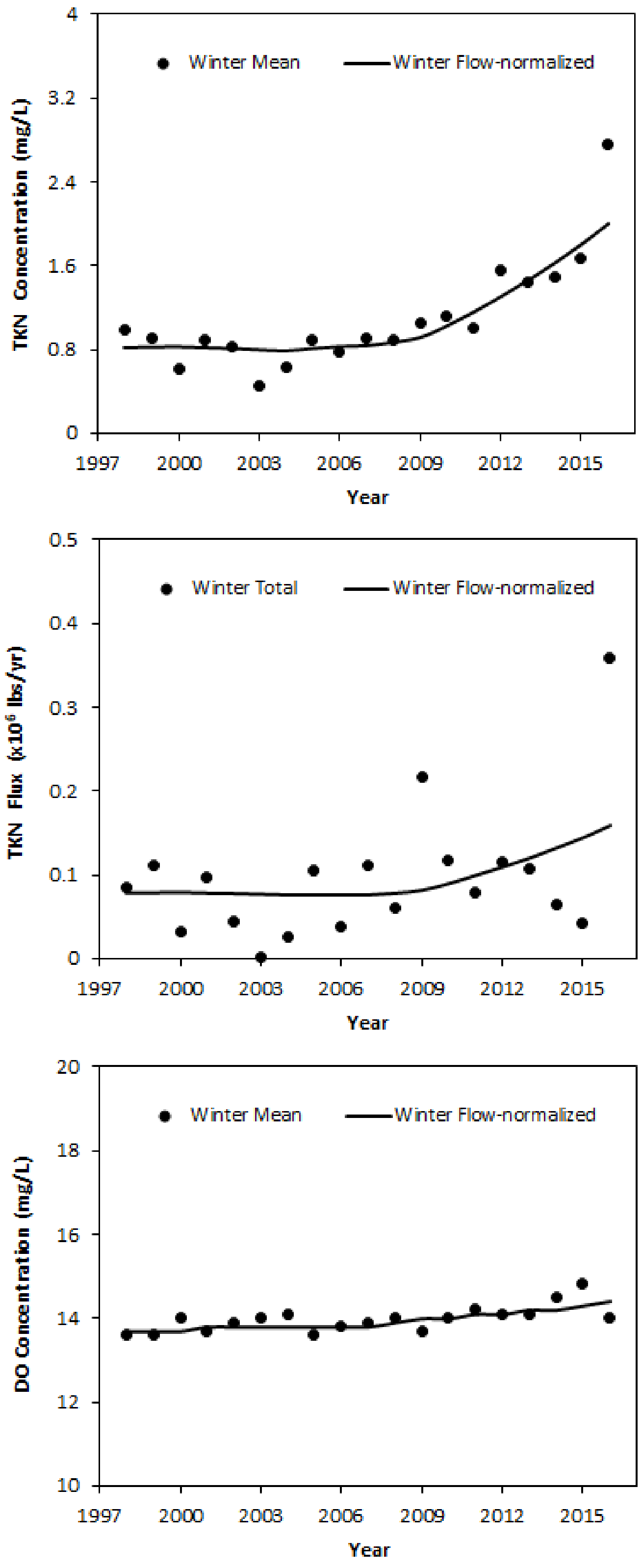

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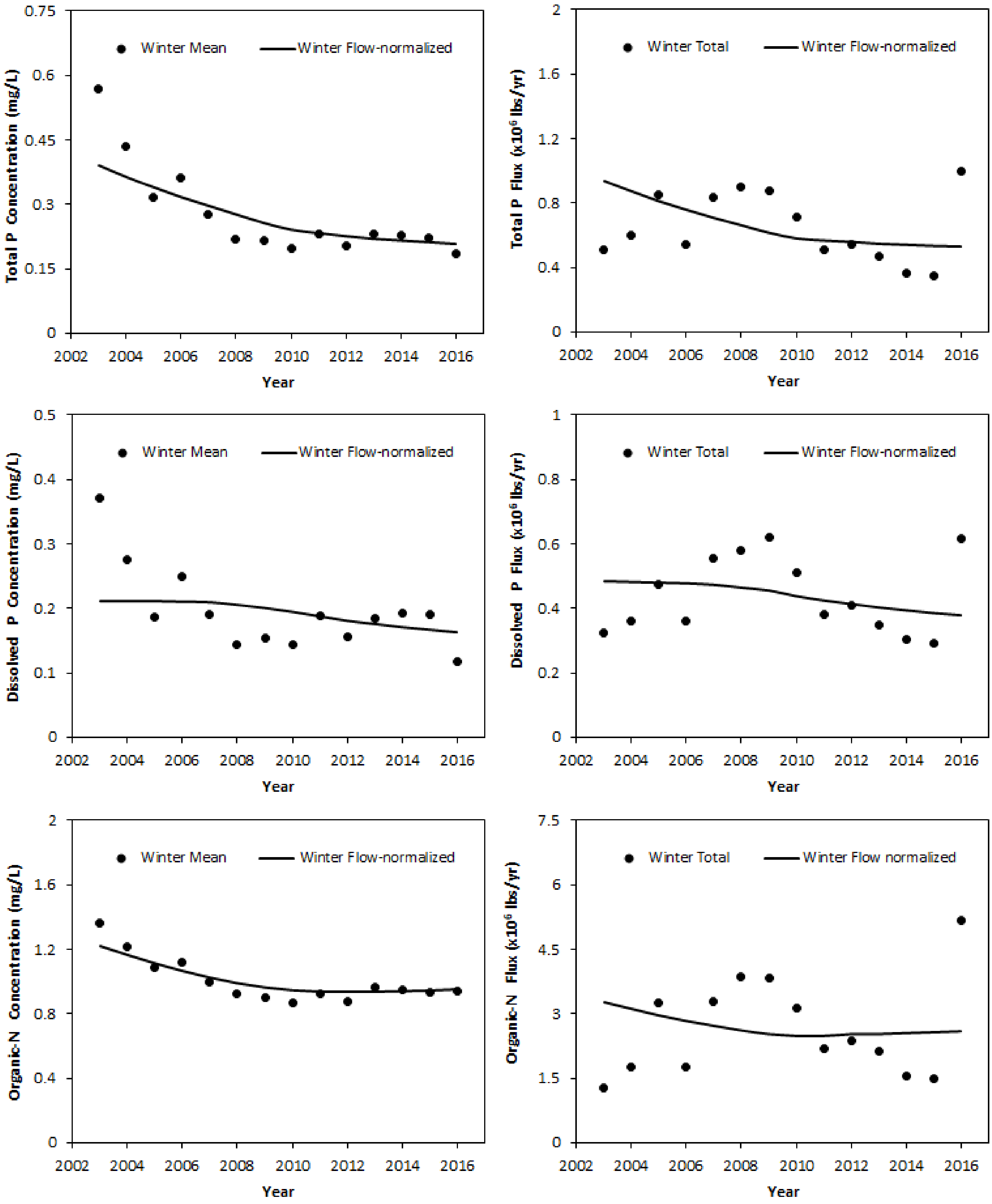

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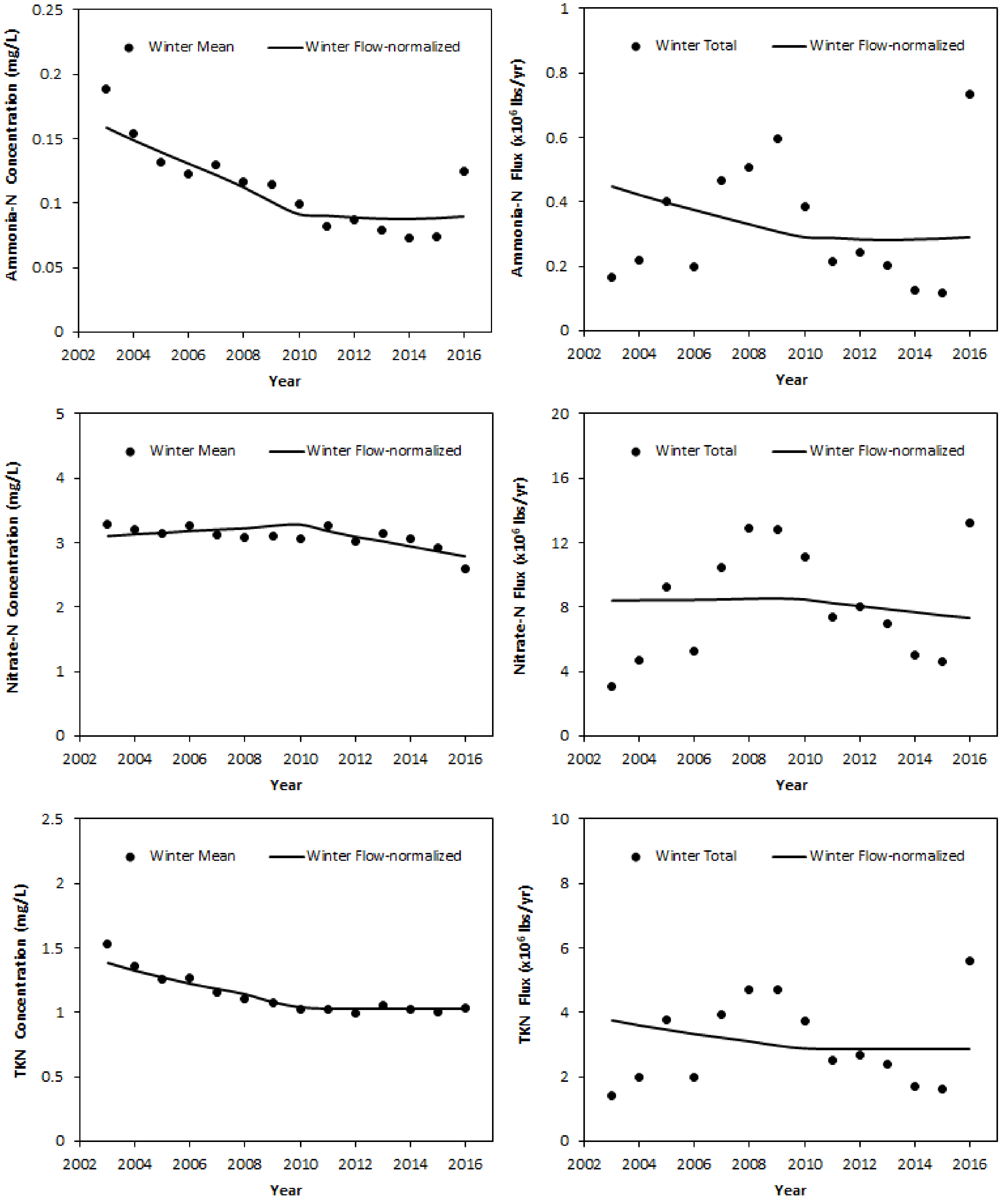

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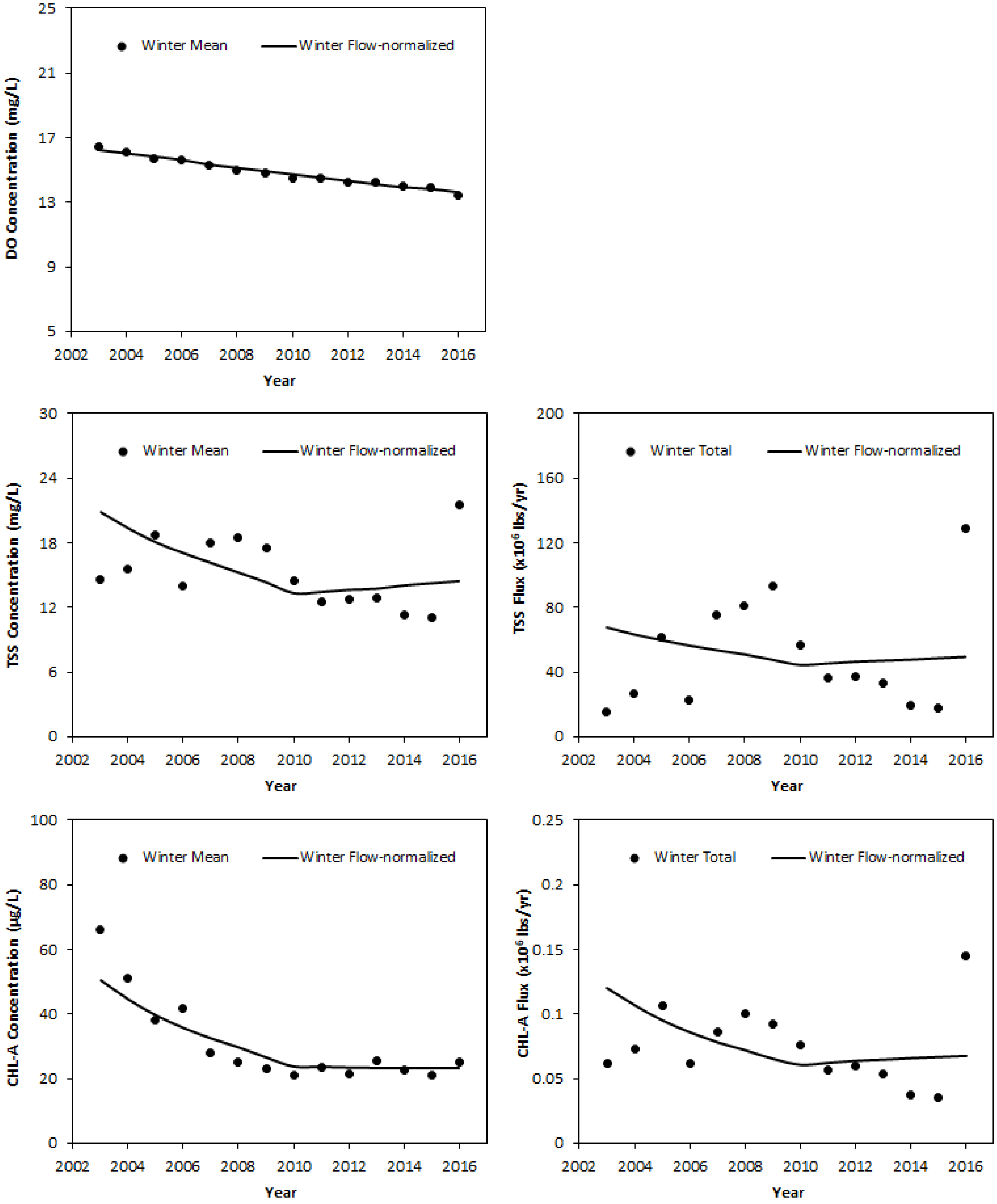

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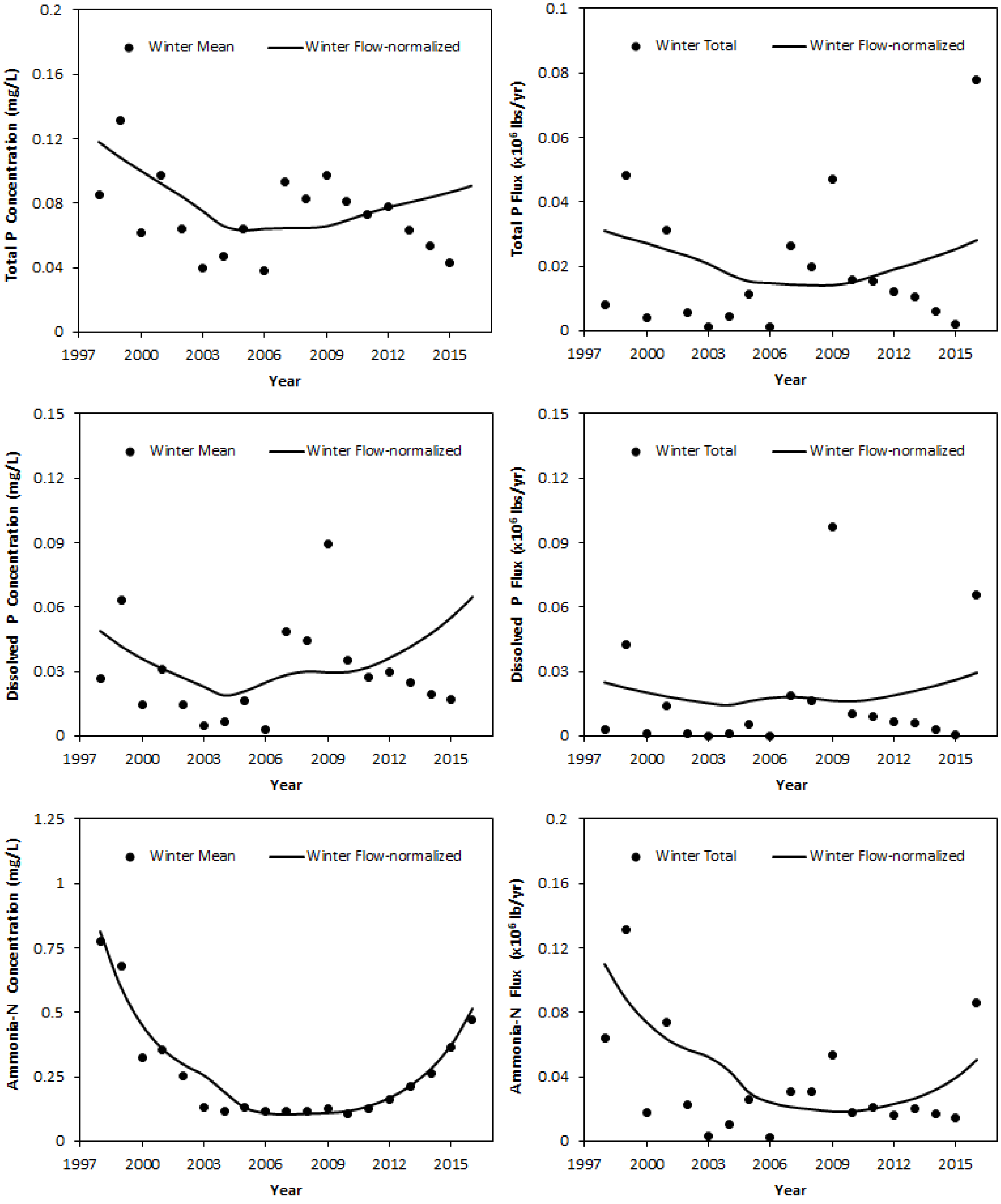

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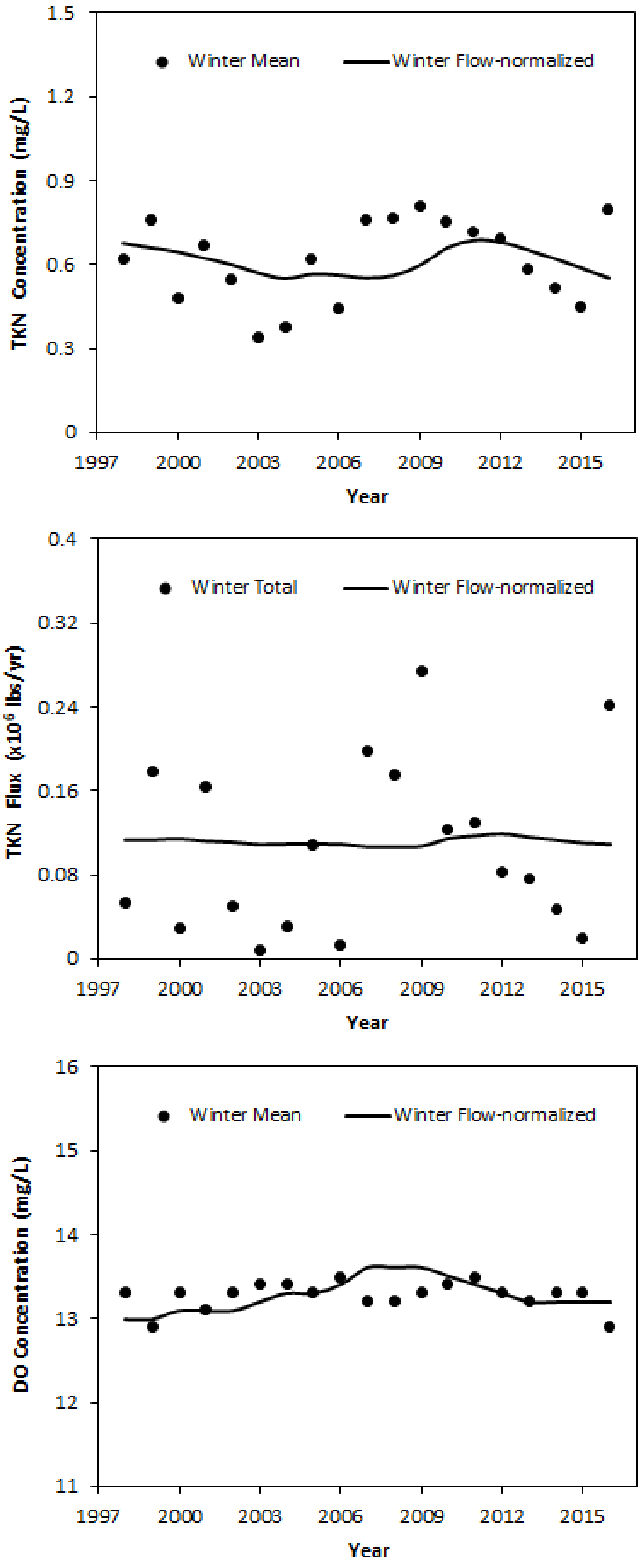

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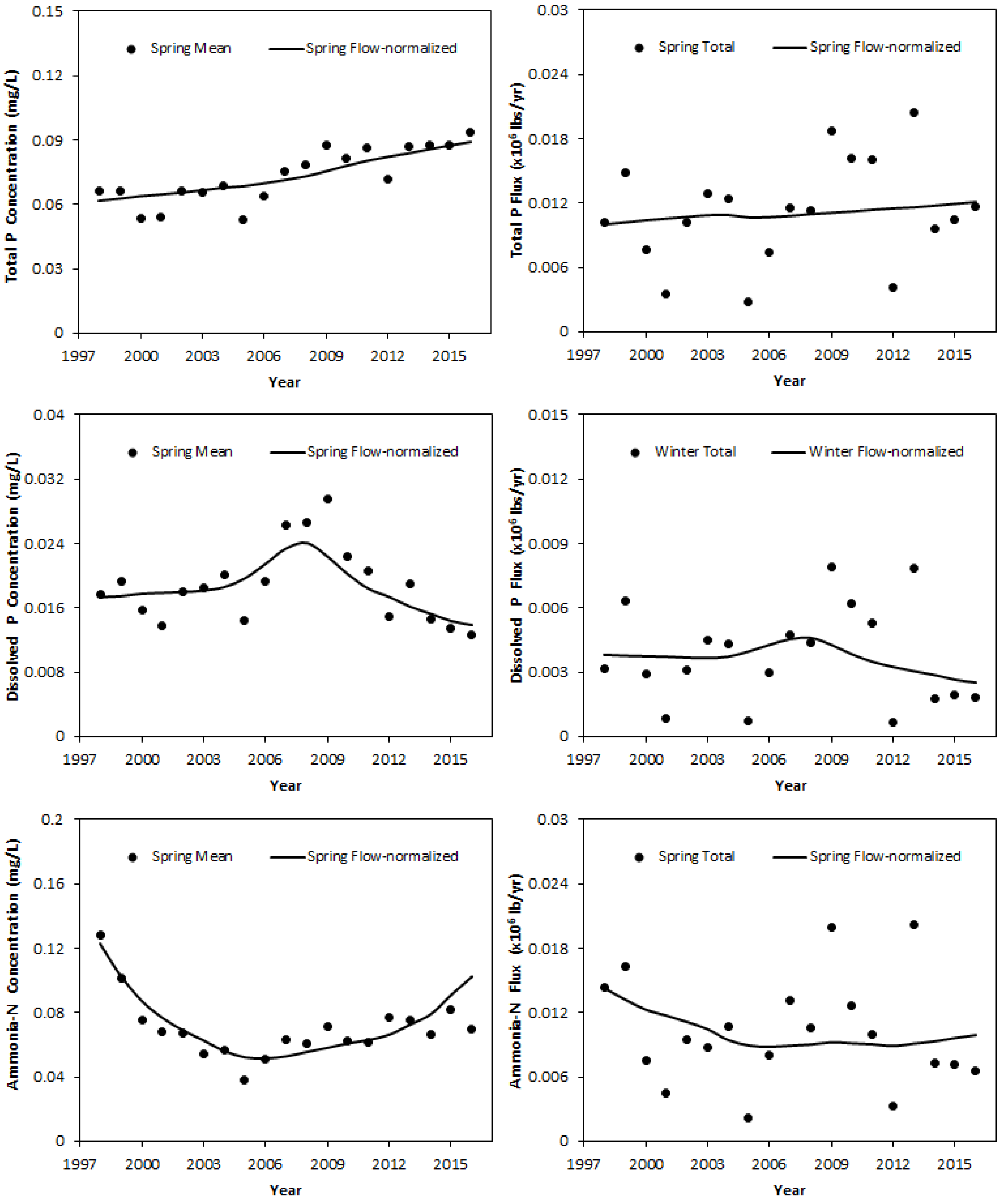

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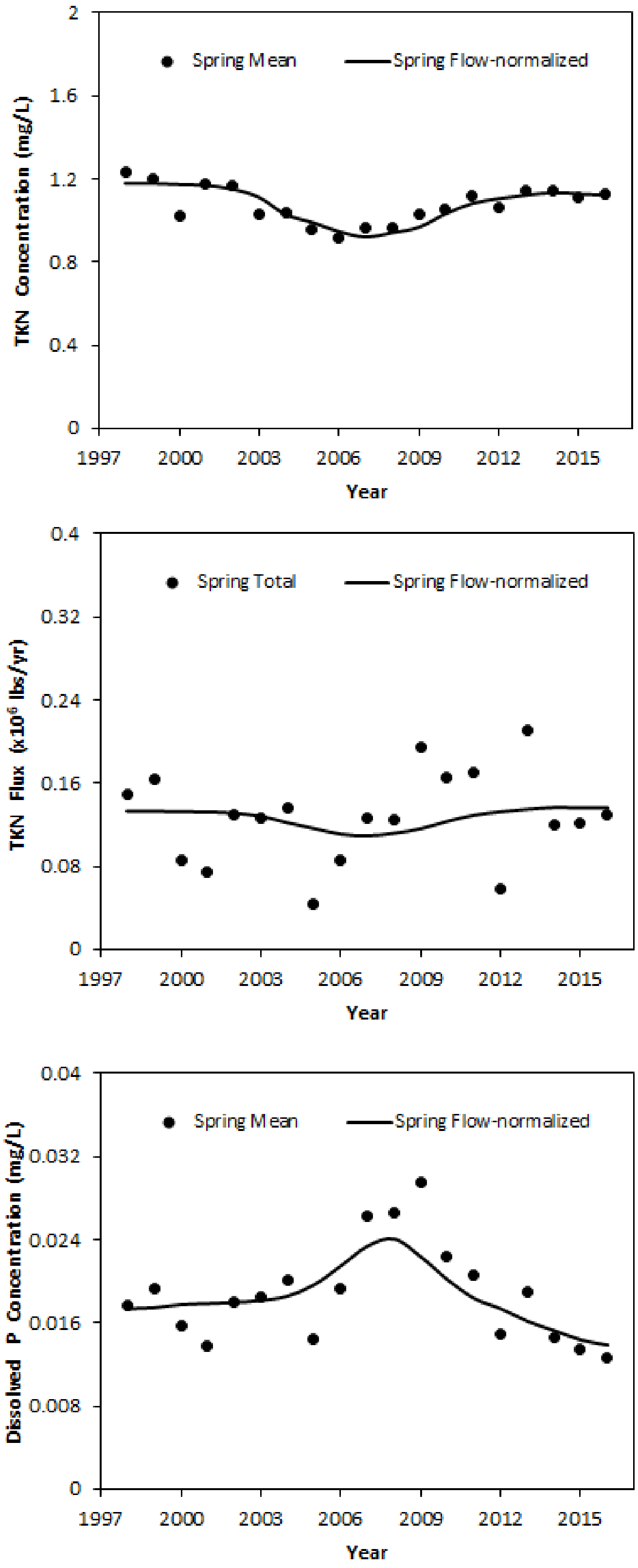

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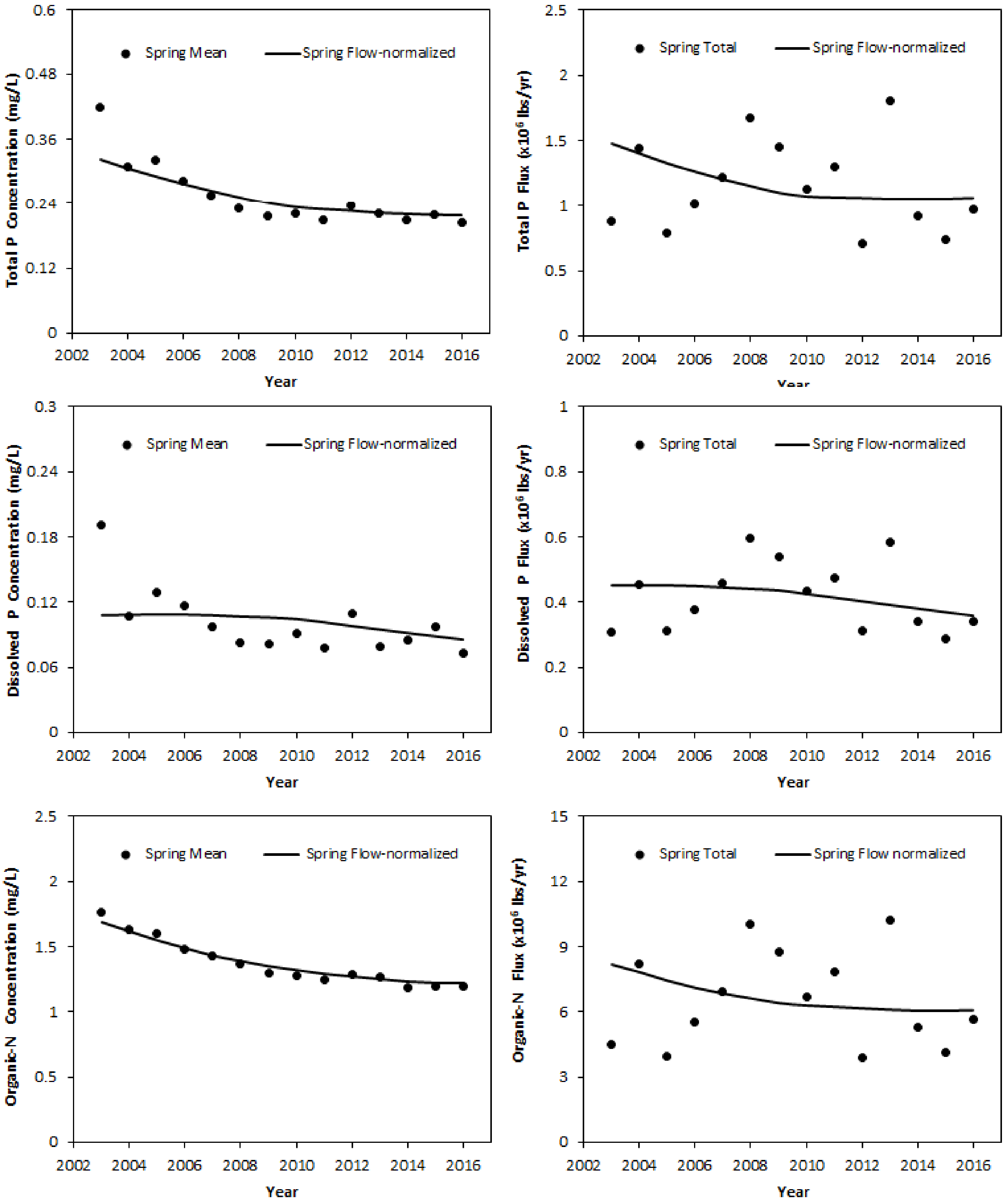

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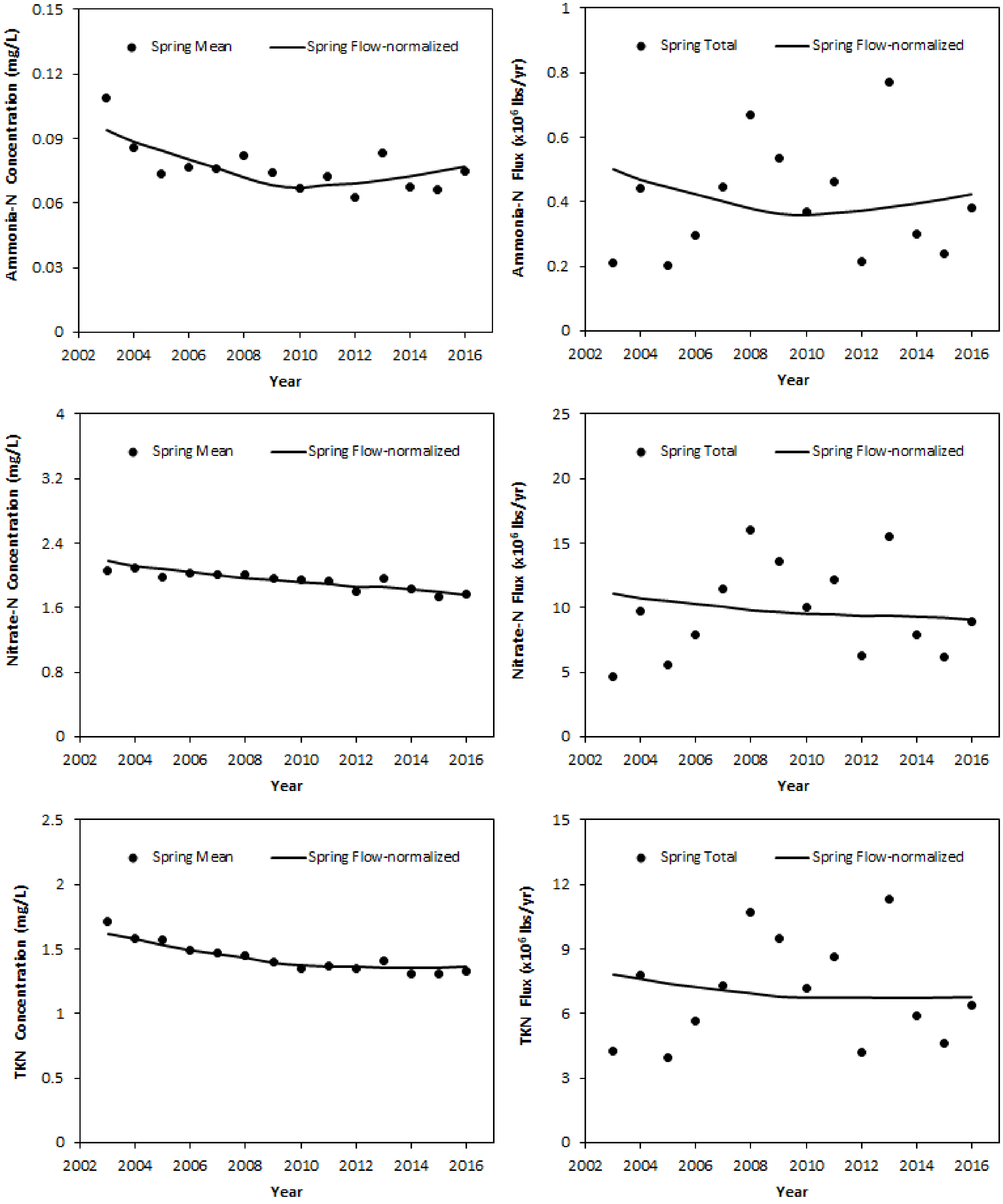

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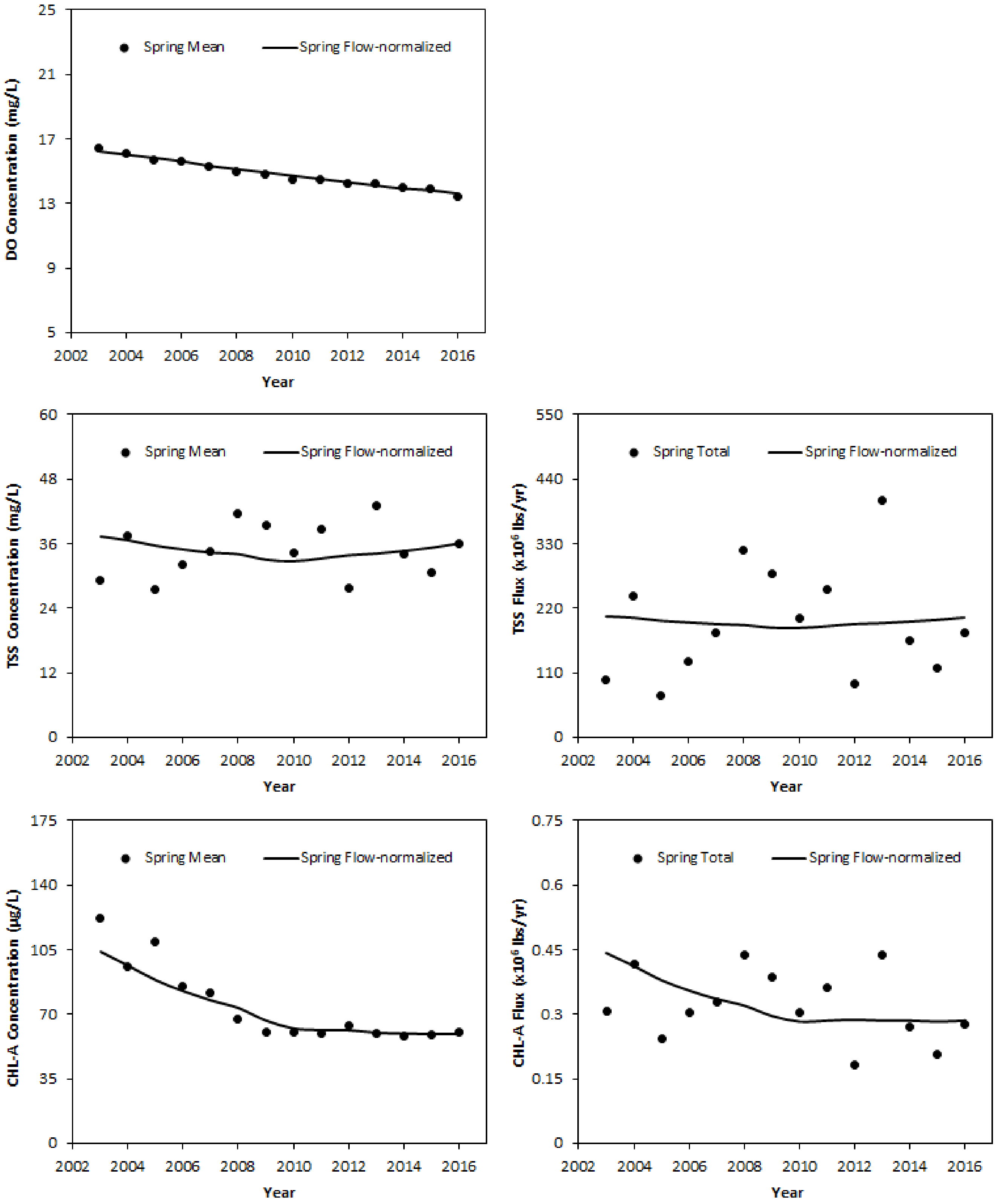

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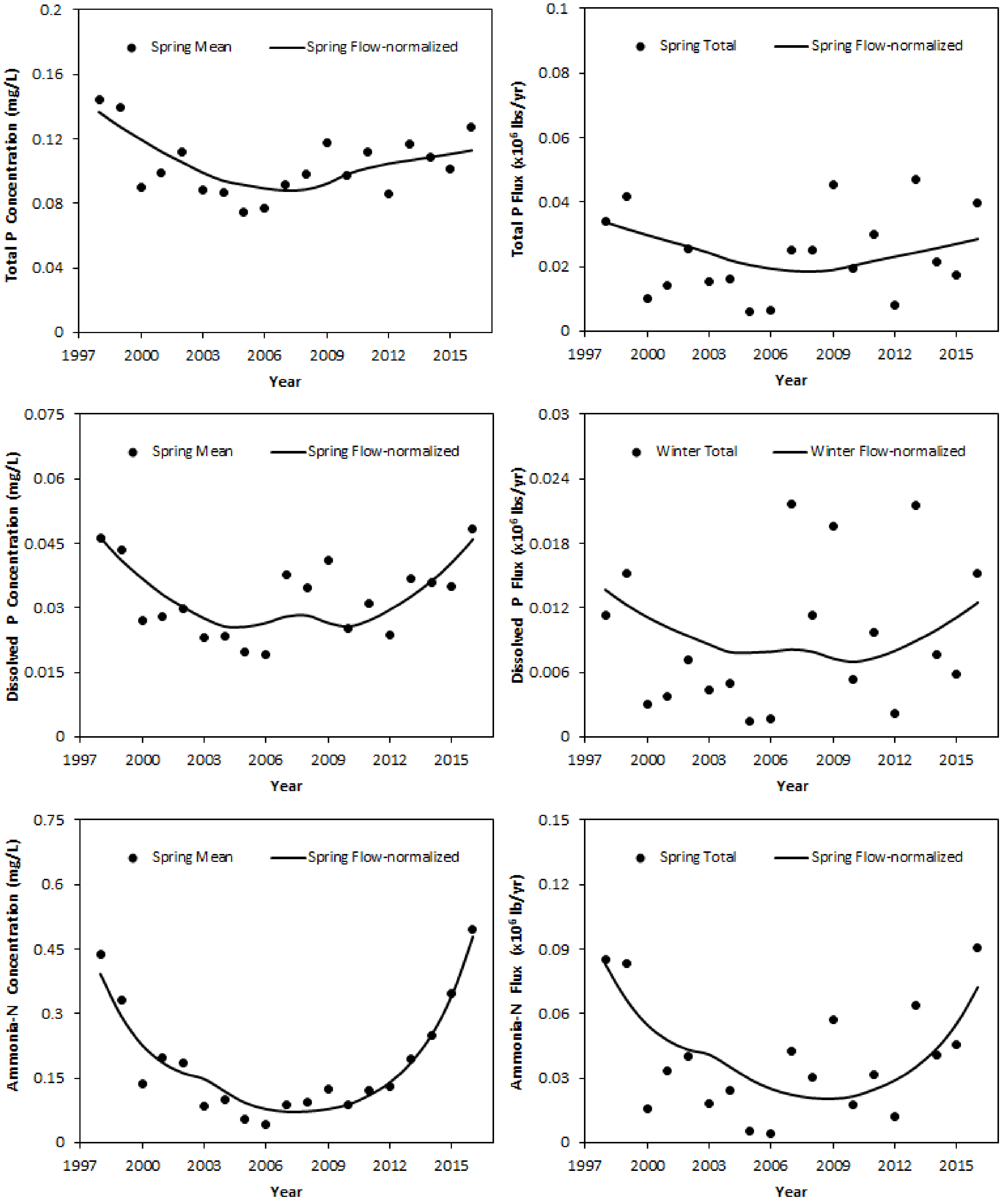

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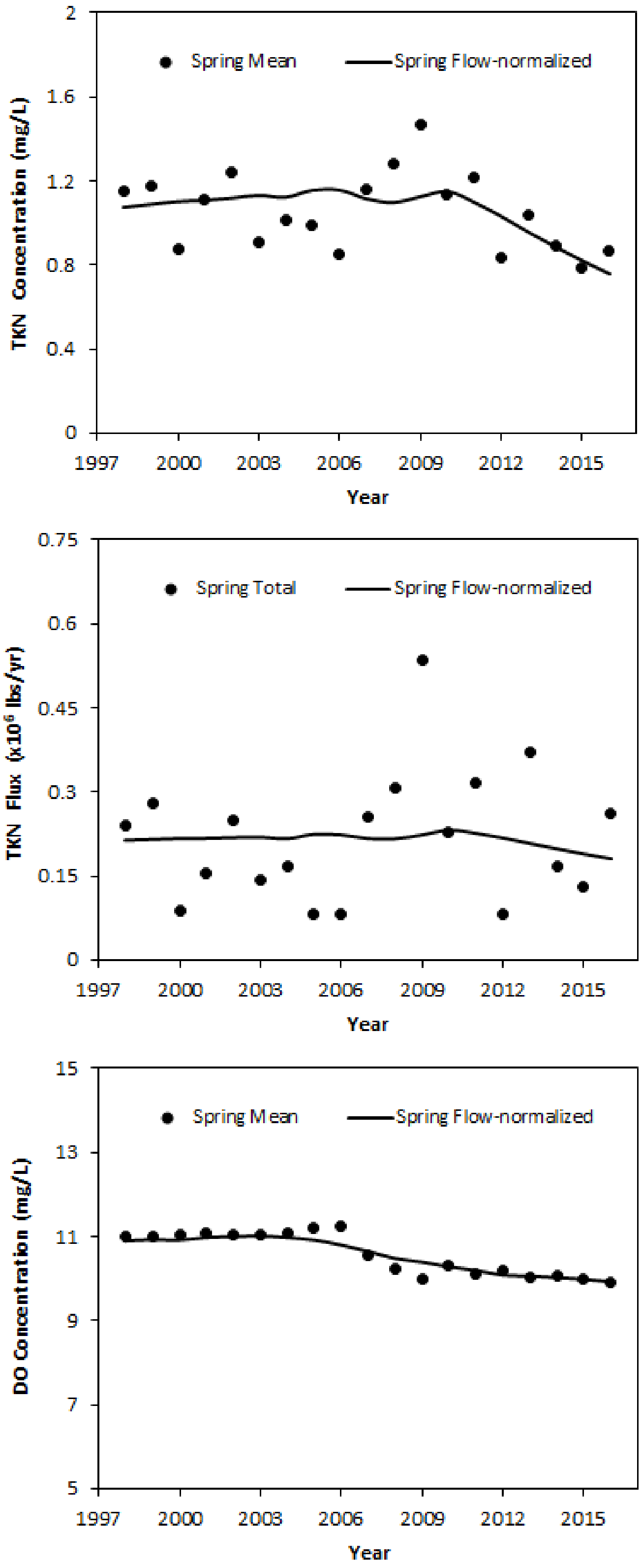

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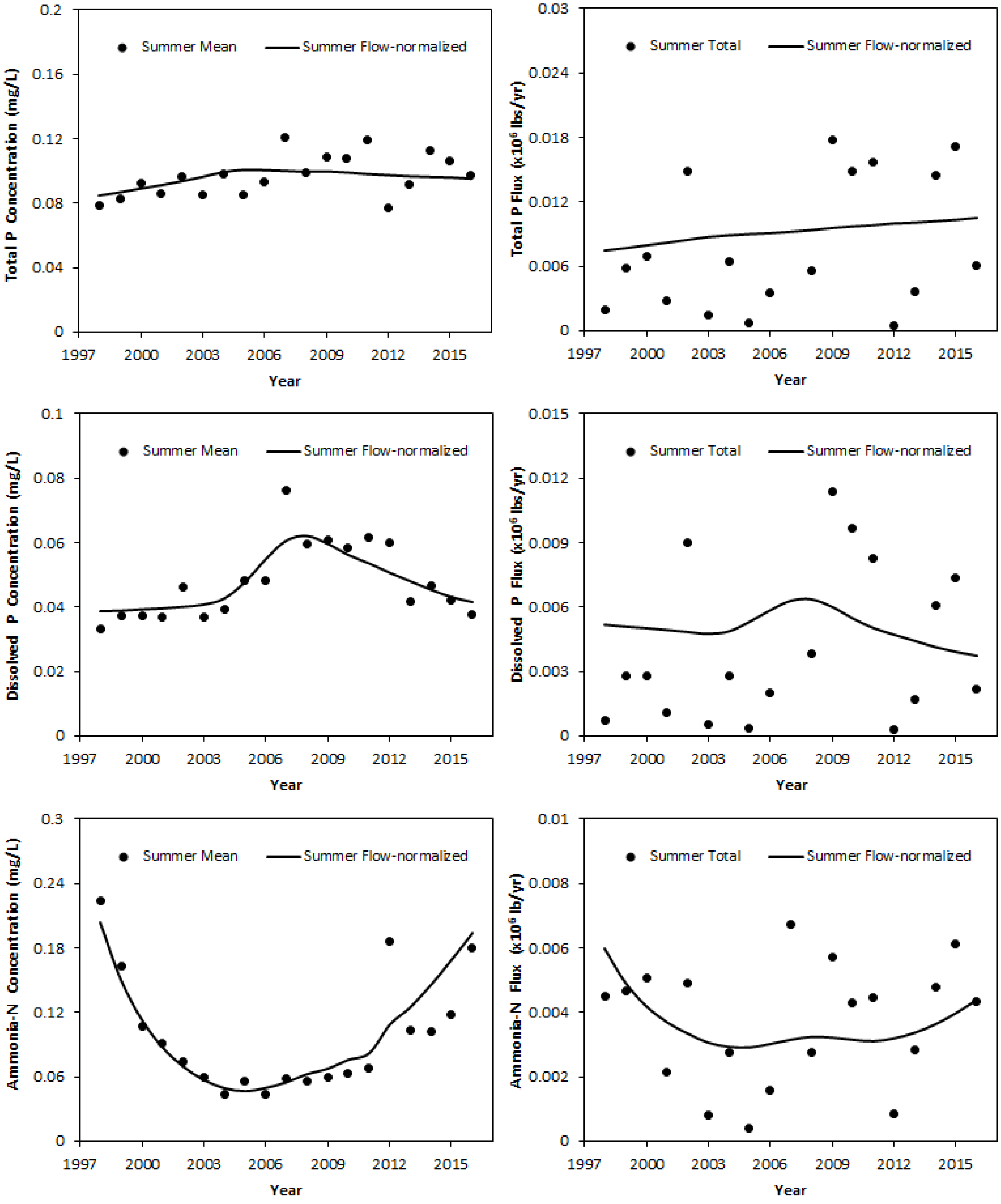

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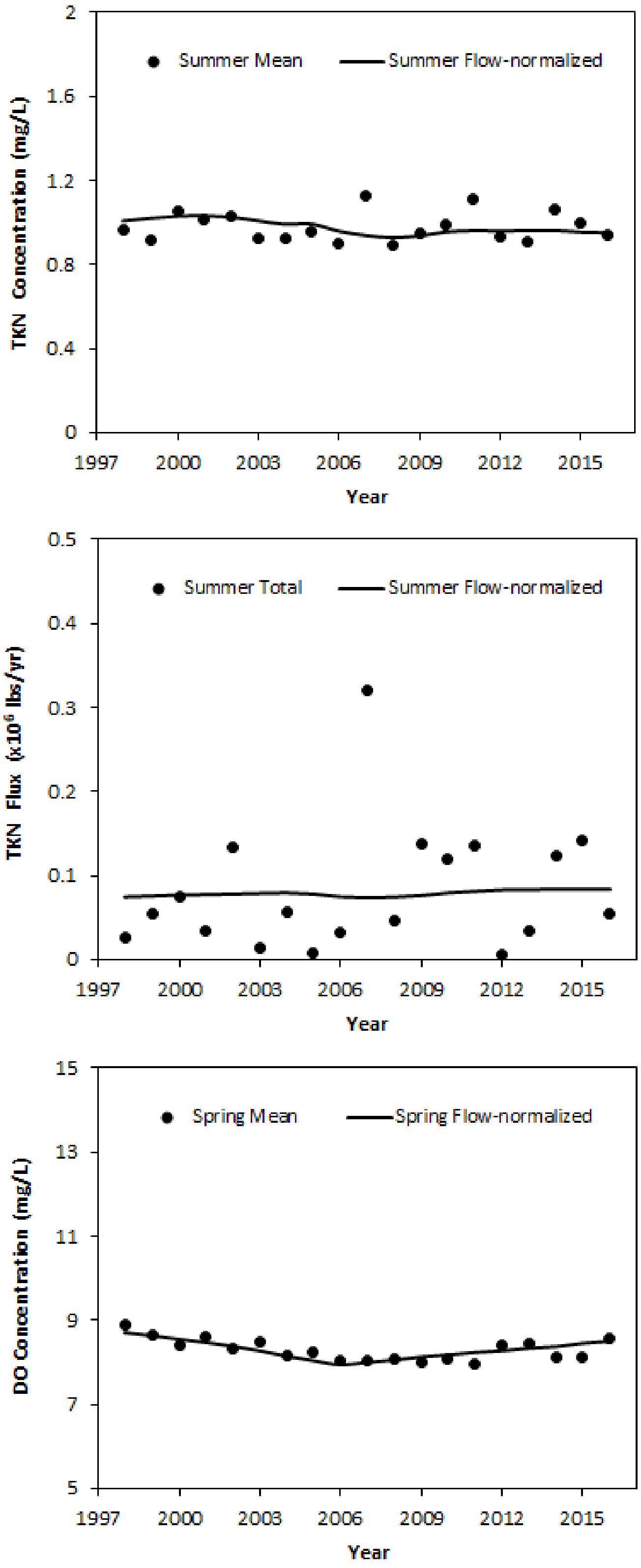

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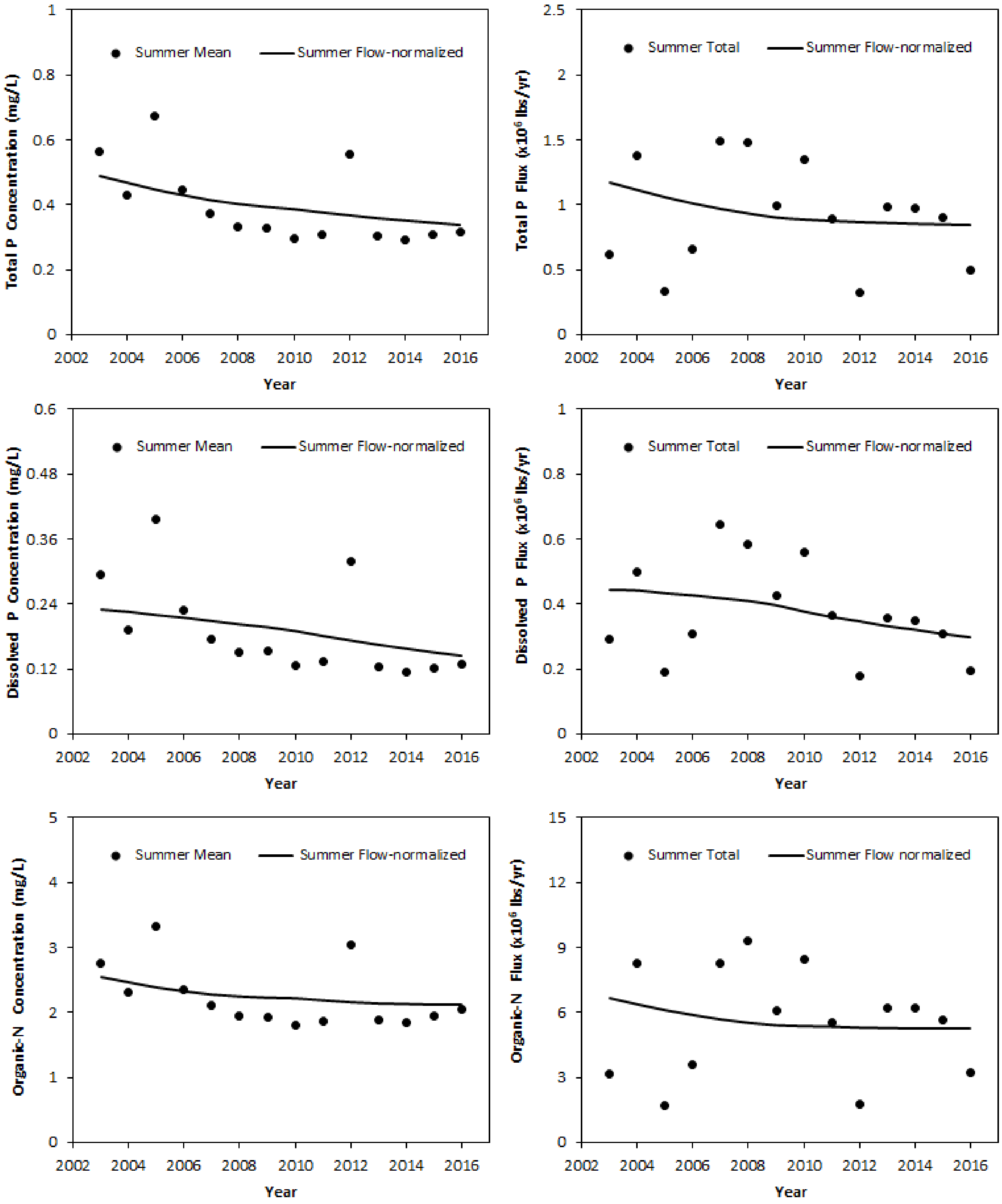

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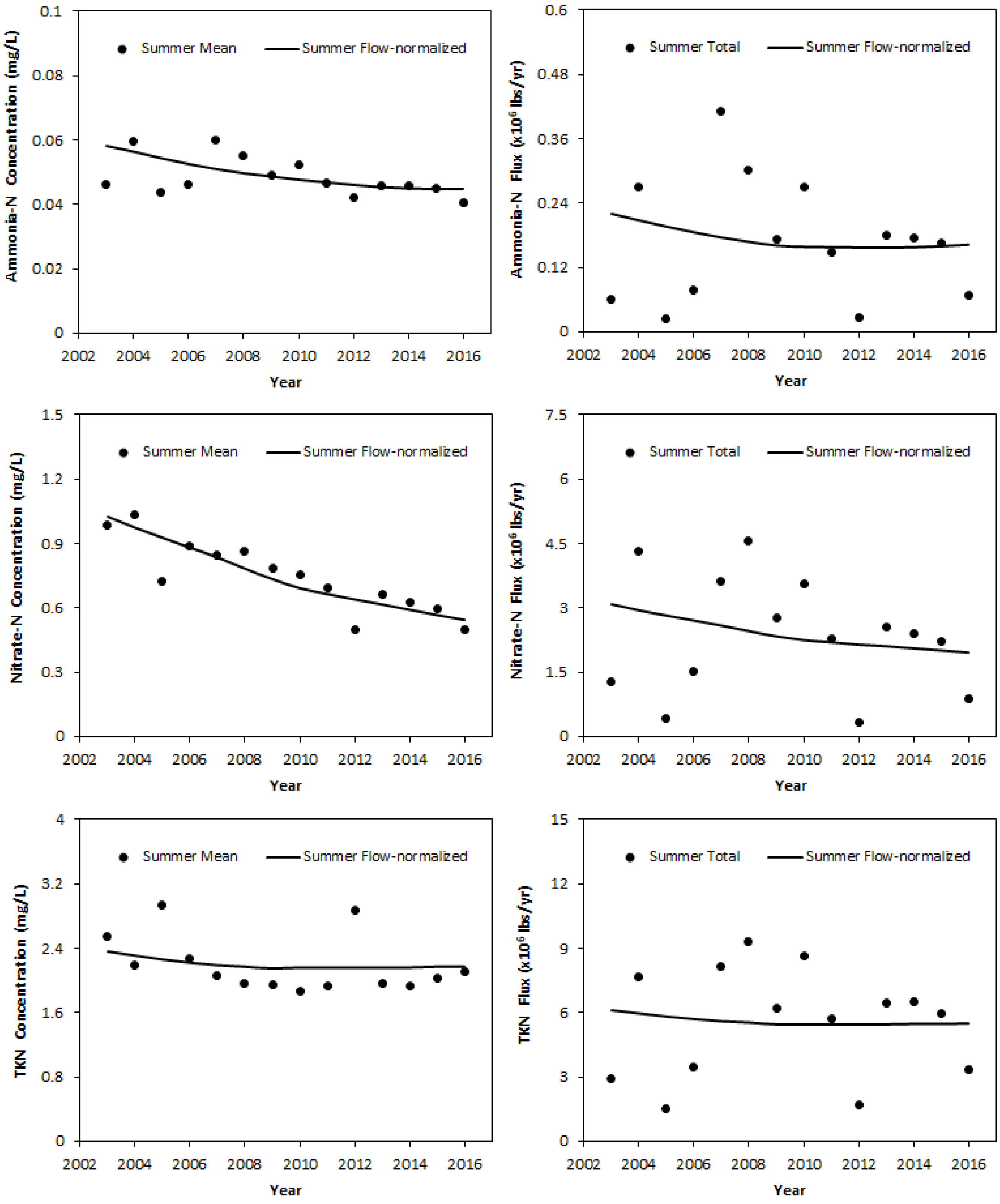

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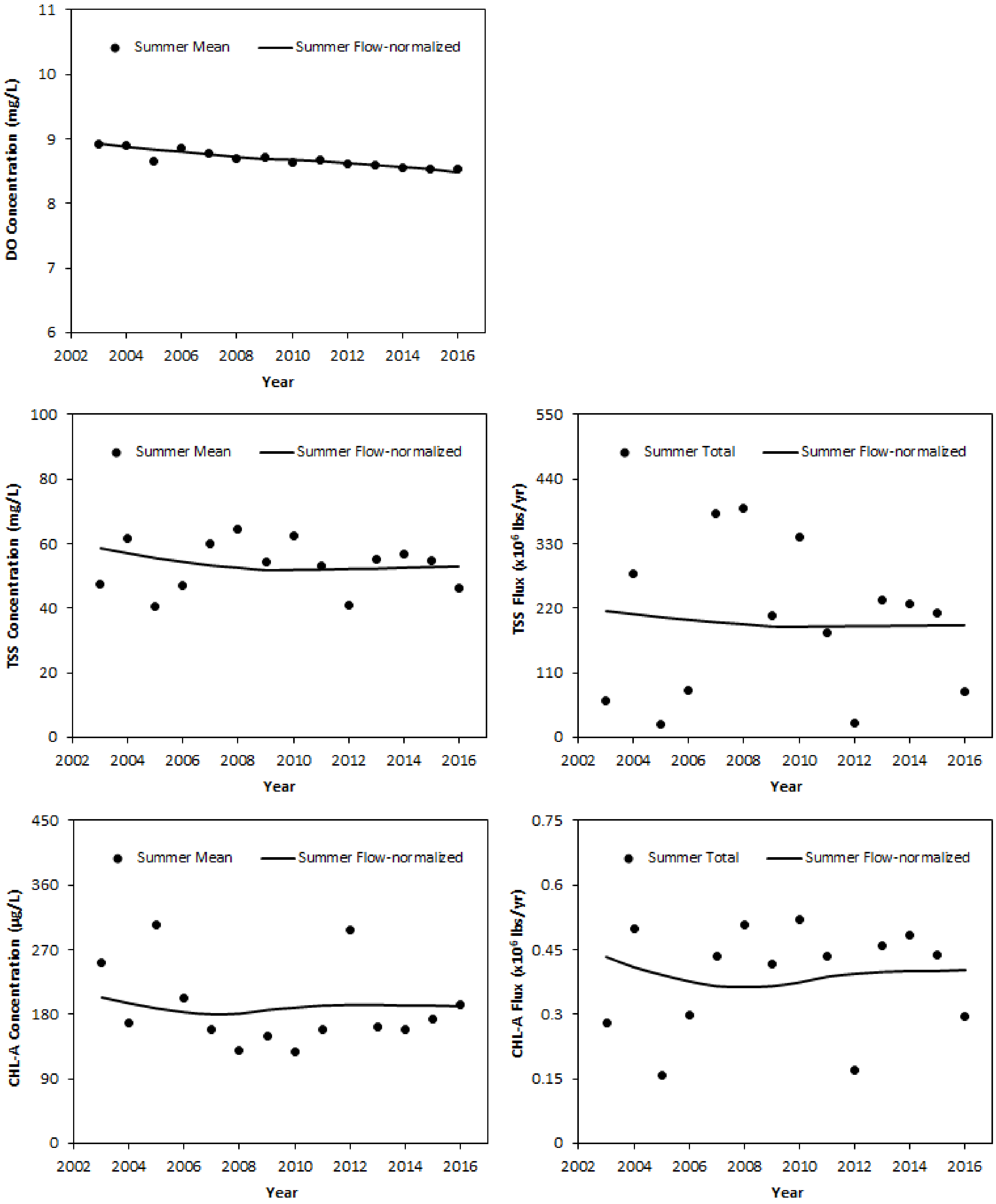

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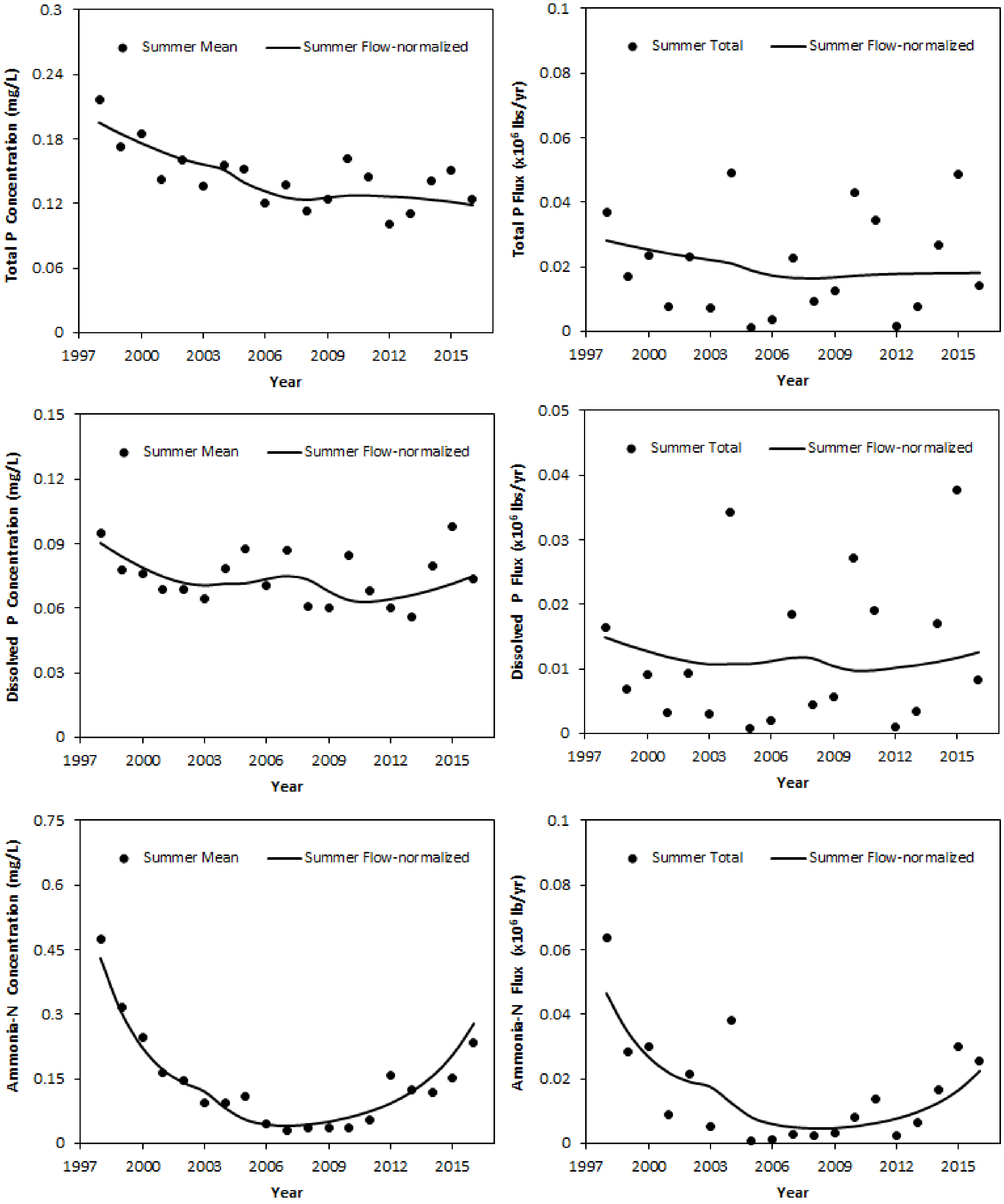

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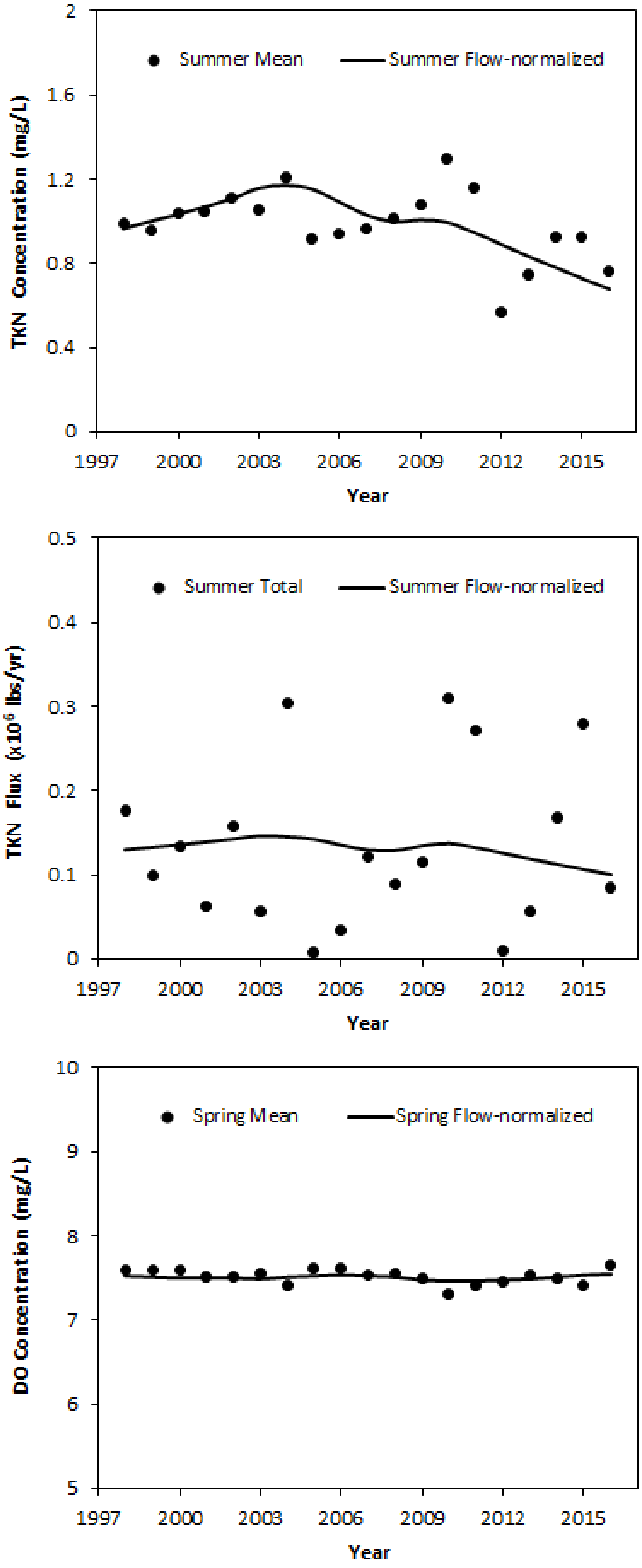

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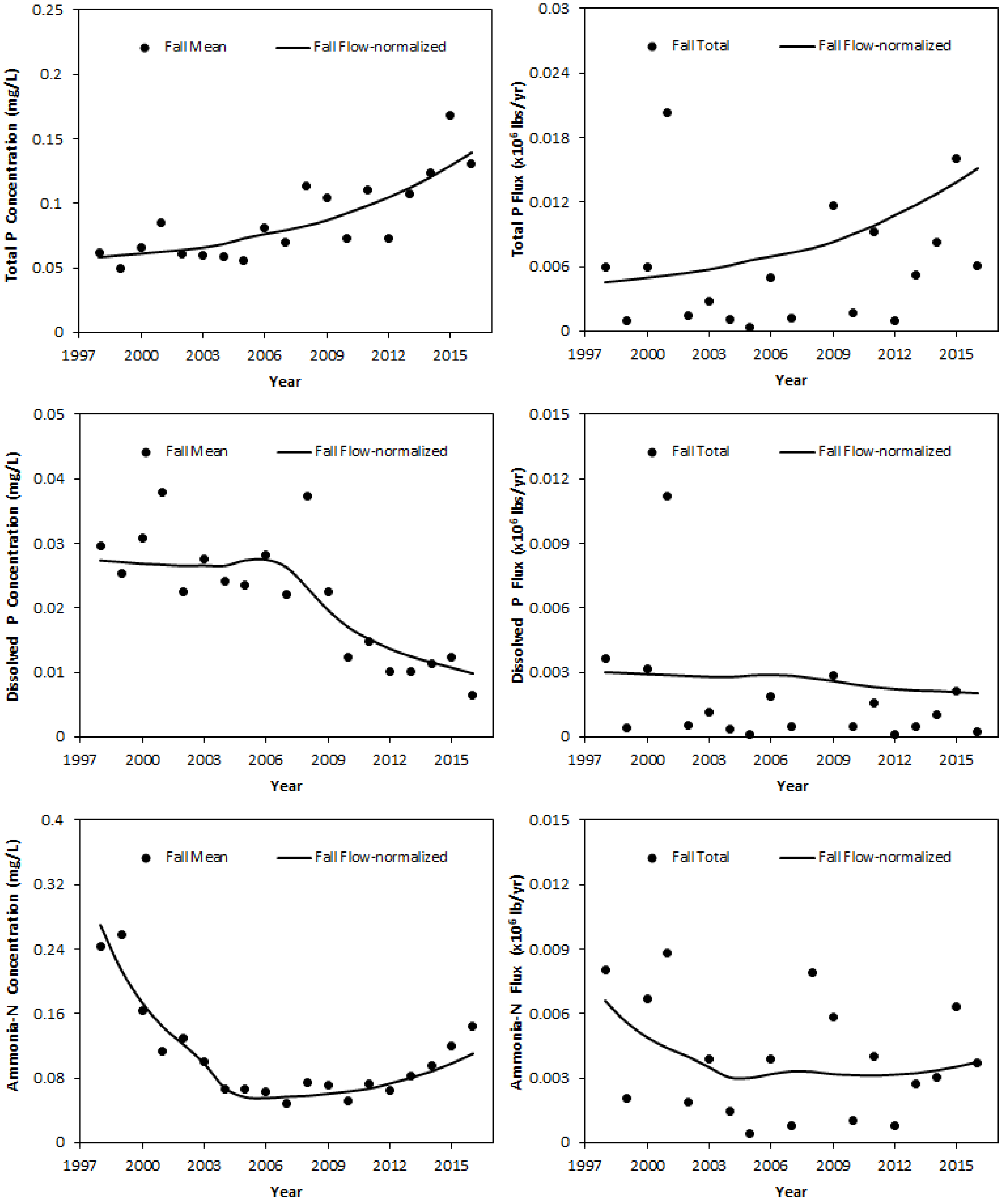

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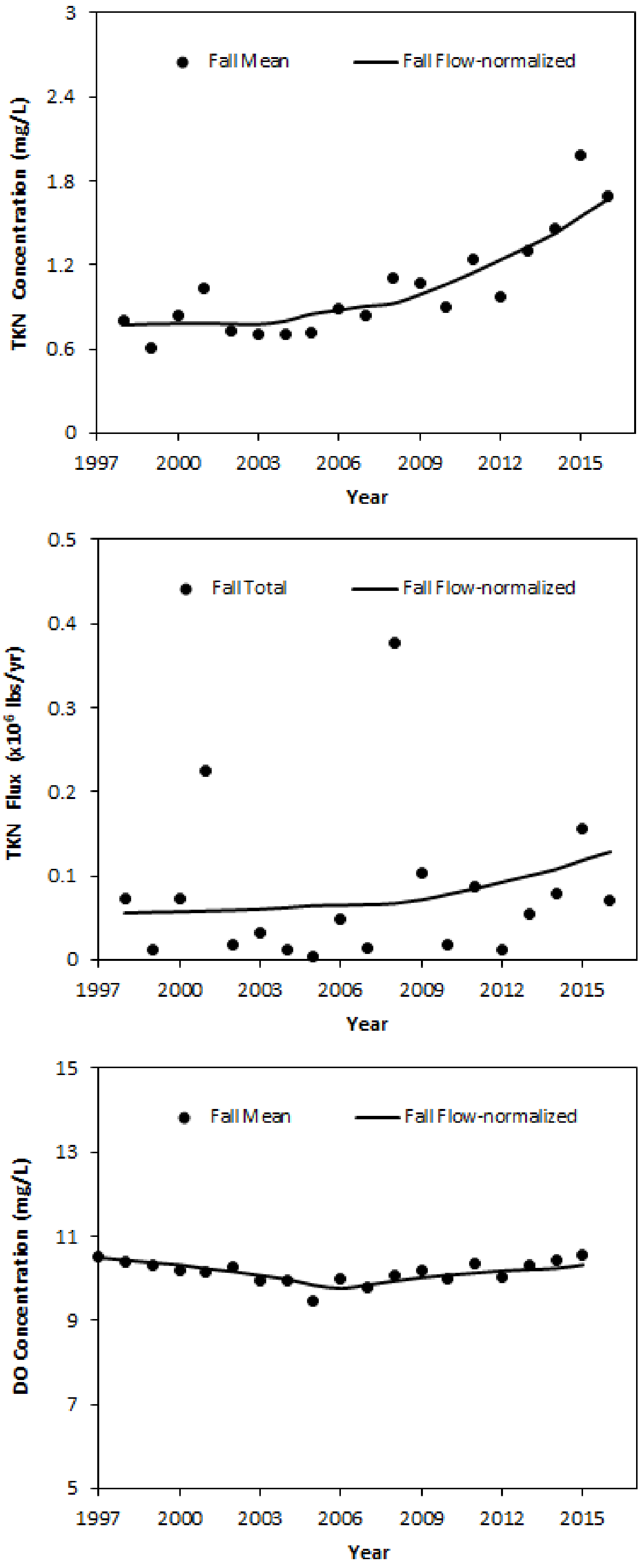

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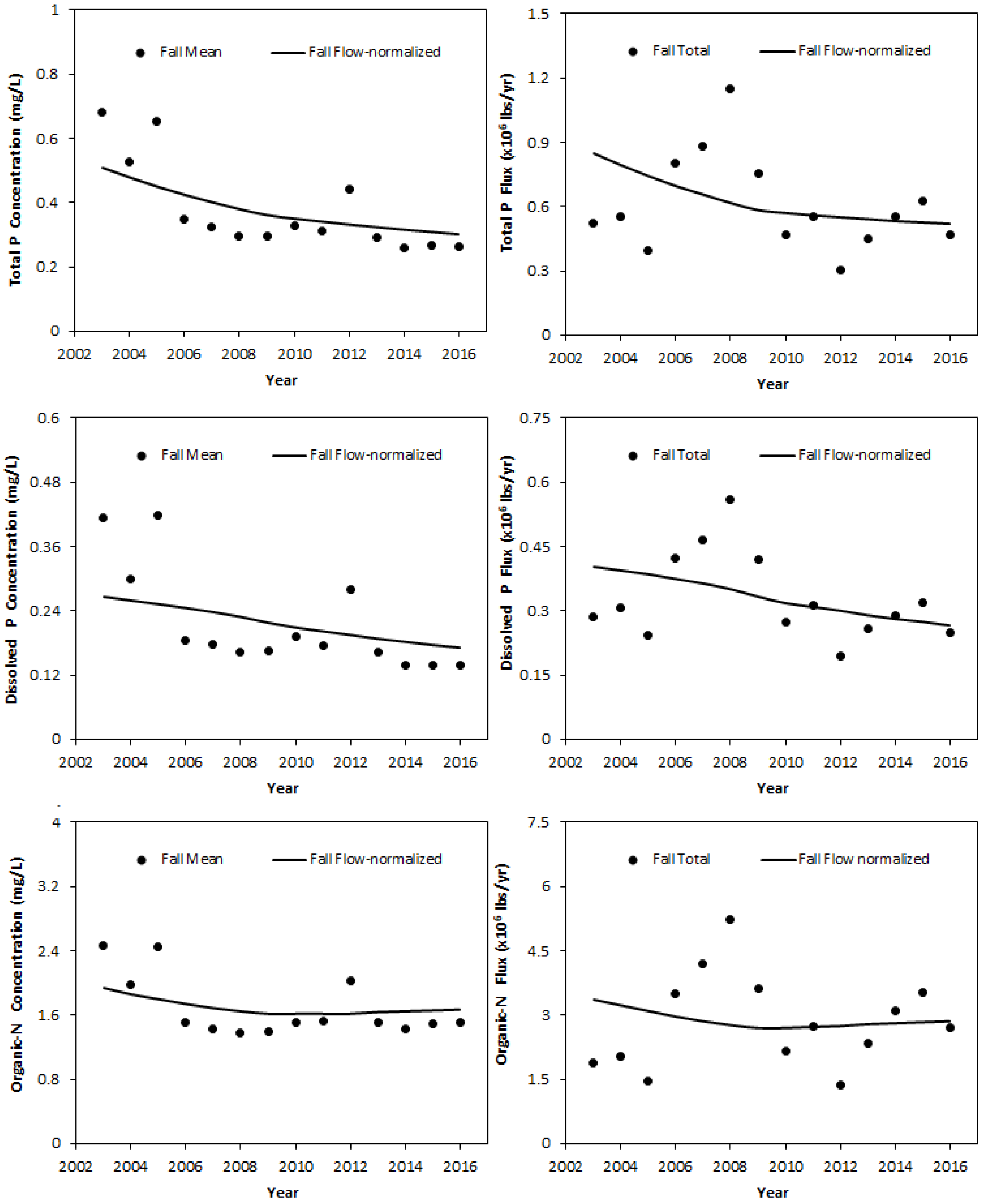

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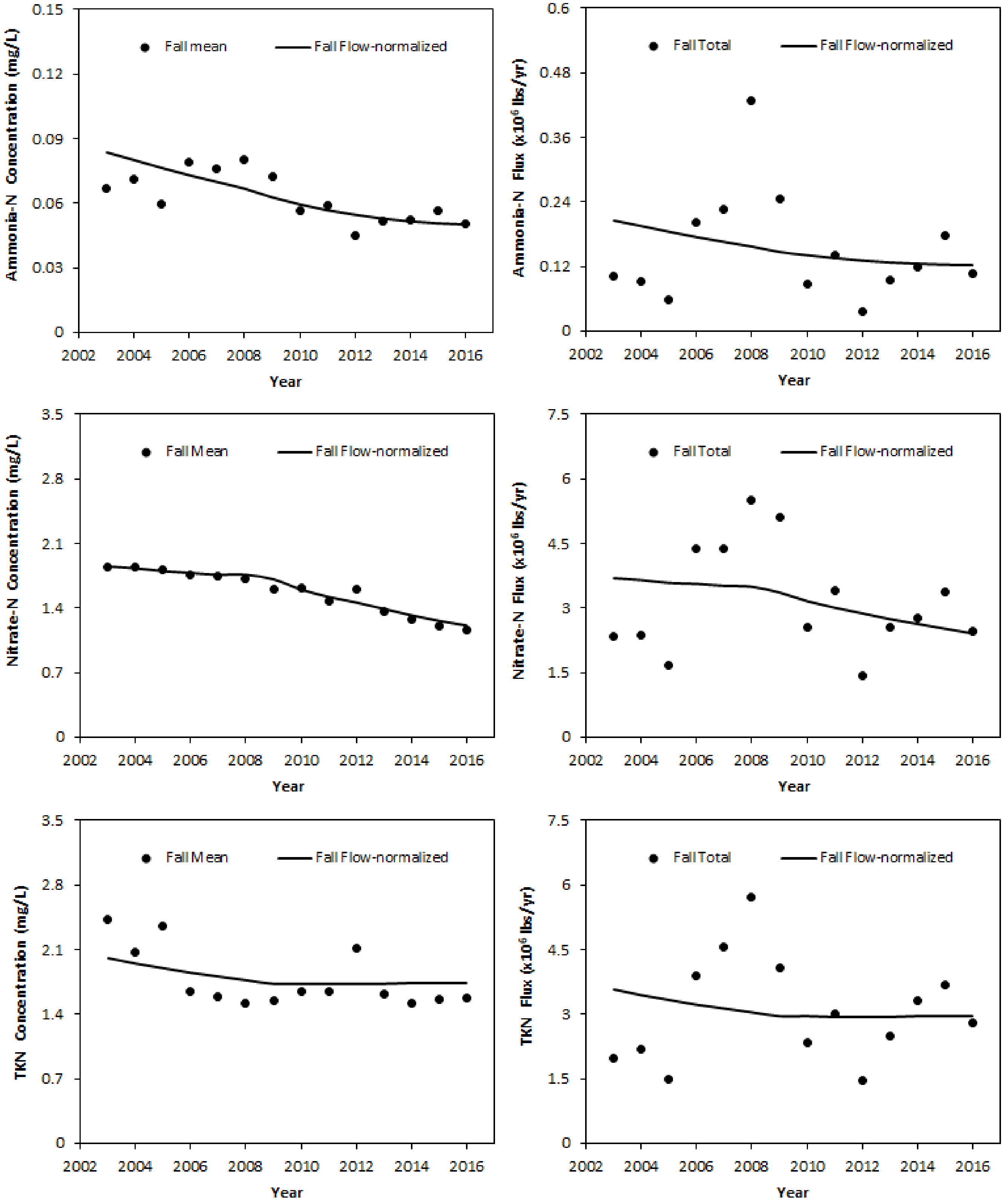

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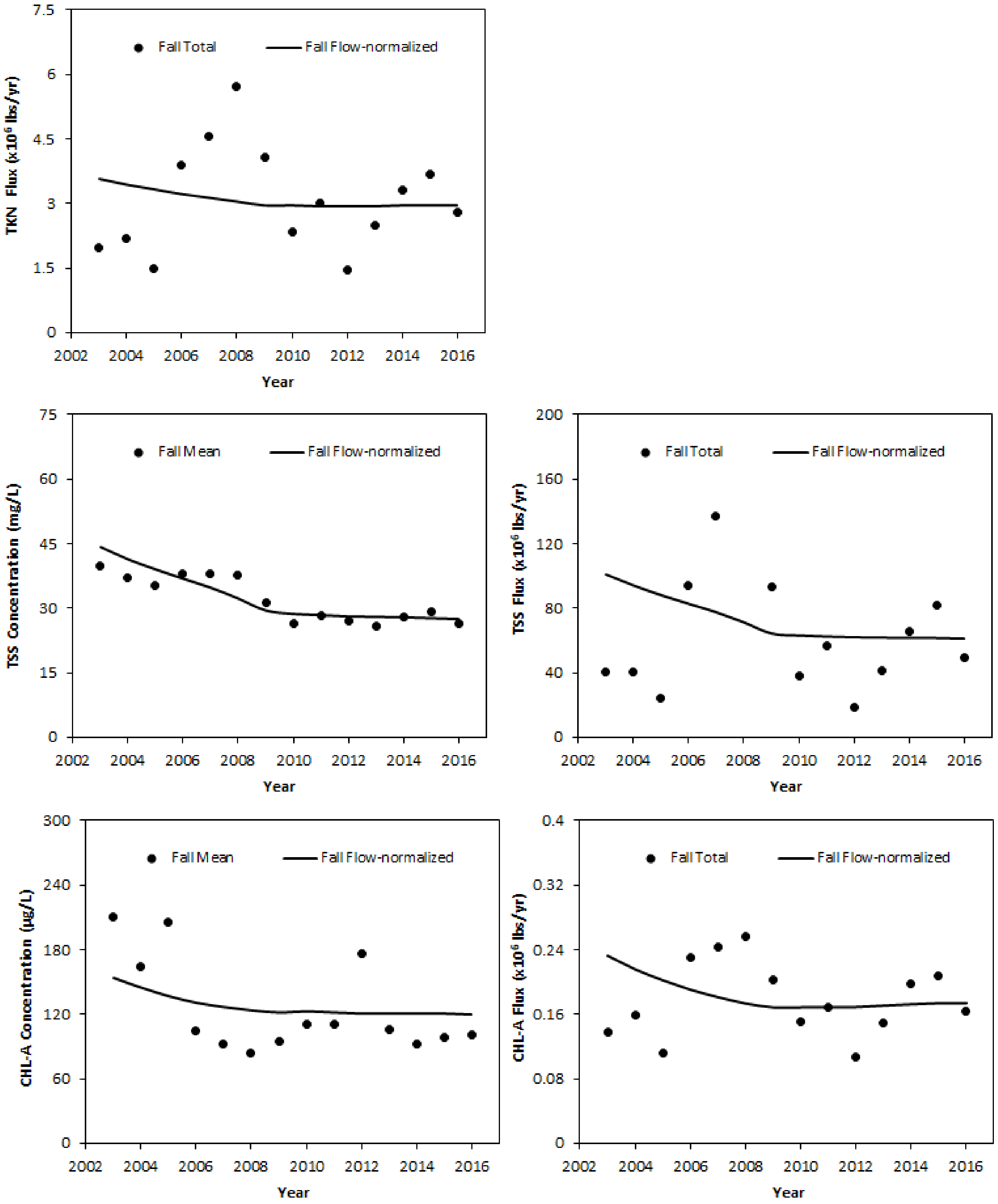

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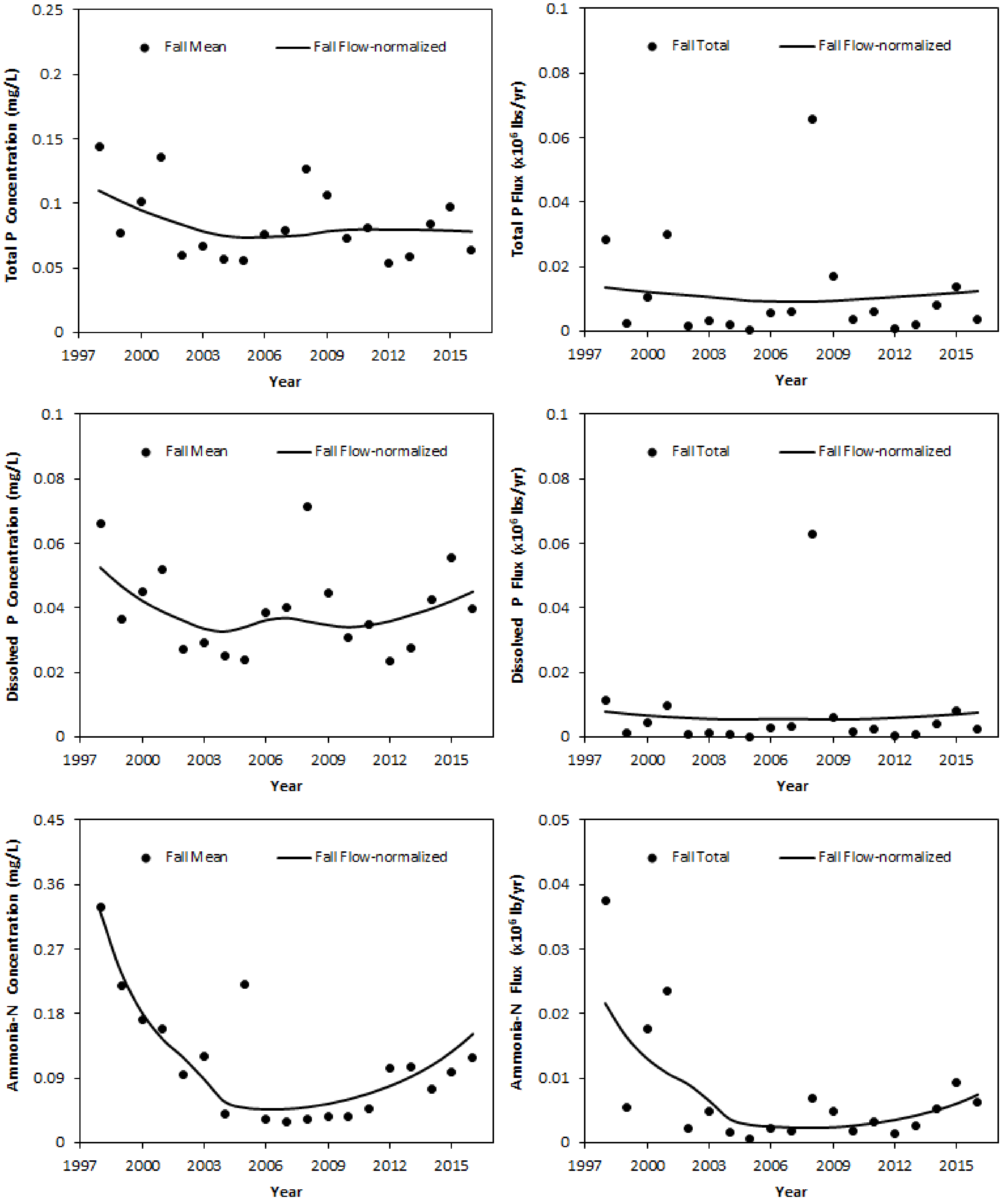

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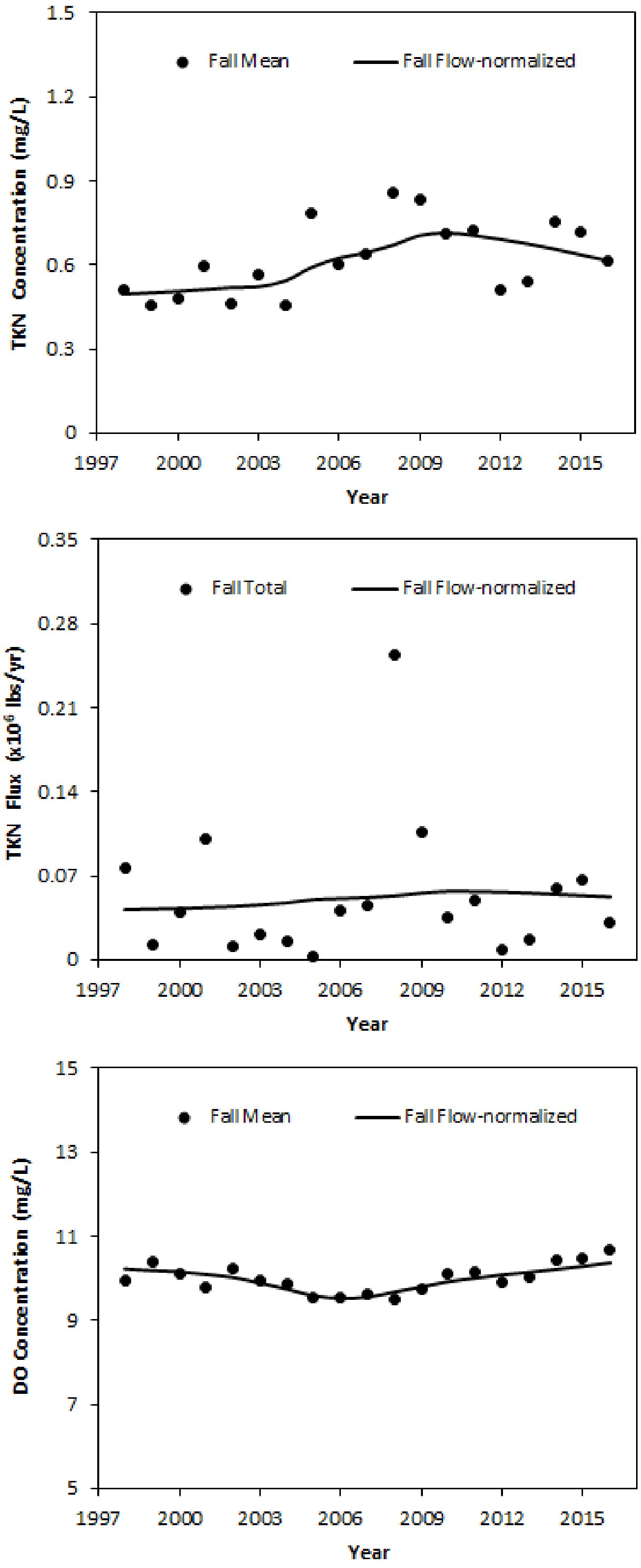

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APPENDIX D
FOX RIVER WATER QUALITY MODEL UPDATE

FOX RIVER
WATER QUALITY MODEL UPDATE

Fox River, IL

Submitted to

Fox River Study Group

Submitted by

Geosyntec
consultants

engineers | scientists | innovators

April 2020

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SECTION 1

INTRODUCTION

1.1 Introduction

The Fox River Study Group (FRSG) is a diverse coalition of stakeholders working together to assess water quality in the Fox River watershed. Participants include Friends of the Fox River, Sierra Club, Blackberry Creek Implementation Council, Chicago Metropolitan Agency for Planning, Environmental Defenders of McHenry County, Fox River Water Reclamation District (Elgin), ConAgra Foods, The Conservation Foundation, Dunham Fund, Illinois River Coordinating Council, Illinois State Water Survey, Fox Metro Water Reclamation District (Aurora), Northern Moraine Wastewater Reclamation District, Yorkville Bristol Sanitary District, Fox River Ecosystem Partnership, Illinois Environmental Protection Agency (IEPA) as well as representatives from Algonquin, Aurora, Lakemoor, Port Barrington, Batavia, Crystal Lake, Elgin, Geneva, Island Lake, Kane County, Plano, Wayne, St. Charles, and Yorkville. The FRSG is implementing a long-term, phased work plan to eliminate water quality impairments due to nuisance algae, low dissolved oxygen (DO), large diel DO swings, and high phosphorus concentrations. This work includes intensive water quality monitoring, development of several watershed and water quality models, and development of a Fox River Implementation Plan (FRIP) which is the roadmap to eliminate the water quality impairments (FRSG, 2015). As part of the FRIP, the FRSG evaluated several water quality improvement alternatives such as load reductions from point, nonpoint, and upstream sources and removal of several dams using a water quality model. Development of the FRIP was challenging as the water quality model provided counter-intuitive results. The FRIP included recommendations for updating the water quality model to address its limitations.

