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 2012

November 2016

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 2012 AWQMP include:

- Fourteen routine water quality surveys were performed on the lower Green Bay, Fox River, and East River. Eleven surveys were performed on the mid Bay. Two surveys included analysis for heavy metals and organic trace contaminants.
- Concentrations of Total Phosphorus (TP) throughout the study area were higher in 2012 as compared to 2011. TP concentrations in the Fox River stations always exceeded the Total Maximum Daily Load (TMDL) target goal of 0.100 mg/L. The seasonal average TP concentration for the Fox River stations was the highest seen since the AWQMP began in 1986.
- Chlorophyll *a* concentrations in the Fox River and Zone 1 were dramatically higher in 2012 as compared to 2011.
- Total Suspended Solids (TSS) concentrations were generally higher as compared to data from 2011, particularly for the river and Zone 1 stations. Fox River flows during the AWQMP period were below average.
- Input from the Fox and East Rivers continues to be the major source of phosphorus and suspended solids to Green Bay.
- Chloride concentrations in the East River during 2012 were almost identical to the 2011 survey results, whereas concentrations found in the Fox River were approximately 40% higher in 2012 as compared to 2011.

- Secchi depth values for the Area of Concern (AOC) were well below (i.e. did not meet) the TMDL target goal of 1.14 meters. Secchi depth values for Zones 2 and 3 recovered somewhat in 2012 after the dramatic decrease noted in 2011.
- Acquisition of the *Bay Guardian* allowed for collaboration with outside researchers, which resulted in approximately $43,520 in grant revenue for GBMSD.

Introduction

The GBMSD AWQMP entered into its 27th year of operation in 2012. 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 program has benefited substantially with the purchase and commissioning of the *Bay Guardian* in 2011. The new vessel has brought major improvements in safety and utility to the program as compared to the smaller boat which it replaced. The ability to safely and efficiently expand the study area into central Green Bay will help GBMSD and the region better understand the aquatic resources of the Bay. Monitoring results from the six stations comprising Zone 4 have already added new insights into the water quality trends exhibited by Green Bay as the lower Bay waters mix with the mid Bay.

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 2012 field season the following activities were conducted under the program:

- Continuous operation of a weather station throughout 2012. This data is available upon request and is not catalogued in this report.
- Fourteen routine water quality surveys were performed on the lower Green Bay, Fox River, and East River. Eleven surveys were performed on the mid Bay. 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 two of the routine water surveys (July 10 and August 20, 2012).
- Deployment of one continuous monitoring station at Entrance Light.
- Co-funding of the US Geological Survey streamflow monitoring station on the lower Fox River at the U.S. Venture dock.

- Bacteriological monitoring June through August on the lower Fox River and Green Bay in partnership with the Brown County Health Department.
- Acquisition of the *Bay Guardian* allows GBMSD to collaborate with other agencies conducting research on Green Bay, and to be included in associated grant funding. During the 2012 field season GBMSD participated in three separate projects, including: participation with the University of Wisconsin – Milwaukee involving hypoxia investigations; participation with Michigan Technological University involving investigations of harmful algal blooms; participation in a Wisconsin Department of Natural Resources (WDNR) investigation into harmful algal blooms and cyanotoxin levels in the Green Bay AOC; (Note: all algal samples were analyzed by the State Lab of Hygiene); and, support for a University of Wisconsin – Madison graduate student conducting research on Green Bay.

Methods

Sampling

GBMSD samples ambient water quality at 23 stations that are located on the lower Green Bay, Fox River, and East River. This report includes data from the 2012 water year; sampling began on June 5, 2012 and was completed on October 3, 2012. Every effort was made to sample the following stations three times per month during the 2012 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
- Zone 4 of Green Bay – Sites 60-75 (new sites added in 2011)

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 July 10 and August 20, 2012 surveys. 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 or an automated pump.

One continuous monitor was deployed during the 2012 field season. The monitor was located in Zone 2 of Green Bay near the Entrance Light House. The monitor collected data for an approximate duration of 14 weeks during the 2012 field season.

