Green Bay Metropolitan Sewerage District

Ambient Water Quality Monitoring Program

Report on Water Quality for Lower Green Bay Fox River and East River for Field Year 2010

November 2016

Cover photo credit – Jim Harper, GBMSD

Green Bay Metropolitan Sewerage District
Cleaning Water Today For Tomorrow's Generations

Executive Summary

The Green Bay Metropolitan Sewerage District (GBMSD) has operated a voluntary Ambient Water Quality Monitoring Program (AWQMP) since 1986 on the waters of the lower Fox River and Green Bay. GBMSD has committed to a long-term monitoring program to better understand the water quality of its receiving waters as well as the effect of its discharge on those waters. It is an integral part of the GBMSD mission statement:

> *"…In conjunction with others the organization will encourage pollution prevention and support programs that help ensure that water contaminated by human activity is returned clean to the environment."*

The purpose of the GBMSD AWQMP is to provide GBMSD with high quality water quality data about the effects of its discharge upon its receiving waters, as well as to provide these data to other institutions and agencies working on water quality issues in the area. The data that is collected is utilized extensively by GBMSD and the scientific and regulatory community.

Notable results or observations from the 2010 AWQMP include:

- Sixteen routine water quality surveys were performed on the lower Green Bay, Fox River, and East River. One survey included analysis for heavy metals and organic trace contaminants.
- Total phosphorus (TP) concentrations in the Area of Concern (AOC) generally exceeded the Total Maximum Daily Load (TMDL) target goal of 0.100 mg/L, though the goal was met during May.
- Chlorophyll *a* continues to show high variability throughout the study area, though a slight downward trend in the AOC area may be evident over the full period of record.
- Total suspended solids (TSS) concentrations in the AOC exceeded the TMDL target goal of 18 mg/L for the Fox River stations, but the Zone 1 annual average just met the target on a seasonal mean basis. Throughout the sampling period, highest concentrations were typically correlated to high Fox River flows, which for 2010 occurred in mid to late summer.
- Input from the Fox and East Rivers continues to be the major source of phosphorus and suspended solids to Green Bay.
- Ammonia concentrations exhibit high spatial variability within the study area. A slight downward trend in ammonia concentrations may be evident since 1993.
- Temporal variations in Secchi depth values are dramatic in the study area. Secchi depth values for Zones 1 and 2 were well below (i.e. did not meet) the TMDL goal of 1.14 meters.

Introduction

The GBMSD AWQMP entered into its 25th year of operation in 2010. GBMSD began work on a long-term monitoring program in 1986 to better understand the water quality of the lower Fox River and Green Bay (also referred to as the Bay), as well as the effect of its discharge upon those waters.

The year 2010 marked the final year of service for GBMSD's workboat, the *Clearwater Revival*. After 25 years of work on the Fox River and Green Bay the stout vessel, purchased in 1986 from Kings Kraft Marine in Florence, Alabama, was scheduled for replacement for the start of the 2011 field season.

Through the Water Resources Program, GBMSD has coordinated one of the longest running monitoring programs in existence for the waters of the lower Fox River and Green Bay. The data collected and generated by the AWQMP is vital in furthering the state of GBMSD's knowledge and understanding of these waters. During the 2010 field season the following activities were conducted under the program:

- Continuous operation of a weather station throughout 2010. This data is available upon request and is not catalogued in this report.
- Sixteen routine water quality surveys were performed on the lower Green Bay, Fox River and East River. All surveys were conducted in conjunction with in-house laboratory analysis for all major physical constituents and nutrients, and the collection of *in-situ* water quality measurements.
- Analysis for heavy metals and organics was included on samples from one of the routine water surveys (August 23, 2010).
- Deployment of two continuous monitoring stations at the Fox River mouth and at Entrance Light.
- Co-funding of the US Geological Survey (USGS) streamflow monitoring station on the lower Fox River at the U.S. Venture dock.
- Co-funding of the USGS streamflow monitoring station at Rapid Croche through the Lower Fox River Dischargers Association.
- Bacteriological monitoring June through August on the lower Fox River and Green Bay in partnership with the Brown County Health Department.

Methods

Sampling

GBMSD samples ambient water quality at 17 stations that are located on the lower Green Bay, Fox River, and East River. This report includes data from the 2010 water year. Sampling began on May 5, 2010 and concluded on October 5, 2010. Every effort was made to sample the following stations three times per month during the 2010 field season. Site locations (Figure 1) are divided into the following zones:

- East River – Sites 10-12
- Fox River Above and Below De Pere Dam – Sites 5-16
- Zone 1 of Green Bay – Sites 22-32
- Zone 2 of Green Bay – Sites 41-51
- Zone 3 of Green Bay – Sites 55-57

Samples were analyzed for chloride, chlorophyll *a*, total suspended solids, volatile suspended solids, total solids, volatile solids, turbidity, and nutrients. Additional analysis for trace contaminants (heavy metals and select organics) was included from the August 23, 2010 survey. Stations with sufficient depth (three meters or more) were sampled at two depths: one meter below the surface and one meter above the bottom. Most of these samples analyzed individually were designated with a "T" or "B" suffix. However, the samples from some of the deeper stations were composited to maintain a workable number of total samples from each survey. Stations located in shallow water (i.e. less than three meters) were sampled at a mid-water depth. All samples are obtained by a Van Dorn grab sampler.

Two continuous monitors were deployed during the 2010 field season. One monitor was located at the mouth of the Fox River. The second monitor was located in Zone 2 of Green Bay just west of Entrance Light House. The Entrance Light monitor collected data for an approximate duration of 24 weeks during the 2010 field season, while the Fox River Mouth monitor collected data for approximately 17 weeks.

Further details on the preparation of sample containers, labware, reagents and laboratory procedures can be found in the GBMSD Quality Control Manual or Standard Methods for the Examination of Water and Wastewater, 20th Edition.

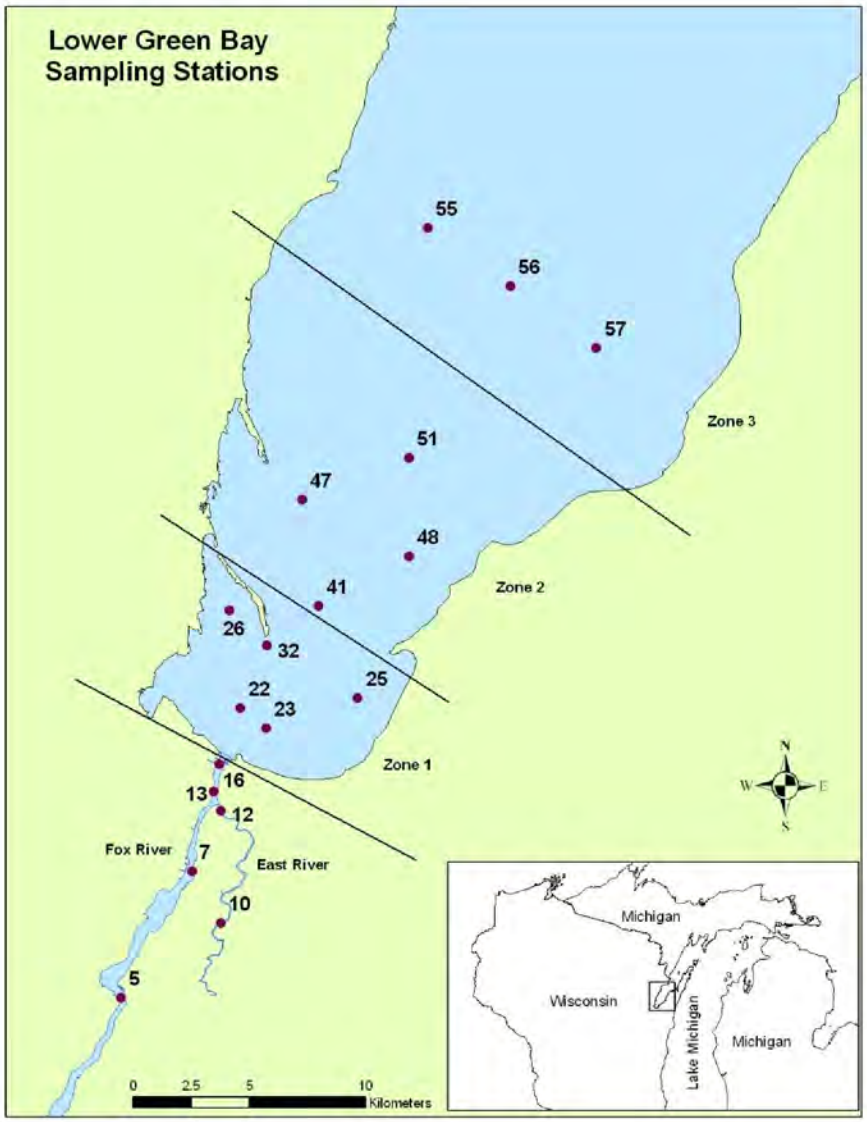

Figure 1: Sampling Location Map

Station Locations

Station locations have been determined in the field since 2004 by a GPS unit; stations were previously identified using Loran and dead reckoning. Note that Stations 23 and 25 are no longer sampled due to shallow water conditions. Figure 1 also does not show Station 11, which was added to the East River at the Mason Street Bridge.

Vertical Profiles

A YSI 600XL sonde was employed to gather vertical profile information at each site. Measurements were recorded for the whole water column at each meter of depth for: temperature, dissolved oxygen, specific conductivity, and pH. A Li-Cor light meter was utilized to determine depth of light penetration in the water column, and a Secchi disk was used to determine water clarity.

Results and Discussion

Overall Summary Statistics

An overall summary of the data collected as part of the GBMSD AWQMP for the waters of Green Bay, Fox and East Rivers is located in Appendix A. These statistics represent all the values obtained during the 2010 field season for all of the 17 stations monitored from May 5, 2010 through October 5, 2010. Some of the minimum values for nutrients reflect the analytical detection limit for the parameter. Collected data, which are not included in Appendix A, include: trace contaminant analyses from the August 23, 2010 survey; light extinction profiles, and continuous monitoring station data. This information can be made available by contacting GBMSD.