This technical report is focused on the update of the water quality model for the Fox River to address the model limitations identified in the FRIP.

1.2 Study Area

The Fox River originates in Waukesha County, Wisconsin and drains through Southeastern Wisconsin and Northeastern Illinois into the Illinois River at Ottawa, IL (**Figure 1**). It drains a watershed area of 938 square (sq.) miles and 1,720 sq. miles in Wisconsin and Illinois, respectively. The study area for the FRIP (FRIP Study Area) is focused on the 98-mile stretch of the Fox River between the Stratton Dam in Nunda Township, McHenry County, IL and the Illinois River. This section of river drains a watershed area of 1,405 sq. miles. Land use in the FRIP Study Area is predominantly rural (58.9%) and urban (29.6%), with the remaining area being surface water, wetlands and forests (11.5%). Although the FRIP watershed is only 3% of the total area in Illinois, the watershed is home to over 10% of the state's population; a number that is likely to increase in the coming years (FRSG, 2015).

The Fox River is a multi-purpose resource that contributes critical habitat for wildlife, serves as a valuable resource for recreation, receives and assimilates pollutants from point and non-point sources, and provides source water for public water supplies serving over 300,000 residents. Habitat modifications, especially the many low head dams present on the river play a significant role in the dynamics of the river. Because of the rapid pace of development in the Fox River watershed, maintaining these resources requires comprehensive planning.

1.3 Water Quality Impairments

IEPA periodically prepares a list of impaired water segments in the state of Illinois to fulfill the requirements of Section 303(d) of the Clean Water Act and the Water Quality Planning and Management regulation at 40 CFR Part 130. IEPA lists a waterbody as impaired for not meeting the designated use due to a variety of stressors. The FRIP is focused on impairment of the designated aquatic life use caused by low DO, nuisance algae and total phosphorus (TP). Table 1 list the impaired reaches of main stem Fox River and cause of its impairment as per the 2018 Integrated Report from Illinois Environmental Protection Agency (IEPA, 2018). **Figure 2** shows the impaired reaches of the mainstem Fox River. These segments were listed as impaired by IEPA since at least one water sample suggests there are water quality concerns.

Table 1: Fox River Mainstem Impaired Reaches and Causes (Illinois EPA, 2018)

Segment	Length	Downstream River Mile	Upstream River Miles	Cause of Impairment
IL_DT-22	7.86	89.84	97.70	Algae
IL_DT-06	8.06	81.78	89.84	Dissolved Oxygen
IL_DT-20	7.23	74.55	81.78	Dissolved Oxygen
IL_DT-18	5.9	68.65	74.55	Dissolved Oxygen
IL_DT-09	8.15	60.50	68.65	Total Phosphorus
IL_DT-58	3.76	56.74	60.50	Dissolved Oxygen
IL_DT-69	4.51	52.23	56.74	Total Phosphorus, Algae
IL_DT-38	10.83	41.40	52.23	Total Phosphorus, Algae
IL_DT-03	7.37	34.03	41.40	Total Phosphorus, Dissolved Oxygen
IL_DT-11	5	29.03	34.03	Total Phosphorus
IL_DT-41	11.01	18.02	29.03	Total Phosphorus, Algae
IL_DT-02	11	7.02	18.02	Other
IL_DT-36	2.63	4.39	7.02	Total Phosphorus, Algae
IL_DT-46	3.71	0.68	4.39	Other
IL_DT-01	3.23	-2.55	0.68	Total Phosphorus

1.4 Purpose of Water Quality Modeling

The FRIP requires determination of phosphorus input reductions by point source discharges and non-point source discharges in addition to other measures necessary to reduce or remove phosphorus-related impairments in the river. Models can serve to define the linkages between the phosphorus loading in the watershed and related impairments such as DO and nuisance algae in the river. Models can be also be used to evaluate the effectiveness of different watershed management scenarios in reducing or removing impairments, assisting decision makers in prioritizing projects for the implementation of the FRIP recommendations.

The Fox River Watershed

Watershed Facts:

Area: 2658 Square Miles
Headwaters: Colgate, WI
Confluence: Ottawa, IL
River Length: 223 miles
Population: 1 Million +
Mainstem Dams: 16
Mainstem WWTP Dischargers: 32

Prepared By:
R. Linke for the Fox River Study Group, Inc.
January 2013
Data Sources: IL Geospatial Data Clearinghouse; IEPA, USGS, Wisconsin DNR, ESRI

Figure 1: Fox River Watershed (Map Courtesy of FRSG)

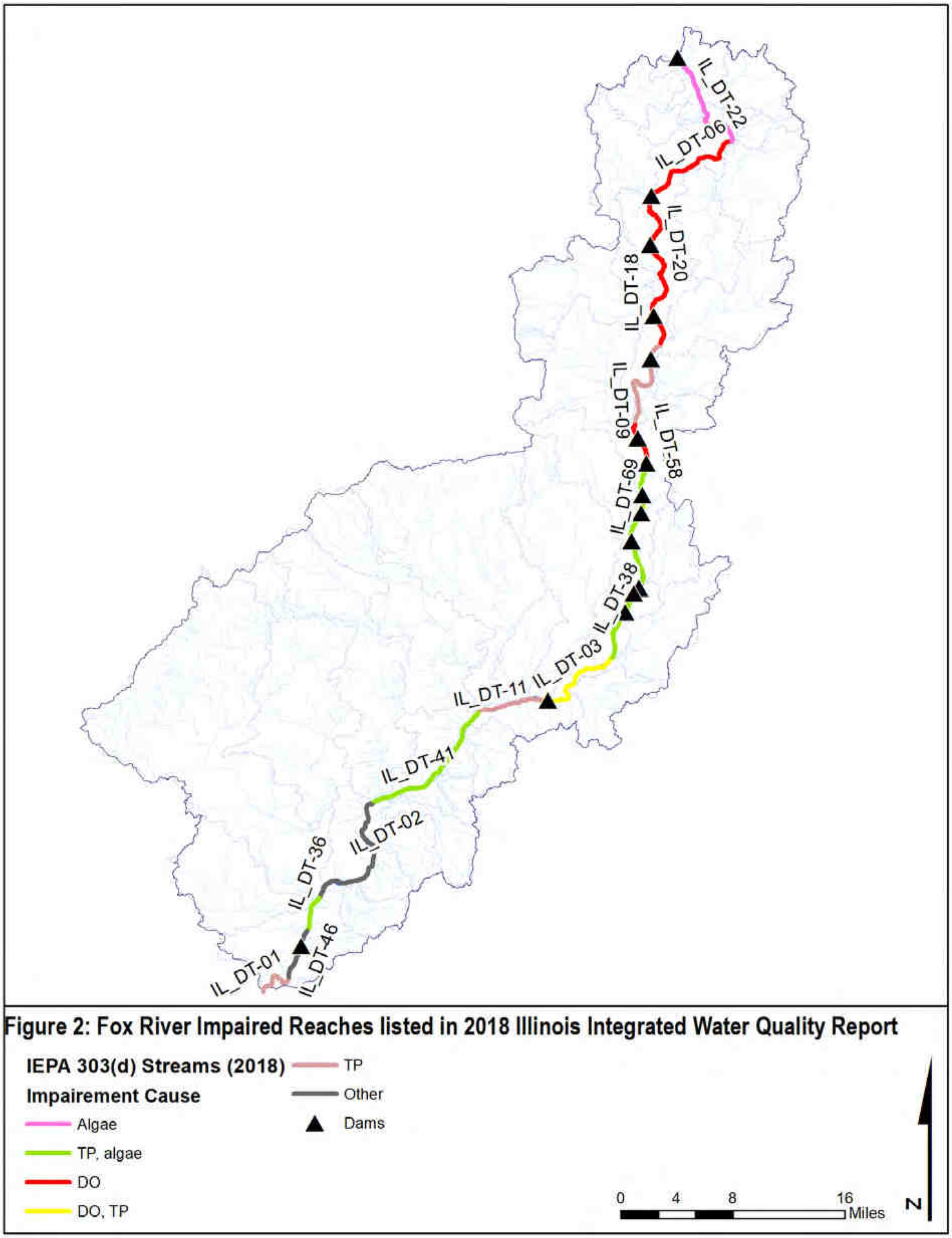


Figure 2: Fox River Impaired Reaches based on Illinois Integrated Water Quality Report (Illinois EPA, 2008)

1.5 Model Development Process Overview

The process for developing the water quality model is shown in Figure 3 and involves the following basic steps.

1.5.1 Data Analysis and Review

The first step in the modeling process is data analysis and review where the available field data are reviewed for their relevancy to developing the numerical model This step is important in determining the spatial and temporal constraints on a model, what data are available as model inputs, what data are available to calibrate and validate the model, and what types of model results (flows, concentrations etc.) are needed from the model to meet the FRIP needs.

1.5.2 Model Development

The model development step includes the segmentation of river reach of concern, and the identification of input parameters and input time series data. The model reach segmentation consists of dividing the reach into segments based on bathymetric data, cross sections, or other geometric data. The model input parameters are often coefficients for the various process equations such as decay rate of biochemical oxygen demand (BOD) in the river. They are typically chosen based on site-specific attributes or from a range of values in the literature. Model input time series also include time series of other information required by the model such as meteorological data and output from the other linked models.

1.5.3 Model Calibration

Model calibration is the process of adjusting the model parameters to match the simulated results with the measured data. The model input parameter adjustments are often based on literature, site specific data or knowledge or best professional judgment. Model calibration is an important component for fine-tuning the model to provide more accurate results and to increase confidence that the model is correctly simulating reality.

1.5.4 Model Validation

During model validation, the model is tested for accuracy by comparing model results to a dataset independent of the one used for model calibration. This allows the model performance to be evaluated without making any adjustments to the model inputs. This step is intended to increase the confidence that the model calibration successfully included the relevant processes and the model is correctly simulating reality outside of the time period used for calibration. The model calibration and validation steps are sometimes combined to increase the amount of data available for parameterizing the model.

1.5.5 Sensitivity Analysis

In a sensitivity analysis, the model input parameters are adjusted by a fixed amount. This process establishes the degree of model sensitivity to changes in the various model input parameters. This allows the modeler to focus on the most sensitive parameters to improve the calibration, if necessary.

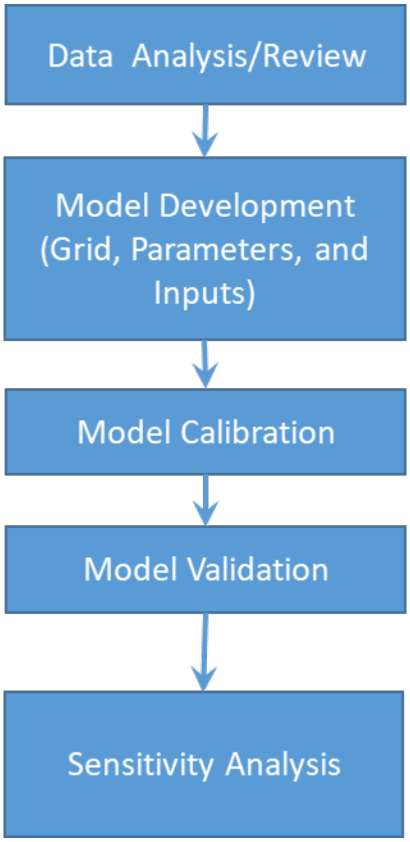


Figure 3: Model Development Process

SECTION 2

MODELING TOOLS TO SUPPORT FRIP

Given the complexities of the Fox River watershed and the limitations of the available data, several linked numerical models (including a watershed model and an instream model consisting of hydraulic and water quality components) were used to model the impact of nutrients on instream water quality. The FRSG has developed a linked modeling framework to help address the impairments in the Fox River (Figure 4). An overview of modeling framework components is provided below.

2.1 Watershed Model

A watershed model estimates the flows and loads of nutrients and sediments that are generated as result of precipitation and wash-off from land surfaces that end up in streams. Watershed models include meteorology, land cover, vegetation, topography, soil, and geology. The processes simulated in the watershed model include evapotranspiration, overland runoff, and infiltration. Some watershed models can also simulate the instream nutrient dynamics to a limited extent. A watershed model provides a tool for testing and prioritizing management scenarios for upland nutrient load reductions.

2.2 Instream Model

An instream model simulates the impact of flow and pollutant loadings on the instream hydraulics and water quality. An instream model for applications similar to the current study typically has two components: (1) a hydraulic component, and (2) a water quality component. The hydraulic component calculates the flows, velocities, and water levels in a stream based on the flow inputs. Flow inputs can either be specified (upstream boundary, point source discharges to the mainstem river) or generated by the watershed model (tributary runoff, directly connected non-point source flows). Hydraulic outputs, along with specified loads or loads calculated from the watershed model, are used as inputs in the instream model for water quality simulation. The water quality component of the instream model simulates the fate and transport of nutrients as well as the impact on DO and algae. For the purposes of the FRIP, an instream model can be used to evaluate management alternatives to meet the instream water quality targets.

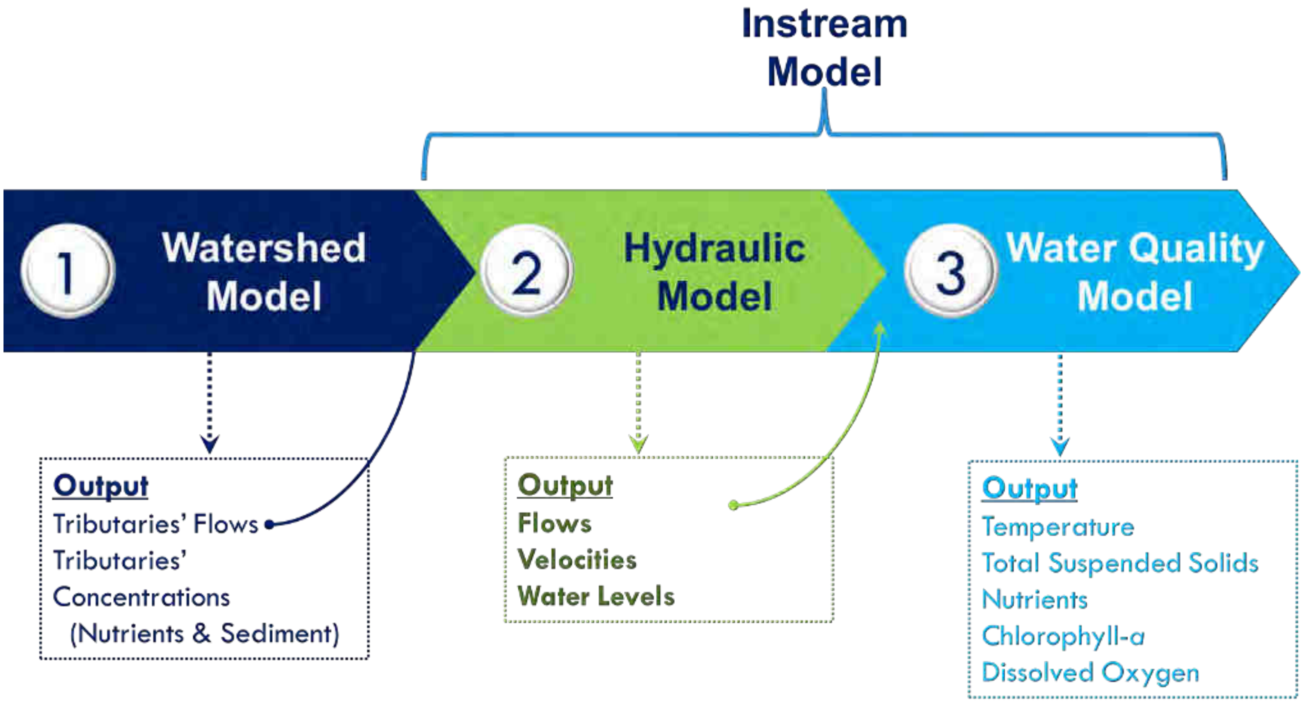


Figure 4: Model Framework

SECTION 3

WATERSHED MODEL FOR THE FOX RIVER

3.1 Previous Watershed Modeling

The Illinois State Water Survey (ISWS) developed the watershed model for the FRIP Study Area using the Hydrological Simulation Program Fortran (HSPF, Bicknell et al., 2001) platform. The ISWS documented the development of the HSPF model for the Fox River in a series of reports (Bartosova 2007a, 2007b, 2007c, 2011, 2013a, 2013b; Singh et al., 2007). HSPF is a widely used, continuous-simulation, lumped-parameter model capable of simulating surface and simple subsurface hydrology, snow accumulation and melt, and stream routing. It is approved and maintained by the US EPA and is especially well suited for mixed land use watersheds like the Fox River watershed.

The HSPF model for the FRIP Study Area consists of 33 subwatershed models which includes the thirty-one (31) major tributary subwatersheds (such as Blackberry Creek, Indian Creek, Buck Creek) as well two mainstem subwatersheds (Upper and Lower Fox River) directly draining to the Fox River (**Figure 5**). More than half of the total annual average TP loading into the Fox River is simulated in the HSPF model (FRSG, 2015), including agricultural areas, municipal separate storm sewer systems (MS4s) and tributary wastewater treatment plants (WWTPs). The HSPF model developed by ISWS was setup for the time period of January 1990 to September 2011 and is not reflective of the current loadings from different sources in the watershed. Hence as part of the current work, the HSPF model was updated for the time period of January 2011 to December 2016 to represent the current loadings into the mainstem Fox River.

3.2 Data for Modeling Update

The data utilized for updating the watershed model include the flow and water quality for point sources discharging into the Fox River tributaries as well as the meteorological data.

3.2.1 Point Source Data

HSPF requires time varying inputs of flow and water quality concentration data for the point sources such as WWTPs. The water quality constituents include DO, carbonaceous biochemical oxygen demand (CBOD), ammonia (NH3), nitrate-nitrite (NO2-NO3), organic nitrogen (ON), organic phosphorus (OP), inorganic phosphorus (IP) and Total Suspended Solids (TSS). The frequency of available data ranged from daily or monthly for flow to bi-weekly or monthly for water quality constituents. The available data were used to develop a daily time series of flow and water quality constituents for model input. For some point sources, concentration data were not available for some of the water quality constituents such as NH3, NO2-NO3, ON, OP, and IP. As a result, the water quality concentrations were estimated for these missing water quality constituents based on correlation relationships with CBOD. These relationships were developed by ISWS for the previous HSPF watershed modeling (Bartosova, A., 2013a). **Table 2** shows the point sources included in the HSPF model along with the data availability.

3.2.2 Meteorological Data

The HSPF model requires meteorological inputs of precipitation, dew point temperature, air temperature, cloud cover, and relative humidity for hydrology calculations. Meteorological stations in or near the Fox River watershed were identified from National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC). Thiessen polygons were developed using the station locations (**Figure 6**). Each subwatershed was assigned the meteorological station that fell within its corresponding Thiessen polygon. For subwatersheds which intersected with more than one polygon, the polygon (station) with the largest area was selected.

3.3 Modeling Updates

The HSPF model was updated for the FRIP Study Area to simulate the flow and loading of phosphorus and nitrogen for the time period of 2011 to 2016 using the data described above. The HSPF model was used to generate the timeseries of the nitrogen and phosphorus loading from the FRIP Study Area for use as input into the instream model. The previous FRIP instream model had utilized the annual average loading generated from the HSPF model for the period of 1990 to 2011. Using the loadings timeseries in the instream model for the longer time period of 2011 to 2016 greatly improves the ability of the instream model to simulate the impact of non-point source reductions in the FRIP Study Area.

3.4 Results

Figure 7 shows the simulated flow and TP from the Poplar Creek tributary for the period of 2011 to 2016. Flow input from the Poplar Creek watershed into the mainstem Fox River ranged from 0.6 to 1,393 cubic feet per second (cfs), while the TP concentration ranged from 0.03 to 0.46 milligrams per liter (mg/L). Simulated annual loads for TN and TP for the Poplar Creek watershed from 2011 to 2016 are shown in **Figure 8**. The annual average loads are 3.4 and 81.4 tons. for TP and TN respectively. The loads for TN are an order of magnitude higher as compared to TP loads, which results in TP being the limiting nutrient for Fox River main stem.

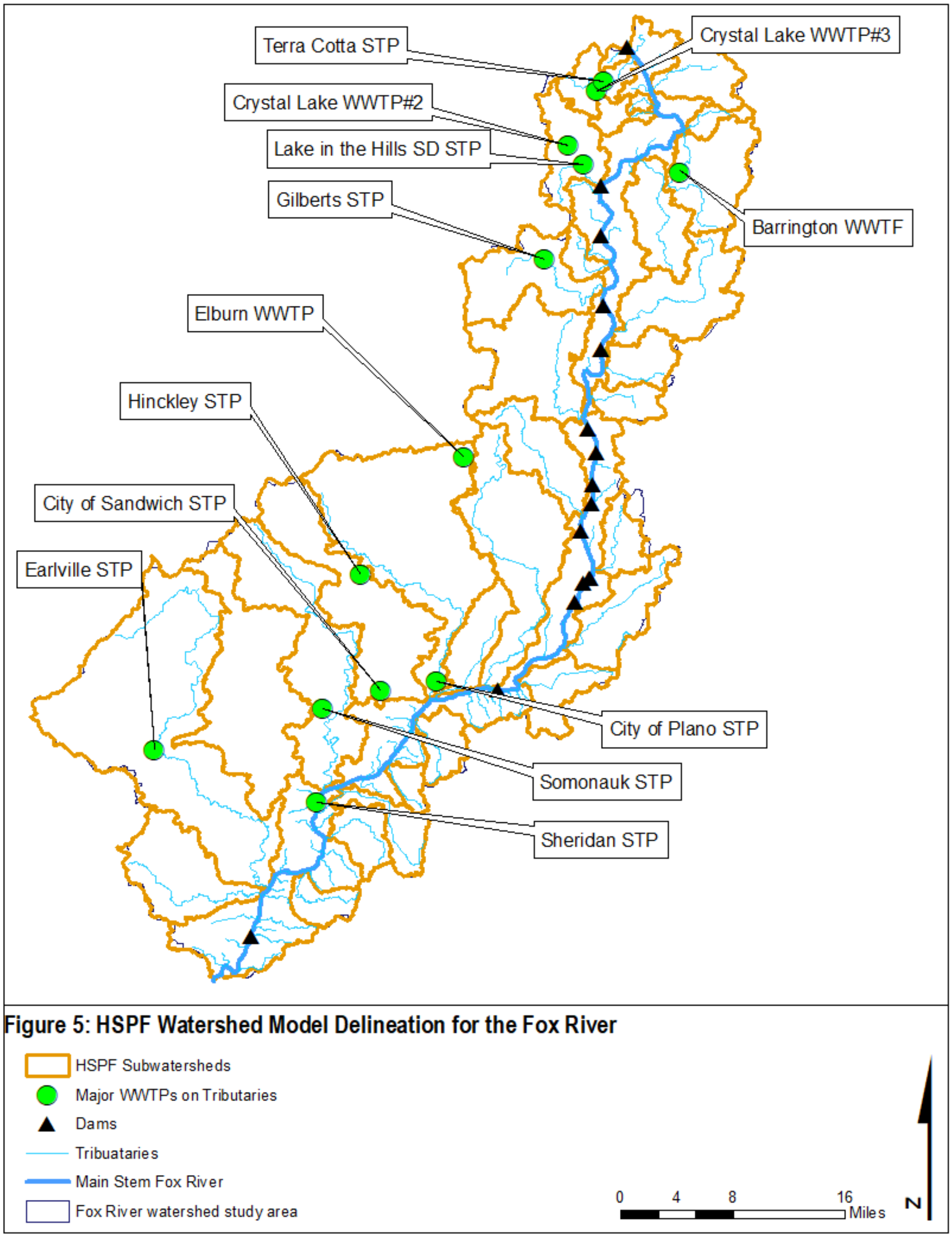


Figure 5: HSPF Watershed Model Delineation for the Fox River developed by the Illinois State Water Survey (ISWS)

Table 2: HSPF Point Sources and Available Datasets, along with Correlation Relationships, where Needed.

Wastewater Treatment Plant (WWTP)	**Flow (cfs)**	**Temp (^{O}C)**	**DO (mg/L)**	**CBOD (mg/L)**	**NH3 (mg/L)**	**NO3-NO3 (mg/L)**	**ON (mg/L)**	**OP (mg/L)**	**IP (mg/L)**	**TSS (mg/L)**
Terra Cotta STP	M	M	M	M	M	3*CBOD	1*CBOD	0.51* CBOD	0.0.26*CBOD	M
Crystal Lake WWTP#3	DAF	Const	W	W	W	3*CBOD	1*CBOD	W	W	W
Crystal Lake WWTP#2	D	Const	W	W	W	3*CBOD	1*CBOD	W	W	W
Lake in the Hills SD STP	D	Const	W	W	W	3*CBOD	W	W	W	W
Barrington WWTF	D	Const	W	W	W	3*CBOD	1*CBOD	0.51*CBOD	0.0.26*CBOD	W
Pingree Grove STP	M	Const	M	M	M	3*CBOD	1*CBOD	M	M	M
Gilberts STP	D	Const	W	W	W	3*CBOD	1*CBOD	W	W	W
Elburn WWTP	M	Const	M	M	M	3*CBOD	M	M	M.0.26*CBOD	M
City of Plano STP	D	Const	W	W	W	3*CBOD	1*CBOD	W	W	W
Hinckley STP	M	Const	M	M	M	3*CBOD	1*CBOD	W	W	M
City of Sandwich STP	D	Const	W	W	W	3*CBOD	1*CBOD	W	W	W
Somonauk STP	M	Const	M	M	M	3*CBOD	1*CBOD	0.51* CBOD	0.0.26*CBOD	M
Earlville STP	M	Const	M	M	M	3*CBOD	1*CBOD	0.51* CBOD	0.0.26*CBOD	M
St. Charles Westside WWTP	D	Const	W	W	W	3*CBOD	W	W	W	W

D – Daily Sample, DAF – Design Average Flow
Const- Assumed Constant Value
W- One or multiple samples in a week
M- Monthly
C- Calculated based on CBOD concentration

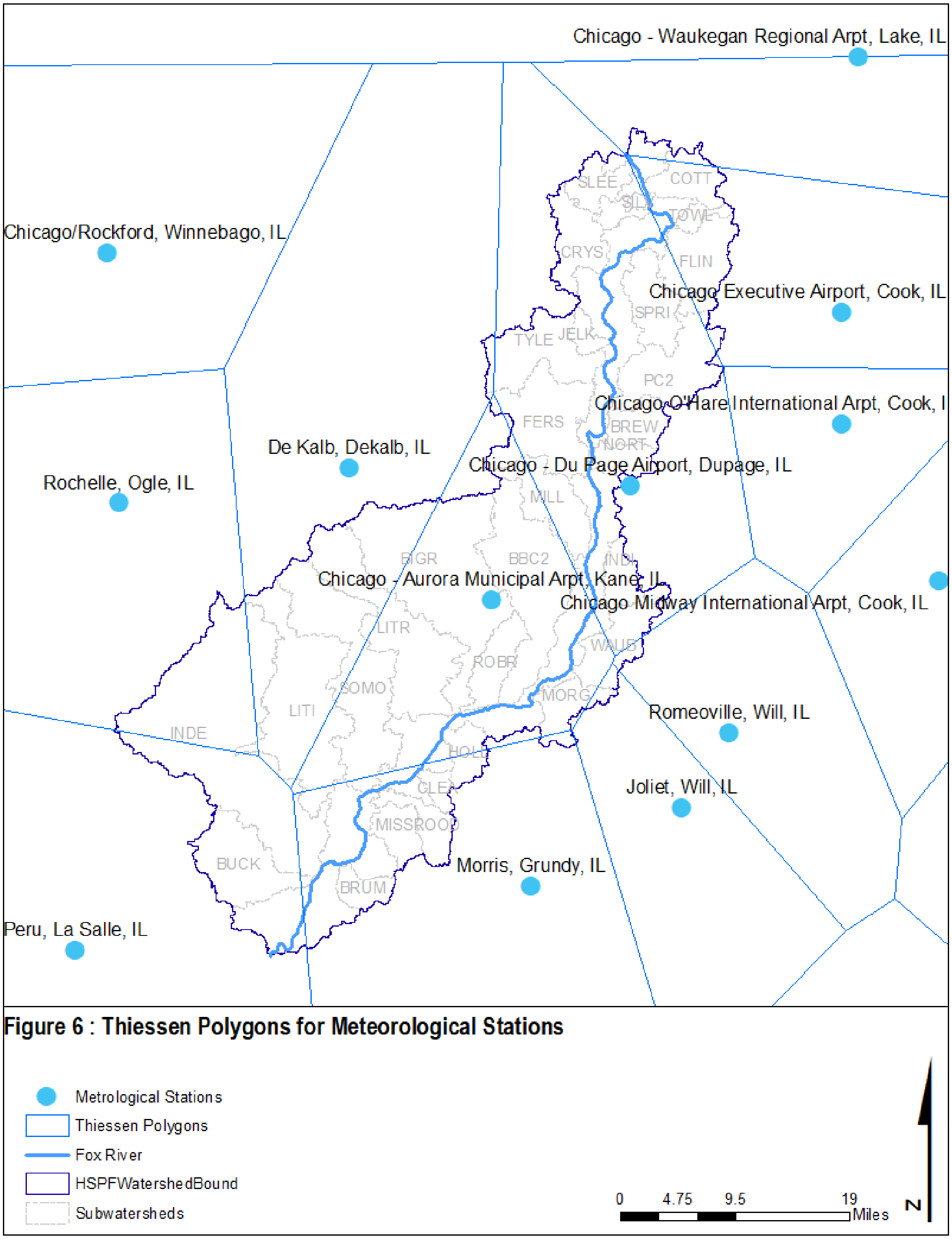


Figure 6: Thiessen Polygons for Meteorological Stations

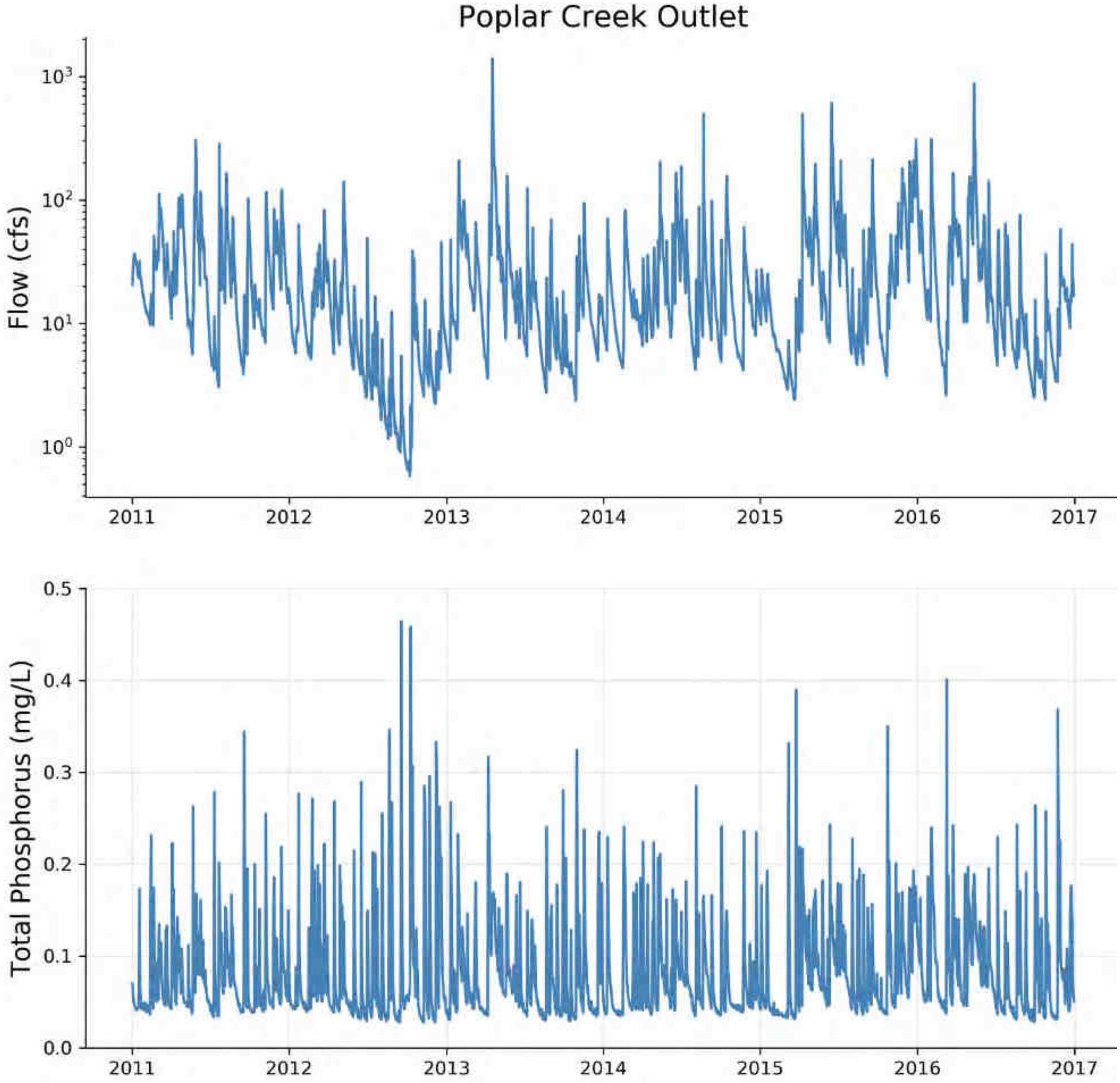


Figure 7: Simulated Timeseries of Flow and Total Phosphorus Concentration from the Poplar Creek Watershed at the Outlet into the Mainstem Fox River

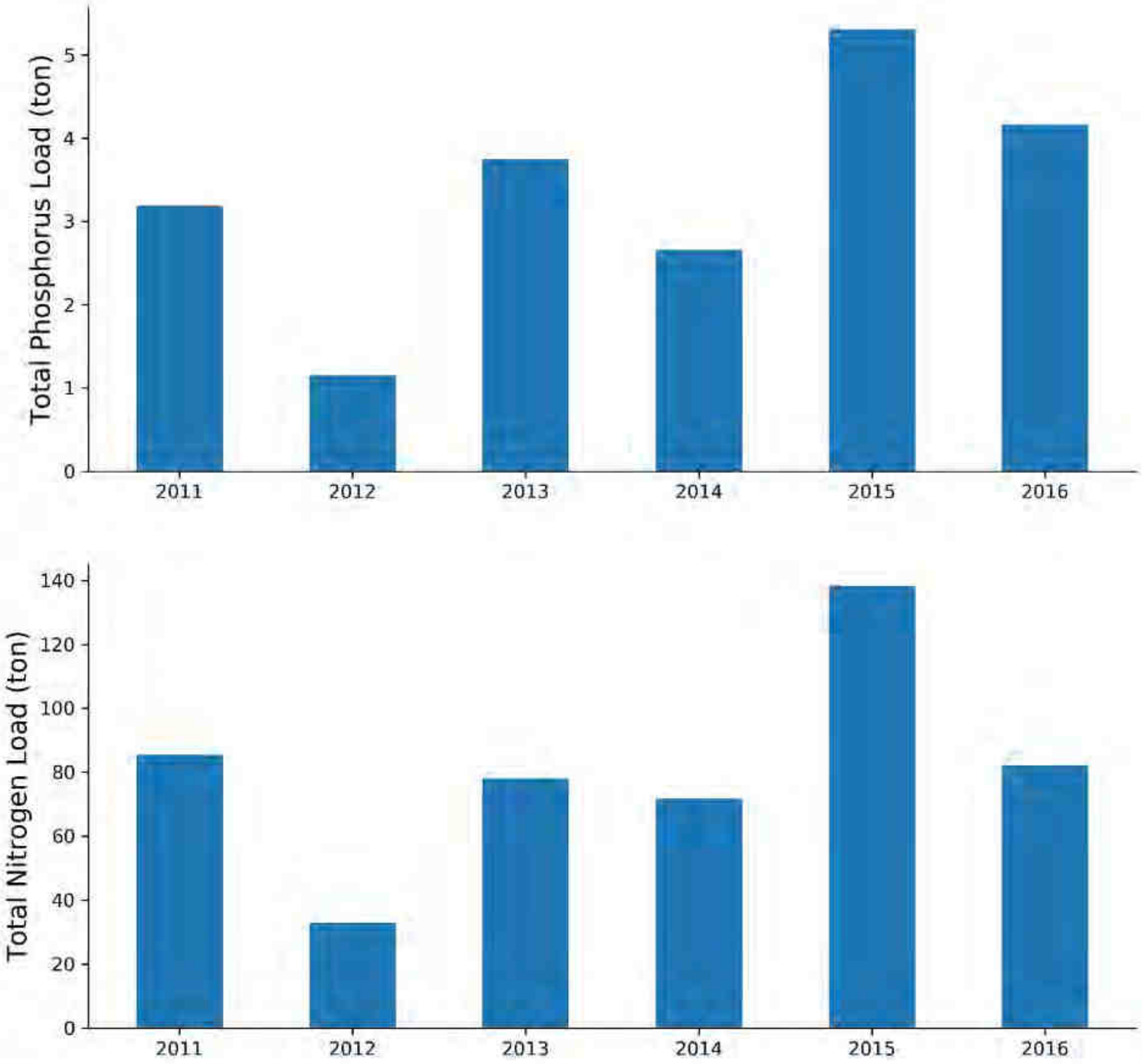


Figure 8: Simulated Annual Loads for Total Phosphorus and Total Nitrogen from the Poplar Creek Watershed at the Outlet into the Mainstem Fox River from 2011 to 2016

SECTION 4

INSTREAM MODEL FOR THE FOX RIVER

4.1 Previous Instream Modeling

The original instream model for the Fox River mainstem was developed by ISWS to simulate hydraulics and water quality. The instream model was developed using the QUAL2k model framework (Chapra et. al, 2008). QUAL2k is a one-dimensional (1-D) steady-state model that can be used to simulate hydraulics such as flow and velocity and water quality constituents such as DO, temperature, chlorophyll-a, and nutrients. The QUAL2k model for the Fox River extends over 98 miles from Stratton Dam to mouth of the Fox River in Dayton, IL (**Figure 9**). LimnoTech recalibrated the QUAL2k model as part of the FRIP development using the data collected by the FRSG during low flow conditions in June 2012 (LimnoTech, 2014).

4.1.1 FRIP Model Issues

The model recalibrated by LimnoTech Inc. for the development of the FRIP is referred to as the FRIP Model in this report. The FRIP Model had several issues which limited its ability to be used for running watershed management scenarios. The major issues in the FRIP QUAL2k model are described in detail below.

4.1.1.1 Inability to Predict Diel Variation in Dissolved Oxygen

Diel DO swings in streams are primarily caused by algal photosynthesis during the day (which produces oxygen) and algal respiration during the night (which depletes oxygen). They are also affected by algal die offs when nutrients are lacking. Diurnal fluctuations in the water temperature also impact diel DO concentrations.

The FRIP Model was poorly calibrated for diel DO swings. The model significantly overpredicted the daily minimum DO and underpredicted the daily maximum DO as compared to the measured data (see FRIP Figure 3-4). The inability of the FRIP Model to predict diel DO variation limits its use for making watershed management decisions and as a result, improving the model during this update became important.

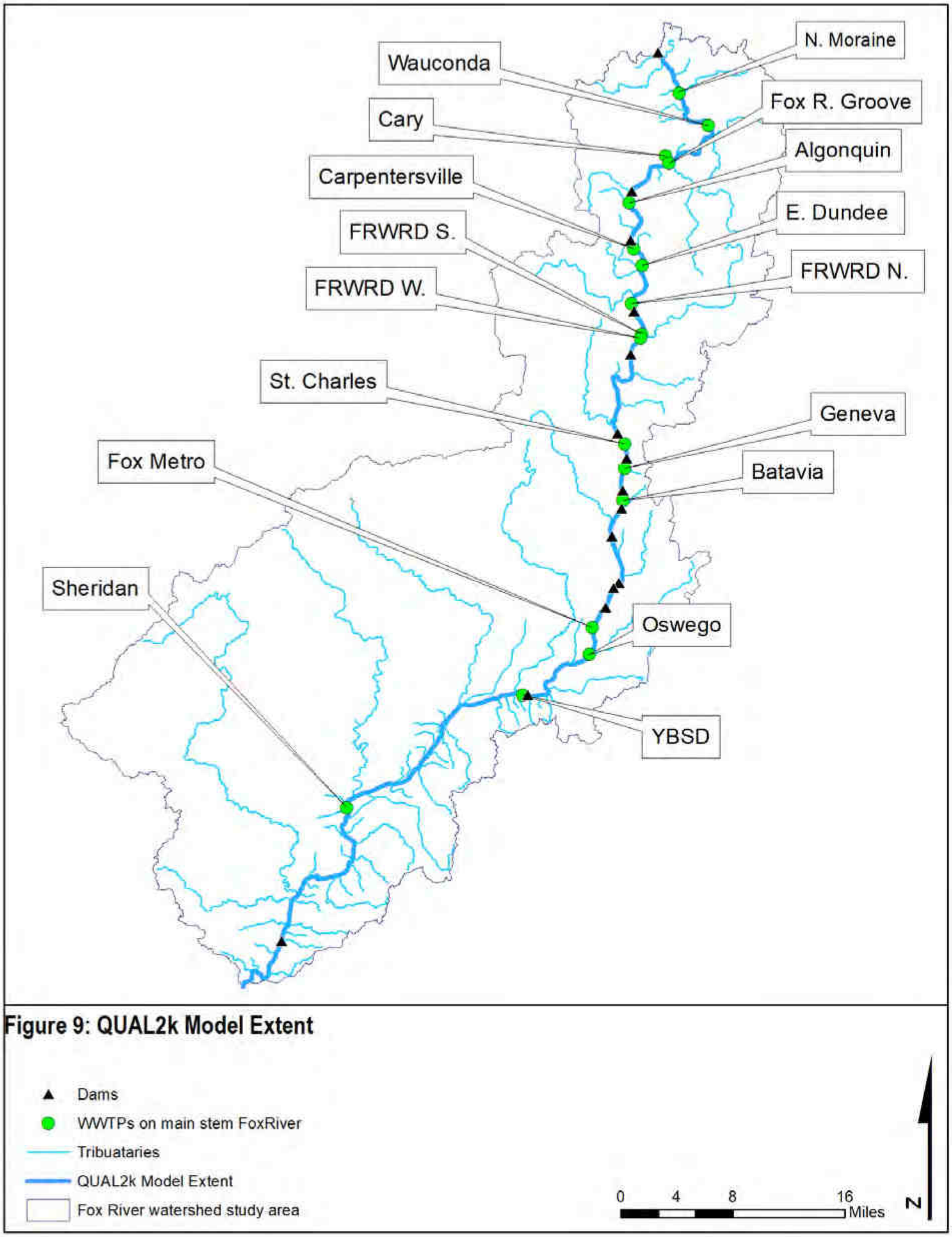


Figure 9: QUAL2k Model of the Fox River

4.1.1.2 Inaccurate Representation of Dams and Impoundments

The low head dams along the Fox River can deplete the DO concentration by slowing down the water, allowing quiescent conditions for algal populations to increase in place; these populations then die, settle, and decay, consuming oxygen. Dams can also result in accumulation of sediments and a corresponding increase in sediment oxygen demand (SOD), which lowers the DO. The ISWS conducted a study in 1978 to measure SOD in Northeastern Illinois streams and found that dam-impounded reaches in the Fox River had a much higher SOD as compared to free-flowing reaches (Butts and Evans, 1978). Dam removals typically increase DO concentrations in the former dam impoundment reaches by increasing natural reaeration and reducing SOD.

The dam removal scenarios conducted using the FRIP Model showed that the dam removals would result in decreased DO concentrations in the impounded reaches of river (see FRIP **Figure 5-5**). These results are contrary to what has been reported in the literature (Stanley and Doyle, 2002). They are also contrary to observations of DO concentrations in the free flowing versus impounded reaches of the Fox River. The inability of the FRIP Model to simulate correctly the impact of dam removal scenarios on DO in the Fox River also limits its usage as tool for informing dam removal decisions by the FRSG. As a result, this was an additional focus of the current update of the FRIP Model.

4.1.1.3 Other Limitations

Additional model limitations and issues were also identified with the FRIP Model. The FRIP Model was poorly calibrated for water temperature compared to measured data. This resulted in the model not accurately predicting the impact of changes in temperatures on DO. The FRIP Model predictions of Sediment Oxygen Demand (SOD) did not match the ISWS estimated SOD rates especially behind the dam impoundments. This discrepancy in the model inputs resulted in predictions of SOD in the FRIP Model overpredicting the DO especially behind the dam impoundments. The FRIP Model used prescribed DO reaeration rates ranging from 0.02 to 0.8 per day downstream of the Algonquin dam, which resulted in reaeration rates not dependent on simulated depth and velocity. This issue was particularly significant for the dam removal scenario, since it would not result in changes in DO reaeration even though the river depth and velocity would change. Nonpoint sources in the FRIP Model were represented by specifying sediment fluxes calculated from the previous season’s nutrient loading. This approach does not consider time varying nutrient loading from nonpoint sources due to localized runoff which might be significant in some cases.

4.2 Data for Modeling Update

The FRIP Model was updated to address the limitation discussed above and more to improve the model's reliability and as part of the current study (e.g., switching to a dynamic 1-D simulation). The data used for updating the FRIP Model are described briefly below.

4.2.1 Point Source Data

The instream model requires inputs of flow and water quality concentrations for the point source inputs such as WWTPs. The water quality constituents include DO, CBOD, NH3, NO2-NO3, ON, OP and IP. The frequency of data available ranged from daily or monthly for flow to bi-weekly or monthly for water quality constituent samples. The available data were used to develop daily timeseries of flow and water quality constituents for model input.

Table 3 shows the point sources included in the instream model along with the data availability. For some point sources, concentration data were not available for some of the water quality constituents such as NH3, NO2-NO3, ON, OP and IP. As was done for the watershed model, the water quality concentrations for these missing water quality constituents were estimated based on the relationship with CBOD. These relationships were developed by ISWS for the previous HSPF watershed modeling (Bartosova, A., 2013a).

4.2.2 Meteorological Data

The instream model requires meteorological inputs of air temperature, dew point temperature, and cloud cover. These data were obtained from the DuPage Airport Station shown in **Figure 5**.

4.2.3 Bathymetric Data

The U.S. Army Corps of Engineers collected river channel bathymetric survey data at two hundred and seventy-five (275) cross sections located upstream of each of the ten (10) dams between Montgomery and Algonquin. Kane County provided additional cross-section data from the Federal Emergency Management Agency Flood Insurance Studies. The location of stream segments with surveyed cross-sections is shown in **Figure 10.** These data were used to develop and refine the river channel bathymetry in the QUAL2kw model.

Table 3 : Instream Model Point Sources and Available Datasets, along with Correlation Relationships, where needed

Wastewater Treatment Plant (WWTP)	Flow (cfs)	Temp (^{O}C)	DO (mg/L)	CBOD (mg/L)	NH3 (mg/L)	NO3-NO3 (mg/L)	ON (mg/L)	OP (mg/L)	IP (mg/L)	TSS (mg/L)
N. Moraine	M	M	M	M	M	M	M	M	M	M
Wauconda	M	M	M	M	M	M	M	M	M	M
Cary	M	Const.	Const.	W	W	3*CBOD		W	W	M
Fox R. Grove	M	M	M	M	M	M	M	M	M	M
Algonquin	D	Const	W	W	W	3*CBOD	1*CBOD	W	W	W
Carpentersville	M	Const.	M	M	M	Const.	Const.	Const.	Const.	Const.
E. Dundee	D	Const.	Const.	Const.	Const.	Const.	Const.	D	D	Const.
FRWRD N.	D	Const.	Const.	W	W	W	W	W	W	W
FRWRD S.	D	Const.	Const.	W	W	W	W	W	W	W
FRWRD W.	D	Const.	Const.	W	W	W	W	W	W	W
St. Charles	D	W	W	Const.	W.	Const.	Const.	Const.	Const.	Const.
Geneva	M	Const.	Const.	Const.	Const.	Const.	Const.	Const.	Const.	Const.
Batavia	D	Const.	D	W	W	3*CBOD	1*CBOD	0.51*CBOD	0.0.26*CBOD	D
Fox Metro	D	Const.	W	W	W	W	W	W	W	W
YBSD	D	W	W	Const.	W	Const.	Const.	W	W	W
Sheridan STP	M	Const	M	M	M	3*CBOD	1*CBOD	0.51*CBOD	0.0.26*CBOD	M

D – Daily Sample
Const.- Assumed Constant Value
W- One or multiple samples in a week
M- Monthly
C- Calculated based on CBOD concentration

4.2.4 Flow Data

The U.S. Geological Survey (USGS) has flow monitoring at four (4) locations on the mainstem Fox River in the FRIP Study Area. The USGS gages utilized in the current study are shown in **Figure 11**, and provided stage and flow data.

4.2.5 Instream Water Quality Data

The current study used instream water quality data collected by multiple agencies for model development and calibration. These data were retrieved from the Fox River Water Quality Database (FoxDB), which is maintained by ISWS for the FRSG. A brief description of the data sets is provided in the following subsections.

4.2.5.1 IEPA Ambient Water Quality Monitoring

The IEPA collected instream water quality samples in the Fox River as part of its ambient water quality monitoring program. These samples were analyzed for field pH, temperature, specific conductance, DO, suspended solids, nutrients, fecal coliform bacteria, and total and dissolved heavy metals.

4.2.5.2 FRSG Monthly Monitoring

The FRSG conducts regular monthly grab sample monitoring at seven (7) sites along the Fox River (**Figure 12).** Water quality constituents analyzed included DO, chlorophyll-a, NH4, NO3, and TP. The water quality samples are collected by the FRSG and other volunteers and analyzed by the Fox River Water Reclamation District (FRWRD) lab.

4.2.5.3 FRSG Low-Flow Intensive Monitoring

The FRSG conducted an intensive low-flow monitoring program at several locations in the Fox River during 2012 and 2016 to support the modeling efforts. Water quality constituents analyzed included DO, sestonic chlorophyll-a, benithic chlorophyll-a, NH4, NO3, and TP. The locations of the 2012 and 2016 monitoring stations are shown in **Figure 12**. The monitoring effort included continuous monitoring of selected parameters such as DO, temperature, pH and specific conductance over several days.

In June 2012, an intensive 72-hour monitoring effort was completed to define the low-flow DO regimes in the Fox River. Data from this effort was utilized to calibrate and validate the FRIP Model. Analysis of the FRIP Model results indicated that simulated benthic algae affects the DO regime significantly. The FRSG decided to collect additional data in 2016 with a focus on algal community assessment. The data were collected in accordance with a Quality Assurance Project Plan and Standard Operating Procedures during prescribed flow conditions in the summer season. The 2016 data collection occurred on September 7 and 8 at six (6) sites in the Study Area. To maintain data consistency with the 2012 project, any sestonic algae data collection occurred within the 4 p.m. to 7 p.m. Central Daylight Time period.

The FRSG used a third-party lab to analyze the samples collected during the 2012 and 2016 low-flow monitoring period. During the current study, an issue was found with the chlorophyll-a data measured by the third-party lab for the low-flow monitoring periods. The measured chlorophyll-a data for the period of August to September 2016 is shown in

Figure 13**.** The samples represented by circles were measured by the FRWRD laboratory and the samples represented by triangles and diamonds were measured by a third-party laboratory. The measurements made by the third-party laboratory were consistently lower as compared to the FRWRD laboratory. A similar trend was observed for the data collected in 2012. It was discovered that this was due to the use of non-standard method by the third-party laboratory and these data were deemed unusable for the model calibration.

4.2.5.4 FMWRD Monthly Monitoring and Sondes

Deuchler Environmental (Deuchler) collects monthly grabs sample for FMWRD at four (4) locations along the Fox River (**Figure 12)**. The samples are analyzed by in-house FMWRD lab for the water quality constituents except chlorophyll-a. Chlorophyll-a were analyzed by the same third-party lab using the non-standard method and, hence these chlorophyll-a were not utilized for the model update and calibration. Deuchler also maintains continuous water quality sondes at Orchard Road and Route 34 locations in the Fox River that measure DO, pH, temperature and specific conductance (**Figure 12**).

4.2.5.5 USGS Data

USGS collected continuous data for DO, pH, temperature and specific conductance at Gage 05550001 Fox River (Tailwater) at Algonquin, IL. These data were utilized for the current study (**Figure 12)**.

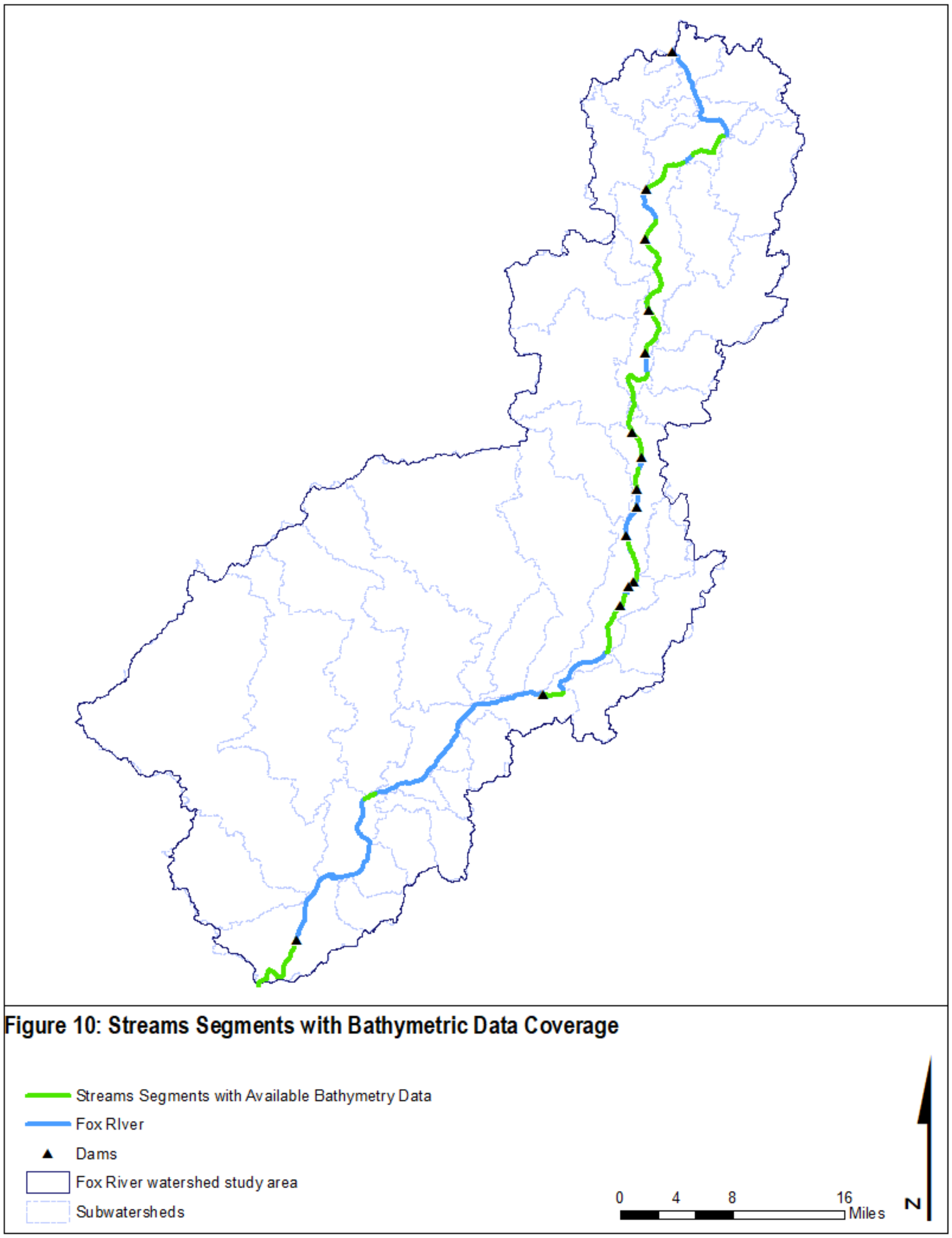


Figure 10: US Army Corps of Engineers Bathymetric Data Coverage

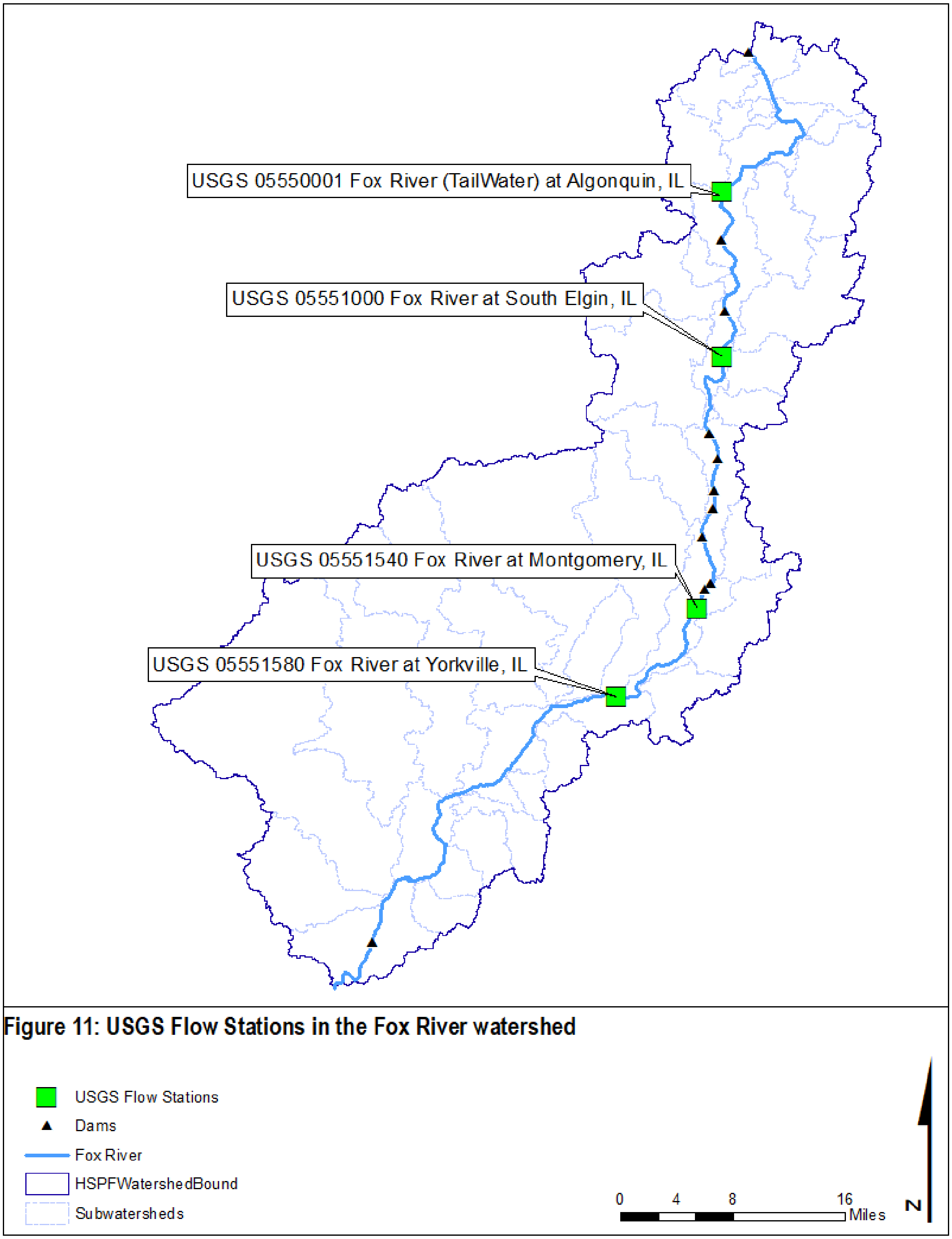


Figure 11: USGS Flow Stations in the Fox River Watershed

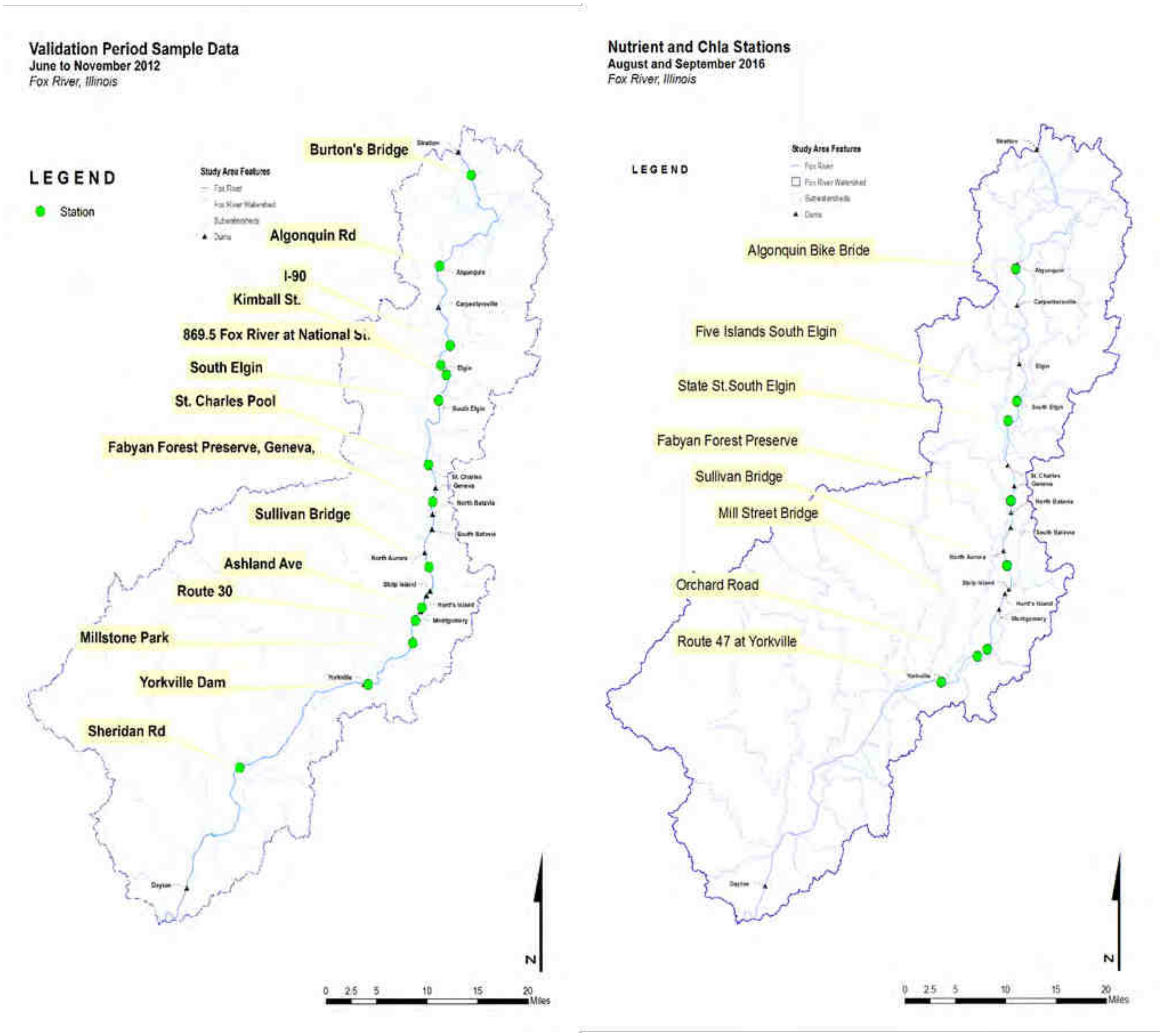
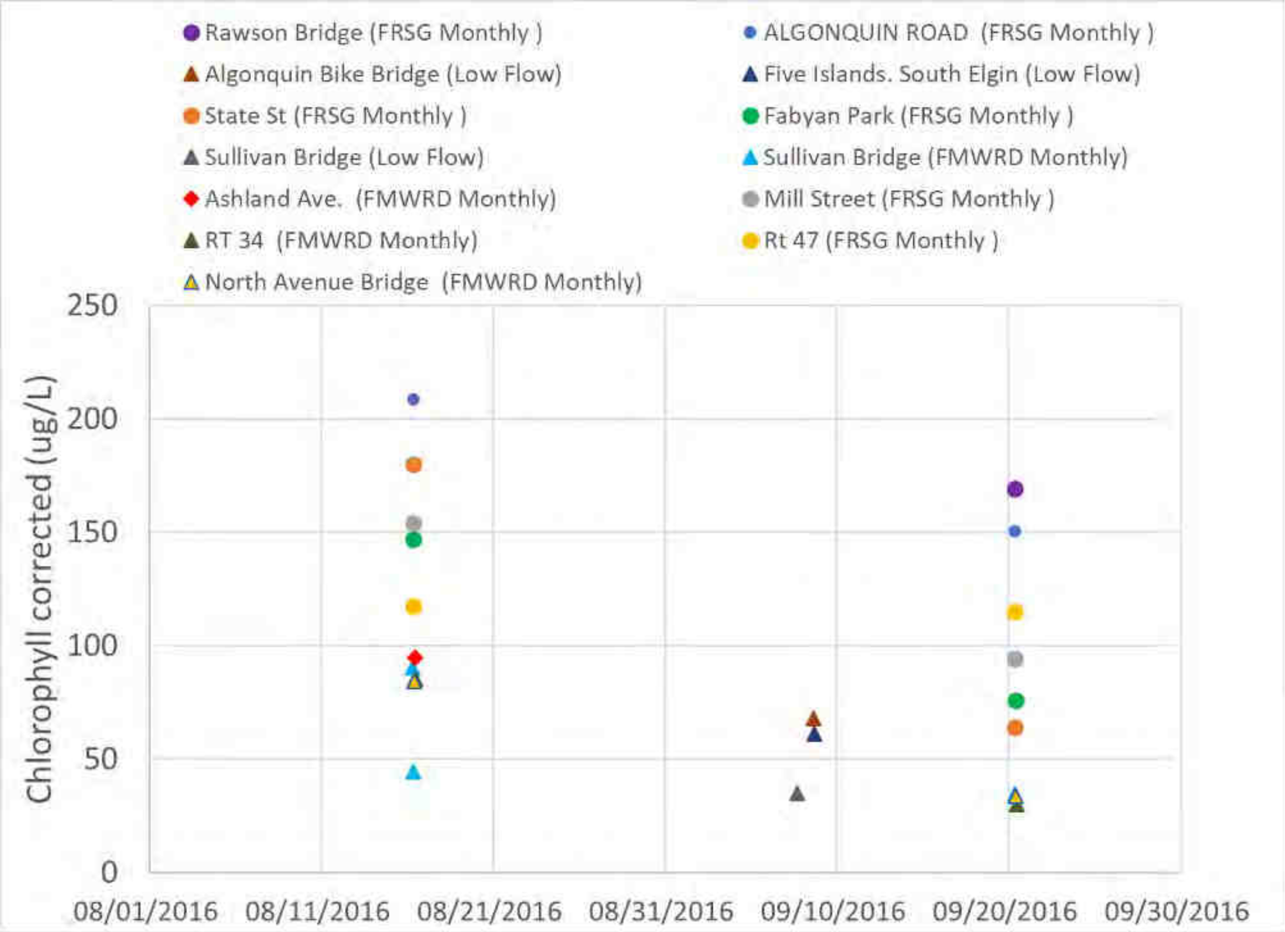


Figure 12: Location of Water Quality Monitoring Stations Utilized for the Current Study



Legend for Laboratory
Circles -FRWRD Lab
Diamond – Third Party Lab
Triangles- Third Party Lab

Figure 13: Measured Chlorophyll-a Concentration in the Fox River from August to September 2016

4.3 Modeling Updates

The FRIP Model was updated to address the model limitations and improve its reliability. The following subsections briefly describe the updates.

4.3.1 Use of Calculated Reaeration Rates for Dissolved Oxygen

Reaeration in streams is a function of the depth, velocity, water temperature, and effective wind on the water surface. The QUAL2K model framework can calculate the DO reaeration rates using the simulated depth and velocity or use prescribed reaeration rates. For the FRIP, the DO reaeration rates are prescribed at a low value of 0.02 to 0.8 per day downstream of the Algonquin dam, which results in reaeration rates not dependent on simulated depth and velocity. Geosyntec updated the model to ensure that the DO reaeration rates are calculated internally by the model as function of depth and velocity. This update helped address the limitation of the FRIP Model where it showed a decreased in DO with the removal of dams.

4.3.2 Dynamic Version of QUAL2k- QUAL2kw

The FRIP Model is a steady state QUAL2k model which assumes a constant input of flow into the model over time. Hence the FRIP Model is not able to simulate the changes in flow and water quality over time. Geosyntec updated the FRIP Model to a dynamic version of QUAL2k, QUAL2kw (Pelletier et. al, 2005). QUAL2kw can perform continuous simulation of flow and water quality simulation. This update will provide a better tool for the FRSG to inform management decisions concerning water quality over different periods of times of the year.

4.3.3 Upstream Boundary Condition

The FRIP Model used a constant input of flow at the upstream boundary based on the average monthly flow. QUAL2kw requires timeseries inputs of flow and water quality at the upstream boundary. The upstream flow boundary condition input at the Stratton Dam was calculated by area-weighting the measured flow at the USGS 05550000 Fox River at Algonquin using the equation below.

$$Q_2 = Q_1 * \frac{A_2}{A_1}$$

where, Q_2 is estimated flow at Stratton Dam,

Q_1 is the measure flow estimated flow at USGS Gage 05550000 at Algonquin, IL,

A_2 is the drainage area at Stratton Dam, and

A_1 is the drainage area at USGS Gage 05550000 at Algonquin, IL.

The upstream water quality boundary conditions inputs were based on measured data collected at the Rawson Bridge station for 2012 and at the Burton's Bridge station for 2016. The FRIP Model upstream boundary condition for chlorophyll were based on the faulty chlorophyll data which resulted in underprediction of chlorophyll-a. A summary of model inputs for the upstream boundary is presented in **Attachment 1**.

4.3.4 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 were used to calculate the velocity-discharge and depth-discharge rating curves for reaches of the Fox River. These curves define the velocity and depth as a function of flow. The observations noted in the field sheets of the low-flow 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.

4.3.5 Tributary Inputs

The HSPF-simulated flow and water quality concentrations were used as inputs for the tributaries and mainstem direct drainage areas into the QUAL2kw model. A summary of model inputs for tributary and direct drainage areas is presented in **Attachment 1**.

4.3.6 Point Source Inputs

The point source data provided by the FRSG members were used as input for the point sources. The processing of the point source data is described in Section 4.2.1. A summary of model inputs for the point sources is presented in **Attachment 1**.

4.4 Model Calibration

The QUAL2kw model was calibrated to the available flow and water quality data for two time periods: June 1 to July 31, 2012 and August 1 to September 30, 2016. These time periods were chosen because of data availability for the different water quality constituents. For the current study, model validation was not undertaken since sufficient data were not available and there was an interest in maximizing the use of the data for model calibration. **Table 4** provides a summary of water quality data utilized for model calibration.

Table 4: Summary of Water Quality Data Utilized for Model Calibration

Dataset	Data Type	Number of Sites	Number of Sample Days
June 1 - July 31,2012			
2012 FRSG Low Flow Study	Continuous/Grab	13/13	3/3 per site
FRSG Monthly Monitoring	Grab	7	2 per site
FMWRD Ammonia Sampling	Grab	3	8 per site
IEPA/IDNR Intensive Monitoring	Grab	0	0
FMWRD Sondes	Continuous	1	22
FMWRD Monthly	Grab	4	2 per site
IEPA Ambient Water Quality Monitoring	Grab	13	1-4 per site
August 1- September 30, 2016			
2016 FRSG Low Flow Study	Continuous/Grab	4/6	3.5/1 per site
FRSG Monthly Monitoring	Grab	7	1-2 per site
FMWRD Sondes	Continuous	3	49 per site
FMWRD Monthly	Grab	4	2 per site
IEPA Ambient Water Quality Monitoring	Grab	6	1-2 per site
USGS Monthly Sampling at Montgomery (05551540)	Grab	1	1
USGS Water Quality Sonde at Algonquin (05550001)	Continuous	1	49

Model calibration was performed for the various constituents in the following order: stream flow, temperature, nutrients, chlorophyll-a and DO. Some of the chlorophyll-a data during the low flow studies in 2012 and 2016 were not utilized for model calibration because the collection and analysis of that data did not follow the standard protocol as discussed in Section 4.2.5.3.

The model input parameters were adjusted to improve the model predictions to better match the measured data. The model calibration results were presented to the FRSG modeling subcommittee through a series of meetings. The water quality model calibration was further refined based on the feedback from the modeling subcommittee.

The results of model calibration are briefly described below. Details of the model calibration, including timeseries plots and statistics comparing model simulations with measured data, are included in **Attachment 2**.

4.4.1 Model Calibration Results for June to July 2012

4.4.1.1 Flow

The time period of June 1 to July 31, 2012 is a low flow period with flow ranging from 200 to 400 cfs at USGS Gage 05550001 at Algonquin (River Mile 82.5) and 250 to 1,000 cfs at USGS Gage 05551540 at Montgomery (River Mile 68.5). **Table 5** presents a comparison of statistics of simulated results and measured data at the four (4) USGS gages along with model-data error statistics. The model predictions for flow are reasonably close to the measured data at these locations. **Figure 14** shows a timeseries comparison of model simulated flow with measured data at USGS 05551000 Fox River at South Elgin, IL (River Mile 68.5). The model overpredicts the flow values around July 1, 2012. This overprediction is caused due to uncertainty associated with HSPF-predicted flows. The model underpredicts the peak flow values at this location and also at downstream USGS gages around July 23 because of uncertainty associated with HSPF-predicted flows. The calibration of flow in the QUAL2Kw model could be improved by calibrating individual HSPF models to measured flow data in the tributaries of the Fox River.

Table 5: Comparison of Statistics of Simulated and Measured Flow for June to July 2012

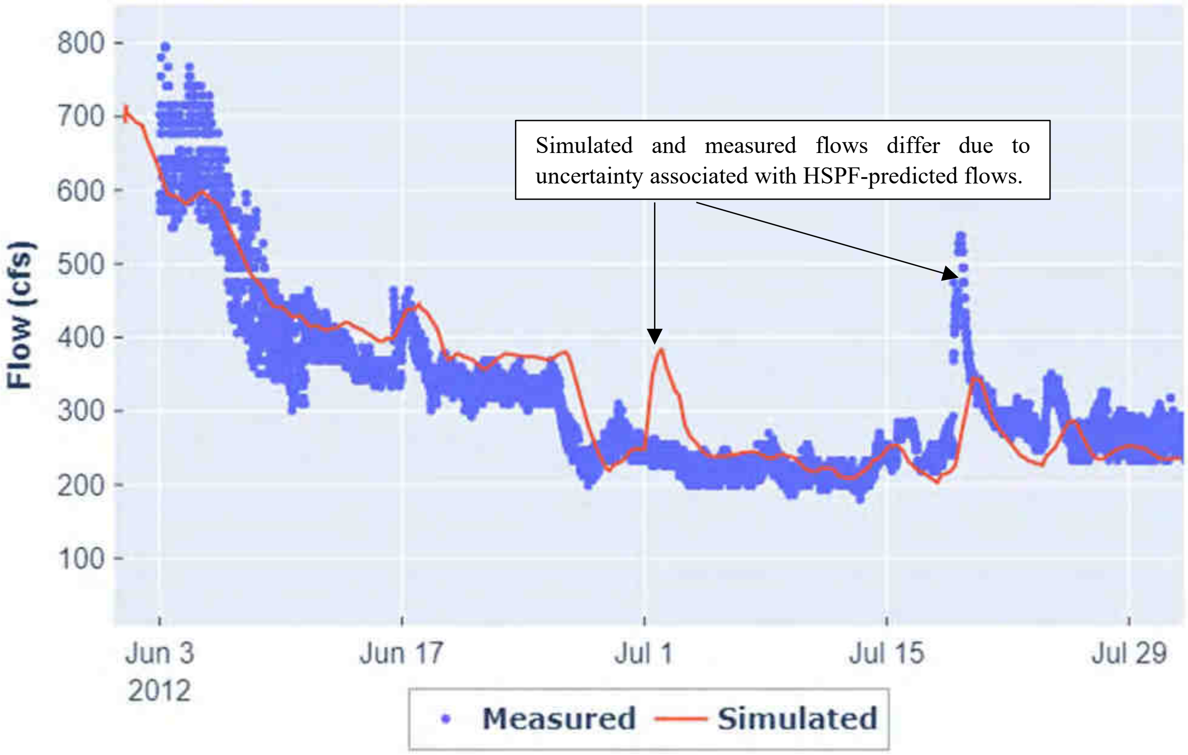
Station	Count	Measured		Simulated		R^2[b]	RMS Err[c] (cfs)	Index of Agreement[d]	Calibration Assessment
		Mean (cfs)	Std Dev (cfs)	Mean (cfs)	Std Dev (cfs)				
USGS 05551580 Fox River at Yorkville, IL[a]	1,057	252	33	336	29	0.4	88.4	0.4	N/A
USGS 05551540 Fox River at Montgomery, IL	5,857	329	169	367	137	0.8	82.2	0.9	Good
USGS 05551000 Fox River at South Elgin, IL	5,647	320	111	328	108	0.8	53	0.9	Good
USGS 05550001 Fox River (Tailwater) at Algonquin, IL	5,851	271	115	292	110	1	33.9	1	Very Good

[a] Limited number of data points for statistics to be meaningful.

[b] R^2: Coefficient of determination (R^2) is a statistical measure of how well the model predictions approximate the real data points. An R2 of 1 indicates that the model predictions perfectly fit the data.

[c] RMS Err : Root Mean Square Error (RMS Err) is a measure of the differences between model predictions and observed data. A low value of RMS Err indicates close agreement between data and model values.

[d] Index of Agreement is a measure of the degree of model prediction error which ranges from 0 to 1. An index of agreement of 1 indicates complete agreement of model predictions with data.



Simulated and measured flows differ due to uncertainty associated with HSPF-predicted flows.

Figure 14: Simulated and Measured Flows at USGS 05551540 Fox River at Montgomery, IL

4.4.1.2 Temperature

The model does a satisfactory job capturing the daily and seasonal variation in water temperature**. Table 6** shows the comparison of statistics of simulated and measured water temperature at different locations along the Fox River, along with model-data error statistics at each location. In some reaches, the model underpredicts temperature. This underprediction could be caused by the spatial variability in air temperature or riparian shading along the length of river. Also, QUAL2kw is a 1-D model and cannot simulate vertical variability in water temperature in the dam pool reaches. Figure 15 show an example plot comparing the simulated results and measured data for water temperature results at Fox River - Route 30 (FMWRD Station 53, River Mile 46.0). The figure shows an underprediction of water temperature with an average root mean square error of 2 degrees Celsius (°C).

This underprediction is reasonable given the limitations of the 1-D model and its inputs of riparian shading. The QUAL2kw model uses a constant input of percent of solar radiation blocked by riparian shading along the whole length and breadth of a river reach. In reality, the shading is variable along the length and breadth of river reach. In reality, as flows decrease and the channel narrows, more water will be exposed to sunlight, causing measured temperatures to increase. The model, however, will continue to reduce the impact of solar radiation as evidenced in the low flow period of June to July 2012. The updated model, however, reasonably captures daily and seasonal variation in temperature which is important for simulating variation in DO. If the FRSG is interested in having the model more accurately simulate water temperature, then additional data and model refinements will be needed, such as collection of more detailed bathymetric data and utilization of a 2-D model with vertical layers.