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.

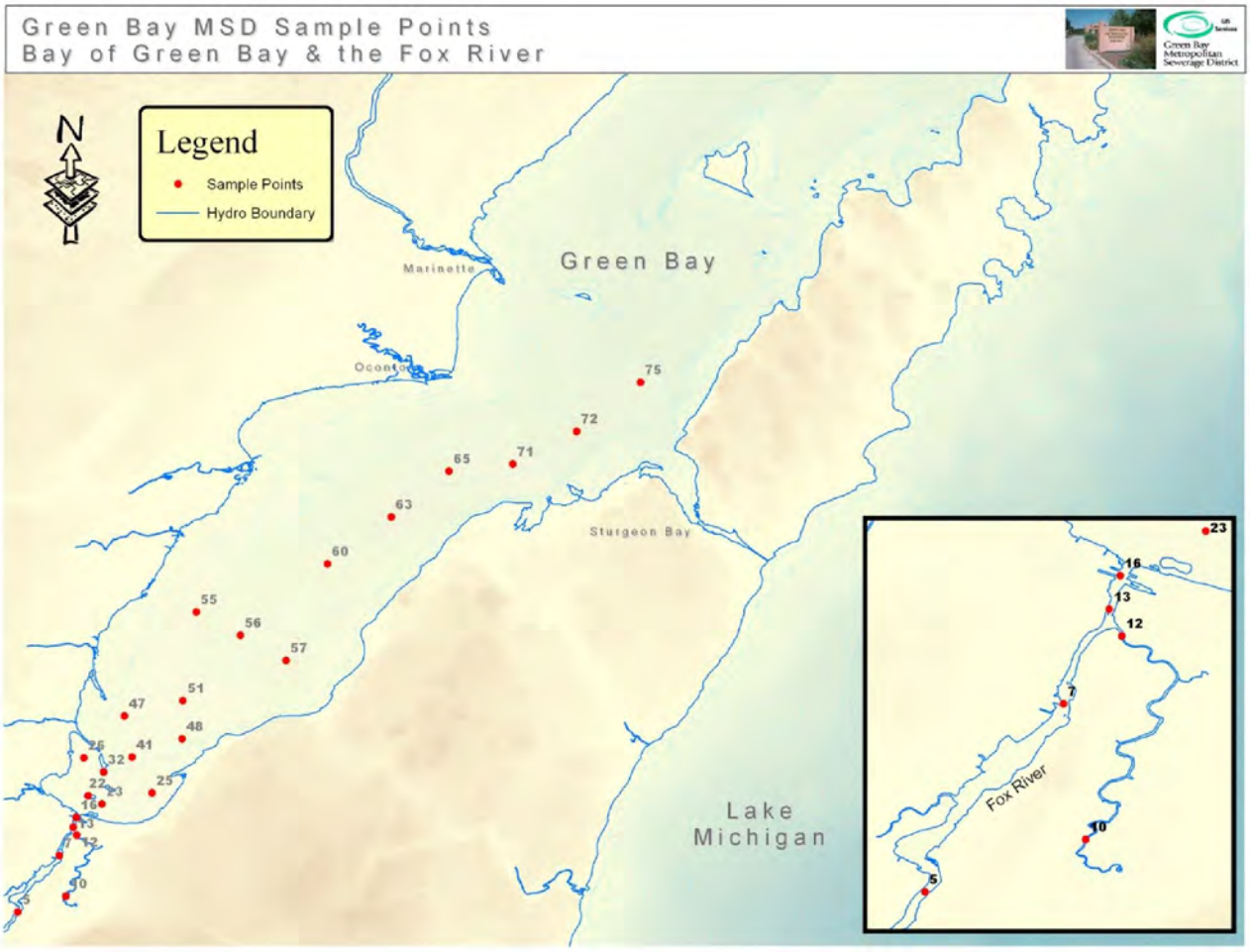

Figure 1: Sampling Location Map

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 2012 field season for all of the 23 stations monitored from June 5, 2012 through October 3, 2012. 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 July 10 and August 20, 2012 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 2012 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 Zone 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. Zone 4 stations begin 18 miles north of the Fox River. The stations are located approximately five miles apart and run on a northerly transect ending a few miles north of the Sturgeon Bay ship channel, approximately four miles southwest of Monument Shoal. 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 2012 data, expressed as mean concentration of all stations within that specific zone. The x - axis shows the dates, but the reader is cautioned