Annual reports from the GBMSD AWQMP are designed to provide an overview of the work accomplished and information generated. Each year thousands of individual data points are generated and archived. Rather than attempt to capture them all in this report, the goal is to provide a document that is summative in nature and readily digestible by a broad audience. The reader is encouraged to contact GBMSD for more detailed information than is contained in this report if so desired.

For ease of discussion, results from the 2010 AWQMP are presented in this report by parameter and in graphical format. Two graphs will be presented for each of the key parameters - total phosphorus (TP), orthophosphorus (OP), chlorophyll *a*, total suspended solids (TSS), ammonia-nitrogen (NH3), chloride, and Secchi disk depth. Data has been grouped by zone, as identified in the Methods section of this report. Also see Figure 1. Zone designations have been designed to be geographically contiguous and reflect similar water quality characteristics. This designation is more fully described in a thesis by Qualls, 2003. Zone 1 is the area of the Bay that receives direct discharge from the Fox River and exhibits similar water quality characteristics. (The lower Fox River below the De Pere dam and Zone 1 are also identified as the AOC per the Lower Fox River and Green Bay Remedial Action Plan [WDNR, 1993].) Zone 2 is a transition zone between Zones 1 and Zone 3, showing the interactions between the Fox River discharge and Green Bay. Zone 3 stations are approximately 14 miles from the mouth of

the Fox River. Water quality typically improves as the waters of the lower Bay mix with the cleaner waters of the upper Bay.

The first graph displayed for each key parameter presents a summary of all the 2010 data, expressed as mean concentration of all stations within that specific zone. The x - axis shows the dates, but the reader is cautioned that these data are presented chronologically. Thus, the graph line for any zone will show a break if sampling within that zone was not completed during one of the 16 sampling surveys. The second graph displayed for each key parameter presents the long term trend of all data collected since the AWQMP began in 1986, expressed as annual mean concentration of all stations within a specific zone. Note that the long-term trend graphs combine all Fox River stations (5 – 16) in a single trend line. Station 5 (above the De Pere dam) was originally included in order to identify variations in water quality between the reach above the dam versus below, which is impacted by other tributary and point and non-point source discharges, as well as seiche effects with Green Bay. Review of the long-term data, however, suggests that there is no statistical difference between the two data sets. Therefore, the annual graph combines the two data sets. Finally, note that the long-term trend graphs do not include data from the East River sites.

Total Phosphorus

Figure 2 presents TP data for all survey dates during 2010, while Figure 3 presents TP long-term trend data for the period 1986 – 2010.

Phosphorus is considered to be the main contributor to excess algae growths in the Fox River and lower Green Bay. Significant reductions in point source discharges of phosphorus were realized in the late 1970s following implementation of the Clean Water Act. However, concentrations were seen to plateau by the early 1980s at levels which continue to produce excessive algal blooms.

Concentrations of TP in the AOC generally exceed the target goal of 0.100 mg/L, which was set by the TMDL initiative (WDNR, 2012). It is notable, however, that during May and June 2010 the Zone 1 stations were below 0.100 mg/L, as were the Fox River stations during May. Within the GBMSD AWQMP study area, the East and Fox Rivers and Zone 1 of Green Bay consistently exhibit highly eutrophic (Wetzel, 2001) conditions, mostly related to excess phosphorus.

Review of Figure 2 shows little in the way of any trend for phosphorus during the 2010 sampling season, at least for the river stations and Zone 1. Concentrations were mostly lower early in the season, then rose to a fairly consistent level for the summer. Concentrations in Zones 2 and 3 did show a slight upward trend during the summer months. The East River discharge represents a major source of phosphorus to Green Bay.

The 2010 TP data was slightly higher as compared to 2009 on a seasonal average basis, particularly in the Fox River and in Zone 1 (see Figure 3). Review of Figure 3 indicates a relative "settling" of TP data in 2008 through 2010, which followed an extended period of very high TP values for the 2001 – 2007 period.

The unusual trend observations seen in Figure 3 for the 2001 – 2004 period, particularly for Zones 2 and 3, cannot be fully explained at this time. Review of the data shows that the TP values were generally higher both temporally and spatially. But, the annual averages were clearly affected by a small number of very high individual results. Laboratory Quality Control results for all samples were acceptable.

Additional review of ancillary factors suggested that there was evidence of possible sampling bias resulting from entrained *Microcystis* colonies within the sample aliquot. This has been shown to be a concern in hypereutrophic systems (personal communication with Wisconsin State Laboratory of Hygiene) where incomplete homogeneity of the sample can result in higher TP values due to the contribution of algal cell mass. This observation may

contribute to the unusual results seen during the 2001 – 2004 period, though other factors are likely involved. Atypically high values were observed randomly throughout the stations within all zones.

The option to censor these “visually anomalous data” was considered. However, the prevailing opinion among GBMSD staff and others was to include all Quality Control approved data in conjunction “with qualification” as discussed here. Therefore, Figure 3 includes all of the approved data and the reader is cautioned to consider this discussion concerning the confidence related to the absolute concentrations for the reported annual averages as shown.

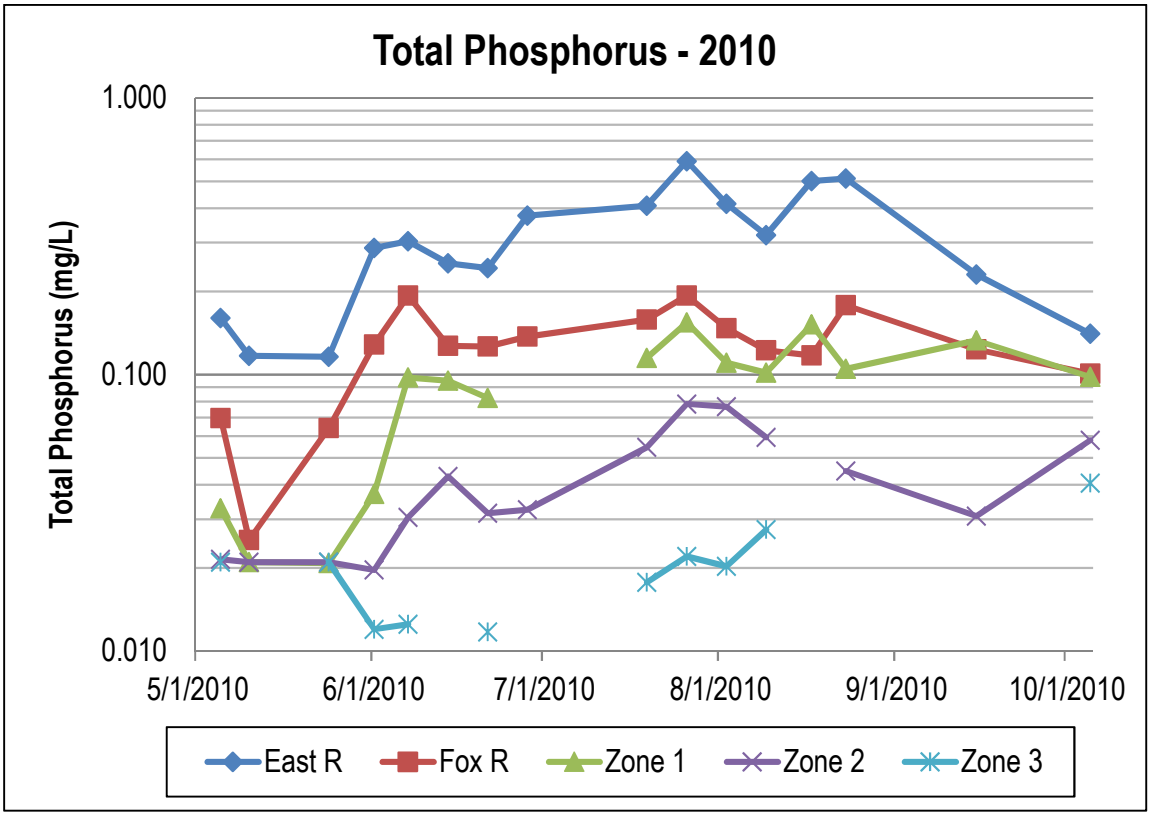

Figure 2. Mean TP concentrations for all survey dates during 2010.
Note: Vertical axis is log scale.

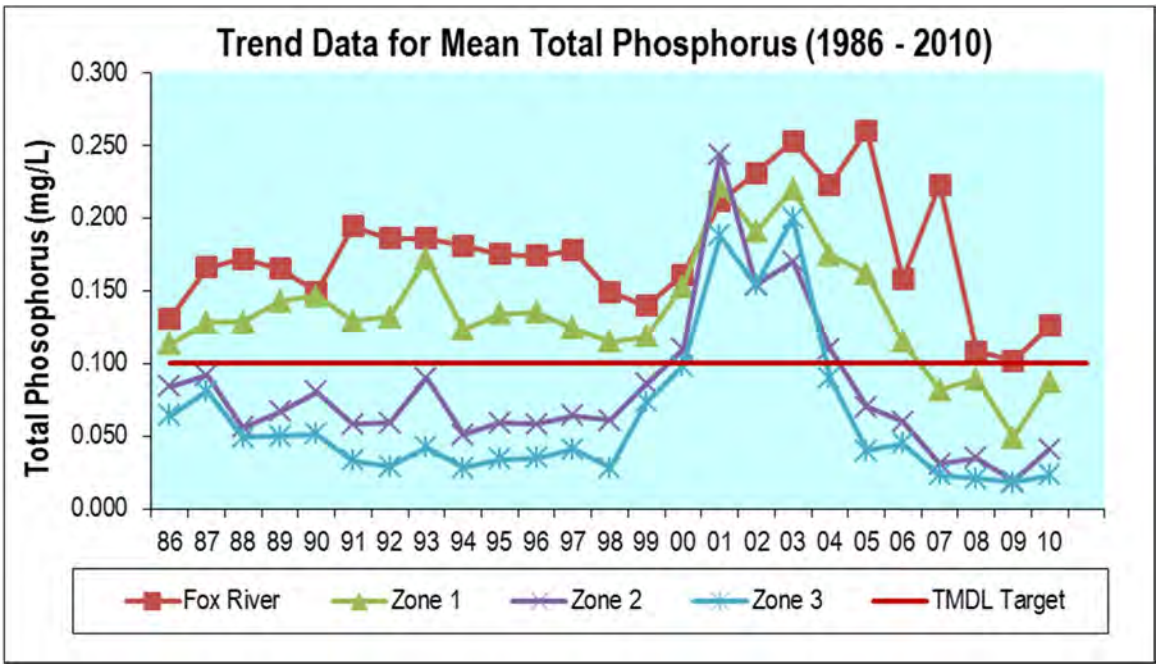

Figure 3. Long-term mean TP concentrations by zone (1986 – 2010).