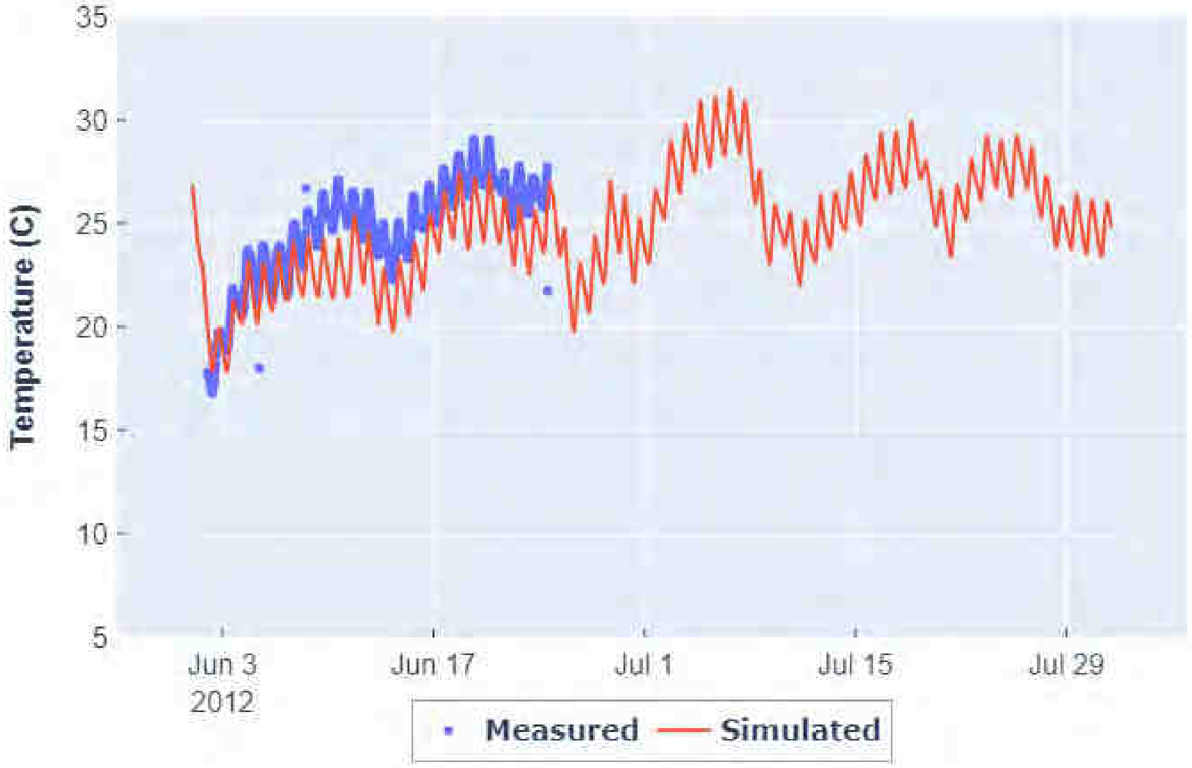


Figure 15: Simulated and Observed Temperature at FMWRD Station 53 (River Mile 46.0)

Table 6: Comparison of Statistics of Simulated and Measured Temperature for the Period of June to July 2012

Sonde	Station	Sonde Location[a]	Count of Data	Measured (deg C)				Simulated (deg C)				R^2 (c)	RMS Err (deg C) [d]	Index of Agreement[e]	Calibration Assessment
				Mean	StdDev	Min	Max	Mean	StdDev	Min	Max				
800_	Sheridan Road		497	27.2	2.5	22.0	32.5	25.1	1.7	22.0	29.5	0.8	2.4	0.7	Fair
807_B	Yorkville Dam	B	498	24.9	2.2	21.6	30.1	24.4	1.8	20.9	28.1	0.3	2.0	0.7	Good
807_T		T	497	25.8	2.3	21.8	30.5	24.4				0.5	2.2	0.7	
815_	Millstone Park		480	25.6	1.9	22.4	30.0	23.9	2.0	20.1	28.2	0.6	2.1	0.7	Good
53	Route 30		1084	24.7	2.4	16.8	29.1	24.4	0.9	23.0	25.8	0.1	2.3	0.4	Fair
825_B	Ashland Avenue	B	470	25.9	1.2	23.3	28.7	23.6	2.2	19.4	27.9	0.6	2.7	0.6	Fair
825_T		T	469	26.2	1.5	23.3	29.4	23.6				0.8	2.8	0.7	
832_	Sullivan Road		446	26.4	1.7	22.9	30.6	23.2	2.4	19.3	29.3	0.8	3.4	0.7	Fair
840_	Fabyan Forest Preserve		446	25.7	2.1	22.4	30.6	23.2	1.9	19.5	26.9	0.1	3.4	0.5	Fair
850_	St. Charles Pool		441	25.7	1.3	23.3	28.7	23.1	2.8	18.8	31.0	0.4	3.5	0.6	Fair
860_B	South Elgin	B	360	24.5	0.8	23.2	26.3	22.8	1.7	19.9	26.3	0.4	2.1	0.6	Fair
860_T		T	359	25.2	1.2	23.2	27.8	22.8				0.8	2.5	0.6	
869.5_	National St.		475	25.4	1.4	22.7	29.4	23.4	2.1	19.7	28.1	0.8	2.2	0.7	Fair
870_	Kimball St.		467	25.3	1.3	22.9	29.8	23.4	2.4	19.5	29.7	0.6	2.5	0.7	Fair
880_	I-90		473	25.0	1.9	21.1	28.7	23.5	2.4	19.7	29.8	0.4	2.4	0.7	Fair
890_B	Algonquin Road[b]	B	463	25.2	0.8	23.8	27.0	23.9	2.1	19.9	28.1	0.6	2.1	0.6	Fair
890_B2		B2	295	26.9	0.8	25.8	28.5	24.8	1.6	22.2	27.5	0.6	2.3	0.6	
890_T		T	463	25.6	1.2	23.6	28.7	23.9	2.1	19.9	28.1	0.4	2.4	0.6	
890_T2		T2	296	27.5	0.9	26.0	29.3	24.8	1.6	22.2	27.5	0.4	3.0	0.5	
895_	Burtons Bridge		285	27.8	1.0	26.1	29.7	25.8	2.3	21.2	30.8	0.8	2.5	0.6	Fair

[a] B - Bottom, Top

[b] Sondes were in place at different times

[c] R2: Coefficient of determination (R2) is a statistical measure of how well the model predictions approximate the real data points. An R2 of 1 indicates that the model predictions perfectly fit the data.

[d] RMS Err : Root Mean Square Error (RMS Err) is a measure of the differences between model predictions and observed data. A low value of RMS Err indicates close agreement between data and model values.

[e] Index of Agreement is a measure of the degree of model prediction error which ranges from 0 to 1. An index of agreement of 1 indicates complete agreement of model predictions with data.

4.4.1.3 Total Phosphorus

The model captures spatial and temporal variation in TP concentrations well. **Figure 16** compares the range of simulated and measured TP along the length of the river for the period of June 25 to 29, 2012. The location of the WWTPs, dams, and tributary mouths are shown along the x-axis from upstream to downstream order. The green, black (dotted), and red lines show the simulated maximum, mean and minimum values of TP at different locations in the Fox River for the five-day time period. The lines match up well with the observed maximum, mean, and minimum values shown by green, black, and red dots respectively.

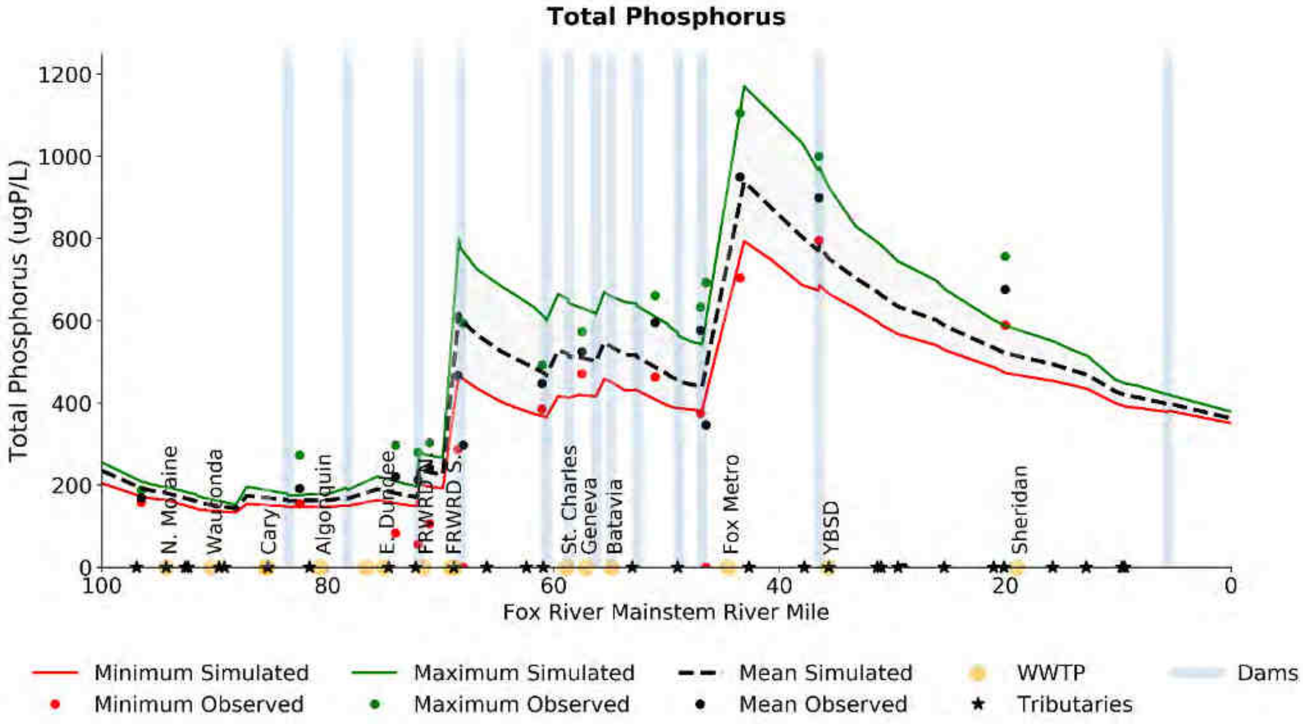


Figure 16: Total Phosphorus Concentration Longitudinal Plot for June 25-29, 2012

4.4.1.4 Ammonia

The model underpredicts the ammonia concentrations for the upstream reaches but matches the measured mean data to a satisfactory degree for the downstream reaches (see **Figure 17** for a longitudinal ammonia plot for June 25 to 29, 2012). The model overpredicts the maximum concentration downstream of the Fox River Water Reclamation District (FRWRD) West and South water reclamation facilities (WRFs) around River Mile 70 and downstream of the Batavia WRF. These sudden increases in predicted maximum ammonia concentrations is documented in a technical memorandum submitted by Geosyntec to the FRSG Modeling Subcommittee (Geosyntec, 2020, Attachment 3). The QUAL2kw model is not well calibrated for ammonia (and nitrate) but is suitable for purpose of developing the FRIP, which is focused on phosphorus-related impairments. Additional model calibration will be needed if the model is to be applied to evaluate nitrogen concentrations in the river.

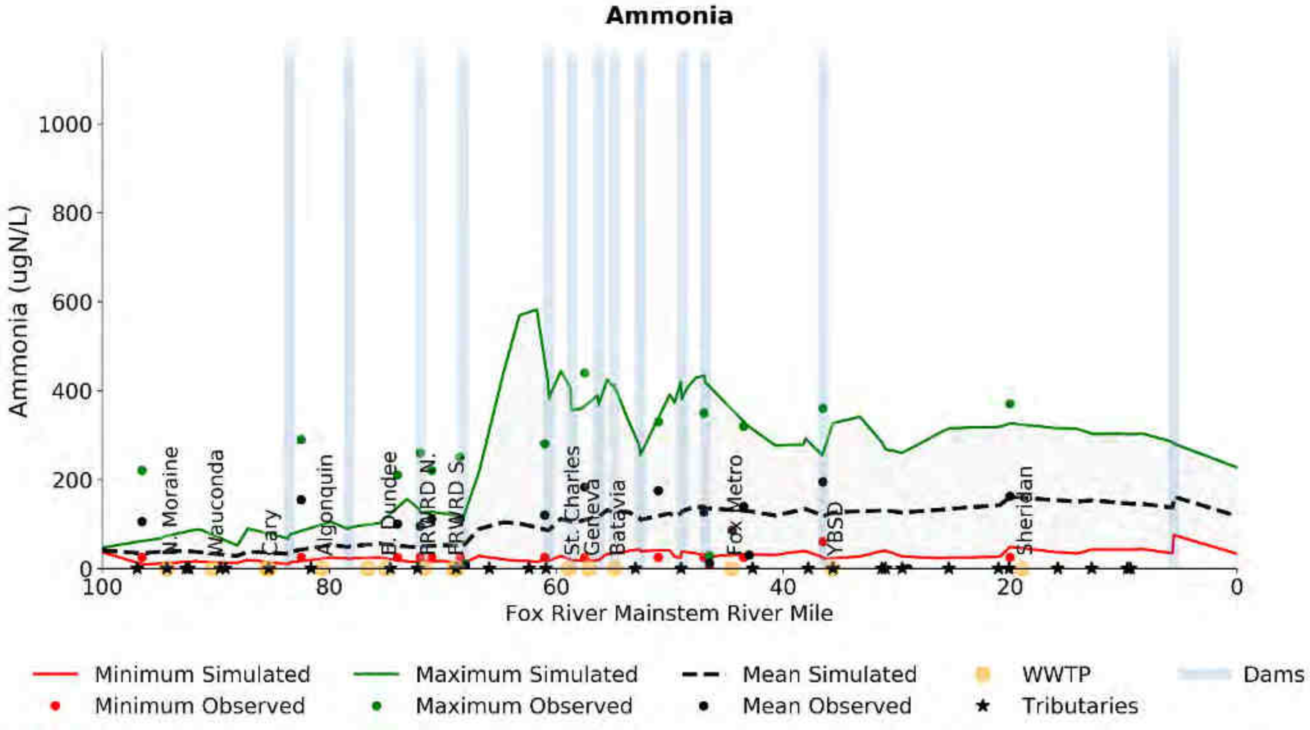


Figure 17: Ammonia Concentration Longitudinal Plot for June 25-29, 2012

4.4.1.5 Chlorophyll-a

During the course of updating the model and calibrating to data, an investigation was conducted to review the chlorophyll-a data collected during the low flow monitoring periods in 2012 and 2016. The data reported by the third-party laboratory turned out to be faulty and hence should not be used for calibration. Unfortunately, the FRIP Model was calibrated to these faulty chlorophyll-a measurements for the period of June 25-29, 2012 as discussed in Section 4.2.5.3. The measurements collected between June 25 to 29, 2012, were not utilized for the current study to recalibrate the model. The model was recalibrated to measured chlorophyll-a data collected as part of FRSG monthly and IEPA ambient water quality monitoring programs. The calibrated model matches observed chlorophyll-a data fairly well. **Figure 18** compares the range of simulated and measured TP along the length of the river on July 17, 2012, focusing on valid data.

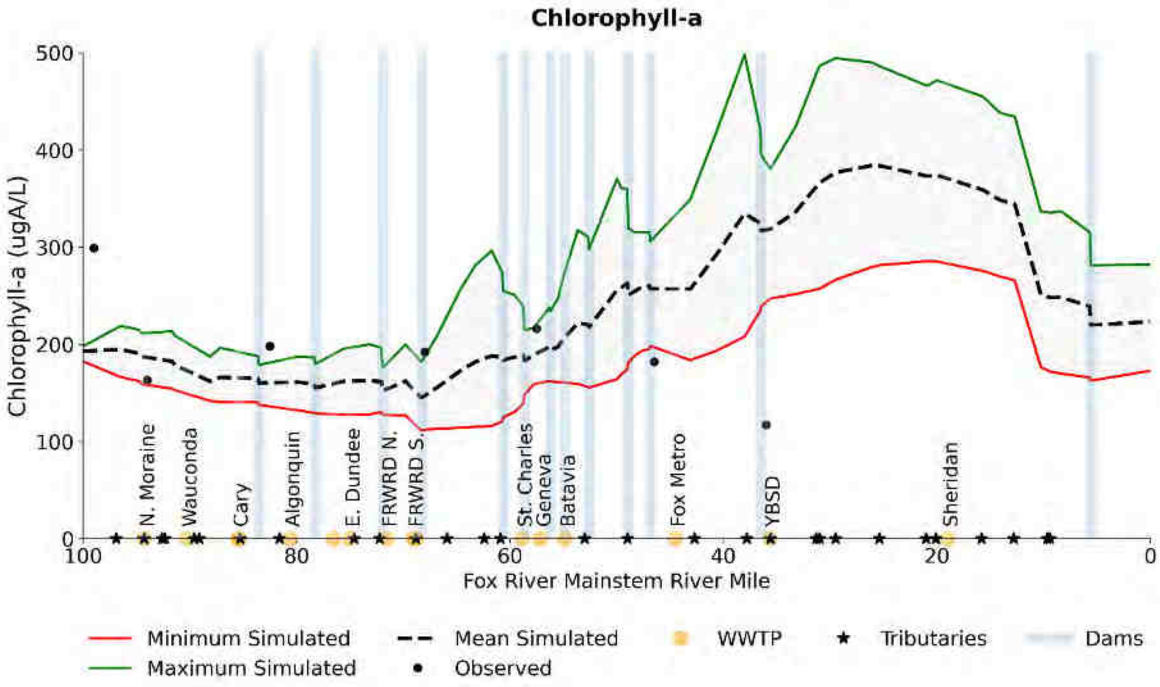


Figure 18: Chlorophyll-a Longitudinal Plot for July 17, 2012

4.4.1.6 Dissolved Oxygen

As a result of the model updates and recalibration the updated QUAL2Kw model results show better agreement between the simulated and observed data DO concentrations compared to the FRIP Model. **Table 7** shows a comparison of statistics for simulated results and measured DO concentrations at different locations along the Fox River, along with model-data error statistics. Model calibration for DO was classified as being “Very Good”, “Good” or “Fair” based on agreement with the observed using best professional judgment and discussion with FRSG Modeling Subcommittee. For the dam pool reaches, the model predictions deviate from the observed data since QUAL2kw is a 1-D model, and hence cannot simulate the vertical variability of DO at the stations located in dam pool reaches such as Algonquin Road, South Elgin, Ashland Avenue and Yorkville Dam. This issue was discussed with the FRSG modeling subcommittee, who agreed with this reasoning. FRSG Modeling Subcommittee deemed the updated model and the model recalibration sufficient to use the updated model as a tool for FRIP development. **Figure 19** compares the range of simulated and measured DO concentration along the length of the river for June 25 to 29, 2012. **Figure 20** show the timeseries comparison of simulated and observed DO concentration at Fox River – Sullivan Bridge, Aurora. The improvement in the model’s ability to simulate the daily variation in DO is because of its dynamic nature of the model simulation, updated model inputs and the model being calibrated to more accurate chlorophyll-a concentrations measured by the FRWRD lab.

Table 7: Comparison of Statistics of Simulated and Measured Dissolved Oxygen Concentration for June to July 2012

Sonde Location	Station	Sonde Location[a]	Count of Data	Measured (mg/L)				Simulated (mg/L)				R^2(c)	RMS Err (mg/L)[d]	Index of Agreement[e]	Calibration Assessment
				Mean	StdDev	Min	Max	Mean	StdDev	Min	Max				
800_	Sheridan Road		497	16.1	8.5	3.1	32.0	10.1	4.6	3.1	17.5	0.8	7.8	0.7	Good
807_B	Yorkville Dam	B	498	5.6	4.1	0.3	19.6	8.2	4.8	2.0	17.3	0.4	4.9	0.7	Good
807_T		T	497	8.2	4.7	0.8	18.8					0.7	2.8	0.9	
815_	Millstone Park		480	10.8	5.5	3.4	19.7	10.0	6.3	2.4	20.9	0.9	2.4	1.0	Very Good
53	Route 30		1084	9.4	3.1	4.4	16.2	9.3	4.8	4.4	16.9	0.9	2.2	0.9	Very Good
825_B	Asland Avenue	B	470	7.9	3.7	0.2	15.7	8.9	2.8	4.9	13.8	0.6	2.5	0.8	Good
825_T		T	469	8.4	3.5	3.0	15.3	8.8				0.7	1.9	0.9	
832_	Sullivan Road		446	9.3	3.4	4.5	16.4	9.1	4.6	3.9	16.9	0.9	1.6	1.0	Very Good
840_	Fabyan Forest Preserve		446	10.9	6.1	3.0	34.5	8.9	3.4	4.3	15.8	0.7	4.2	0.8	Good
850_	St. Charles Pool		441	13.2	3.0	7.0	23.3	8.8	2.0	6.2	12.1	0.0	5.6	0.4	Fair
860_B	South Elgin	B	360	9.7	3.7	3.1	18.0	9.2	2.4	5.2	13.4	0.0	4.2	0.5	Fair
860_T		T	359	14.0	2.3	9.4	21.9					0.1	5.7	0.4	
869.5_	National St.		475	9.2	2.5	6.0	16.7	9.7	2.5	5.6	13.8	0.5	2.0	0.8	Very Good
870_	Kimball St.		467	12.4	2.7	7.1	22.5	9.6	3.7	4.4	15.5	0.3	4.5	0.6	Good
880_	I-90		473	12.0	4.6	4.3	21.9	9.5	3.9	4.5	16.4	0.0	6.3	0.5	Good
890_B	Algonquin Road[b]	B	463	7.1	1.7	3.2	14.2	8.9	3.8	3.3	15.2	0.1	4.2	0.5	Fair
890_B2		B2	295	4.6	1.0	2.7	7.5		4.1	3.0	15.2	0.0	5.9	0.4	
890_T		T	463	7.8	2.5	4.3	15.1		3.8	3.3	15.2	0.5	3.0	0.8	
890_T2		T2	296	7.2	1.7	4.5	11.5		4.1	3.0	15.2	0.5	3.4	0.7	
895_	Burtons Bridge		285	11.9	2.3	8.1	16.9	8.8	0.8	6.6	9.4	0.3	4.4	0.3	Fair

[a] B - Bottom, T - Top

[b] Sondes were in place at different times

[c] R2: Coefficient of determination (R2) is a statistical measure of how well the model predictions approximate the real data points. An R2 of 1 indicates that the model predictions perfectly fit the data.

[d] RMS Err : Root Mean Square Error (RMS Err) is a measure of the differences between model predictions and observed data. A low value of RMS Err indicates close agreement between data and model values.

[e] Index of Agreement is a measure of the degree of model prediction error which ranges from 0 to 1. An index of agreement of 1 indicates complete agreement of model predictions with data.

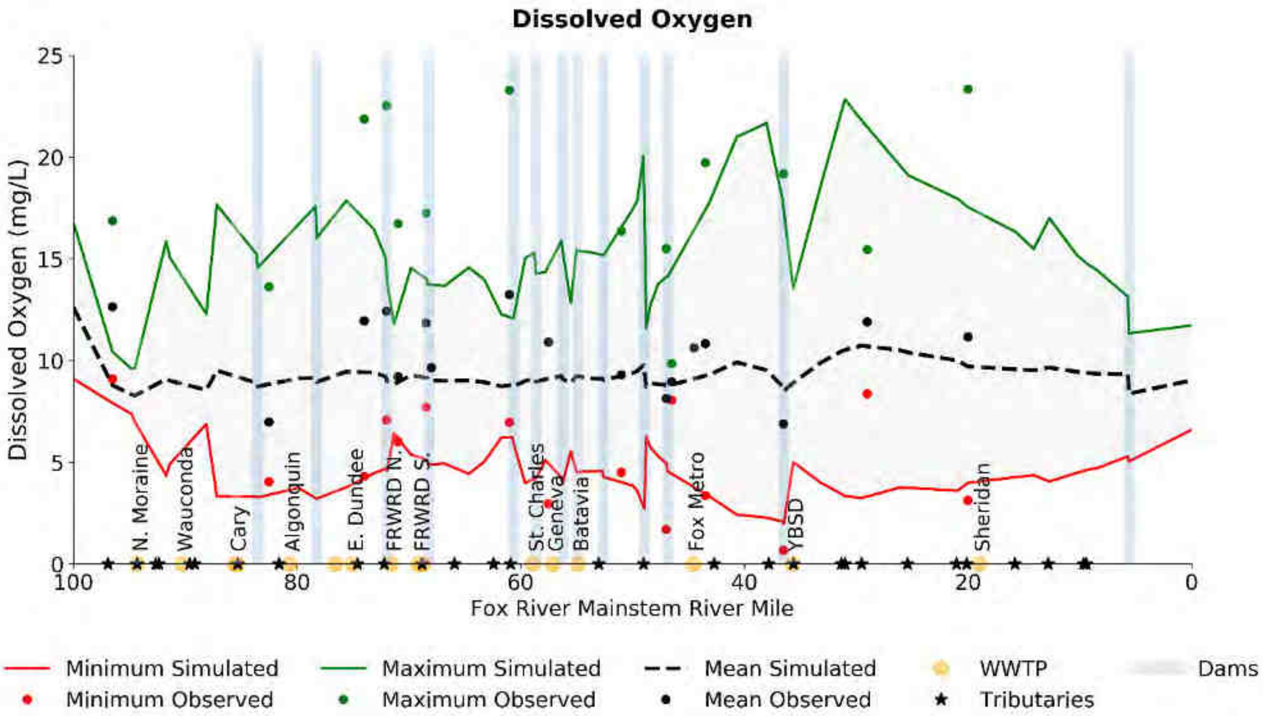


Figure 19: Dissolved Oxygen Concentration Longitudinal Plot for June 25-29, 2012.

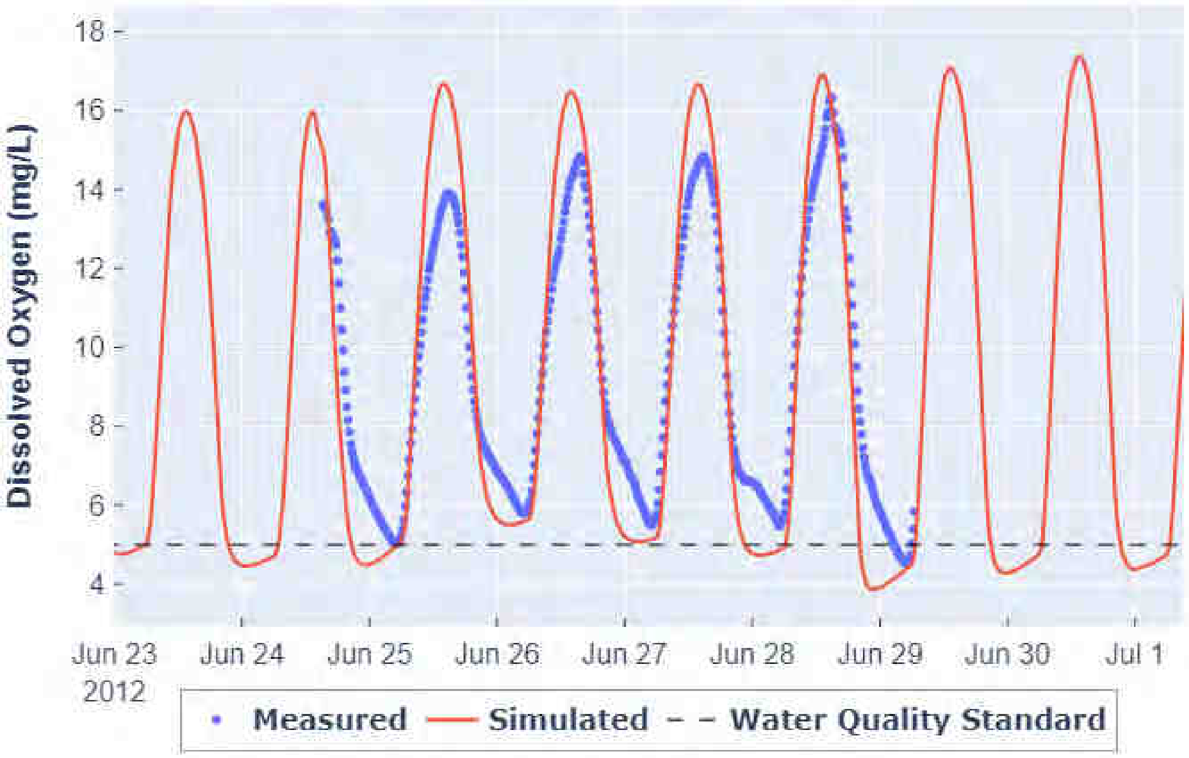


Figure 20: Comparison of Simulated and Measured Dissolved Oxygen Concentration at Fox River – Sullivan Bridge for June 25-29, 2016.

4.4.2 Model Calibration Results for August to September 2016

The model calibration results for the 2016 time period showed good agreement between simulated results and observed data for most of the constituents, similar to 2012. The following section provides a summary of model calibration results for August to September 2016.

4.4.2.1 Flow

Flow in the Fox River ranged from 400 to 800 cfs at the USGS Gage 05550001 at Algonquin and from 400 to 1,300 cfs at the USGS 05551540 Fox River at Montgomery for August to September 2016. The model underpredicts the peak flow values at this location and the downstream USGS gages because of uncertainty associated with HSPF predicted flows for tributary inputs.

Table 8 shows the comparison of simulated results and measured data statistics at four USGS gages in the Fox River, along with model-data error statistics. The model predictions for flow match observed data well at low flows; however, the flow peaks due to local storms are not captured by the model as shown in **Figure 21**. The model underpredicts the peak flow values at this location and the downstream USGS gages because of uncertainty associated with HSPF predicted flows for tributary inputs.

Table 8: Comparison of Statistics of Simulated and Measured Flow for the Period of August to September 2016

Station	Count of Data	Measured		Simulated		$R^{2(a)}$	RMS Err (cfs)[(b)]	Index of Agreement[(c)]	Calibration Assessment
		Mean (cfs)	Std Dev (cfs)	Mean (cfs)	Std Dev (cfs)				
USGS 05551580 Fox River at Yorkville, IL	2,928	836	176	639	140	0.6	229	0.6	Good
USGS 05551540 Fox River at Montgomery, IL	2,928	642	172	558	129	0.7	126	0.8	Good
USGS 05551000 Fox River at South Elgin, IL	2,684	457	93	523	114	0.7	90	0.8	Very Good
USGS 05550001 Fox River (Tailwater) at Algonquin, IL	2,784	431	89	443	98	0.8	49	0.9	Very Good

(a) R^2: Coefficient of determination (R^2) is a statistical measure of how well the model predictions approximate the real data points. An R2 of 1 indicates that the model predictions perfectly fit the data.

(b) RMS Err : Root Mean Square Error (RMS Err) is a measure of the differences between model predictions and observed data. A low value of RMS Err indicates close agreement between data and model values.

(c) Index of Agreement is a measure of the degree of model prediction error which ranges from 0 to 1. An index of agreement of 1 indicates complete agreement of model predictions with data.

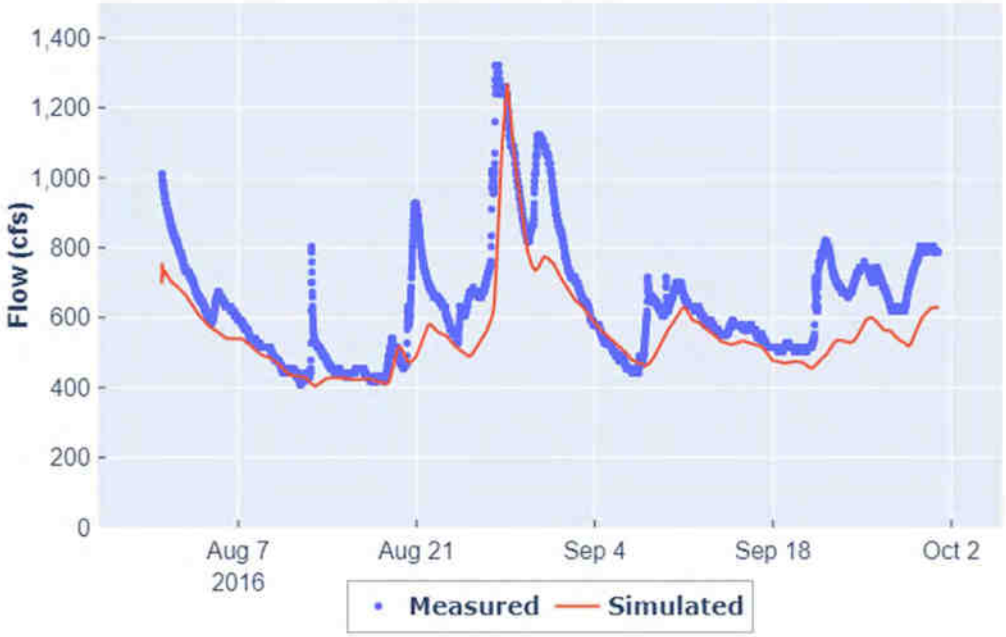


Figure 21: Simulated and Observed Flows at USGS 05551540 at Montgomery, IL (River Mile 47.0)- August to September 2016.

4.4.2.2 Temperature

The calibrated QUAL2kw model captures daily and seasonal variations in water temperature well in 2016. **Table 9** shows the comparison of simulated results and measured data statistics at five (5) locations along the Fox River, along with model-data error statistics. The root-mean square at four (4) stations is about 1 ºC, which indicates very good agreement between the simulated and measured data. **Figure 22** shows the simulated and observed temperature at Fox River - Sullivan Bridge (River Mile 51.0).

Table 9: Comparison of Statistics of Simulated and Measured Temperature for the Period of August to September 2016.

Station	Count of Data	Measured		Simulated		$R^{2(a)}$	RMS Err (cfs)$^{(b)}$	Index of Agreement$^{(c)}$	Calibration Assessment
		Mean (cfs)	Std. Dev (cfs)	Mean (cfs)	Std. Dev (cfs)				
Orchard Road	1,468	25.3	2.8	24.9	2.9	0.8	1.3	1	Very Good
Route 34	173	26.3	1.2	26.8	1	0.4	1.1	0.7	Very Good
Route 30	1,389	25.2	2.4	24.6	2.7	0.9	1	1	Very Good
Sullivan Bridge	1,474	25.3	2.4	25.1	2.9	0.9	1	1	Very Good
Algonquin Bike Bridge	2,775	25	2.3	25	3	0.9	1.2	0.9	Very Good

[a] R^2: Coefficient of determination (R^2) is a statistical measure of how well the model predictions approximate the real data points. An R2 of 1 indicates that the model predictions perfectly fit the data.

[b] RMS Err : Root Mean Square Error (RMS Err) is a measure of the differences between model predictions and observed data. A low value of RMS Err indicates close agreement between data and model values.

[c] Index of Agreement is a measure of the degree of model prediction error which ranges from 0 to 1. An index of agreement of 1 indicates complete agreement of model predictions with data.

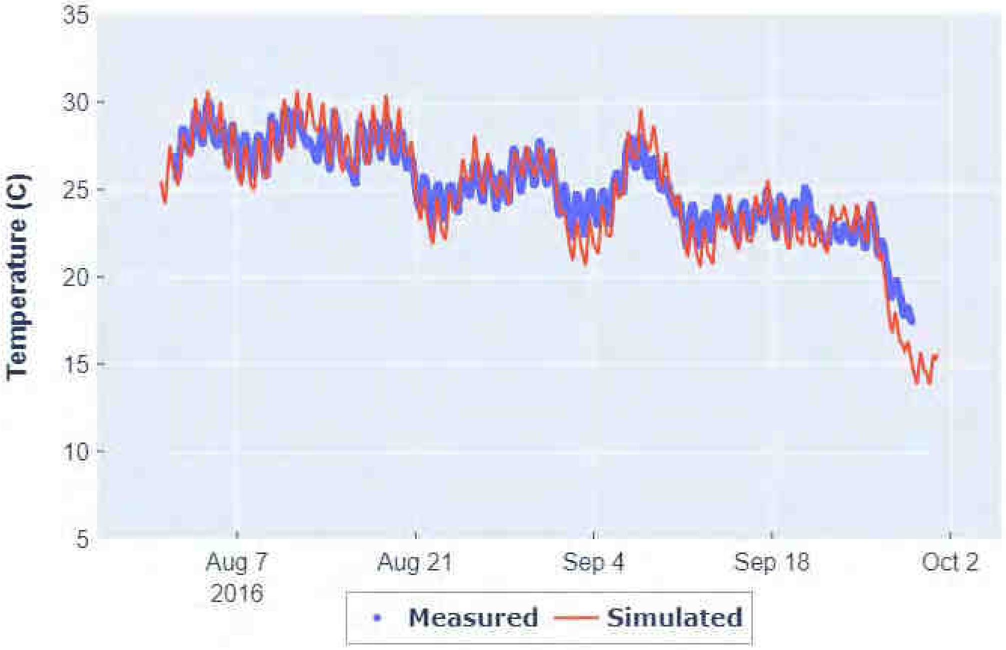


Figure 22: Simulated and Observed Temperature at Fox River - Sullivan Bridge for August to September 2016.

4.4.2.3 Total Phosphorus

The model captures spatial and temporal variation in TP concentrations well. **Figure 23** shows a comparison of range of simulated and measured TP along the length of the river for September 7 to 8, 2016.

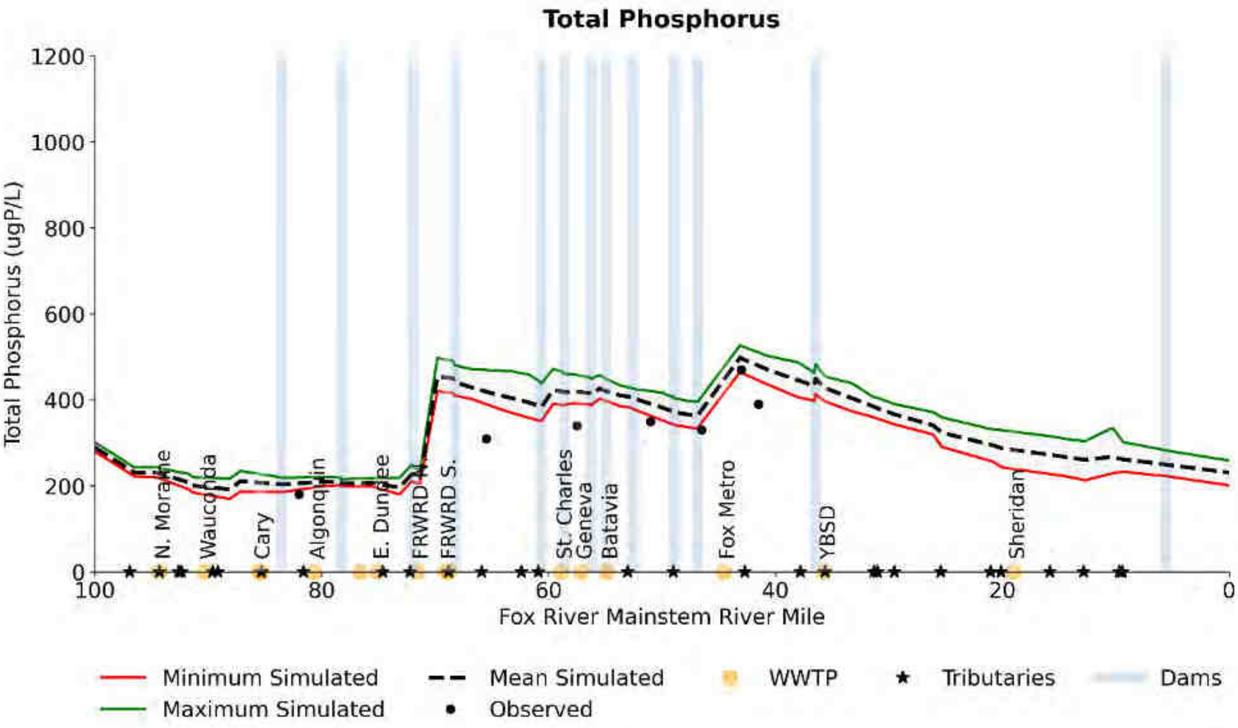


Figure 23: Longitudinal Plot for Simulated and Observed Total Phosphorus Concentration for September 7 to 8, 2016.

4.4.2.4 Ammonia

The model overpredicts observed ammonia concentrations for September 7-8, 2016. **Figure 24** shows a longitudinal plot of simulated and observed ammonia for the period of September 7 to 8, 2016. As discussed in Section 4.4.1.4, the QUAL2kw model is not well calibrated for ammonia, but is suitable for purpose of developing the FRIP which is focused on phosphorus related impairments.

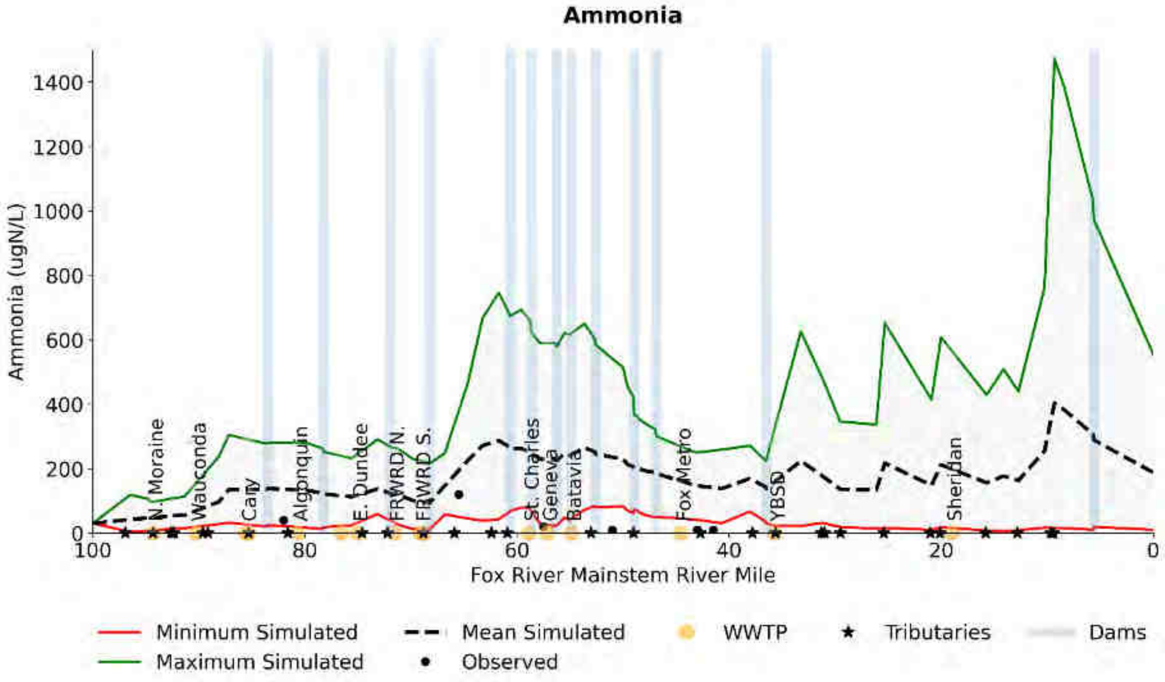


Figure 24: Longitudinal Plot for Observed and Simulated Ammonia Concentration for September 7 to 8, 2016.

4.4.2.5 Chlorophyll-a

The model was calibrated to measured chlorophyll-a collected as part of FRSG monthly and IEPA ambient water quality monitoring. The model simulated chlorophyll-a fairly well as compared to measured data for the periods except on September 20. 2016. **Figure 25** and **Figure 26** shows a longitudinal plot of simulated and measured chlorophyll-a for August 16 and September 20, 2016 respectively. The model predictions for chlorophyll-a for September 20, 2016 in the downstream reaches are overpredicted as compared to the measured data. This overprediction is reasonable since the model calibration is aimed at balancing the closeness of model predictions to different periods. In addition, only one grab sample measurement was made in the downstream reaches on September 20, 2016.

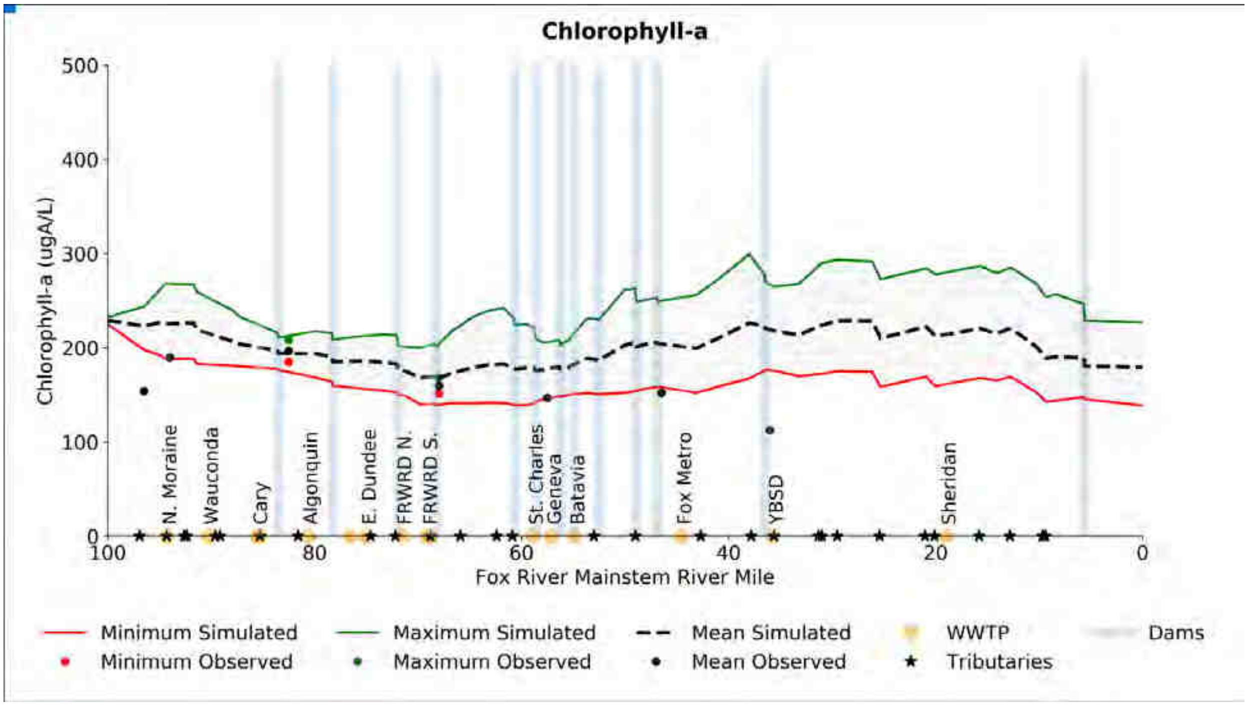


Figure 25: Longitudinal Plot for Observed and Simulated Chlorophyll-a for August 16, 2016.

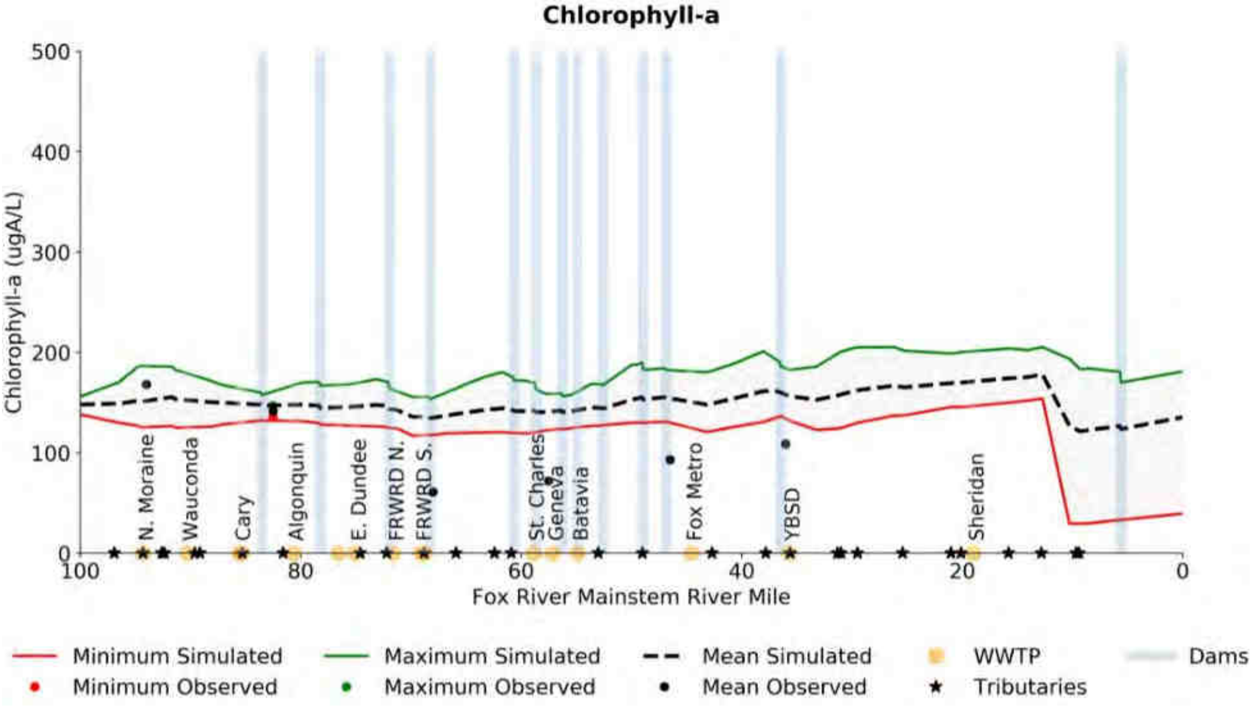


Figure 26: Longitudinal Plot for Observed and Simulated Chlorophyll-a for September 20, 2016.

4.4.2.6 Dissolved Oxygen

The model simulated diurnal variations and minimum DO concentration in most reaches well as compared to measured data. **Table 10** shows the statistics for the measured data and model results and the model-data error statistics. **Figure 27** shows simulated and observed DO concentration at Fox River - Algonquin Bike Bridge (Station 890, RM 82.5). The model predicts larger diurnal variation in DO as compared to observed data at this location but is reasonably close to the observations. The FRIP is focused on the low DO concentrations, and hence the model results are satisfactory as compared to measured data.

Table 10: Comparison of Statistics of Simulated and Measured DO for the Period of August 1 to September 2016.

Station	**Count of Data**	**Measured**				**Simulated**				**$R^{2(a)}$**	**RMS Err(b)**	**Index of Agreement(c)**	**Calibration Assessment**
		Min	**Max**	**Mean**	**Std. Dev**	**Min**	**Max**	**Mean**	**Std. Dev**				
Orchard Road	1,468	3.2	23.1	10.5	4.4	3.5	20.7	9	5	0.7	3.1	0.9	Fair
Route 34	173	5.1	17.7	9.1	3.5	4.2	16.6	8.7	4.1	0.9	1.7	1	Very Good
Route 30	1,389	5	14.5	8.8	1.6	4.8	16.1	8.7	3	0.4	2.3	0.7	Good
Sullivan Bridge	4,257	4.3	13.4	7.4	2.2	4.8	17	8.8	3.5	0.6	2.7	0.8	Good
Algonquin Bike Bridge	2,010	5.3	11.4	7.6	0.9	5.4	12.9	8.3	1.9	0.4	1.7	0.7	Good

(a) R^2: Coefficient of determination (R^2) is a statistical measure of how well the model predictions approximate the real data points. An R2 of 1 indicates that the model predictions perfectly fit the data.
(b) RMS Err : Root Mean Square Error (RMS Err) is a measure of the differences between model predictions and observed data. A low value of RMS Err indicates close agreement between data and model values.
(c) Index of Agreement is a measure of the degree of model prediction error which ranges from 0 to 1. An index of agreement of 1 indicates complete agreement of model predictions with data.

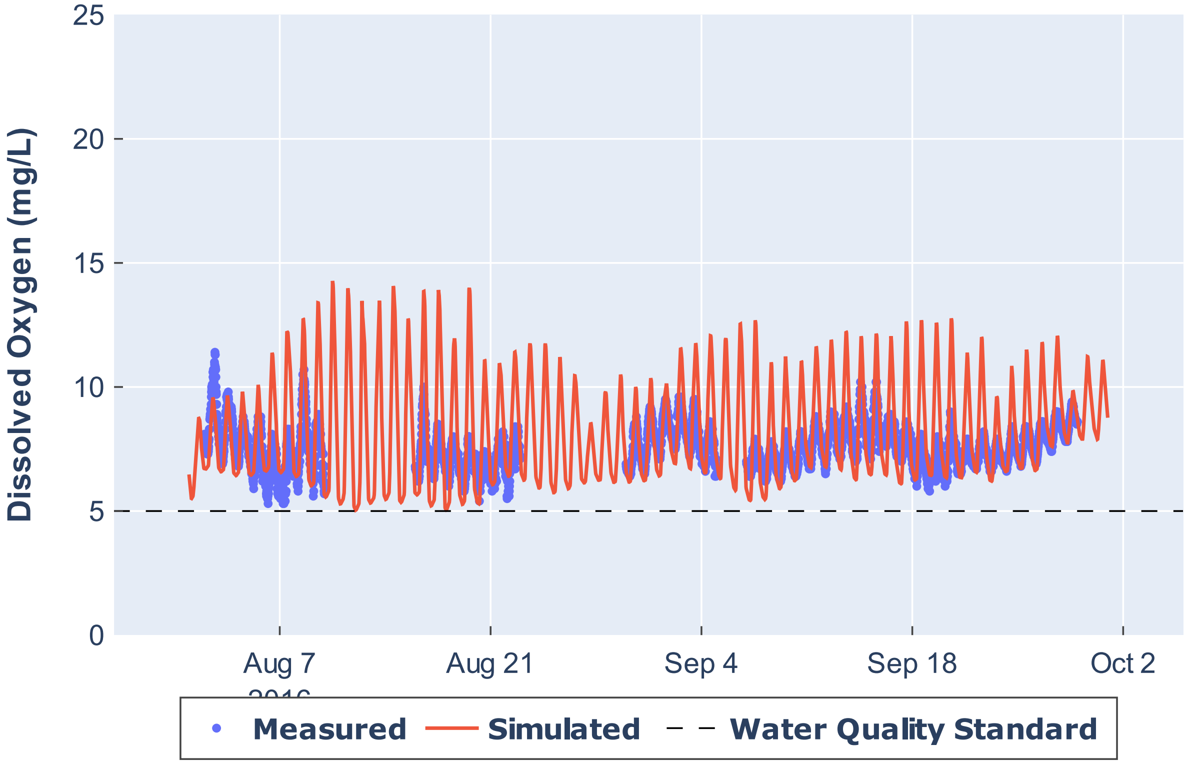


Figure 27: Simulated and Observed Dissolved Oxygen Concentration at Algonquin Bike Bridge for August to September 2016

4.4.3 Model Calibration Summary

Figure 28 presents a summary of the model calibration results at different locations along the Fox River. The model calibration for the different water quality constituents was classified as being “Very Good”, “Good” or “Fair” based on agreement with the observed data using best professional judgment. Model calibration for flow and total phosphorus was classified as being “Very Good”. For water temperature, the model calibration results ranged from “Very Good” to “Fair” at different locations along the Fox River. The model calibration for ammonia and chlorophyll-a were classified as being “Good” and “Fair”. The model calibration for the DO concentration ranged from “Very Good” to “Fair” at different locations along the Fox River.

Figure 28: Summary of Model Calibration Results

4.5 Sensitivity Analysis

A model sensitivity analysis is used to assess the effect of changes in input values or assumptions on a model's results. For the current study the impact of upstream and tributary boundary conditions (flows and concentrations) on the model results were assessed by changing these inputs by a fixed amount. The model sensitivity runs were run using the June 1 to July 31, 2012 model time period, which includes critical low flows of 523 cfs at USGS Gage 05551540 at Montgomery and 360 cfs at USGS Gage 05550001 at Algonquin. The target critical low flows were identified by the FRSG modeling subcommittee as important to the FRIP. **Table 11** provides a summary of sensitivity analysis scenarios. A detailed description of sensitivity analysis runs is provided below.

Table 11: Sensitivity Analysis Scenarios.

	Baseline	Upstream Boundary								Non Point Source Reduction	
	1A	2A	2B	2C	2D	2E	2F	2G	2H	3A	3B
Time Period											
June-July 2012 (Validation)	X	X	X	X	X	X	X	X	X	X	X
Upstream Conditions											
Existing Flow	X			X	X	X	X	X	X	X	X
Existing Flow + 20 %		X									
Existing Flow -20%			X								
Existing TP	X	X	X			X	X	X	X	X	X
Existing TP + 20 %				X							
Existing TP -20%					X						
Existing TN	X	X	X	X	X			X	X		
Existing TN + 20%						X					
Existing TN -20%							X				
Existing Chla	X	X	X	X	X	X	X				
Existing Chla + 50%								X			
Existing Chla -50%									X		
Non-Point Sources											
Existing TP Load	X	X	X	X	X	X	X	X	X		
Existing TP Load + 50%										X	
Existing TP Load - 50 %											X

4.5.1 Baseline Scenario 1A

The baseline scenario (Scenario 1A) represents the existing conditions in the Fox River simulated by the calibrated model for June 1 to July 31, 2012. For the sensitivity analyses, the baseline scenario results were compared with other sensitivity scenarios for June 25 to June 29, 2012. This time period was selected since it coincided with the period of low flow monitoring by the FRSG.

4.5.2 Upstream Flow Scenarios 2A and 2B

The relative contribution of the upstream sources, WWTPs, and tributaries to changes in flow along the Fox River is shown in **Figure 29**. This figure serves as reference for understanding the results of the sensitivity analysis scenarios for upstream flow input. Scenarios 2A and 2B were run by changing model inputs of upstream flow at Stratton Dam by +20% and -20 % respectively from the baseline scenario.

Figure 30 shows the impact of change in upstream flows on the five (5)-day mean simulated TP concentration in the Fox River. The figure indicates that increasing the upstream flows results in slight increases in TP concentrations compared to the baseline scenario in the upstream reaches because of increased upstream TP load. For the downstream reaches, increasing the upstream flow results in decreased TP concentration since it results in higher relative proportion of upstream flow (with lower TP concentration), as compared to the WWTP flows. Reducing the upstream flows results in impacts opposite on simulated TP to the description above for increase in upstream flow.

Figure 31 shows the impact of changes in upstream flow on the mean simulated chlorophyll-a in the Fox River. Increasing the upstream flows results in slight increases in chlorophyll-a compared to the baseline scenario in the upstream reaches because of increased upstream chlorophyll-a load. For the downstream reaches, increasing the upstream flow results in decreased chlorophyll-a concentration compared to the baseline scenario since it results in higher velocities in the steeper downstream reaches (average slope of 2.7 feet per mile) which reduces the decay of chlorophyll-a. The reduction in upstream flow has an opposite impact on simulated chlorophyll-a to the description above for increase in upstream flow.

Figure 32 shows the impact of changes in upstream flow on the minimum simulated DO concentration in the Fox River. The figure indicates that increasing the upstream flows results in slightly decreased levels of minimum DO concentrations compared to the baseline scenario in the upstream reaches because of increased chlorophyll-a levels. For the downstream reaches of the Fox River, increasing the upstream flow results in increased DO concentration compared to the baseline scenario because of reduced chlorophyll-a levels. The reduction in upstream flow has an opposite impact on simulated minimum DO concentrations to the description above for increase in upstream flow.

Overall, these sensitivity analysis results show that model predictions for TP, chlorophyll-a, and minimum DO are not very sensitive to the changes in the model inputs for upstream flow.

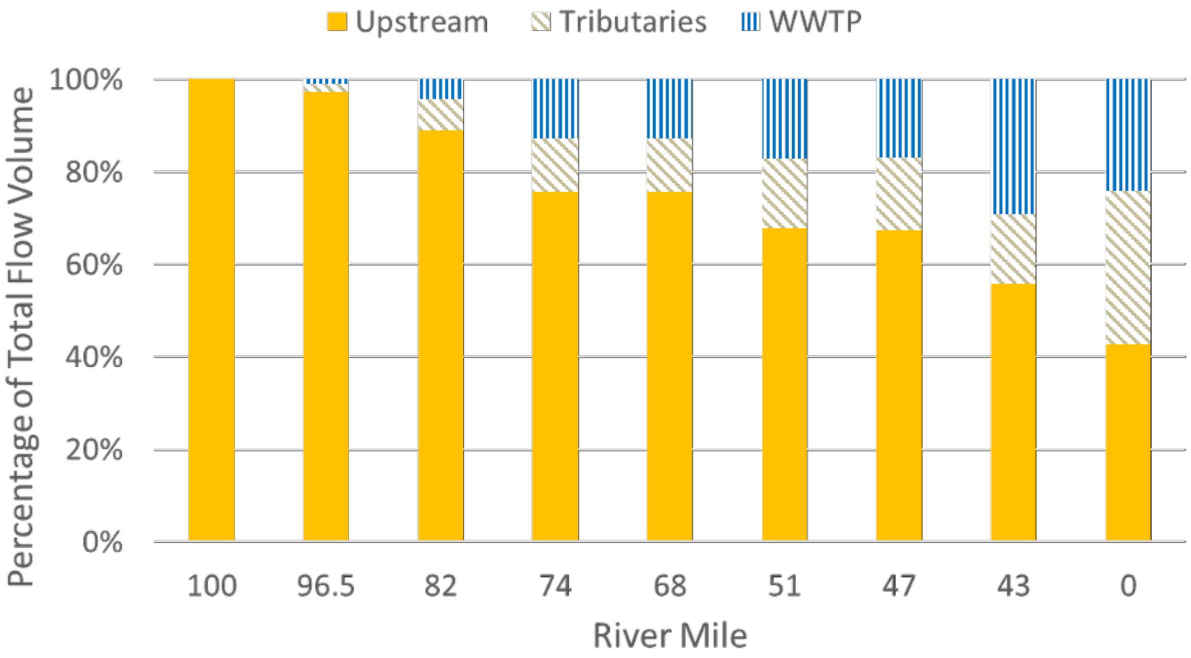


Figure 29: Simulated Relative Contribution to Volumes along the Fox River for the Baseline Scenario

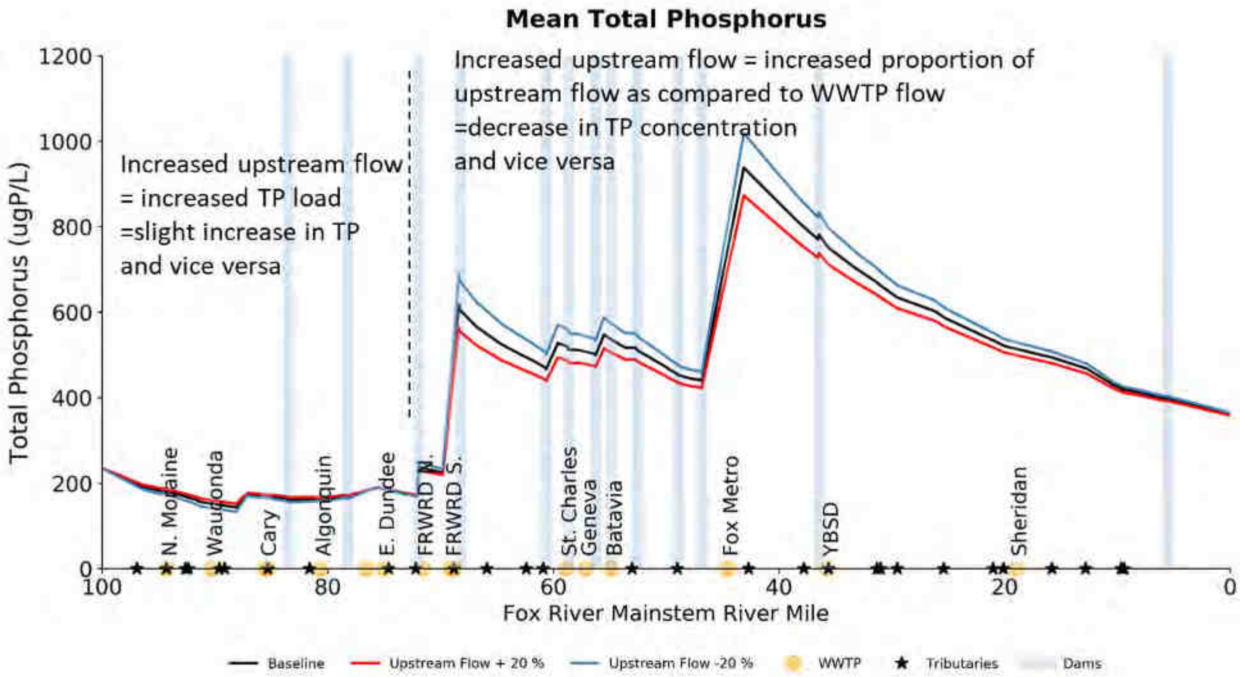


Figure 30: Impact of Change in Upstream Flow on Simulated Total Phosphorus in Fox River for the Period of June 25 to 29, 2012

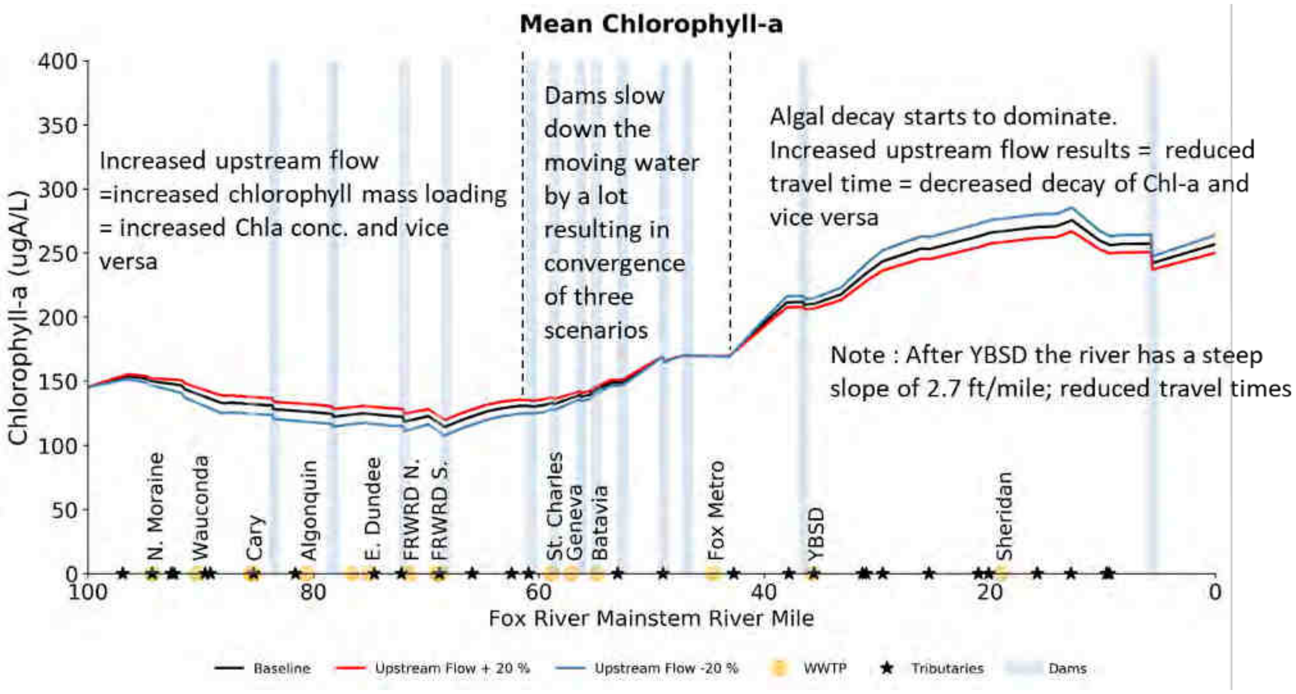


Figure 31: Impact of Change in Upstream Flow on Simulated Chlorophyll-a in Fox River for the Period of June 25 to 29, 2012

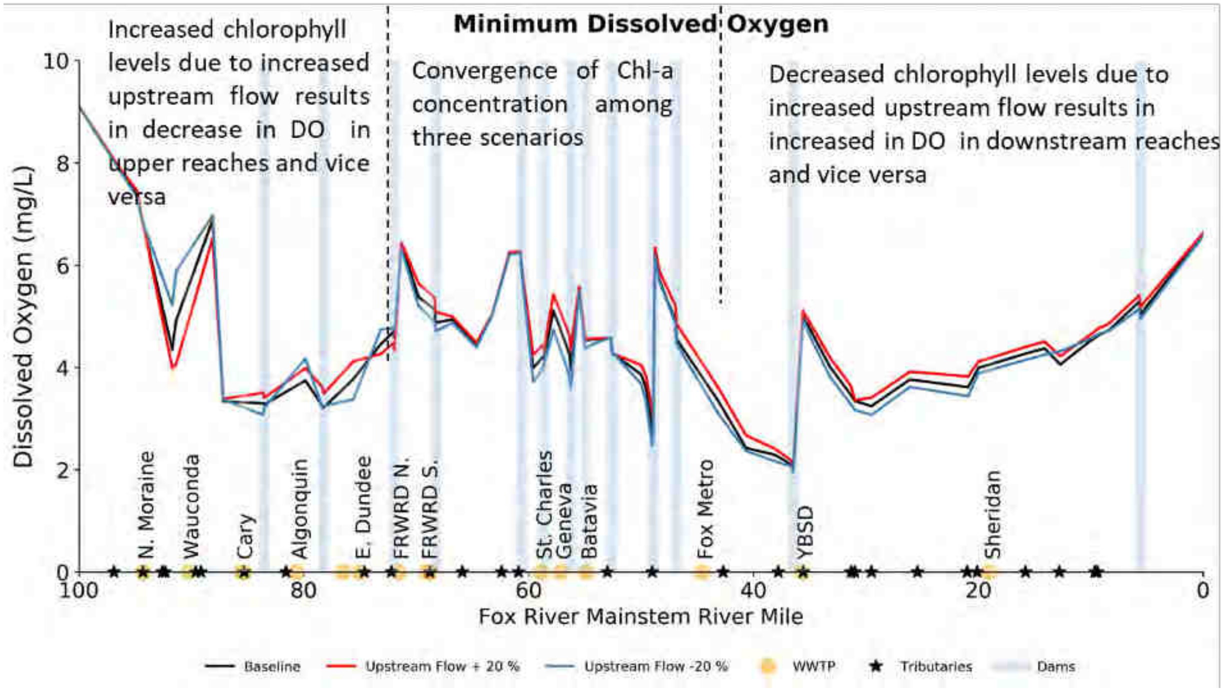


Figure 32: Impact of Change in Upstream Flow on Simulated Dissolved Oxygen in Fox River for the Period of June 25 to 29, 2012

4.5.3 Upstream Total Phosphorus Boundary Concentration Scenarios 2C and 2D

The relative contribution of upstream sources, WWTPs, and tributaries to TP loading inputs for the baseline condition along the Fox River is shown in **Figure 34**. This figure serves as reference for understanding the results of sensitivity analysis scenario for the upstream TP boundary concentration scenarios. Scenarios 2C and 2D were run by changing model inputs of the upstream TP boundary concentration at Stratton Dam by +20% and -20% respectively as compared to baseline scenarios; upstream flows were unchanged. **Figure 34** shows the impact of changes in upstream TP boundary concentration on the simulated mean TP. The results show that the change in upstream TP boundary concentration results in a slight change in simulated TP in the upstream reaches of the Fox River. For the downstream reaches of the Fox River, the impact of the change in the upstream TP concentration is minimal because of increased relative contribution of WWTP and tributaries to TP load in the downstream reaches. The slight change in TP concentration due to change in upstream TP boundary concentrations results in only a small change in model predictions for chlorophyll-a and DO (**Figure 35** and **Figure 36**). These results indicate that the model was not sensitive to changes in the current upstream TP boundary concentration. This is because the reduction in upstream TP concentration (in particular) did not result in phosphorus limitation of algal growth in the upper reaches of the Fox River.

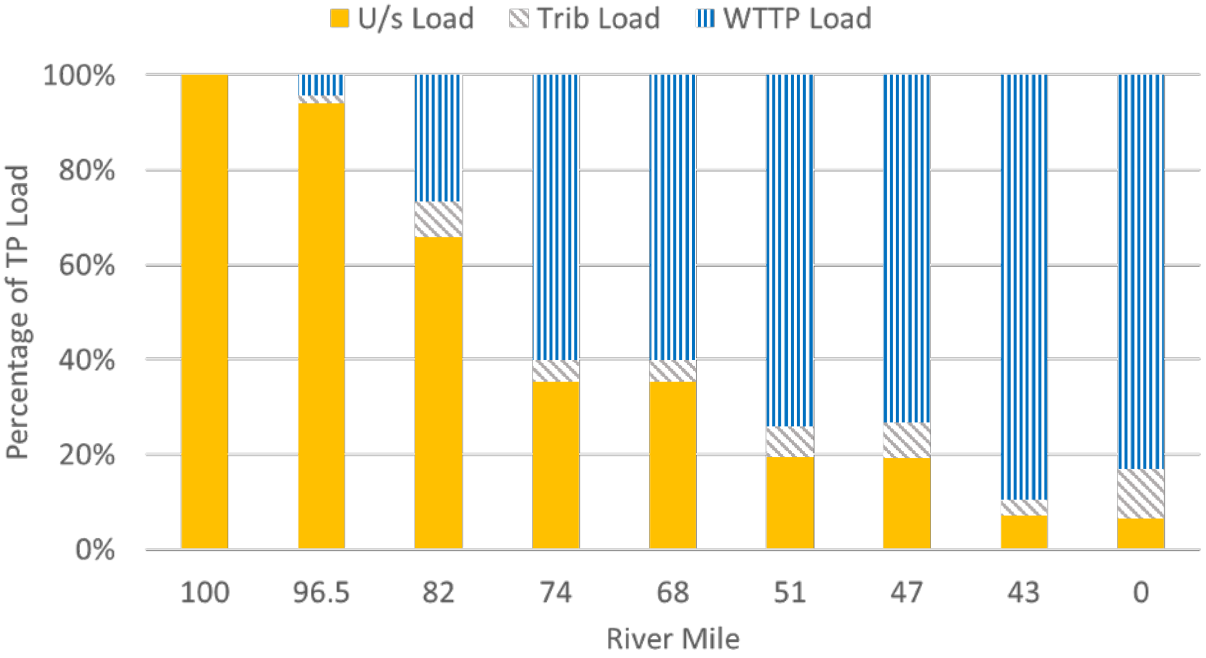


Figure 33: Simulated Relative Contribution to Total Phosphorus Load along the Fox River for the Baseline Scenario

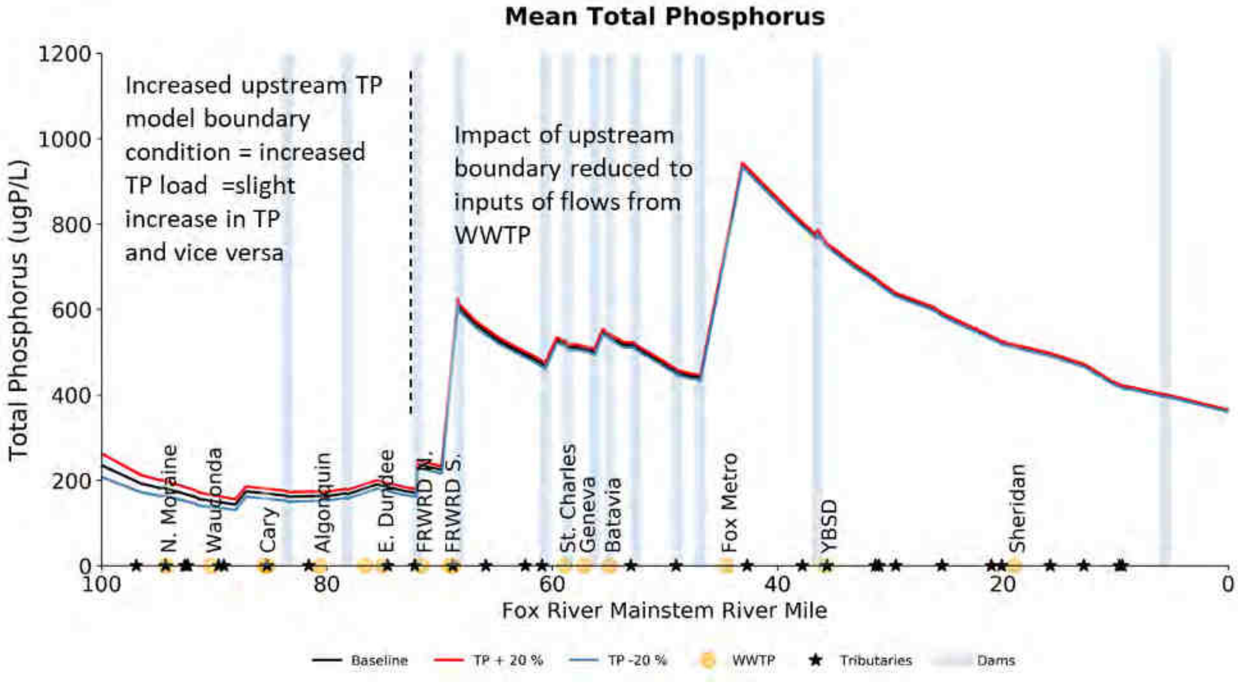


Figure 34: Impact of Change in Upstream Total Phosphorus Boundary Concentration on Simulated Total Phosphorus in Fox River for the Period of June 25 to 29, 2012

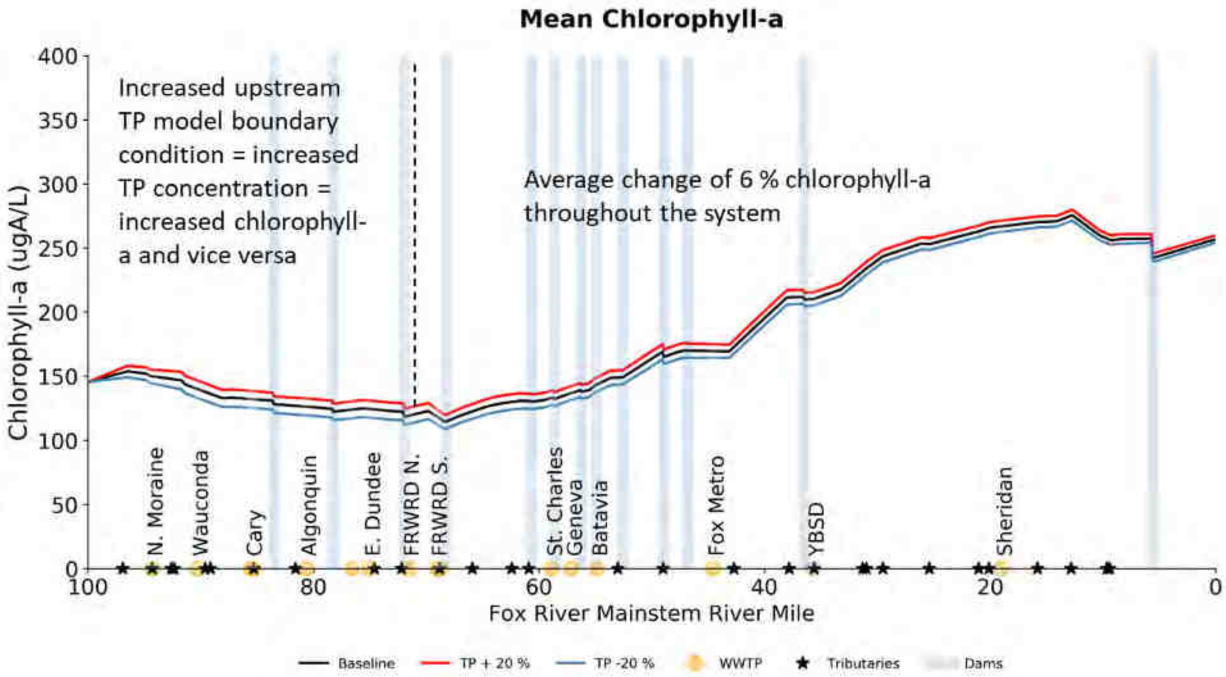


Figure 35: Impact of Change in Upstream Total Phosphorus Boundary Concentration on Simulated Chlorophyll-a in Fox River for the Period of June 25 to 29, 2012

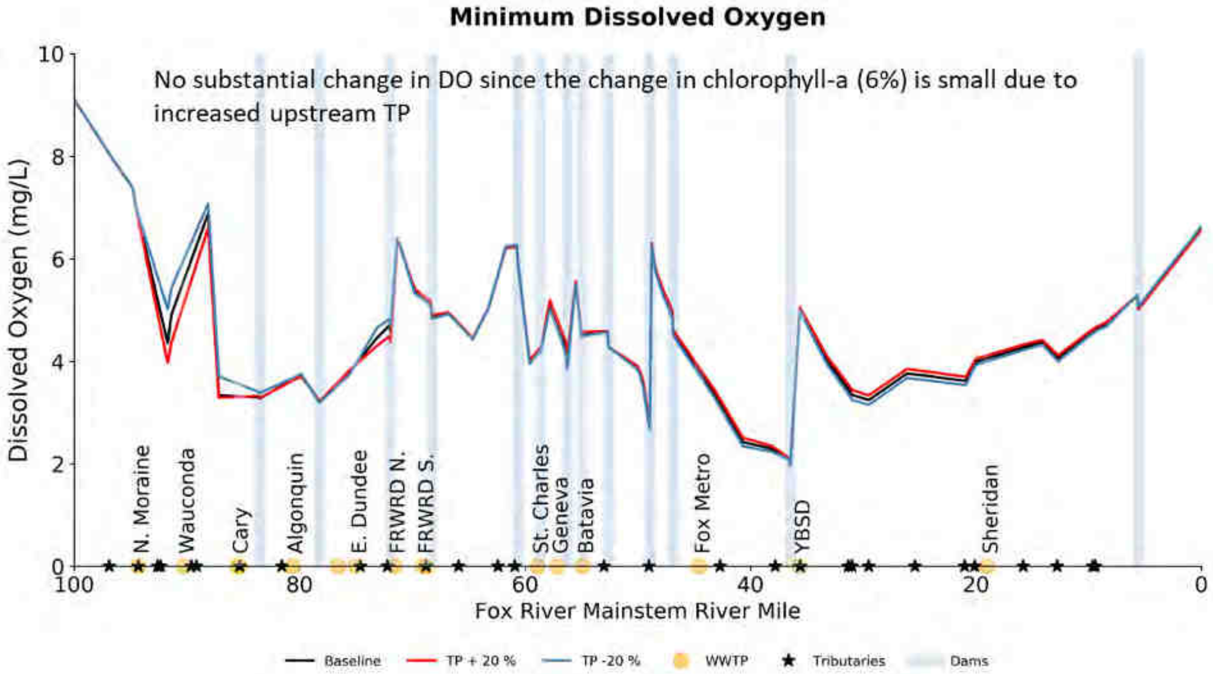


Figure 36: Impact of Change in Upstream Total Phosphorus Boundary Concentration on Simulated Dissolved Oxygen in Fox River for the Period of June 25 to 29, 2012

4.5.4 Upstream Total Nitrogen Boundary Concentration Scenarios 2E and 2F

The relative contribution of upstream sources, WWTPs, and tributaries to TN loading inputs along the Fox River is shown in **Figure 37**. This figure serves as reference for understanding the results of sensitivity analysis scenario for upstream TN boundary concentration scenarios. Scenarios 2E and 2F were run by changing model inputs of upstream TN boundary concentration at Stratton Dam by +20% and -20 % respectively as compared to the baseline scenario. The change in upstream TN concentrations results in a change in the relative contribution of upstream load along the Fox River. **Figure 38** shows the impact of change in upstream TN boundary concentration on the simulated mean TN. The results show that a change in the upstream TN boundary condition results in a large change in simulated TN in the Fox River since the relative proportion of upstream TN load is much higher as compared to WWTP and tributary load. This change in simulated TN does not result in changes in simulated mean chlorophyll-a and minimum DO since TN is not the limiting nutrient in the Fox River (**Figure 39** and **Figure 40**). These results indicate the model results for TN are very sensitive to the upstream TN boundary concentration, however it does not have much impact on the chlorophyll and DO model predictions.