that the data is 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 14 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. For this report, the Zone 4 data are not included in the long-term trend graphs, but are listed in Appendix A. Also 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 2012, while Figure 3 presents TP long-term trend data for the period 1986 – 2012.

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 throughout the study area were higher in 2012 as compared to 2011. TP concentrations in the Fox River stations always exceeded the TMDL target goal of 0.100 mg/L (WDNR, 2012) (Figure 2). The Zone 1 stations exhibited TP concentrations below the 0.100 mg/L target in May and June, but then exceeded the target for the rest of the monitoring season. 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 that TP concentrations in the rivers and Zone 1 increased noticeably by late June. Concentrations in Zones 2 – 4 increased more slowly as the summer advanced. Figure 2 also shows that concentrations in the Fox River approached concentrations observed for the East River stations, especially as compared to 2011 data. Concentrations of TP in the East River also increased between 2011 and 2012, from a seasonal average of 0.28 mg/L to 0.39 mg/L. TP concentrations are seen to decrease dramatically between the Fox River and Zone 4. However, even the Zone 4 stations exceeded the Lake Michigan TP Criterion of 0.007 mg/L (Wisconsin Natural Resources Chapter NR 102).

Figure 3 shows the dramatic increase for TP in 2012 compared to 2011. The TP increase was most dramatic for the Fox River stations and Zone 1. The seasonal average TP concentration for the Fox River stations was the highest seen since the AWQMP began in 1986. Concentrations increased to a lesser extent in Zones 2 and 3, most likely a result of dilution with mid Bay water. A full explanation for the 2012 concentration increase is currently unknown. Seasonal flow for the Fox River exhibited a typical spring pulse, but the remainder of the summer period exhibited fairly low flows (Figure 10).

Review of Figure 3 demonstrates the high degree of historic variability seen in phosphorus data for the entire study area. 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 high for those years both temporally and spatially. But the annual averages were also 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.