Orthophosphorus

Figure 4 presents OP data for all survey dates during 2010, while Figure 5 presents OP long-term trend data for the period 1986 – 2010.

OP, also known as inorganic soluble phosphorus, is the species of phosphorus which is immediately usable by algae for growth. This feature typically results in highly variable concentrations exhibited in fresh water systems. Though an important indicator of the overall trophic state of a water body, it is chemically transient in nature so total phosphorus is generally viewed as the main nutrient indicator for trophic status.

For 2010, OP concentrations show high levels in the river stations and in Zone 1, then decrease through Zones 2 and 3 (Figure 4). The very high river concentrations indicate an excess of available phosphorus as the river is discharged into Green Bay, thus providing the "fuel" for excessive algal growth.

Looking at the long-term trend data (Figure 5), the higher concentrations observed for TP during the 2001 – 2007 period are also evident for OP, though the variability is greater for OP.

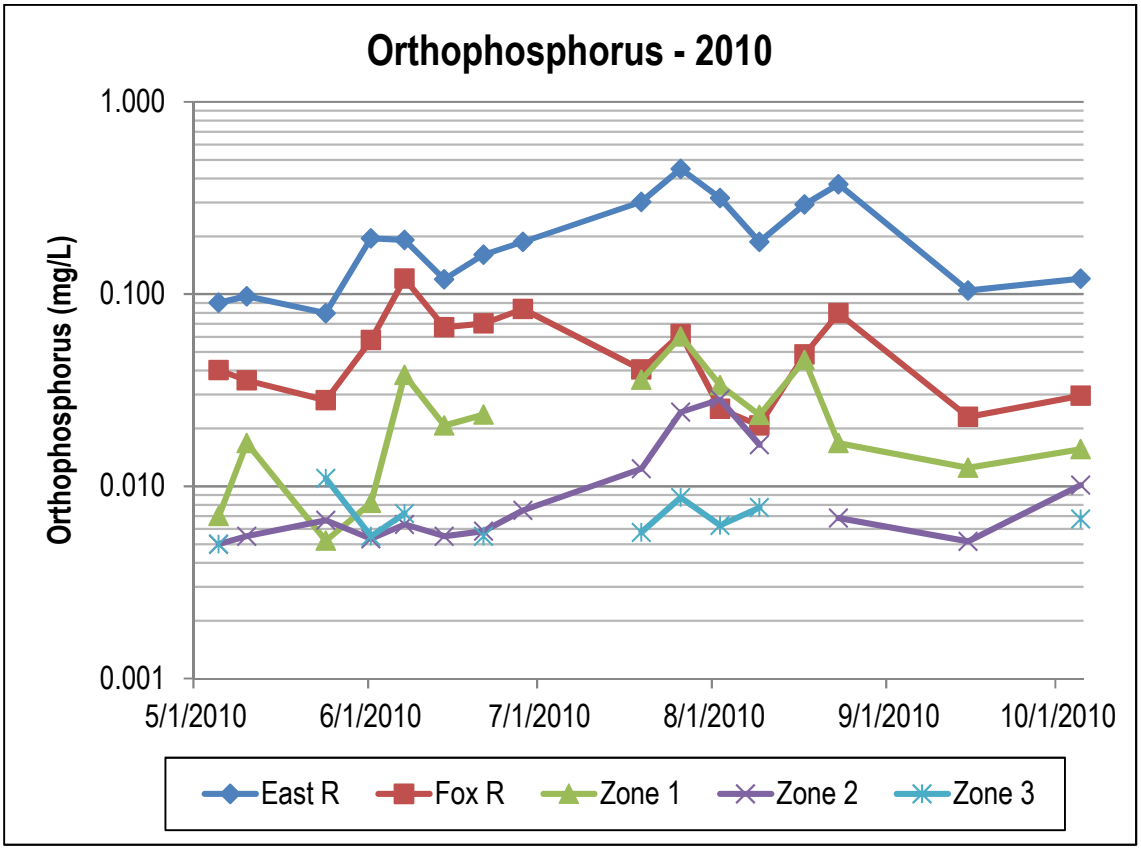

Figure 4. Mean OP concentrations for all survey dates during 2010.

Note: Vertical axis is log scale.

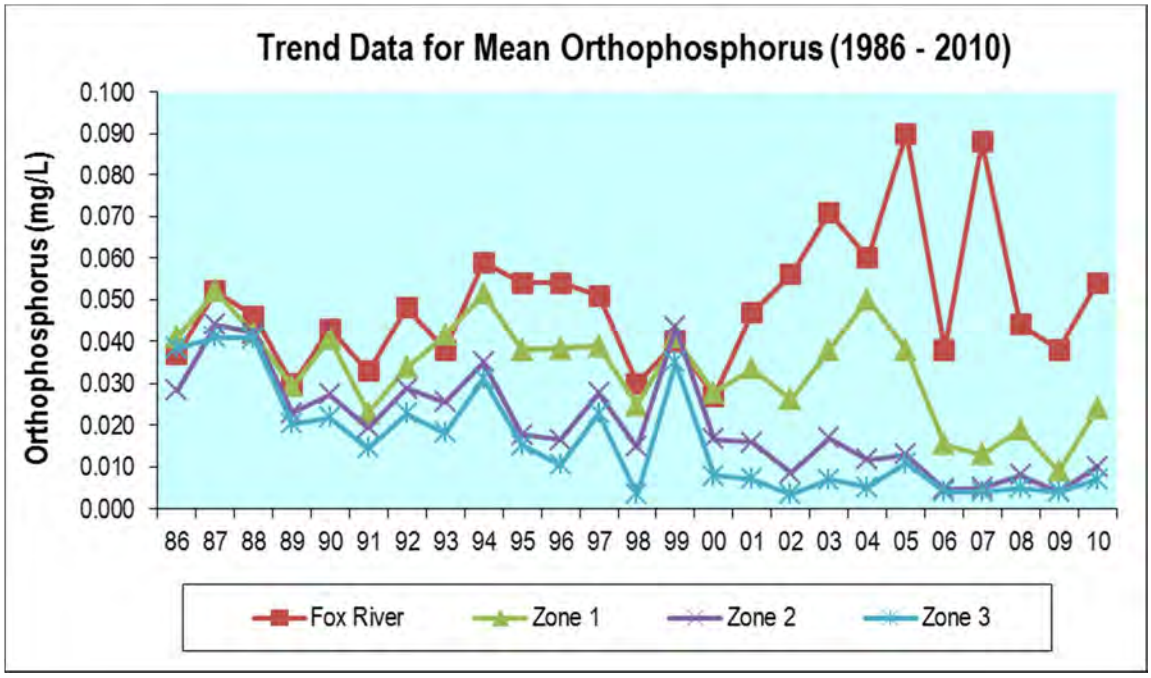

Figure 5. Long-term mean OP concentrations by zone (1986 – 2010).

Chlorophyll *a*

Figure 6 presents chlorophyll *a* data for all survey dates during 2010, while Figure 7 presents chlorophyll *a* long-term trend data for the period 1986 – 2010.

Chlorophyll *a* can generally be used as an indicator of phytoplankton biomass. However, in the hypereutrophic East River, lower Fox River, and southern Green Bay system, the relationship between nutrients and algal biomass is typically unstable due to the wide swings in water quality characteristics, such as suspended solids and light penetration which can limit algal growth even when nutrients are available. In the lower Bay, the relationship between phosphorus, light penetration, and chlorophyll *a* was evaluated against the arrival of zebra mussels by Qualls (2003), who found that the historically demonstrated relationship had essentially "decoupled" post zebra mussel invasion.

Review of Figure 6 clearly demonstrates the "noise" seen in chlorophyll concentration data for this area. Dramatic spikes in concentration are seen in the Fox River stations. Zone 1 stations reflect high and variable results. Concentrations stabilize somewhat in the more northern stations of Zones 2 and 3.

Review of Figure 7 suggests a very slight downward trend in chlorophyll *a* concentration in the Fox River and Zone 1, even though the corresponding period for total phosphorus (Figure 3) shows a much more variable trend line. The data for Zones 2 and 3 from Figure 7 basically show no trend.