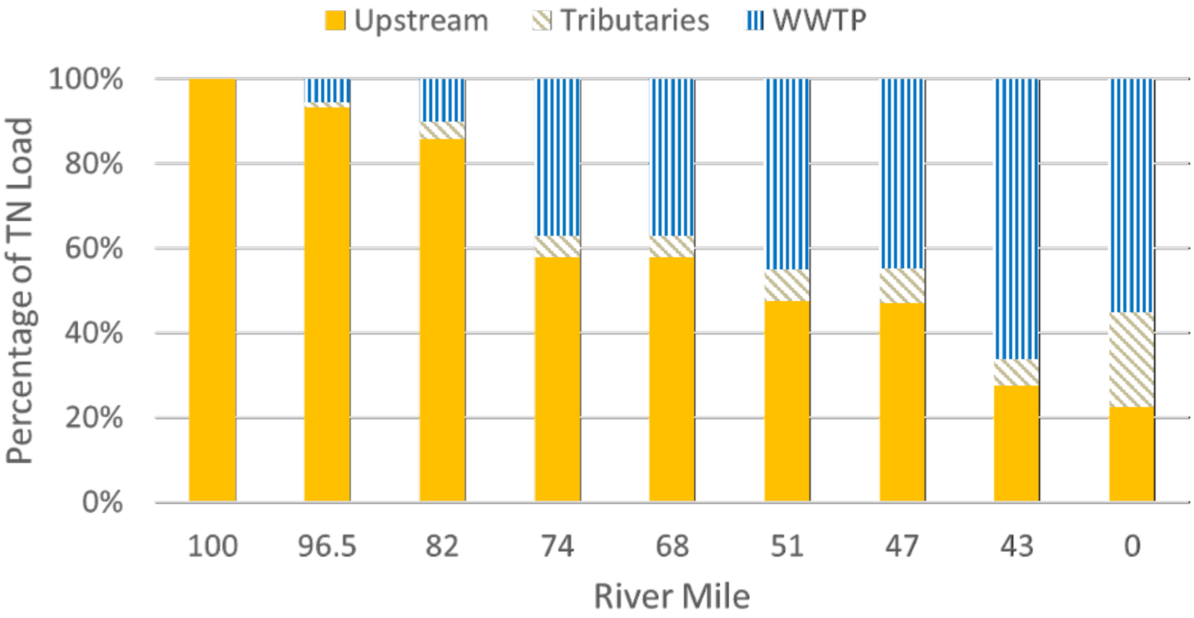


Figure 37: Simulated Relative Contribution to Total Nitrogen Load along the Fox River for the Baseline Scenario

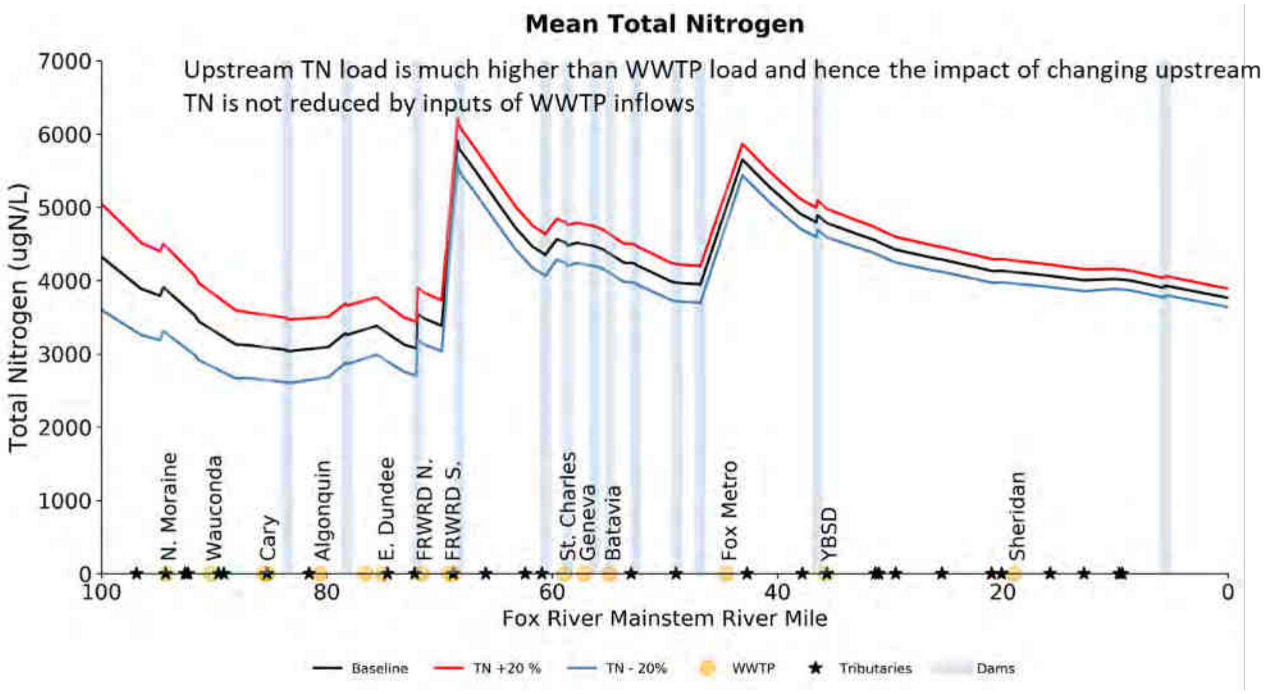


Figure 38: Impact of Change in Upstream Total Nitrogen Boundary Concentration on Simulated Total Nitrogen in Fox River for the Period of June 25 to 29, 2012

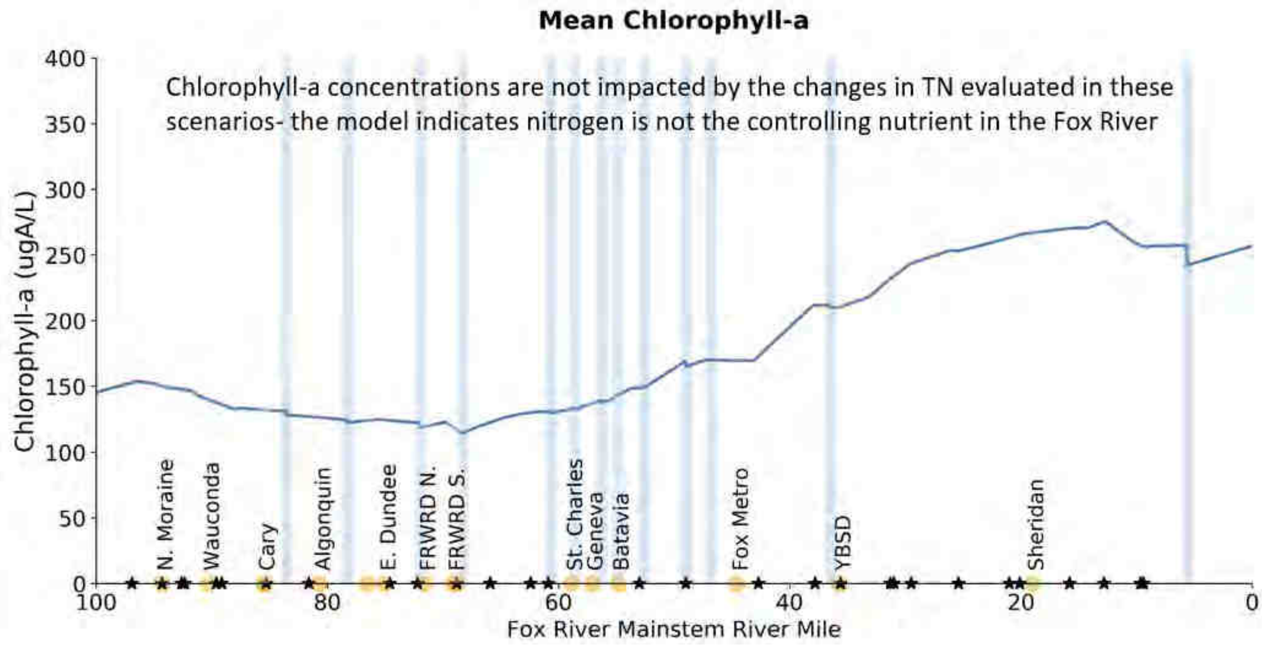


Figure 39: Impact of Change in Upstream Total Nitrogen Boundary Concentration on Simulated Chlorophyll-a in Fox River for the Period of June 25 to 29, 2012

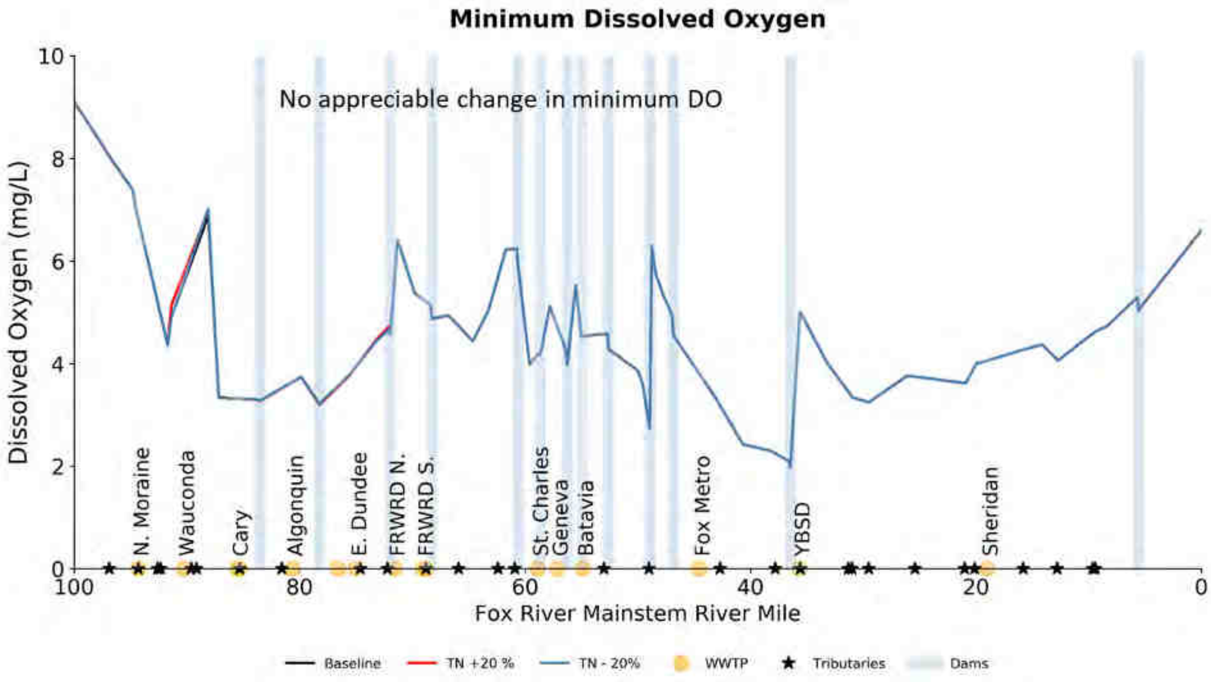


Figure 40: Impact of Change in Upstream Total Nitrogen Boundary Concentration on Simulated Dissolved Oxygen in Fox River for the Period of June 25 to 29, 2012

4.5.5 Upstream Chlorophyll-a Boundary Concentration Scenarios 2G and 2H

Scenarios 2G and 2H were run by changing model inputs of the upstream chlorophyll-a boundary concentration at Stratton Dam by +50% and -50 % respectively as compared to the baseline scenario. The upstream chlorophyll-a was changed by a higher percentage as compared to TP and TN boundary condition since the upstream chlorophyll-a has a higher degree of variability.

Figure 41 show the impact of changes in upstream chlorophyll-a boundary concentration on mean simulated chlorophyll-a. The increase in upstream chlorophyll-a boundary concentration results in increased chlorophyll-a levels as compared to the baseline scenario and vice-versa. This impact is reduced in the downstream reaches of Fox River because of inputs of flows from WWTP and tributaries, i.e. the upstream boundary conditions have less impact the further downstream. The simulated TP in the Fox River also increased compared to the baseline scenario due to increase in upstream chlorophyll-a boundary condition which represents an increase in algal mass (**Figure 42**), which contains phosphorous. In reviewing the figure, the difference in TP concentration narrows over the distance due to 1) the upstream boundary condition having less influence on the river than more immediate WWTPs and 2) some of the phosphorous being transformed in the environment. The increased chlorophyll-a levels via increase in sestonic algae (assumed) results in a decrease in bottom algae concentration because of reduction in light availability and vice-versa (**Figure 43**). **Figure 44** shows the impact from changing the upstream chlorophyll-a boundary concentration on the minimum DO concentration over June 25th to 29th. It should be noted that the DO concentration changes over time due to algal productivity (benthic and sestonic), location in the water column and overall water depth which influences reaeration and light attenuation. The instream water quality model is well mixed over depth (1-D) and so this "averages" out differences that might exist over depth due to productivity. As sestonic algae increases in concentration the benthic algae concentration decreases due to less light availability. In the upper reaches of the Fox River where the upstream boundary conditions dominate the minimum DO concentration decreases due to an increase in algal productivity (e.g. larger diurnal swings) in the fast-moving reach before the first dam. As the water slow down for a series of dams then the sestonic productivity increases with increased loading but the benthic algal productivity decreases when the Chlorophyll-a concentration is reduced the benthic algae tends to dominate more. The result is that in large stretches of the Fox River an increase in Chlorophyll-a loading from upstream results in higher minimum DO concentrations, and when the Chlorophyll-a loading is reduced the minimum DO drops.

These results indicate that the minimum DO concentration model predictions are sensitive to changes in upstream chlorophyll-a boundary condition. As a result, it is recommended to continue monitoring of upstream chlorophyll-a at the upstream boundary for future modeling updates and for understanding when upstream loading in particular year could be heavy or light.

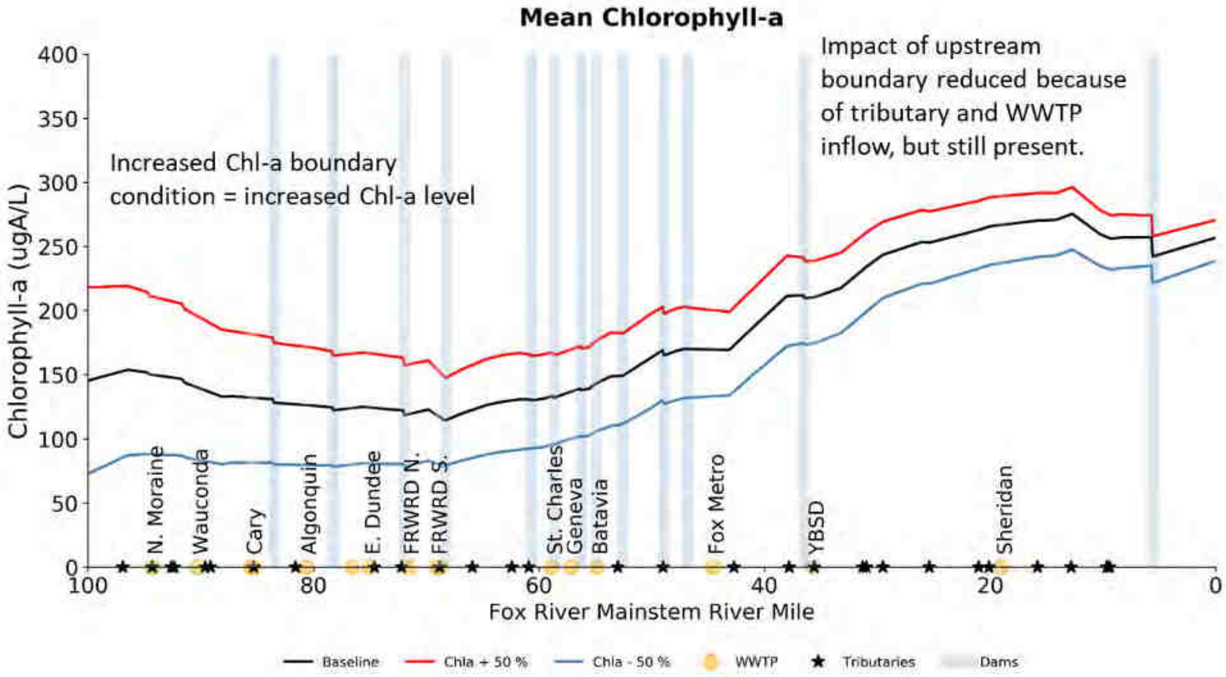


Figure 41: Impact of Change in Upstream Chlorophyll-a Concentration on Simulated Chlorophyll-a in Fox River for the Period of June 25 to 29, 2012

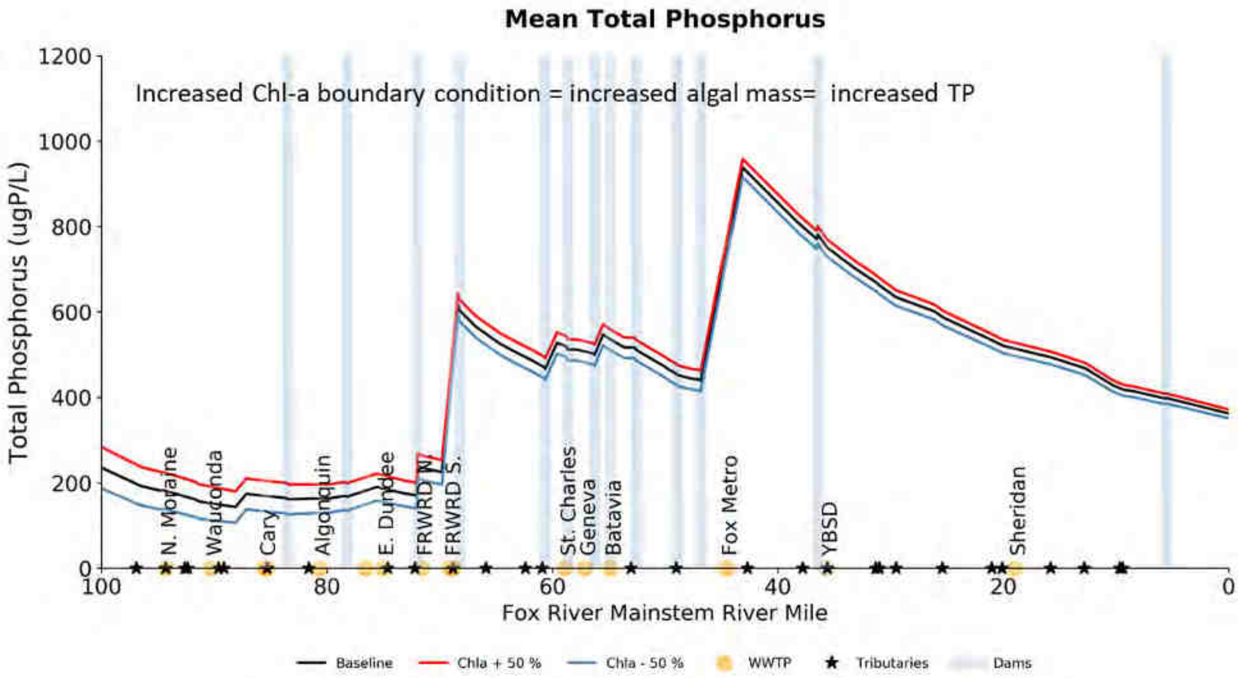


Figure 42: Impact of Change in Upstream Chlorophyll-a Boundary Concentration on Simulated Total Phosphorus in Fox River for the Period of June 25 to 29, 2012

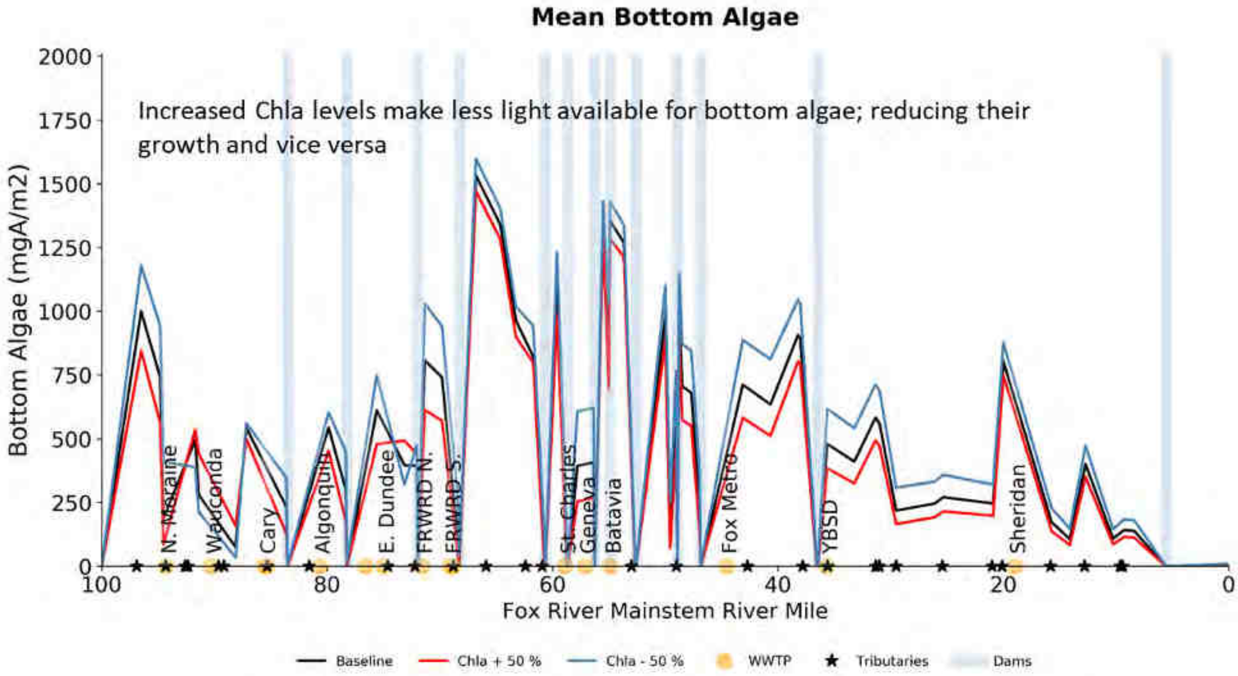


Figure 43: Impact of Change in Upstream Chlorophyll-a Boundary Concentration on Simulated Chlorophyll-a in Fox River for the Period of June 25 to 29, 2012

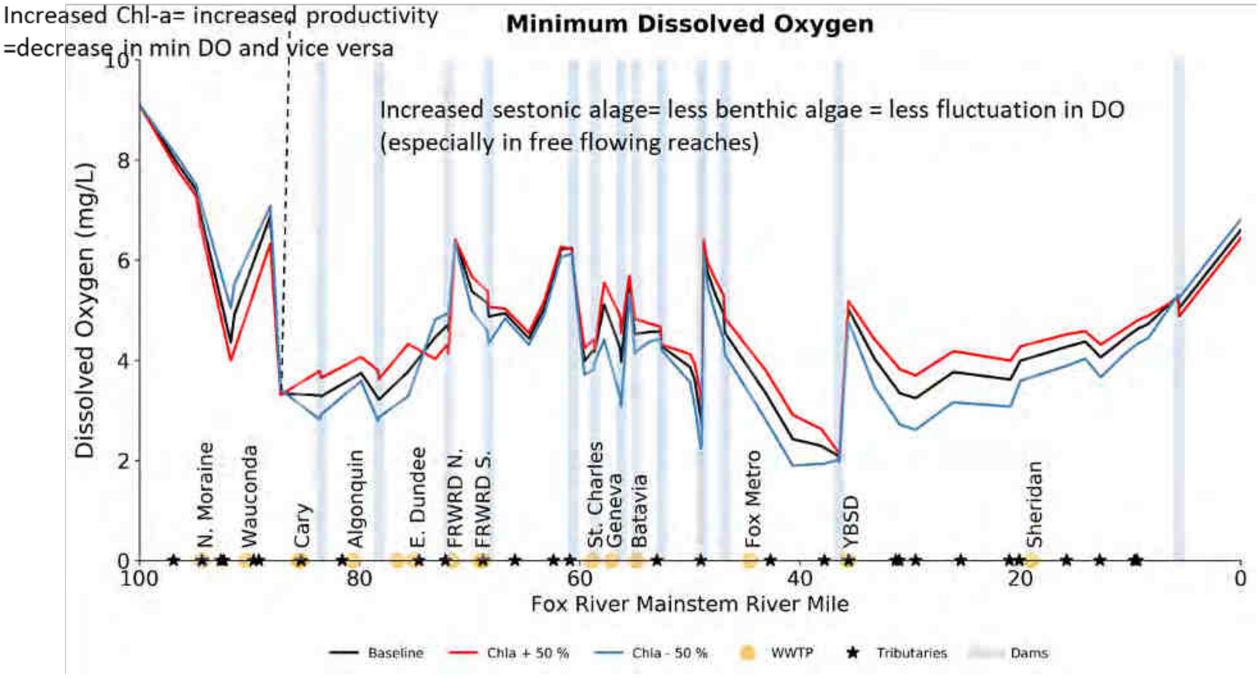


Figure 44: Impact of Change in Upstream Chlorophyll Boundary Concentration on Simulated Dissolved Oxygen in Fox River for the Period of June 25 to 29, 2012

4.5.6 Tributary Loads Scenarios 3A and 3B

Scenarios 2G and 2H were run by changing of the tributary TP loading to the model by +50% and -50 % respectively. **Figure 45** and **Figure 46** show the impact of this loading change on the simulated mean TP and Chlorophyll-a in the Fox River over June 25th to June 29th, 2012. These figures indicate the TP and chlorophyll-a increase with successive increased tributary inputs and vice-versa and when moving downstream. For the upstream reaches, as TP loading to the river increases from more and more tributary inflows productivity increases which results in larger diurnal swing in DO concentration and hence a decreased minimum DO and vice-versa when the TP loading is decreased (**Figure 47**). The minimum DO is increased in the downstream free-flowing reaches of the Fox River where the bottom algae are decreased because of increase in sestonic chlorophyll-a levels (and from the increase in cumulative loading). These results indicate that model predictions are more sensitive to changes in tributary TP loading as compared to change in the upstream TP boundary concentrations (Scenarios 2C and 2D). This is because the impact of upstream boundary diminishes as more tributary flow drain into the main stem Fox River from upstream to downstream.

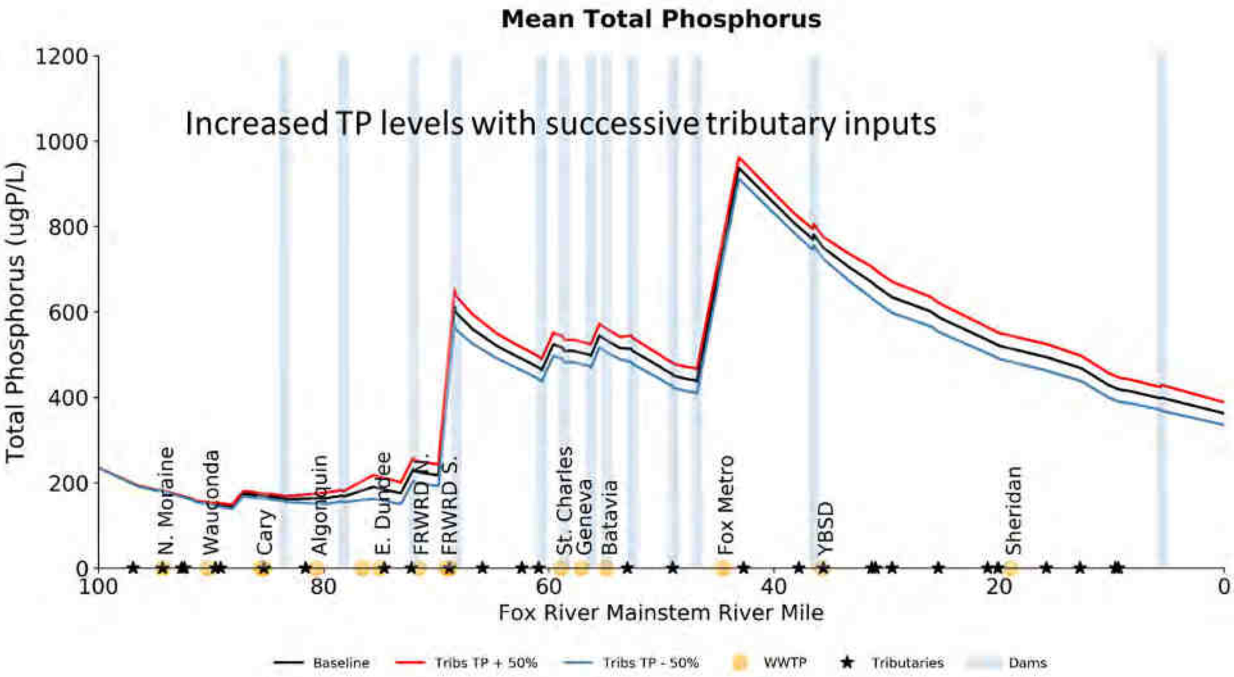


Figure 45: Impact of Change in Tributary Total Phosphorus Loading on Simulated Total Phosphorus in Fox River for the Period of June 25 to 29, 2012

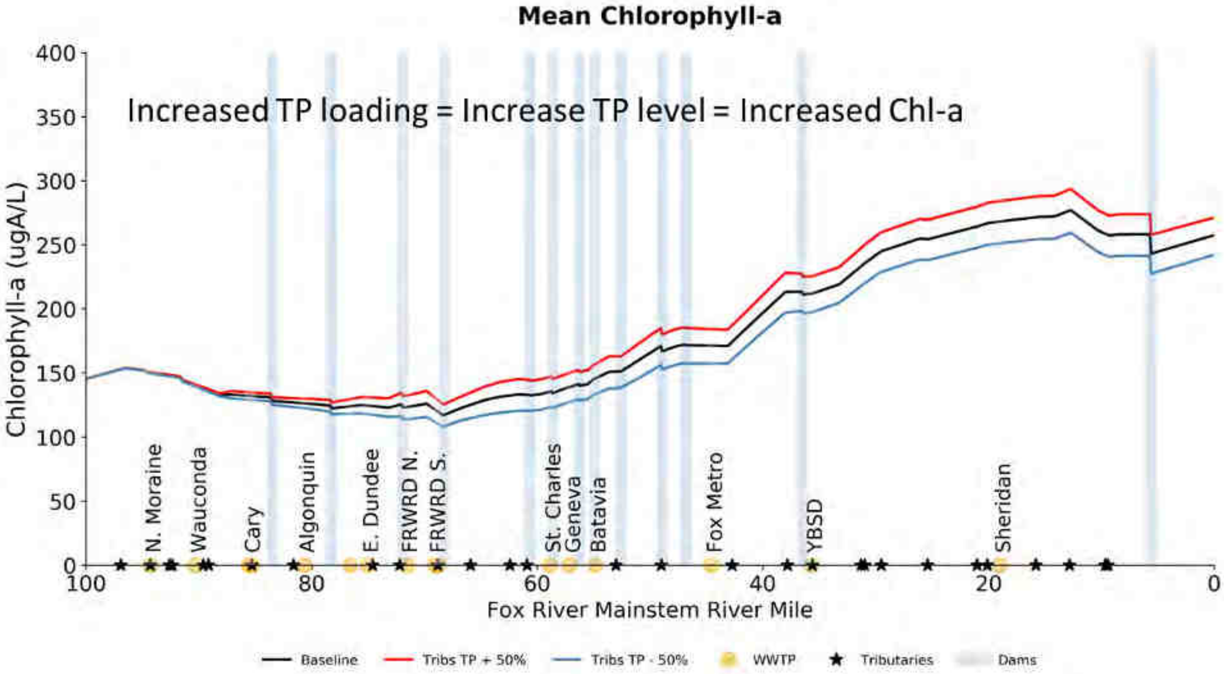


Figure 46: Impact of Change in Tributary Total Phosphorus Loading on Simulated Chlorophyll-a in Fox River for the Period of June 25 to 29, 2012

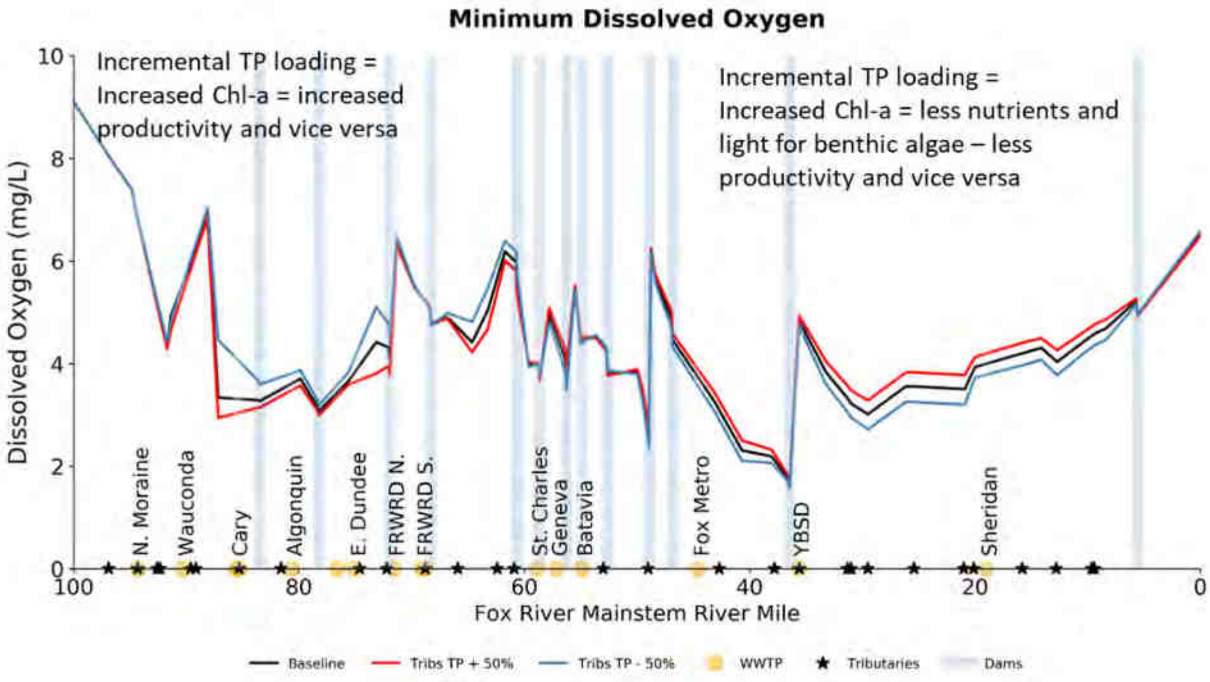


Figure 47: Impact of Change in Tributary Total Phosphorus Loading on Simulated Dissolved Oxygen in Fox River for the Period of June 25 to 29, 2012

SECTION 5

SUMMARY AND CONCLUSIONS

The QUAL2k water quality model of Fox River was updated and recalibrated for the FRSG to support the development of the FRIP. This report documents the update, recalibration and performance of the water quality model. As part of this effort, the issues associated with the FRIP Model were diagnosed and addressed. The existing HSPF watershed model for the FRIP study area was also updated to more accurately simulate the flows and loading of TP and TN for the period of 2011 to 2016. The timeseries of flow and loadings from the HSPF model were used as inputs into the instream water quality model.

The instream model was updated to a dynamic version of QUAL2k, QUAL2kw, to ensure the model can simulate the changes in water quality over time. Model inputs updated as part of the current study included upstream boundaries, sediment oxygen demand, point sources and tributary inputs, channel characteristics, and benthic algae based on recent data. The updated model was calibrated to measured data for flow, temperature, nutrients, chlorophyll-a and DO to observed collected during low flow time periods of June to July 2012 and August to September 2016. The calibrated model predictions for flow, temperature, phosphorus, and chlorophyll-a are in reasonably close agreement with the observed data. The calibrated model simulates the observed diurnal variations in DO at different locations in the Fox River and sufficiently captures the minimum DO levels in most reaches of the river.

This effort provides the FRSG with an improved tool that can be applied to help identify the management actions related to the impact of phosphorus loads on algae and dissolved oxygen. As described in Section 4.4.1.4, the model would require further calibration if it is to be applied to evaluate levels of nitrogen in the river.

SECTION 6

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Attachments 1 Water Quality Model Inputs (Excel Workbook)

Table A-1 QUAL2kw Model Flow and Concentration Input for June to July 2012

Model Reach	Inflow	Flow (cfs)			Dissolved Oxygen (mg/L)			Chlorophyll-a (ug/L)			Organic Phosphorus (ug/L)			Inorganic Phosphorus (ug/L)			Organic Nitrogen (ug/L)			Ammonia (ug/L)			Nitrate-nitrite (mg/L)		
		Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max
0	Flow from Upstream	113.3	237.0	517.0	9.1	12.6	16.9	93.4	154.2	207.7	67.2	112.5	142.5	13.8	23.0	29.2	3372.5	3372.5	3372.5	29.3	40.2	54.2	98.6	209.4	98.6
1	Sleepy Hollow	3.0	6.4	30.5	8.1	10.0	12.1	0.1	0.1	0.2	76.5	139.0	356.2	8.5	15.4	39.6	558.4	809.9	1,824.3	14.9	182.2	2,745.7	591.1	1,463.4	4,021.7
2	Northern Moraine	0.7	0.7	0.7	6.0	6.0	6.0	0.0	0.0	0.0	178.2	178.2	178.2	19.8	19.8	19.8	4,000.0	4,000.0	4,000.0	70.0	70.0	70.0	5,000.0	5,000.0	5,000.0
3	Wauconda	1.6	1.6	1.6	8.4	8.4	8.4	0.0	0.0	0.0	639.0	639.0	639.0	71.0	71.0	71.0	481.0	480.9	481.0	329.4	329.4	329.4	23,433.3	23,433.3	23,433.3
4	Cotton,Silver Lake,Silx	1.2	3.6	25.2	5.6	7.9	10.9	0.1	0.2	0.5	62.1	91.2	248.4	6.9	10.1	27.6	362.4	500.9	1,296.5	28.1	405.5	3,409.7	665.9	1,323.5	5,542.8
5	MainStem_Reach 5	3.1	5.7	10.3	6.6	7.9	10.9	2.4	17.8	45.1	7.8	29.0	83.5	0.9	3.2	9.3	31.9	154.6	320.7	0.0	83.5	488.1	889.8	1,322.6	2,250.5
6	Flint,Tower Lake	8.7	11.9	44.5	8.0	10.6	12.2	0.1	0.1	0.1	139.9	222.1	282.1	15.5	24.7	31.3	515.8	812.0	965.7	33.0	191.2	1,229.4	1,198.2	1,671.7	3,526.5
7	Cary WWTP,Fox River	3.3	3.3	3.3	6.3	6.3	6.3	0.0	0.0	0.0	2,170.3	2,889.2	4,795.5	241.1	321.0	532.8	2,013.8	2,736.8	4,737.4	990.0	1,052.1	2,318.6	2,803.0	8,051.9	9,770.2
8	Spring Creek	0.5	2.0	10.0	6.7	8.9	12.5	0.1	0.1	0.2	41.2	73.4	120.2	4.6	8.2	13.4	264.8	422.5	776.5	13.2	374.3	2,014.1	385.4	945.6	3,167.9
9	MainStem_Reach 9	2.2	4.0	7.3	6.6	7.9	10.9	2.4	17.8	45.1	7.8	29.0	83.5	0.9	3.2	9.3	31.9	154.6	320.7	0.0	83.5	488.1	889.8	1,322.6	2,250.5
10	Crystal Lake	7.8	11.0	54.8	8.9	11.8	13.3	0.1	0.1	0.1	267.6	444.7	712.9	29.7	49.4	79.2	1,322.1	1,616.2	2,124.6	45.8	252.1	2,064.5	4,033.0	6,404.1	11,001.1
11	Algonquin WWTP	4.0	4.5	5.3	6.2	6.8	7.5	0.0	0.0	0.0	315.0	498.7	1,080.0	35.0	55.4	120.0	2,261.9	3,519.7	5,057.6	33.6	107.8	199.0	6,785.8	10,559.0	15,172.7
12	MainStem_Reach 12	1.9	3.5	6.2	6.6	7.9	10.9	2.4	17.8	45.1	7.8	29.0	83.5	0.9	3.2	9.3	31.9	154.6	320.7	0.0	83.5	488.1	889.8	1,322.6	2,250.5
13	Carpentersville,East Du	3.7	4.0	4.6	7.6	7.8	8.0	0.0	0.0	0.0	1,785.6	1,925.8	2,139.7	198.4	214.0	237.7	5,083.0	5,083.0	5,083.0	236.4	489.5	613.5	15,249.0	15,249.0	15,249.0
14	Jelkes,Tyler	3.0	8.7	49.5	3.2	6.6	13.1	0.1	0.1	0.3	43.0	72.8	193.5	4.8	8.1	21.5	275.4	512.9	1,228.3	10.7	418.2	2,648.6	1,310.6	2,561.8	4,630.4
15	Elgin WTP intake	-16.6	-27.0	-35.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	FRWRD North	5.5	6.3	7.8	6.4	6.4	6.4	0.0	0.0	0.0	1,806.1	2,428.8	2,664.0	200.7	269.9	296.0	1,195.5	1,517.8	1,900.0	76.7	100.8	160.0	12,600.0	21,342.8	25,200.0
17	Poplar Creek	1.9	6.5	49.0	6.8	8.4	12.2	0.1	0.1	0.7	26.5	61.6	260.3	2.9	6.8	28.9	166.1	414.3	1,438.8	7.8	549.8	3,192.8	346.9	1,641.7	4,337.0
18	MainStem_Reach 18	0.0	0.0	0.0	6.6	7.9	10.9	2.4	17.8	45.1	7.8	29.0	83.5	0.9	3.2	9.3	31.9	154.6	320.7	0.0	83.5	488.1	889.8	1,322.6	2,250.5
19	FRWRD S. and W.	28.1	31.1	35.4	6.4	6.4	6.4	0.0	0.0	0.0	2,248.7	3,141.9	3,797.9	249.9	349.1	422.0	961.7	1,377.8	1,801.1	91.4	130.3	289.9	22,590.9	27,823.4	30,884.7
20	MainStem_Reach 20	2.0	3.7	6.6	6.6	7.9	10.9	2.4	17.8	45.1	7.8	29.0	83.5	0.9	3.2	9.3	31.9	154.6	320.7	0.0	83.5	488.1	889.8	1,322.6	2,250.5
22	Brewster	0.6	2.4	28.7	5.3	9.2	12.2	0.1	0.1	0.8	41.8	81.7	312.8	4.6	9.1	34.8	232.9	478.0	1,629.5	16.7	474.9	3,601.8	254.6	1,018.5	4,271.2
23	IL Water RG	0.0	0.0	0.0	6.8	6.8	6.8	0.0	0.0	0.0	4,950.0	4,950.0	4,950.0	550.0	550.0	550.0	9,500.0	9,500.0	9,500.0	100.0	100.0	100.0	14,610.0	14,610.0	14,610.0
24	Norton	0.5	1.7	15.8	6.0	8.6	12.2	0.1	0.1	0.4	40.3	63.8	241.9	4.5	7.1	26.9	264.7	404.6	1,333.5	14.3	349.8	2,936.7	333.6	966.6	4,286.9
25	Ferson	2.7	7.9	44.5	7.5	8.9	12.6	0.1	0.1	0.1	37.5	65.1	138.9	4.2	7.2	15.4	252.4	465.8	917.8	5.9	333.7	1,925.9	431.0	1,424.3	4,185.7
26	MainStem_Reach 26	0.1	0.4	0.8	0.4	1.3	2.0	0.1	11.1	44.1	292.8	576.2	1,166.0	32.5	64.0	129.6	38.5	245.6	580.6	40.7	347.4	697.2	4,325.2	5,984.6	9,750.7
27	St Charles WWTP	5.5	6.2	8.0	7.3	7.7	8.4	0.0	0.0	0.0	4,123.0	4,123.0	4,123.0	217.0	217.0	217.0	5,083.0	5,083.0	5,083.0	15.7	226.0	882.0	15,249.0	15,249.0	15,249.0
30	Geneva	5.7	5.8	5.9	0.0	0.0	0.0	0.0	0.0	0.0	1,143.0	1,143.0	1,143.0	127.0	127.0	127.0	1,057.0	1,057.0	1,057.0	160.0	200.7	240.0	9,610.9	9,610.9	9,610.9
32	MainStem_Reach 32	0.8	2.1	4.7	0.4	1.3	2.0	0.1	11.1	44.1	292.8	576.2	1,166.0	32.5	64.0	129.6	38.5	245.6	580.6	40.7	347.4	697.2	4,325.2	5,984.6	9,750.7
33	Batavia WWTP	4.3	4.9	6.9	6.3	7.3	8.3	0.0	0.0	0.0	4,683.5	4,683.5	4,683.5	246.5	246.5	246.5	1,626.6	3,098.6	10,964.7	170.0	313.2	630.0	4,879.7	9,295.9	32,894.2
35	MainStem_Reach 35	0.2	0.6	1.4	0.4	1.3	2.0	0.1	11.1	44.1	292.8	576.2	1,166.0	32.5	64.0	129.6	38.5	245.6	580.6	40.7	347.4	697.2	4,325.2	5,984.6	9,750.7
37	Mill Creek	1.8	4.8	38.1	7.4	11.7	15.5	0.1	0.1	0.2	226.1	878.1	2,108.7	25.1	97.6	234.3	735.9	1,574.9	2,629.6	9.0	265.7	2,478.0	1,117.4	3,962.2	7,266.3
39	Aurora WTP intake	-10.7	-16.4	-20.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	MainStem_Reach 42	0.7	2.0	4.4	0.4	1.3	2.0	0.1	11.1	44.1	292.8	576.2	1,166.0	32.5	64.0	129.6	38.5	245.6	580.6	40.7	347.4	697.2	4,325.2	5,984.6	9,750.7
44	MainStem_Reach 44	0.0	0.1	0.1	0.4	1.3	2.0	0.1	11.1	44.1	292.8	576.2	1,166.0	32.5	64.0	129.6	38.5	245.6	580.6	40.7	347.4	697.2	4,325.2	5,984.6	9,750.7
46	MainStem_Reach 46	0.3	0.8	1.8	0.4	1.3	2.0	0.1	11.1	44.1	292.8	576.2	1,166.0	32.5	64.0	129.6	38.5	245.6	580.6	40.7	347.4	697.2	4,325.2	5,984.6	9,750.7
48	IL Water TC	0.0	0.0	0.1	6.1	6.3	6.6	0.0	0.0	0.0	3,600.0	3,600.0	3,600.0	400.0	400.0	400.0	5,083.0	5,083.0	5,083.0	100.0	114.8	131.0	15,249.0	15,249.0	15,249.0
49	FMWRD	44.7	50.5	61.4	7.5	8.0	8.4	0.0	0.0	0.0	4,560.0	4,560.0	4,560.0	48.0	48.0	48.0	1,483.0	1,655.9	1,859.2	111.0	540.0	2,060.0	13,400.0	18,016.0	22,100.0
50	Waubonsie	1.4	5.8	73.6	4.7	7.1	12.5	0.1	0.3	1.0	41.6	87.6	292.8	4.6	9.7	32.5	212.8	434.2	1,845.0	13.4	545.8	3,681.3	644.0	1,561.1	4,813.0
51	Morgan Creek	0.9	2.3	7.7	4.4	6.9	12.3	0.1	0.2	0.5	71.4	93.4	158.1	7.9	10.4	17.6	366.0	434.0	702.8	18.5	167.2	2,021.1	1,214.3	2,458.2	3,826.2
53	MainStem_Reach 53	1.7	4.5	10.0	0.4	1.3	2.0	0.1	11.1	44.1	292.8	576.2	1,166.0	32.5	64.0	129.6	38.5	245.6	580.6	40.7	347.4	697.2	4,325.2	5,984.6	9,750.7
54	Yorkville Bristol	2.9	3.3	3.8	8.0	8.6	9.2	0.0	0.0	0.0	2,430.0	2,739.6	3,060.0	270.0	304.4	340.0	5,083.0	5,083.0	5,083.0	10.0	80.9	110.0	15,249.0	15,249.0	15,249.0
55	Blackberry	4.4	12.0	34.3	7.6	9.0	11.9	0.1	0.1	0.2	53.3	101.8	221.9	5.9	11.3	24.7	401.9	672.5	1,229.1	13.1	341.2	2,935.0	123.9	1,575.8	4,435.7
56	Big Rock Creek,Rob Rc	8.1	21.1	57.3	5.0	8.0	13.5	0.1	0.1	0.1	77.1	399.6	952.9	8.6	44.4	105.9	475.2	663.9	1,063.0	11.4	174.3	1,793.2	995.1	2,902.7	5,297.8
57	Little Rock	4.0	9.8	27.6	3.7	7.2	12.3	0.1	0.1	0.2	97.3	674.9	1,395.4	10.8	75.0	155.0	394.9	1,042.1	1,684.3	7.1	176.8	1,678.0	2,968.8	5,289.6	8,021.6
58	Hollenback	0.6	1.5	4.8	3.4	6.0	12.6	0.1	0.2	0.3	72.7	98.3	124.8	8.1	10.9	13.9	337.5	405.1	534.7	25.2	92.0	921.5	1,115.5	2,892.3	4,605.2
59	MainStem_Reach 59	1.7	4.5	10.1	0.4	1.3	2.0	0.1	11.1	44.1	292.8	576.2	1,166.0	32.5	64.0	129.6	38.5	245.6	580.6	40.7	347.4	697.2	4,325.2	5,984.6	9,750.7
60	Clear Creek	0.5	2.9	15.4	5.1	8.3	11.9	0.1	0.1	0.3	84.0	118.1	452.3	9.3	13.1	50.3	363.5	507.5	1,776.2	18.2	153.2	2,976.4	1,072.7	2,628.0	9,664.0
61	Roods Creek	1.1	6.9	31.6	5.1	8.5	11.0	0.1	0.1	0.4	61.1	107.1	676.6	6.8	11.9	75.2	350.7	519.7	2,612.3	15.4	199.0	5,938.1	899.6	3,221.5	16,191.5
62	Somonauk	4.0	10.0	26.7	5.2	7.8	11.9	0.1	0.1	0.1	23.5	65.8	168.3	2.6	7.3	18.7	151.9	288.5	506.2	6.8	72.8	600.9	1,350.4	2,846.4	4,140.1
63	Mission Creek	0.5	5.8	49.4	4.3	8.6	13.0	0.1	0.2	1.0	61.9	134.4	846.6	6.9	14.9	94.1	320.8	596.1	3,461.0	12.3	293.1	7,212.4	890.4	3,629.5	18,138.6
64	MainStem_Reach 64	2.4	6.2	14.0	0.4	1.3	2.0	0.1	11.1	44.1	292.8	576.2	1,166.0	32.5	64.0	129.6	38.5	245.6	580.6	40.7	347.4	697.2	4,325.2	5,984.6	9,750.7
65	Brumbach	0.2	4.1	47.0	2.1	8.1	12.6	0.1	0.3	1.5	74.2	170.0	741.8	8.2	18.9	82.4	323.4	609.5	2,951.0	22.0	278.4	5,691.5	800.3	3,680.2	15,519.5
67	Indian Creek	25.3	256.0	1,900.6	7.4	9.0	10.8	0.1	0.8	10.5	43.9	190.5	699.3	4.9	21.2	77.7	299.1	848.1	2,798.4	11.3	590.5	5,258.5	441.7	4,258.1	11,838.0
68	Buck	3.5	9.3	24.9	6.3	8.5	11.2	0.1	0.1	0.1	36.5	54.8	196.6	4.1	6.1	21.8	243.4	353.7	1,202.6	5.9	90.3	1,747.0	937.5	3,189.1	5,820.6
71	MainStem_Reach 71	3.5	9.2	20.7	0.4	1.3	2.0	0.1	11.1	44.1	292.8	576.2	1,166.0	32.5	64.0	129.6	38.5	245.6	580.6	40.7	347.4	697.2	4,325.2	5,984.6	9,750.7

Legend

Upstream Boundary	Tributary	WWTP	Main Stem Direct Drainage	Drinking Water Intake

Attachment 2 Water Quality Model Calibration Detailed Results

Geosyntec consultants

FRSG Model Recalibration

September 1, 2019

Revised September 25, 2019

QUAL2kw Recalibration

- Calibrated the model using data for two periods
  - June 1 – July 31, 2012
  - August 1 – September 2016

- Updated the rating curves of few reaches to match reported depths
- Updated upstream boundary condition for TP, NH4 and Chl-a based on measured data collected at Rawson Bridge (2012) and Burton’s Bridge (2016) Stations
- Calibrated the model to higher values of chlorophyll-a
- Calibrated the model to better match the minimum DO

Summary of Model Results for June to July 2012

Geosyntec
consultants

Low Flow Period 2012

- June 1 – July 31, 2012
  - More spatial distribution of stations along the river
  - Secondary dataset for calibration

- Flow range during the period
  - Algonquin Gauge: 200 to 400 cfs
  - Montgomery Gauge: 250 to 1,000 cfs

- Datasets used for recalibration
  - IEPA data
  - FRSG Monthly data
  - Low Flow Data except chlorophyll-a*

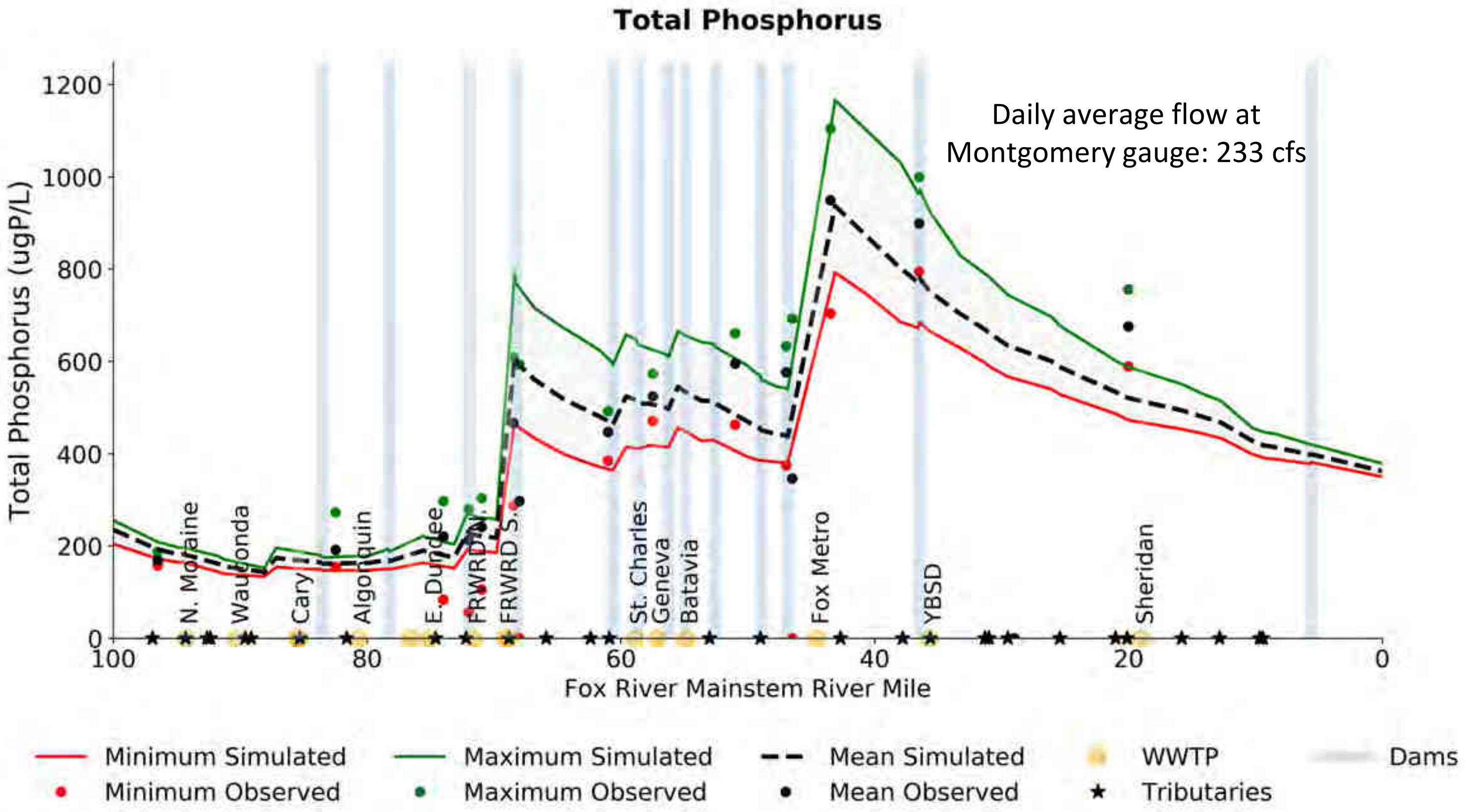
*Chlorophyll-a data measured by First Environment was not utilized since it was assessed to have issues

Model results summary for June – July 2012

- Model predictions of flow is good
- Temperature is underpredicted in several reaches
- Model matches measured TP well
- Model matches measured ammonia reasonably well
- Model matches the measured Chl-a fairly well
- Model does a good job in capturing diurnal variation and minimum DO in most reaches
- Much better prediction as compared to FRIP model
  - Limitation of 1D model in ‘pool’ reaches

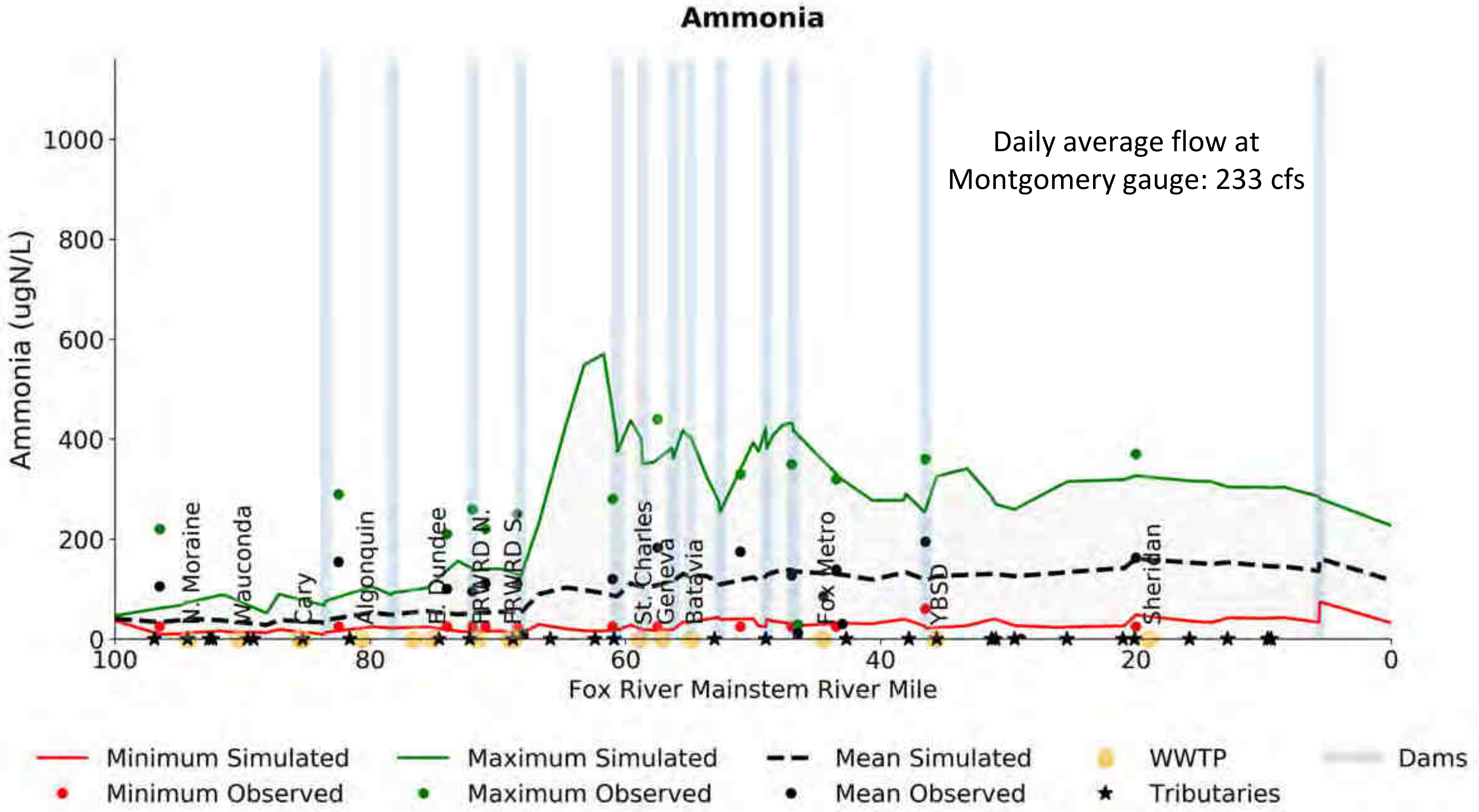
Total Phosphorus June 25-29, 2012

(Figure comparable to Figure 3-3 in FRIP)



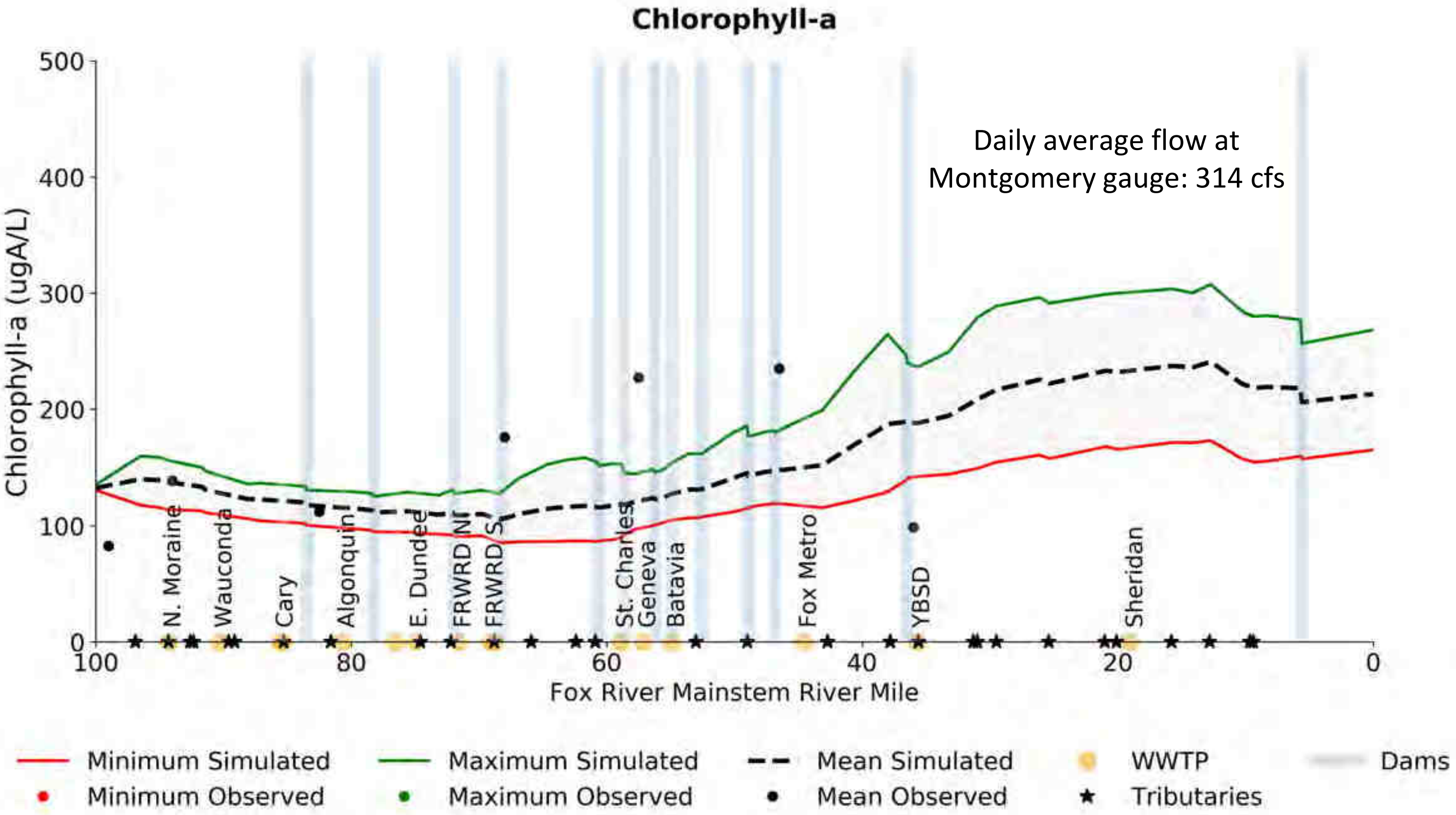
Daily average flow at Montgomery gauge: 233 cfs

Ammonia, June 25-29, 2012

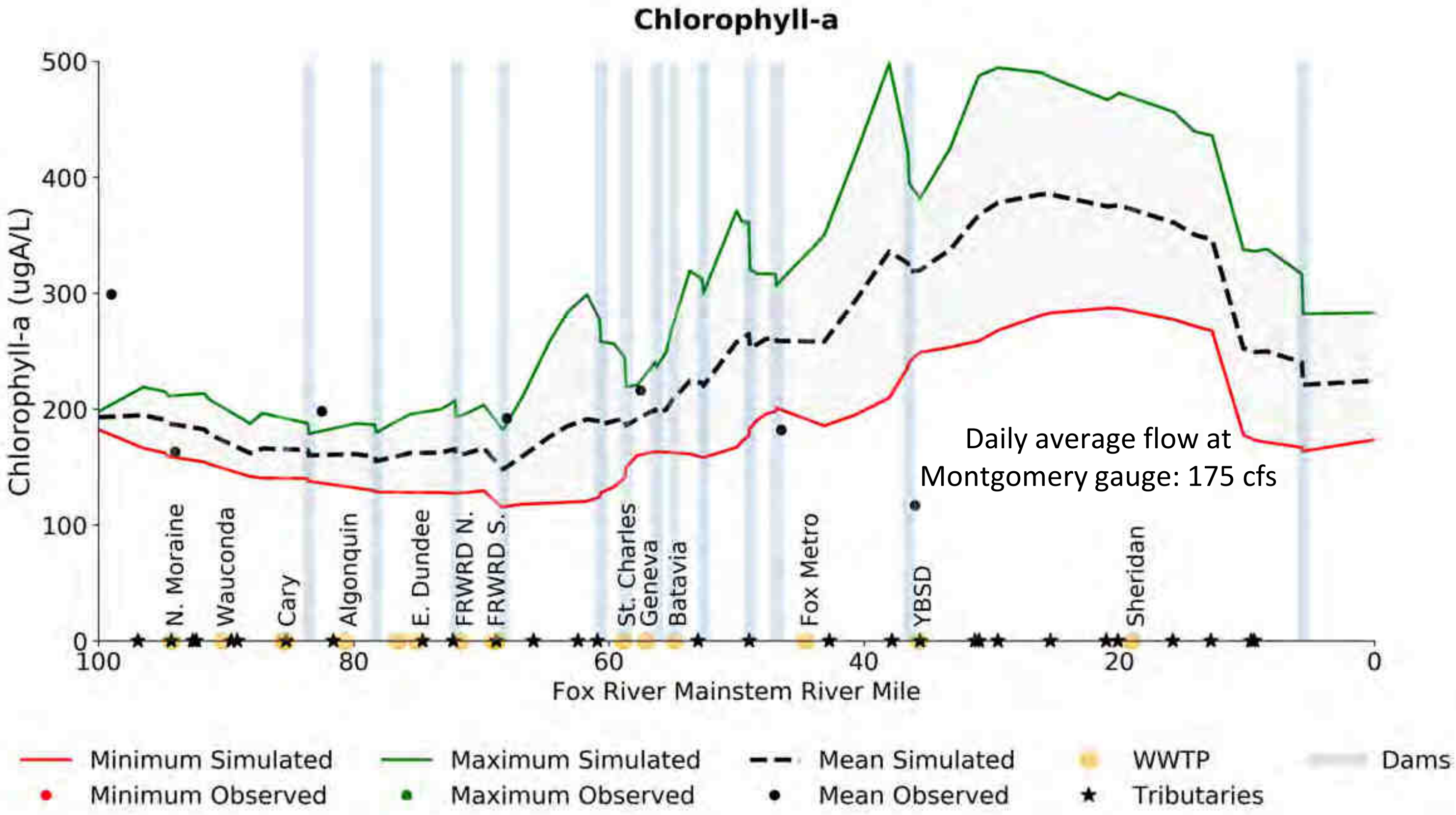


Daily average flow at Montgomery gauge: 233 cfs

Chlorophyll-a, June 19, 2012

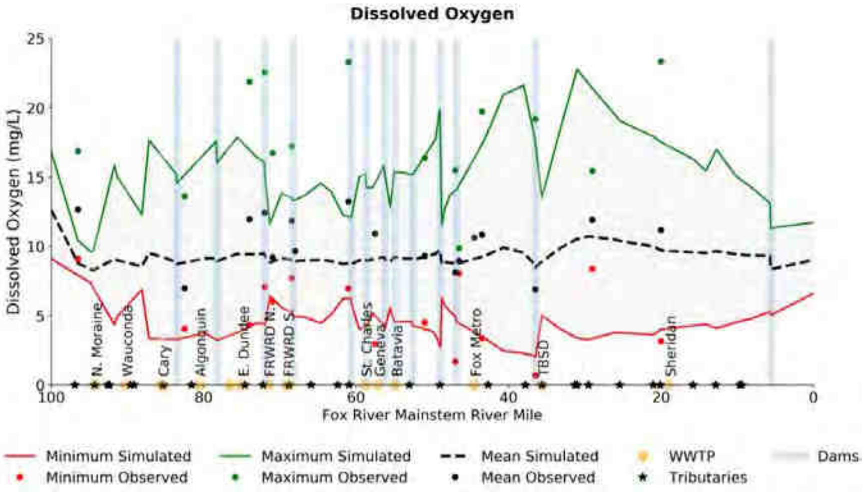


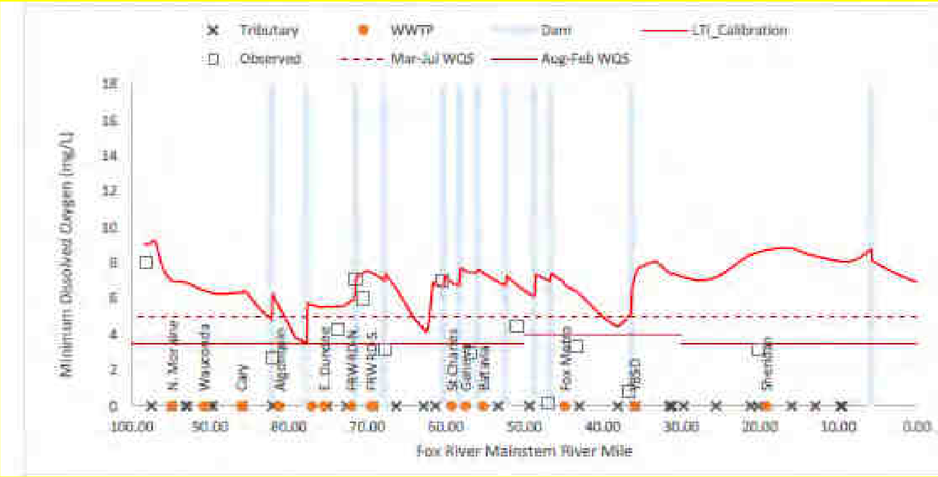
Chlorophyll-a, July 17, 2012



Daily average flow at Montgomery gauge: 175 cfs

Dissolved Oxygen June 25-29, 2012





Recalibrated Model

FRIP Model

Recalibrated model matches the minimum dissolved oxygen and diurnal fluctuations much better as compared to FRIP model

Summary of Model Results August to September 2016

Low Flow Period 2016

- August 1 – September 30, 2016
  - Less spatial distribution of stations along the river
  - Secondary dataset for calibration

- Flow range during the period
  - Algonquin Gauge: 400 to 800 cfs
  - Montgomery Gauge: 400 to 1,300 cfs

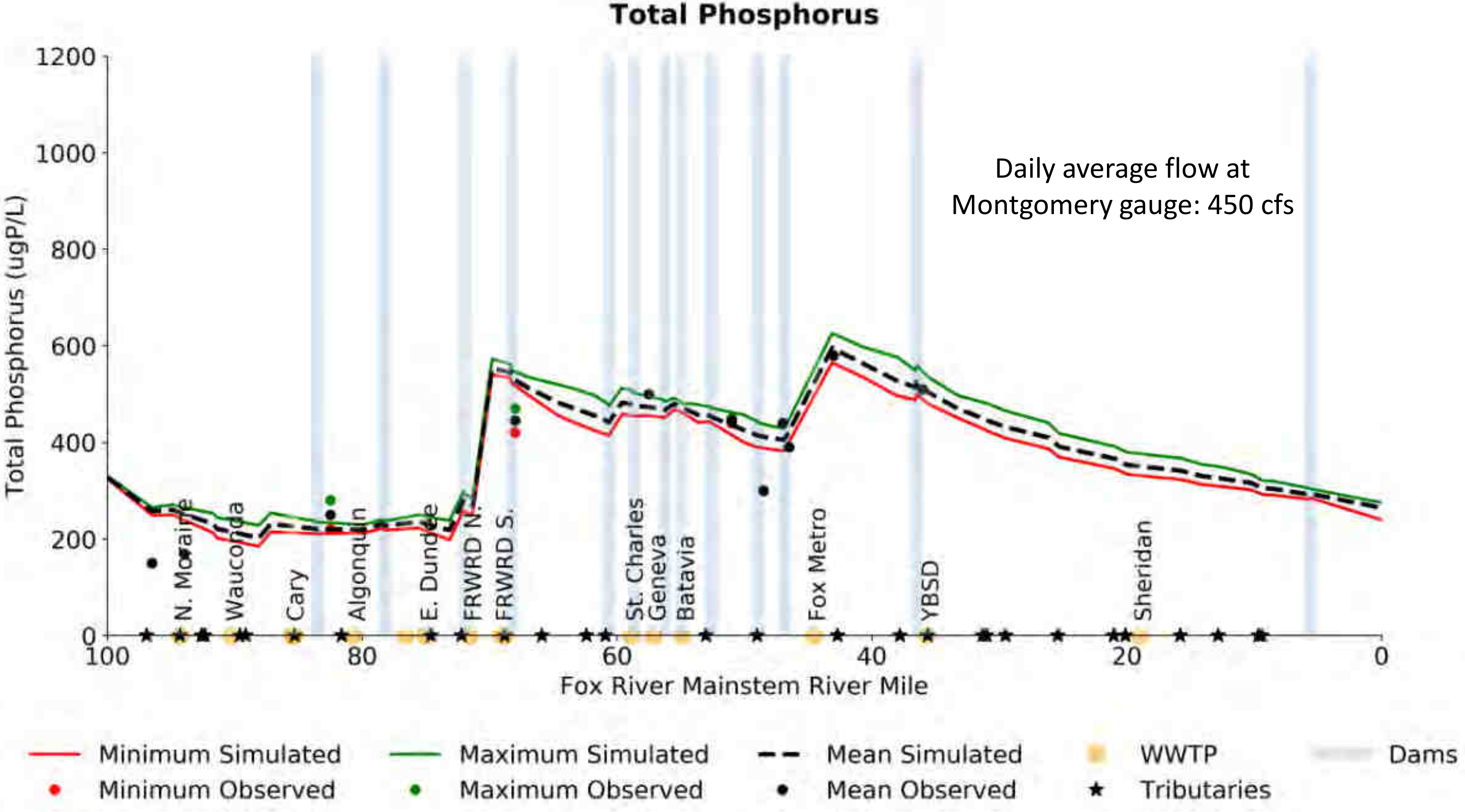
- Datasets used for recalibration
  - IEPA data
  - FRSG Monthly data
  - Low Flow Data except chlorophyll-a*

*Chlorophyll-a data measured by First Environment was not utilized since it was assessed to have issues

Model results summary for August- September 2016

- Model predictions of flow is good as compared to data
- Model captures the daily and seasonal variation in temperature
- Model matches measured TP well
- Model matches ammonia fairly well
- Model matches the measured Chl-a fairly well except in September, 2016
- Model does a good job in capturing diurnal variation and minimum DO in most reaches
  - Much better prediction as compared to FRIP model
  - Limitation of 1D model in ‘pool’ reaches

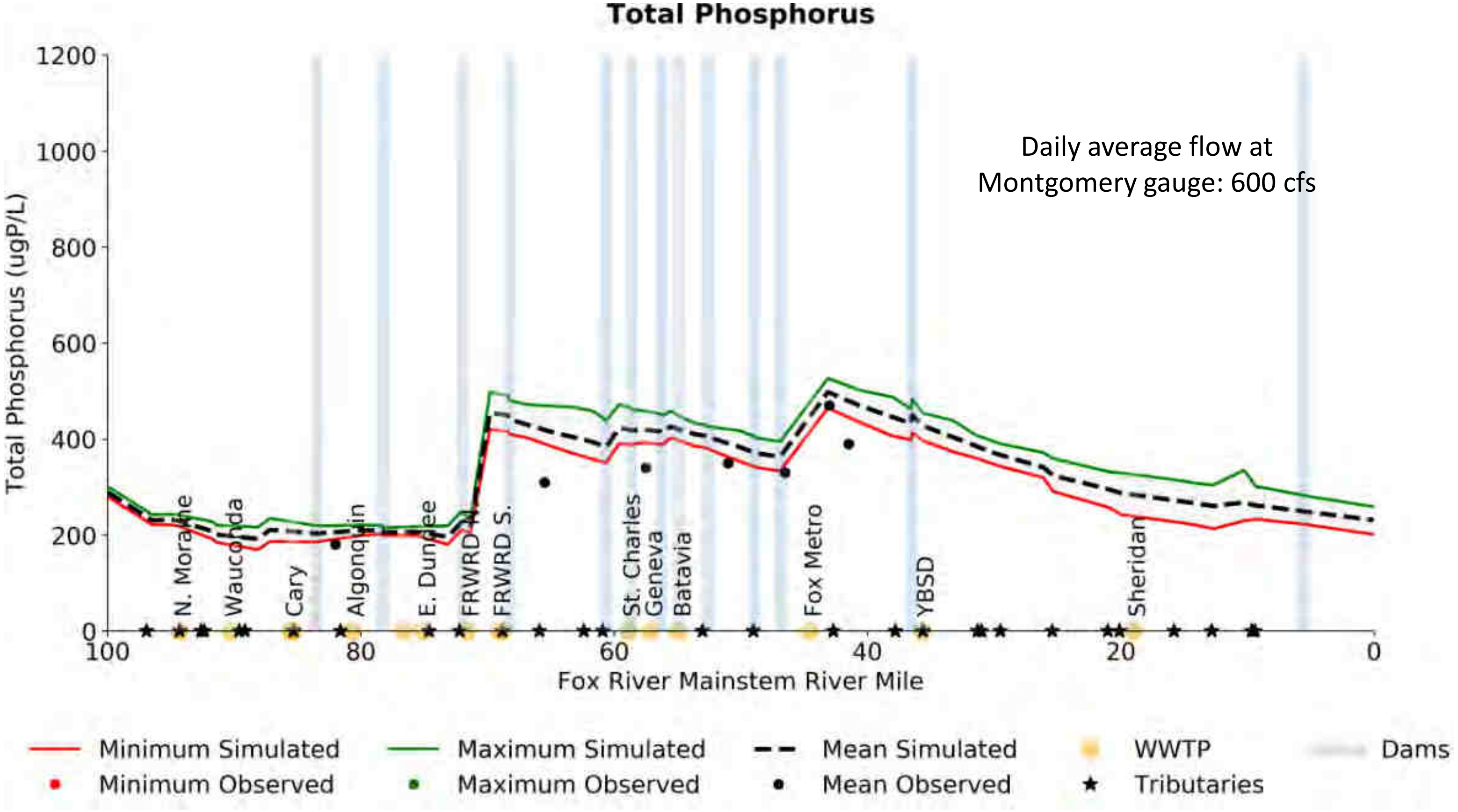
Total Phosphorus August 16, 2016



Total Phosphorus

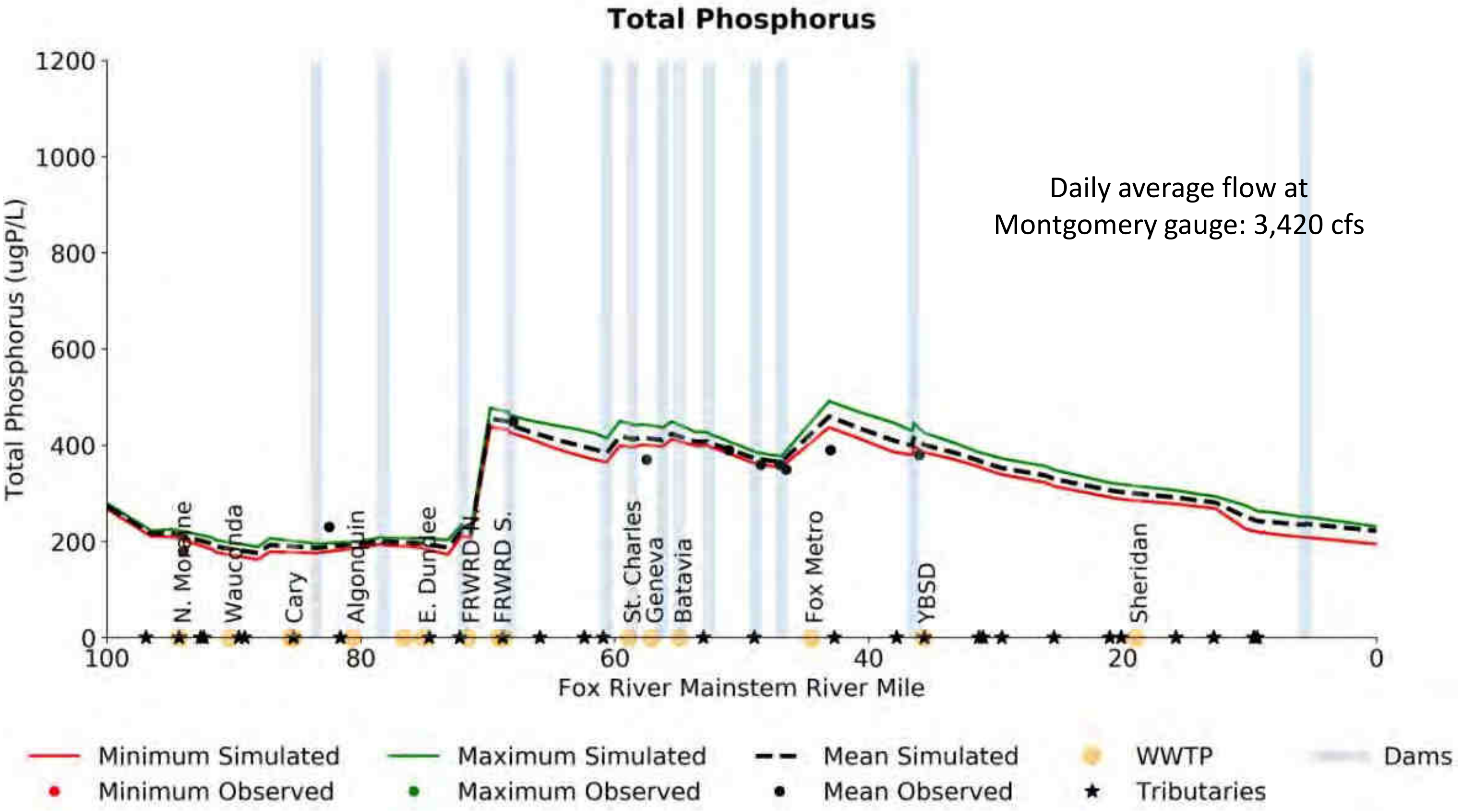
Daily average flow at Montgomery gauge: 450 cfs

Total Phosphorus September 7-8, 2016



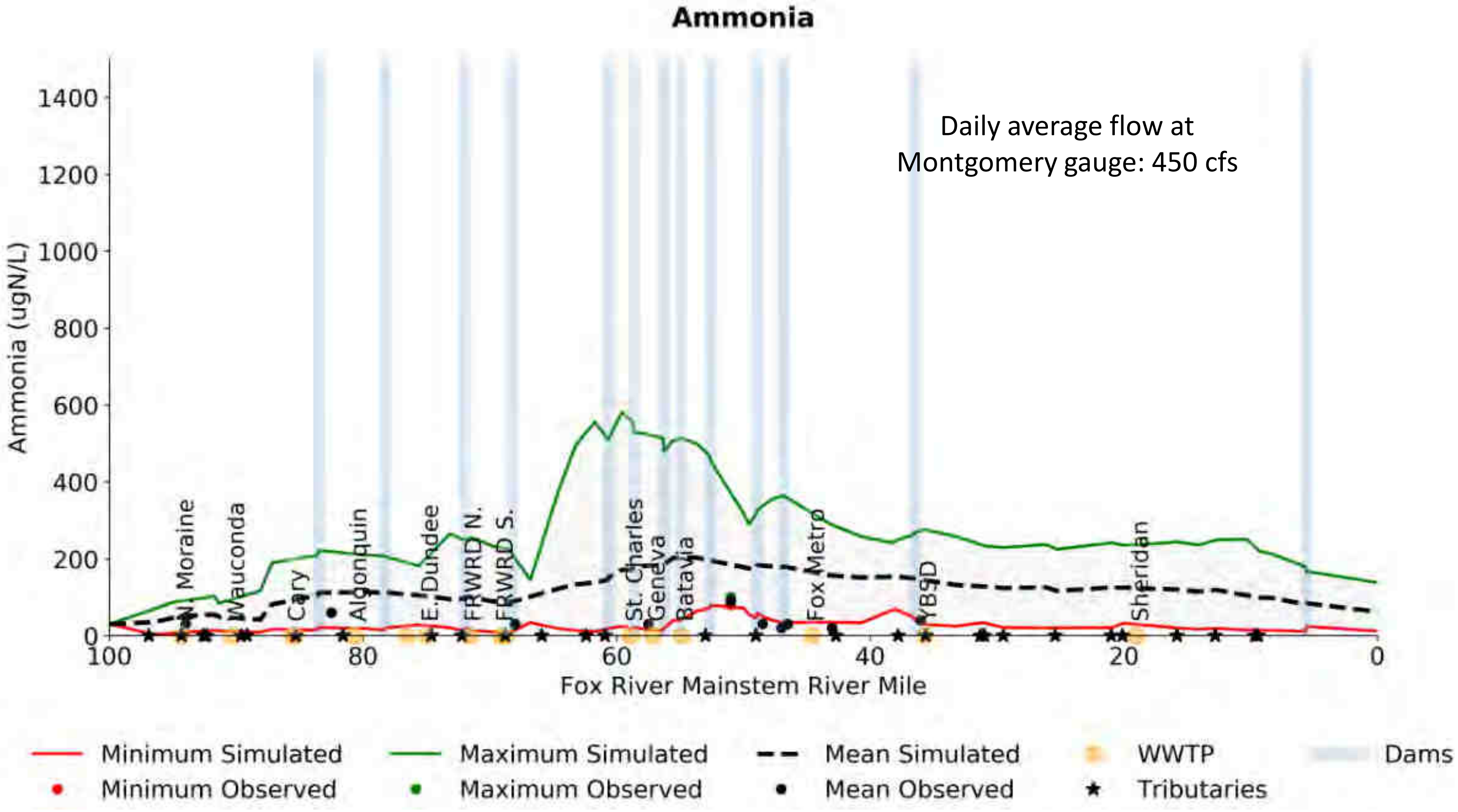
Daily average flow at Montgomery gauge: 600 cfs

Total Phosphorus September 20, 2016



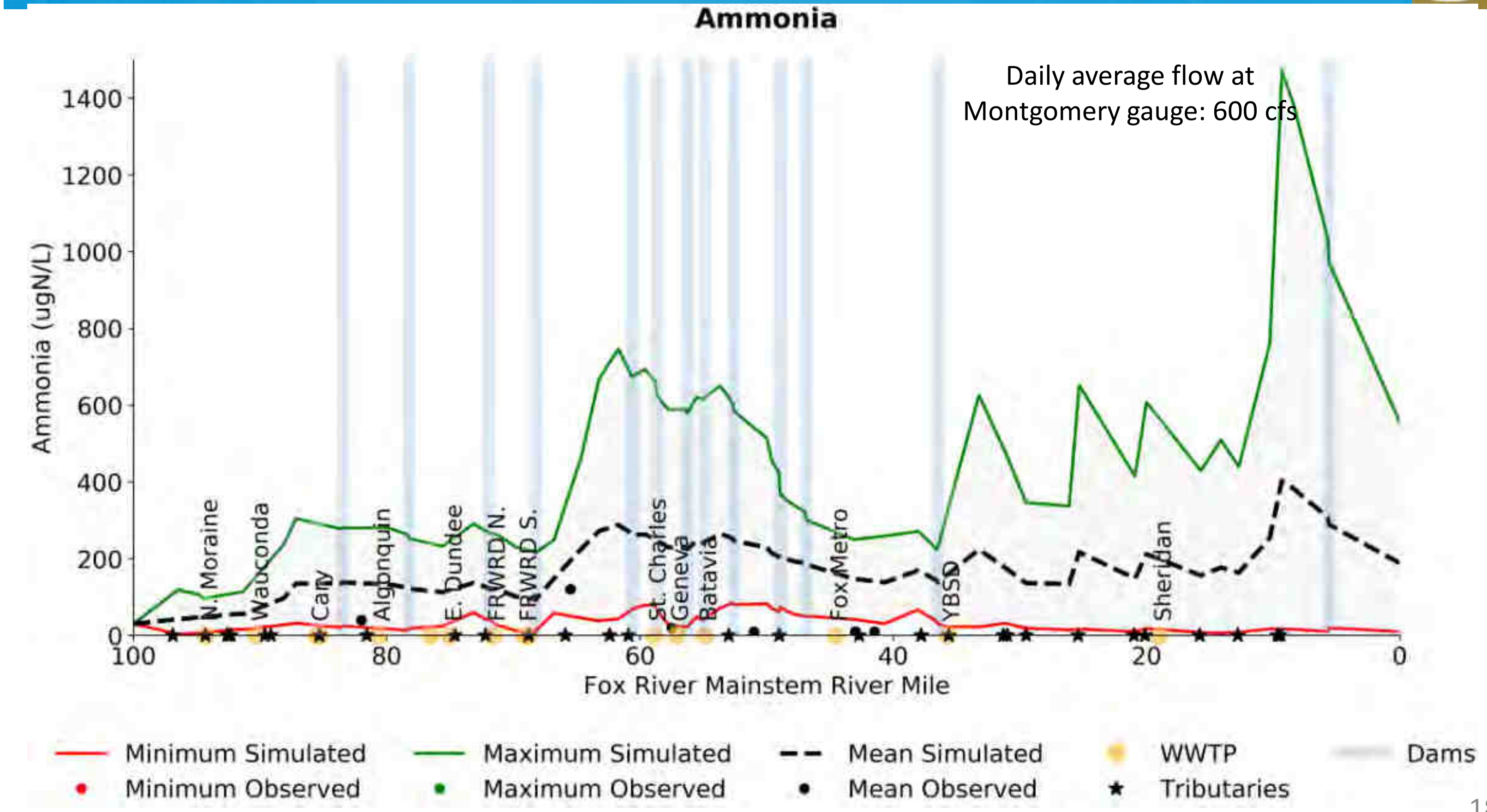
Daily average flow at
Montgomery gauge: 3,420 cfs

Ammonia August 16, 2016



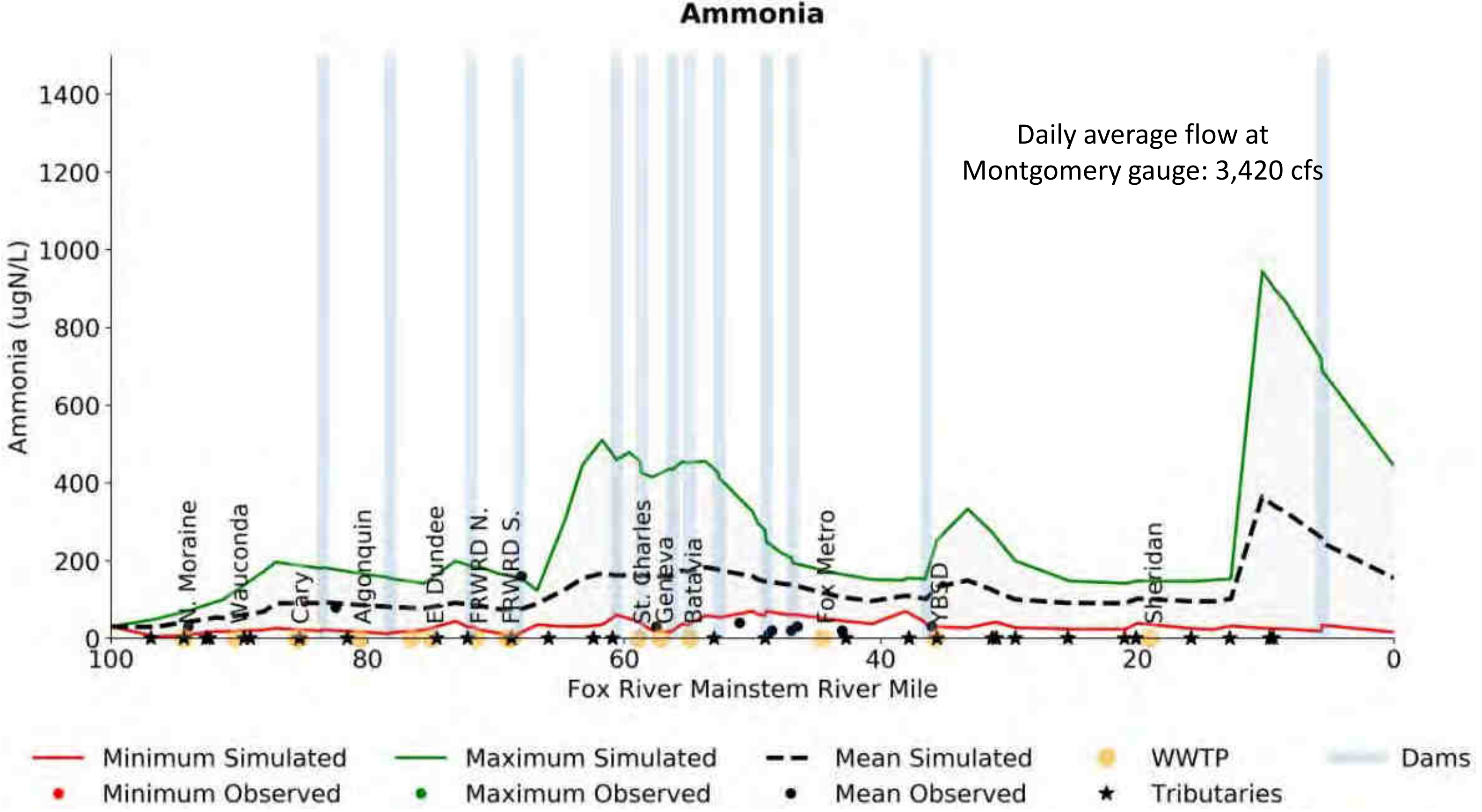
Daily average flow at
Montgomery gauge: 450 cfs

Ammonia September 7-8, 2016



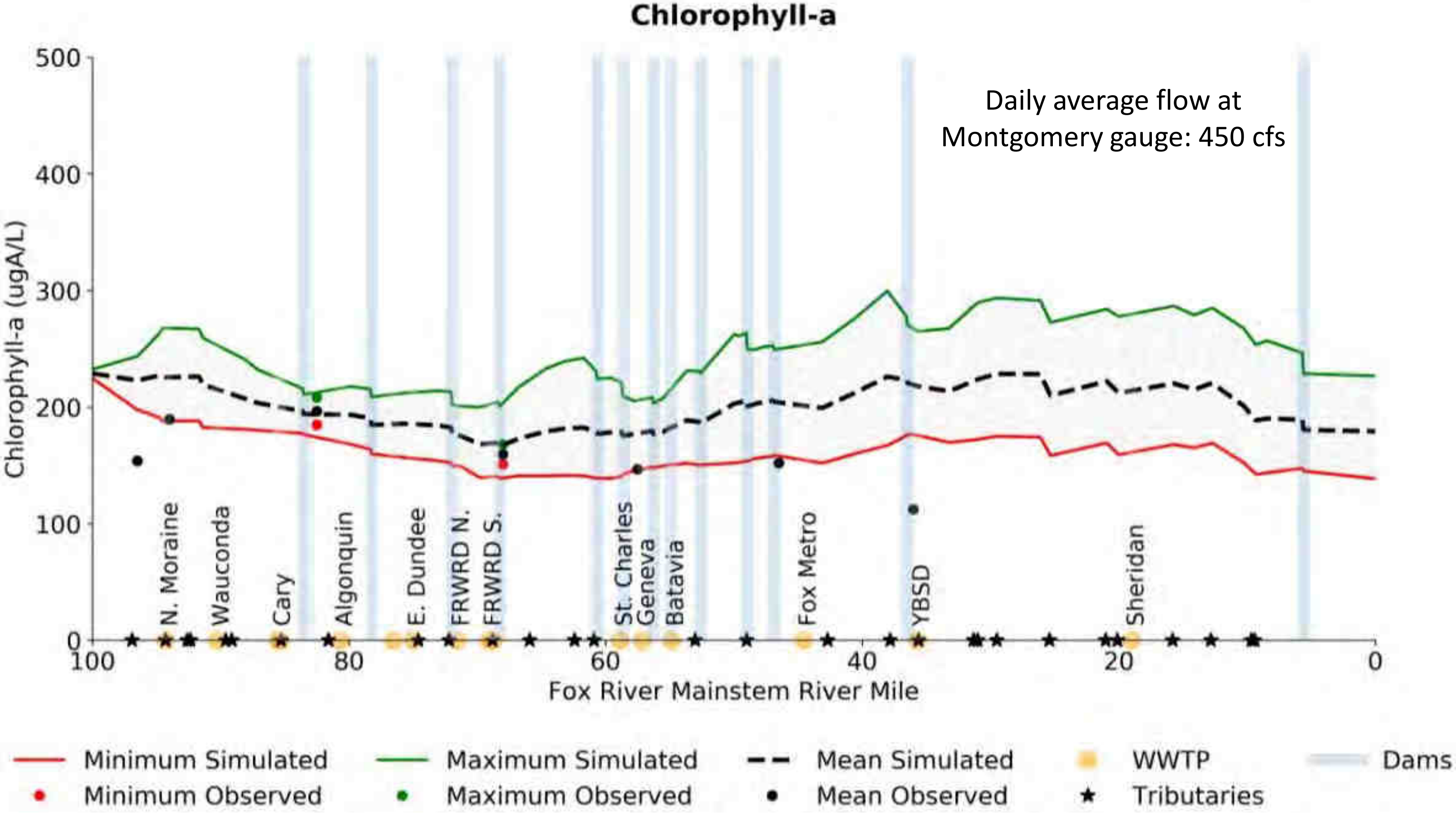
Daily average flow at
Montgomery gauge: 600 cfs

Ammonia September 20, 2016

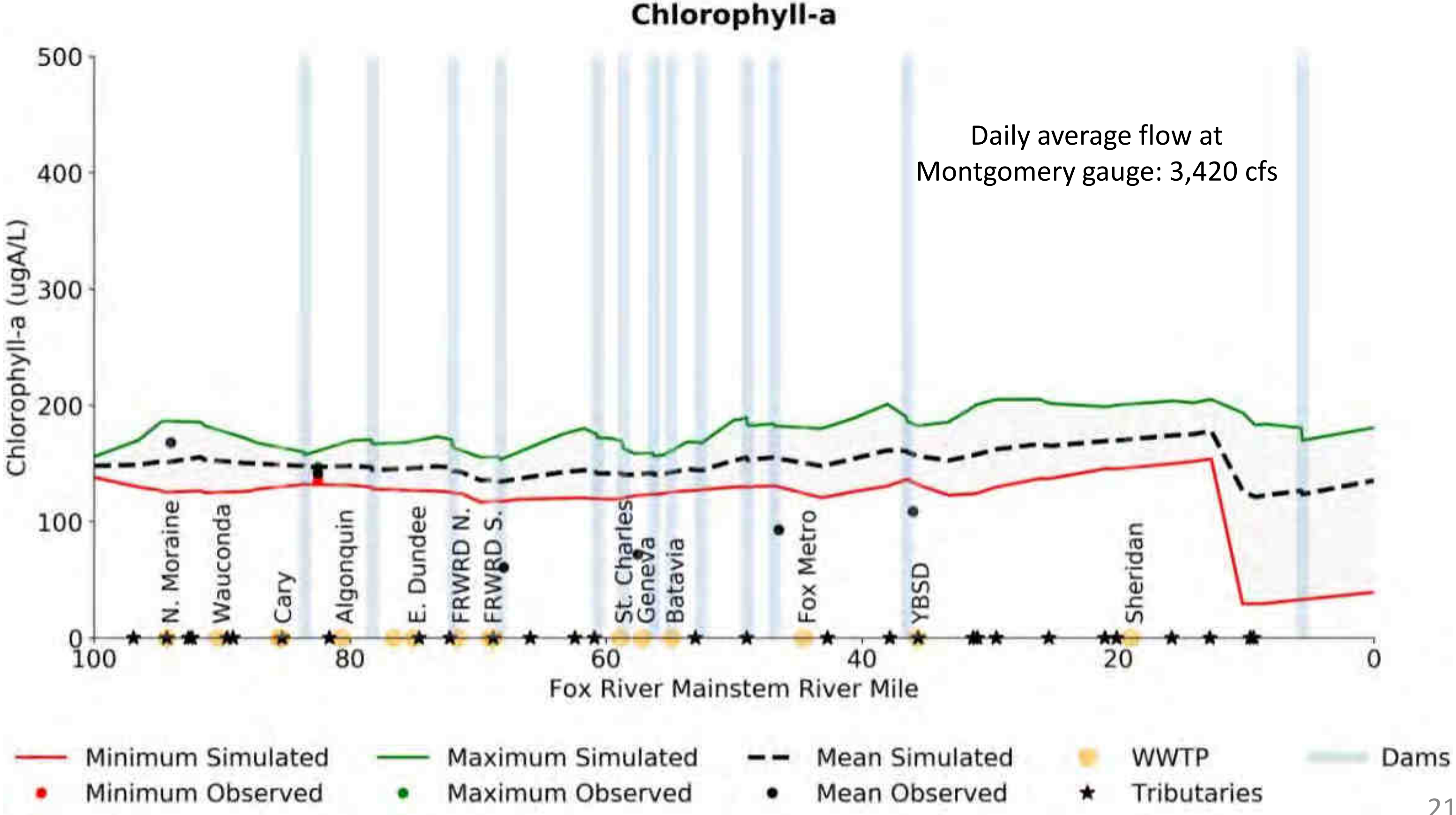


Daily average flow at Montgomery gauge: 3,420 cfs

Chlorophyll-a, August 16, 2016



Chlorophyll-a, September 20, 2016



Daily average flow at Montgomery gauge: 3,420 cfs

GEOSYNTEC CONSULTANTS

Calibration Summary (2012 & 2016)

Q	Flow	🟢		
T	Temperature	🟢	🟡	
TP	Total phosphorus	🟢		
NH4	Ammonia		🟡	
Chla	Chlorophyll-a		🟡	⚫
DO	Dissolved oxygen	🟢	🟡	⚫

Level of Calibration

🟢	Very Good
🟡	Good
⚫	Fair

Next Steps

COMPLETE THE SENSITIVITY ANALYSIS OF INSTREAM MODEL

DOCUMENT THE RESULTS IN A TECHNICAL REPORT

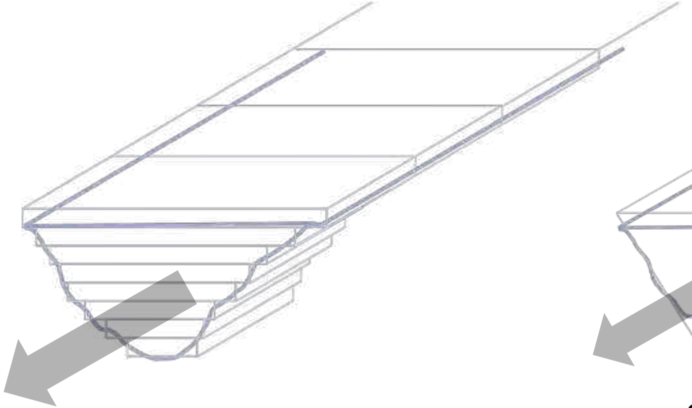
SIMULATE WATERSHED MANAGEMENT SCENARIOS

UPDATE THE FRIP

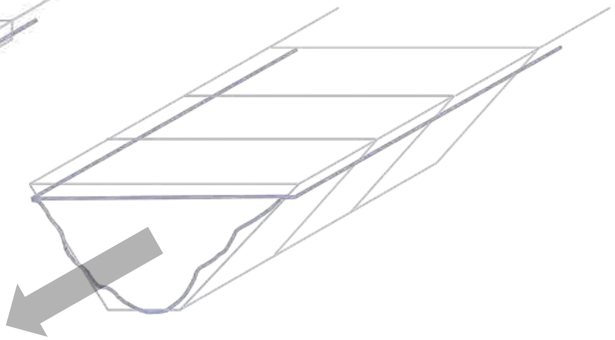
QUAL2kw model

- Unsteady
  - Simulates the changes in hydraulics and water quality over time
- One Dimensional
  - Assumes that the reaches are

  laterally and depth averaged
- In reality there are 2-dimensional processes influencing the river hydrodynamics and water quality.