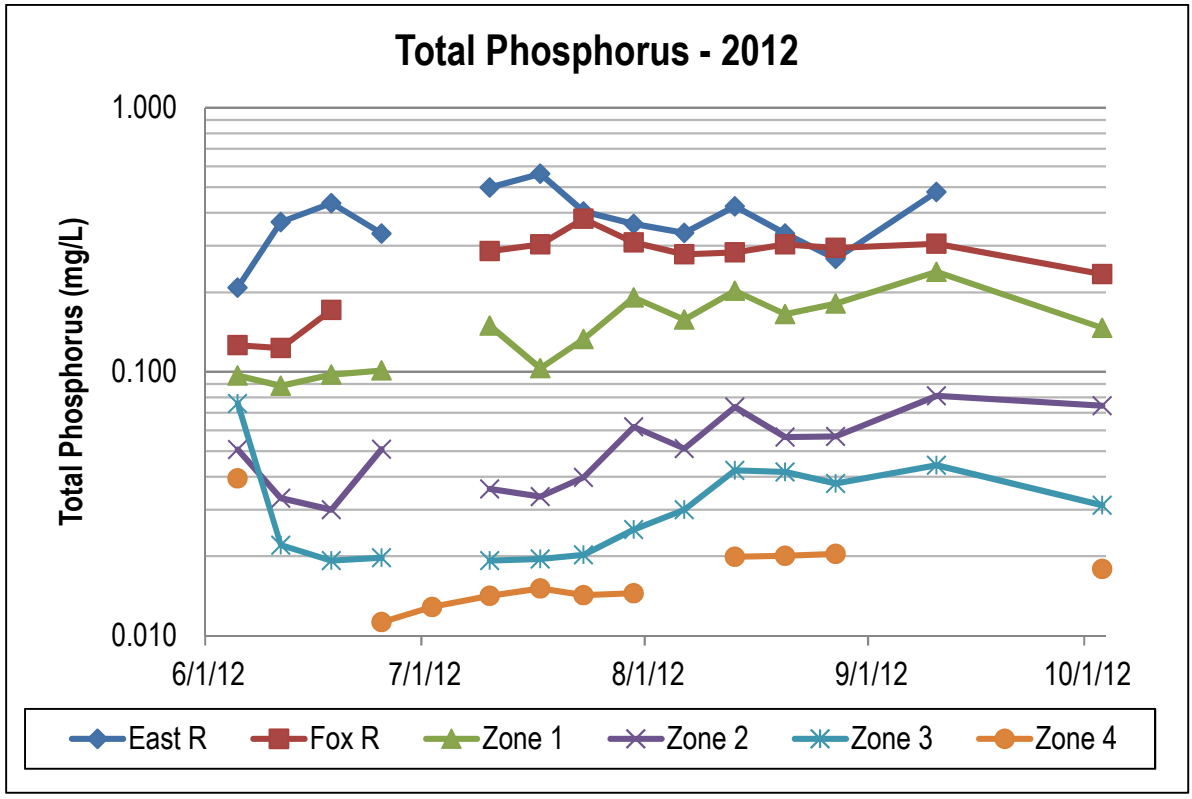

Figure 2. Mean TP concentrations for all survey dates during 2012.

Note: Vertical axis is log scale.

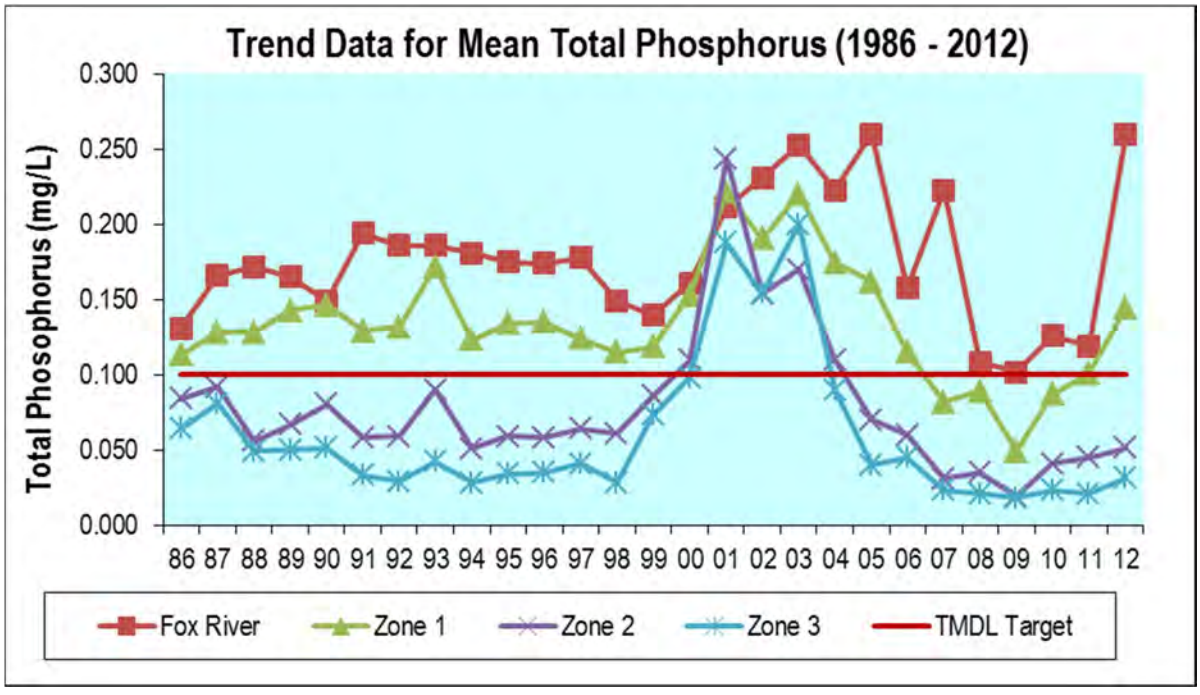

Figure 3. Long-term mean TP concentrations by zone (1986 – 2012).