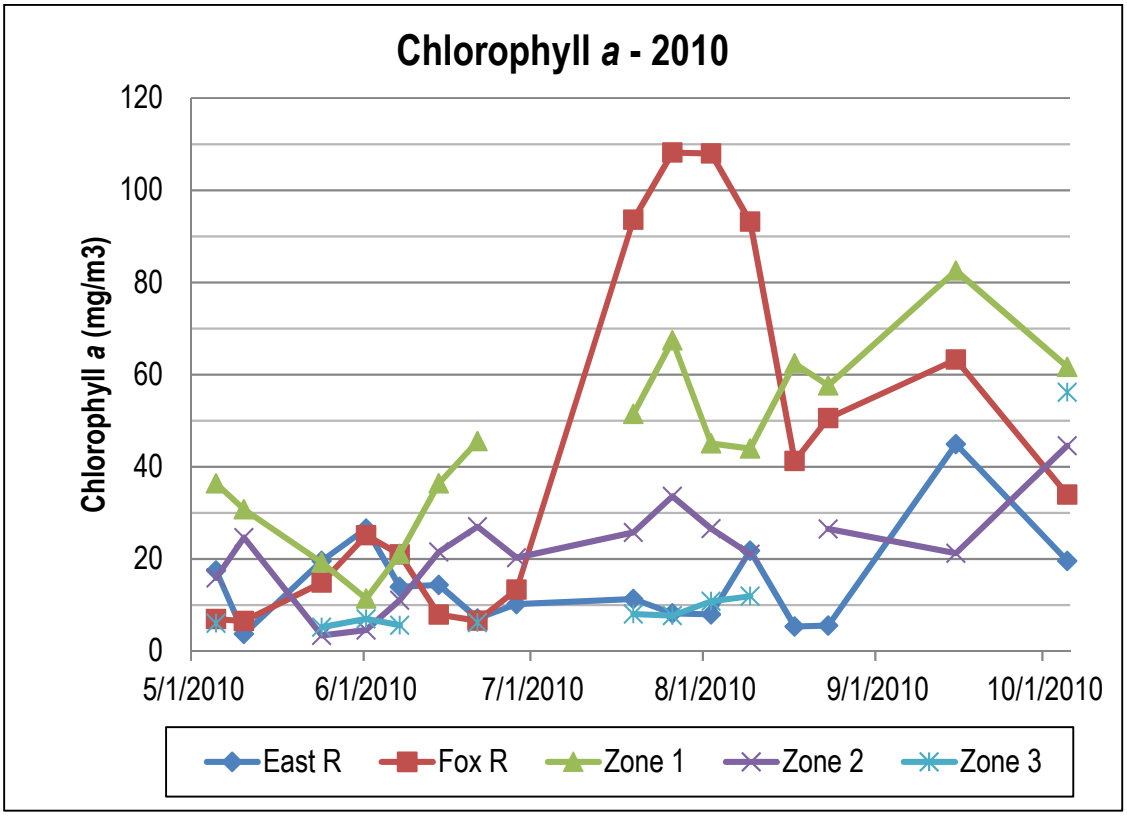

Figure 6. Mean chlorophyll *a* concentrations for all survey dates during 2010.

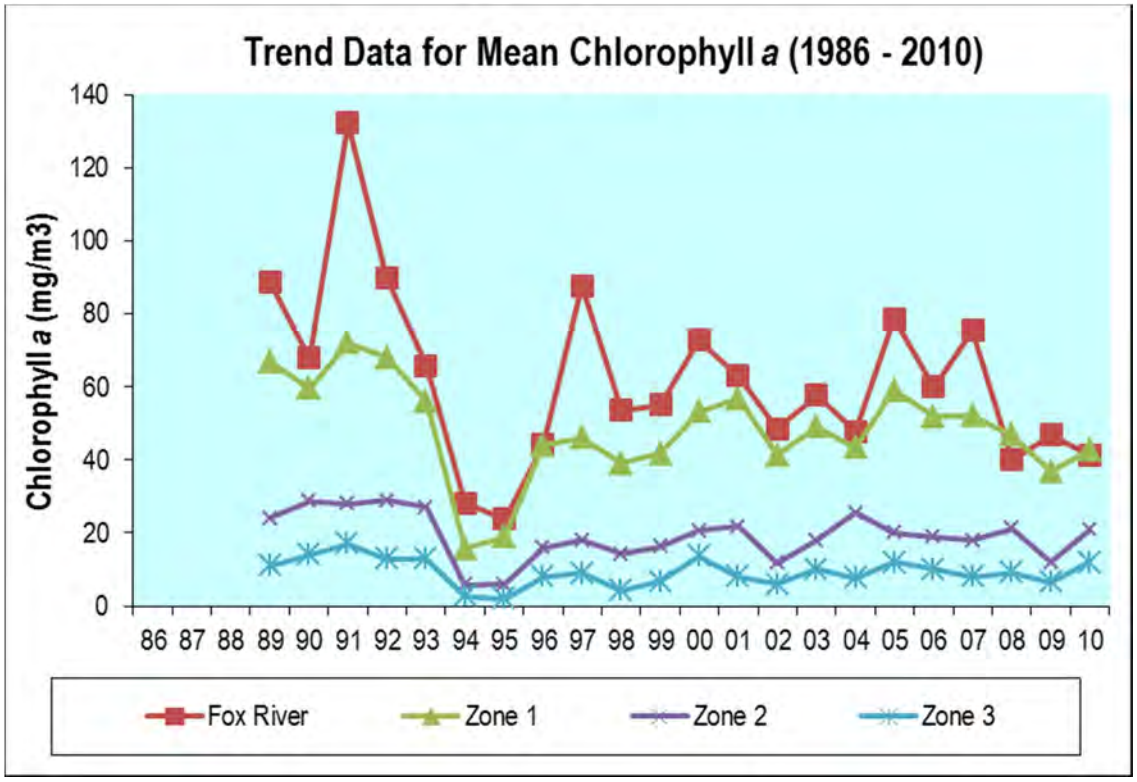

Figure 7. Long-term mean chlorophyll *a* concentrations by zone (1986 – 2010).

Total Suspended Solids

Figure 8 presents TSS data for all survey dates during 2010, while Figure 9 presents TSS long-term trend data for the period 1986 – 2010.

TSS was identified along with phosphorus in the DNR's TMDL as requiring reductions in the mass currently being discharged from all sources to the Fox River. The approved TMDL lists a summer mean target concentration for TSS of 18 mg/L at the outlet of the lower Fox River. For the full sampling period (May 5 – October 5, 2010) the mean TSS value for the Fox River stations was 23 mg/L, while the Zone 1 mean was 18 mg/L.

Several observations can be made from review of Figure 8. First, the East River stations, typically high in TSS, showed a major peak on the June 28, 2010 sample survey. This value was dominated by a single sample result of 372 mg/L at Station 10. No obvious factors helped explain this single anomalous result. These events typically correspond to above average run-off conditions (Figure 10). Fox River flows were somewhat atypical for 2010, as the spring flow was only slightly above average, but high flows were observed in late July and early August. This higher flow period resulted in elevated TSS concentrations, particularly in the river sites.

Review of Figure 9 shows a similar response to the long-term trend graph for phosphorus (Figure 3), i.e. a period of high, though variable, annual concentrations corresponding to the 2000 – 2007 period followed by lower and more stable concentrations during the 2008 – 2010 period.

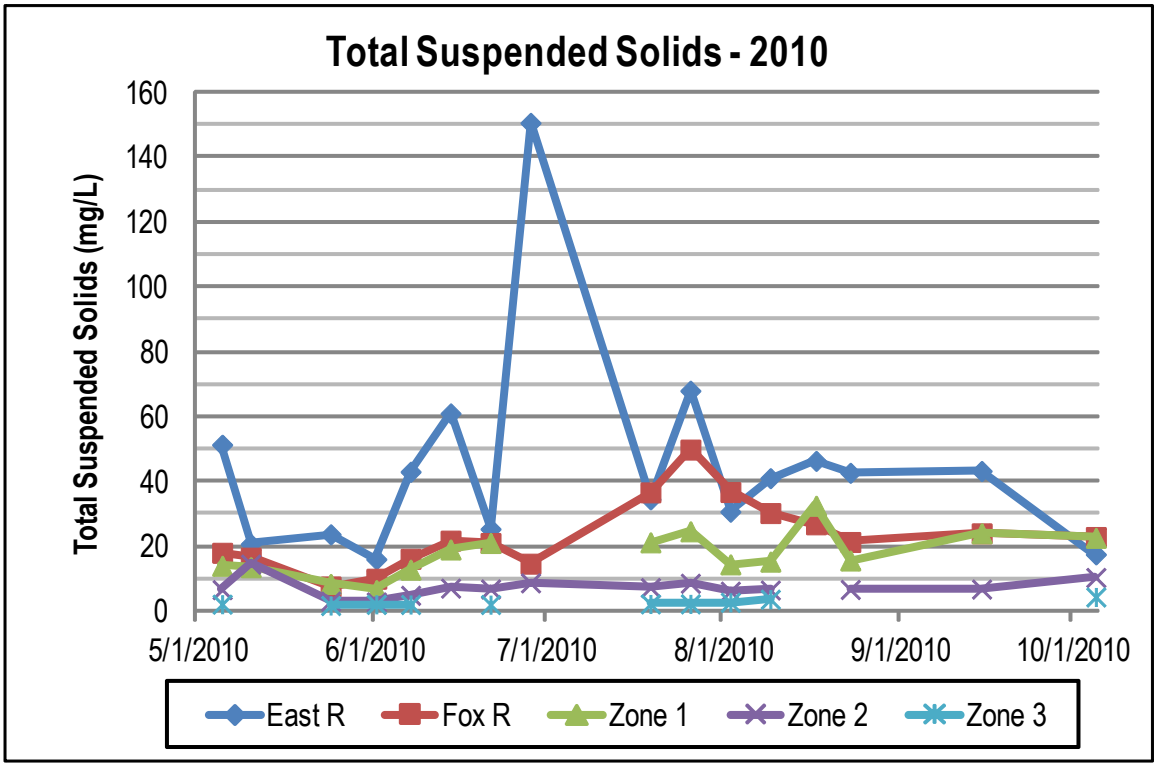

Figure 8. Mean TSS concentrations for all survey dates during 2010.