Two dimensional model – CE-QUAL-W2



One dimensional model – QUAL2k

Attachment 3 Fox River QUAL2kw Ammonia Predictions

Geosyntec
consultants

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Oak Brook, Illinois 60523
PH 630.203.3340
FAX 630.203.3341
www.geosyntec.com

Memorandum

Date: February 26, 2020

To: Cindy Skrukrud, Chair, Fox River Study Group (FRSG) Modeling Subcommittee

Copies to:

From: Rishab Mahajan, Karoline Qasem and Adrienne Nemura

Subject: Fox River QUAL2kw Ammonia Model Predictions

SUMMARY

Geosyntec Consultants, Inc. (Geosyntec) is updating and recalibrating the QUAL2k water quality model of the Fox River for the Fox River Study Group (FRSG). The purpose of this update is to evaluate the impact of phosphorus on algal growth and dissolved oxygen levels in the Fox River to update the Fox River Implementation Plan (FRIP). Geosyntec and the FRSG Modeling Subcommittee reviewed the results of QUAL2kw model sensitivity results on December 2, 2019. During the webinar, the FRSG modeling subcommittee expressed concerns regarding the sudden increase in model-predicted maximum ammonia during a five-day, low flow simulation in June 2012. The model-predicted increases occurred downstream of the Fox River Water Reclamation District (FRWRD) West and South water reclamation facilities (WRFs) and downstream of the Batavia WRF. Geosyntec investigated the reasons for the increases in model-predicted ammonia downstream of the WRFs, which are documented below.

This investigation revealed that the current version of the QUAL2kw model is not well calibrated for ammonia and nitrate-nitrite (NO2-NO3). These limitations do not affect the model's usefulness for updating the FRIP, as algae in the Fox River is currently phosphorus limited. If the FRSG requires that the model more accurately simulate these constituents, then additional model calibration will be needed. This will include reassessing the model inputs for ammonia and NO2-NO3 (loads and parameters) and other factors. In particular, the excretion rates of ammonia from benthic and sestonic algae may need to be re-evaluated. Additional monitoring focused on capturing benthic and sestonic algal growth in different reaches of the river may also be required.

MODEL RESULTS

The QUAL2Kw predicts timeseries of water quality concentrations along the different locations of the Fox River. **Figure 1** compares the range of simulated and measured ammonia along the length of the river for the period of June 25 to 29, 2012. The location of the WRFs, dams, and tributary mouths are shown along the x-axis from upstream to downstream order. The green, black (dotted), and red lines show the simulated maximum, mean, and minimum values of ammonia at different locations in the Fox River for the five-day period. While the model does a decent job of matching the mean measured ammonia levels, the model predictions show sudden increases in the maximum ammonia concentrations downstream of FRWRD's WRFs (River Mile 69) and the Batavia WRF (River Mile 56) that are not reflected in the measured data. These sudden increases in model predicted maximum ammonia cannot be explained by the input of ammonia from the WRFs since effluent concentrations for ammonia are relatively small, ranging from 90 to 300 micrograms per liter (ug/L) during this period.

Figure 2 shows the longitudinal plot of simulated NO2-NO3. The model overpredicts the NO2-NO3 concentrations as compared to data just downstream of FRWRD plants and overpredicts the maximum NO2-NO3 concentration downstream of the Batavia WRF.

EXPLANATION FOR SIMULATED AMMONIA INCREASES

The high NO2-NO3 loading from the FRWRD indirectly results in increased ammonia in the downstream reaches. The increased NO2-NO3 concentrations are assimilated by the phytoplankton and benthic algae into inter-cellular nitrogen in the downstream reaches. The phytoplankton and benthic algae excrete nitrogen in the form of ammonia in the downstream reaches, which causes the rise in ammonia**.** Figure 3 shows the timeseries of model predictions of temperature, chlorophyll-a, benthic algae, ammonia, NO2-NO3 and organic nitrogen from model reaches 18 to 22 (the inputs to each reach are specified in the legend). For Reach 18, the ammonia concentration varies during the day due to increased uptake by phytoplankton. The FRWRD WRFs' load comes into Reach 19 and the ammonia concentration is increased in Reaches 21 to 23, due to excretion of ammonia from phytoplankton and benthic algae. Reaches 18 and 19 are deeper pool reaches which have very little benthic algal growth. Reaches 20 to 23 have high levels of benthic algae since they are shallower, free-flowing reaches. The NO2-NO3 concentrations in Reach 19 increase due to the FRWRD WRFs' loading; this loading is assimilated by the benthic algae in Reaches 20 to 23. During the day, the benthic algae excrete ammonia which results in increased concentration of ammonia downstream of the FRWRD plants. The ammonia concentration for Reaches 20 to 23 is increased during the day due to increased excretion

The same phenomenon is observed to a limited extent downstream of Fox Metro Water Reclamation District (Fox Metro) WRF as shown in Figure 4. The high NO2-NO3 load from the Fox Metro WRF into Reach 49 is diluted due to higher river flow at this location. Ammonia concentrations are increased during the day due to the excretion from benthic algae in Reaches 51 and 52.

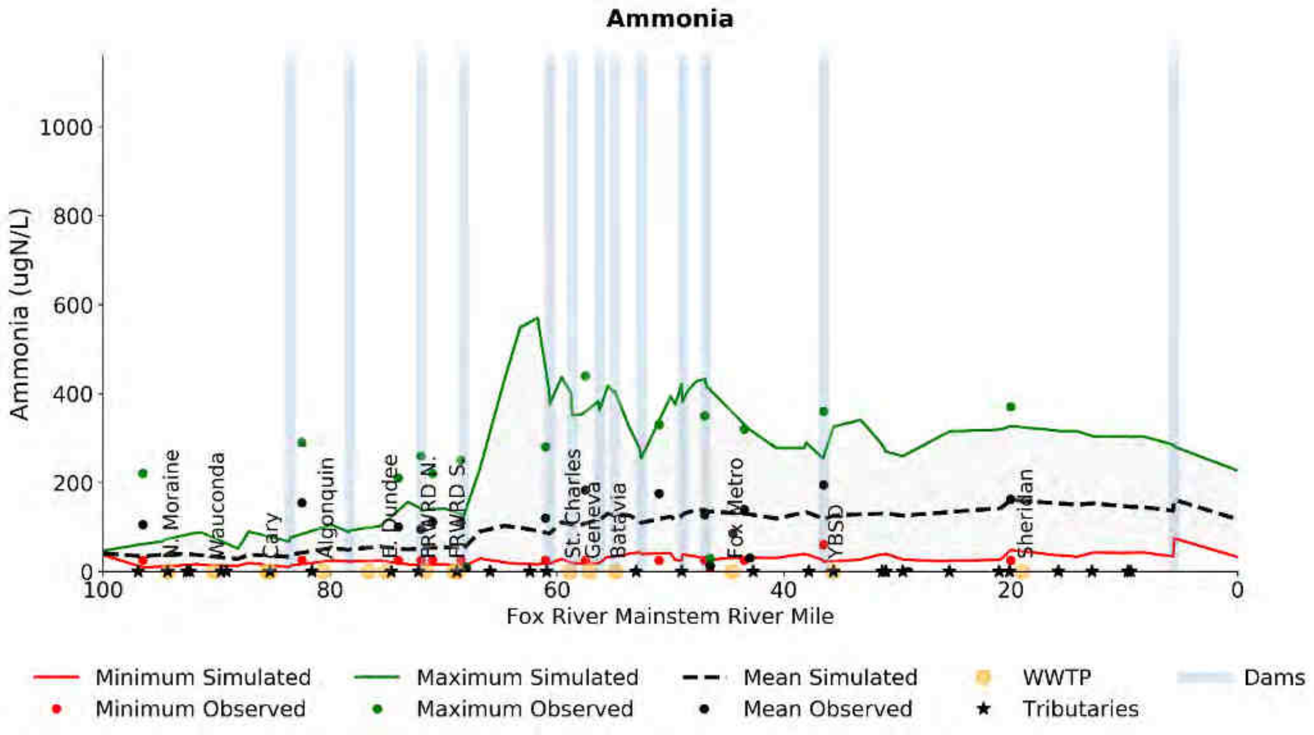

Figure 1: Ammonia Longitudinal Plot for the Period June 25-29, 2012

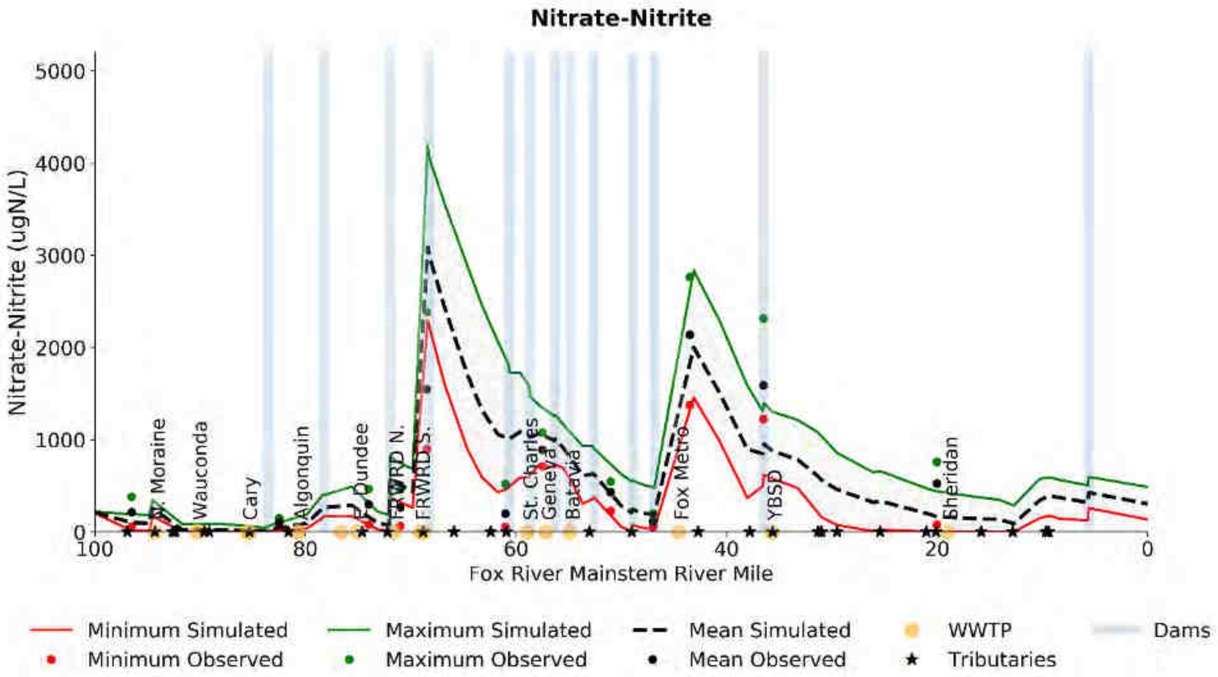

Figure 2: Nitrate-Nitrite Longitudinal Plot for the Period June 25-29, 2012

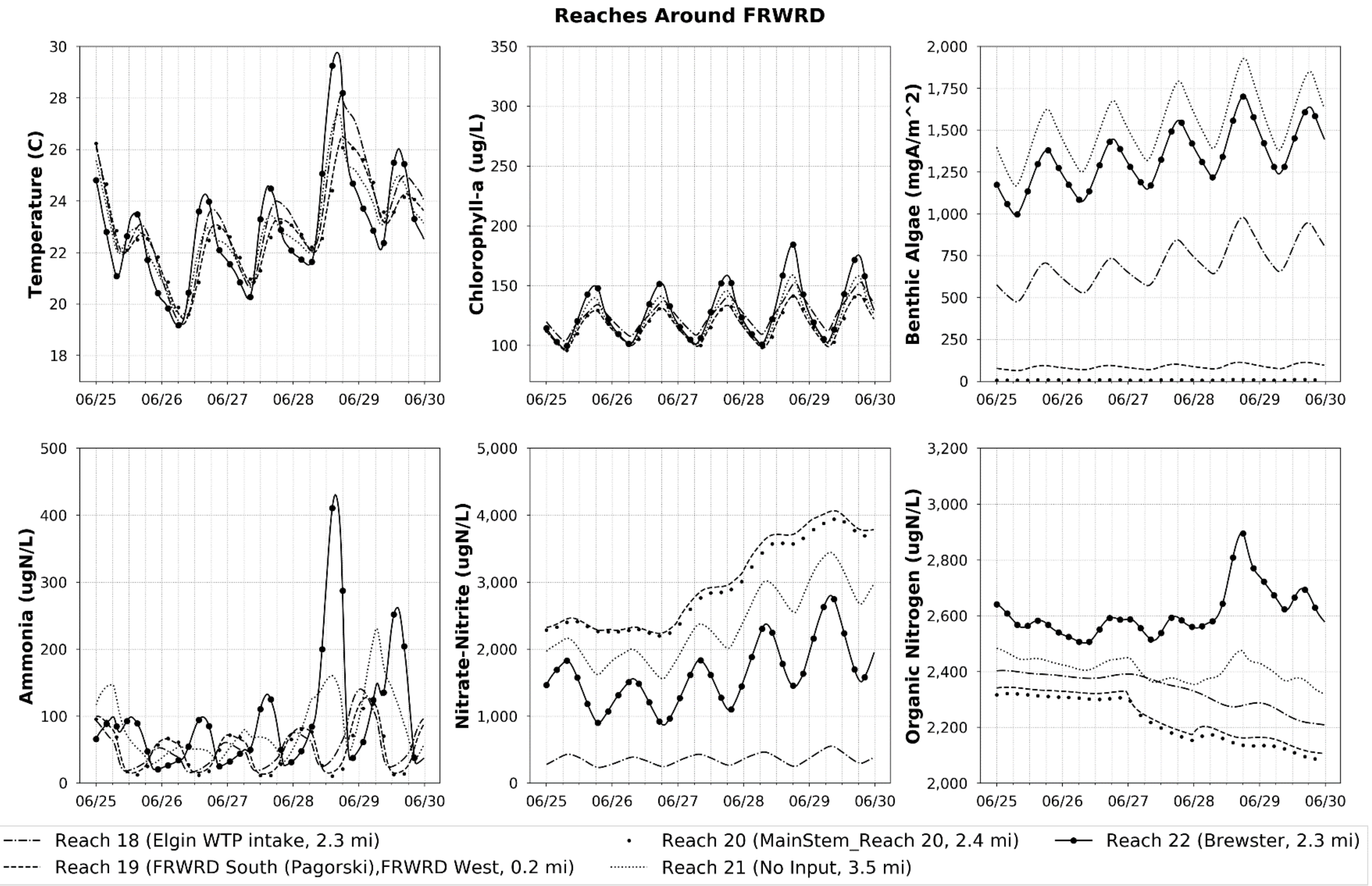

Figure 3: Timeseries of Model Predictions for June 25-29, 2012

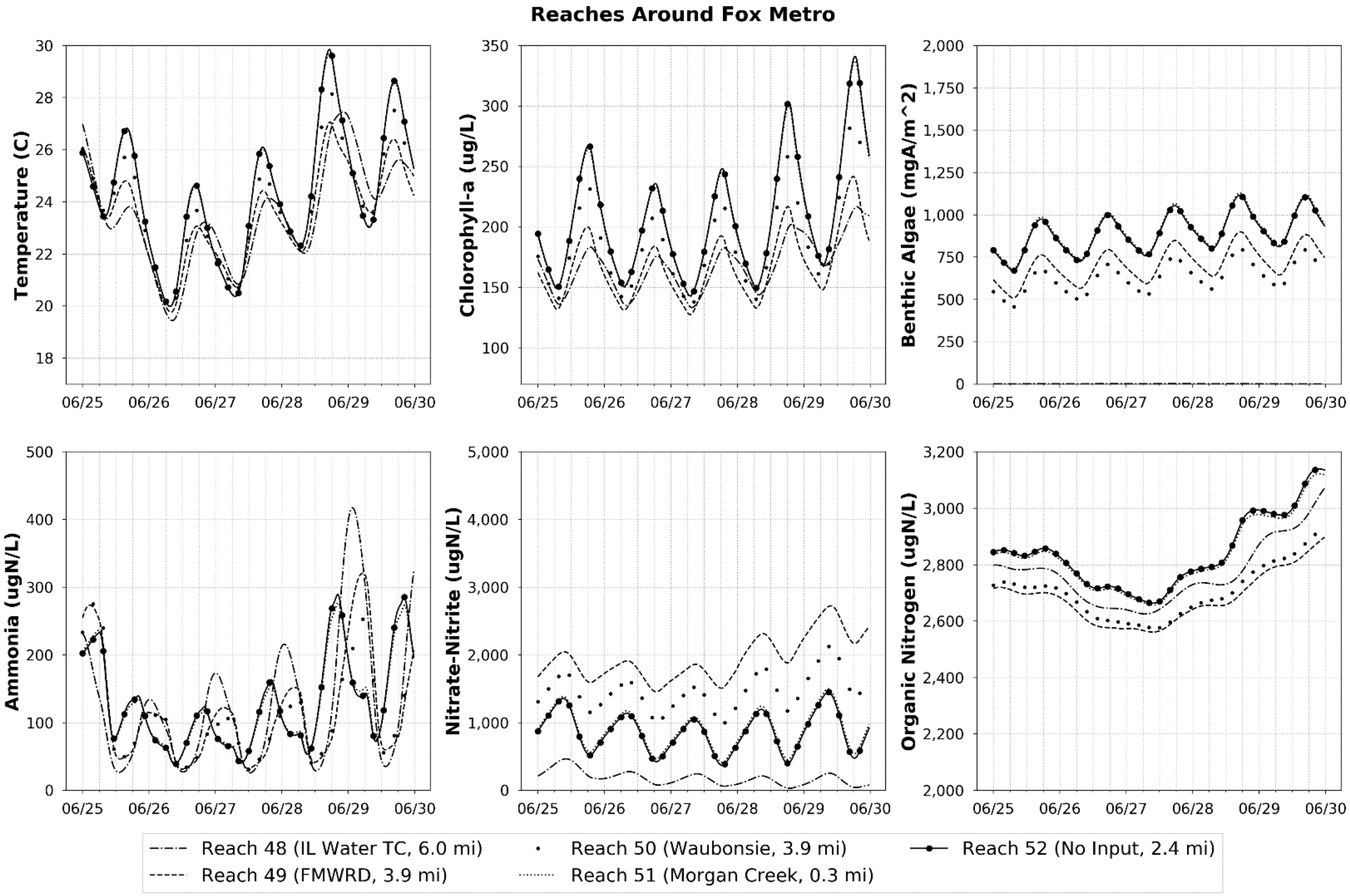

Figure 4: Timeseries of Model Predictions for June 25-29, 2012

APPENDIX E

FOX RIVER WATERSHED MANAGEMENT SCENARIOS

APPENDIX E
FOX RIVER WATERSHED MANAGEMENT SCENARIOS

Background and Introduction

The Fox River Implementation Plan (FRIP) Study Area covers 98 miles of the Fox River between Stratton Dam in Nunda Township, McHenry County, and the Illinois River. Several segments of the Fox River within the FRIP Study Area are listed as impaired for aesthetic and aquatic life water quality by the Illinois Environmental Protection Agency (Illinois EPA) due to total phosphorus (TP) levels, low dissolved oxygen (DO), and nuisance algae (Illinois EPA, 2022). Additionally, several segments of the Fox River are also listed as impaired for sedimentation/siltation and fecal coliform. The 2015 FRIP focused on DO and nuisance algae impairments. The current FRIP retains the focus on DO and nuisance algae impairments, but also includes recommendations for addressing other impairments such as sedimentation/siltation and fecal coliform (See Chapter 4 of the FRIP).

For the current FRIP, Geosyntec updated and recalibrated the models used for developing the 2015 FRIP (Geosyntec, 2020, *Appendix C: Fox River Water Quality Model Update*). The updated models were then applied to evaluate management actions to address DO and nuisance algae impairments in the mainstem Fox River. This appendix documents the modeling results.

Impairment Causes

The DO and nuisance algae impairments are caused by phosphorus loading from upstream sources, tributaries, and wastewater treatment plants (WWTPs), as well as dams on the mainstem Fox River. These are described below.

Upstream Load

The upstream load to the FRIP Study Area includes loading from the Fox River watershed upstream of Stratton Dam, with a drainage area of 1,250 square miles in Wisconsin and Illinois. The portion of the Fox River watershed in Wisconsin has no formal Total Maximum Daily Load (TMDL) or completed watershed-wide analysis. The portion upstream of Stratton Dam in Illinois includes the Chain O'Lakes, a series of 15 lakes connected by the Fox River, which has been identified as being impaired for phosphorus (Illinois EPA, 2022). The Illinois EPA has developed two TMDLs for this portion of the Fox River. The TP targets for the lakes in both of these TMDLs was 0.05 milligrams per liter (mg/L), the Illinois General Use Water Quality Standard for lakes.

The Upper Fox River/Chain O' Lakes TMDL focused on the impairments in the Chain O' Lakes watershed in Illinois (CDM Smith, 2020a). The Upper Fox River/Flint Creek Watershed TMDL addresses impairments in 14 impaired waterbody segments within the Upper Fox River downstream of the Chain O'Lakes (CDM Smith, 2020b). The Fox Waterway Agency (FWA) is currently in the process of completing a watershed-based plan for this area, with an anticipated completion date of 2024. Once the plan is complete and approved by Illinois EPA, the FWA will be able to pursue funding for implementation projects.

The upstream load constitutes approximately 16 percent of the annual average load into the Fox River for the period of 2012 to 2016 (Geosyntec, 2021, *Appendix A: Contribution of point and non-point sources to total phosphorus load in the Fox River watershed downstream of Stratton Dam for the period of 2012 to 2016*). Results of these TMDLs and the watershed-based plan could provide the basis for future reductions in the upstream load.

Tributary Load

There are 31 tributaries draining an area of approximately 1,150 square miles to the Fox River mainstem within the FRIP Study Area. About 255 additional square miles drain directly to the Fox River mainstem. Most of the non-point source TP load in the Upper FRIP Study Area comes from urban runoff, while agriculture is the most significant contributor of human impact phosphorus in the Lower FRIP Study Area. Naturally occurring phosphorus dissolution into groundwater is also a source, which requires further study. Tributary loads account for 10% of the annual average TP loading to the Fox River mainstem from 2012 to 2016 (Geosyntec, 2021, *Appendix A: Contribution of point and non-point sources to total phosphorus load in the Fox River watershed downstream of Stratton Dam for the period of 2012 to 2016*).

WWTP Load

The loading from the WWTPs constitutes about 37 percent of the total TP loading from 2012 to 2016 to the Fox River mainstem in the FRIP Study Area. The National Pollutant Discharge Elimination System (NPDES) permits for major WWTPs (Design Flow >1 Million Gallons per Day) in the FRIP Study Area require that the facilities meet TP effluent limits of 1.0 mg/L (12-month rolling average, calculated monthly) by 2022-2023 and 0.5 mg/L (12-month rolling geometric mean, calculated monthly) by 2030. If enhanced biological phosphorus removal technology is combined with supplemental chemical treatment and advanced effluent filtration, it is generally believed that a limit of 0.1 mg/L represents the limit-of-technology for the wastewater treatment.[1] Several WWTPs in the FRIP study area are currently meeting the target of 0.5 mg/L, well ahead of the 2030 goal.

Dam Removal

The ten dams on the Fox River between Carpentersville and Yorkville are classified as “run of the river” dams, which means that they are simply a weir structure built across the width of the river for the purpose of raising the water level upstream. These low head dams impound 67 percent of river length from river mile (RM) 81.71 to RM 36.06. These dams are in close proximity of each

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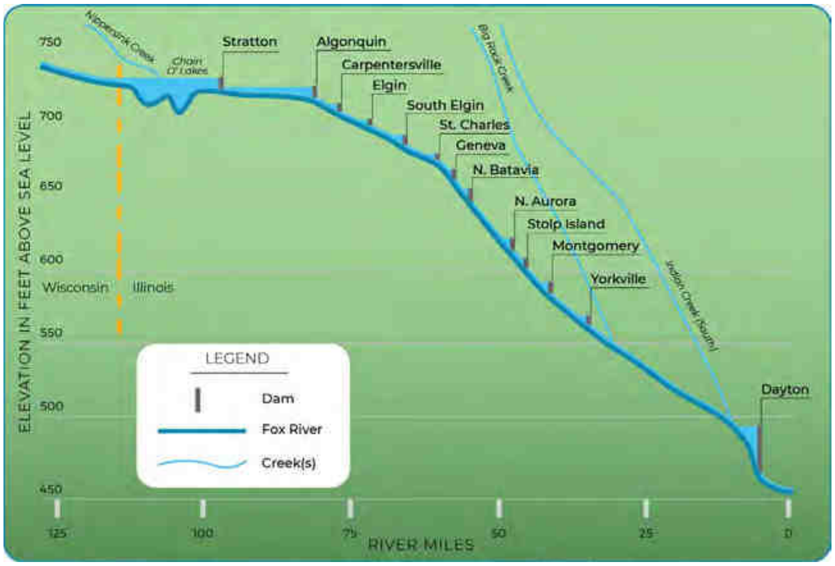
[1] High-Efficiency Nutrient Removal and Recovery for Achieving Low Regulatory Limits.US EPA Office of Research and Development. EPA Contract Number EPD17007

other with impoundment lengths ranging from 0.5 to 6.3 miles. The impact of these dams on the Fox River water quality is described briefly below.

The low head dams do not have long residence times. Consequently, there is not much buildup of sestonic algae behind these dams. This is supported by the recent data collected for the Carpentersville dam pre-removal study conducted by Deuchler (Deuchler 2020). However, the volume of water in the impoundment behind the dam results in sestonic algae contributing more to DO demand in these locations than in the rest of the river. This large volume of impounded water results in increased sestonic algae mass in the impounded reaches, which causes DO depletion in the impounded reaches.



Dams on the Fox River

The series of dams creates shallow and wide non-impounded reaches upstream of each dam. These reaches provide suitable conditions of more light availability and less scour potential for benthic algae growth. The growth of benthic algae in these reaches results in DO depletion in these reaches.

The slow water velocities behind the dam also cause the accumulation of silt and organics, materials that settle behind the dams to form benthic detritus. Together, the benthic detritus and benthic algae act to remove oxygen from the river. This deoxygenation effect is especially apparent on the river bottom behind the dams, where only pollution-tolerant species of fish such as carp and a few macroinvertebrates such as midge flies can thrive. The accumulated sediment behind the dam also serves as a sink for DO and provides poor habitat for broader macroinvertebrate types, mussels, and fish, all important components of the river's food web.

Methodology

Linked numerical models (including watershed models and an instream model consisting of hydraulic and water quality components) were used to model the impact of nutrients on instream water quality. The models include inputs of estimated loadings from the upstream watershed, tributaries, WWTPs, and direct drainage. The instream model was calibrated to measured flow, temperature, and water quality data in 2012 and 2016 (Geosyntec, 2020, *Appendix C: Fox River Water Quality Model Update*).

A baseline scenario was developed to represent the existing conditions in the Fox River during the summer of 2012. The period of May to October 2012 was selected for the baseline scenario since it includes target critical low and high flows, warm temperatures, and drought resulting in algae blooms in the Fox River. The FRSG modeling subcommittee defined the target critical low flows as 523 cfs at USGS Gage 05551540 at Montgomery and 360 cfs at USGS Gage 05550001 at Algonquin. The target critical low flows were identified by the FRSG modeling subcommittee as important to the FRIP. The measured and target critical flows at Algonquin and Montgomery gages on the mainstem Fox River during this period are shown in **Figure 1.** The FRSG modeling defined the target low flows low flows of 523 cfs at USGS Gage 05551540 at Montgomery and 360 cfs at USGS Gage 05550001 at Algonquin. The relative contribution of the upstream sources, WWTPs, and tributaries along the mainstem Fox River for the baseline scenario are shown in **Figure 2**. River mile (RM) 100 is the upstream extent of the model, while RM 0 is the confluence with the Illinois River. Under these low flow conditions, the relative contribution of tributaries to the total TP loading along the length of the Fox River mainstem is less than five percent, except downstream of the confluence of Indian Creek South (LaSalle County) around RM 10, where it represents five percent of the total TP load.

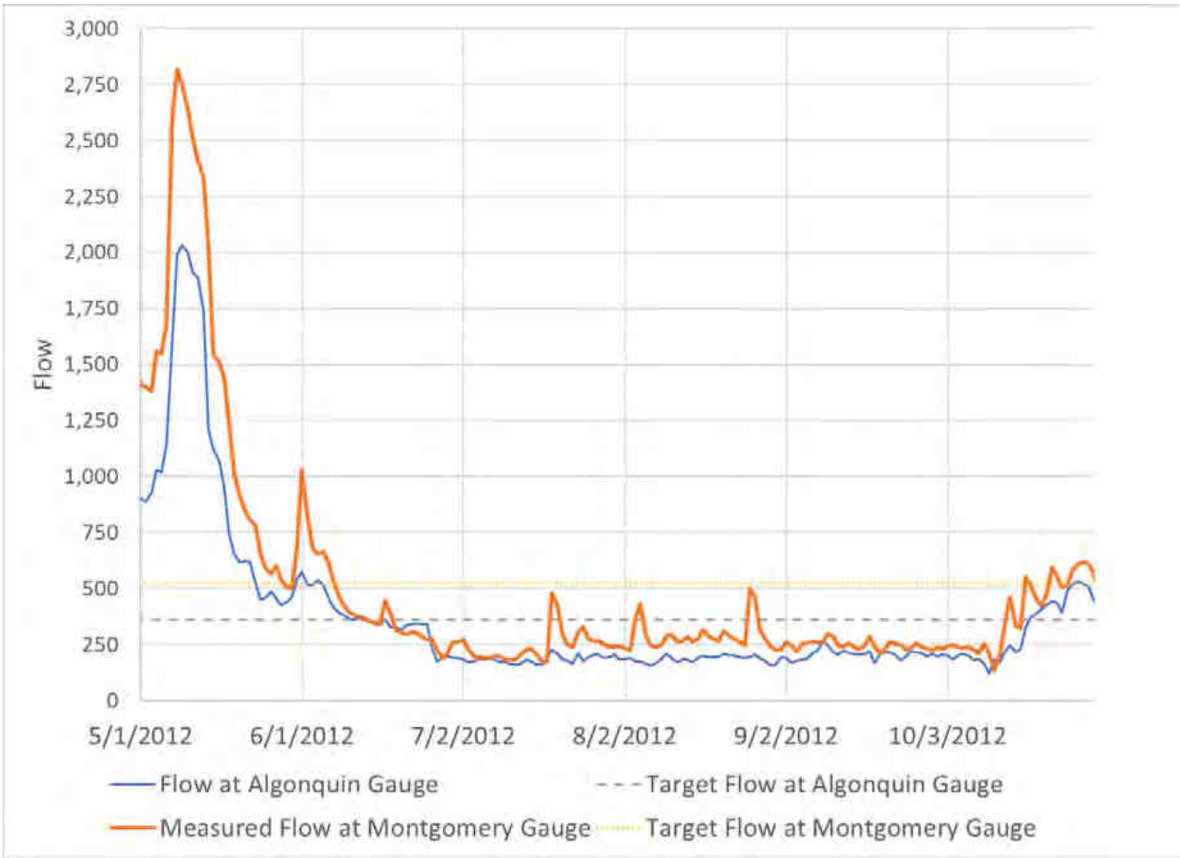


Figure 1: Measured Flows at the Algonquin and Montgomery Gages on the Fox River Mainstem, May to October 2012

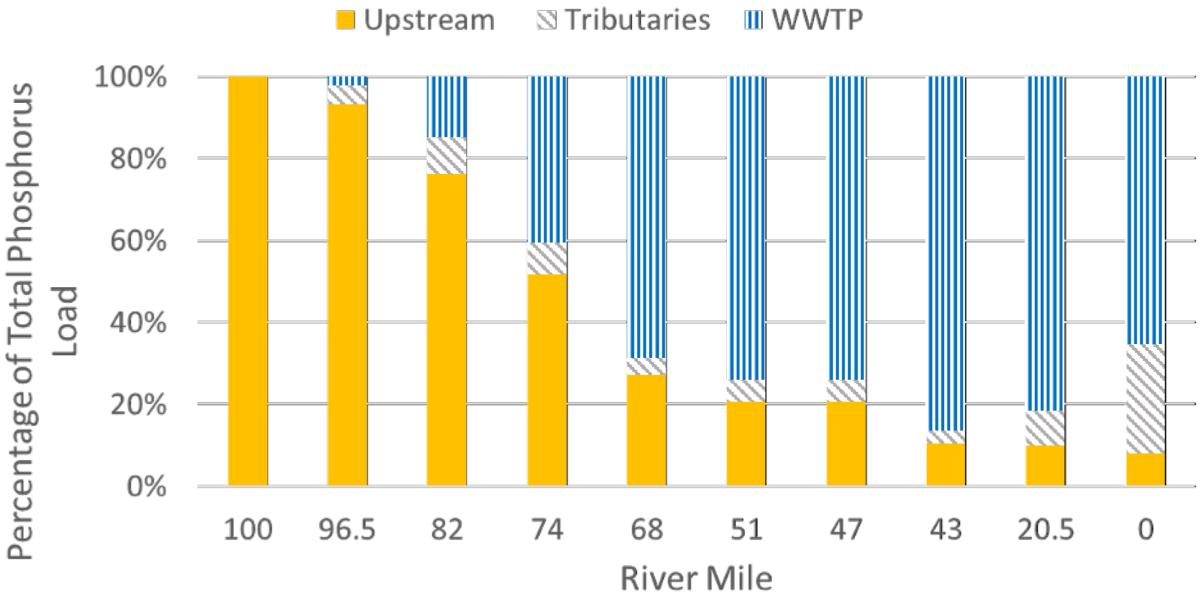


Figure 2: Relative Contribution of Loading along the Mainstem Fox River, May to October 2012

The DO sinks (demand) in the baseline model include the following components:

- Sestonic Chlorophyll-a Respiration: Occurring during the night. The oxygen demand is proportional to the sestonic chlorophyll-a mass in the water column.
- Benthic Algae Respiration: Occurring during the night. The oxygen demand is proportional to the benthic algae mass in the reach and inversely proportional to the height of the water column.
- Sediment Oxygen Demand (SOD): Constant oxygen demand exerted by decaying organic matter in the sediment.
- Biochemical Oxygen Demand: First-order demand exerted by decaying organic matter in the water column.

The proportion of oxygen removed by each DO sink depends upon the reach type. The total simulated mass of DO removed for each reach by each DO sink is included in *Attachment 3: DO Mass Sinks for Baseline Model*. For an impounded reach, the oxygen demand exerted by sestonic algae is the largest contributor to DO mass removed from the water column. This is due to the higher water level increasing the volume of water and, therefore, the mass of sestonic algae in the reach. Additionally, the higher water level in the impoundments shades the river bottom reducing benthic algae growth. However, between the impoundments, there are significant shallow reaches, due largely to the backwater created by the dams, that promote benthic algae growth. **Figure 3** shows the simulated proportion of DO mass sinks in the Carpentersville impoundment (Model reach 15; Length - 1.1 miles; Average Width – 199.1 ft) and the non-impounded reach just downstream of the Carpentersville Dam ((Model reach 17; Length – 0.62 miles; Average Width – 95.6 ft) for the baseline scenario. The DO demand exerted by benthic algae is significantly larger than sestonic algae for non-impounded reaches and is second largest demand in the impoundments. As a result, benthic algae is the largest sink for DO in the Fox River in the modeling results.

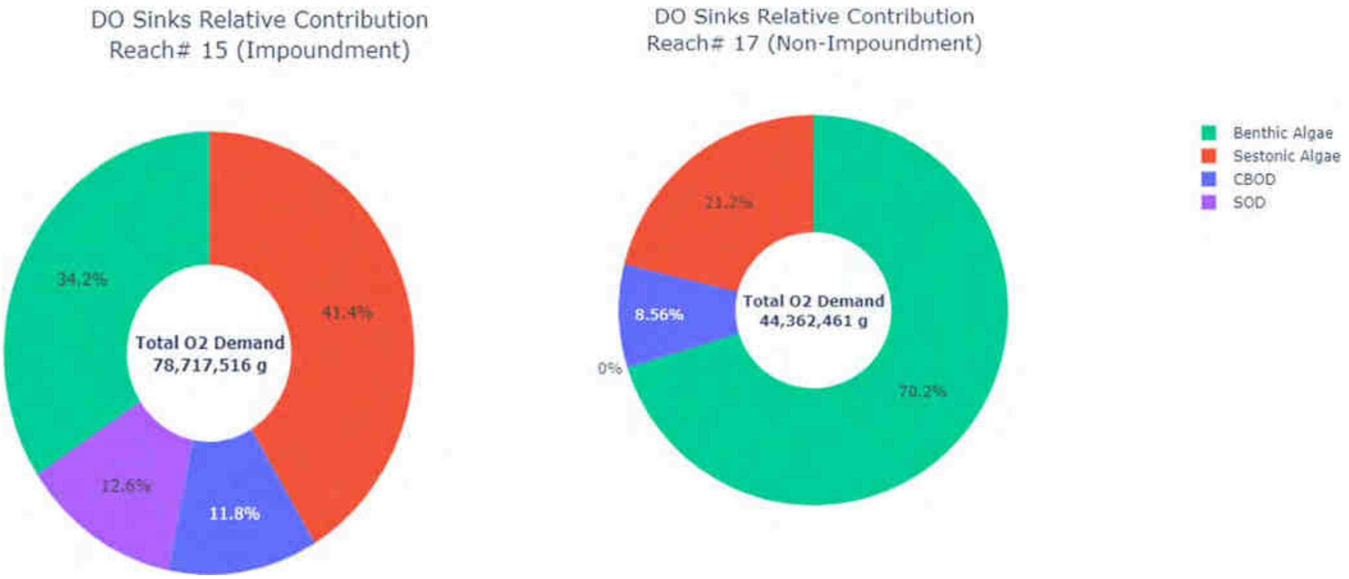


Figure 3: : Simulated Proportion of Dissolved Oxygen Demand (g) for the period of May to October 2012 in the Carpentersville Dam impounded reach (Model Reach 15) and the non-impounded reach just downstream of Carpentersville Dam (Model Reach 17)

Watershed Management Scenarios

Numerous scenarios were simulated to evaluate the effectiveness of watershed-based strategies in improving water quality in the Fox River. These scenarios focused on TP load reductions from the tributaries, upstream watershed, and WWTPs, in addition to two dam removal scenarios (Mahajan et al., 2021).

1. **Upstream load reduction:** The upstream load constitutes about 16 percent of the total TP load into the Fox River study area. The instream model was run for scenarios with 50 percent and 75 percent reduction in upstream TP load. The reduction in upstream TP load was simulated by proportionally reducing the upstream boundary concentration for organic phosphorus, inorganic phosphorus, and internal phosphorus within sestonic algae (algae suspended in the water column). The upstream TP boundary condition for the baseline and two upstream TP load reduction scenarios is shown in the upper panel **of Figure 4**. The sestonic chlorophyll-a upstream boundary was reduced in proportion to the reduction in internal phosphorus **(Figure 4 lower panel**). The upstream boundary sestonic chlorophyll-a values for the baseline scenario ranged from 46 micrograms per liter (ug/L) to 235 ug/L over the growing season. For the 50 percent reduction scenario, the upstream sestonic chlorophyll-a boundary ranged from 23 ug/l to 117 ug/L. For the scenario with a 75 percent upstream load reduction, the TP concentration was capped at 50 µg/L or 0.05 mg/L, which corresponds to the Illinois TP criterion for the Fox Chain O'Lakes, located upstream of the

FRIP Study Area. The upstream sestonic chlorophyll-a boundary for the 75 percent scenario ranged 11 ug/L to 37 ug/L.

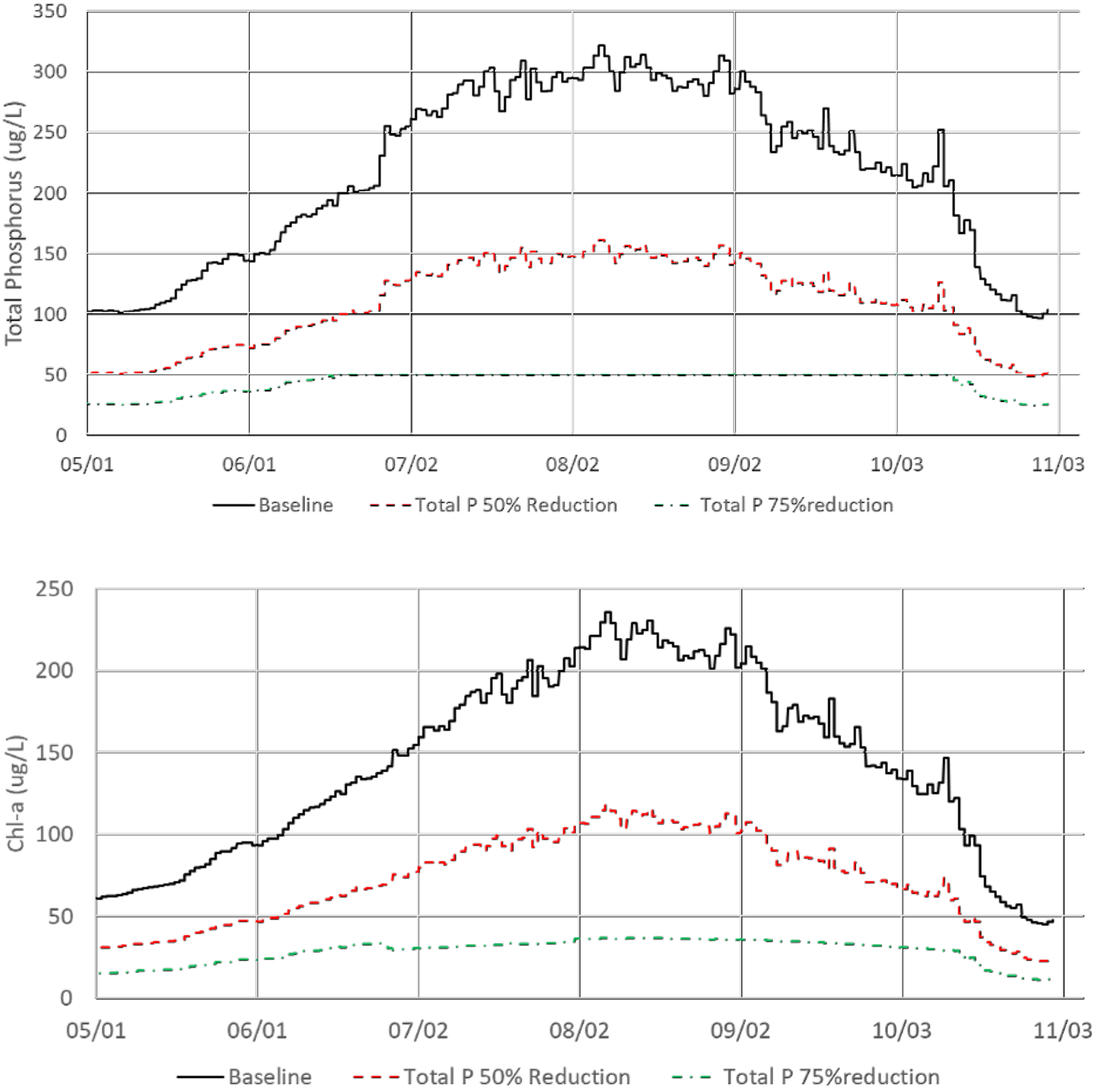
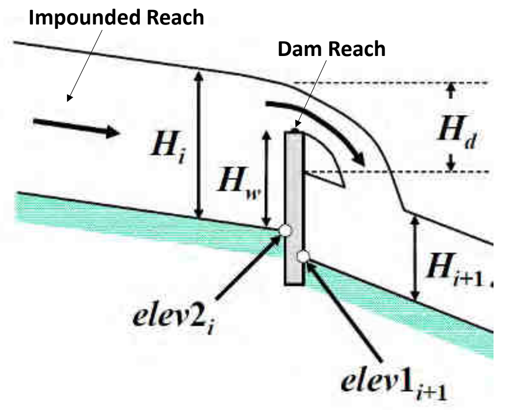


Figure 4: Upstream Total Phosphorus Boundary Condition for the Baseline Scenario and the 50% and 75% Reduction in Upstream TP Loading Scenarios

2. **Tributary load reductions:** The contribution of tributary loads vary by river mile (**Figure 2**). The instream model was run for scenarios with a reduction of 50 percent and 75 percent in TP load from each tributary.

3. **WWTP load reductions:** The average TP concentrations for WWTPs in the baseline scenario range from 0.2 to 5.5 mg/L. WWTP load reduction scenarios were conducted by setting TP effluent concentrations to constant values of 1.0 mg/L, 0.5 mg/L, and 0.1 mg/L in the instream model (for the mainstem major WWTPs) and in the watershed model for the tributary WWTPs

4. **Dam removals:** The dam removal scenarios involve assessing the impact of dam removal on the DO and sestonic and benthic algae in the Fox River. In the instream model, a dam is represented by two reaches: an upstream impoundment reach with deeper water, and a dam reach to represent the dam weir structure. The impact of dam removal on river hydraulics and water quality was simulated in the instream model using the following methodology:



Dam Representation in QUAL2kw; Source: QUAL2kw manual

- Removing the weir structure representing the dam.

- Updating the dam reach from the weir equation to a non-impounded reach using the downstream rating curve.

- Updating the impounded reach to a free-flowing reach similar to upstream of the impounded reach.

- Reducing the dam's SOD and impounded reaches to 0.15 grams per square meter per day (the 10th percentile of SOD values for free-flowing reaches).

- Reducing the benthic algae coverage to 20 percent for the impounded reach and in the tailwater reach of the dam. This was done based on observations in the Fox River and a literature review. Dam removals will create rapids, increasing velocities and scouring benthic algae coverage. The non-impounded reaches in the Fox River, which are not influenced by dams, have relatively low levels of benthic algae coverage. In addition, dam removal in the Fox River is expected to increase macroinvertebrate densities, which would further reduce the benthic algae coverage on the river bottom.

The FRSG plans to confirm the validity of the above assumptions for simulating dam removals based on pre-and post-monitoring of water quality upstream and downstream of the dam in Carpentersville. This dam is currently scheduled for removal in 2023 by the Forest Preserve District of Kane County.

Two dam removal scenarios representing the likely anticipated short- and long-term dam removals were simulated in the model:

1. Removal of only two dams, the Carpentersville and North Aurora Dams: At the time the modeling was conducted, these two dams were anticipated as slated for removal in the pre-2032timeframe; and

2. Removal of ten dams: Carpentersville, Elgin, South Elgin, St. Charles, Geneva, North Batavia, North Aurora, Stolp Island, Montgomery, and Yorkville. The actual timing of the dam removal will be driven by the Section 519 Fox River Connectivity and Habitat Study currently underway by the US Army Corps of Engineers.

Combined Watershed Management Scenarios

The watershed management scenarios described above were grouped into short- and long-term combined management scenarios to evaluate the impacts on Fox River water quality. A total of 15 combined scenarios were simulated (**Table 1**). Short-term combined scenarios focused on management scenarios to be implemented pre-2032 (e.g., 0.5 mg/L effluent TP limit, three dams removed, and 50 percent upstream TP load reduction), while long-term combined scenarios focused on management scenarios which, if selected, would be implemented post-2032. (e.g., 0.1 mg/L WWTP effluent TP limits, all dams removed, 75 percent upstream TP load reductions, and 50 percent non-point sources TP load reductions).

Table 1: Combined Watershed Management Scenarios

	Scenario Number												
	5A	**5B**	**5C**	**5D**	**5E**	**5F**	**5G**	**5H**	**5I**	**5J**	**5K**	**5L**	**5M**
Time Period													
May - October 2012	X	X	X	X	X	X	X	X	X	X	X	X	X
Tributary													
Existing													
25% TP Reduction													
50% TP Reduction											X		
Upstream Conditions													
Existing TP			X		X							X	
Existing TP - 50%	X	X		X		X	X		X				
Existing TP - 75%								X		X	X		X
Treatment Plant Effluent													
Existing Flows	X	X	X	X	X	X	X	X	X	X	X	X	X
WWTP discharged at 1 mg/L TP	X		X	X									
WWTP discharged at 0.5 mg/L TP		X			X	X		X	X			X	X
WWTP discharged 0.1 mg/L TP							X			X	X		
Dams Removed													
Algonquin													
Carpentersville			X	X	X	X	X	X	X	X	X	X	X
Elgin									X	X	X	X	X
South Elgin									X	X	X	X	X
St. Charles									X	X	X	X	X
Geneva									X	X	X	X	X
North Batavia			X	X	X	X	X	X	X	X	X	X	X
North Aurora			X	X	X	X	X	X	X	X	X	X	X
Stolp Island									X	X	X	X	X
Montgomery									X	X	X	X	X
Yorkville													

Results of the Watershed Management Scenarios

The results of the watershed management scenarios were compared with the baseline scenario to assess the impact of watershed-based strategies on DO and algae (sestonic and benthic) in the mainstem Fox River. The impacts are more pronounced for the critical period of July 2012, which had the lowest flows, and are presented below. Longitudinal plots show the comparison of baseline scenario results with watershed management scenarios. The X-axis for the longitudinal plots represents the river miles along the Fox River mainstem from Stratton Dam (RM 100) to the Illinois River confluence (RM 0). The results are shown for the following parameters for July 2012:

a. **Percent of Time DO Concentration is Less Than the Instantaneous Criteria (%):** Calculated percentage of time in a month when the simulated DO concentrations is less than the instantaneous criteria;

b. **Monthly Minimum DO (mg/L):** Calculated monthly minimum for each reach based on the timeseries of simulated DO values;

c. **Monthly Average TP (mg/L):** Calculated average for each reach based on the timeseries of simulated TP values;

d. **Monthly Median Chlorophyll-a (µg/L):** Calculated median for each reach based on the timeseries of simulated sestonic chlorophyll-a values;

e. **Monthly Median Benthic Algae Mass (Kilogram Algae or KgA):** Calculated median mass for each reach based on the timeseries of simulated benthic algae chlorophyll-a values (milligrams per square meter or mg Chl-a/m2) and area of reach (m2). The mass of benthic algae (kgA) is calculated by multiplying the model reported benthic algae density (mgA/m2) by the length, wetted width of the reach, and percentage of benthic algae coverage; and

f. **Monthly Percent of Time Chlorophyll-a is Greater Than or Equal to 149 µg/L (%):** Calculated percentage of time when the simulated sestonic chlorophyll-a is greater than a threshold value of 149 µg/L. The 149 µg/L represents the mean chlorophyll-a value when Illinois EPA determined the Fox River reaches to be impaired due to nuisance algae based on a visual assessment by a trained biologist.

A summary of the watershed management scenario results is presented below. Details of the watershed management scenario results are included in *Attachment 1: Watershed Management Scenarios Results Presentation, dated January 5, 2021.*

Upstream Load Reduction

As stated above, the scenarios for the upstream TP load reduction also included a modeled reduction in upstream sestonic chlorophyll-a since a percentage of TP is also bound up as internal phosphorus in sestonic chlorophyll-a.

Figure 5 shows the comparison of simulated results for the baseline scenario (black solid line); a scenario with a 50 percent reduction in upstream TP load (red dashed line); and a scenario with a 75 percent reduction in upstream TP load (green dashed line). The reductions in the model's upstream TP concentration have a negligible impact on mainstem TP level below RM 70, where baseline WWTP discharges to the mainstem render the upstream TP reductions insignificant. For the baseline and reduction scenarios, the growth of sestonic algae within the Fox river is slow until RM 70. The sestonic algae does increase going downstream due to the increased residence time caused by the series of low head dams. This exacerbates the effect of the increased phosphorus loading into Fox River downstream of RM 70. The reduction of upstream sestonic algae concentrations (associated with reduced TP concentration) results in reduction of sestonic algae downstream. This reduced sestonic algae results in less shading in the downstream reaches. Importantly, the model suggests minimum DO levels in the mainstem appear more associated with the proliferation of benthic algae than sestonic algae. The benthic algae increase in the middle and downstream reaches because of the availability of more light due to a reduction in sestonic chlorophyll-a. The increased oxygen demand due to increased benthic algae concentration (or mass) is much higher than the decreased oxygen demand due to decreased sestonic chlorophyll-a concentration. This manifests in the simulated decreased monthly DO concentration from RM 70 onwards.

Taken together, while upstream P reductions may have profound implications for algae populations and DO concentrations in the Chain O' Lakes, river hydraulics with far shorter residence times suggest a fundamentally different growth environment exists in the mainstem. From this scenario, it appears at least sestonic algae levels in the mainstem are dependent upon the algae populations introduced upstream until RM 70. Further downstream, sestonic algae levels are largely independent of upstream TP concentrations.

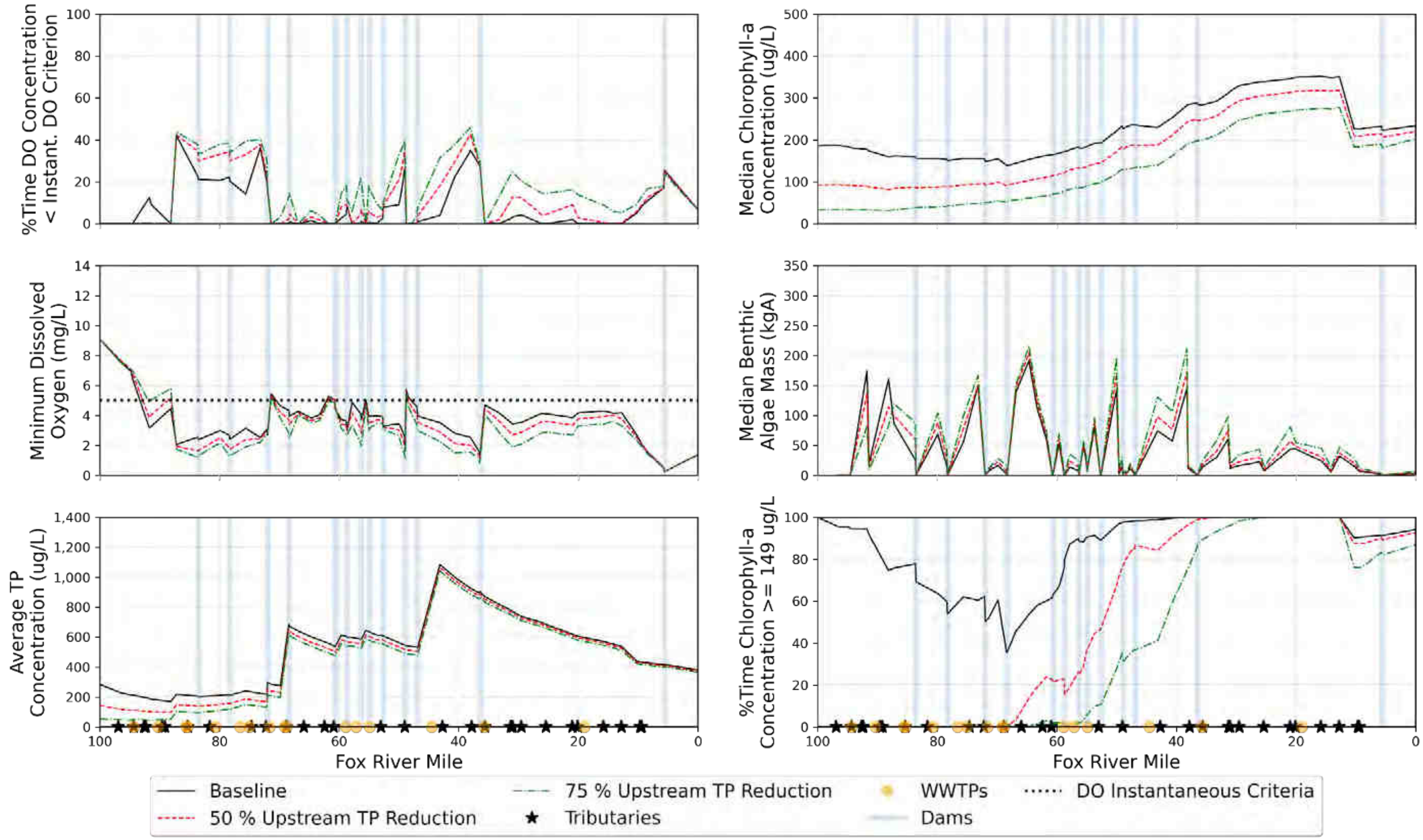


Figure 5: Comparison of Model Results for the Baseline Scenario and 50% and 75% Reductions in Upstream Total Phosphorus Loads

Tributary Load Reduction

The impact of reducing tributary loads on the mainstem Fox River was assessed by running scenarios with 50 percent and 75 percent reductions in simulated tributary TP loadings. Only negligible impacts of tributary phosphorus on the mainstem were seen, and limited to upstream reaches above RM 63.

Figure 6 shows the comparison of simulated results from July 1 to July 31, 2012, for the baseline scenario (black solid line); a scenario with a 50 percent reduction in tributary TP load (red dashed line); and a scenario with a 75 percent reduction in tributary TP load (green dashed line). The results show that the impact of reducing tributary TP loading on simulated instream water quality is minimal.

There is only one instance where any impact from tributary load reduction is predicted. It occurs downstream of RM 10, where Indian Creek South (LaSalle County)(with a large tributary load) comes into the Fox River. The reduction in tributary loading has no impact on simulated DO in the Fox River since the relative contributions of tributary loadings are small compared to loadings from WWTPs and upstream sources.

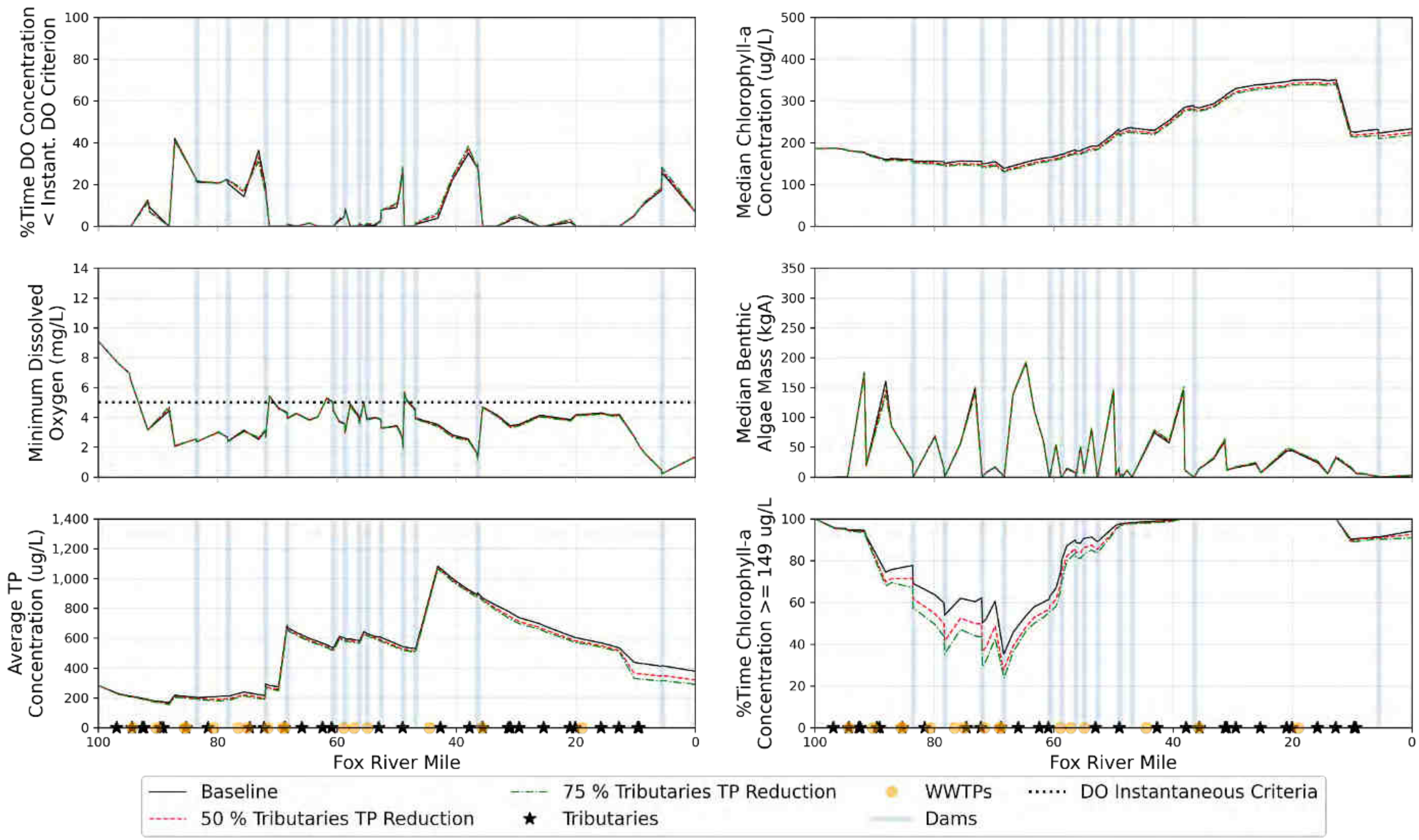


Figure 6: Comparison of Model Results for the Baseline Scenario and 50 percent and 75 percent Reductions in Tributary Total Phosphorus Loads

WWTP Load Reductions

The impact of load reductions associated with more stringent effluent TP limits for WWTPs was simulated by setting the WWTP (tributary and mainstem dischargers) effluent concentrations to 1 mg/L, 0.5 mg/ L, and 0.1 mg/L in the model.

Figure 7 compares simulated results for the baseline scenario (black solid line) and a scenario with the WWTP TP effluent concentration set to 1 mg/L (red dashed line). These results show that the instream TP is substantially reduced when the WWTPs meet a limit of TP of 1 mg/L and quantifies the positive impact of these changes on Illinois' nutrient removal strategy.

The decreased TP concentrations result in decreased sestonic chlorophyll-a in the middle and lower reaches of the Fox River, downstream of RM 70, where several WWTPs discharge from the Elgin area into the Fox River. The benthic algae also decreased in the middle reaches because of the increased phosphorus limitation factor[2] with about a one-third reduction in instream total phosphorus from the baseline scenario. For the lower reaches, the benthic algae increased compared to the baseline scenario because of increased light availability due to reductions in sestonic chlorophyll-a. As a result, the minimum DO concentration increases for the middle reaches and decreases for the lower reaches with the reduction in WWTP TP loading.

Figure 8 shows the comparison of simulated results for the baseline scenario (black solid line); a scenario with WWTP TP effluent concentrations set to 1 mg/L (red dashed line); and a scenario with WWTP TP effluent concentrations set to 0.5 mg/L (green solid line). The results show a further improvement of sestonic chlorophyll-a for the middle and lower reaches, with the simulated chlorophyll-a concentrations mostly below the threshold target value of 149 ug/L, with the reduction of TP effluent concentrations from 1 mg/L to 0.5 mg/L. The simulated benthic algae further decreased, which resulted in improved DO concentrations in the middle reaches, with the reduction of TP effluent concentrations from 1 mg/L to 0.5 mg/L. The impact of benthic algae on DO levels has been validated by data collected in the non-impounded reach upstream of the Carpentersville dam (Deuchler, 2020).

Figure 9 shows the comparison of simulated results for the baseline scenario (black solid line); a scenario with WWTP TP effluent concentration set to 0.5 mg/L (solid green line); and a scenario with WWTP TP effluent concentration set to 0.1 mg/L (blue dashed line). The results show little improvement in simulated DO and sestonic chlorophyll-a with decreases in TP effluent concentrations from 0.5 to 0.1 mg/L.

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[2] Nutrient limitation factor ranges from 0 to 1. It is dependent on the algae biomass and instream nutrient concentrations. A factor of 1 implies no nutrient factor limitation

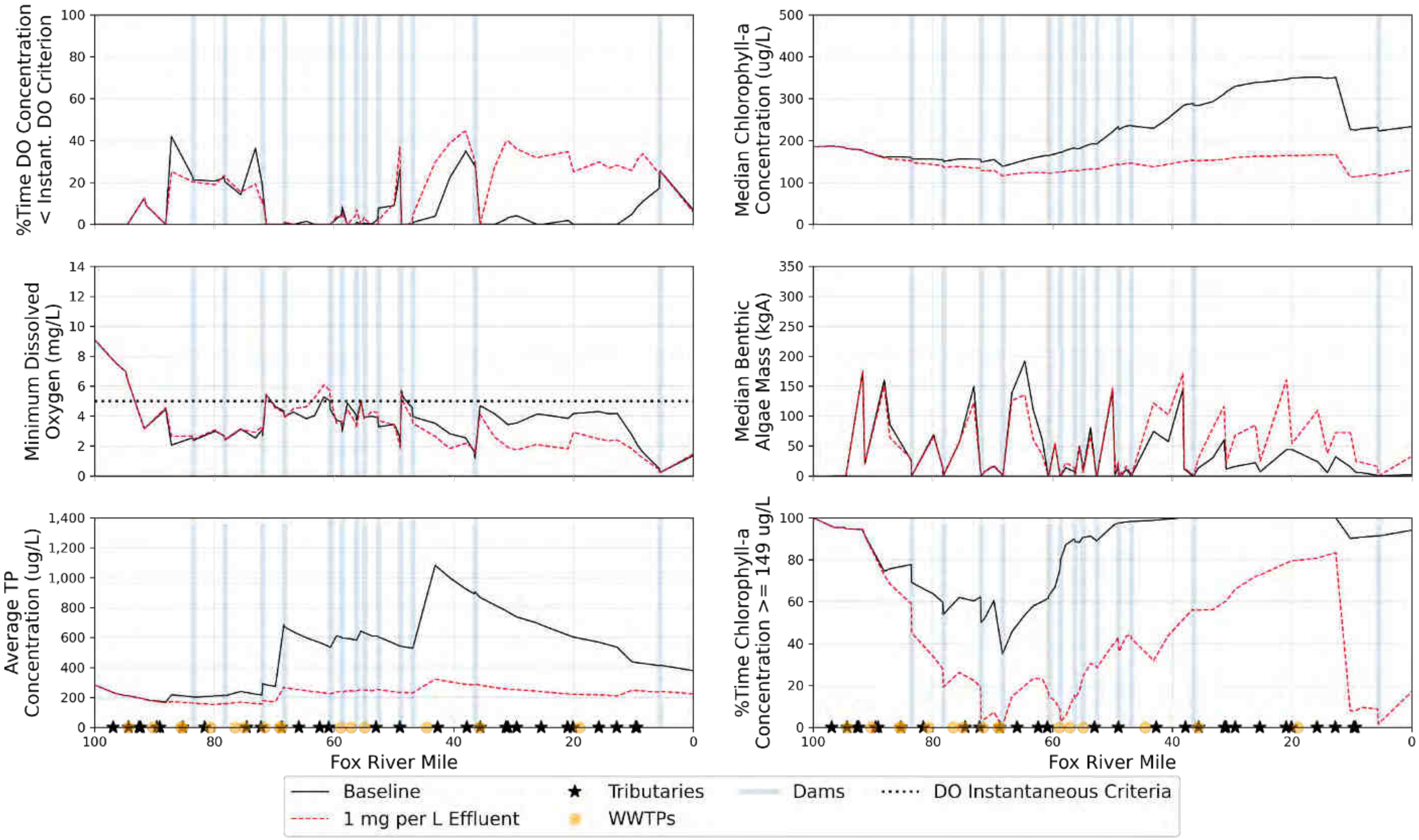

Figure 7: Comparison of Model Results for the Baseline Scenario and a Scenario with WWTP Effluent Discharge at 1 mg/L Total Phosphorus

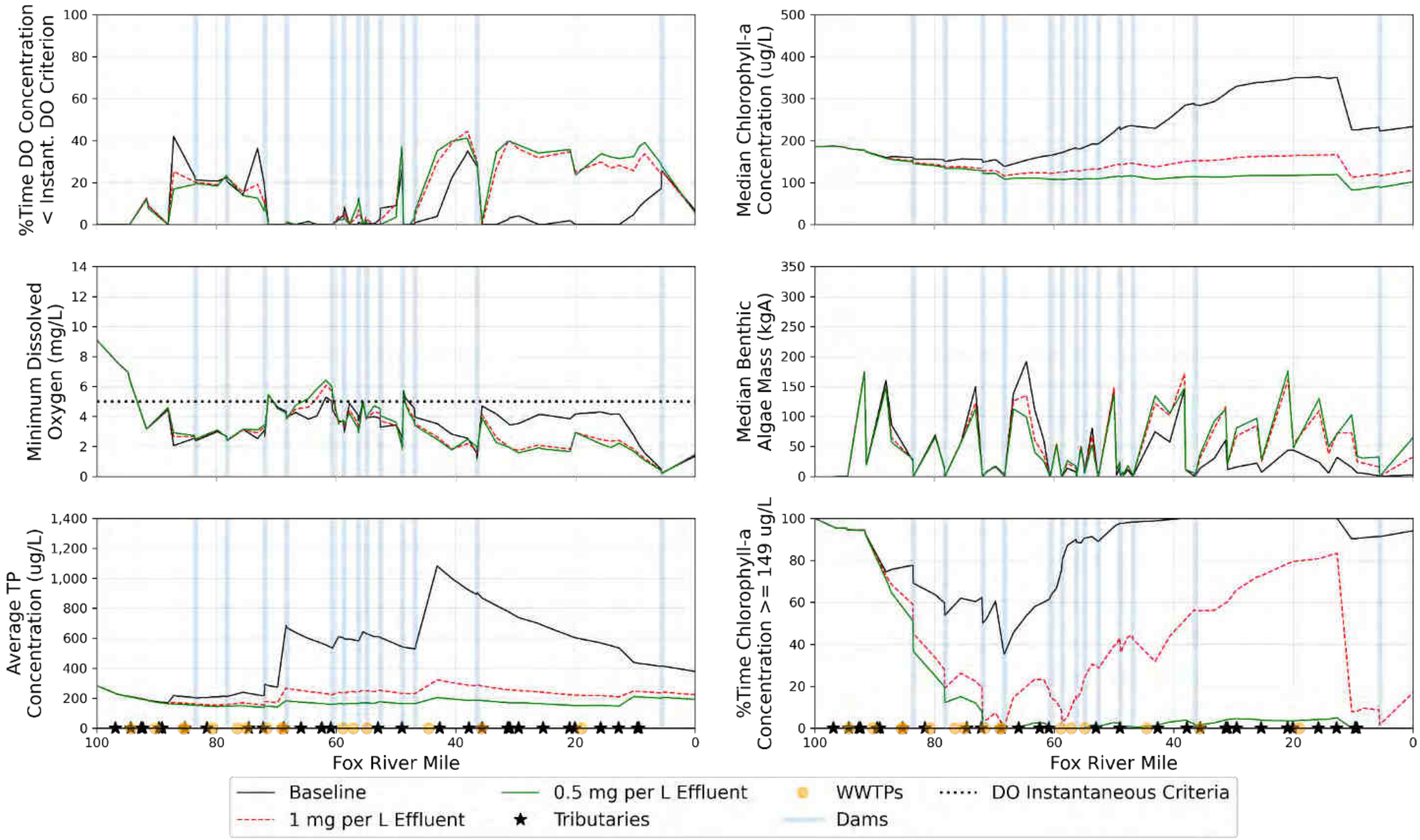

Figure 8: Comparison of Model Results for the Baseline Scenario and Scenarios with WWTP Effluent Discharge at 1 and 0.5 mg/L Total Phosphorus

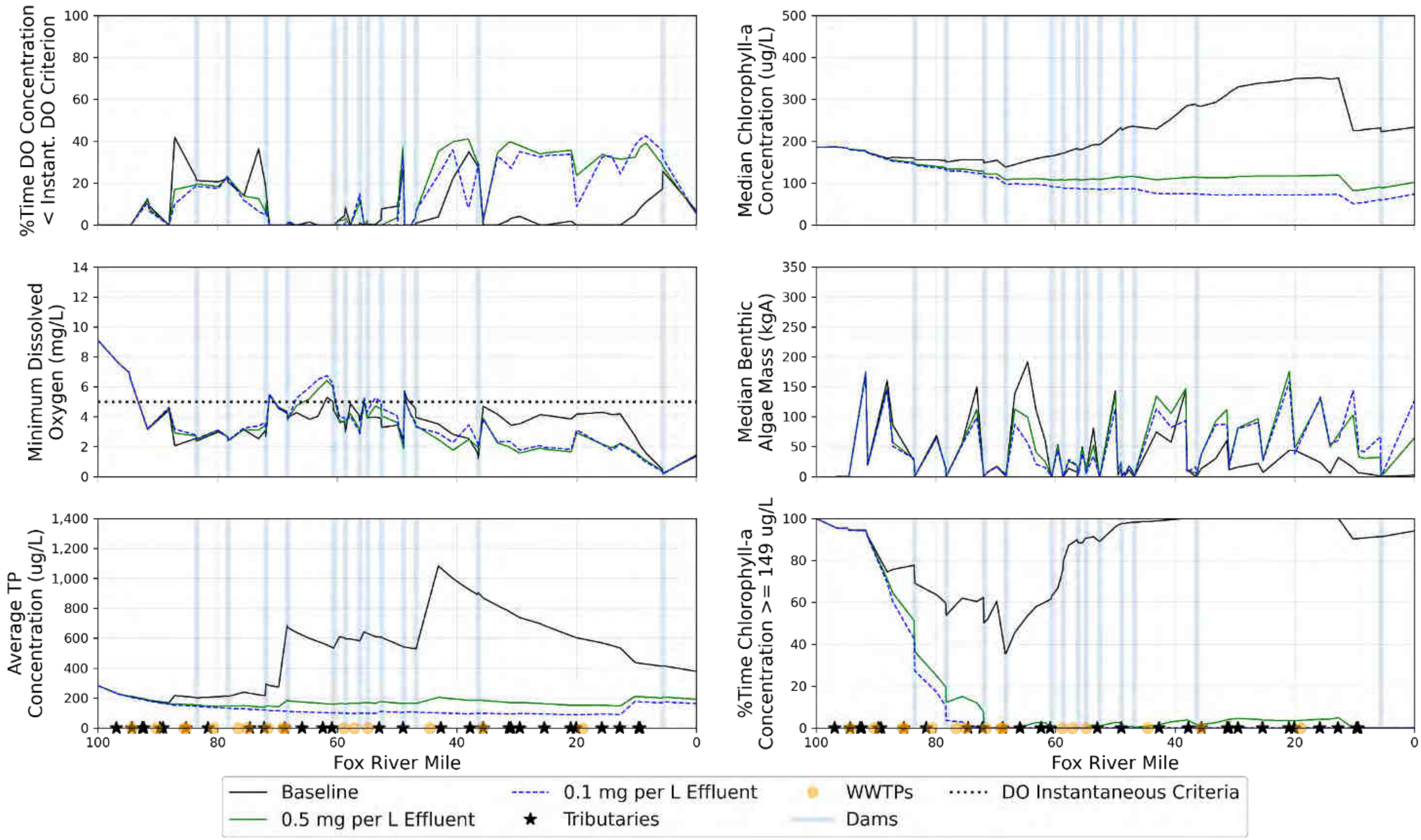

Figure 9: Comparison of Model Results for the Baseline Scenario and Scenarios with WWTP Effluent Discharge at 0.5 and 0.1 mg/L Total Phosphorus

Dam Removal

Dam removals were simulated in the model by updating the model parameter for impounded and dam reaches as described above.

Figure 10 shows the comparison of results for the baseline scenario (black solid line); a scenario with the Carpentersville and North Aurora dams removed (red dashed line); and a scenario with ten dams removed from the Carpentersville to Yorkville dams (green dashed line). The results show that removing a single dam will significantly reduce benthic algae and locally improve DO concentrations to above the 5 mg/l standard in the reach just downstream of the removed dam. For the scenario with ten dams removed, the model shows substantial decreases in benthic algae from Carpentersville to Yorkville due to rapidly flowing waters, which do not provide a suitable habitat for the growth of benthic algae. As a result, the simulated minimum DO increases, and the percentage of time DO is below the instantaneous DO standard increases with the dam removals.