Orthophosphorus

Figure 4 presents OP data for all survey dates during 2012, while Figure 5 presents OP long-term trend data for the period 1986 – 2012.

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, and so total phosphorus is generally viewed as the main nutrient indicator for trophic status.

For 2012, OP concentrations show increases similar to the TP observations for the river and Zone 1 stations. OP results from Zones 2 – 4 show no large difference from the 2011 data. Concentrations throughout the system dropped precipitously in late September.

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.

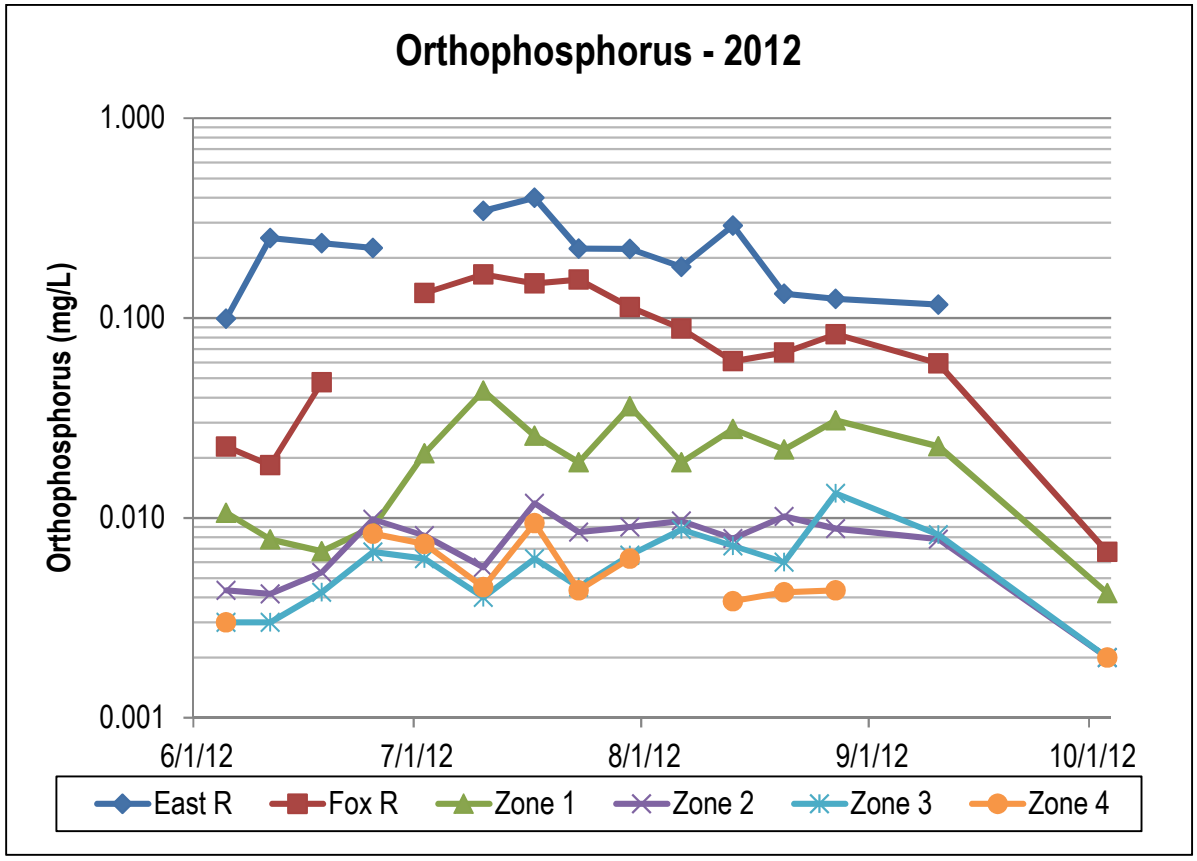

Figure 4. Mean OP concentrations for all survey dates during 2012.