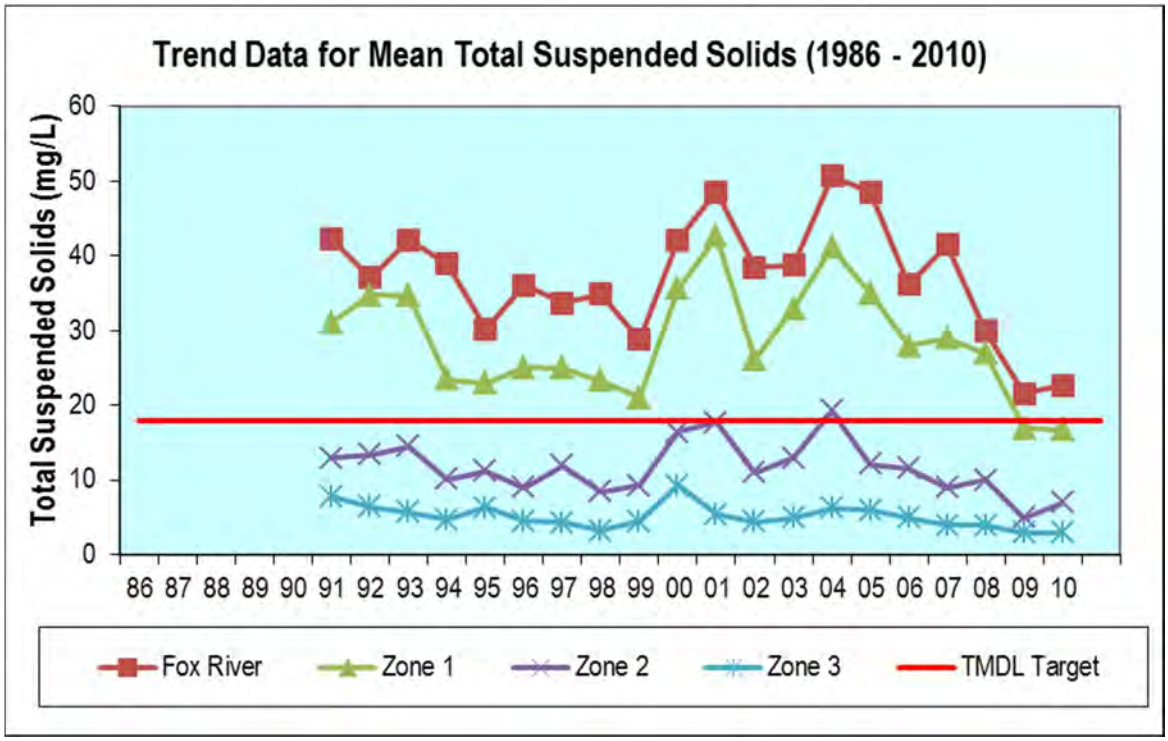

Figure 9. Long-term mean TSS concentrations by zone (1986- 2010).

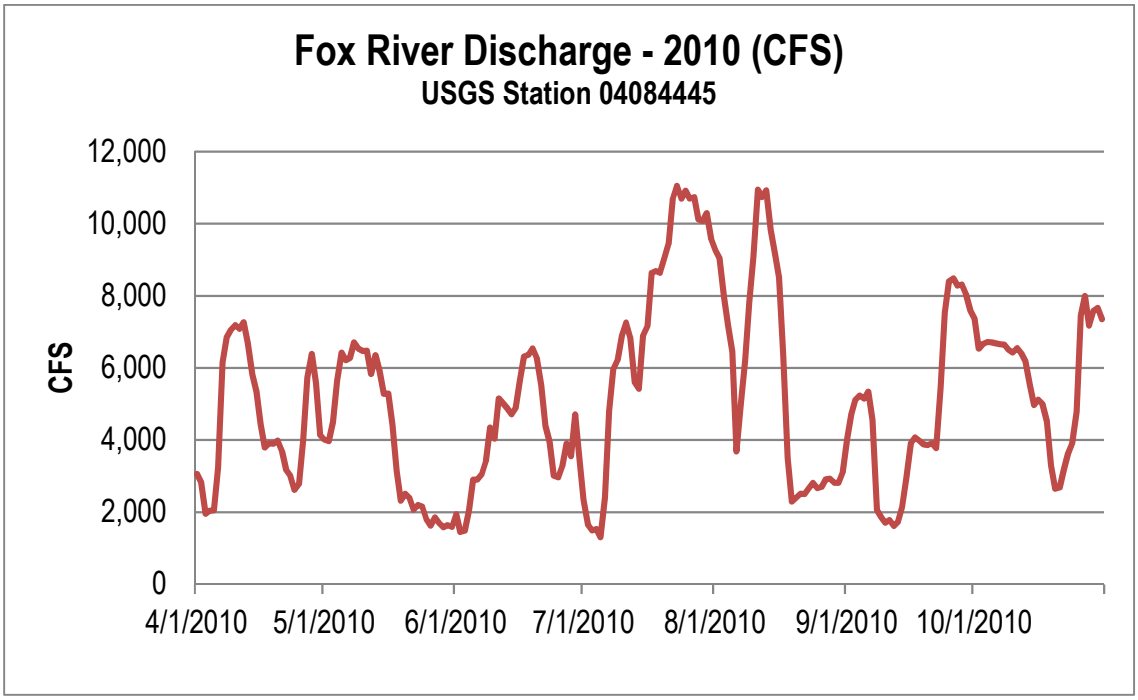

Figure 10. Lower Fox River discharge in CFS; April 1 – October 31, 2010.

Ammonia

Figure 11 presents ammonia data for all survey dates during 2010, while Figure 12 presents ammonia long-term trend data for the period 1986 – 2010.

Ammonia is a second essential nutrient that can contribute to excess algae growth in the Fox River and lower Green Bay. The un-ionized fraction of ammonia is also toxic to fish and other aquatic organisms. Ammonia tends to be a volatile component in the nitrogen cycle of fresh water systems. In freshwater, ammonia can be generated (by decomposition) or broken down (via nitrification) as well as utilized by algae. Decomposition in sediments can result in ammonia accumulations in the pore water, which can be released during resuspension events. All of these reactions can occur quickly. Though not as tightly regulated in point source discharges as phosphorus, most significant Wisconsin Pollutant Discharge Elimination System (WPDES) permits now include ammonia limits. GBMSD was required to meet a new ammonia discharge limit in 1992. Concentrations of ammonia observed at the Fox River stations and Zone 1 since that time have shown measurable reductions.

Review of Figure 11 shows the dramatic differences between ammonia concentrations in the river stations as compared to the Bay stations. Concentrations were very high for the Fox and East River stations during the late May to mid-June period. Concentrations in the East River stations also spiked in late August.

Review of Figure 12 shows the long-term variability for this parameter. Concentrations throughout the system exhibited dramatic swings during the 1986 – 1993 period, then leveled off somewhat. However, minor spikes in concentration can be seen in 1997 and 2005, primarily in the river stations.

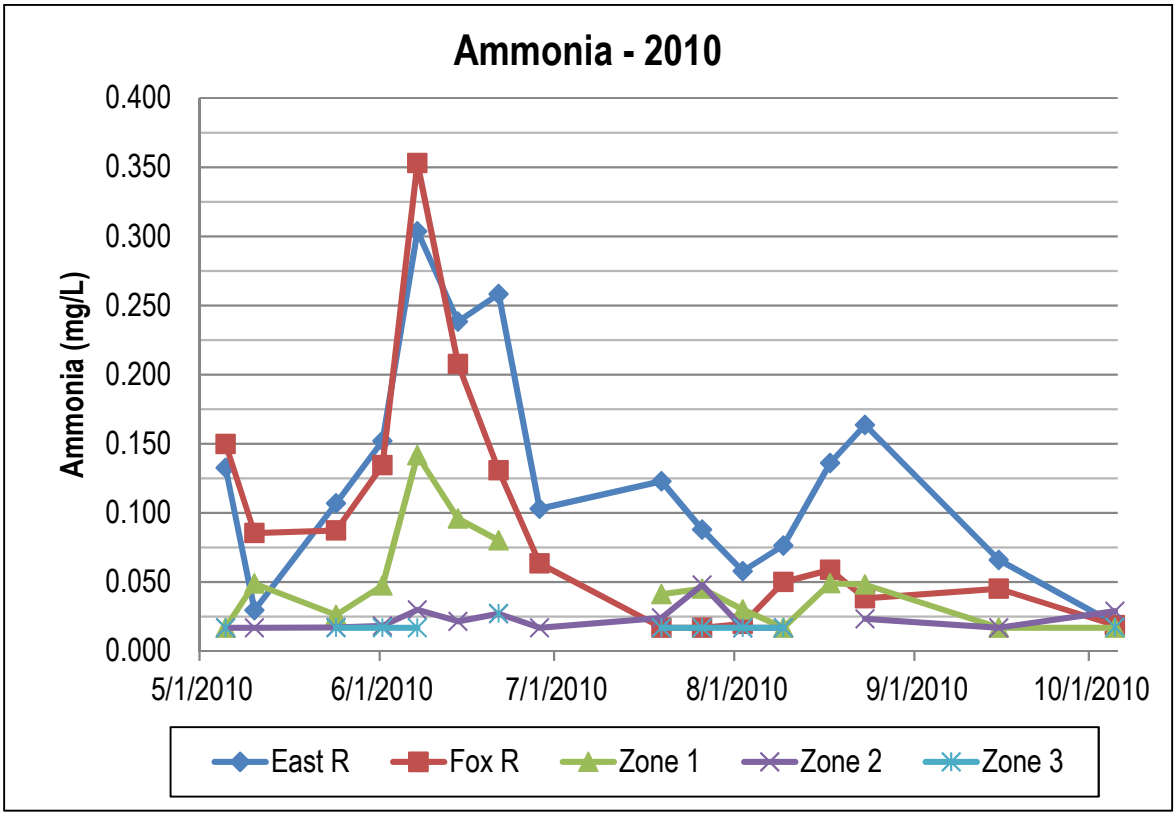

Figure 11. Mean ammonia concentrations for all survey dates during 2010.