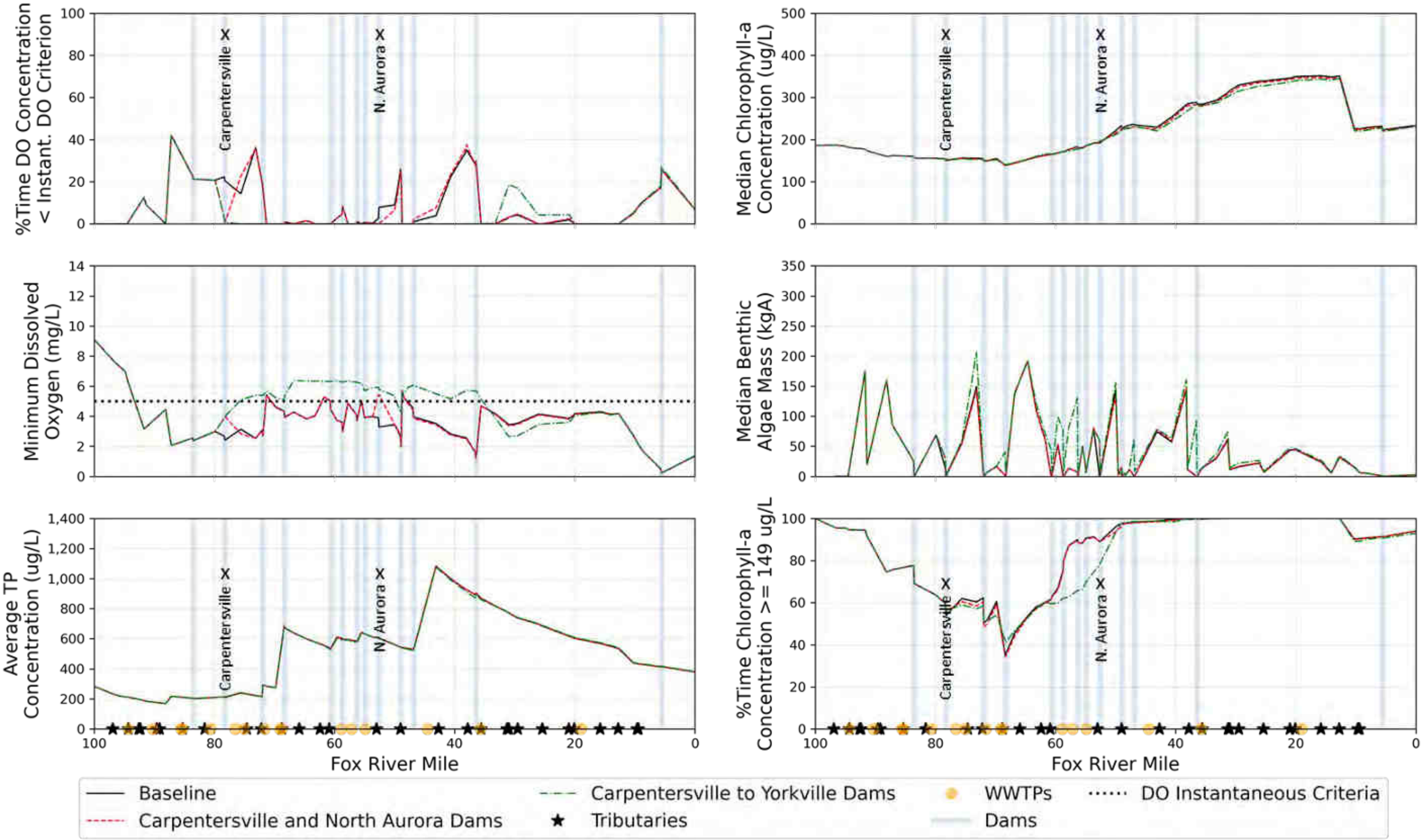

Figure 10: Comparison of Model Results for the Baseline Scenario, Carpentersvilleand North Aurora Dam Removals, and Ten Dam Removals from Carpentersville to YorkvilleDams; 'X' indicates locations of Carpentersvilleand North Aurora Dams

Results of Combined Watershed Management Scenarios

This section summarizes simulation results for two combined scenarios that showed the greatest water quality improvements for the short- (Pre 2030) and long-term periods (see *Attachment 3: Combined Management Scenarios Results Presentation. July 29, 2021*, for more combined scenarios results).

Short-term (Pre 2030) combined scenario: 1) Baseline; 2) 50 percent upstream TP load reduction and 0.5 mg/L WWTP effluent TP limit; 3) 50 percent upstream TP load reduction, 0.5 mg/L WWTP effluent TP limit and 3 dams removed.

Individual management scenarios showed that upstream TP load reduction improves Fox River water quality in the upper reaches while increasing benthic algae in the lower reaches. Furthermore, management scenarios showed that reducing WWTP effluent TP provided rapidly diminishing returns on water quality improvement. Using chlorophyll-a as a measure, the data suggests reducing the annual average effluent TP for WWTP below 0.5 mg/l would likely have no significant positive environmental impact. A set of combined scenarios were run to simulate the impact of coupling dam removal with upstream TP and WWTP effluent TP reductions to confirm whether dam removal reduces benthic algae growth in the reach just downstream of the dam because of increased velocities.

Figure 11 shows the comparison of results from July 1 to July 31, 2012, for the baseline scenario (black solid line); a scenario with 50 percent upstream TP load reduction and 0.5 mg/l WWTP effluent TP limit (red dashed line); and a scenario with 50 percent upstream TP load reduction, 0.5 mg/l WWTP effluent TP limit, and three dams removed (green dashed line). The dams removed for the third scenario are the Carpentersville, North Batavia, and North Aurora dams.

Results show that combining upstream TP reduction with reductions in WWTP effluent TP improves DO and reduces benthic algae in the upper and middle reaches before RM 50, and reduces both TP and sestonic chlorophyll-a throughout the river. For the downstream reaches after RM 50[3], the sestonic algae levels are reduced to levels similar to the upper and middle reaches with reductions in the upstream TP and WWTP loads. Benthic algae can survive at low nutrient levels, and there is sufficient phosphorus to sustain the benthic algae. The reduced sestonic algae levels in downstream reaches result in more light being available to benthic algae, which results in the simulated benthic algae growth. The increased benthic algae growth exerts much more oxygen demand as compared to the baseline scenario resulting in the reduction of DO in downstream reaches. When combining upstream and WWTP TP reductions with three dam removals (Carpentersville, North Batavia, and North Aurora), DO is further improved in the middle reaches.

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[3] Reaches downstream of RM 50 had the least amount of data to parametrize the model. This data includes bathymetry, benthic algae, and instream water quality data. Recommendations for additional data monitoring in the downstream reaches are provided in Chapter 5 of the FRIP.

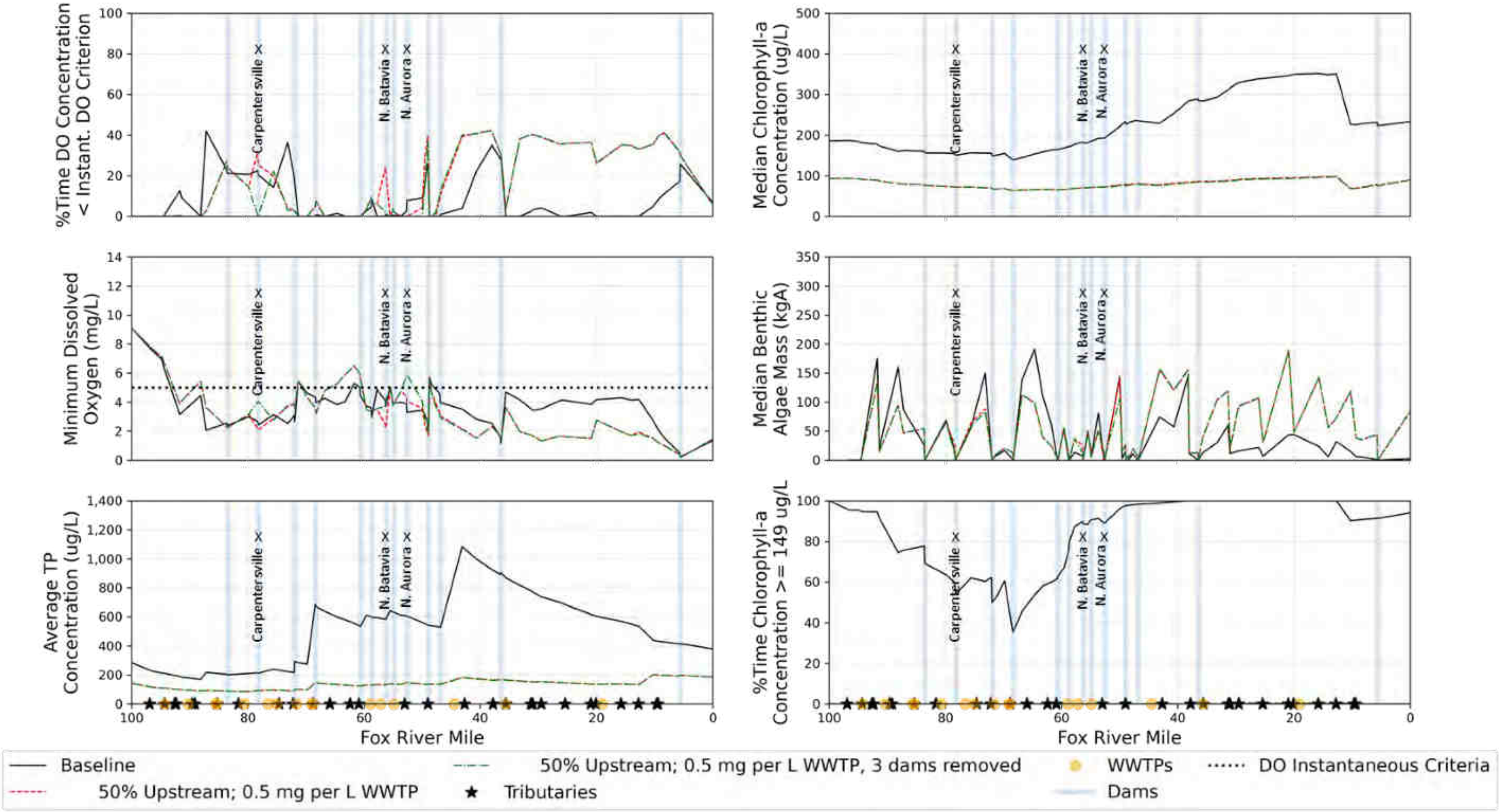


Figure 11: Short-term Combined Scenarios: Baseline (black solid line); 50% Upstream TP Load Reduction and 0.5 mg/L WWTPs Effluent TP Limit (red dashed line); 50% Upstream TP Load Reduction, 0.5 mg/L WWTPs Effluent TP Limit and Three Dams Removed (green dashed line); 'X' indicates locations of dams removed

Long-term (Post 2030) combined scenarios: 1) 0.5 mg/L WWTP effluent TP limit; 2) 0.5 mg/L WWTP effluent TP limit, 50 percent upstream TP load reduction, and three dams removed; and 3) 0.5 mg/L WWTP effluent TP limit, 75 percent upstream TP load reduction, and all dams removed.

Another set of combined scenarios were run to evaluate the long-term impact of management scenarios on the Fox River water quality.

Figure 12 shows the comparison of results from July 1 to July 31, 2012, for a scenario with 0.5 mg/L WWTPs effluent TP limit (black solid line); a scenario with 0.5 WWTPs effluent TP limit, 50 percent upstream TP load reduction, and three dams removed (red dashed line); and a scenario with 0.5 WWTPs effluent TP limit, 75 percent upstream TP load reduction, and all dams removed (green dashed line). Results show that reducing upstream TP load from 50 percent to 75 percent further increases minimum DO and reduces benthic algae in the upstream reaches. It also reduces both TP and sestonic chlorophyll-a throughout the entire Fox River. Finally, long-term combined scenarios results show that a combination of removal of all dams, WWTP TP reductions, and upstream load reductions substantially improves water quality in the Fox River. The reduction in WWTP TP effluent alone has little impact on benthic algae in the Fox River since the algae can grow at very low TP levels in suitable habitat conditions. The removal of dams would increase river velocities in the non-impounded reaches, and hence would remove suitable habitats for benthic algae in these reaches between the dams.

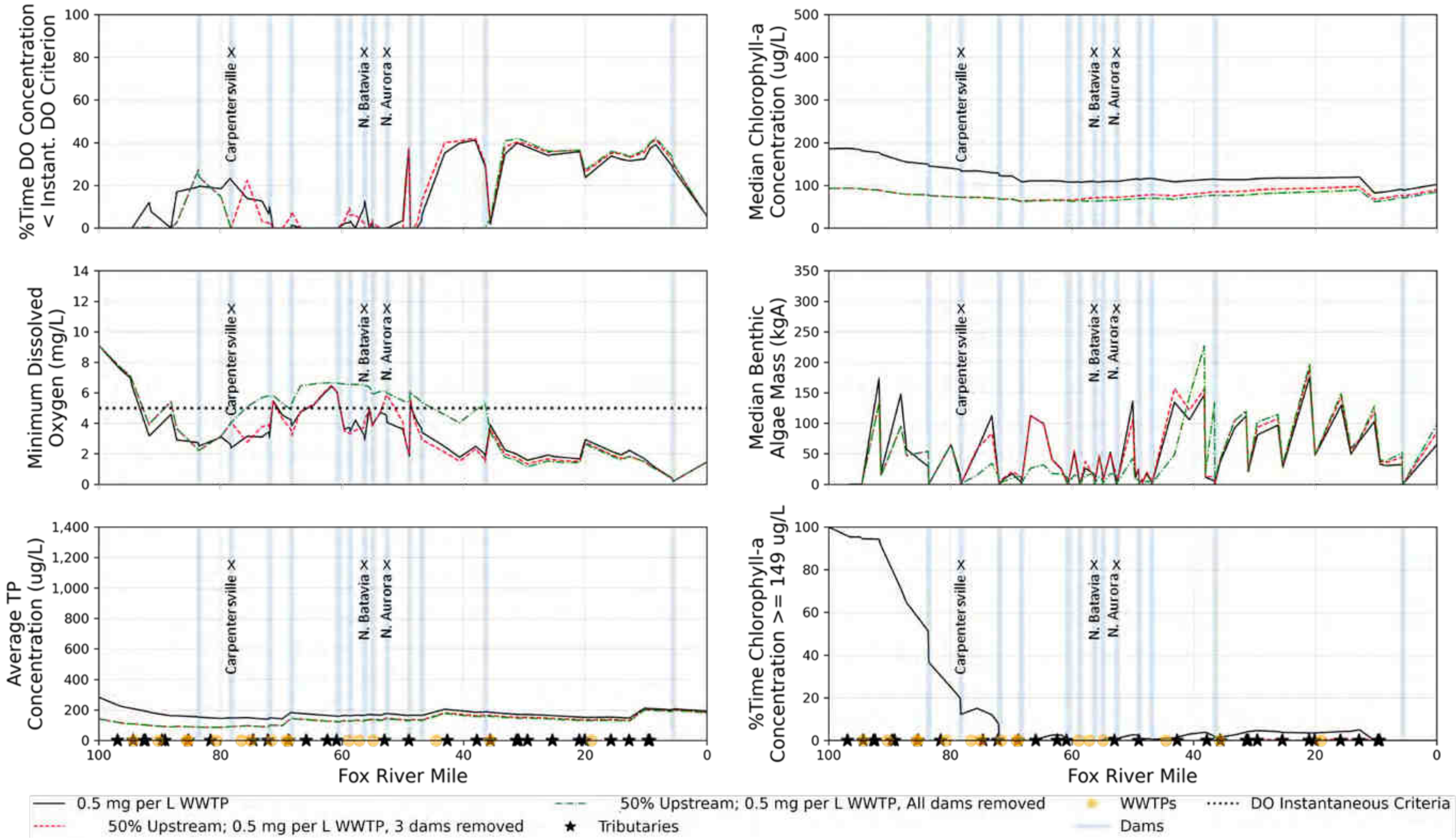
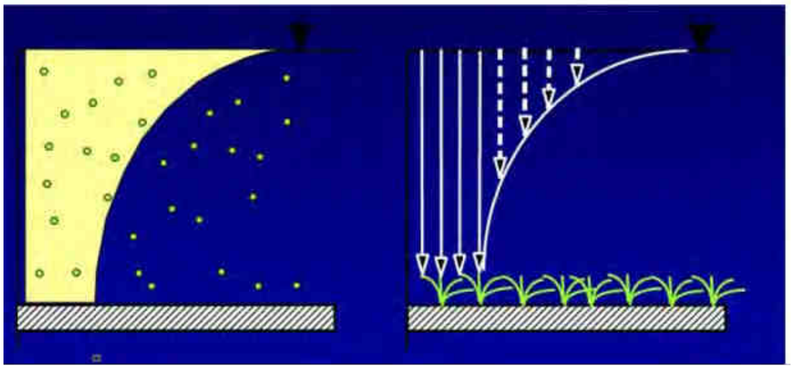


Figure 12: Long-term Combined Scenarios: 0.5 mg/L WWTPs Effluent TP Limit (black solid line); 0.5 WWTPs Effluent TP Limit, 50% Upstream TP Load Reduction, and Three Dams Removed (red dashed line); and 0.5 WWTPs Effluent TP Limit, 50% Upstream TP Load Reduction, and All Dams Removed (green dashed line); 'X' indicates locations of dams removed

Discussion

Sestonic algae (reported in water column chlorophyll-a levels), has long been considered the primary cause of DO impairments. The data collection and modeling conducted in support of the FRIP show that sestonic algae is not the primary cause of DO impairments in the Fox River. Benthic algae, which grows primarily in the shallow and wide non-impounded reaches of the river, cause much larger DO fluctuations in the Fox River. Hence, management actions need to focus on reducing the benthic algae growth in the Fox River to address the DO impairments in the Fox River.

The results of the watershed management scenarios showed an interesting feedback loop between phosphorus, sestonic algae, benthic algae, and DO for the Fox River. Decreasing TP loading from upstream sources and WWTPs substantially reduces the simulated sestonic algae in the Fox River. However, for the Fox River lower reaches, the reduction in sestonic algae makes more light available for benthic algae, which actually results in increased productivity from benthic algae, causing decreased DO levels. TP load reduction measures will therefore need to be complemented by dam removals to reduce the impact of benthic algae on DO. Dam removal, along with streambank restoration, riparian shading, and creation of rapids will create conditions that inhibit the growth of benthic algae. The results also highlight the need to collect additional data to improve the model's simulation of benthic algae to help inform future watershed-based strategies for the Fox River.



Sestonic Algae

Benthic Algae

Conclusions

Dam removal clearly shows the most benefit to water quality. The results of the watershed management scenarios showed that further reductions of TP from WWTPs below 0.5 mg/L would not substantially improve water quality in the Fox River. Therefore, a combination of watershed-based strategies, including load reductions from point and non-point sources and dam removals, is recommended to address phosphorus-related impairments. The results also highlight the need to collect additional data to improve the model's simulation of benthic algae to help inform future watershed-based strategies for the Fox River.

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Mahajan, R.; Nemura, A.; and Skrukrud, S. 2021. Development of watershed-based strategies to eliminate phosphorus-related impairments in the Fox River. *2021 Water Environment Federation's Technical Exhibition and Conference (WEFTEC)*. November 16-18, 2021.

Attachments

1. Watershed Management Scenarios Results Presentation. January 5, 2021.
2. Combined Management Scenarios Results Presentation. July 29, 2021.
3. DO Mass Sinks for Baseline Model

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Attachment 1:

Watershed Management Scenarios Results Presentation, January 5, 2021

Geosyntec
consultants

Watershed Management Scenarios Results

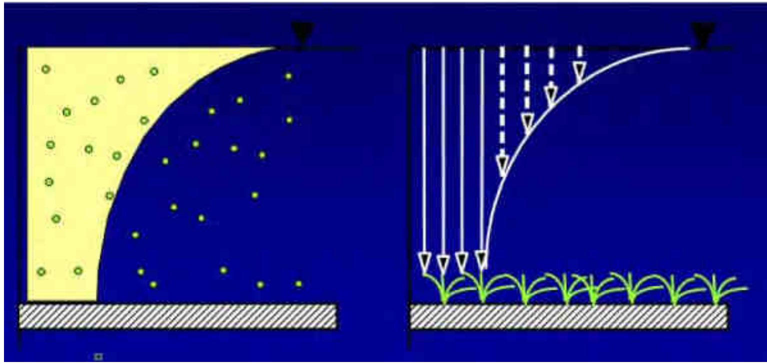
January 5, 2021

Benthic and Sestonic Algae Background

Geosyntec
consultants

Sestonic and Benthic Algae

- Both sestonic and benthic algae impact DO in Fox River
- Benthic algal growth dependent on
  - Light availability (turbidity, sestonic algae)
  - Suitable substrate
- Benthic algae occur in slow moving, shallow reaches of Fox River
- Sestonic algae lowers light availability through shading
  - Reducing sestonic algae would increase benthic algae keeping all factors same



Sestonic Algae Benthic Algae

Image courtesy: WASP 7 manual

Benthic Algae Representation in Model

- Each reach is specified with a percentage of benthic algae cover

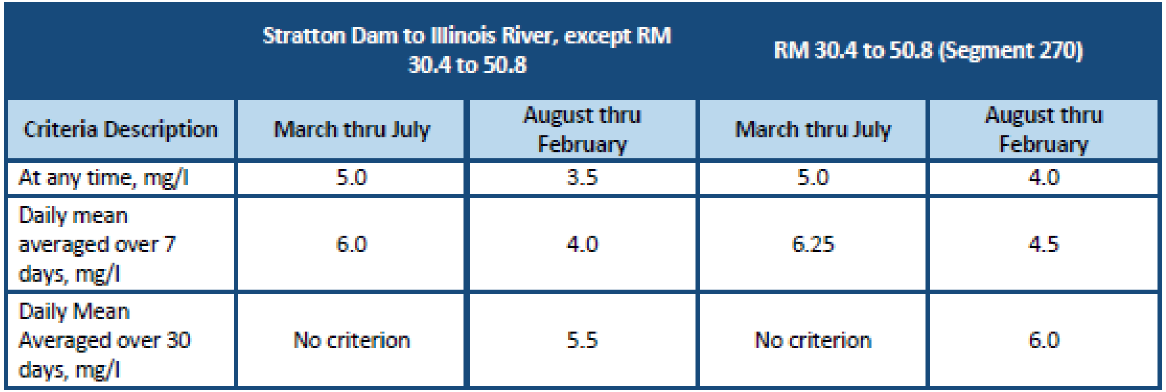
- Based on limited algae coverage data from 2016
  - No data available for benthic algae calibration
  - Percentage coverage fine tuned during the calibration to match observed DO diurnal fluctuations after chlorophyll-a calibration

Watershed Management Scenarios

Geosyntec consultants

Water Quality Targets

- Dissolved Oxygen standards (from FRIP, 2015)

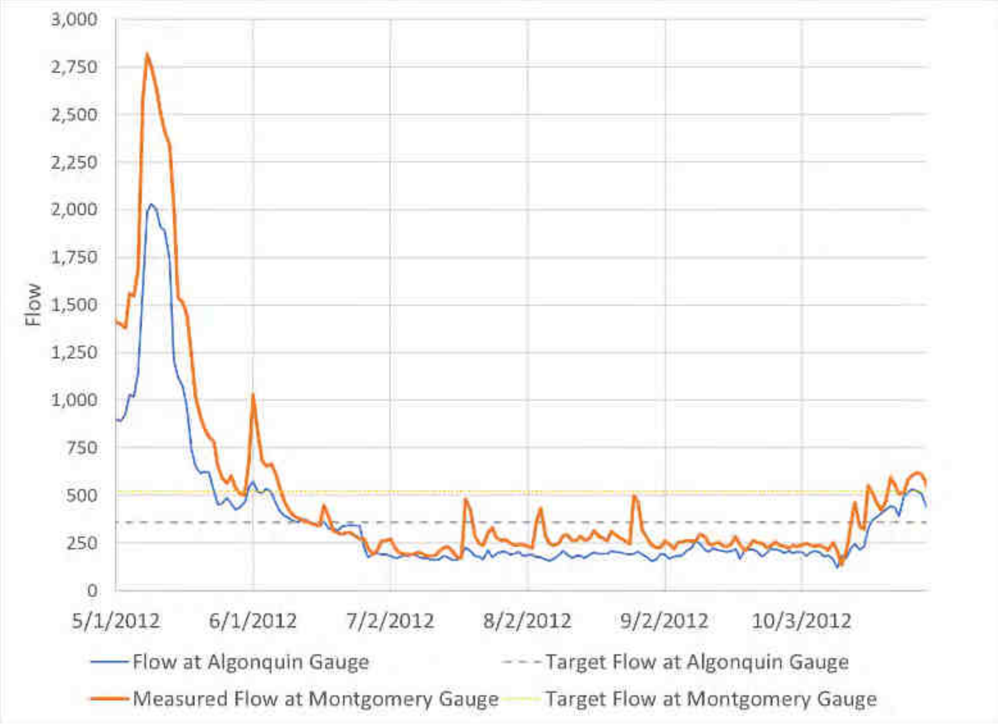


	Stratton Dam to Illinois River, except RM 30.4 to 50.8		RM 30.4 to 50.8 (Segment 270)	
Criteria Description	March thru July	August thru February	March thru July	August thru February
At any time, mg/l	5.0	3.5	5.0	4.0
Daily mean averaged over 7 days, mg/l	6.0	4.0	6.25	4.5
Daily Mean Averaged over 30 days, mg/l	No criterion	5.5	No criterion	6.0

- Chlorophyll-a target based on Jack Russell’s work – 149 ug/L
  - Based on 2018 Illinois EPA impairments and associated chlorophyll-a data from 2012 to 2019

Baseline Model Scenario

- Baseline model scenario represents the existing conditions from May to October 2012
- River Flow
- Shared results with Modeling Subcommittee on August 11, 2020
- Next few slides compare results of management scenarios with baseline scenario
  - TP Load Reductions (50% & 75%)
  - Upstream TP Load Reductions (50% & 75%)
  - Treatment Plants TP (1.0, 0.5, & 0.1 mg/L)
  - Dam Removals



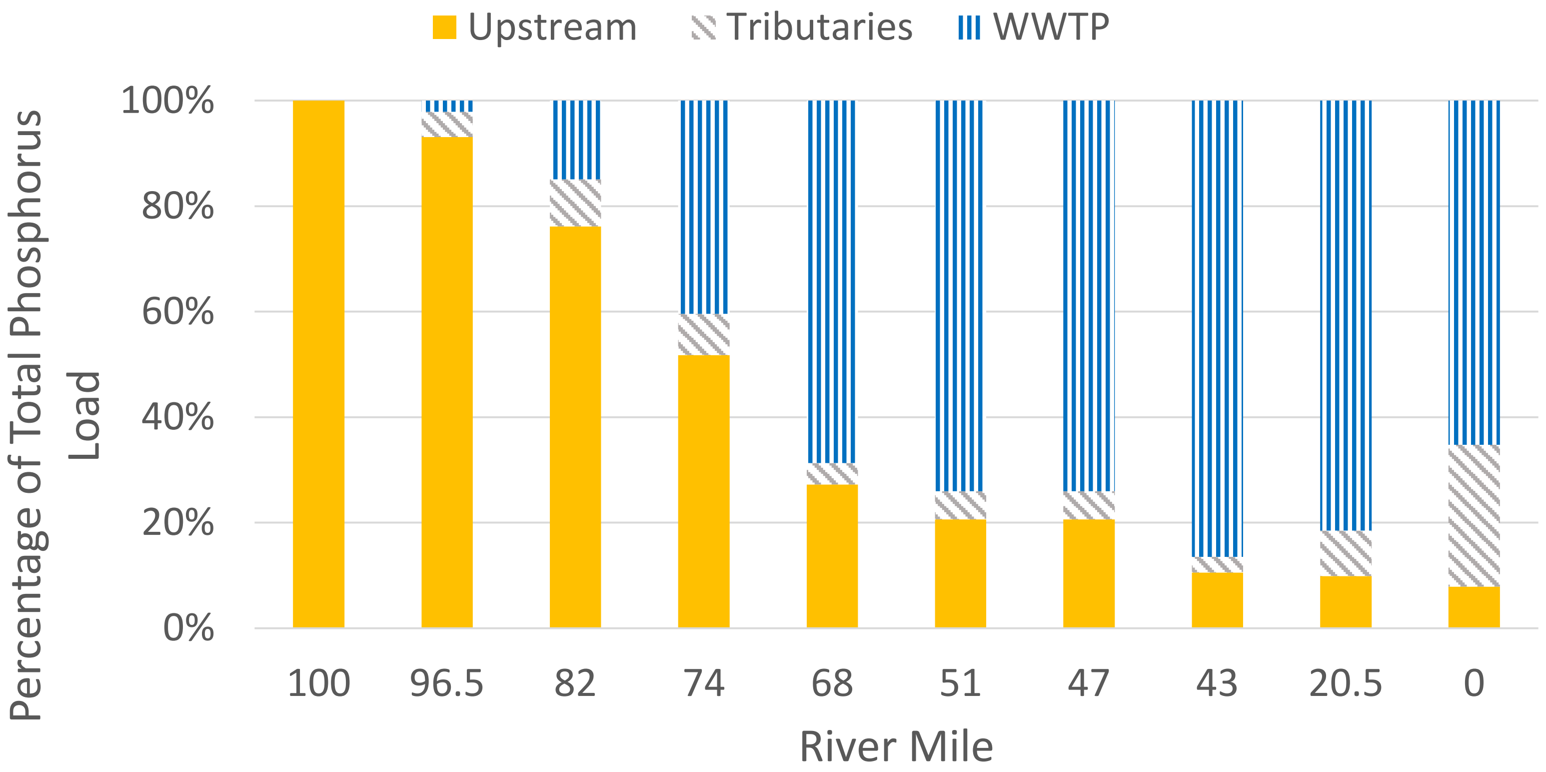
Tributary TP Loads Scenarios

Tributary TP Loads Scenarios Description

- Baseline model used HSPF simulated tributary loads

- Management Scenarios
  - Scenario 1A - Decreased tributary TP loads by 50%
  - Scenario 1B - Decreased tributary TP loads by 75%

Baseline TP load from May 1 to October 31, 2012

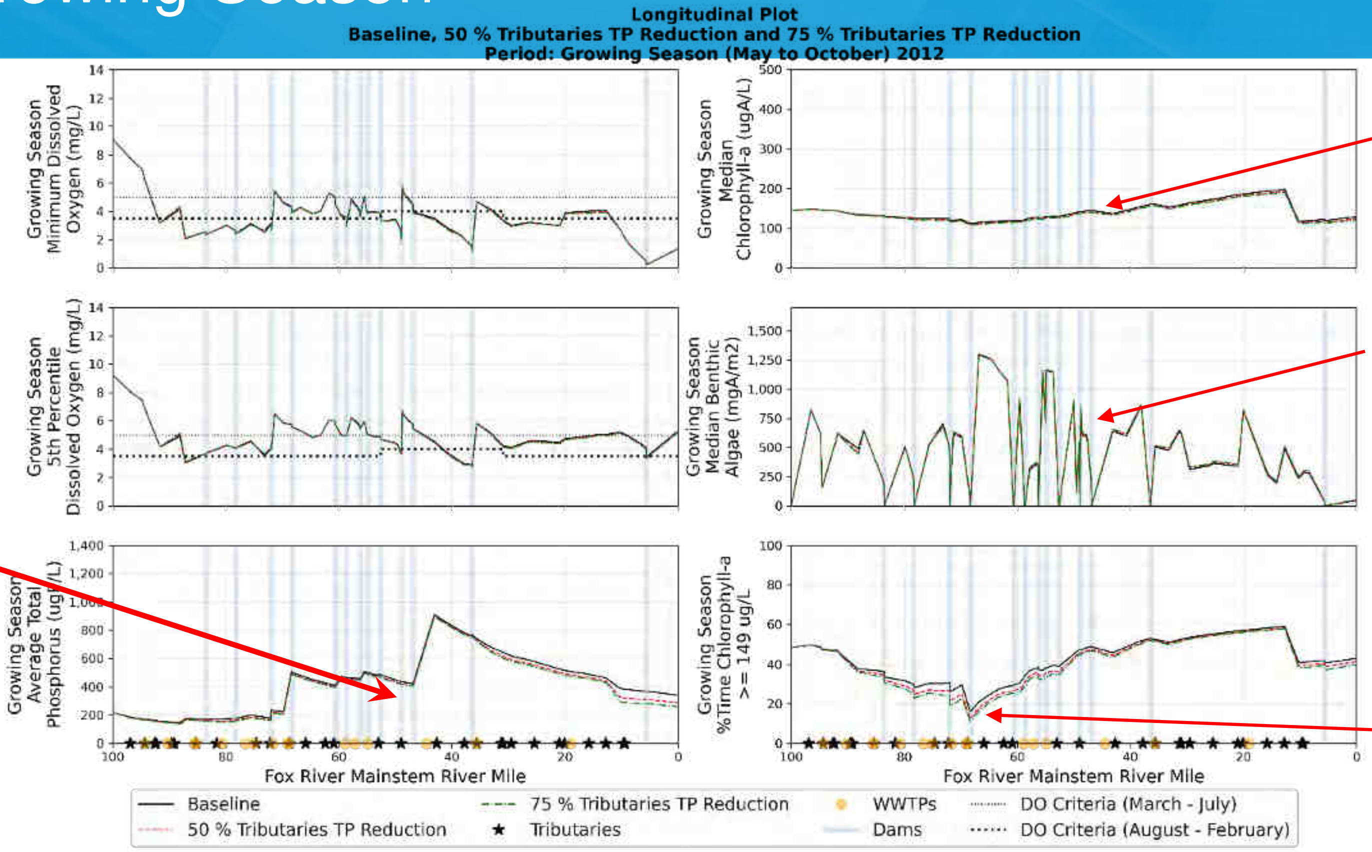


Between River Mile 68 to River Mile 43, tributary loading constitutes only a small proportion of total TP loading

Summary of Results

- Reduction in tributary load alone results in
  - Slight decrease in instream TP and sestonic chlorophyll-a
  - Slight increase in benthic algae
  - No substantial impact on DO

Growing Season



Slight decrease in chlorophyll-a concentration

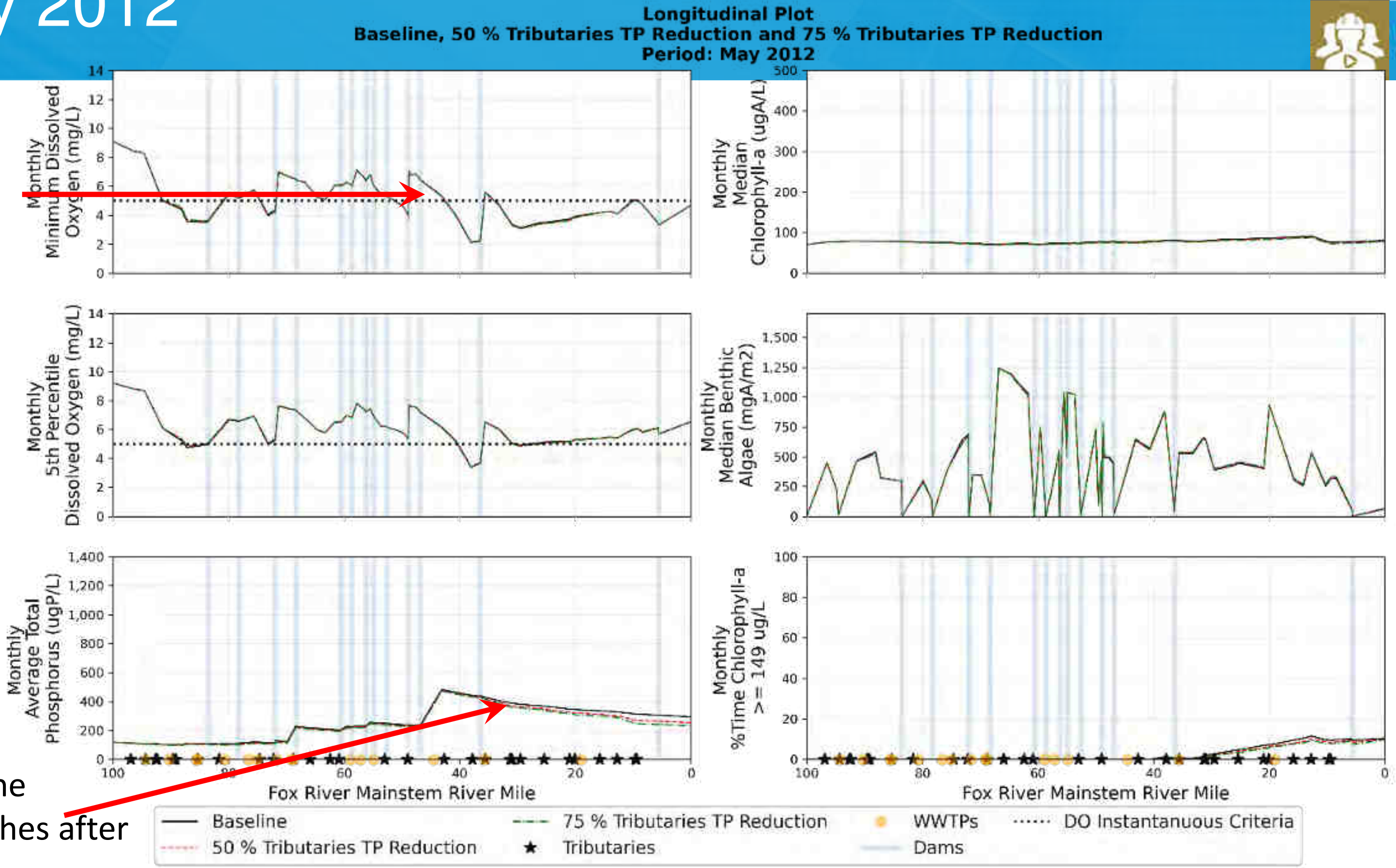
Slight increase in benthic algae concentration

Slight reduction in TP; more noticeable after River Mile 43

% of time when chlorophyll-a is above target is slightly reduced in reaches where simulated chlorophyll is close to target

May 2012

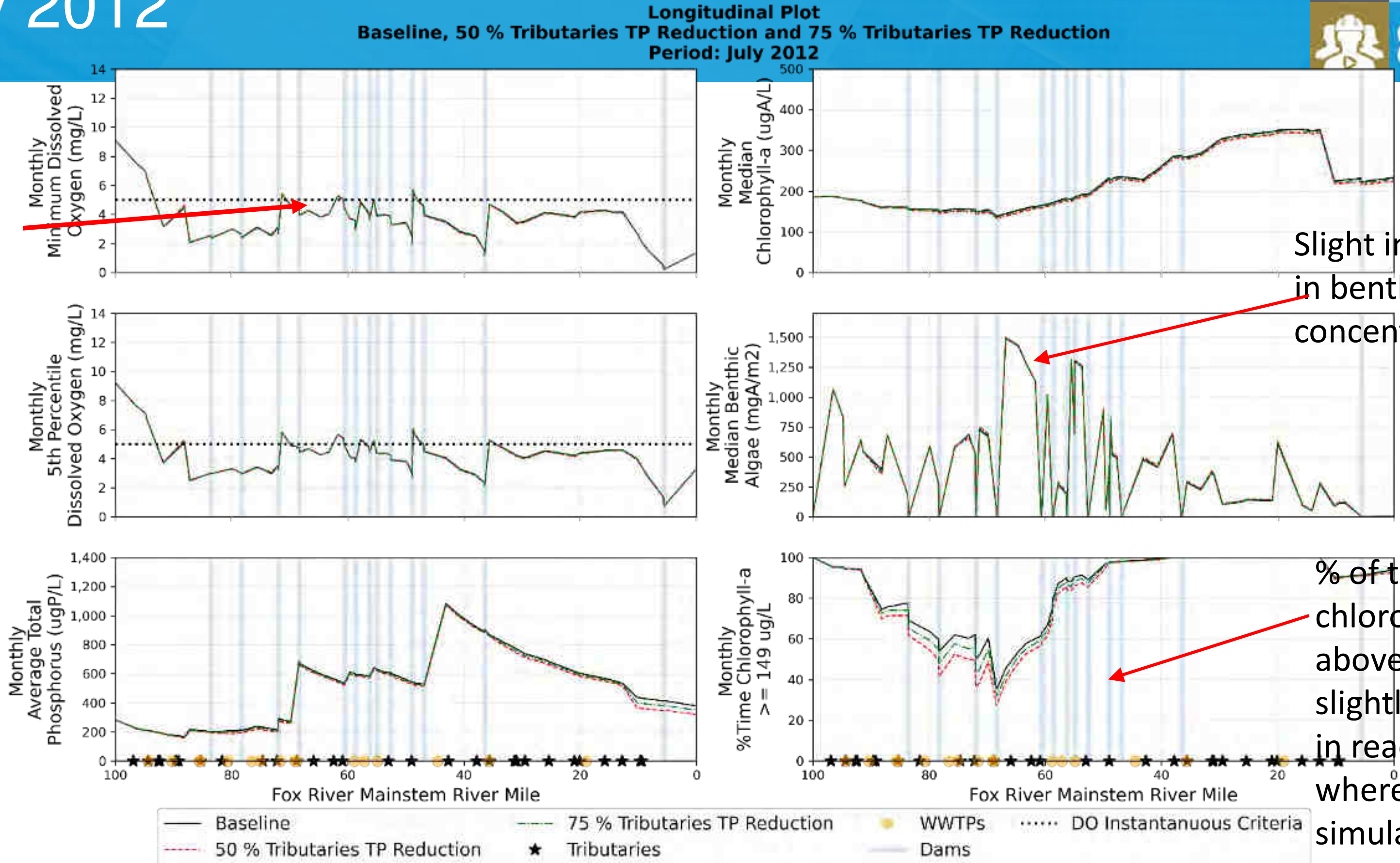
No impact on DO



TP decreases in the downstream reaches after River Mile 43

July 2012

No impact on DO since system is dominated by benthic algae



Longitudinal Plot
Baseline, 50 % Tributaries TP Reduction and 75 % Tributaries TP Reduction
Period: July 2012

Slight increase in benthic algae concentration

% of time when chlorophyll-a is above target is slightly reduced in reaches where simulated chlorophyll is close to target

Similar results for other low flow months – June, August, September and October

Summary of Results

- Reduction in tributary load alone results in
  - Slight decrease in instream TP and sestonic chlorophyll-a
  - Slight increase in benthic algae
  - No substantial impact on DO

Upstream Total Phosphorus (TP) Boundary Conditions Scenarios

Geosyntec consultants

Summary

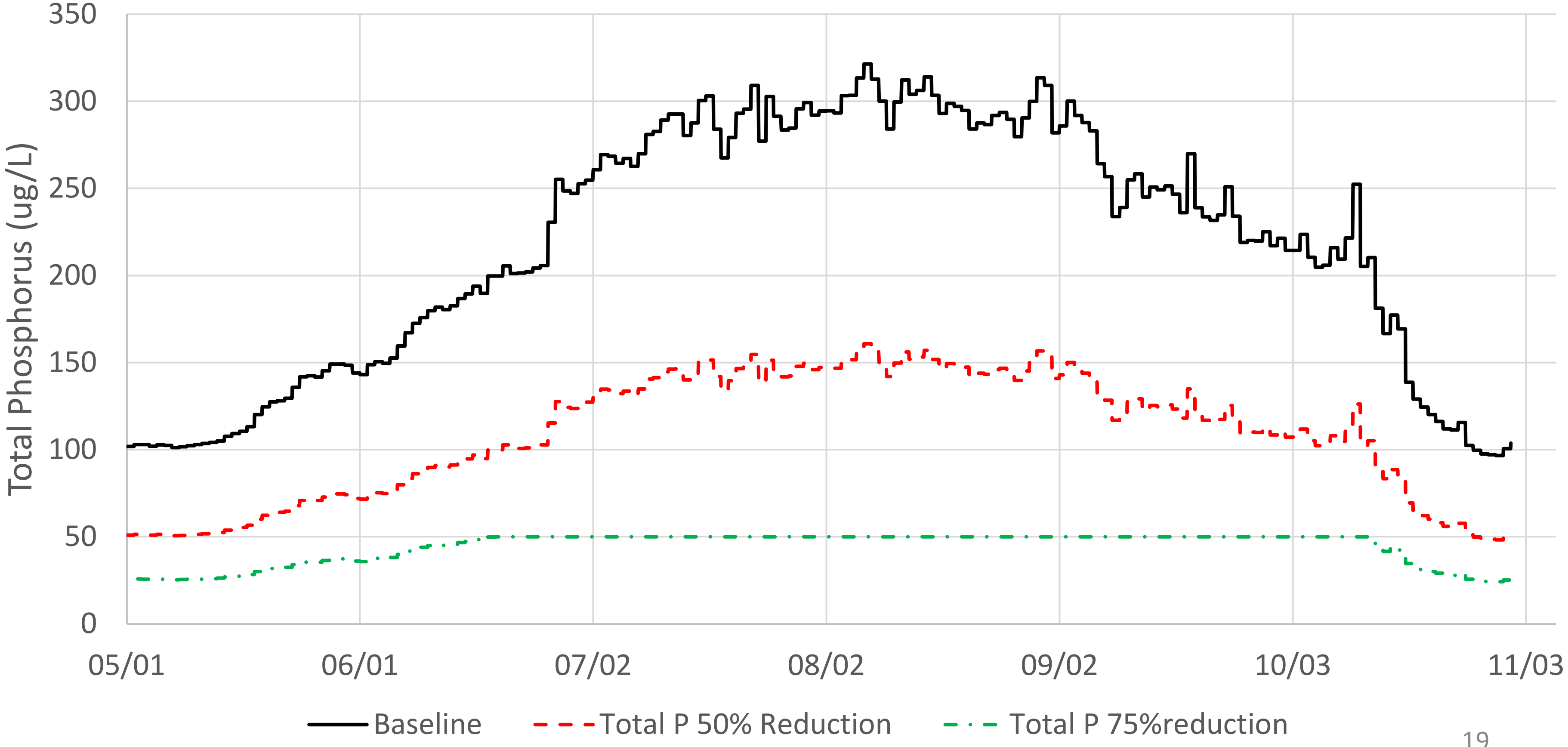
- Reduction in tributary load alone results in
  - Slight decrease in instream TP and sestonic chlorophyll-a
  - Slight increase in benthic algae
  - No substantial impact on DO

Upstream TP Boundary Scenarios Description

- Baseline model uses a time-varying TP boundary condition based on measured data in 2012

- Management Scenarios
  - Scenario 2A: Reduce upstream TP boundary condition by 50%
  - Scenario 2B: Reduce upstream TP boundary condition by 75%
    - Capped upstream TP boundary condition at 0.05 mg/L (50 ug/L) – Illinois EPA criteria for lakes

Upstream Total Phosphorus Boundary

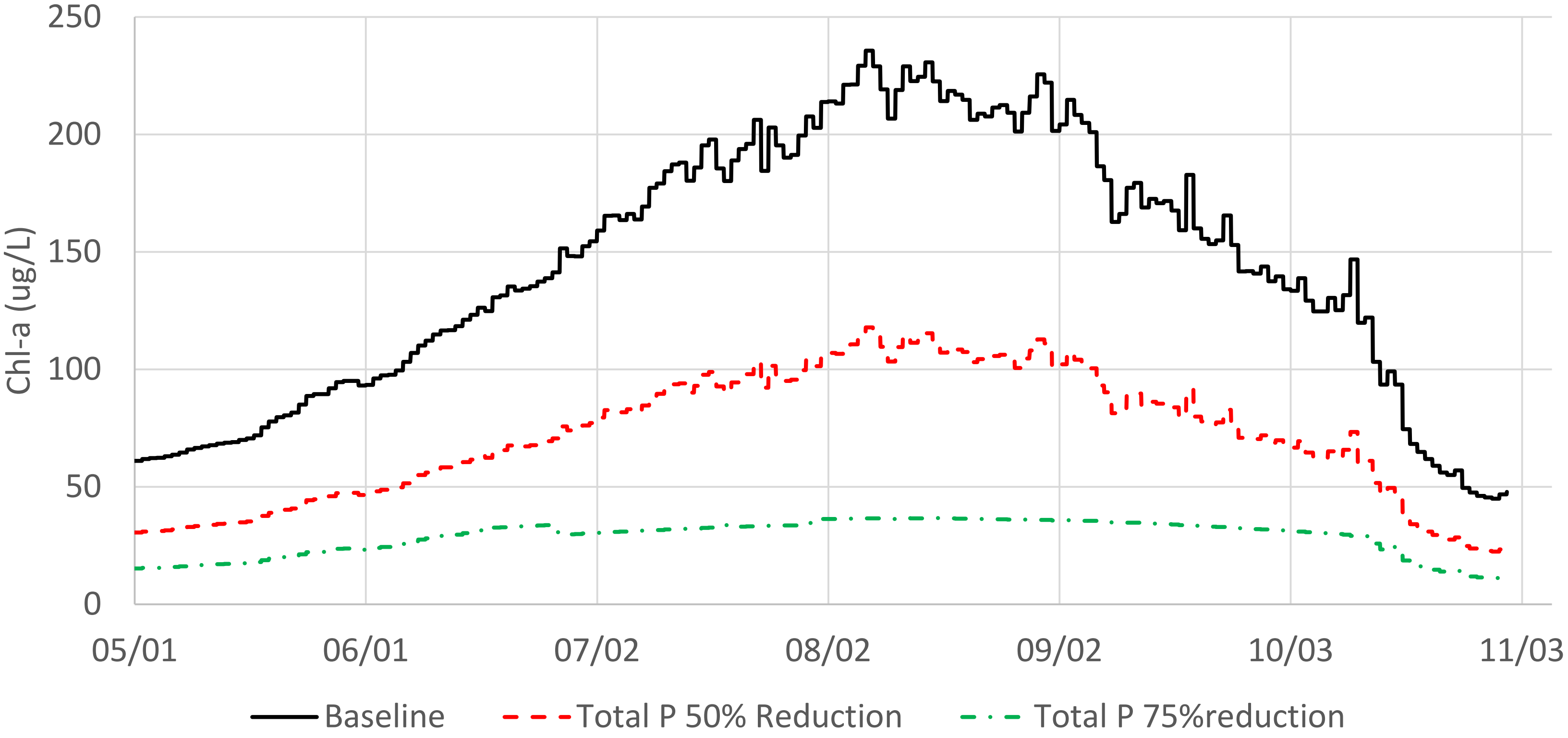


Model Representation

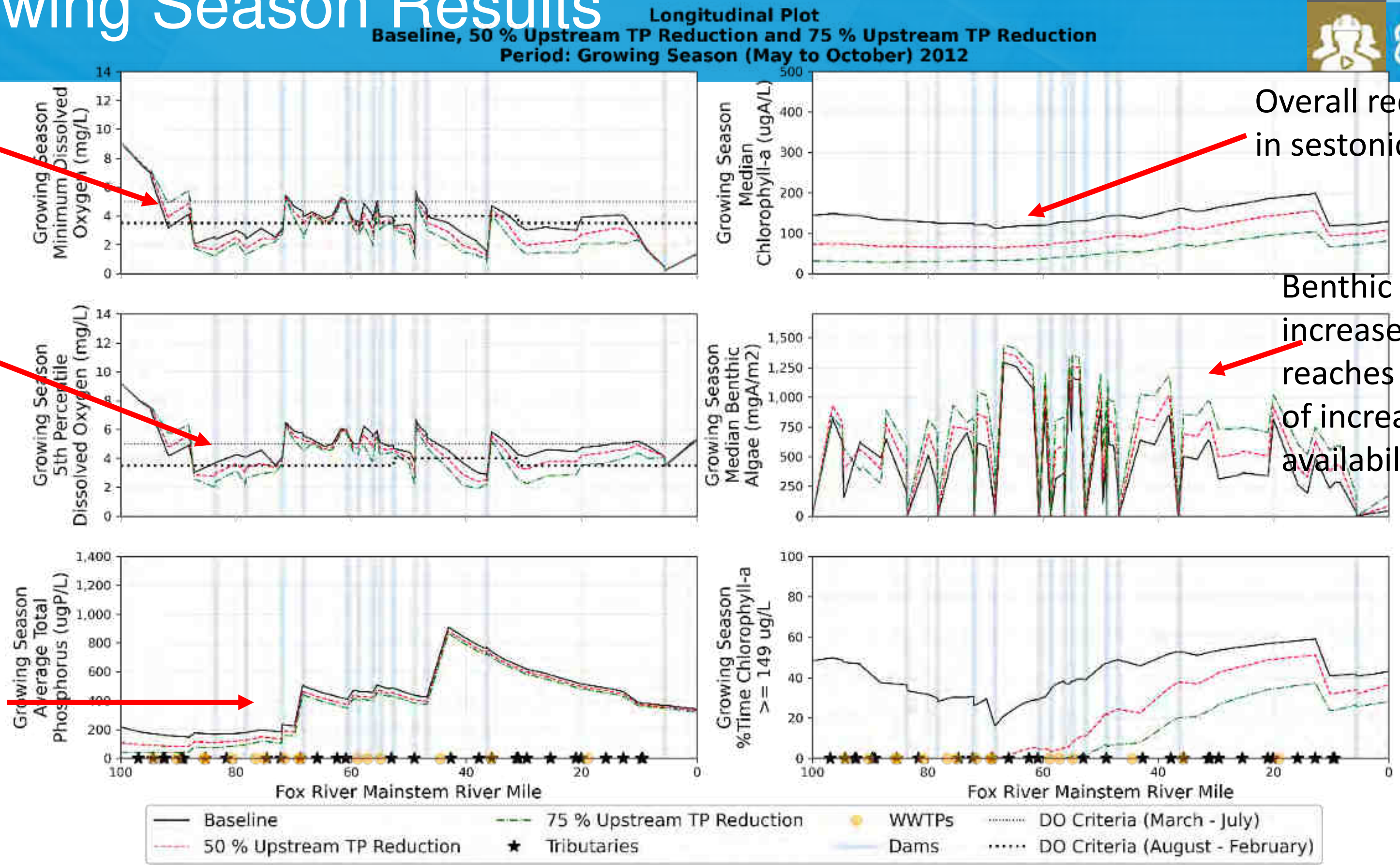
- Upstream TP is composed of
  - Organic P
  - Inorganic P
  - Internal P: Based on Chl-a: P ratio – 1.5:1

- Proportioned the components based on ratios in timeseries from baseline scenario
  - Chlorophyll-a also had to be reduced to achieve the required reduction in TP

Upstream Chlorophyll-a Boundary



Growing Season Results



DO improves in the upstream reaches

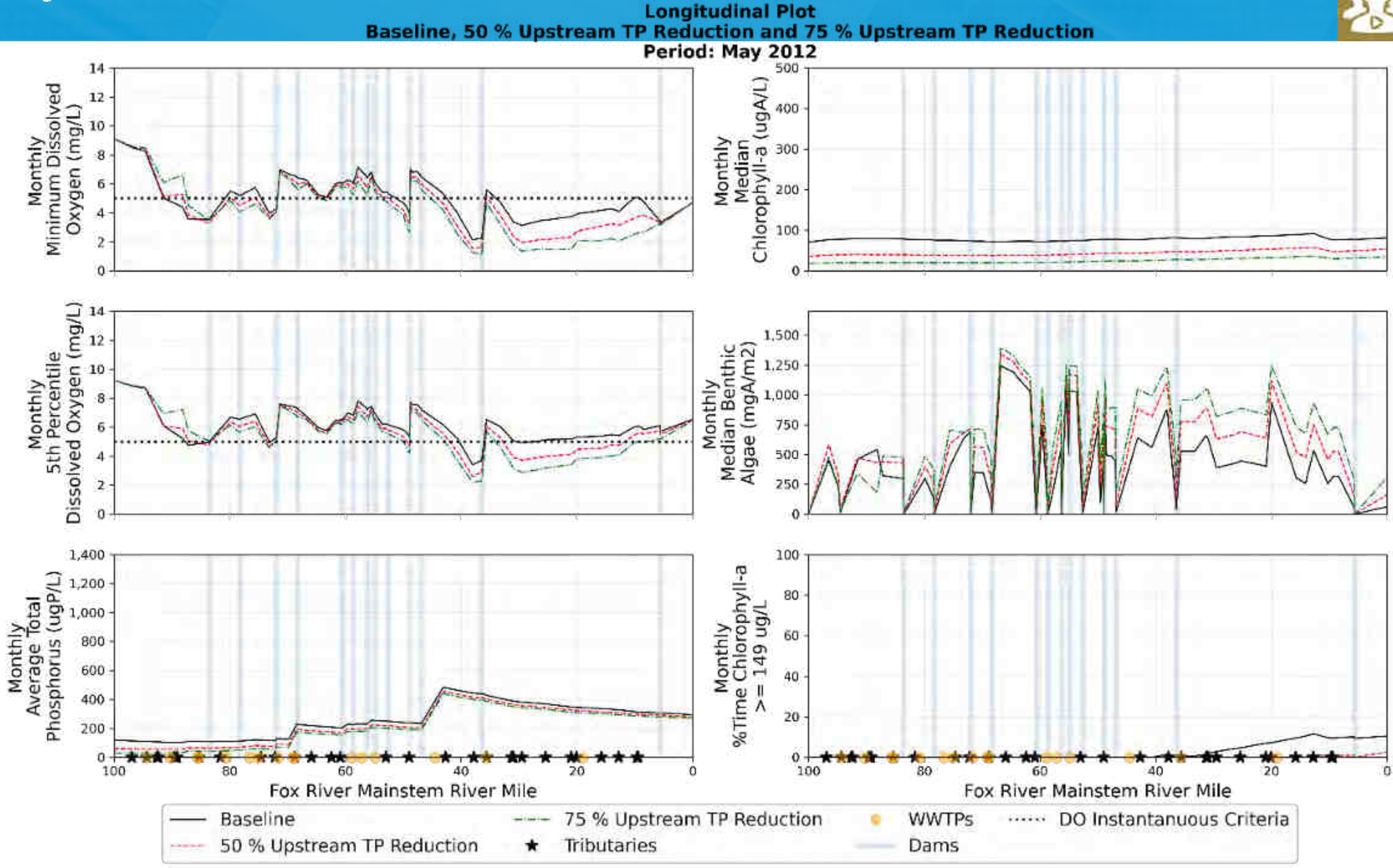
DO decreases in downstream reaches

Overall reduction in instream TP

Overall reduction in sestonic Chl-a

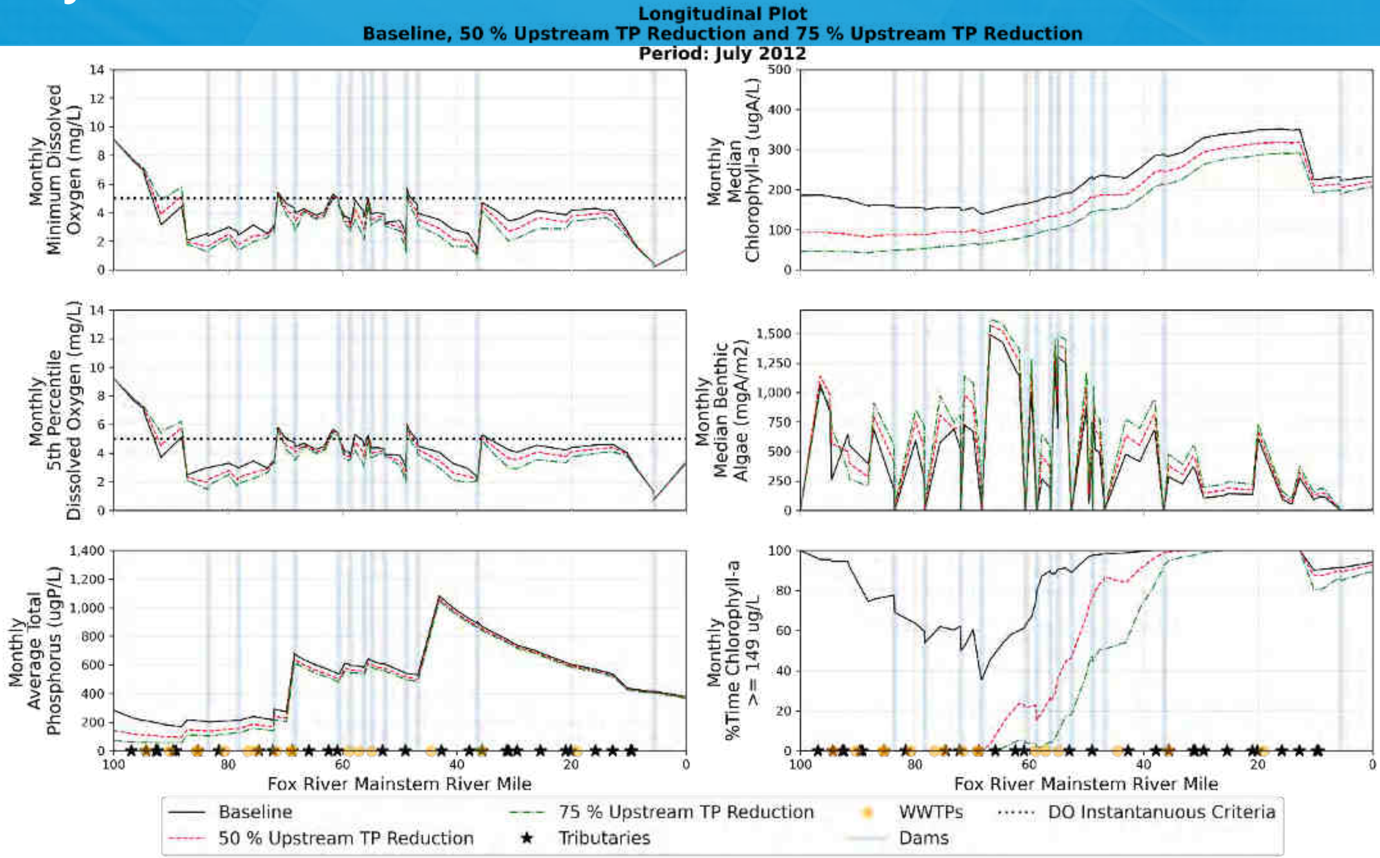
Benthic algae increased in d/s reaches because of increased light availability

May 2012



Longitudinal Plot
Baseline, 50 % Upstream TP Reduction and 75 % Upstream TP Reduction
Period: May 2012
Monthly Minimum Dissolved Oxygen (mg/L)
0
2
4
6
8
10
12
14
Monthly Median Chlorophyll-a (ugA/L)
0
100
200
300
400
500
Monthly 5th Percentile Dissolved Oxygen (mg/L)
Monthly Median Benthic Algae (mgA/m2)
0
250
500
750
1,000
1,250
1,500
Monthly Average Total Phosphorus (ugP/L)
0
200
400
600
800
1,000
1,200
1,400
Monthly %Time Chlorophyll-a >= 149 ug/L
0
20
40
60
80
100
100
80
60
40
20
0
Fox River Mainstem River Mile
Baseline
50 % Upstream TP Reduction
75 % Upstream TP Reduction
★ Tributaries
● WWTPs
Dams
DO Instantanuous Criteria

July 2012



Similar results for other low flow months – June, August, September and October

Summary of Results

- Reduction in only upstream TP load leads to
  - Improvement of DO only in upstream reaches
  - Reduction in sestonic chlorophyll-a
  - Increase in benthic algae in downstream reaches and consequently decreased DO

Treatment Plant TP Scenarios

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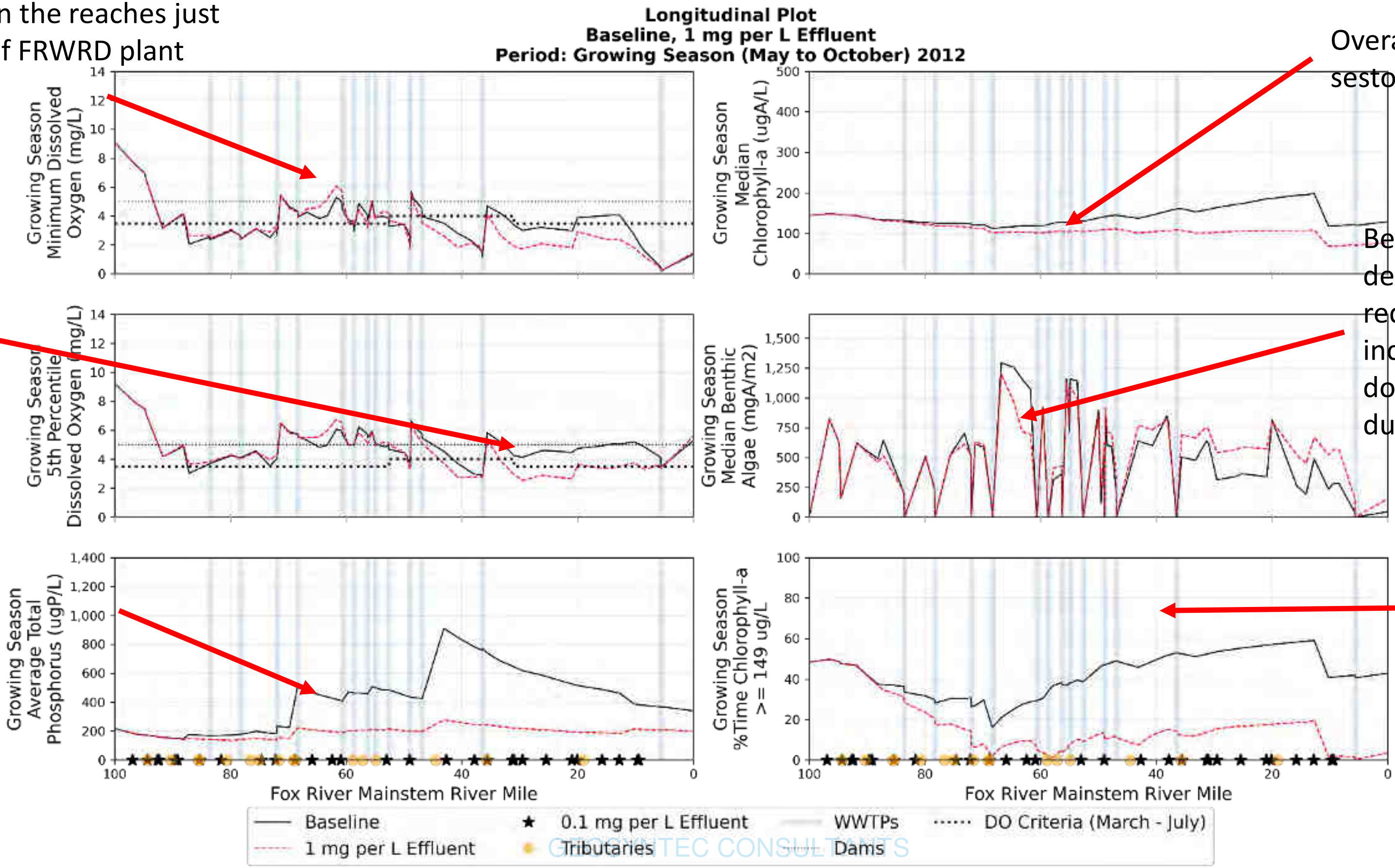
Summary of Results

- Reduction in only treatment plant loads results in
  - Substantial reduction in instream TP
  - Substantial reduction in sestonic chlorophyll-a
  - Improvement of DO in middle reaches
  - Increase in benthic algae in downstream reaches and consequently decrease in DO
- Water quality improvement in going from TP 0.5 mg/L to TP 0.1 mg/L will not be substantial

Treatment Plants

- Timeseries of baseline flows and effluent concentration based on data
- Constant TP effluent concentration management scenarios for existing flows (leave other effluent concentrations the same)
  - Scenario 3A: 1.0 mg/L TP effluent
  - Scenario 3B: 0.5 mg/L TP effluent
  - Scenario 3C: 0.1 mg/L TP effluent

Growing Season
Baseline & TP 1 mg/L



DO improves in the reaches just downstream of FRWRD plant

Downstream reaches DO decreases because of increased benthic algae

Substantial reduction in instream TP

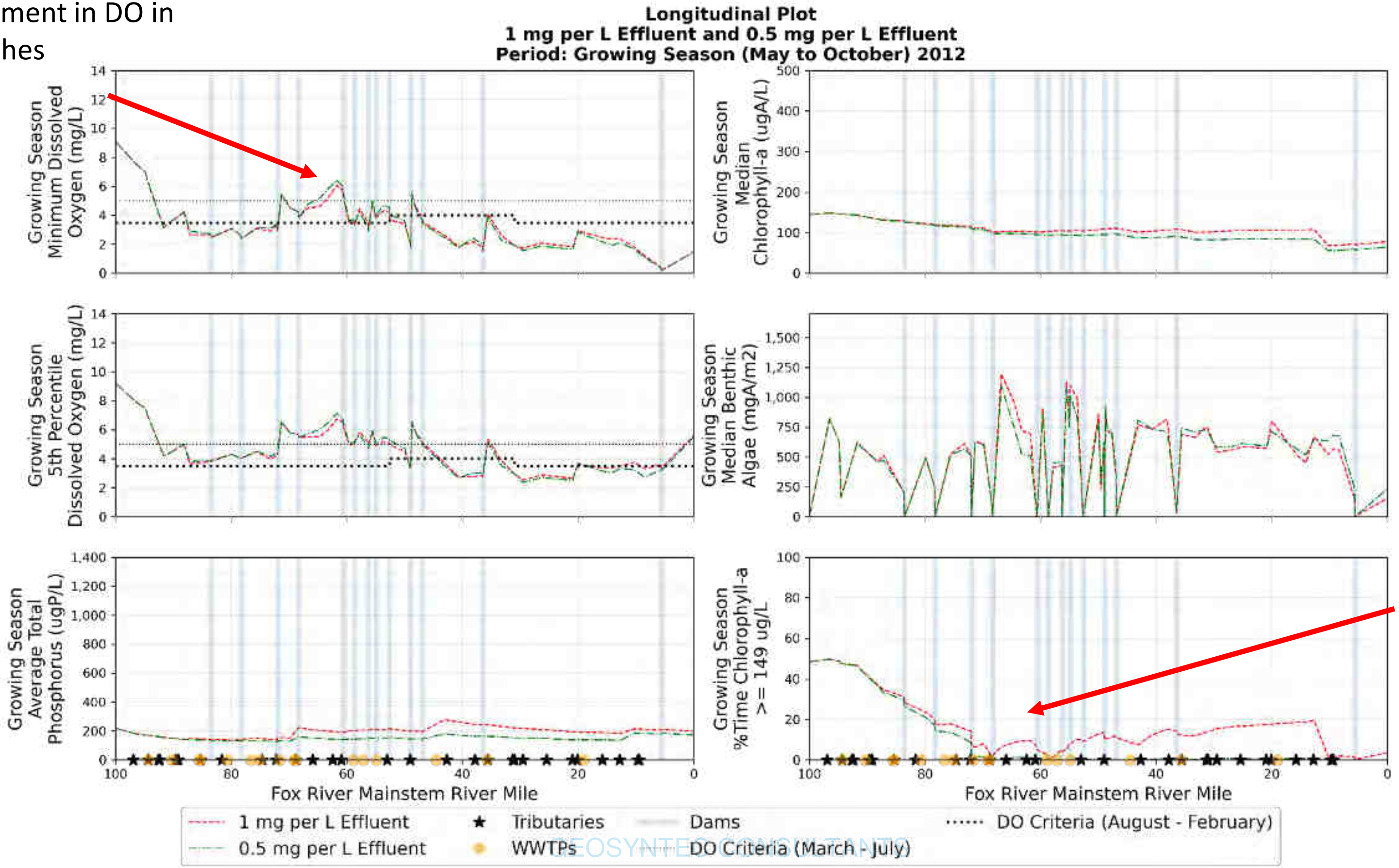
Overall reduction in sestonic Chl-a

Benthic algae decreases due to reduction in P; but increases in the downstream reaches due to more light

% Time chlorophyll - a above targets is substantially reduced even at TP 1mg/L

Growing Season
TP 1 mg/L & TP 0.5 mg/L

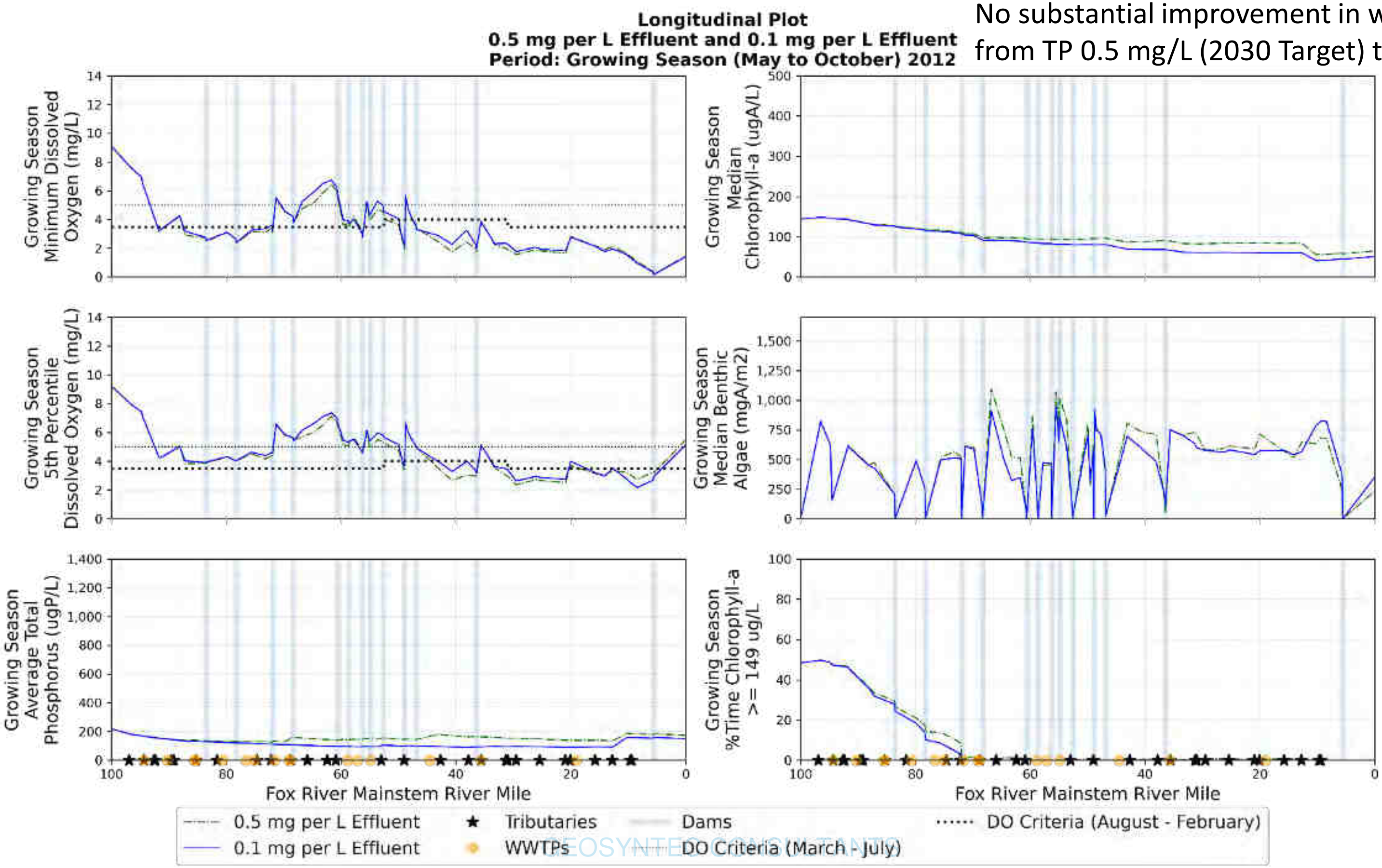
Slight improvement in DO in upstream reaches



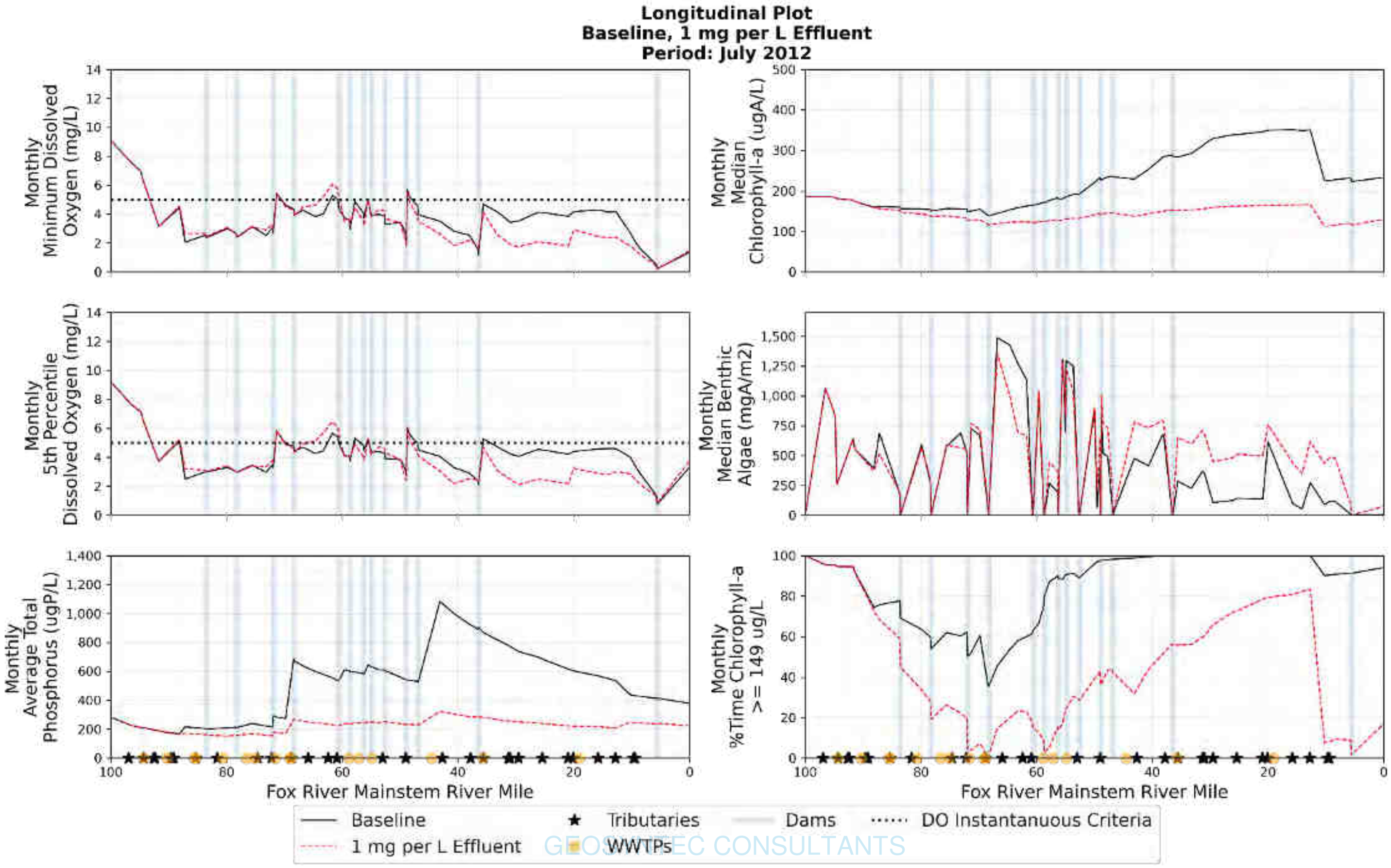
Except for upstream reaches sestonic algae is below target for TP 0.5 mg/L

Growing Season
TP 0.5 mg/L & TP 0.1 mg/L

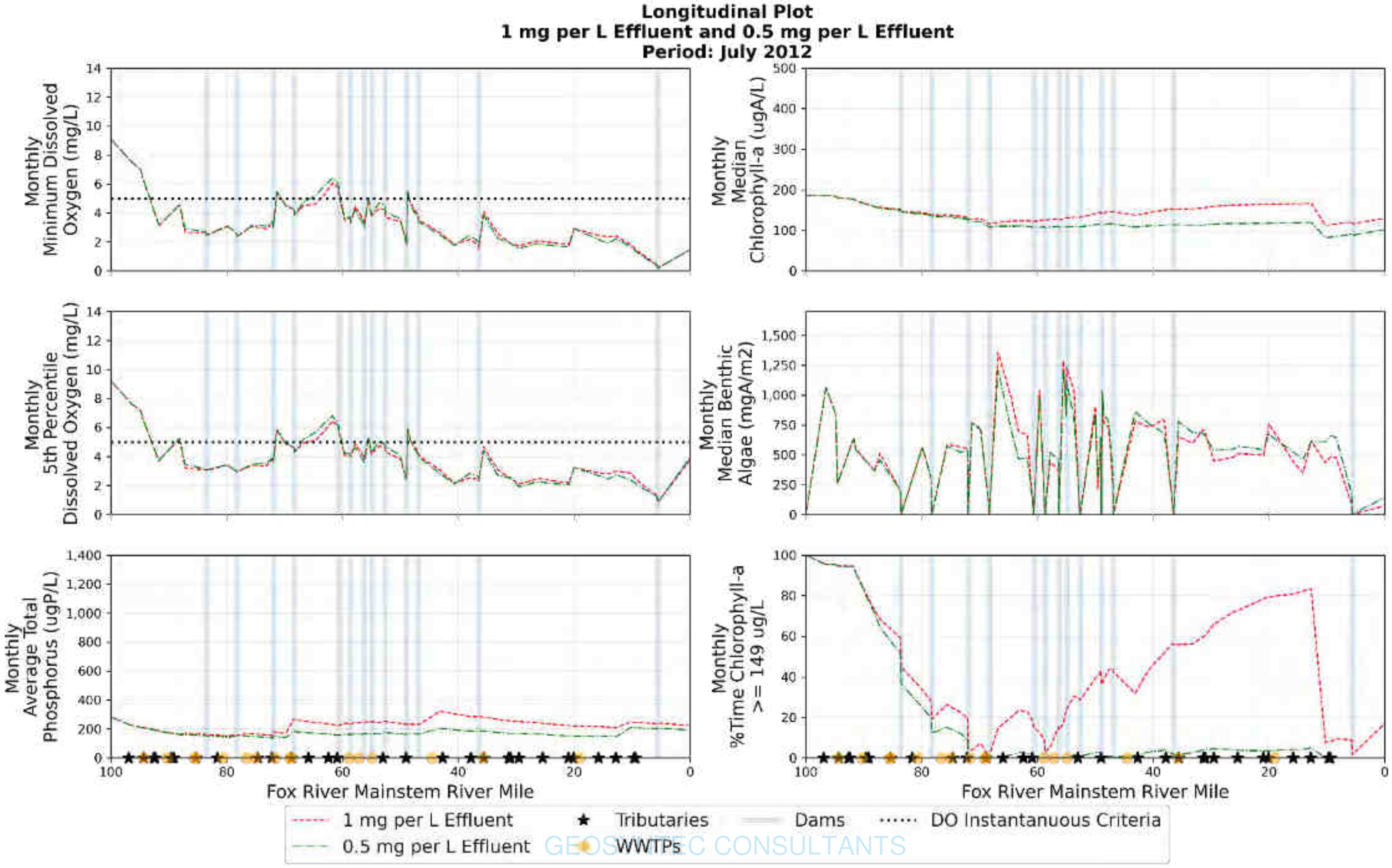
No substantial improvement in water quality in going from TP 0.5 mg/L (2030 Target) to TP 0.1 mg/L



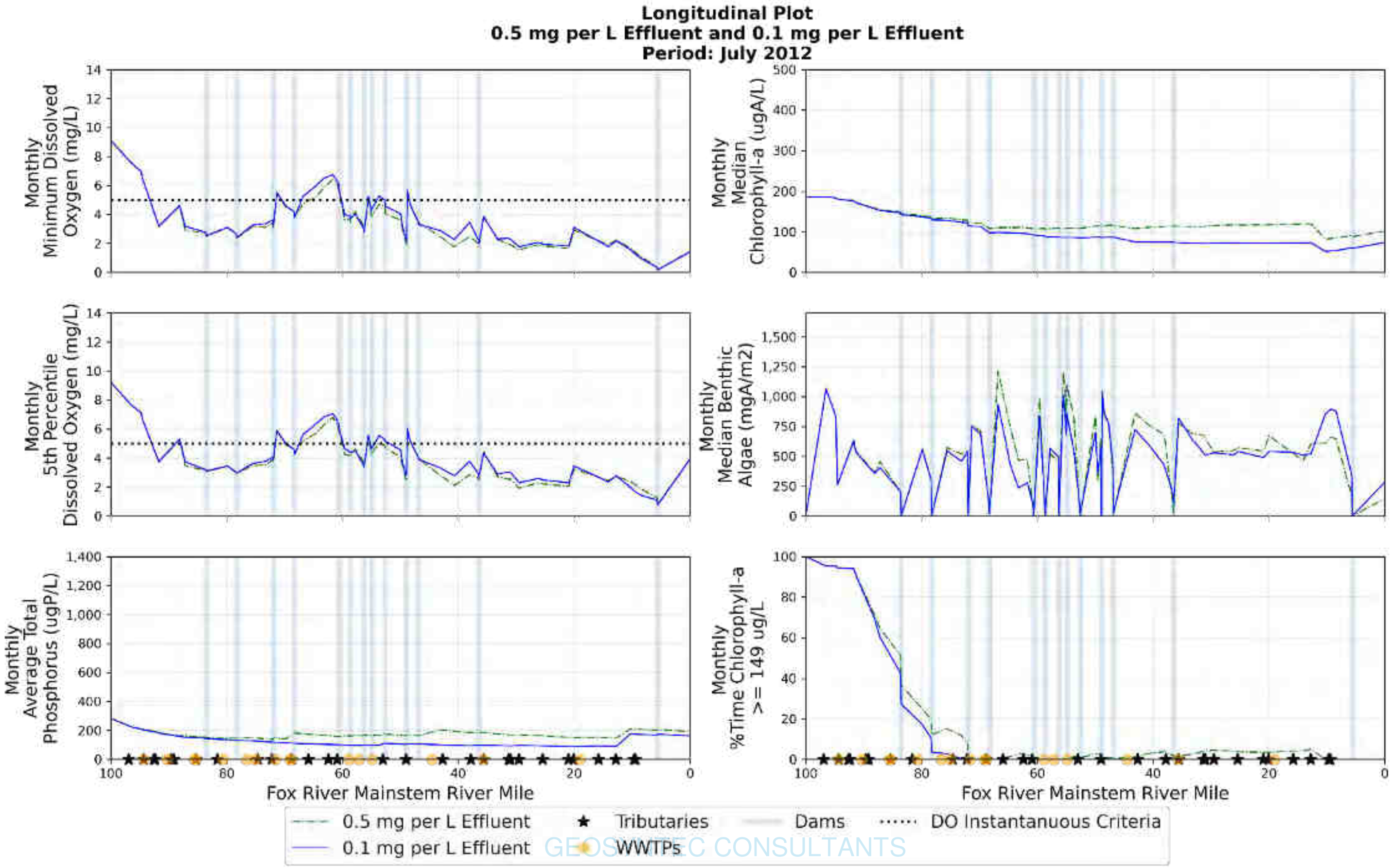
July 2012
Baseline & TP 1 mg/L



July 2012
TP 1 mg/L & TP 0.5 mg/L



July 20012
TP 0.5 mg/L & TP 0.1 mg/L



Summary

- Reduction in only treatment plant loads results in
  - Substantial reduction in instream TP
  - Substantial reduction in sestonic chlorophyll-a
  - Improvement of DO in middle reaches
  - Increase in benthic algae in downstream reaches and consequently decrease in DO
- Water quality improvement in going from TP 0.5 mg/L to TP 0.1 mg/L will not be substantial

Dam Removal Scenarios

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Summary of Results

- Dam removal improves DO in upstream impoundment and downstream reaches
- Dam removal does not significantly affect sestonic chlorophyll-a

Dam Removal Scenarios Description

- Management Scenarios
  - Scenario 4A: Carpentersville and North Aurora dams
  - Scenario 4B: 9 dams from Carpentersville to Montgomery

- Higher slopes in reaches for dam removal
  - System currently behaves as a series of lakes
  - Shallow and slow-moving water in free-flowing reaches allows benthic algae to grow

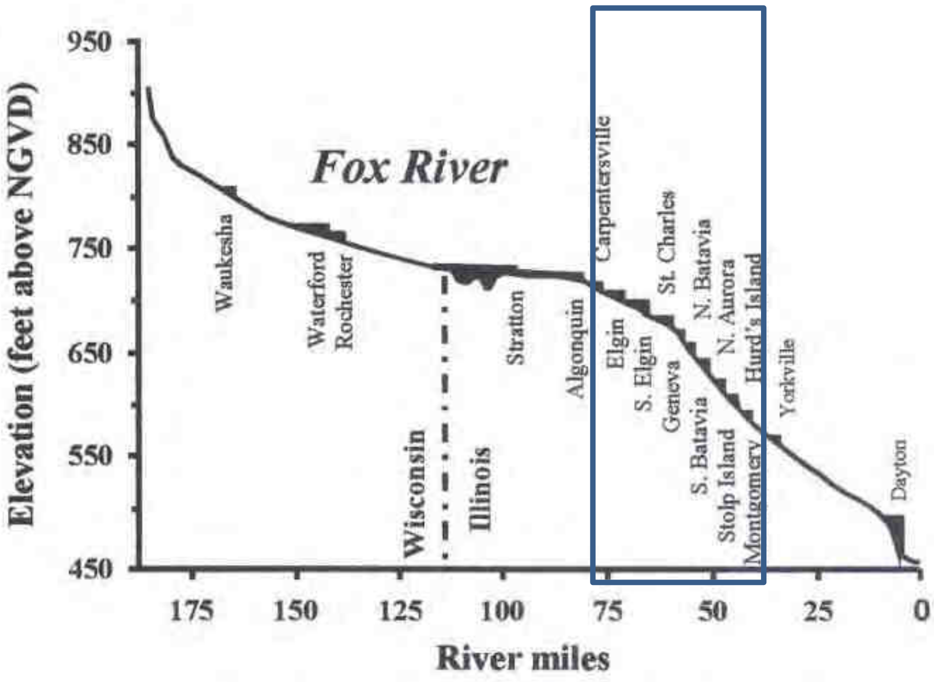


Figure from Knapps, 1988

Dam Removal Simulation in Model

- Remove the weir structure representing the dam
- Update the dam reach from weir equation to free-flowing reach using rating curve to just downstream of reach
- Update the impounded reach to free-flowing reach like just upstream of impounded reach
- Update the SOD for the dam and impounded reach to 0.15 g/m2/day (10th percentile of SOD for free-flowing reaches)
  - Legacy sediments will be removed from the dam impounded reach

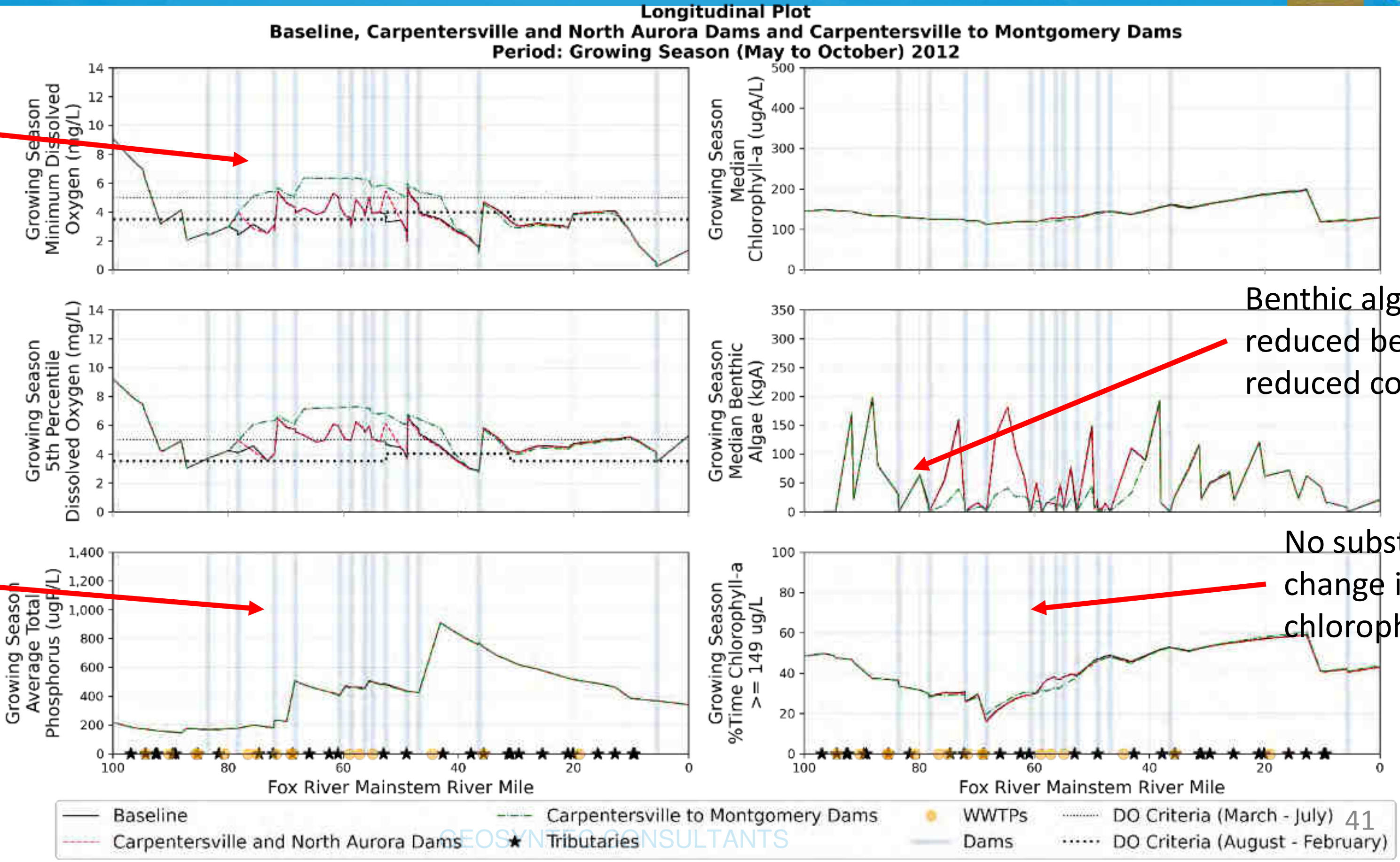
Dam Removal Simulation in Model (Cont.)