Note: Vertical axis is log scale.

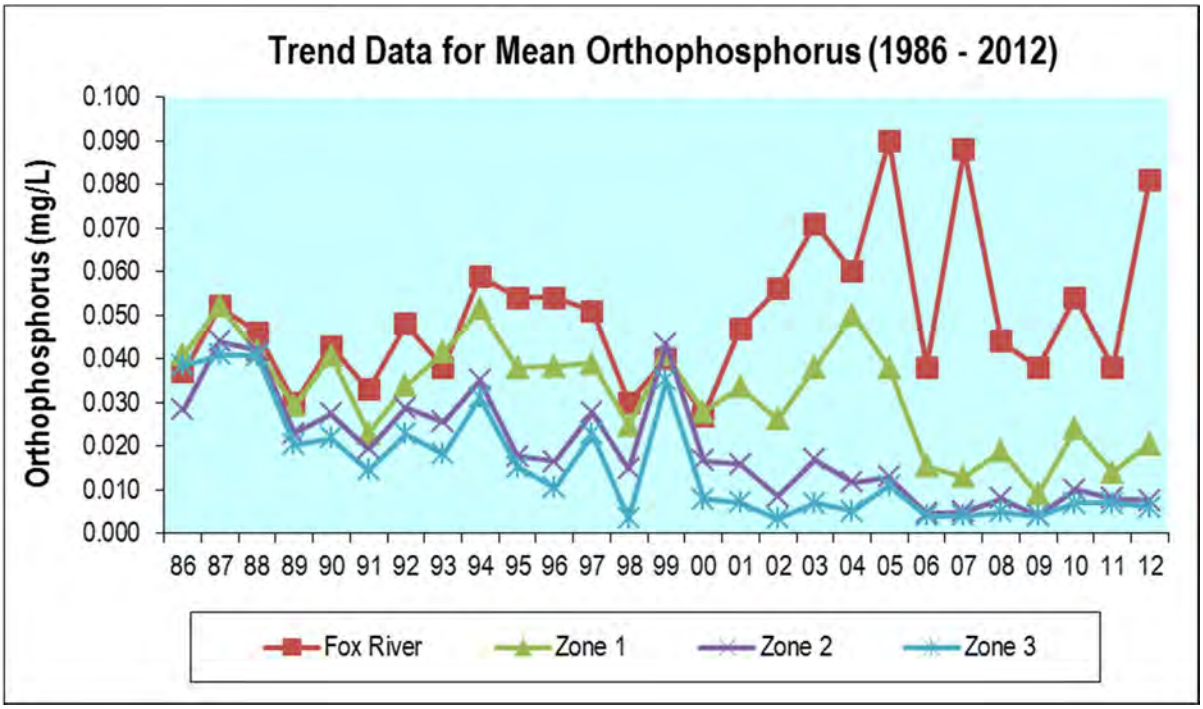

Figure 5. Long-term mean OP concentrations by zone (1986 – 2012).

Chlorophyll *a*

Figure 6 presents chlorophyll *a* data for all survey dates during 2012, while Figure 7 presents chlorophyll *a* long-term trend data for the period 1986 – 2012.

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. This tends to result in "noisy" chlorophyll *a* observations throughout the AWQMP study area. 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.

Chlorophyll *a* concentrations in the Fox River and Zone 1 were dramatically higher in 2012 as compared to 2011, following the trend observed with phosphorus. Chlorophyll *a* concentrations in the Fox River and Zone 1 reached elevated levels by mid - July and continued until October.