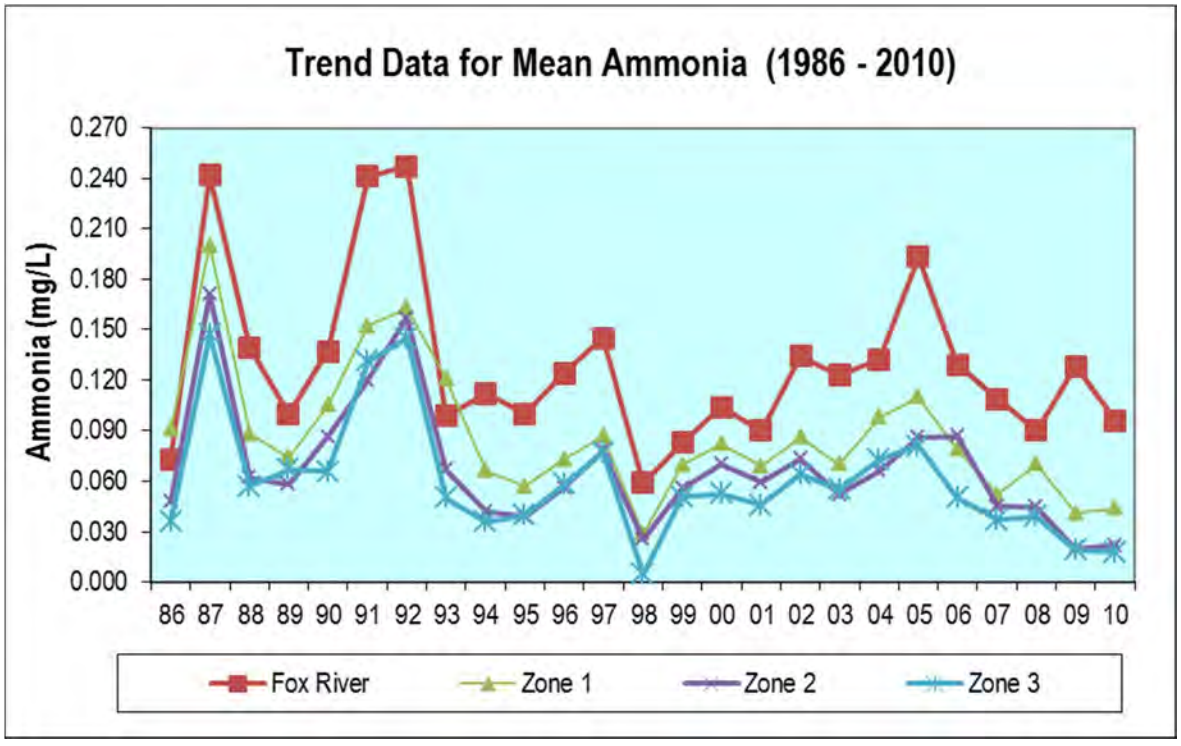

Figure 12. Long-term mean total ammonia concentrations by zone (1986 – 2010).

Chloride

Figure 13 presents chloride data for all survey dates during 2010, while Figure 14 presents chloride long-term trend data for the period 1986 – 2010.

Chloride is considered an important indicator compound for the lower Fox River and Green Bay, as it reflects the extent of various salt compounds that have been discharged to the watershed. Chloride can be toxic to aquatic organisms in high concentrations. Chloride is a conservative compound, which means that it does not readily break down or convert chemically into other compounds. Because of this feature, chloride concentrations are often used to help calibrate water quality computer models.

Review of Figure 13 shows that the East River drainage basin must receive significant inputs of chloride. Concentrations are considered very high (e.g., 25 – 87 mg/L), i.e., more than twice those found in the Fox River stations.

Figure 14 shows some long-term variability in chloride concentrations, but no distinct trend is apparent. Concentrations decrease as the Fox River plume is diluted with Green Bay water.

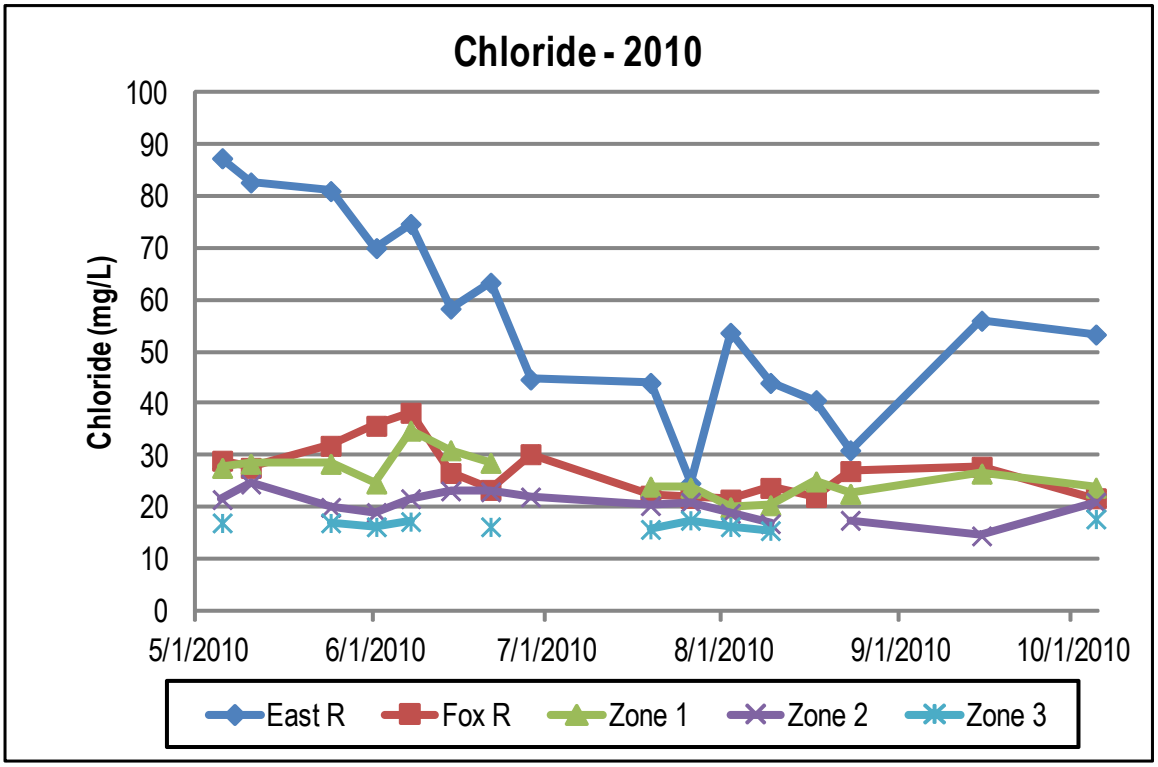

Figure 13. Mean chloride concentrations for all survey dates during 2010.

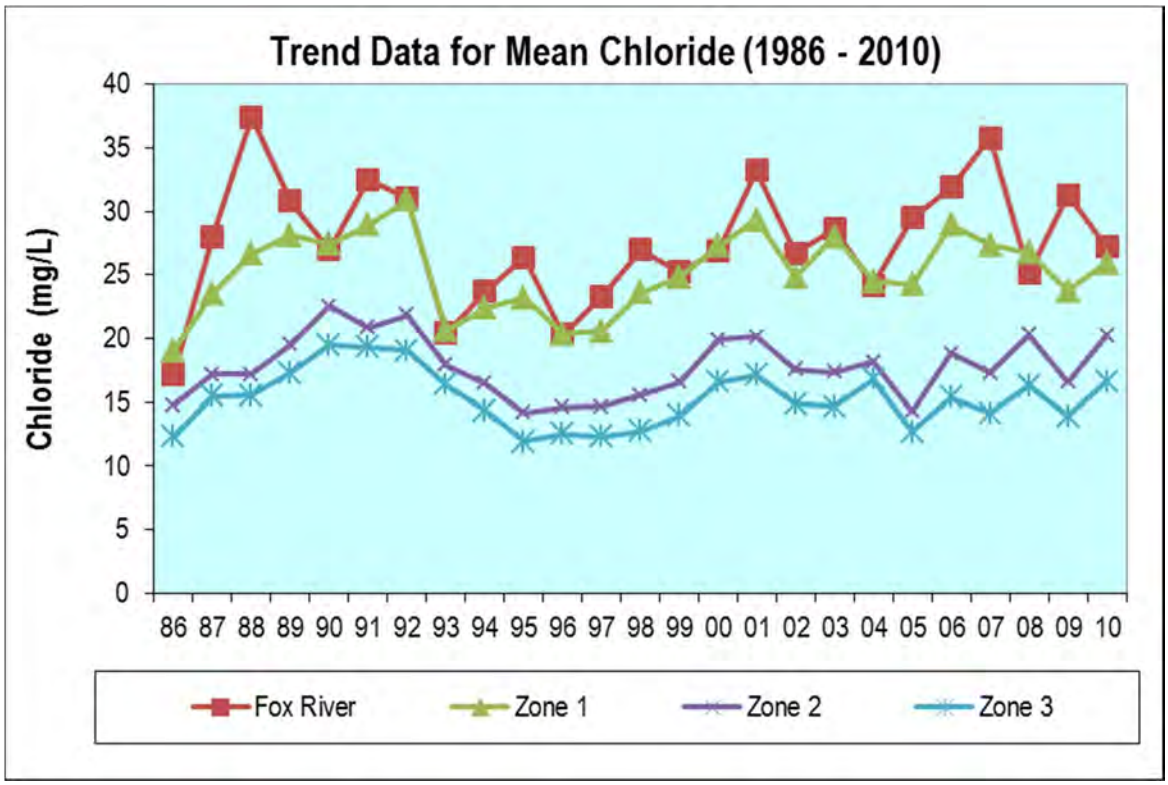

Figure 14. Long-term mean total chloride concentrations by zone (1986 – 2010).

Secchi Depth

Figure 15 presents Secchi depth data for all survey dates during 2010, while Figure 16 presents Secchi depth long-term trend data for the period 1986 – 2010.

Temporal variations in Secchi depth readings are dramatic in the Fox River and Green Bay. Runoff within the basin from the spring thaw typically contributes substantial amounts of suspended solids and nutrients to the water system, resulting in major reductions in clarity. Correlation between Secchi depth, total phosphorus, and chlorophyll *a* has been observed historically, though this relationship has become less significant since the zebra mussel invasion (Qualls, 2003).