- Update the benthic algae coverage to 20% for impounded reach and downstream[1]
  - Creation of rapids in the dam impoundment reaches after dam removal would increase velocities and scour away benthic algae[2]
  - Five Island Station located in free-flowing reach had relatively minimal periphyton coverage during 2016
  - Sedimentation impact downstream due to larger velocities (Thomson et. al 2012)
  - Increased macroinvertebrate density with dam removal would also reduce benthic algae coverage
  - Would be important to validate these assumptions
- Results presented in the next slides
  - Benthic algae presented in terms Kg-Algae for each since the % of benthic algae coverage is different between the scenarios

[1] For Scenario 4B, this is done for the whole stretch of river in which dams are removed

[2] Model currently does not simulate the scouring of benthic algae but has the ability to do so

Growing Season Results, Dam Removals



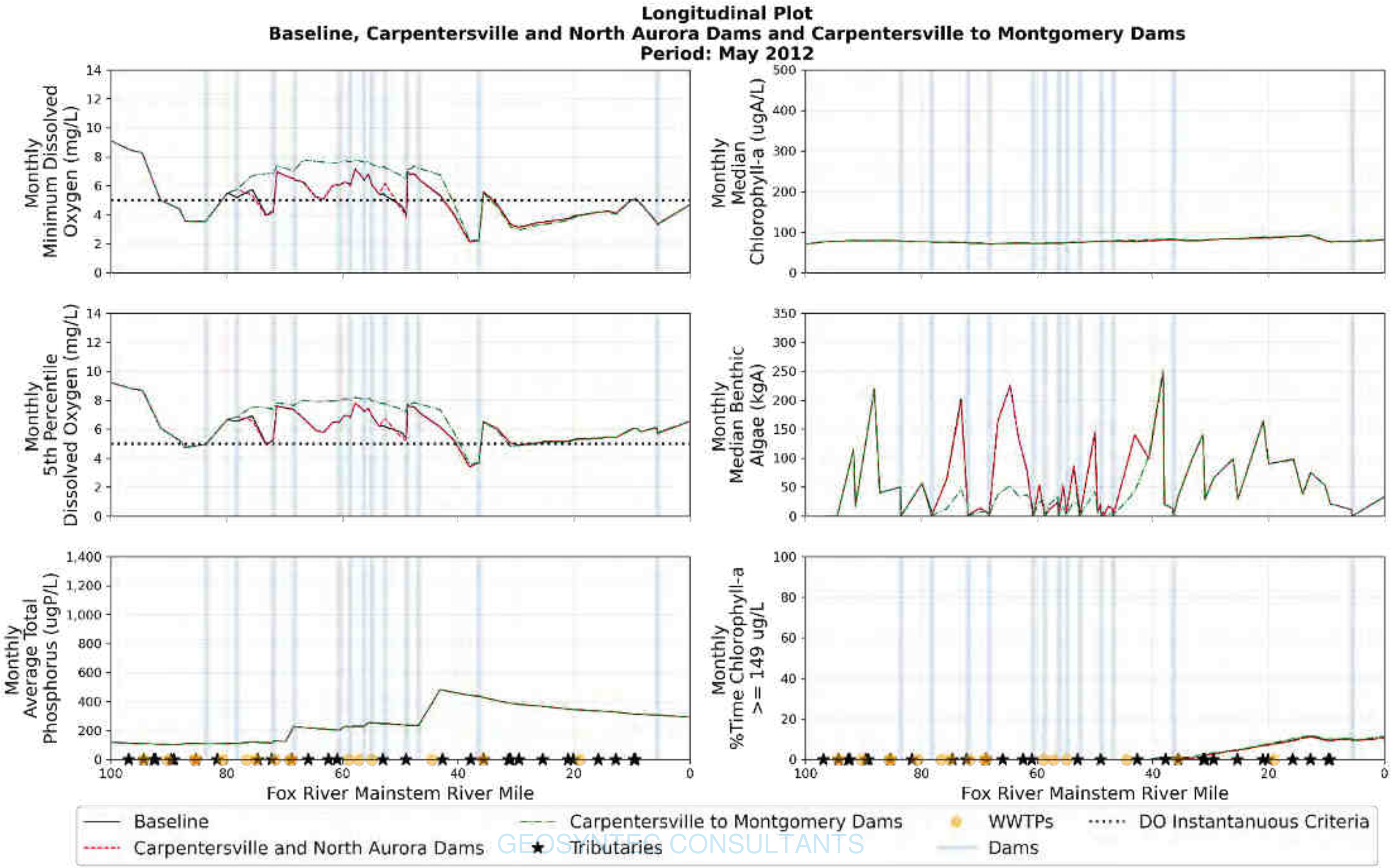
DO substantially improved once all dams are removed due to assumed benthic algae reduction

Benthic algae reduced because of reduced coverage

No change in TP

No substantial change in chlorophyll-a

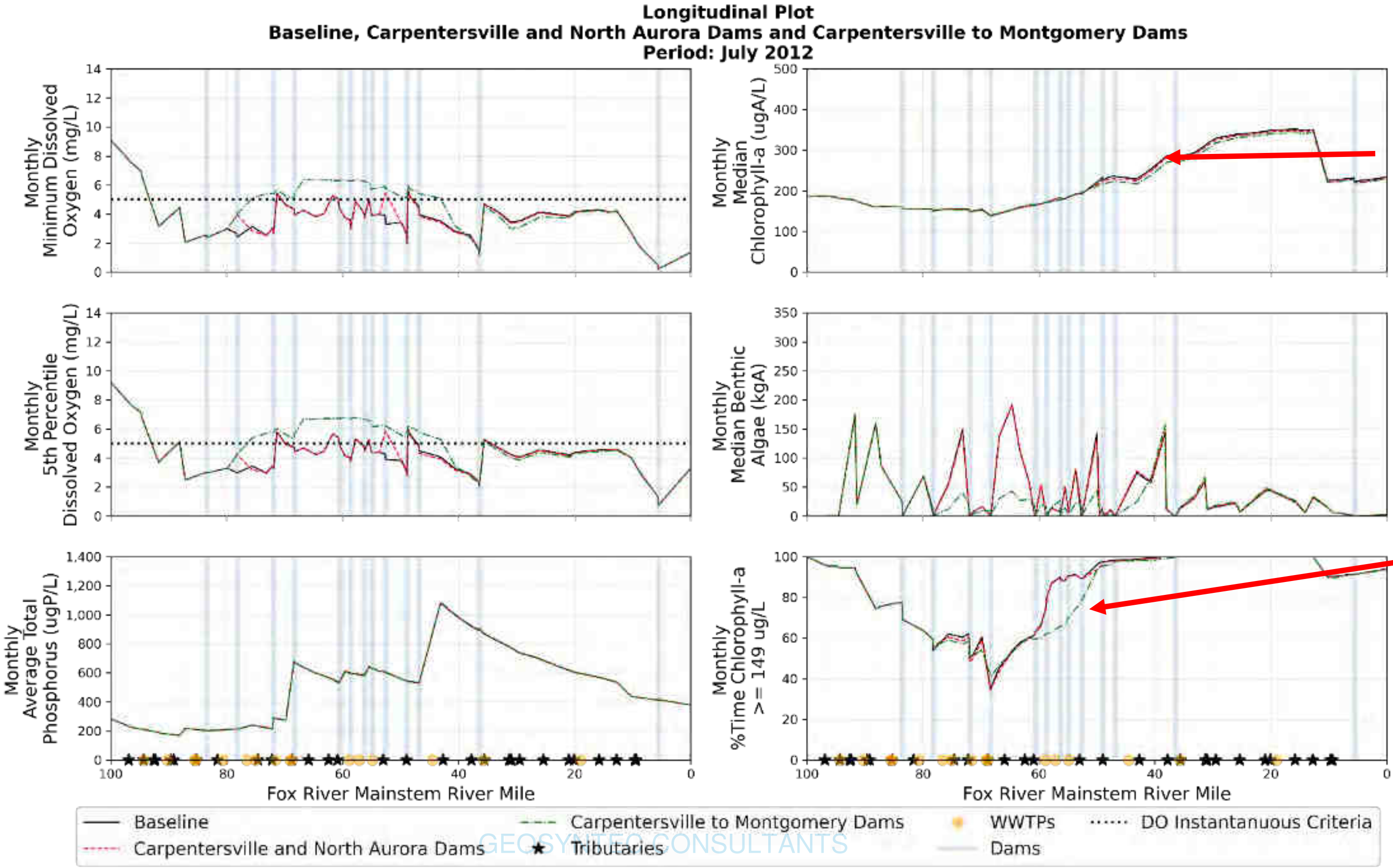
May 2012



Longitudinal Plot
Baseline, Carpentersville and North Aurora Dams and Carpentersville to Montgomery Dams
Period: May 2012
Monthly Minimum Dissolved Oxygen (mg/L)
Monthly Median Chlorophyll-a (ugA/L)
Monthly 5th Percentile Dissolved Oxygen (mg/L)
Monthly Median Benthic Algae (kgA)
Monthly Average Total Phosphorus (ugP/L)
Monthly %Time Chlorophyll-a >= 149 ug/L
Fox River Mainstem River Mile
Fox River Mainstem River Mile
100
80
60
40
20
0
Baseline
Carpentersville and North Aurora Dams
Carpentersville to Montgomery Dams
Tributaries
WWTPs
Dams
DO Instantanuous Criteria

July 2012

Similar results for other low flow months – June, August, September and October



Slight reduction in chlorophyll-a

Reduction in % of time chlorophyll-a greater than threshold because of faster velocities

Summary of Results

- Reduction in benthic algae associated with dam removal improves DO in upstream impoundment and downstream reaches
- Dam removal does not significantly affect sestonic chlorophyll-a
  - Dams removed are run-of-the-river which have short retention times

Recommendations for Combined Scenarios

Geosyntec consultants

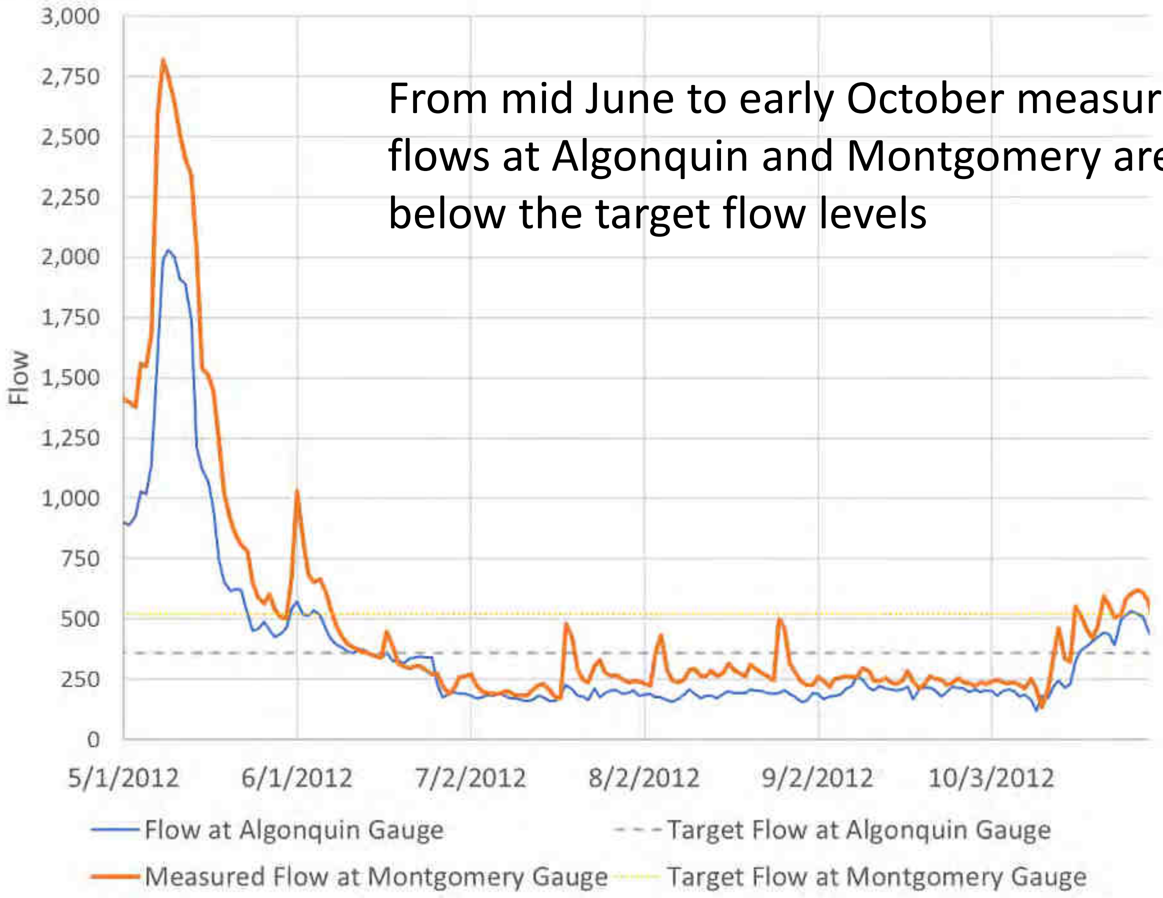
Combined Scenarios Recommendations

	Combined								
	5A	5B	5C	5D	5E	5F	5G	5I	5J
Time Period									
May - October	X	X	X	X	X	X	X	X	X
Upstream Conditions									
Existing TP			X		X				
Existing TP -50%				X		X			
Existing TP - 75%	X	X					X	X	X
Treatment Plant Effluent									
Existing Flows	X	X	X	X	X	X	X	X	X
Total Phosphorus @ 1.0 mg/L			X	X					
Total Phosphorus @ 0.5 mg/L	X	X			X	X	X	X	X
Total Phosphorus @ 0.1 mg/L								X	X
Dams Removed									
Algonquin									
Carpentersville			X	X	X	X	X	X	X
Elgin								X	X
South Elgin								X	X
St. Charles								X	X
Geneva								X	X
North Batavia								X	X
North Aurora			X	X	X	X	X	X	X
Stolp Island			X	X	X	X	X	X	X
Montgomery			X	X	X	X	X	X	X
Yorkville									
Non-Point Sources									
Existing									
25% TP Reduction									
50% TP Reduction									X

Additional Scenario Recommendation

- Increased riparian shading along the river
  - Reduction of light available to benthic algae (**Halliday et. al 2016**) **by creation of stream buffer**
  - Barrington Area Community Foundation (BACF) project to increase stream buffer in Flint Creek could serve as a model for implementation

River Flows



From mid June to early October measured flows at Algonquin and Montgomery are below the target flow levels

Attachment 2

Combined Management Scenarios Results Presentation, July 29, 2021

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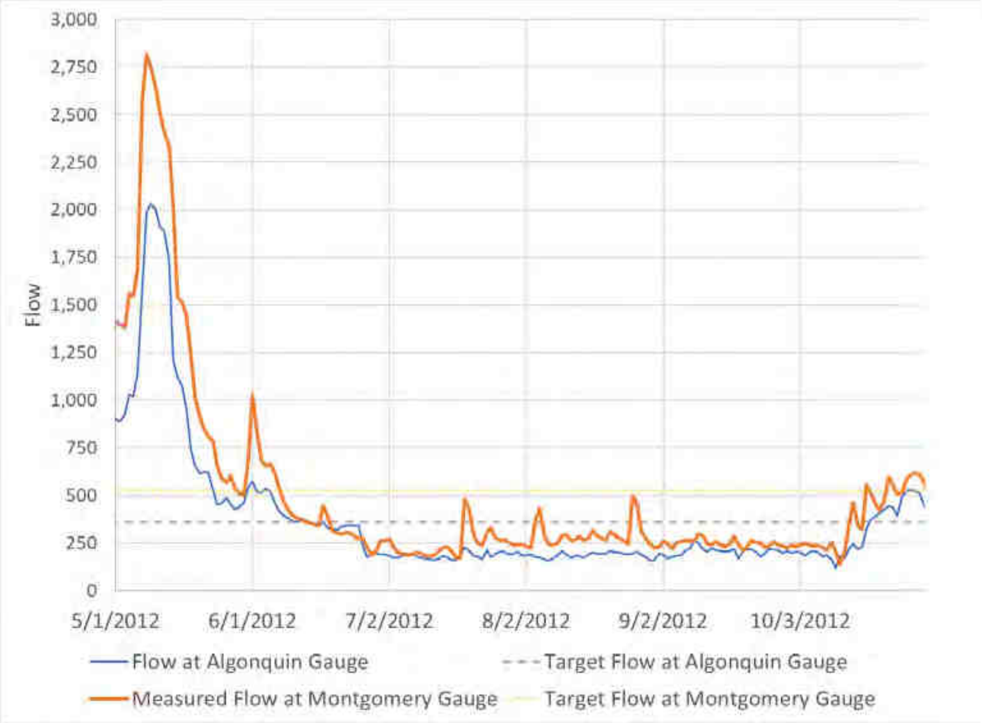
Combined Watershed Scenarios

07/21/2021

Revised 07/29/2021

Baseline Model Scenario

- Baseline model scenario represents the existing conditions from May to October 2012
- River Flow



Watershed Scenarios

- Impact of management actions alone
  - Tributaries TP (total phosphorous) reduction
  - Upstream TP reduction
  - WWTPs TP reduction
  - Dam removal
- Results presented on conference call dated January 5, 2021

Recap of Watershed Scenario Results

- Reduce only upstream TP load
  - Reduces sestonic algae in all downstream reaches because of decrease in upstream TP
  - Improves DO (dissolved oxygen) only in upper reaches
  - Increases benthic algae in lower reaches due to decreased sestonic chlorophyll-a, which decreases DO

- Reduce only WWTP TP loads
  - Improves DO in middle reaches
  - Increases benthic algae in lower reaches due to decreased sestonic chlorophyll-a, which decreases DO
  - Reduction beyond 0.5 mg/L effluent concentration provide very little benefit for river water quality

- Remove dams
  - Reduces benthic algae in impoundments in middle reaches which increases DO
  - Sestonic chlorophyll-a not impacted in all reaches

- Reduce only tributary TP loads
  - No major impact on DO or algae

Key Take Away from Watershed Scenarios

- Benthic and detritus load between series of dams on the Fox river drives low DO
- River flushing precludes significant algae growth

Combined Watershed Scenarios

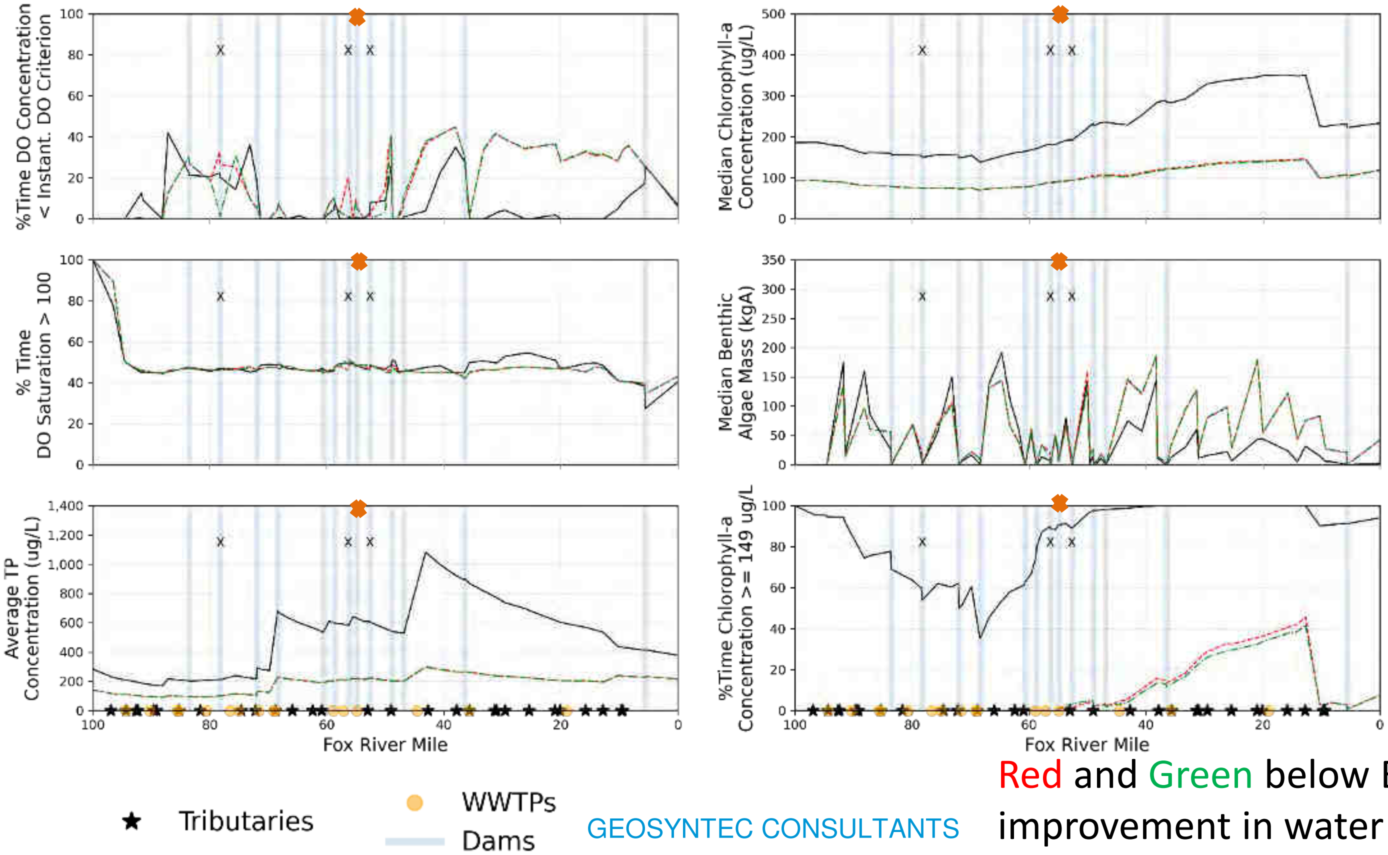
- Total of 13 scoped scenarios (5A-5K)
- Added two additional scenarios (5L and 5M)

	Scenario Number												
	5A	5B	5C	5D	5E	5F	5G	5H	5I	5J	5K	5L	5M
Time Period													
May - October 2012	X	X	X	X	X	X	X	X	X	X	X	X	X
Upstream Conditions													
Existing TP			X		X							X	
Existing TP -50%	X	X		X		X	X		X				
Existing TP - 75%								X		X	X		X
Treatment Plant Effluent													
Existing Flows	X	X	X	X	X	X	X	X	X	X	X	X	X
WWTP discharged at 1 mg/L TP	X		X	X									
WWTP discharged at 0.5 mg/L TP		X			X	X		X	X			X	X
Total Phosphorus @ 0.1 mg/L							X			X	X		
Dams Removed													
Algonquin													
Carpentersville			X	X	X	X	X	X	X	X	X	X	X
Elgin									X	X	X	X	X
South Elgin									X	X	X	X	X
St. Charles									X	X	X	X	X
Geneva									X	X	X	X	X
North Batavia			X	X	X	X	X	X	X	X	X	X	X
North Aurora			X	X	X	X	X	X	X	X	X	X	X
Stolp Island									X	X	X	X	X
Montgomery									X	X	X	X	X
Yorkville													
Non-Point Sources													
Existing													
25% TP Reduction													
50% TP Reduction											X		

Short-term (2020-2035) Scenarios

Group No.	Scenario 1	Scenario 2	Scenario 3
Group 1 (G1)	Baseline	Upstream 50% reduction WWTPs 1 mg/L	Upstream 50% reduction WWTPs 1 mg/L 3 dams removed
Group 2 (G2)	Baseline	Upstream 50% reduction WWTPs 0.5 mg/L	Upstream 50% reduction WWTPs 0.5 mg/L 3 dams removed
Group 3 (G3)	Baseline	WWTPs 1 mg/L 3 dams removed	WWTPs 0.5 mg/L 3 dams removed

Presentation of Results



Black line – Scenario 1

Red line – Scenario 2

Green Line – Scenario 3

Indicates location of removed South Batavia Dam

Red and Green below Black line indicates improvement in water quality

Short-term Expected Outcomes

- Upstream and WWTPs TP reduction would improve water quality marginally.
  - In downstream reaches, it might deteriorate water quality due to increased benthic algae with the decrease of chlorophyll-a (i.e., improved water clarity)
- Dam removal is expected to enhance the impact of upstream and WWTPs TP reduction in the upstream and middle reaches.
- Results more pronounced for critical period (July 2012) than across the growing season

Group 1 July 2012 Results

Take Away:

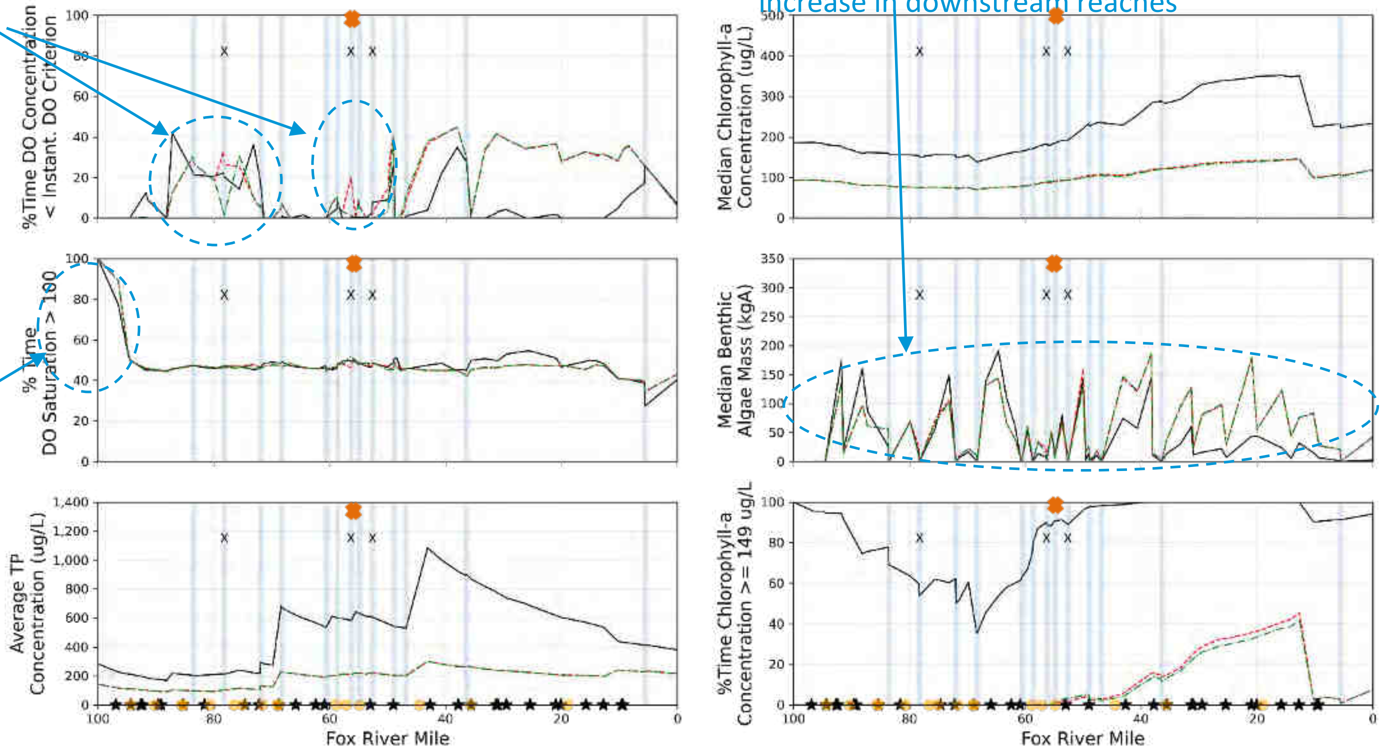
Improves DO in upstream and middle reaches only.

Dam removal only has a localized impact.

Impact of upstream boundary condition

Take Away:

Reduction in benthic algae in upper and middle reaches; increase in downstream reaches



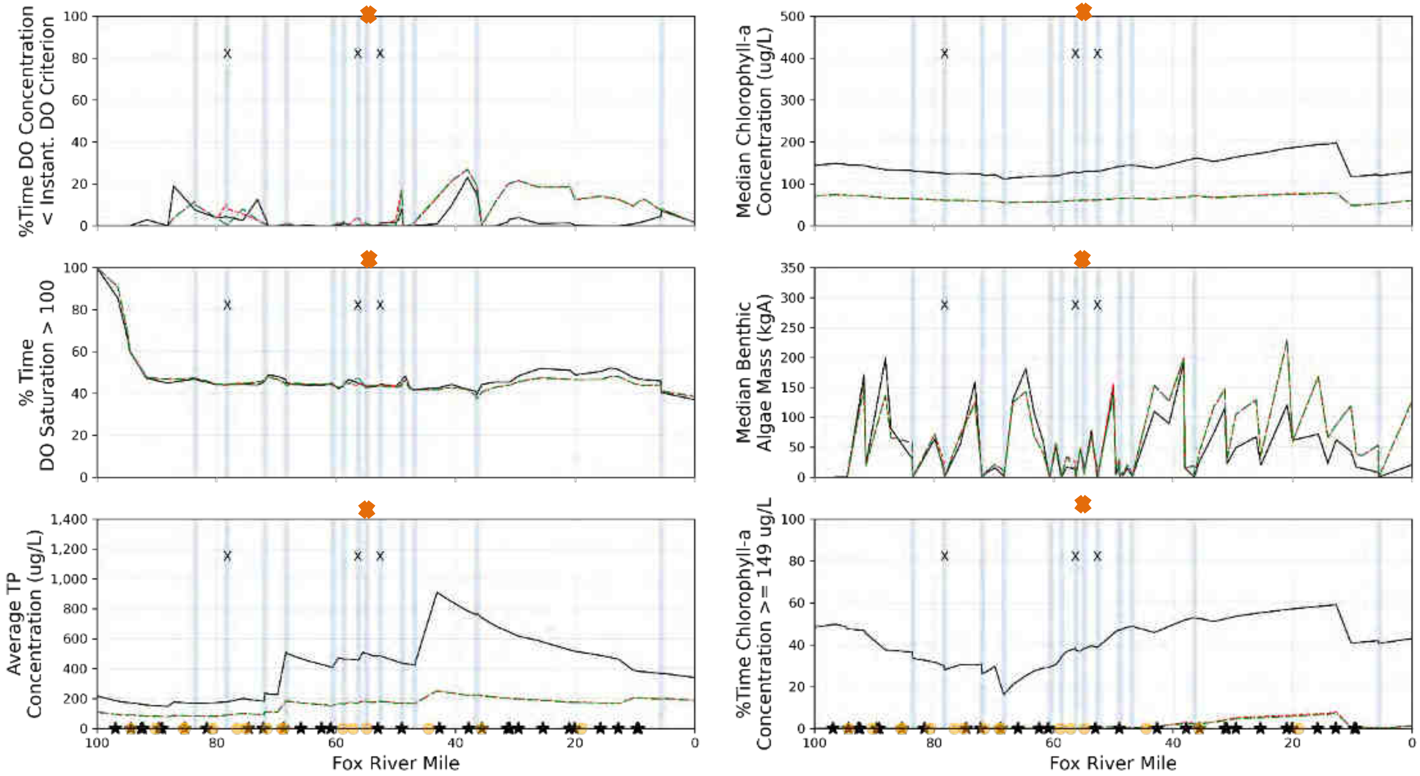
Black line
- Baseline

Red line
- Upstream 50% reduction
- WWTPs 1 mg/L

Green line
- Upstream 50% reduction
- WWTPs 1 mg/L
- 3 dams removed

"X" Indicates location of removed dams

Group 1 Growing Season Results



Black line
- Baseline

Red line
- Upstream 50% reduction
- WWTPs 1 mg/L

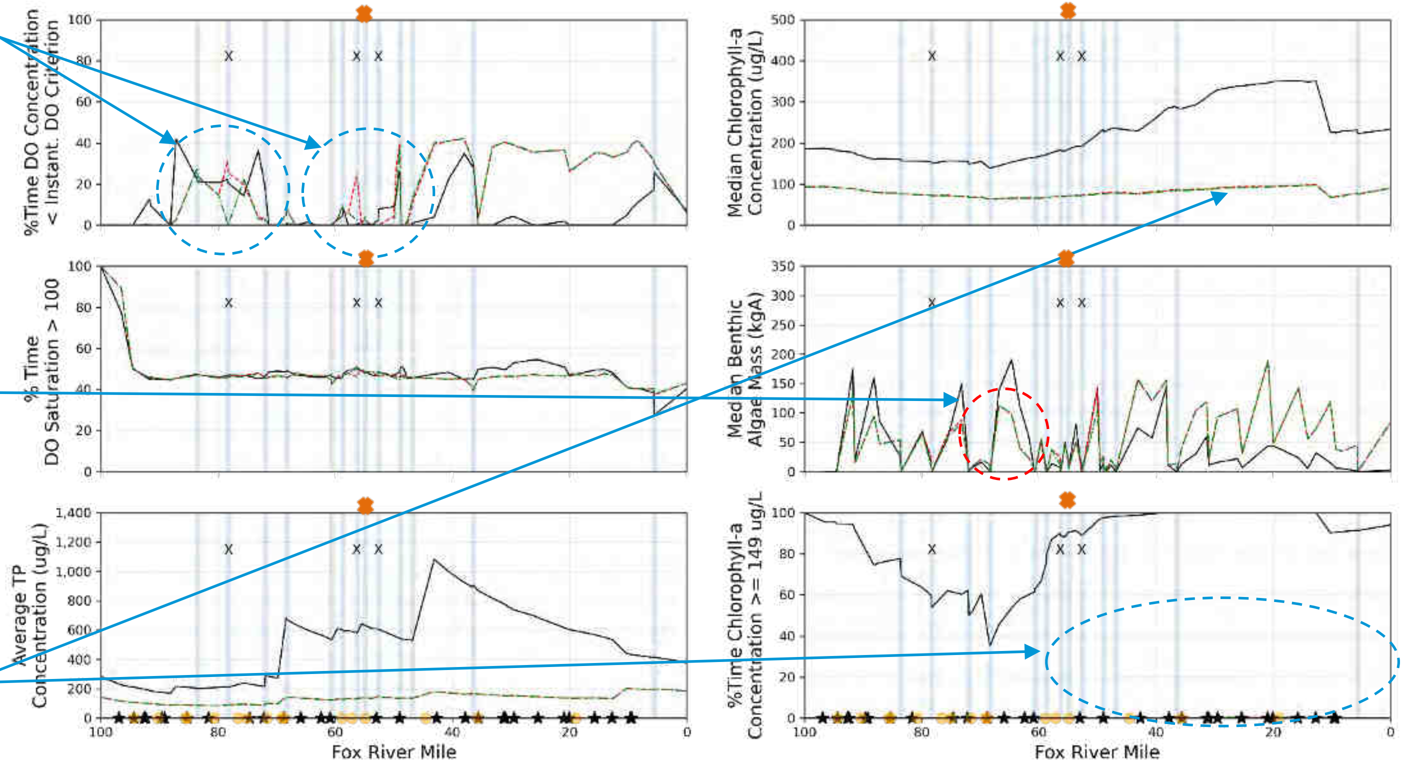
Green line
- Upstream 50% reduction
- WWTPs 1 mg/L
- 3 dams removed

Group 2 July 2012 Results

Take Away: Further improves DO in upstream and middle reaches as compared to G1

Take Away: Further reduction in benthic algae as compared to G1

Take Away: Eliminates Chl a exceedance downstream



Black line
- Baseline

Red line
- Upstream 50%
- reduction
- WWTPs 0.5 mg/L

Green line
- Upstream 50% reduction
- WWTPs 0.5 mg/L
- 3 dams removed

“X” Indicates location of removed dams

Group 3 July 2012 Results

Take Away:

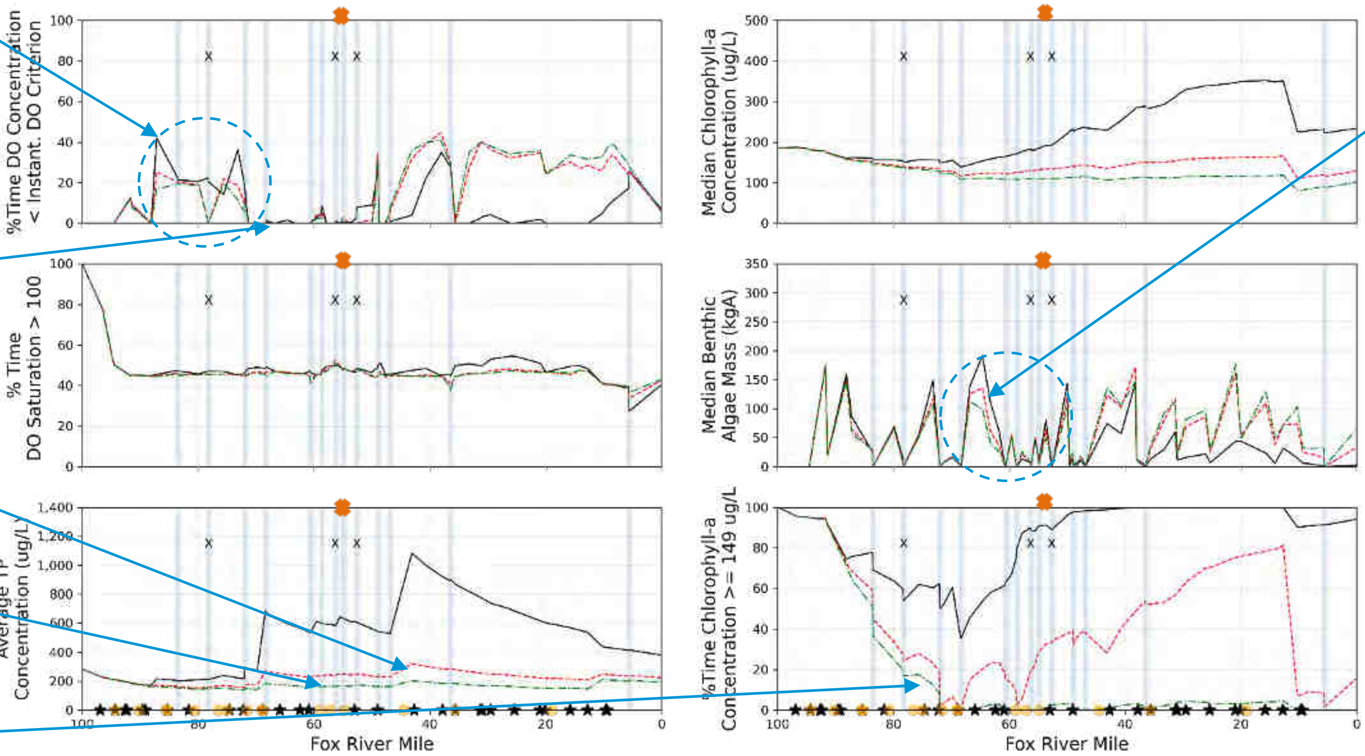
Improves DO in upstream reach.

Compared to G1 & G2, no difference in DO, but does matter for Chl-a

Higher TP in river than G1 and G2

Chl-a is higher than G1 and G2

WWTP reduction from 1 to 0.5 mg/L makes a difference in TP and Chla



Take Away:

Reduction in benthic algae in middle reaches but higher than G1 and G2

Black line

- Baseline

Red line

- WWTPs 1 mg/L
- 3 dams removed

Green line

- WWTPs 0.5 mg/L
- 3 dams removed

“X” Indicates location of removed dams

Slides 29-34 of presentation dated January 5 show the results of Baseline, WWTP 1 mg/L and WWTP 0.5 mg/L

Summary of Key Take Aways

- Improved DO in upstream and middle reaches from combination of upstream reductions and WWTP reductions
- Only localized impacts from removal of three dams (upstream and downstream)
- Benthic algae are reduced from combination of WWTP reduction and dam removal in localized reaches

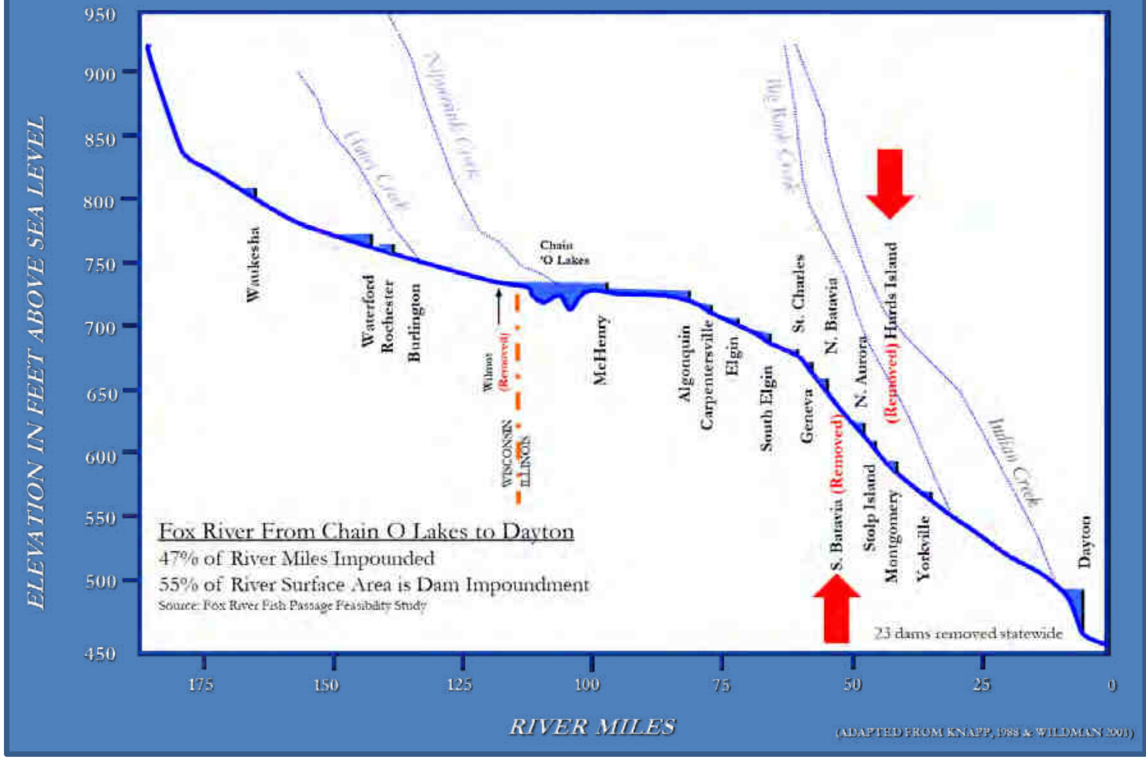
Long-term (2035-2100) Scenarios

Group No.	Scenario 1	Scenario 2	Scenario 3
Group 4	WWTPs 0.5 mg/L	Upstream 75% WWTPs 0.5 mg/L 3 dams removed	Upstream 50% WWTPs 0.5 mg/L All dams removed
Group 5	WWTPs 0.1 mg/L	WWTPs 0.1 mg/L Upstream 50% reduction 3 dams removed	WWTPs 0.1 mg/L Upstream 75% reduction All dams removed
Group 6	WWTPs 0.1 mg/L Upstream 50% reduction 3 dams removed	WWTPs 0.1 mg/L Upstream 75% reduction All dams removed	WWTPs 0.1 mg/L Upstream 75% reduction All dams removed Non-point source 50% reduction
Group 7	WWTP 0.5 mg/L All dams removed	WWTP 0.5 mg/L Upstream 50% reduction All dams removed	WWTP 0.5 mg/L Upstream 75% reduction All dams removed

Long-term Expected Outcomes

- Removing all dams on the Fox River greatly enhances the benefits of WWTP upgrades and upstream reductions
- Dams located on fox river reach with the highest slope

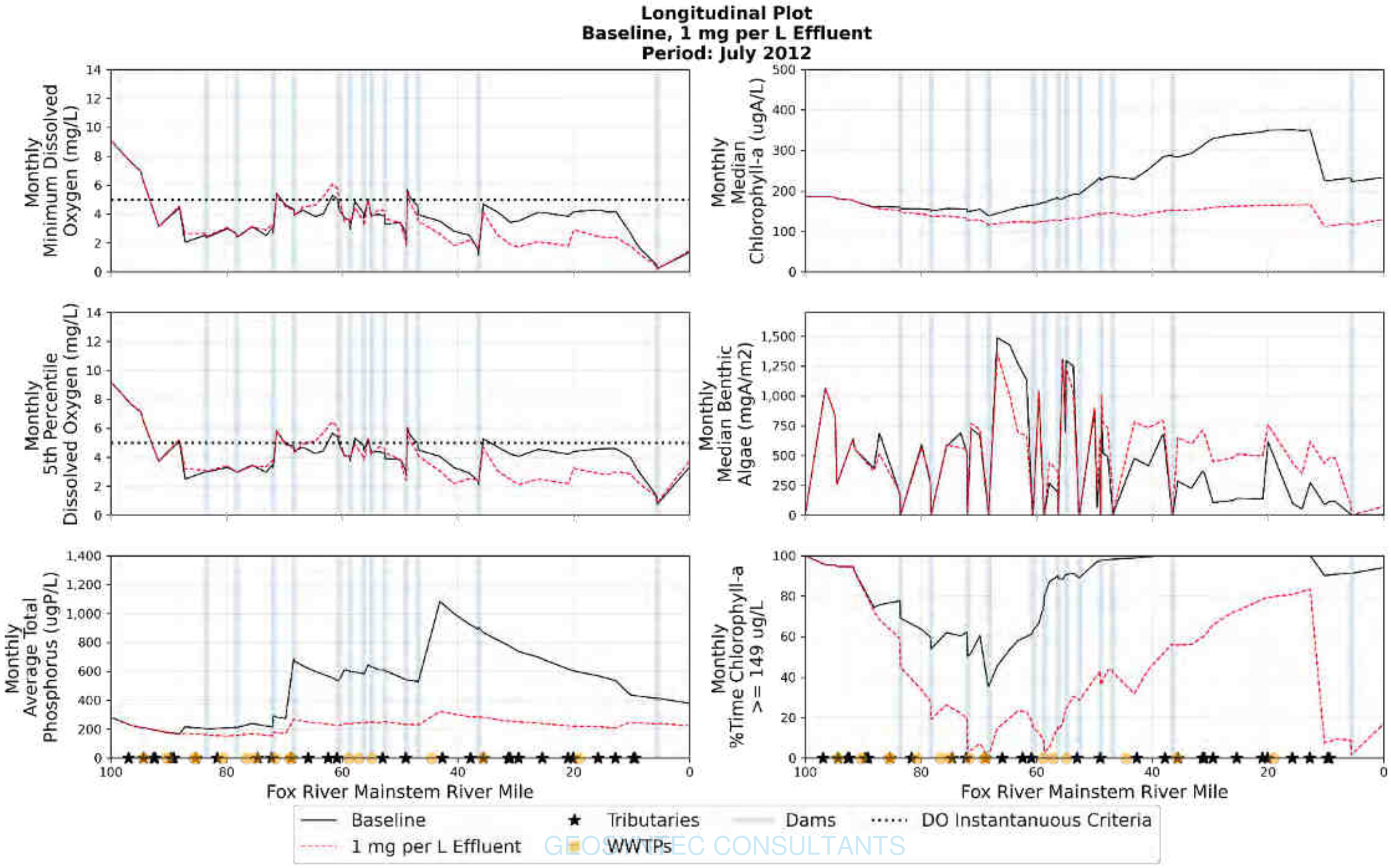
FOX RIVER PROFILE



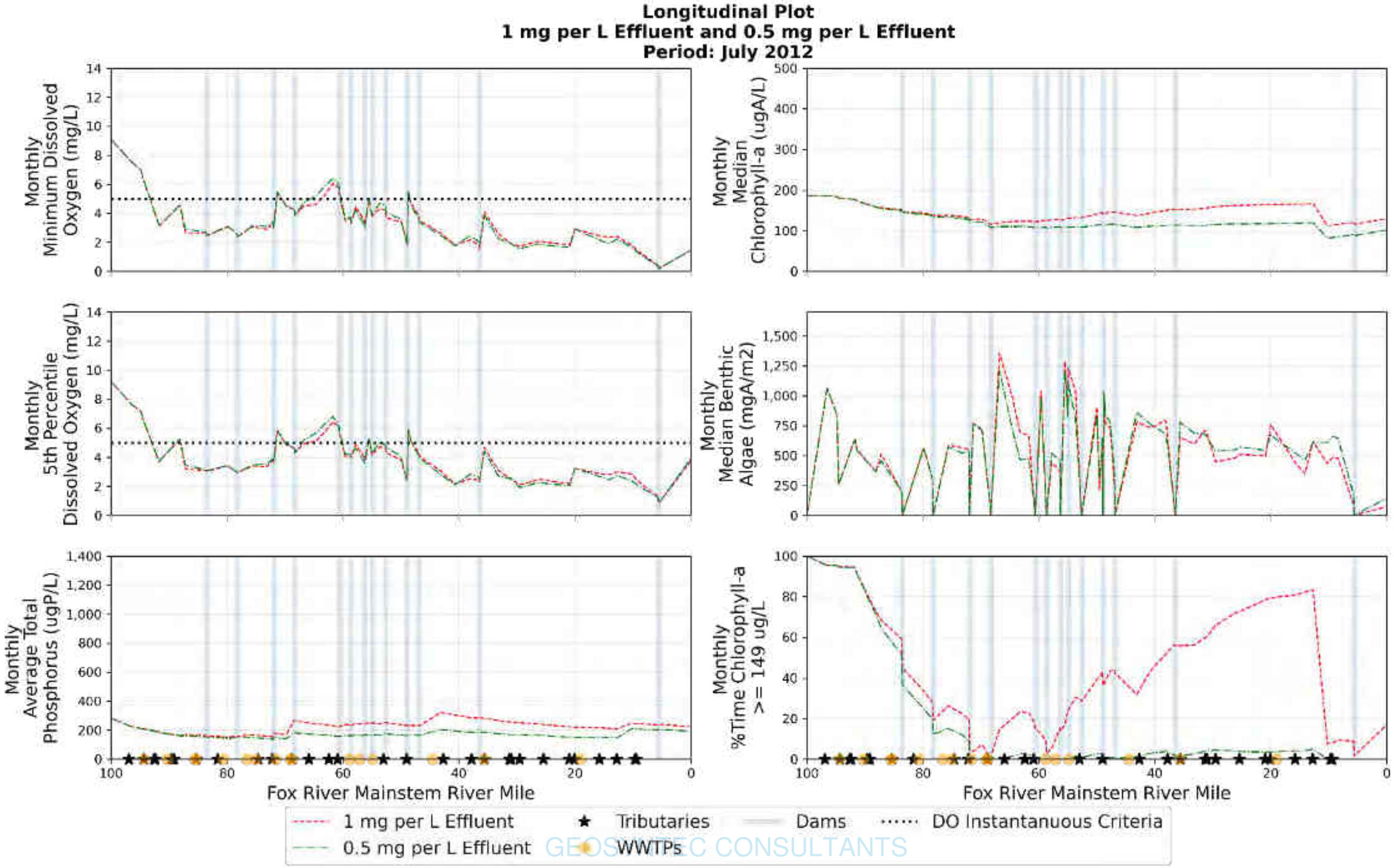
Fox River From Chain O Lakes to Dayton
47% of River Miles Impounded
55% of River Surface Area is Dam Impoundment
Source: Fox River Fish Passage Feasibility Study

(ADAPTED FROM KNAPP, 1988 & WILDMAN 2001)

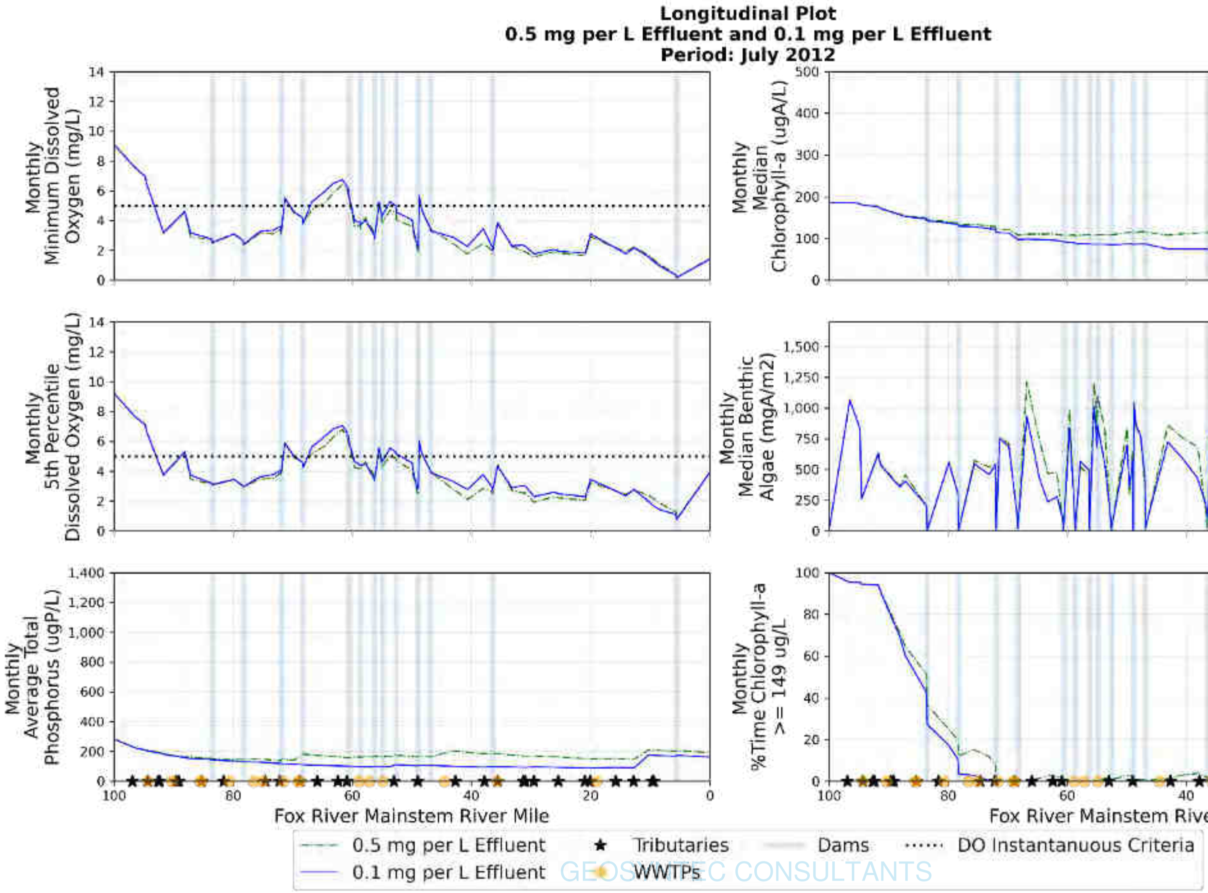
July 2012
Baseline & TP 1 mg/L



July 2012
TP 1 mg/L & TP 0.5 mg/L



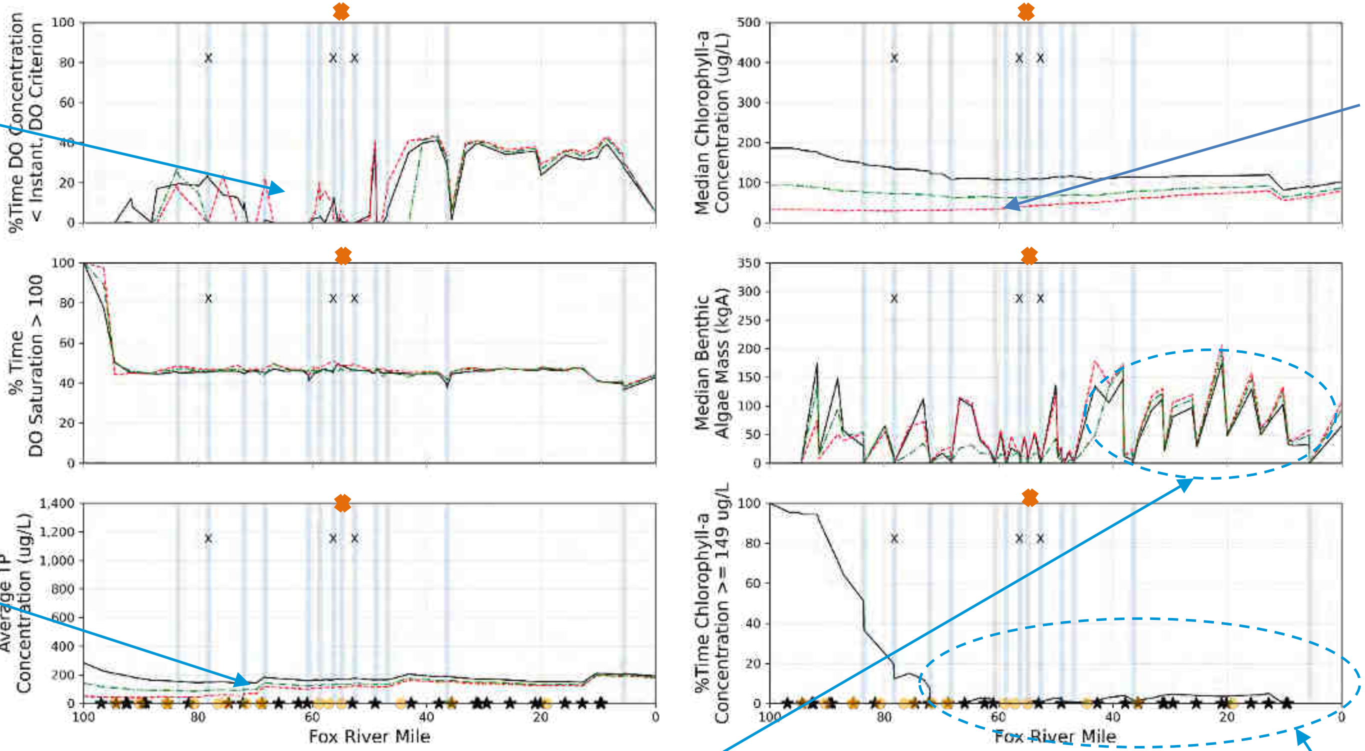
July 20012
TP 0.5 mg/L & TP 0.1 mg/L



Group 4 July 2012 Results

Take Away: Removing all dams substantially reduces DO impairments in middle reaches

Take away: TP reduced because of upstream reduction



Black line
- WWTPs 0.5 mg/L

Take Away: Chl-a is controlled by upstream TP

Red line
- WWTPs 0.5 mg/L
- Upstream 75%
- 3 dams removed

Green line
- WWTPs 0.5 mg/L
- Upstream 50%
- All dams removed

“X” Indicates location of removed dams

Take Away: Eliminating all dams reduced benthic algae but impacts reduced downstream

Take Away: Algae impairment eliminated for red and green scenarios

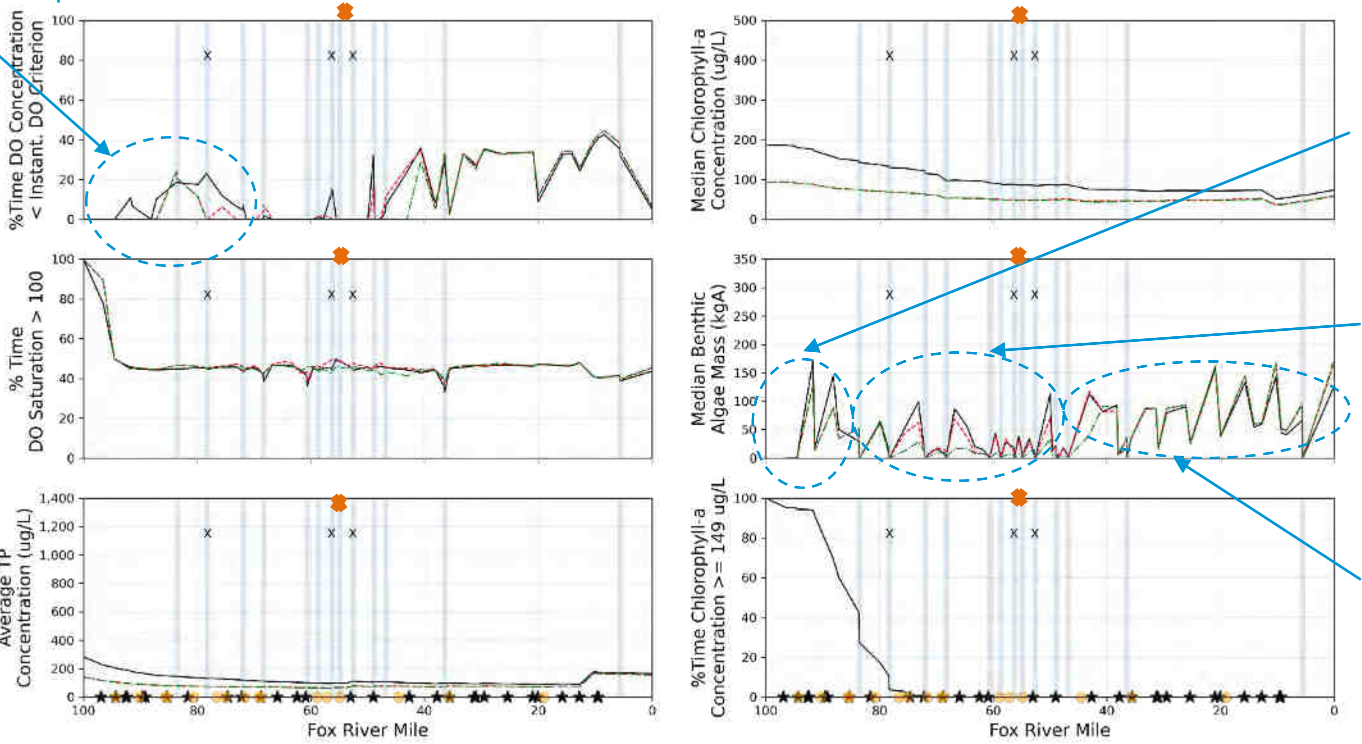
Group 5 July 2012 Results

Take Away: Improve DO in upstream reaches because of upstream reduction

Black line
- WWTPs 0.1 mg/L

Red line
- WWTPs 0.1 mg/L
- Upstream 50% reduction
- 3 dams removed

Green line
- WWTPs 0.1 mg/L
- Upstream 50% reduction
- All dams removed



Take Aways:

Upstream reduction decreases benthic algae

Middle reach has greatest impact of dam removal

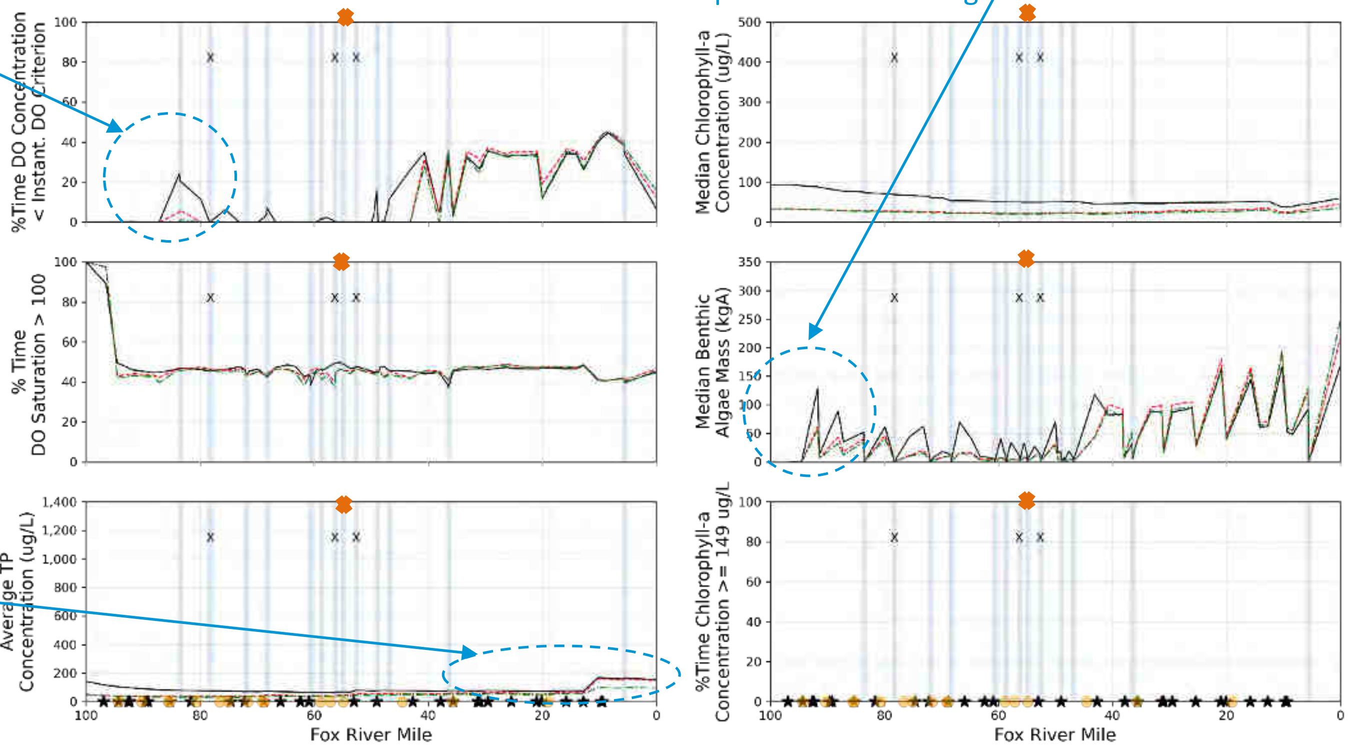
Downstream reach – reduced sestonic algae increases the benthic algae

"X" Indicates location of removed dams

Group 6 July 2012 Results

Take Away: Small reduction in benthic algae because of nonpoint source loading

Take Away: Nonpoint source loading has minimal impact



Take Away: Non-point sources have minimal impact in downstream reaches

"X" Indicates location of removed dams

Black line
- WWTPs 0.1 mg/L
- Upstream 50% reduction
- 3 dams removed

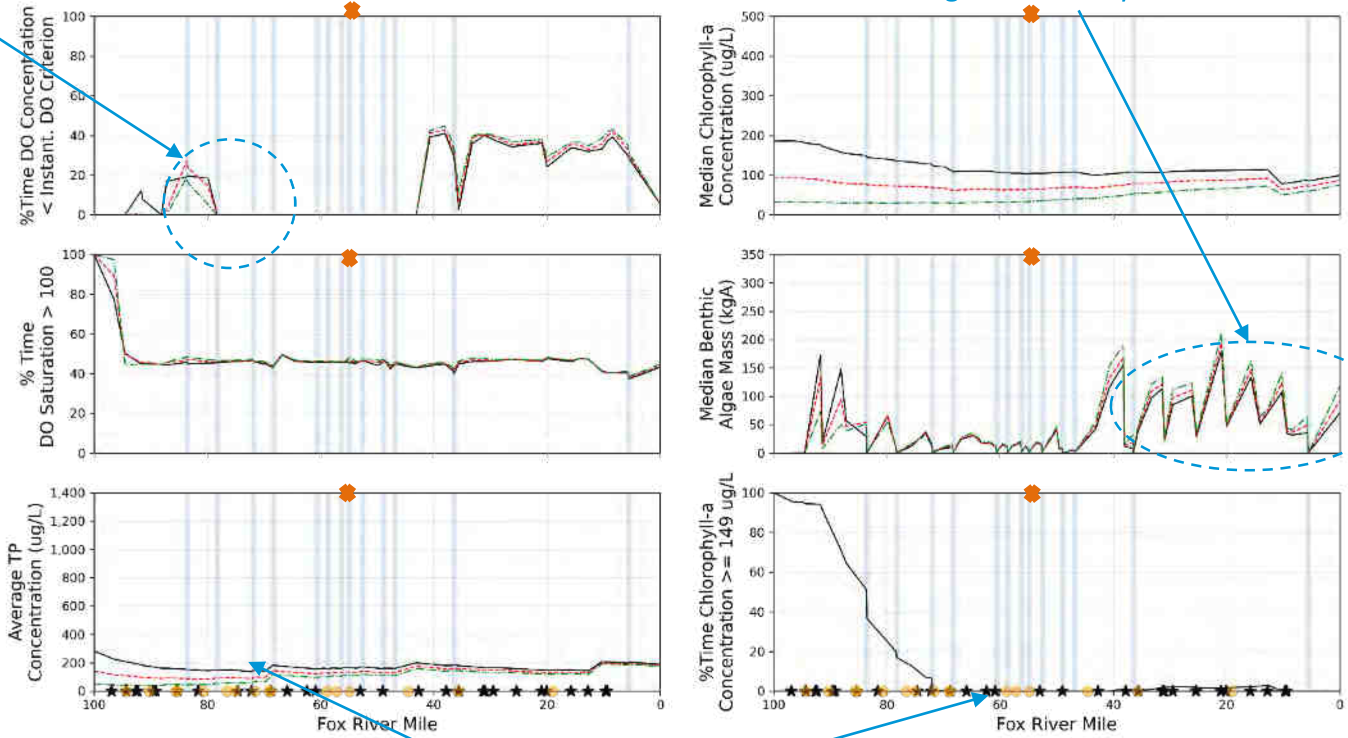
Red line
- WWTPs 0.1 mg/L
- Upstream 75% reduction
- All dams removed

Green line
- WWTPs 0.1 mg/L
- Upstream 75% reduction
- All dams removed
- Non-point source 50% reduction

Group 7 July 2012 Results

Take Away: Benthic algae decreased in upstream reaches because of upstream TP reduction; increased in downstream because of increased light availability

Take Away:
Improved DO in going from 50% to 75% upstream reduction



Black line
WWTP 0.5 mg/L
All dams removed

Red line
WWTP 0.5 mg/L
Upstream 50% reduction
All dams removed

Green line
- WWTP 0.5 mg/L
- Upstream 75% reduction
- All dams removed

“X” Indicates location of removed dams

Take Away: Chl-a and TP reduced because of upstream reduction

Summary of Key Take-Aways

- Coupling reduction of WWTP TP @ 0.5 mg/L with dam removal and upstream reduction will reduce the DO and sestonic algae impairment in the main stem Fox River
- Benthic algae increases in downstream reaches with reduced sestonic chlorophyll-a because of increased light availability
- Dam removal improves substantially improves water quality

Possible Next Steps

- Benthic algae has an impact on the effectiveness of management scenarios – we think it's worth understanding better
  - Run a scenario with benthic algae excluded or constrained
  - Investigate QUAL2kw scour function and shade impact on benthic algae
- Run additional scenarios recommended by the modeling subcommittee

Attachment 3

DO Mass Sinks for Baseline Model

Reach				Total Growing Season									
#	Length (mi)	Average Width (ft)*	% Benthic Alage Coverage	CBOD (gO2)	Sestonic Algae Respiration (gO2)	Benthic Algae Respiration (gO2)	Sediment Oxygen Demand (gO2)	CBOD (gO2/m2)	Sestonic Algae Respiration (gO2/m2)	Benthic Algae Respiration (gO2/m2)	Sediment Oxygen Demand (gO2/m2)	Total	Notes
1	3.50	300.0	0%	76,965,589	136,003,919	1	-	73,324	129,568	0	-	212,969,509	SOD input specified to be zero
2	1.69	182.4	0%	23,020,815	51,807,589	0	-	74,530	167,726	0	-	74,828,404	SOD input specified to be zero
3	0.29	312.1	0%	11,727,423	28,236,440	0	-	131,053	315,540	0	-	39,963,863	SOD input specified to be zero
4	2.81	282.1	70%	27,213,849	93,526,789	1,492,018,503	-	34,319	117,945	1,881,556	-	1,612,759,141	SOD input specified to be zero
5	0.33	312.1	70%	3,210,411	11,333,604	183,697,228	-	30,981	109,370	1,772,688	-	198,241,242	SOD input specified to be zero
6	3.26	282.1	90%	25,418,381	74,579,509	2,181,767,432	-	27,641	81,100	2,372,526	-	2,281,765,322	SOD input specified to be zero
7	0.94	300.1	90%	13,276,264	35,337,137	821,047,527	-	46,900	124,833	2,900,449	-	869,660,928	SOD input specified to be zero
8	3.56	88.3	100%	19,563,410	81,875,185	374,930,192	63,842,676	62,230	260,439	1,192,624	203,079	540,211,463	
9	0.09	242.0	90%	3,756,831	17,319,422	42,572	4,580,595	166,557	767,849	1,887	203,079	25,699,421	
10	3.65	84.6	90%	20,001,059	51,027,560	685,499,383	62,696,741	64,785	165,281	2,220,375	203,079	819,224,743	
11	1.53	88.4	90%	11,283,754	31,963,903	137,147,251	27,444,849	83,494	236,517	1,014,824	203,079	207,839,757	
12	0.09	378.0	90%	6,095,297	21,940,581	357,524	7,154,814	173,006	622,750	10,148	203,079	35,548,216	
13	2.65	87.1	100%	12,726,507	38,595,135	663,175,064	-	55,031	166,891	2,867,664	-	714,496,706	SOD input specified to be zero
14	2.45	200.3	100%	16,995,871	49,472,348	1,902,759,869	-	34,647	100,853	3,878,907	-	1,969,228,087	SOD input specified to be zero
15	1.10	199.1	20%	9,266,310	32,585,144	26,941,640	9,924,423	42,136	148,172	122,510	45,129	78,717,517	
16	0.09	325.0	50%	7,487,233	26,155,116	8,687	6,151,626	247,170	863,438	287	203,079	39,802,663	
17	0.62	95.6	40%	3,795,690	9,414,489	31,152,282	-	63,977	158,682	525,074	-	44,362,462	SOD input specified to be zero
18	1.52	95.9	40%	8,244,754	23,586,209	72,605,670	-	56,472	161,553	497,311	-	104,436,634	SOD input specified to be zero
19	1.42	62.7	90%	18,043,460	30,664,318	27,562,313	8,039,124	202,578	344,276	309,449	90,257	84,309,215	
20	0.09	357.0	90%	8,849,326	17,286,899	1,276,236	15,767,091	265,950	519,525	38,355	473,850	43,179,552	
21	1.49	156.8	90%	6,276,310	12,608,811	1,385,835,981	-	26,841	53,923	5,926,653	-	1,404,721,102	SOD input specified to be zero
22	2.16	157.1	90%	8,642,933	19,333,134	1,940,157,213	-	25,502	57,046	5,724,747	-	1,968,133,279	SOD input specified to be zero
23	1.40	157.1	90%	5,222,167	13,002,807	1,160,614,869	-	23,774	59,197	5,283,809	-	1,178,839,844	SOD input specified to be zero
24	1.52	157.3	50%	5,534,005	14,633,574	361,715,465	-	23,075	61,017	1,508,239	-	381,883,044	SOD input specified to be zero
25	0.99	76.4	50%	11,814,551	32,996,892	3,660,775	3,402,559	156,698	437,642	48,553	45,129	51,874,776	
26	0.09	294.0	90%	6,366,660	20,447,489	246,037	3,586,240	232,339	746,192	8,979	130,873	30,646,426	
27	1.04	112.7	100%	5,474,877	13,055,796	597,626,199	45,865,806	46,866	111,760	5,115,777	392,619	662,022,678	
28	0.84	82.1	100%	8,980,807	27,548,550	22,426,791	-	129,659	397,727	323,782	-	58,956,148	SOD input specified to be zero
29	0.09	441.0	100%	9,663,314	37,294,104	116,290	-	235,096	907,318	2,829	-	47,073,708	SOD input specified to be zero
30	0.86	129.8	100%	9,171,576	26,874,368	177,750,410	-	81,736	239,502	1,584,095	-	213,796,354	SOD input specified to be zero
31	1.44	56.0	100%	5,018,009	19,272,637	149,646,568	29,219,945	62,000	238,124	1,848,967	361,029	203,157,159	
32	0.09	244.0	70%	5,284,208	19,842,795	47,589	4,618,452	232,353	872,511	2,093	203,079	29,793,043	
33	0.75	161.4	70%	3,553,693	9,107,450	385,345,632	24,519,445	29,433	75,431	3,191,568	203,079	422,526,220	
34	0.51	161.4	70%	4,536,310	12,588,640	149,834,764	16,610,050	55,462	153,912	1,831,918	203,079	183,569,764	
35	0.09	161.4	70%	430,889	1,160,082	47,789,376	3,055,923	28,634	77,092	3,175,801	203,079	52,436,269	
36	1.26	161.5	70%	5,405,874	16,288,445	632,194,912	41,153,013	26,676	80,379	3,119,706	203,079	695,042,243	
37	0.97	66.5	70%	10,212,310	31,819,234	5,293,572	13,121,294	158,056	492,467	81,929	203,079	60,446,410	
38	0.09	375.0	70%	6,731,593	24,500,452	476,753	7,098,030	192,595	700,972	13,640	203,079	38,806,828	
39	2.60	192.8	70%	15,748,616	63,840,550	1,183,299,137	101,861,185	31,398	127,278	2,359,121	203,079	1,364,749,487	
40	0.42	225.3	90%	7,081,239	32,075,886	49,148,598	19,212,713	74,849	339,043	519,501	203,079	107,518,436	
41	0.54	164.1	90%	3,540,600	18,072,400	193,338,509	18,111,126	39,700	202,644	2,167,890	203,079	233,062,635	
42	0.09	347.0	90%	6,605,996	41,143,614	26,817	6,568,044	204,252	1,272,128	829	203,079	54,344,472	
43	0.17	63.5	90%	350,661	1,407,205	37,962,859	-	33,445	134,213	3,620,729	-	39,720,725	SOD input specified to be zero
44	0.28	83.2	90%	953,278	4,309,935	57,927,523	4,675,263	41,407	187,210	2,516,189	203,079	67,865,999	
45	0.09	83.2	90%	319,322	1,453,056	19,440,934	1,574,318	41,191	187,436	2,507,778	203,079	22,787,629	
46	0.70	83.2	90%	2,483,551	11,065,347	143,436,205	36,990,235	42,420	188,998	2,449,918	631,800	193,975,337	
47	0.75	50.8	100%	2,070,796	11,091,117	49,296,735	23,981,939	54,555	292,194	1,298,714	631,800	86,440,587	
48	0.09	325.0	90%	3,097,891	21,873,938	1,114,676	6,151,626	102,268	722,107	36,798	203,079	32,238,131	
49	3.73	134.6	70%	95,891,727	87,804,964	804,527,404	102,043,629	190,836	174,742	1,601,103	203,079	1,090,267,724	
50	2.45	177.0	70%	65,259,119	83,706,912	635,975,173	88,055,635	150,504	193,049	1,466,720	203,079	872,996,839	
51	2.45	214.8	90%	44,697,912	78,465,839	1,852,008,226	237,448,914	84,951	149,129	3,519,853	451,286	2,212,620,891	
52	0.20	214.8	90%	3,504,406	6,331,193	147,542,956	19,044,839	83,040	150,024	3,496,173	451,286	176,423,394	
53	1.47	149.4	90%	50,348,915	124,106,231	41,721,569	158,426,850	229,474	565,635	190,153	722,057	374,603,564	
54	0.09	530.0	90%	12,618,805	34,100,654	4,095,058	35,668,915	255,447	690,311	82,898	722,057	86,483,433	
55	0.84	138.5	90%	13,796,628	26,744,974	234,986,677	-	118,353	229,429	2,015,807	-	275,528,279	SOD input specified to be zero
56	2.39	141.5	90%	51,179,132	78,549,287	629,721,644	-	151,321	232,247	1,861,897	-	759,450,063	SOD input specified to be zero

Reach				Total Growing Season									
#	Length (mi)	Average Width (ft)*	% Benthic Alage Coverage	CBOD (gO2)	Sestonic Algae Respiration (gO2)	Benthic Algae Respiration (gO2)	Sediment Oxygen Demand (gO2)	CBOD (gO2/m2)	Sestonic Algae Respiration (gO2/m2)	Benthic Algae Respiration (gO2/m2)	Sediment Oxygen Demand (gO2/m2)	Total	Notes
57	1.88	214.5	90%	46,359,849	80,199,624	1,009,422,320	-	114,980	198,908	2,503,535	-	1,135,981,792	SOD input specified to be zero
58	0.36	226.5	90%	9,551,682	16,546,151	198,634,870	-	116,006	200,954	2,412,437	-	224,732,703	SOD input specified to be zero
59	1.47	240.3	90%	45,854,937	105,296,283	441,447,171	-	129,586	297,566	1,247,526	-	592,598,391	SOD input specified to be zero
60	3.40	128.4	90%	46,349,285	125,223,870	596,715,404	-	106,156	286,806	1,366,683	-	768,288,559	SOD input specified to be zero
61	0.80	153.1	90%	13,308,550	33,935,941	177,792,952	24,871,252	108,667	277,094	1,451,714	203,079	249,908,695	
62	4.40	179.9	90%	67,797,316	227,024,930	1,083,266,847	160,723,981	85,664	286,852	1,368,734	203,079	1,538,813,074	
63	0.91	195.2	90%	9,383,915	28,931,210	613,367,828	36,071,388	52,831	162,880	3,453,206	203,079	687,754,341	
64	4.29	143.8	90%	55,903,747	194,285,054	671,419,272	-	90,590	314,830	1,088,006	-	921,608,073	SOD input specified to be zero
65	1.60	165.8	90%	24,260,476	93,785,547	219,496,561	-	91,462	353,572	827,504	-	337,542,584	SOD input specified to be zero
66	1.40	200.2	90%	16,211,777	67,624,111	557,124,869	-	57,834	241,245	1,987,506	-	640,960,756	SOD input specified to be zero
67	2.45	166.2	90%	218,381,334	113,573,431	393,599,568	-	536,268	278,896	966,542	-	725,554,333	SOD input specified to be zero
68	0.95	129.8	90%	60,679,960	31,984,791	138,662,606	-	492,174	259,428	1,124,690	-	231,327,357	SOD input specified to be zero
69	0.90	129.8	90%	54,042,424	30,501,827	129,914,326	-	462,676	261,137	1,112,243	-	214,458,577	SOD input specified to be zero
70	2.73	170.6	90%	242,208,452	215,679,149	108,579,173	-	519,563	462,655	232,914	-	566,466,773	SOD input specified to be zero
71	0.09	454.5	90%	81,846,895	96,315,015	5,416	-	1,931,909	2,273,414	128	-	178,167,326	SOD input specified to be zero
72	5.58	199.2	90%	321,576,806	505,504,561	292,016,122	195,619,424	289,327	454,809	262,731	176,002	1,314,716,914	
Average				29,701,782	54,272,794	393,608,397	23,263,250					500,846,222	

*Width changes over time with water level

APPENDIX F1
DAM REMOVAL IMPLEMENTATION

APPENDIX F1
DAM REMOVAL IMPLEMENTATION

Introduction

The removal of ten low-head dams in the study area is the most important recommendation in the FRIP. These removals would affect the 46-mile river stretch from the Carpentersville impoundment to the Yorkville Dam impoundment. Over 30 miles of channel, or about 67 percent of this reach, is impounded. The primary water quality objective of dam removal is to eliminate the conditions causing low dissolved oxygen and algae-related impacts in the Fox River. The algae-related conditions include not only high levels of sestonic algae in dam pools but also benthic algae growth in the slow-moving and shallow non-impounded reaches between the dam impoundments. A secondary objective of the FRIP is to improve the aquatic habitat for fish, benthic macroinvertebrates, and mussels. Other ancillary benefits include improved navigability for paddling and the elimination of drowning hazards associated with spillways. The US Army Corps of Engineers, in cooperation with the Illinois DNR, is evaluating the benefits and feasibility of dam removal as part of the Fox River Connectivity & Habitat Study.

To facilitate low-head dam removals on the Fox River with an emphasis on water quality improvements, recommendations for conceptual design, sediment removal, and design of the upstream river channel are discussed below. A review of three case studies provides further context and guidance for dam removal projects. These recommendations were informed by input from the Illinois Department of Natural Resources (IDNR), Forest Preserve District of Kane County (FPDKC), and the Illinois Natural History Survey.

Conceptual Design

The recommended design approach for dam removal is to eliminate the existing dam impoundment and return the upstream channel profile to something approaching pre-dam conditions. Notably, some dam owners may be considering alternative dam “modification” approaches. These may include alterations to create whitewater paddling courses or fish ladders. To the extent that these modifications retain the existing impoundment and its associated sediment, they do not meet the water quality objectives of the FRIP.

Ideally, the entire dam structure would be removed to allow a return to a pre-impoundment hydraulic regime. However, partial removal of the dam may be sufficient if the remaining dam elements do not substantially constrict the river during low to moderate flow conditions. For example, peripheral edges of the dam could be left in place, or the at-grade/below-grade portion of the dam could be left in place for grade control, as long as the main channel reflects the approximate elevation and cross-section of the historical channel bottom. Alternatively, the rubble resulting from dam deconstruction could be redistributed and used for riffle creation at the former dam site. In this scenario, care should be taken to avoid spreading rubble in areas known to contain mussel communities.

Sediment Removal and Attenuation

The design objectives for low-head dam removal include the removal of accumulated sediments upstream of the existing dam that contributes to sediment oxygen demand, nutrient release to the water column, and degraded benthic habitat. Practically speaking, it is not cost-effective or desirable to remove all of the accumulated sediment upstream of a dam that has been in place for over 100 years and impounds a pool that extends several miles upstream. However, depending on the composition of the sediment and the presence of problematic pollutants, it may be necessary to remove some sediment near the dam.

Removal options can range from sediment dredging with on- or off-site disposal to natural attenuation that allows accumulated sediment to move downstream and disperse over time. The USACE will be evaluating sediment removal/attenuation options in consultation with IDNR and Illinois EPA during the design and permitting process. If the design process concludes that some sediment removal is necessary, there may be an option to utilize this sediment as part of an engineered design to reshape adjacent riverbanks (for example, in conjunction with trail or recreational uses). In general, natural sediment attenuation will be the lowest-cost option for sediment removal. Attenuation allows sediment to move gradually downstream via natural erosional processes over months or years. For example, this process was permitted for Brewster Creek (near South Elgin), in which a dam was taken down in a stepwise fashion over several months. This cost-effective solution allowed impounded sediment to slowly move downstream while a stable channel and revegetated floodplain formed upstream.

Design of the Upstream River Channel

Without any intervention, the river upstream of dam removal will begin to form an incised, meandering channel with associated pools and riffles. This process can be quite active in the short term but will move toward a state of dynamic equilibrium over time. Allowing these natural processes to re-form the channel may be the most practical and cost-effective course of action for most Fox River dam removal projects.

The Corps of Engineers will evaluate channel design options. There are several factors that can affect water quality outcomes. In general, and where feasible, the channel design should incorporate meandering with alternating pools and riffles, recognizing that narrower and deeper channels can increase flow velocity, moderate summertime water temperatures, and reduce shallow zones that could be conducive to excess growth of benthic algae and aquatic plants. In addition, incorporating native vegetation and trees into the bank design can enhance aquatic habitat and provide shade that will limit the growth of problematic benthic algae in nearshore areas. Guidance on channel restoration and riparian revegetation is provided in Appendix F2.

Illustration of Raney Well; Courtesy: City of St/ Helens, OR

Another specific situation that may necessitate a unique channel design is the presence of water supply intake structures upstream of a dam, such as in Aurora and Elgin. For these situations, an engineering design will need to address maintaining sufficient water depth near intake structures post-dam removal. Sedimentation issues near existing and proposed intakes would also need to be addressed. There are conventional screened intakes that could be used in such settings. There also are specialized intake structures designed to handle variable flow conditions in shallow rivers like the Fox. An example is a Ranney Collector Well which utilizes a large caisson with lateral screens that radiate from the well below the ground under the riverbed.

Case Studies

The following case studies of dam removals provide additional guidance and insights for future dam removals on the Fox River.

South Batavia Dam Removal

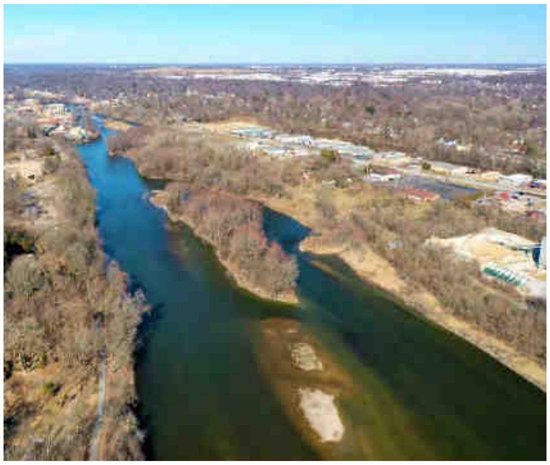
The South Batavia Dam was removed by its owner, the FPDKC, in 2006. The dam consisted of an earthen island in the center of the river channel with two concrete spillways located on each side of the island. The east and west spillways were 143 feet and 203 feet in length, respectively. The approximate heights for the east and west spillways were approximately six (6) and five (5) feet, respectively. The impoundment of the dam was approximately 1.5 miles long, and it was estimated that 23,500 cubic yards of sediment were accumulated behind the dam, with the bulk immediately upstream of the earthen island and the east spillway.

In the early 2000s, a breach occurred near the west end of the east spillway on the island. By 2002, the breach had enlarged, the dam had partially failed, and subsequently, a significant amount of the sediment in the central portion of the channel was washed downstream. During this period, the FPDKC, through collaboration with numerous project stakeholders (City of Batavia, Batavia Park District, state and federal regulators, non-profit organizations, and the general public), made the decision to remove the dam.

The final design implemented in 2006 consisted of the following elements:

- Complete removal of the west spillway and filling of the scour hole downstream of the spillway with the broken concrete;
- Minor grading of the breach in the earthen island and armoring of the side slopes of the breach with riprap; and
- Minimal modification to the east spillway, including armoring it and the surrounding area with riprap.

The east spillway was left in place largely for sediment management; the sediment accumulated upstream of the spillway was stabilized with vegetation. Project construction within the river channel was facilitated through the construction of a temporary riprap causeway from the eastern riverbank to the western spillway. The causeway was used as both a work platform and an access road for the delivery and removal of materials. The causeway was removed following construction, with some of the material being used for the aforementioned riprap armoring.



Former South Batavia Dam Site; Courtesy: Art Malm, FRSG Board

Hofmann Dam Removal

The Hofmann Dam on the Des Plaines River, situa in 2012 as part of a larger effort to remove three dams. The dam, installed in the early 20th century and rebuilt over several iterations, originally was built to provide a reliable pool of water for recreation. Dam removal justification was based on concerns that it impeded the migration of fish, impaired water quality and converted riverine habitat to stagnant reservoir habitat. The dam also posed serious safety issues for river users. Dam removal was undertaken by the Army Corps of Engineers as an Aquatic Ecosystem Restoration project (Section 206) under the Water Resources Development Act of 1996. The total cost to remove the 150 foot structure was $7.3 million, with a non-federal share of $2.5 million. The primary local cooperators and supporters included the Illinois DNR and the Forest Preserve District of Cook County (which owns the riparian lands). Post-dam removal monitoring showed dramatic improvements to the ecosystem. Upstream, riffles, runs, and pools were restored throughout the former pool and at the mouth of Salt Creek. A sampling of the fish population by Illinois DNR found a total of 10 species that were not previously found in the upstream pool including northern pike, rockbass, channel catfish, and blackside darter.

Carpentersville Dam Removal

The Carpentersville Dam removal is undergoing final design and permitting by its owner, the FPDKC. The dam is nine feet high and 378 feet wide and impounds a pool 4.5 miles long. The dam also has mill races on either side of the main structure. The FPDKC went through the TACO procedure and determined that there were no contaminated sediments of concern in the dam impoundment. It also followed the Nationwide Permit No. 53 process, including consultation with state and federal agencies regarding design options and associated water quality and habitat impacts. The dam removal design approach involves opening the two mill races to lower the upstream pool. After dewatering, dam removal is planned to be completed without coffer dams. The rubble from the existing dam, minus rebar and other objectionable materials, will be distributed to create a large riffle-like structure on the base of the existing dam. This will effectively lower the current dam height by seven feet and is designed to preserve the hydrology in an adjacent seep zone. The design calls for natural sediment attenuation and channel reformation upstream.

This design avoids the need for expensive sediment dredging and removal. The FPDKC is anticipating that the upstream channel will naturalize with the formation of meanders, pools, and riffles in the dewatered channel. It is expected that exposed riverbanks upstream of the dam will naturally revegetate without a formal planting plan. This approach recognizes that Fox River floodway zones are inundated with seeds from native and non-native grasses, forbs, and trees spread by floodwaters and that it may be difficult to try to force a designed planting in such low-lying areas. The FPDKC anticipates that this riparian zone will eventually be populated with common floodplain tree species such as cottonwood, box elder, and silver maple, thus providing both beneficial shading and bank stabilization to this area.

Dam Removal Advocacy

Public outreach and advocacy are essential for low-head dam removal projects. The FRSG has developed a factsheet on dam removal and its benefits. Additional information on Fox River dams, including detailed information and mapping of individual dams, can be found on the FRSG website. The FRIP recommends that FRSG continue to advocate to decision-makers and the public on the benefits of dam removal

APPENDIX F2
RIVER CHANNEL RESTORATION AND RIPARIAN REVEGETATION

APPENDIX F2
RIVER CHANNEL RESTORATION AND RIPARIAN REVEGETATION

Introduction

The most important recommendation of the FRIP is to remove ten dams in the study area. These dams impound over 30 miles of channel (approximately 67 percent of the study area reach). As dams are removed, there are opportunities to improve river channel conditions for aquatic life. Water levels upstream of each dam will drop substantially, re-exposing hundreds of acres of riparian land. These riparian landscapes will be important targets for revegetation and restoration.

There are several broad objectives for river channel restoration and riparian revegetation. These include shoreline shading, bank stabilization, and enhancing habitat for aquatic organisms. Shoreline shading is critical to help limit the growth of benthic algae in shallow water zones after dam removal. Bank stabilization is important to help limit inputs of sediment, including particulate phosphorus. Enhancing habitat should help restore and sustain aquatic life, as this is the designated use and ultimate goal of water quality standards for the Fox River.

Conditions of riparian areas and riverbanks in the FRIP Study Area are highly variable. Much of the shoreline is undeveloped and in a relatively natural vegetated state. Other areas are highly developed, particularly in downtown zones where impervious surfaces and buildings can extend to the river banks. River banks in most urban areas are often very steep and armored with riprap, sheet pile, or concrete walls. While there are isolated locations of problematic riverbank erosion, this is not a substantial issue in the FRIP Study Area.

Historical Conditions

Understanding the historical conditions of the river and its floodplain corridor is useful for identifying appropriate restoration and revegetation strategies. Historical vegetation cover has been identified during pre-European settlement times in several studies. A valuable resource is "Pre-European Settlement Vegetation of Kane County" (Bowles and McBride, 2003). (Similar pre-settlement vegetation surveys were done for McHenry and Kendall Counties.) This study identifies and coarsely maps vegetation patterns, particularly tree cover and species, based on the federal Public Land Survey conducted in 1837. The study notes that vegetation patterns in the river corridor reflect the effects of large landscape fires driven by prevailing southwest winds. The Fox River functioned as a firebreak, and consequently most of the landscape east of the river was historically wooded. Areas west of the river were generally more open, with scattered open floodplain forests, particularly in locations sheltered by bluffs above the river. The study identifies various floodplain tree species including ash, maple, elm, basswood, hackberry, cottonwood, willow, and walnut.

Another useful reference for identifying historical vegetation patterns along the river corridor are the plat maps from the early 1870s. These are available from the respective counties. While downtown areas had been substantially developed by the 1870s, and much of the corridor had been platted into parcels, the maps depict much of the historical vegetation such as tree groves. The maps also show the historical locations of early dams, river islands, and approximate channel widths.

Current Conditions

A study of aerial photos provides additional information about current conditions of the river corridor to help inform restoration strategies. Notably, channel widths are relatively variable. Downstream of dams in free-flowing river sections, channel widths generally range from 100 to 300 feet. Upstream of dams, impounded channels are commonly over 400 feet wide, and as wide as 700 feet in some locations. The current aerial photos also reveal extensive wooded islands and channel bifurcations, primarily from Batavia downstream through Montgomery. These islands effectively narrow the widths of local channels, and woody vegetation on many of the islands creates more shading in nearshore, shallow water zones.

RECOMMENDATIONS:

Based on a review of historical and current conditions, the following broad strategies are recommended for river restoration and revegetation:

1. Revegetation in riparian areas upstream of dam removal projects
2. River edge redevelopment and retrofits

1. Revegetation upstream of dam removal projects:

Dam heights range from seven to fifteen feet, and dam removal will thus result in a substantial lowering of normal water levels and will expose hundreds of acres of bare soil in riparian zones upstream of existing dam sites. There are two broad approaches for revegetating these areas to help ensure stable streambanks and meet objectives related to shading vegetation in riparian areas.

The first approach involves reintroducing native herbaceous vegetation and trees. Deep-rooted native vegetation adapted to occasional to frequent flooding has proven to be more effective in stabilizing riverbanks and riparian zones than traditional landscaping such as turf grass. The reintroduction of native vegetation also supports plant diversity and habitat in sensitive areas like seeps, fens, sedge meadows, and floodplain forests that currently border portions of the Fox River corridor, including some Illinois Nature Preserves and Illinois Natural Area Inventory sites.

Native vegetation can also be combined with ‘bio-engineered’ structures to stabilize areas where bank erosion may be more challenging to address, such as steep slopes and high velocities zones. Techniques such as vegetated geogrids, live fascines, and live crib walls have been successfully installed in numerous river and stream stabilization projects in northeastern Illinois.

Introducing native trees to riverbanks and riparian zones also is recommended to provide shading to nearshore, shallow water zones. While this will have little effect on the main river channel, enhanced shading in nearshore areas can moderate extreme summer water temperatures and mitigate conditions that lead to excessive benthic algal growth in shallow water. Based on the pre-settlement vegetation surveys, recommended trees include fast-growing species like maple, elm, basswood, hackberry, cottonwood, and willow.

An alternative approach for revegetating shorelines and riparian zones is to allow these areas to naturally revegetate with seeds carried by floodwaters and blown in from adjacent natural landscapes. This strategy may be the most pragmatic for most areas considering the extensive riparian area exposed by dam removals and the relative cost of introducing and maintaining native vegetation. It also recognizes that there is an overwhelming number of seed sources for species like reed canary grass flowing into riparian areas during floods. It may not be cost-effective to control such species along the extensive length of the river channel as would be done in conventional upland ecological restoration projects.

The Forest Preserve District of Kane County (FPDKC) has adopted this alternative approach in its planning for the removal of the Carpentersville Dam. The FPDKC is the single largest owner of Fox River riparian areas in Kane County and has a wealth of expertise in ecological restoration practices. It is anticipated that both herbaceous vegetation and trees will repopulate riparian areas exposed by dam removal. Based on observations from other dam removal projects, this is expected to provide both effective bank stabilization and shading over time.

If trees do not become established over time, for the Carpentersville project or upstream of other dam removals, then a planting strategy in riparian zones should be pursued. It also is recommended that appropriate controls be put into place to limit the potential spread of highly invasive riparian plants like giant reed (phragmites).

2. River Edge Redevelopment and Retrofits

River edges, particularly in urban zones, provide excellent opportunities for restoration and retrofits. Over time, buildings and infrastructure will need to be replaced as they age. Notably, many of the historical urban Fox River edges were developed when there was little awareness of the habitat or scenic value of the river. Buildings often were constructed with their backs to the river, and no space was allocated for natural buffers or public access. Modern riverfront planning and design practices include alternatives that can enhance riparian shading and habitat, mitigate untreated stormwater runoff, and improve recreational access. These practices have been effectively implemented in urban river communities around the country.

Locally, the Chicago Metropolitan Agency for Planning (CMAP) has worked with a number of Fox River communities to develop river corridor plans that embrace opportunities for more sustainable river edge development and redevelopment. These corridor plans (developed for Carpentersville, Algonquin, and a series of communities stretching from Fox River Grove to Island Lake) identify recommended policies and practices that broadly embrace green infrastructure designs. Recommendations include strengthening local ordinance provisions for setbacks, buffers, and stormwater management and incorporating green infrastructure into capital improvement plans.

The City of Chicago has adopted a comprehensive set of *Chicago River Design Guidelines*. Its goals include restoring and protecting landscaping and natural habitats along the river, particularly fish habitat; developing the river edge as a recreational amenity; and encouraging economic development compatible with the river as an environmental and recreational amenity.

The *Chicago River Design Guidelines* are implemented through the city's Zoning Ordinance, which requires that all new development within 100 feet of the river be processed as a Planned Development. The ordinance further requires new developments to provide a 30 foot setback from the river and comply with the goals of the river design guidelines. Relevant elements of the *Chicago River Design Guidelines* applicable to the Fox River include:

1. Plant palettes
2. River edge treatments
3. Sloped bank treatments
4. Naturalized shoreline applications
5. Aquatic habitat applications
6. Stormwater best management practices

A related resource for sustainable design that addresses water quality and riparian habitat in urbanized riparian zones is a publication of the Friends of the Chicago River, *Case Studies, Resources, and Examples for River Edge Development*.

Fox River communities should evaluate the feasibility of adopting elements of the Chicago design guidelines in urban riparian zones, particularly via zoning, stream buffer, and landscaping codes. These provisions also could be incorporated into capital improvement plans for river edge redevelopment.

It also is recommended that communities consider opportunities to plant riverbank trees as part of development and redevelopment projects and plant additional trees on public land and parks bordering the river.

In a related vein, the Kane County Stormwater Management Ordinance exempts any redevelopment on sites adjacent to the main channel of the Fox River from its buffer requirements any redevelopment on sites adjacent to the main channel of the Fox River. It is recommended that this exemption be modified, either in the countywide ordinance or in municipal ordinances, to stipulate the need for appropriate shade trees and native vegetation buffers, to the extent practicable, in riparian development and redevelopment zones.

APPENDIX F3
ORDINANCE UPDATE RECOMMENDATIONS

APPENDIX F3
ORDINANCE UPDATE RECOMMENDATIONS

Introduction

Urban runoff and related development impacts contribute to a number of water quality impairments in the Fox River and its tributaries. Stormwater runoff destabilizes the hydrology, particularly in tributary streams, causing bank erosion and unstable conditions for fish and aquatic organisms. Physical alterations to drainageways and wetlands due to urban development also results in impairments. While the Fox River Implementation Plan (FRIP) specifically addresses low dissolved oxygen levels and excess algal growth due to too much phosphorus, eliminating these issues will not restore aquatic life if other impairments such as excess sedimentation and siltation, high total suspended solids, and high chloride levels are not addressed. A comprehensive approach to regulating development and stormwater runoff is an important strategy that can be leveraged by the Fox River watershed communities. This approach will reduce phosphorus as well as other pollutant loadings from urban sources and provide co-benefits such as stabilized hydrology and reduced flooding and streambank erosion.

To put the importance of sustainable development ordinances into perspective, population in the FRIP study area is forecasted to grow substantially by 2050. Kane and McHenry counties are expected to grow by over 40 percent and Kendall County is projected to grow by over 80 percent. In addition to mitigating the impacts of new development, sound development ordinances will also benefit redevelopment in areas built prior to the adoption of modern stormwater and development ordinances. This will be particularly beneficial in older river valley communities, such as Aurora and Elgin, that discharge runoff from downtown areas and old neighborhoods directly to the main stem Fox River with little or no mitigation of stormwater impacts.

Under the Clean Water Act, each municipal separate storm sewer system (MS4) is required to have a National Pollutant Discharge Elimination System (NPDES) permit. The permit, issued by Illinois EPA, identifies important goals and design elements for post-construction stormwater management for new development and redevelopment. The permit requires controls that will protect water quality, reduce the discharge of pollutants, and reduce the velocity and volume of stormwater flow. The permit requires strategies that incorporate the infiltration, reuse, and evapotranspiration of stormwater and consideration of the implications of climate change. Finally, the permit identifies a best management practice (BMP) design approach that includes the following design elements:

- Preservation of natural storage and drainage characteristics
- Preservation of natural streams, channels, and drainageways
- Minimization of new impervious surfaces
- Conveyance of stormwater in open vegetated channels

The counties in the FRIP study area have adopted countywide stormwater ordinances that require compliance from municipalities. The Kane and McHenry counties' ordinances provide overarching regulations for stormwater management, soil erosion, sediment control, floodplain management, and wetland protection. Over time, the original focus of these countywide ordinances has evolved from addressing stormwater quantity and flood prevention to water quality and aquatic habitat concerns due to urban runoff and have begun to align with most of the Illinois EPA's MS4 permit requirements. The Kendall County countywide ordinance primarily emphasizes stormwater quantity and does not address stormwater quality or stream and wetland protection. A review of ordinances in several Kane, Lake and McHenry County communities shows that the countywide ordinances establish a good starting framework for managing stormwater runoff during rain events. However, only municipal policies and ordinances can guide the location of development, reduce impervious surfaces associated with development, and promote other needed water quality protection practices.

Recognizing the gaps between requirements for NPDES permits and local ordinances, Geosyntec worked with organizations such as the Chicago Metropolitan Agency for Planning (CMAP) and The Conservation Foundation to develop guidance for watershed-friendly development practices and a detailed ordinance checklist. The checklist is included in *Attachment 1: CMAP Checklist*. This green infrastructure-based approach recognizes that countywide stormwater ordinances provide a good starting point but that municipal development ordinances will need to address a number of other requirements to achieve the goal of protecting water resources from the adverse water quality, hydrologic, and aquatic habitat impacts of conventional development.

The ordinance guidance and checklist provide a holistic approach for development regulation that begins with comprehensive stormwater management, including stormwater quantity and quality management; soil erosion and sediment control; stream and wetland protection; and floodplain management. These topics are generally addressed in the countywide stormwater ordinances which municipalities are also required to adopt and enforce. This approach also calls for reviewing and revising community zoning, subdivision, and landscaping ordinances to remove barriers to green infrastructure[1] design and to help ensure that development codes reduce impacts to aquatic habitat and natural resources. The checklist addresses specific ordinance provisions and includes local and regional references to communities that have adopted advanced ordinances. A holistic approach allows subdivision, zoning, landscaping, and stormwater ordinances to work synergistically and makes it easier for developers to efficiently and cost-effectively meet multiple requirements simultaneously.

Because the largest portion of the FRIP watershed is in Kane County, a high-level review of Kane County's Stormwater Management Ordinance and typical municipal ordinances was performed

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[1] Green infrastructure as "the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters." – Water Infrastructure Act of 2019

using the guidance and checklist at the end of this document. The results of this review lead to the following recommended ordinance updates. Conducting this review for ordinances in McHenry County would likely lead to similar recommendations, while doing the review for Kendall County would identify additional recommendations.

Stormwater Drainage and Detention

Development sites should be designed with drainage and detention systems that minimize urban runoff. This can be accomplished by green infrastructure designs that allow for infiltration, reuse, and evapotranspiration of stormwater. Reducing impervious surfaces and using bioswales, rain gardens, natural landscaping, permeable paving, and green roofs will lower runoff volumes while capturing phosphorus and other pollutants. Naturalized detention basins can also attenuate peak flows and cleanse runoff.

While countywide stormwater ordinances generally embrace these principles and practices, actual developments approved through existing processes may not include a full complement of green infrastructure design elements. The following recommendations include suggestions to both strengthen countywide stormwater ordinances, and change local subdivision, landscaping, and zoning codes that may conflict with, or not fully account for, green infrastructure solutions.

Stormwater detention facilities should be designed as naturalized wet or wetland basins that are naturally landscaped above and below the water line. Community subdivision and landscaping ordinances should be reviewed to ensure they do not conflict with green infrastructure design practices. These ordinances should be updated to allow and encourage the use of natural landscaping, natural drainage practices and detention designs, and permeable paving. In addition, stormwater and landscaping ordinances should specify long-term monitoring and performance standards for the maintenance of practices such as bio-swales, rain gardens, and naturalized detention basins. Finally, ordinances should include provisions for adaptation to climate change. In particular, stormwater drainage and detention designs should utilize the latest rainfall frequency data from the Illinois State Water Survey's Bulletin 75.

Soil Erosion and Sediment Control

The soil erosion and sediment control requirements in the Kane County Stormwater Management Ordinance are relatively brief. Instead, the ordinance refers to the Illinois Urban Manual and the county's Technical Manual for required standards and specifications. These references generally embrace the core principles of effective soil erosion and sediment control, including minimizing the area and time of disturbance, following natural contours, avoiding sensitive areas, and requiring that sediment control measures be in place before significant grading or disturbance is allowed.

There are a few additional recommendations that countywide and local ordinances should consider incorporating:

1. Require an erosion and sediment control permit for any land disturbing activity in excess of 500 square feet if it is adjacent to a stream, lake, or wetland. Currently, a permit is only required if the development is larger than 5,000 square feet or if it is in the regulatory floodplain.

2. Add a goal statement that the erosion of sediment from disturbed sites should be minimized to an extent which would have occurred if the land had been left in its undisturbed state.

3. Require sufficient detail on how inspections will work for phased projects and specifically require inspections at critical stages of the construction process. This will help assure that development practices and erosion control measures are effective. The Illinois Urban Manual is a valuable resource for conducting thorough inspections.

4. Finally, Kane County and local municipalities should evaluate the effectiveness of their enforcement measures. Sometime fines are insufficient to obtain compliance and stop-work orders, and other penalties may be required.

Stream and Wetland Protection

The Kane County Stormwater Management Ordinance includes provisions regulating development in and adjacent to streams and wetlands. In particular, the ordinance requires natural buffers for streams and wetlands that vary based on the size and ecological quality of the resource. However, redevelopment on sites adjacent to the main stem of the Fox River is exempt from the buffer requirements. This exemption should be modified to stipulate the need for appropriate native vegetation buffers, to the extent practicable, in ecologically impaired urban riparian zones. In addition to providing shoreline stabilization and habitat for aquatic biota, buffers are important zones for planting shade trees to mitigate nuisance algal growth and high water temperatures in shallow near-shore areas. Adding more specific performance criteria for maintenance of native vegetation in buffers to the ordinance, particularly stipulating the control of invasive species is also important. As a further protection for situations where narrow buffers are identified, a development setback of 75 to 100 feet from the ordinary high-water mark should be required. Within this setback, development should be limited to the following types of activities: minor improvements like walkways and signs, maintenance of existing roads and utilities (but no new construction), and park and recreational area development.

Natural area protection and Conservation Design

In addition to the natural water resources covered above, other important areas that should be considered for protection, restoration and management include remnant prairies, savannas, woodlands, steep slopes, sensitive recharge areas, farmed wetlands, and hydric soils. Protection of these features can provide additional buffering for aquatic systems, preserve groundwater recharge, avoid severe erosion zones, and provide critical landscape linkages for wildlife. The Kane County 2040 Green Infrastructure Plan maps green infrastructure and open space at a countywide scale and includes policy recommendations for their protection. McHenry County has also adopted a green infrastructure plan and several municipalities have developed local plans based on the countywide plan.

Kane County and McHenry municipalities should also consider adopting the countywide green infrastructure plan. Mapped green infrastructure projects can be identified in a conservation design overlay district linked to ordinance language that offers protection of sensitive landscape features. McHenry County and several McHenry County municipalities have adopted conservation design ordinances that can serve as models for Kane County and other local governments in the Fox River watershed. Conservation design encourages clustering development to preserve sensitive natural areas as communal open space. In contrast to conventional development, conservation design also provides additional flexibility in site layout and design to enable the use of natural drainage practices, native landscaping, and other techniques that help mitigate stormwater runoff and maintain natural drainage systems. For both conventional and conservation design, provisions for funding, ownership, management, and maintenance of naturalized stormwater facilities, natural areas, common open space, and buffers should be specified by ordinance.

Natural Landscaping

Natural landscaping is the use of deep-rooted native vegetation in lieu of turf grass and conventional ornamental landscaping. It can greatly benefit water quality and natural hydrology because it enhances runoff infiltration and filtering and requires minimal chemical (e.g., pesticides or fertilizers) use. Existing subdivision and landscaping codes should be evaluated for provisions that discourage natural landscaping (e.g., "weed" prohibition language). These provisions should be amended to allow for and encourage natural landscaping in appropriate settings such as common open space, residential yards, and stormwater facilities. The ordinances should also include provisions for long-term maintenance, including required landscape management and performance criteria.

Road and Parking Design

Streets and parking lots comprise a substantial proportion of a community's impervious surfaces and are thus the most significant generator of stormwater runoff and associated pollutants. Many of the design requirements for streets and parking are outdated and should be evaluated for opportunities to reduce the footprint of impervious surfaces.

Streets should be designed for the minimum required pavement width needed to support travel lanes, on-street parking, and emergency access. In addition to narrowing the pavement width, naturalized stormwater infiltration and conveyance systems should be encouraged. Instead of requiring conventional curb and gutter designs in every setting, subdivision ordinances should be revised to encourage bioswales and rain gardens as part of the stormwater management system in appropriate settings along streets. Driveways are also a significant source of impervious surface on individual parcels, and design requirements could be modified to allow and encourage reduced widths and lengths, shared driveway designs, and permeable paving.

Parking lot design requirements should be evaluated and modified to reduce parking to the minimum needed to support adjacent land uses. In particular, criteria for the number of parking spaces, the size of individual spaces, and aisle design standards should be evaluated and modified. Communities should also consider creative design options such as shared parking with nearby land uses and reducing parking requirements based on location (e.g., downtown locations). Ordinances should explicitly allow and encourage the use of permeable parking surfaces and recessed landscape islands that incorporate bioswales and rain gardens.

Pollution Prevention

Several municipalities in the study area have adopted groundwater protection ordinances. These ordinances could be duplicated in other communities and expanded to include pollution prevention standards to protect surface water. Some pollution prevention measures may likely be addressed in the housekeeping provisions of community MS4 NPDES stormwater permits. However, specific measures that should be identified include prohibition of coal tar-based seal coating, provisions for salt storage, handling and application, and prohibition of phosphorus fertilizers on turf.

The Kane County ordinance which is described in the Appendix should serve as an example of updates that should be made to all county and municipal ordinances in the watershed

Attachments

1. CMAP Checklist for Stormwater Ordinances

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Attachment 1:

CMAP Checklist for Stormwater Ordinances

Tables 1 - 11

Table 1: Stormwater drainage and detention			Yes / No	Code section	Current KCSMO standard (as relevant)	Recommended standard or action	References
1	Purpose	Include control of runoff rate, volumes, and quality in the purpose statement?	Yes	KCSMO Article 1, Sec. 102.	Protect the public from the degradation of water quality on a watershed basis; preserve and enhance the natural hydrologic and hydraulic functions and natural characteristics of watercourses and floodplains to protect water quality, aquatic habitats, reduce flood damage, reduce soil erosion; require appropriate and adequate provision for site runoff control, especially when the land is developed with a large amount of impervious surface; encourage the use of stormwater storage and infiltration of stormwater in preference to stormwater conveyance; protected and improve surface water quality and protecting the beneficial uses of ponds, lakes, wetlands, rivers and streams by reducing point source and non-point source discharges of pollutants; require control of stormwater quantity and quality at the most site-specific or local level and preventing unauthorized or unmitigated discharge of flow offsite.		
2	Minimize quantity of stormwater runoff	Encourage the use of permeable paving, greenroofs, and similar practices that reduce the quantity of runoff that must be handled with innovative or conventional drainage practices?	Mostly addressed	KCSMO Article 2, Sec. 200 e5	Sites meeting established criteria are eligible to receive credit for BMP-in-lieu of site runoff storage requirements with permeable pavements and rain gardens and rain garden-infiltration trench systems.	Add language about additional best management practices, such as greenroofs and other techniques that reduce the quantity of runoff, and indicate that such practices may allow for an approved reduction in the size of the required conveyance and detention facilities.	Village of Lakewood's Best Management Practices for R-2 Zoning, BMP hierarchy
3	Natural drainage practices	Encourage and/or require the use of natural drainage practices (e.g., swales, filter strips, bio-infiltration devices, and natural depressions over storm sewers)	Mostly addressed	KCSMO Article 2, Sec. 201.(f) & (g)	The design of any development shall incorporate the following specific planning principles: impervious surfaces are the minimum necessary to satisfy the intended design function; where feasible, allow sufficient right-of-way and easement widths so that stormwater runoff may be conveyed in vegetated swales; existing open channels have been preserved and incorporated into the design; best management practices have been used in the site drainage plan; retention and infiltration of stormwater onsite have been enhanced to the extent practicable to reduce the volume of stormwater runoff and the quantity of runoff pollutants. The function of existing onsite depressional storage shall be preserved as an additional volume to required site runoff storage.	Consider creating a hierarchy of treatment methods and requiring the use of vegetated filter strips and swales.	NIPC Model Stormwater Drainage and Detention Ordinance, Sections 500.0 and 711
4						Encourage or require the use of natural drainage systems in place of storm sewers in subdivisions where the average distances between driveways is more than 50 feet and there are diminished on-street parking needs. Where curb and gutter is required, flat or "ribbon" curbs or curb cuts may be used to allow use of naturalized drainage systems and streetside bioswales.	Campton Hills Zoning Code Analysis and Ordinance Language Recommendations
5							
6	Detention design	Require detention design standards that maximize water quality mitigation benefits, with a requirement for “naturalized” wet bottom and/or wetland basins over dry basins?	Mostly addressed	KCSMO Sec. 203(g) and 203(h)	Site runoff storage requirements allow the facility to be designed for evapotranspiration and infiltration of this volume into a subsurface drainage system and shall not be conveyed through a direct connection to downstream areas. Native wetland plantings shall be introduced. Storage facilities shall minimize impacts of stormwater runoff on water quality by incorporating best management practices. No preference for wet basins over dry basins is identified.	Designers shall give preference to wet bottom and wetland designs. Requests to allow detention basins with vertical retaining walls generally should be discouraged (unless there are no practical alternatives) because such designs can eliminate important pollutant removal functions of wetland edges that are preferred on the periphery of detention basins. Design of wetland-type detention basins can sometimes lead to growth of nuisance cattail populations. While cattails provide a beneficial water quality function, large/dense stands can be problematic to maintain via controlled burning in urban/suburban locations because of the intense heat generated. To minimize this problem, it is recommended that wetland basins be constructed with water depths of 2 feet or more in the interior of the basin to limit growth of cattails and associated emergent wetland plants to the periphery of the basin.	NIPC Model Stormwater Drainage and Detention Ordinance, Sections 600, 705, and 706, provide design guidelines
7	Detention credits	Provide detention credit for practices, such as permeable paving or bio-infiltration, that provide temporary storage of runoff in the sub-surface void spaces of stone or gravel?	Yes	KCSMO Article 2, Sec. 200 e5	Sites meeting established criteria are eligible to receive credit for BMP-in-lieu of site runoff storage requirements with permeable pavements and rain gardens and rain garden-infiltration trench systems.		
8	Peak discharge	Require that peak post-development discharge from events less than or equal to the two-year, 24-hour event be limited to 0.04 cfs per acre of watershed?	Yes	KCSMO Sec. 203 (b)	Absent any applicable watershed plan or interim watershed plan, sufficient storage shall be provided such that the probability of the post-development release rate exceeding 0.1 cfs/acre of development shall be less than 1% per year and the probability of the post-development release rate exceeding 0.04 cfs/acre of development shall be less than fifty percent (50%) per year. Design runoff volumes shall be calculated using event hydrograph methods. The administrator may specify more restrictive release rates when downstream conditions warrant.		
9	Water quality performance standards	Require conformance to numerical water quality performance standards (such as percent removal of sediment or phosphorus)?	No		N/A	Consider requiring conformance to numerical water quality performance standards (such as percent removal of sediment or phosphorus).	New practice being used elsewhere in the country.

10	Floodway restrictions	Prohibit detention in the floodway?	No	KCSMO Article 2, Sec. 203. (i) and (j)	Storage facilities located within the regulatory floodway shall (a) comply with Article 4 [Protection of special management areas]; and (b) store the required amount of site runoff to meet the release rate requirement under all streamflow and backwater conditions up to the ten-year flood elevation on the adjacent receiving watercourse. The Administrator may approve designs which can be shown by detailed hydrologic and hydraulic analysis to provide a net watershed benefit not otherwise realized by strict application of the requirements set forth in (a) and (b) of this subsection. Storage facilities located within the regulatory floodway shall (a) meet the requirements for locating storage facilities in the regulatory floodplain; (b) be evaluated by performing hydrologic and hydraulic analysis consistent with the standards and requirements for watershed plans; and (c) provide a net watershed benefit.	Consider updating to include the environmental criteria listed in NIPC Model Stormwater Drainage and Detention Ordinance Section 708.3	NIPC Model Stormwater Drainage and Detention Ordinance Section 708.3
11	On-stream detention restrictions	Prohibit on-stream detention, unless it provides a regional stormwater storage benefit (e.g., for upstream properties and/or multiple sites) and is accompanied by other upstream water quality BMPs, such as bio-infiltration?	Yes	KCSMO Article 2, Sec. 203.(m)	Structures built across the channel to impound water to meet site runoff storage requirements shall be prohibited on any perennial stream unless part of a public flood control project with a net watershed benefit.		NIPC Model Stormwater Drainage and Detention Ordinance Section 708.3
12	Stormwater discharge	Prohibit the direct discharge of undetained stormwater into wetlands?	Mostly addressed	KCSMO Article 2, Sec. 201.(f) and Article 4, Sec. 418 h.	The design of any development shall incorporate the following specific planning principles: existing high quality wetlands have been avoided, preserved or enhanced. Undetained stormwater which has not passed through a site runoff storage facility shall discharge through an area or structure meeting the definition of best management practices or buffer before entering a jurisdictional Waters of the U.S. or wetland.	Wetlands and other depressional storage areas shall be protected from damaging modifications and adverse changes in runoff quality and quantity associated with land development. NIPC Model Stormwater Drainage and Detention Ordinance, Section 709.4 outlines that all runoff from the development shall be routed through a preliminary detention/sedimentation basin designed to capture the two-year, 24-hour event with the release rate of 0.04 cfs per acre which should provide a holding time of at least 24 hours, before being discharged to the wetland.	NIPC Model Stormwater Drainage and Detention Ordinance, Section 709.4
13	Maintenance	Require formal maintenance plans and contracts for the long-term maintenance and vegetative management of all new detention facilities?	Mostly addressed	KCSMO Article 6, Sec. 600	Except for those portions of the stormwater drainage system dedicated to the permitting authority or other public entity, stormwater permit applications shall include a plan for the long term management, operation, and maintenance of the stormwater drainage system and special management areas and a description of the sources of funding therefor. Criteria for the maintenance plan are not specified.	Consider updating to require the maintenance plan to include performance standards for all natural open space areas and naturalized stormwater management facilities and buffers. The performance standards shall identify proposed methods for establishing the areas and shall require monitoring and maintenance for at least three full growing seasons following initial enhancement, restoration, and planting, or until initial performance standards have been met. The standards are intended to address the establishment of native vegetation cover and control of invasive plant species. The maintenance plan should be included in the requirements for site plan submittal.	Performance criteria outlined in the stewardship plan section (A1118) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures. NIPC Model Stormwater Drainage and Detention Ordinance, Sections 713 and 1100
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Table 2: Soil Erosion and Sediment Control			Yes / No	Code section	Current standard	Recommended standard or action	References
1	Purpose (Limiting sediment delivery)	Include a comprehensive purpose statement which limits sediment delivery, as close as practicable, to pre-disturbance levels and minimizes effects on water quality, flooding, and nuisances?	No	KCSMO Article 1, Sec. 102.	Controlling sediment and erosion in and from stormwater facilities, developments, agricultural fields, and construction sites and reducing and repairing streambank erosion.	Add that the delivery of sediment from sites affected by land disturbing activities should be limited, as closely as practicable, to that which would have occurred if the land had been left in its natural undisturbed state.	NIPC Model Soil Erosion and Sediment Control Ordinance, Section 100
2	Minimize sediment transport	Include a comprehensive set of principles that minimize sediment transport from the site for all storms up to the ten-year frequency event? (These principles should include provisions to minimize the area disturbed and the time of disturbance; follow natural contours; avoid sensitive areas; require that sediment control measures be in place as part of land development process before significant grading or disturbance is allowed; and require the early implementation of soil stabilization measures on disturbed areas.)	Yes	KCSWO Article 3, Sec. 300 a	Erosion and sediment control planning shall be part of the initial site planning process; the applicant shall consider the sensitivity of existing soils to erosion and topographical features such as steep slopes, stream corridors, and special management areas which must be protected to reduce the amount of erosion and sediment which occurs. In the planning process the applicant shall also address the following: for phased projects, if existing land cover lacks vegetation, then these phases shall be planted temporarily to reduce erosion; and preference shall be given to reducing erosion rather than controlling sediment.		
3	Ordinance applicability - size	Require ordinance applicability for any land disturbing activity in excess of 5,000 square feet?	Yes	KCSWO Article 5, Sec. 500 a4	A stormwater management permit is required if the development disturbs more than 5,000 sq. ft. of ground or 250 cubic yards of soil.		
4	Ordinance applicability - location	Require ordinance applicability for any land disturbing activity in excess of 500 square feet if adjacent to stream, lake, or wetland?	Mostly addressed	KCSWO Article 5, Sec. 500 a1-3	A stormwater management permit is required if the development is located in the regulatory floodplain; a substantial improvement is to be located in the regulatory floodplain; or there is any regulatory floodplain within the site.	Consider updating to include land disturbing activity that will affect an area in excess of 500 square feet if the activity is within 25 feet of a lake, pond, stream, or wetland.	NIPC Model Soil Erosion and Sediment Control Ordinance, Section 400
5	Site design - requirements	Include explicit site design requirements for sediment control measures, conveyance channels, soil stabilization, construction adjacent to water bodies, construction entrances, etc.?	Yes	KCSWO Article 3, Sec. 300	Includes specific site design requirements for sediment control measures, conveyance channels, soil stabilization, construction adjacent to water bodies, construction entrances, etc.		
6	Site design - references	Adopt by reference the "Illinois Urban Manual" published by the Natural Resources Conservation Service and the Illinois Environmental Protection Agency (1995, updated 2010) and the "Illinois Procedures and Standards for Urban Soil Erosion and Sedimentation Control" published in 1988 (the Greenbook)?	Yes	KCSWO Article 3, Sec. 300 b	Current standard references the *Illinois Urban Manual and Procedures and Standards for Urban Soil Erosion and Sedimentation Control in Illinois* .		

7	Maintenance	Require routine maintenance of all erosion and sediment control practices?	Yes	KCSWO Article 3, Sec. 300 [Erosion and sediment control]	A maintenance schedule of each measure used shall be indicated on the plan. As a minimum, all erosion and sediment control measures onsite shall be inspected weekly or after a one-half inch or greater rainfall event and any required repairs shall be made to keep these measures functional as designed.		
8	Inspection	Require inspection by appropriately trained personnel of construction sites at critical points in the development process to ensure that measures are being correctly installed and maintained?	Mostly addressed	KCSWO Article 3, Sec. 300 and Article 7, Sec. 701	A maintenance schedule of each measure used shall be indicated on the plan. As a minimum, all erosion and sediment control measures onsite shall be inspected weekly or after a one-half inch or greater rainfall event and any required repairs shall be made to keep these measures functional as designed.	Consider adding language on how inspections will be scheduled for phased projects and specifically require inspections at critical stages of the construction process.	NIPC Model Soil Erosion and Sediment Control Ordinance, Section 506
9	Enforcement	Provide effective enforcement mechanisms including performance bonds, stop-work orders, and penalties, as appropriate?	Yes	KCSMO Article 7, Sec. 702 and Sec. 703 and Article 12, Sec. 1202	If a person is found guilty of an offense under this ordinance, the administrator may impose a civil fine, revoke any stormwater management permit, issue an order requiring the suspension of any further work on the site, require the area impacted be fully restored to its existing condition prior to such development, and/or require the person apply after the fact for the appropriate permit for an unpermitted development. The administrator may bring any action, legal or equitable, including an action for injunctive relief, as they deem necessary. Erosion and sediment control plans are required to include a letter of credit in an amount equal to 110% of the approved estimated probable cost to install and maintain the required erosion and sediment control measures.		

Table 3: Floodplain Management			Yes / No	Code section		Recommended standard or action	References
1	Purpose	Include protection of hydrologic functions, water quality, aquatic habitat, recreation, and aesthetics in the purposes for the ordinance?	Yes	KCSMO Article 1, Sec. 102. [Purposes of this ordinance]	Preserving and enhancing the natural hydrologic and hydraulic functions and natural characteristics of watercourses and floodplains to protect water quality, aquatic habitats, reduce flood damage, reduce soil erosion, provide recreational and aesthetic benefits and enhance community and economic development.		
2	Floodway restrictions - use	Restrict modifications in the floodway to the following appropriate uses: public flood control projects, public recreation and open space uses, water dependent activities, and crossing roadways and bridges?	No	KCSMO Article 4, Sec. 411 a	Allows public flood control structures and private improvements relating to the control of drainage and flooding; modifications and improvements to existing wastewater treatment plants and facilities (not including new wastewater treatment plants or habitable structures at existing wastewater treatment plants); storm and sanitary sewer outfalls; recreational facilities and improvements relating to recreational boating; detached garages, storage sheds, boat houses or other non-habitable structures without sanitary facilities; bridges, culverts and associated roadways, sidewalks and railway; parking lots built at or below existing grade; floodproofing activities; repair, replacement, an deconstruction of a damaged building, and modifications to an existing building.	Consider updating to the alternative language presented in NIPC Model Floodplain Ordinance, Section 802.1, which is more restrictive than the appropriate uses allowed by State rules. In particular, uses such as pumping and treatment facilities, garages and sheds, roadways running longitudinally along a watercourse, and parking lots are not considered appropriate because of concerns that they will increase flood damages, interfere with natural functions of floodways, and/or impair water quality and habitat.	NIPC Model Floodplain Ordinance, Section 802.1
3							
4	Floodway restrictions - erosion	Require effective soil erosion and sediment control measures for ALL disturbances in the floodway?	Yes	KCSWO Article 5, Sec. 500 a1-3 and Sec 504 a	A stormwater management permit is required if the development is located in the regulatory floodplain; a substantial improvement is to be located in the regulatory floodplain; or there is any regulatory floodplain within the site. All stormwater permit applications shall include a sediment and erosion control plan.		
5	Stream channel modification	Discourage stream channel modification and require mitigation of unavoidable adverse water quality and aquatic habitat impacts? (This would be done in cooperation with the Army Corps of Engineers for federally jurisdictional waterways.)	Mostly addressed	KCSMO Article 2, Sec. 201, Article 4, Sec. 405, and Article 5, Sec. 507	The design of any development shall incorporate the following specific planning principle: existing open channels have been preserved and incorporated into the design. General performance standards require that for all projects involving a channel modification, fill, stream maintenance or a levee, the flood conveyance and storage capacity of the regulatory floodplain shall not be reduced. For permit applications, involving stream modifications, the following shall be submitted: (a) a plan and profile of the existing and proposed channel; and (b) supporting calculations for channel width, depth, sinuosity, riffle locations and the like.	Consider updating so that for proposed channel modification, the applicant shall submit the following information: (i) a discussion of the purpose of and need for the proposed work; (ii) a discussion of the feasibility of using alternative locations or methods to accomplish the purpose of the proposed work; (iii) an analysis of the extent and permanence of the impacts each feasible alternative would have on the physical and biological conditions of the body of water affected; (iv) an analysis of the impacts of the proposed project, considering cumulative effects on the physical and biological conditions of the body of water affected. Designated floodway regrading, without fill, to create a positive non-erosive slope toward a watercourse.	NIPC Model Floodplain Ordinance, Sections 801.1.q and 802.1.i

Table 4: Stream and Wetland Protection			Yes / No	Code section	Current standard	Recommended standard or action	References
1	Purpose	Include a comprehensive purpose statement which addresses the protection of hydrologic and hydraulic, water quality, habitat, aesthetic, and social and economic values and functions of wetlands?	Mostly addressed	KCSMO Article 1, Sec. 102.	Protecting and improving surface water quality and promoting beneficial uses of ponds, lakes, wetlands, rivers and streams by reducing point source and non-point source discharges of pollutants; and protecting the quantity and quality of wetlands.	Consider updating to include the ten objectives in the NIPC Model Stream and Wetland Protection Ordinance, Section 3.00	NIPC Model Stream and Wetland Protection Ordinance, Section 3.00
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3	Protection	Protect the beneficial functions of streams, lakes, and wetlands from damaging modifications, including filling, draining, excavating, damming, impoundment, and vegetation removal?	No	KCSMO Article 15, Sec. 1501 and 1503.	Wetlands identified as having an FQI greater than or equal to 25 shall not be filled or dredged as part of any development. Activities are subject to mitigation requirements with performance standards and monitoring.	Establish a minimum setback of development activity from streams, lakes, ponds, and wetlands. Development activities will only be approved based upon a report, prepared by a qualified professional, which demonstrates that they will not adversely affect water quality; destroy, damage or disrupt significant habitat area; adversely affect drainage and/or stormwater retention capabilities; adversely affect flood conveyance and storage; lead to unstable earth conditions, etc.	NIPC Model Stream and Wetland Protection Ordinance, Sections 6.03, with the definition of development outlined in Section 4.00.h.

4	Modification	Prohibit the modification of high quality, irreplaceable wetlands, lakes, and stream corridors?	Mostly addressed	KCSMO Article 2, Sec. 201 f5 and Article 15, Sec. 1501.	The design of any development shall incorporate the following specific planning principles: existing high-quality wetlands have been avoided, preserved or enhanced. Wetlands identified as having an FQI greater than or equal to 25 shall not be filled or dredged as part of any development.	Expand development design prinicples to also include avoiding, perserving, and/or enhancing high-quality lakes and streams. Prohibit modifications unless no feasible alternatives exist and all applicable regulatory approvals or clearances are granted.	
5	Wetland Modification - stormwater	Discourage the modification of wetlands for stormwater management purposes unless the wetland is severely degraded and nonpoint source BMPs are implemented on the adjacent development?	No	KCSMO Article 15, Sec. 1503 b	Wetland impacts upon wetlands with an FQI of less than 7 shall be mitigated at a ratio of 1:1. The applicant may request permission to mitigate within the site runoff storage facility area. The applicant may earn wetland credits by enhancing preserved wetlands with an FQI of 5 or less at the ratio of one-quarter wetland credit per acre of wetland enhanced. If this option is chosen the entire wetland shall be enhanced even if credit in excess of that required for the development is generated.	Consider updating to state that modification of degraded wetlands for purposes of stormwater management is permitted where the quality of the wetland is improved (e.g. via removal of invasive plant species) and total wetland acreage is preserved.	NIPC Model Stream and Wetland Protection Ordinance, Section 6.03
6	Setback	Designate a minimum 75 to 100 foot setback zone from the edge of identified wetlands and water bodies in which development is limited to the following types of activities: minor improvements like walkways and signs, maintenance of highways and utilities, and park and recreational area development?	No	KCSMO Article 4	N/A	Update to state that absolutely no development activity (except as provided) may occur within the minimum setback which is defined as at least 75 to 100 feet from the ordinary high water mark of streams, lakes, and ponds, or the edge of wetlands, or within a designated depressional area.	NIPC Model Stream and Wetland Protection Ordinance, Section 6.03
7	Buffer	Establish a minimum 25-foot wide protected native vegetation buffer strip along the edge of identified wetlands and water bodies?	Mostly addressed	KCSMO Article 4, Sec. 418	Buffers shall be identified on development plans for all areas defined as Waters of the U.S. Buffer areas are divided into two types, linear buffers and waterbody buffers. The required buffer width ranges from 15 to 50 ft., depending on factors such as resource quality. Buffers shall be replanted or reseeded using appropriate predominately native deep-rooted vegetation, appropriately managed and maintained.	Update to require a natural vegetation strip to extend landward a minimum of 25 feet from the ordinary highwater mark of a perennial or intermittent stream, lake, or pond and the edge of a wetland regardless of size or quality.	NIPC Model Stream and Wetland Protection Ordinance, Section 6.08
8							
9	Relocation	Prohibit watercourse relocation or modification except to remedy existing erosion problems, restore natural habitat conditions, or to accommodate necessary utility crossings; and require mitigation of unavoidable adverse water quality and aquatic habitat impacts?	No	KCSMO Article 4, Sec. 405 b and Article 5, Sec. 507 b4	For all projects involving a channel modification, fill, stream maintenance or a levee, the flood conveyance and storage capacity of the regulatory floodplain shall not be reduced. For all stream modifications, the following shall be submitted: a plan and profile of the existing and proposed channel; and supporting calculations for channel width, depth, sinuosity, riffle locations and the like.	Prohibit watercourse relocation or modification except where certain problems can be mitigated by relocation and/or minor modification, including improvements to water quality, habitat, and other natural functions and to remedy erosion and flooding problems and unstable soil and geologic conditions. Modification and relocation plan must address specific environmental criteria.	NIPC Model Stream and Wetland Protection Ordinance, Sections 7.00, 7.01, and 7.02
10	Restoration	Encourage the restoration of stream and wetland habitat, hydrology, and morphology on development sites that contain degraded aquatic systems? (This could be accomplished through a streamlined permitting process and/or other development incentives.)	No	KCSMO Article 15, Sec. 1502 a	A wetland impact created by the dredging of a wetland with an FQI of less than 7 need not be mitigated.	Update to encourage restoration of stream and wetland habitat, hydrology, and morphology on development sites that contain degraded aquatic systems. Consider combining this with a streamlined permitting process and/or other development incentive, as well as encouraging it through conservation design provisions.	Minimum performance standards for restoration, planting, maintenance, and monitoring of natural open space and naturalized stormwater facilities are included in Stewardship Plan section (A1118) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures.

Table 5: Natural Area and Open Space			**Yes / No**	**Code section**	**Current standard**	**Recommended standard or action**	**References**
1	Natural areas - protection	Protect remnant natural areas, including steep slopes, prairies, woodlands, and savannas (in addition to regulated wetlands and floodplains)?				Expand definition of natural features to include woods and savannas, wetland buffers, prairies and grasslands, slopes greater than 12%, in addition to inherently unbuildable areas like wetlands and floodplains.	
2						Create a conservation design overlay for areas that contain and/or abut sensitive natural resource areas, and that is also mandatory due to automatic and cumulative triggers based on the presence of specific features present on the site. Automatic and cumulative triggers could include woods and savannas, wetland buffers, prairies and grasslands, slopes greater than 12%, in addition to inherently unbuildable areas like wetlands and floodplains.	Applicability section (A1102) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures; Village of Algonquin Conservation Design Standards and Procedures (Zoning Sec. 21.11 J); City of Crystal Lake Conservation Developments (UDO Article 5 Section 5-300).
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4							
5	Open space - amount	Set aside onsite open space for residential development, generally conforming to the following guidelines: estate residential: 60%; moderate residential: 45%; urban residential: 30%				Using a Conservation Design District, require specific amounts of open space depending on the underlying zoning. For example, for residential conservation developments, at least 40% of the site shall be set aside as required open space. Common open space is preferable, but deed-restricted open space also is acceptable.	Bulk requirements section (A1112) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures.
6	Restoration	Encourage the restoration of protected natural areas to reduce invasive species and enhance biodiversity?				For Conservation Design Districts, update to require that development shall preserve, restore, and/or create environmentally sensitive areas and shall include plans and the means to restore, manage, and maintain such areas. Degraded remnant natural areas shall be restored to a natural state.	Stewardship plan section (A1118) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures.
7	Open space - ownership	Require the identification of an open space ownership entity, with a preference for a qualified public or				For Conservation Design Districts, require identification of the ultimate owner of the dedicated open space as well as the entity responsible for maintaining it.	Open space ownership and funding section (A1117) of the McHenry County Subdivision Ordinance on

8		private land conservation organization?				Ownership options for common open space includes qualified public or private land conservation organizations with experience in managing natural areas.	Conservation Design Standards and Procedures
9	Open space - easement	Require the dedication of natural open space via a binding conservation easement or similar binding legal instrument that ensures protection in perpetuity?				For Conservation Design Districts, require dedicated open space shall be protected in perpetuity by a binding conservation easement or similar legal instrument.	Open space ownership and funding section (A1117) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures
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11							
12	Open space - management	Require secure and permanent funding arrangements for the long-term management and maintenance of open space, natural areas, and stormwater facilities once responsibilities are turned over to a conservation entity or the homeowners/property owners association?				For standard development and Conservation Design Districts, outline specific options for secure and permanent funding arrangements for the long-term management and maintenance of open space, natural areas, and stormwater facilities once responsibilities are turned over to a homeowners/property owners association or conservation entity.	Open space ownership and funding section (A1117) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures
13	Open space - funding	Encourage the establishment of a back-up special service area (SSA) in order to provide funds necessary to support the maintenance of open space and stormwater management areas (in the event that the responsible land owner/manager does not meet the required maintenance standards)?	Mostly addressed	KCSMO Article 6, Sec. 605	Unless a public entity has accepted primary maintenance responsibility for the stormwater drainage system, the Administrator will require, as a condition of approving of any application for a stormwater management permit, the establishment of a special service area either as the primary means of providing for the long term maintenance of the facilities, or as a backup vehicle.	Identify a back-up special service area as one of the potential funding options to support the maintenance of open space areas in addition to stormwater drainage systems.	Open space ownership and funding section (A1117) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures
14	Open space - management plans	Require or encourage long-term management/stewardship plans for all common open space areas, natural areas, and stormwater facilities?				Require a stewardship plan be submitted to identify the means to properly maintain and manage dedicated open space in perpetuity.	Stewardship plan section (A1118) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures
15							
16	Open space - performance criteria	Establish measurable performance criteria for managed natural areas, including ground coverage, species diversity, and control of invasive species?				Require that the stewardship plan include performance standards for all natural open space areas and naturalized stormwater management facilities and buffers. The performance standards shall identify proposed methods for establishing the areas and shall require monitoring and maintenance for at least three full growing seasons following initial enhancement, restoration, and planting.	Minimum performance standards for restoration, planting, maintenance, and monitoring of natural open space and naturalized stormwater facilities are included in the Stewardship Plan section (A1118) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures.

Table 6: Conservation Design and Infill			Yes / No	Code section	Current standard	Recommended standard or action	References
1	Natural Resource inventory	Require a site analysis map that includes a natural resources inventory at the Concept Plan stage or prior to the Preliminary Plan stage?				Expand natural resource inventory mapping requirements to include hydrologic soil groups; highly erodible soils; steep slopes; zero-order (ephemeral) streams; farmed wetlands; springs and seeps; stream buffers; wetland buffers; forest stand, savanna, and prairie delineation; high priority groundwater recharge areas (Class III Special Resource Groundwater areas); designated natural areas; threatened and endangered species; existing drainage patterns/flow paths; and existing drainage areas to the site's perennial and ephemeral streams, ponds, and wetlands. Broaden the inventory requirements to extend to a distance of at least 200 ft. beyond the project site. Update to match tree survey requirements in new tree protection ordinance (requires the location, species, DBH, and condition of every tree with a DBH of 2 inches or larger).	Site analysis (A1104.1) requirements of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures
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3	Site Design	Require that the proposed development be designed to preserve natural drainage patterns, use and preserve native vegetation, stabilize soils during construction, and protect, enhance, and maintain natural resources (such as remnant woodlands, prairies, and steep slopes)?				The existing natural features shall be preserved and protected to the greatest extent possible from any negative impacts generated as a result of the development or other land disturbing activities. For Conservation Design Districts, areas to be preserved shall be identified on a site-specific basis in an effort to conserve and provide the best opportunities to restore and enlarge the best quality natural features of each particular site. Establish an open space protection hierarchy to guide the decision-making process of which areas are the priority areas to preserve.	Site analysis (A1104.1), general standards for design (A1108), and open space (A1114) requirements of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures; Village of Algonquin Conservation Design Standards and Procedures (Zoning Sec. 21.11 J); City of Crystal Lake Conservation Developments (UDO Article 5 Section 5-300 E2).
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7	Clearing and Grading	Restrict to on-site clearing and grading locations and extent?				On-site clearing and grading shall be restricted to avoid environmentally sensitive areas and mass grading should be avoided wherever possible.	Campton Hills Zoning Code Analysis and Ordinance Language Recommendations
8	Clustering	Encourage or require clustering of residential lots around sensitive natural areas, thereby creating a protected common open space area?				For Conservation Design Districts, require a site capacity analysis to first establish the buildable acreage. The resulting acreage shall then be multiplied by the maximum allowable dwelling units per acre for the underlying zoning district. Lots, buildings or building sites should be clustered to minimize the negative impacts on the natural, visual, and cultural resources of the site and between incompatible uses and activities.	Site capacity (A1105) and conservation design development standards (A1108.1) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures; Crystal Lake's Conservation Development District (Sec 5-300 E3, Sec 5-300 F2).
9							
10	Open space	Require a minimum area of protected naturalized open space in new residential developments?				For Conservation Design Dstricts, require at least 40% of the site shall be set aside as required open space for residential developments, and require open space for nonresidential land uses based on the site coverage ratio and any associated site coverage bonuses and a minimum of 25 percent of the gross acreage.	Bulk requirements section (A1112) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures; Crystal Lake's Conservation Development District (Sec 5-300 G1).
11	Density bonus	Provide density bonuses for conservation developments that exceed minimum standards (such as additional open space, providing for regional trails and greenways, or incorporating environmentally sensitive design features beyond what is required by the Ordinance)?				For Conservation Design Districts, allow applicants to request an increase in density if it is demonstrated that the proposed conservation design plan offers a superior layout and quality of design which incorporates environmentally sensitive design features that substantially exceed the minimum requirements of the ordinance. The maximum increase in density shall be limited to 20% of the permitted density.	Density bonuses for open space and innovative design section (A1106) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures; Crystal Lake's Conservation Development District (Sec 5-300 E4).
12	Conservation design - by right	Allow conservation design as a "by-right" form of development?				Allow conservation design as a by-right form of development by either adding conservation design to the list of permitted uses in existing zoning districts, creating a conservation design overlay district, or designating certain districts on the zoning map as conservation design districts.	NIPC Conservation Design Resource Manual; Applicability section (A1102) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures; Village of Plainfield Conservation District (Zoning 9-52).
13	Conservation design - zoning map	Does the zoning map indicate areas where conservation development is required?				After creating a Conservation Design District or Overlay District, establish areas where the standards apply on the zoning map. These areas should correspond with known green infrastructure resources, such as streams, wetlands, floodplains, groundwater recharge areas, mature tree stands, prairies, savannahs, and steep slopes.	Applicability section (A1102) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures
14	Mixed Use	Is there a mechanism to encourage mixed-use and compact development?				Encourage compact development in specific business and neighborhood centers.	
15							
16						Consider allowing non-residential uses to follow traditional development patterns, with neighborhood centers on collectors as well as arterial streets.	
17	Impact fees	Are there reduced impact fees or other incentives to encourage infill development?				Consider tailoring fees based on the location to encourage redevelopment of previously developed land that is already connected to City infrastructure.	
Table 7: Landscaping			**Yes / No**	**Code section**	**Current standard**	**Recommended standard or action**	**References**
1	Native landscaping - preclusion	Include "noxious weed" provisions that might intentionally, or unintentionally, preclude natural landscaping because of vegetation height standards or similar restrictive provisions?				Identify native plant growth, which should consist of grasses, wildflowers, shrubs, and trees that are indigenous to the greater Chicago region, as an example of a cultivated garden. Consider adding buffer provisions along property lines and updating vegetative height to encourage appropriately-scaled native landscaping on individual private lots.	*Plants of the Chicago Region* (Swink and Wilhelm, 1994); Green Landscaping: Greenacres; *A Source Book on Natural Landscaping for Public Officials* (NIPC); City of Naperville, Private naturally landscaped lots (4-3-2.6)

2	Native landscaping - common areas	Encourage/require the use of native plant materials for the default landscaping of common areas, stormwater facilities, common open space areas, and the buffers of streams, lakes, wetlands and other natural areas?				Encourage the use of native plant materials as the default landscaping of stormwater facilities and for the buffers of streams, lakes, wetlands, and other natural areas and encourage integrating native plant materials in common areas. For standard subdivisions, the City could set a minimum percent coverage using native vegetation.	Natural landscaping standards section (A1110) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Procedures
3						For Conservation Design Districts, encourage the use of native plant materials as the default landscaping of stormwater facilities and for the buffers of streams, lakes, wetlands, and other natural areas and encourage integrating native plant materials in common areas.	
4	Native landscaping - management	Require provisions for long-term oversight, management, funding, and performance criteria for common areas and natural landscapes (as referenced above in greater detail)?				For Conservation Design Districts, require that the stewardship plan include performance standards for all natural open space areas and naturalized stormwater management facilities and buffers (not individual residential lots). The performance standards shall identify proposed methods for establishing the areas and shall require monitoring and maintenance for at least three full growing seasons following initial enhancement, restoration, and planting. Long-term monitoring after initial restoration has been completed should also be required.	
5	Street landscape requirements	Require planting street trees? If yes, how many trees?				Consider locating this provision to the zoning ordinance so that it applies to all new development, not just subdivisions, in order to help establish street trees in already developed areas.	
6	Tree protection	Require protection of native/desirable trees (i.e., a tree protection ordinance)?					
7	Tree replacement	Require replacement of any trees that are unavoidably impacted by construction activities?				Tree survey should include consideration of trees that are outside of the property line but may have their Critical Root Zone extending into the subject site.	
8							
9							
10	Tree replacement - funding	Require payment into a tree replacement fund or “mitigation bank” when removed trees cannot be replaced/mitigated on site?					

Table 8: Transportation			Yes / No	Code section	Current standard	Recommended standard or action	References
1	Street network - location	Require the street network to minimize encroachment in sensitive natural resources and take advantage of open space vistas, while providing an interconnection of internal streets and street connections to adjoining land parcels to create opportunities for future connectivity?				To the greatest extent possible, new roadways shall respect natural contours and ridgelines to minimize grading. The street layout should minimize encroachment onto sensitive natural resources such as wetlands, designated natural areas, woodlands, significant tree stands, and wildlife habitats, and should be designed to take advantage of open space vistas.	Blackberry Creek Zoning Code Analysis and Ordinance Language Recommendations
2	Street network - stream crossings	Limit stream crossings by the street network?				Stream crossings shall be limited to the minimum necessary to provide safe circulation and ensure two ingress/egress locations. Stream crossings shall be located to minimize stream disturbance. Bridges or culverts of sufficient size shall be used for all perennial stream crossings to preserve stream channel width and natural stream substrates.	Campton Hills Zoning Code Analysis and Ordinance Language Recommendations
3	Street connectivity - internal	Require subdivisions to achieve a certain score on an index for internal street connectivity?				Consider establishing a maximum block length of 800 feet and a preferred length of 300 feet to 600 feet for residential subdivisions.	Park Forest Sustainability Audit of Zoning and Subdivision Codes
4	Street connectivity - external	Require connections to surrounding areas?				Consider incluing a connectivity measurement to ensure future connections at regular intervals that promote walkability. For example, the standard of one through-street intersecting or terminating at the project boundary at least every 800 feet could be established, with exceptions for natural resources, open spaces, existing buildings, and other physical obstructions.	LEED for Neighborhood Development Walkable Streets Prerequisite.
5	Street - widths	Encourage narrower street widths to reduce the amount of impervious surface?				Design streets for the minimum required pavement width needed to support travel lanes, on-street parking, and emergency access. These widths should be based on desired travel speeds as well as traffic volumes.	Model language in Conservation Design Resource Manual, NIPC and Chicago Wilderness; CWP BSD page 29; ITE Designing Walkable Urban Thoroughfares: A Context Sensitive Approach; CNU Emergency Response & Street Design; Village of Plainfield Traditional Neighborhood District (Zoning Sec. 9-54); City of Crystal Lake Street Standards for Conservation Design (UDO Article 4 Section 4-100 E).
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8							
9	Street - length	Encourage reduced or flexible lot widths to reduce imperviousness and street length?				Reduce lot widths to limit the total length of the street network in the community and overall site imperviousness.	Village of Plainfield Traditional Neighborhood District (Zoning Sec. 9-54).
10	Cul-de-sacs	Discourage cul-de-sacs and limit their size?				Cul-de-sac streets shall be limited to a maximum of 15% of total road footage in a residential development, maximum of 10% in a non-residential or mixed-use development with exemptions for natural resource protection or other barriers. Reduce the impervious cover by reducing the radius of the turnaround bulb, with a minimum radius allowed of less than 35 feet, maximum of 45 feet. Allow landscaped island in center of cul-de-sac to store and treat stormwater runoff. Allow other turnaround options such as T-shaped turnarounds or loop roads. Clarify discrepancy in ordinance.	Center for Watershed Protection Better Site Design
11							
12							
13	Curb and gutter requirements	Encourage or require the use of natural drainage practices wherever practical?					
14							
15	Paving materials - streets	Promote use of pervious materials for paved areas, including alleys and streets?				Encourage permeable surfacing materials (e.g., interlocking concrete pavers, porous concrete, or porous asphalt) in all such vehicle use areas except for vehicle service stations, gas stations, and other areas used for transfer or storage of hazardous materials.	Center for Watershed Protection Better Site Design
16							

Table 9: Parking			Yes / No	Code section	Current standard	Recommended standard or action	References
1	Purpose	Does the purpose include a statement about tailoring parking requirements to meet average day-to-day demand as opposed to peak demand?				Establish off-street vehicle and bicycle parking requirements that balance the City's goal to encourage walking, bicycling, and transit use with the goal to provide adequate off-street parking to meet the needs of shoppers, visitors, and residents and reduce on-street parking demand on nearby residential streets. Parking requirements are designed to accommodate average day-to-day demand, as opposed to peak demand, in order to reduce excessive off-street parking and free up land for other uses.	
2	Applicability	Apply off-street parking requirements only to parcels of a certain size or greater?				Create an exemption for small lots regardless of use to ensure economically productive use of small parcels.	The Village of Riverside: no off-street parking spaces are required for non-residential uses until the gross floor area is above 3,000 square feet. The City of Evanston allows buildings between 2,000 to 3,000 square feet in specific districts to be exempt from off-street parking requirements.
3	Requirements	Establish parking requirements as a maximum or a minimum?				In addition to the minimum requirements, establish a maximum threshold (for example, 10% over the requirement) to prevent projects from including too much off-street parking. Require that all parking provided in excess of the maximum shall be designed and maintained as permeable paving.	Center for Watershed Protection Better Site Design; Campton Hills Zoning Code Analysis and Ordinance Language Recommendations
4	Parking ratio - office	Require a parking ratio for a professional office building that is 3 spaces, or less, per 1,000 square feet?				Consider model standards that require a minimum of 2 or 3 spaces per 1,000 feet of GFA. Could be tied to providing or supporting alternatives to driving. For example, bicycle parking or carpool programs.	NW Connecticut Model Zoning Regulations for Parking; State of Oregon's Model Development Code and User's Guide for Small Cities
5	Parking ratio - retail	Require a parking ratio for retail that is 3 spaces, or less, per 1,000 square feet?	No			Consider model standards that require a minimum of 2 spaces per 1,000 sq. ft. of GFA for Big Box or Large Scale Retail, 1 space per 1,000 sq. ft. of GFA for Free Standing Retail, and 3 spaces per 1,000 sq. ft. of GFA for small shopping centers.	NW Connecticut Model Zoning Regulations for Parking; State of Oregon's Model Development Code and User's Guide for Small Cities
6	Parking ratio - residential	Require a parking ratio for a single family home that is 2 spaces, or less?				1 space per studio and 1-bedroom units, 1.5 spaces per 2-bedroom units, and 2 spaces per 3-bedroom or larger units.	NW Connecticut Model Zoning Regulations for Parking; State of Oregon's Model Development Code and User's Guide for Small Cities
7	Requirements - flexibility	Allow a reduction in the number of current parking spaces?				Provide flexibility to reduce parking spaces if it can be demonstrated that the original provision of parking was in excess of the day-to-day demand for parking. Simplify process by allowing this to be an administrative decision instead of requiring a variance.	
8							

9							
10	Shared parking	Provide flexibility regarding alternative, reduced parking requirements (e.g., shared parking, off-site parking) and discourage over-parking of developments?				Consider adding an option that allows sharing for uses that do have parking demand overlap. For example, allow up to 30% of the parking spaces required for the predominant use on a site may be shared with other uses operating during the same time of day and days of the week.	NW Connecticut Model Zoning Regulations for Parking; Village of Plainfield Shared parking (Zoning Sec. 9-74).
11	Requirements - location	Provide for uses in downtown areas by reducing or not requiring parking given the walkable, transit served location?					
12	Credits - on-street parking	Allow a reduction in off street parking requirements when nearby on street parking is available?				For all business and industrial zoning districts, allow off-street parking credit for existing on-street parking space located either directly adjacent to the property line or within a certain number of feet from the property on the same side of the street.	State of Oregon's Model Development Code and User's Guide for Small Cities
13	Credits - bicycle parking	Allow a reduction in off street parking requirements when bicycle parking is provided?				Consider allowing the amount of motor vehicle parking spaces be reduced by one space for every 8 bicycle parking spaces.	Campton Hills Zoning Code Analysis and Ordinance Language Recommendations
14	Size - Parking stall	Require parking stalls to be less than or equal to 9 x 18 feet? Allow for reduction in parking stall size to account for vehicle overhang onto landscaped islands or perimeter landscaping? (e.g., such flexibility might allow for an 18-foot deep stall to be reduced to 16 or 16.5 feet deep.)				Establish standard parking stall size as follows: Regular, 90-degree space: 9 ft. by 18 ft.; On-street: 8 ft. by 23 ft.; Compact space: 7.5 ft. by 15 ft. Up to two feet of the required vehicle parking space depth used for a vehicle overhang may be improved and maintained as a landscaped island or perimeter landscaping.	Center for Watershed Protection Better Site Design, State of Oregon's Model Development Code and User's Guide for Small Cities
15	Size - Compact stalls	Specify that a percentage of all parking stalls can be dedicated for compact cars, with correspondingly smaller stall dimensions?				Consider specifying a minimum percentage of all required vehicle parking spaces, excluding accessible spaces, that shall be sized for compact cars (e.g., 15-35%).	Center for Watershed Protection Better Site Design, State of Oregon's Model Development Code and User's Guide for Small Cities
16	Size - Parking aisles	Establish narrower aisle widths to minimize impervious surfaces?				Encourage one-way aisles with angled parking to significantly reduce the overall size of the parking lots. Specify maximum aisle widths for one-way and two-way aisles. Suggested maximum aisle widths: 0 degree (parallel): one-way: 12 ft.; two-way: 22 ft. 30 degree: one-way: 12 ft.; two-way: 22 ft. 45 degree: one-way: 12 ft.; two-way: 22 ft. 60 degree: one-way: 18 ft.; two-way: 22 ft. 90 degree: one-way: 24 ft.; two-way: 22 ft.	Blackberry Creek Zoning Code Analysis and Ordinance Language Recommendations; Model Zoning Regulations for Parking for Northwestern Connecticut
17	Driveways - Commercial	Encourage/require reduced commercial driveway widths?				Consider establishing a maximum width to prevent large commercial driveways.	
18	Driveways - Residential	Encourage/require reduced residential driveway widths?				Design residential driveways for the minimum required pavement to access a garage, 9 feet or less for one lane or 18 feet for two lanes for multi-family developments.	Center for Watershed Protection Better Site Design
19		Encourage reduced front setbacks to limit the length (and amount of impervious surface) associated with a driveway?				Identify opportunities to reduce front setbacks to limit the amount of impervious surface associated with a driveway;	
20	Driveways - Shared	Encourage/require shared driveways and two-track driveways for single-family developments?				Shared or common drives shall be permitted and shall comply with the following standards, provided there is a recorded covenant applicable to the properties utilizing such drive which establishes standards for its maintenance and use. A common drive may serve multiple units and may be built to serve residential or non-residential uses. A common drive shall extend from a public or private street and may connect to other existing or planned public or private streets. A maintenance agreement running with the land for the shared driveway must be executed by all units served and recorded with the County Recorder's office.	Center for Watershed Protection Better Site Design, Street and trail standards section (A1108.1 H) of the McHenry County Subdivision Ordinance on Conservation Design Standards and Practices; NIPC Conservation Design Resource Manual, Common Drives model ordinance. Crystal Lake Conservation Design Districts (Sec 4-100 E4b)
21	Alleys	Encourage alleys to reduce impervious surfaces generated by driveways?				Alleys should be permitted as an alternative to individual driveways.	Center for Watershed Protection Better Site Design
22	Paving materials	Promote use of pervious materials for paved areas, including driveways and parking lots?				Encourage the use of pervious materials over conventional pavement for parking spaces, as well as parking aisles for all areas, provided that the grades, subsoils, drainage characteristics, and groundwater conditions are suitable. Encourage the use of "cool" pavement -- with a solar reflectance index (SRI) of at least 29 -- to reduce the urban heat island effect.	Center for Watershed Protection Better Site Design; LEED for Neighborhood Development Heat Island Reduction Credit.
23	Landscaping - amount	Specify a minimum percentage or amount of pervious landscaping for parking lots?				Define purpose of landscaped islands to include minimizing impervious surface area, maximizing the opportunity to infiltrate and filter stormwater runoff from the lot, reducing heat island effect, and making parking areas more pleasant and comfortable. Require a landscaped island for every 10 spaces and a minimum amount of tree canopy coverage (using a minimum percentage or ratio per	City of Crystal Lake: Site Landscaping (UDO Article 4 Section 4-400 F1 and F2) and Standards for Parking Areas in Conservation Developments (UDO Article 4 Section 4-200 E5); Village of West Dundee Parking Lot Design and Maintenance Standards (Zoning 10.9.1.6.C)
24							
25	Landscaping - design	Encourage/require the use of recessed landscape	No	Zoning 19.45.190	For off street parking facilities, surface water shall be discharged into an	Encourage or require that parking lot runoff shall be routed to internal and/or	Parking lot standards section (A1111.1) of the McHenry

26		islands (vs. raised islands) to facilitate the infiltration and filtering of parking lot runoff?			adequate storm sewer system, or alternate drainage system if storm sewer is not available. The city engineer may require that the facilities be designed with on site stormwater detention capabilities where the existing storm sewer system has insufficient capacity.	peripheral swales and bio-swales. Update to allow a determination of whether curbing is necessary. If deemed necessary, allow frequent curb cuts to allow stormwater runoff to enter stormwater BMPs (bioretention facilities, dry swales, bioswales, perimeter sand filters, filter strips).	County Subdivision Ordinance on Conservation Design Standards and Practices.

Table 10: Water Efficiency and Conservation			Yes / No	Code section	Current standard	Recommended standard or action	Reference
1	Water conservation - indoor	Encourage/require plumbing fixtures and fittings in all new and remodeled construction to not exceed specific flow rates and be labeled a WaterSense product if available? Encourage/require dishwashers and clothes washers in all new and remodeled construction to comply with US EPA Energy Star Program requirements?				Require new and remodeled construction to use the most current, water efficient plumbing fixtures, fittings, and appliances (i.e., WaterSense and US EPA Energy Star Program products). Tailor requirements for residential, commercial, industrial, and institutional uses.	CMAP Model Water Use Conservation Ordinance, 1.0, 2.0, 3.0, 8.0, 9.0, 10.0, 11.0, 12.0, and 13.0.
2	Outdoor - landscape design	Set guidelines for the amount of development area dedicated to turf, high water use plants, or water features; and the minimum amount of topsoil for turf areas?				Minimize the amount of turf area, require a minimum of 6 inches of topsoil depth for areas planted with turf grass, and encourage the use of native or low water use plants. Tailor requirements for residential, commercial, industrial, and institutional uses.	CMAP Model Water Use Conservation Ordinance, 4.0., 14.0
3	Outdoor - irrigation equipment	Set requirements for automatic landscape irrigation systems?				Set requirements on landscape irrigation equipment (such as requiring rain and moisture sensing devices and freeze gauges) and prohibit watering of impervious surfaces. Tailor requirements for residential, commercial, industrial, and institutional uses.	CMAP Model Water Use Conservation Ordinance, 5.0., 15.0
4	Outdoor - irrigation schedule	Set requirements for landscape watering days and schedules?				Set everyday requirements for landscape irrigation days and schedules, establish irrigation permit system for new landscape watering. Tailor requirements for residential, commercial, industrial, and institutional uses.	Northwest Water Planning Alliance's Regional Water Conservation Lawn Watering Ordinance; CMAP Model Water Use Conservation Ordinance, 5.0., 6.0, 7.0, 15.0, 16.0, 17.0, and 23.0.
5	Rainwater harvesting and water reuse	Allow the installation of a rainwater harvesting system to be used for landscape irrigation and indoor non-potable uses?				Pending state legislation permitting the use of rainwater harvesting for non-potable purposes, the City should prepare to allow rainwater harvesting for landscape irrigation and toilet flushing.	CMAP Model Water Use Conservation Ordinance, 18.0 and 19.0; McHenry County Water Reuse Model Ordinance
6	Downspout - sanitary sewer connection	Restrict downspouts from being directly connected to a sanitary sewer?					
7	Downspout - storm sewer connection	Restrict downspouts from being directly connected to a storm sewer?				Allow downspouts to connect to storm sewers only in areas where soil conditions or other natural features make infiltration and or dispersal difficult.	City of Milwaukee Downspout Disconnection ordinance
8							
9							
10	Water waste prevention	Prohibit water waste or inefficient use of water?				Consider adding requirements for fixing leaks in private water lines within a specified number of days of notification by water utility or discovery of leak.	CMAP Model Water Use Conservation Ordinance, 21.0.
11							
12							
13	Water pricing	Establish a conservation pricing structure or other economic incentive to promote water conservation?				Consider implementing conservation pricing structures and economic incentives that encourage desirable water management practices. Conservation pricing structures include seasonal rates (higher per unit water rate during the peak usage summer months), uniform rates or increasing block rates in which the unit price of water increases as the quantity of water used increases.	CMAP Model Water Use Conservation Ordinance, 32.0

Table 11: Pollution Prevention			Yes / No	Code section	Current standard	Recommended standard or action	Reference
1	Groundwater protection	Regulate activities within groundwater protection areas?				Minimize intensive development activities, minimize impervious surfaces and mass grading, and employ stormwater best management practices that promote infiltration and treatment where possible in sensitive groundwater aquifer recharge areas, including Class III Special Resource Groundwater areas.	City of St. Charles, IL Chapter 13: Groundwater Protection; City of Marengo, IL, M.C. Chapter 30: Groundwater protection; Fox River Grove, IL, M.C. Article IX, Section 23-200 Groundwater protection; McHenry County Groundwater Protection Action Plan; U.S. EPA Model Ground and Surface Protection Overlay District.
2	Surface water protection	Regulate activities within the flood plain or buffer areas of waterbodies?				Specify that such materials as chemicals, explosives, animal wastes, fertilizers, flammable liquids, pollutants or other hazardous or toxic materials shall not be located or stored below the flood plain elevation or in the buffer areas of waterbodies.	
3							
4	Phosphorus reduction	Discourage the use of phosphorus in manufactured fertilizers in order to reduce the amount of phosphorus that enters water resources?				Prohibit commercial and non-commercial application to any turf area any fertilizer, liquid or granular, which contains any amount of phosphorus or other compound containing phosphorus, such as phosphate, except naturally occurring phosphorus in unaltered natural or organic fertilizing products such as yard waste compost. Exceptions are made where soil tests show a need for phosphorus and for newly seeded or sodded lawns.	McHenry County Phosphorus Model Ordinance
5		Discourage the use of phosphorus in dishwasher detergents in order to reduce the amount of phosphorus that enters water resources?				Update to reflect current Illinois law as of July 1, 2010, which limits phosphorus in dishwasher detergents to 0.5% by weight for non-commercial use	
6	Chloride management	Specify road salt storage and handling requirements that ensure proper storage, handling, and transport?				Specify that road deicing salts shall not be located or stored below the flood plain elevation or in the buffer areas of waterbodies unless such materials are stored in a specified way. Address the proper handling, transport, and application of road deicing salts.	

7		Specify alternative compounds or methods for dust control?				Consider requiring appropriate alternatives to calcium chloride for this use.	
8		Encourage water softeners be set to recharge on demand?				Encourage the setting of water softeners to recharge on an as-needed/on demand basis rather than via a timer.	
9	Coal tar sealants	Discourage use of coal tar sealants to prevent loss of aquatic life?				Prohibit the use, sale, or retail display of sealcoat products for use on an asphalt or concrete surface, including driveways or parking areas, which contain high levels of carcinogens and are harmful to aquatic life.	McHenry County Coal Tar Sealants Model Ordinance
10	Pet waste disposal	Include pet waste disposal requirements?					
11							
12	Private sewage treatment and disposal	Require regular inspection and maintenance of private sewage treatment (septic) systems?				Consider adopting the Illinois Private Sewage Disposal Code, or use the McHenry Co. Code as a model, and amending it to require a regular schedule of inspections and maintenance by the landowner.	Public Health Ordinance for McHenry County, Article X, Wastewater & Sewage Treatment and Disposal for McHenry County Illinois

APPENDIX G
WASTEWATER TREATMENT PLANT UPGRADES PROGRESS

Appendix G: Wastewater Treatment Plant Upgrades Progress

Facility Name	Is the facility meeting 1.0 mg/L Ann Avg Total Phosphorus (TP) (Y/N)	If No to the previous question, when will 1.0 mg/L TP be met? MM/YY	What is the facility's most recent Annual Average effluent TP (mg/L)?	Is the facility meeting 0.5 mg/L TP Annual Geometric Mean now? (Y/N)	If No to the previous question, when will 0.5 mg/L TP Annual Geometric Mean be met? MM/YY	Will Additional Improvements be required to meet 0.5 mg/L TP in the future? Y/N	If Yes to the previous question, what is projected $ needed to meet 0.5 mg/L TP?	Add any additional explanatory comments here.	Contact Person	Contact's email
Cary	Y		0.46 Mg/L	0.398Mg/L		unknown but unlikely		Geomean July 2021 - June 2022	John Stein	jstein@caryillinois.com
Fox R. Grove	Y	-	.0.84	N	06/2030	Y	Additional cost in chemicals and equipment and land purchase		Tim Zintl	t.zintl@foxrivergrove.org
Algonquin	Y		.76 mg/L	N	06/2030	Y	15K	Sidestream treatment will be piloted in 2022 with an overhaul of the Biosolids Dewatering to follow in 23/24.	Thomas Hall	thall@algonquin.org
Carpentersville	Y		0.34 mg/L thru 12/21	Y, 0.29mg/L		unknown but unlikely			Joe Egler	jegler@cville.org
East Dundee	Y		0.58 mg/ l	N	06/01/2030	Y	Additional Chemical / Building and		Dan Hughes	dhughes@eastdundee.net
Fox River Water Reclamation District (FRWRD) - ADP (South)	N	11/23	3.41	N	06/2030	unknown		As of March 2022 construction of side stream (West Bank) Bio-P process is complete. We are working on process optimization to achieve less than 1 mg/L effluent TP.	Jack Russell	jrussell@frwrd.com
FRWRD - North	N	3/23	1.88	N	06/2030	unknown		Side stream Bio-P upgrades complete. Effluent TP of less than 1 mg/L consistently being met as of March 2022.	Jack Russell	jrussell@frwrd.com
FRWRD - West	Y		0.38	Y		unknown		The annual average effluent TP of less than 0.5 mg/L can only be met using approximately $70,000 per year of glycerin for enhanced denitrification.	Jack Russell	jrussell@frwrd.com
St Charles Main (East)	Y		0.53 Mg/L	Y- 0.50 Mg/l		Y	$10 M	Note: The city is currently reaching the 0.5 goal but this is not at full capacity, the addtional work would include $10 M in upgrades. Also note this is 2015 cost the actual expense is expected to be higher.	Tim Wilson	twilson@stcharlesil.gov
Geneva	Y		0.526 Mg/l	Y - 0.418 Mg/l				There is a possibility that addtional improvements will be requires in the future to meet 0.5 mg/L. It all depends on future loadings. When we did the phosphorus if needed. At this time its is difficule to give a number for projected cost at this point.	Bob VanGyseeghem	bvangyseghem@geneva.il.us
Batavia	Y		0.75 Mg/l	N		1.0 Current Limit		Yes, BNR Process is scheduled to implemented in future plant expansion. Until then we are relisant on chemical reduction of TP	Zac Bonesz	zbonesz@cityofbatavia.net
Fox Metro Water Recalmation District	Y	--	0.43 mg/l through 12/21	mostly (0.31 mg/l through 12/21 due to excellent plant performance and a dry, warm winter last year)	06/2030	unknown but unlikely	$100K per year in extra chemicals	We are mostly meeting the annual 0.5 geo mean limit as different preceding 12 months roll through the calculation cycle. We use bio-P for removal and are planning on experimenting with chemical supplementation over the next few winters to better meet the 0.5 limit.	Karen Clementi	kclementi@foxmetro.org
Wauconda	Y		0.506	Y, 0.473		unknown but unlikely	Increase in cost for chemicals and equipment		Anna Kootstra	akootstra@wauconda-il.gov
Sandwich	N	04/23	3.47	N	01/30	Y	$12M (current est.)	Design is in progress for WWTF Modifications to meet both 1.0 and future 0.5 mg/L TP Limits (one project); Capital cost estimate shown includes all improvements for meeting both limits	Brad Eade	beade@sandwich.il.us
Lake in the Hills Sanitary	Y		0.2	Y		N		have VLR for biological P removal	Tamara Mueller	tmueller@lithsd.com
Elburn WWTF	Y		0.745	N	01/2030	Y	$4M (high level est.)	cost est. based on P removal feasibility study from 2013; Village is collecting additional data to reevaluate improvements needed and costs	Phil Van Bogaert	publicworks@elburn.il.us
St Charles West Plant	n	02/2023	3.33 Mg/L	N	02/2023	N	$17 M	This City is currently under construction of a $ 17 M plant rehab that will include P removal	Tim Wilson	twilson@stcharlesil.gov