The 2013 State of the Bay Report (UWSG, 2013) includes a discussion of modeling that was done during the TMDL development to predict future expected Secchi depths, which should result from meeting the TP and TSS targets. Results of that modeling effort estimated that a Secchi depth value of 1.14 meters in Zones 1 and 2 would be achieved. The report goes on to state:

> *As the numeric targets for this TMDL are met, improved water clarity in lower Green Bay is expected, as well as other conditions suitable to support a diverse biological community, including a robust and sustainable area of submersed aquatic vegetation (e.g., Vallisneria americana) in shallow water areas. Meeting the numeric targets for this TMDL will achieve the aquatic life uses in the water bodies in the basin*.

Historically, Secchi depths observed in Zone 1 are very similar to the Fox River, as Zone 1 essentially acts as a mixing zone for the Fox River discharge. Both the lower Fox River and Zone 1 are also impacted by wind driven re-suspension due to the shallow depths observed. Zone 2 Secchi values typically improve dramatically as compared to Zone 1, the result of mixing with mid-Bay water as well as enhanced settling due to the hydrologic and geomorphological characteristics of that region. Figure 15 demonstrates the comparison between observed Secchi disc values in Zones 1 and 2 during the 2010 monitoring period to the 1.14 meter TMDL prediction.

Unusually low spring Fox River flows may be responsible for the relatively higher spring Secchi depth values seen in Zones 2 and 3 in May and early June. However, mean Secchi depth of the lower Bay (i.e. Zone 1 and 2) observed for the 2010 field season was approximately 0.46 meters, well below the 1.14 meter TMDL prediction.

Water clarity improves dramatically in stations north of the AOC, i.e. through Zones 2 and 3. This trend is seen for most parameters, but may be most dramatic for Secchi depth. As water from the AOC enters Green Bay, it is mixed with clearer water from the mid and upper Bay. Also, the water depth increases which allows for sediment settling and limits the amount of wind induced re-suspension.

Review of Figure 16 may suggest an increasing (i.e. improving) trend in Secchi depth for Zones 2 and 3 for the 2009 – 2010 period. However, review of the long-term trend data for the river stations and Zone 1 suggests no observable trend.

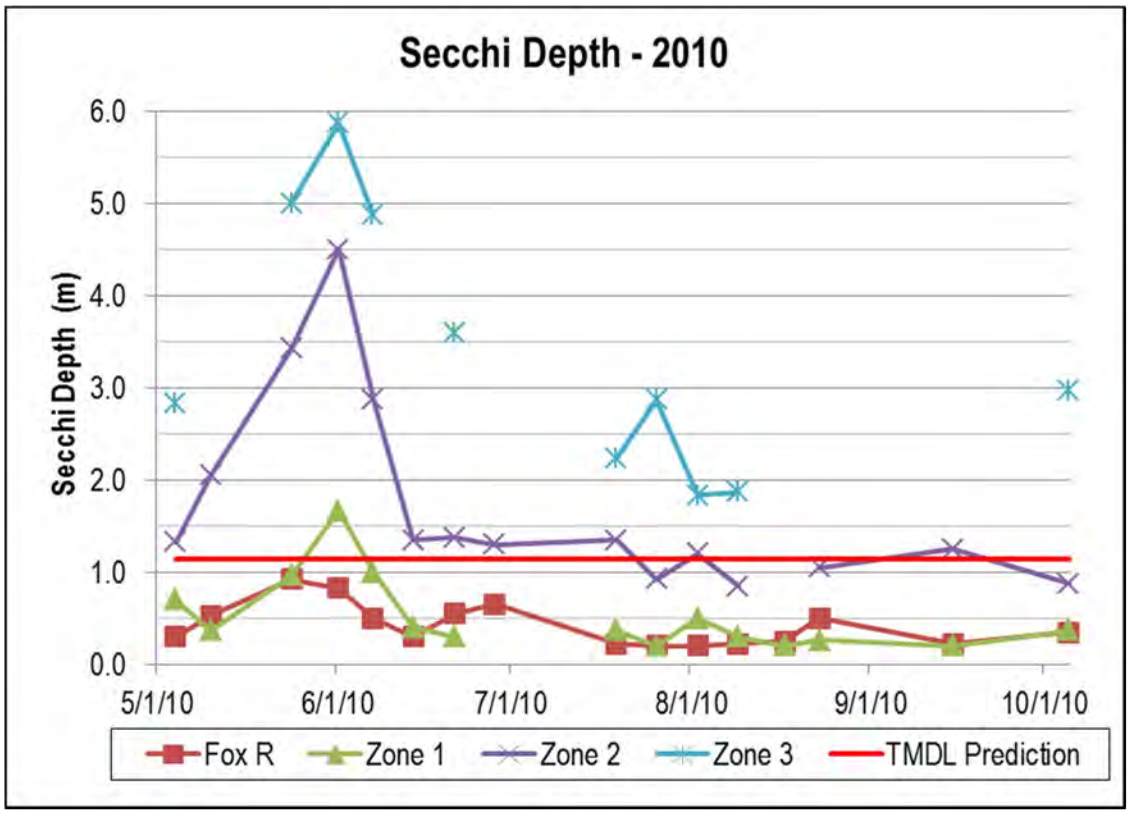

Figure 15. Mean Secchi depth values for all survey dates during 2010.

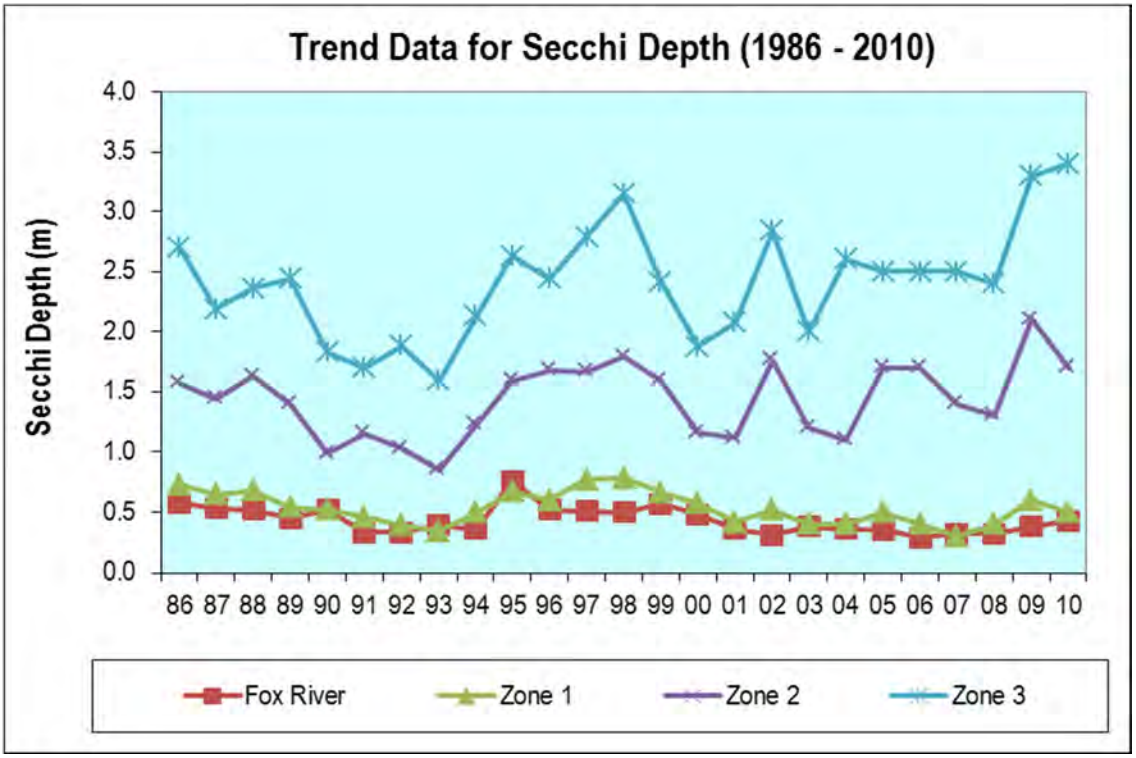

Figure 16. Long-term mean Secchi depth values by zone (1986 – 2010).

Summary of Findings from 2010 Monitoring

Notable water quality observations during the 2010 sampling year are as follows:

- Sixteen routine water quality surveys were performed on the lower Green Bay, Fox River, and East River. One survey included analysis for heavy metals and organic trace contaminants.
- Phosphorus concentrations in the AOC generally exceeded the TMDL target goal of 0.100 mg/L, though the goal was met during May.
- Chlorophyll *a* continues to show high variability throughout the study area, though a slight downward trend in the AOC area may be evident over the full period of record.
- Suspended solids concentrations in the AOC exceeded the TMDL target goal of 18 mg/L for the Fox River stations, but the Zone 1 annual average just met the target on a seasonal mean basis. Throughout the sampling period, highest concentrations were typically correlated to high Fox River flows, which for 2010 occurred in mid to late summer.
- Input from the Fox and East Rivers continues to be the major source of phosphorus and suspended solids to Green Bay.
- Ammonia concentrations exhibit high spatial variability within the study area. A slight downward trend in ammonia concentrations may be evident since 1993.
- Temporal variations in Secchi depth values are dramatic in the study area. Secchi depth values for Zones 1 and 2 were well below (i.e. did not meet) the TMDL goal of 1.14 meters.

Operation of the AWQMP clearly demonstrates the level of commitment towards environmental stewardship by GBMSD. Collaborative efforts with the WDNR, US Geological Survey, University of Wisconsin Sea Grant Institute, the University of Wisconsin – Milwaukee, and the Brown County Health Department have been mutually beneficial and should be continued. These partnerships are vital to gaining a better understanding of the water quality of the lower Fox River and Green Bay.

Acknowledgments

For 2010, the GBMSD AWQMP was conducted by Tracy Valenta, Water Resources Specialist. The Water Resources Technician, who provided essential assistance with field work, was Allie Thut. Assistance from other GBMSD Laboratory staff is gratefully acknowledged, including: Doris Buyarski, Debra Cawley, Erik Hepp, Bonnie Perrigoue, Mary Pischke, and Mike Urbancic. Finally, expert technical assistance with statistical analysis and Access database management was provided by Theresa Qualls.

This report was produced as a team effort by Tracy Valenta (Water Resources Specialist 2003 – 2013), John Kennedy (Environmental Programs Manager – retired), and Erin Wilcox (Water Resources Specialist since 2014). This work is part of an ongoing monitoring effort, which is funded by GBMSD.

For further information, please contact:

Erin Wilcox
Water Resources Specialist
GBMSD
2231 North Quincy Street
Green Bay, WI 54302
920-438-1088
ewilcox@newwater.us

References

Qualls, T.M. 2003. *Analysis of the Impacts of the Zebra Mussel, Dreissena polymorpha, on Nutrients, Water Clarity, and the Chlorophyll-Phosphorous Relationship in Lower Green Bay, Lake Michigan*. M.S. Thesis University of Wisconsin-Green Bay. 104 pp.

UWSG. 2013. State of the Bay Report. *University of Wisconsin Sea Grant*, Madison, WI. 153 pp.

WDNR. 2012. Total Maximum Daily Load and Watershed Management Plan for Total Phosphorus and Total Suspended Solids in the Lower Fox River Basin and Lower Green Bay. Prepared by Cadmus Group, Inc. 172 pp.

WDNR. 1993. Lower Green Bay Remedial Action Plan Update. *Wisconsin Department of Natural Resources*, Madison, WI. 152 pp.

Wetzel, R.G., Limnology: Lake and River Ecosystems, 3rd Edition. 2001. Gulf Professional Publishing. 1006 pp.

APPENDIX A

2010 Overall Summary Statistics

This Appendix contains the overall summary of the data collected for the waters of Green Bay, lower Fox River, and East River as part of the GBMSD AWQMP. The statistics represent all the values obtained during the 2010 field season for all of the 17 stations monitored from May 5, 2010 through October 5, 2010. Some of the minimum values for nutrients reflect the analytical detection limit for the parameter.

Sampling Location	Parameter	N	Mean	Maximum	Minimum	Standard Deviation
East River	Ammonia (mg/L)	47	0.129	0.425	0.017	0.103
Fox River	Ammonia (mg/L)	110	0.096	0.566	0.017	0.099
Bay Zone 1	Ammonia (mg/L)	68	0.049	0.256	0.017	0.052
Bay Zone 2	Ammonia (mg/L)	86	0.023	0.203	0.017	0.023
Bay Zone 3	Ammonia (mg/L)	40	0.018	0.044	0.017	0.004
East River	Nitrate (mg/L)	47	1.766	14.450	0.037	2.887
Fox River	Nitrate (mg/L)	110	0.375	1.005	0.012	0.263
Bay Zone 1	Nitrate (mg/L)	68	0.149	0.668	0.002	0.161
Bay Zone 2	Nitrate (mg/L)	86	0.054	0.234	0.002	0.052
Bay Zone 3	Nitrate (mg/L)	40	0.055	0.178	0.008	0.048
East River	Nitrite (mg/L)	47	0.059	0.239	0.004	0.052
Fox River	Nitrite (mg/L)	110	0.030	0.086	0.003	0.021
Bay Zone 1	Nitrite (mg/L)	68	0.014	0.053	0.004	0.012
Bay Zone 2	Nitrite (mg/L)	86	0.006	0.020	0.001	0.003
Bay Zone 3	Nitrite (mg/L)	40	0.004	0.012	0.002	0.002
East River	Total Phosphorus (mg/L)	47	0.309	0.644	0.025	0.165
Fox River	Total Phosphorus (mg/L)	110	0.126	0.237	0.021	0.048
Bay Zone 1	Total Phosphorus (mg/L)	68	0.086	0.195	0.019	0.047
Bay Zone 2	Total Phosphorus (mg/L)	86	0.042	0.129	0.010	0.028
Bay Zone 3	Total Phosphorus (mg/L)	40	0.021	0.051	0.009	0.010
East River	Orthophosphorus (mg/L)	47	0.202	0.469	0.042	0.120
Fox River	Orthophosphorus (mg/L)	110	0.054	0.131	0.010	0.030
Bay Zone 1	Orthophosphorus (mg/L)	68	0.024	0.083	0.005	0.022
Bay Zone 2	Orthophosphorus (mg/L)	86	0.010	0.045	0.005	0.010
Bay Zone 3	Orthophosphorus (mg/L)	40	0.007	0.016	0.005	0.003
East River	Total Solids (mg/L)	47	548	932	312	144
Fox River	Total Solids (mg/L)	110	305	368	248	24
Bay Zone 1	Total Solids (mg/L)	68	287	392	220	33
Bay Zone 2	Total Solids (mg/L)	86	238	296	192	26
Bay Zone 3	Total Solids (mg/L)	40	216	268	104	28

Sampling Location	Parameter	N	Mean	Maximum	Minimum	Standard Deviation
East River	Total Volatile Solids (mg/L)	47	194	364	104	55
Fox River	Total Volatile Solids (mg/L)	110	121	172	48	21
Bay Zone 1	Total Volatile Solids (mg/L)	68	113	260	64	26
Bay Zone 2	Total Volatile Solids (mg/L)	86	95	140	56	19
Bay Zone 3	Total Volatile Solids (mg/L)	40	79	108	32	19
East River	Total Suspended Solids (mg/L)	46	45.5	372	11	52.5
Fox River	Total Suspended Solids (mg/L)	110	22.7	64	6	12.2
Bay Zone 1	Total Suspended Solids (mg/L)	68	16.7	40	3	7.7
Bay Zone 2	Total Suspended Solids (mg/L)	86	7.0	16	1	4.0
Bay Zone 3	Total Suspended Solids (mg/L)	40	2.5	6	1	1.2
East River	Total Suspended Volatile Solids (mg/L)	46	7.15	46	3	6.53
Fox River	Total Suspended Volatile Solids (mg/L)	110	6.21	17	2	3.53
Bay Zone 1	Total Suspended Volatile Solids (mg/L)	68	6.10	16	2	3.00
Bay Zone 2	Total Suspended Volatile Solids (mg/L)	86	3.58	10	1	1.99
Bay Zone 3	Total Suspended Volatile Solids (mg/L)	40	1.51	3	1	0.64
East River	Chlorophyll *a* (mg/m3)	47	14.9	63	2	14.2
Fox River	Chlorophyll *a* (mg/m3)	110	41.3	151	2	38.5
Bay Zone 1	Chlorophyll *a* (mg/m3)	68	42.6	99	6	22.4
Bay Zone 2	Chlorophyll *a* (mg/m3)	86	21.9	68	2	16.2
Bay Zone 3	Chlorophyll *a* (mg/m3)	40	12.5	79	2	17.4
East River	Chloride (mg/L)	47	57.1	99	23	22.9
Fox River	Chloride (mg/L)	110	27.2	42	20	5.4
Bay Zone 1	Chloride (mg/L)	68	25.9	40	16	5.2
Bay Zone 2	Chloride (mg/L)	86	20.2	29	13	4.0
Bay Zone 3	Chloride (mg/L)	40	16.7	21	14	1.8
East River	Turbidity (mg/L)	47	49.99	476	11.8	67.4
Fox River	Turbidity (mg/L)	110	17.61	45.6	5.7	8.20
Bay Zone 1	Turbidity (mg/L)	68	12.89	32.0	3.8	6.09
Bay Zone 2	Turbidity (mg/L)	86	4.57	12.1	0.6	2.65
Bay Zone 3	Turbidity (mg/L)	40	1.92	5.0	0.6	0.97

Sampling Location	Parameter	N	Mean	Maximum	Minimum	Standard Deviation
East River	Temperature (Cº)	101	20.7	25.8	9.2	3.86
Fox River	Temperature (Cº)	352	21.8	26.3	12.2	4.21
Bay Zone 1	Temperature (Cº)	242	19.7	26.4	11.4	4.13
Bay Zone 2	Temperature (Cº)	340	18.7	25.5	11.0	4.25
Bay Zone 3	Temperature (Cº)	253	17.9	24.0	10.3	4.35
East River	Dissolved Oxygen (mg/L)	94	6.63	11.7	1.1	2.40
Fox River	Dissolved Oxygen (mg/L)	334	8.80	14.4	3.5	2.02
Bay Zone 1	Dissolved Oxygen (mg/L)	224	8.76	15.7	1.2	2.68
Bay Zone 2	Dissolved Oxygen (mg/L)	310	9.94	15.9	1.3	2.69
Bay Zone 3	Dissolved Oxygen (mg/L)	229	9.97	16.3	1.6	2.85
East River	Dissolved Oxygen %	94	74	144	14	26.32
Fox River	Dissolved Oxygen %	334	101	177	39	22.50
Bay Zone 1	Dissolved Oxygen %	224	96	168	13	28.15
Bay Zone 2	Dissolved Oxygen %	310	107	182	14	28.66
Bay Zone 3	Dissolved Oxygen %	229	106	155	16	28.73
East River	Specific Conductivity (umho/cm)	101	623	914	346	166.5
Fox River	Specific Conductivity (umho/cm)	352	393	448	327	30.6
Bay Zone 1	Specific Conductivity (umho/cm)	242	364	429	288	33.6
Bay Zone 2	Specific Conductivity (umho/cm)	340	324	380	268	26.5
Bay Zone 3	Specific Conductivity (umho/cm)	253	296	345	263	18.6
East River	pH (SU)	101	7.92	8.75	7.48	0.29
Fox River	pH (SU)	352	8.17	8.85	7.13	0.42
Bay Zone 1	pH (SU)	242	8.26	9.18	7.22	0.46
Bay Zone 2	pH (SU)	340	8.38	9.20	7.16	0.44
Bay Zone 3	pH (SU)	253	8.36	8.97	7.32	0.38
East River	Secchi (m)					
Fox River	Secchi (m)	52	0.43	1.0	0.2	0.25
Bay Zone 1	Secchi (m)	39	0.56	1.8	0.2	0.44
Bay Zone 2	Secchi (m)	56	1.74	5.7	0.2	1.32
Bay Zone 3	Secchi (m)	30	3.35	7.5	0.8	1.66