Review of Figure 7 demonstrates the difficulty towards identification of any long term trends in concentration for this parameter. Visually, a very slight downward trend in chlorophyll *a* concentration in the Fox River and Zone 1 may be seen for the 1997 – 2011 period, but the 2012 data indicates otherwise. What can be stated is that the relationship between nutrients, suspended solids, light penetration, and algal growth in the lower Fox River and Green Bay is highly complex and may be better explained with sophisticated statistical and empirical analyses.

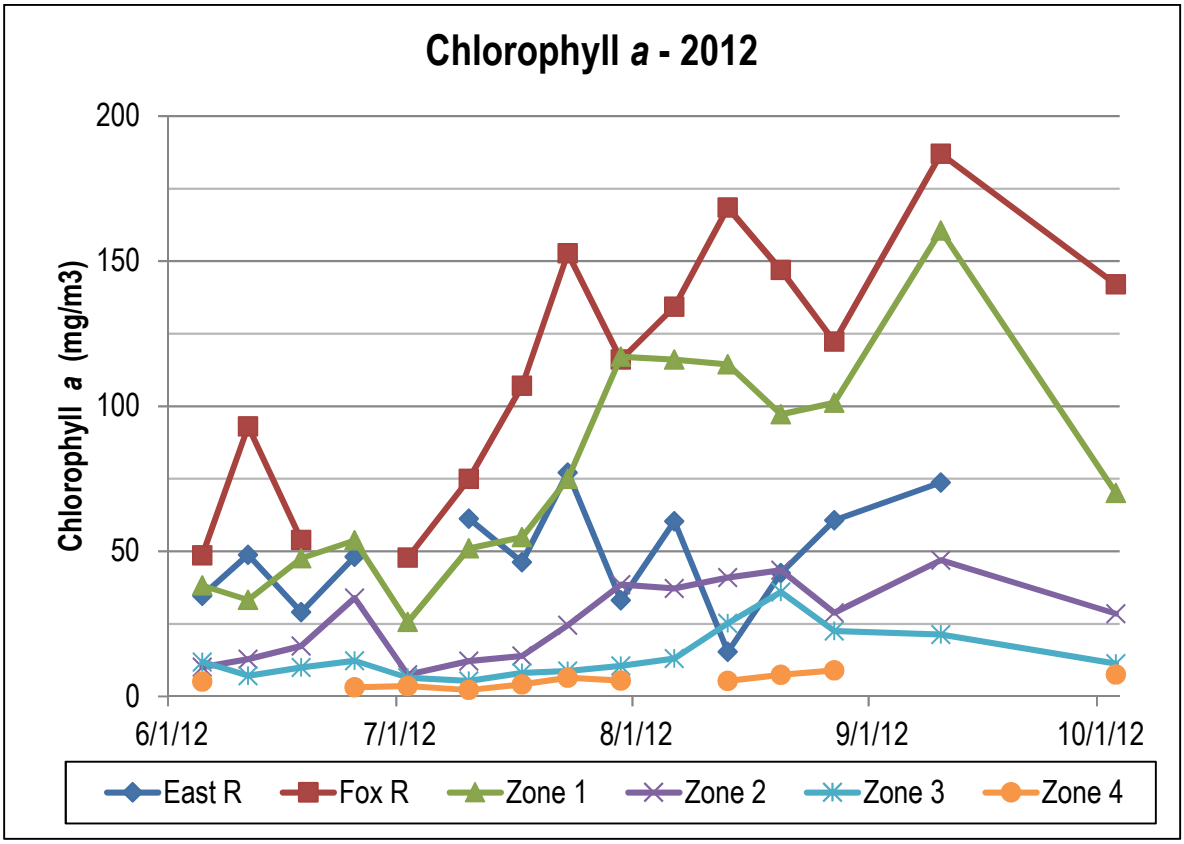

Figure 6. Mean chlorophyll *a* concentrations for all survey dates during 2012.

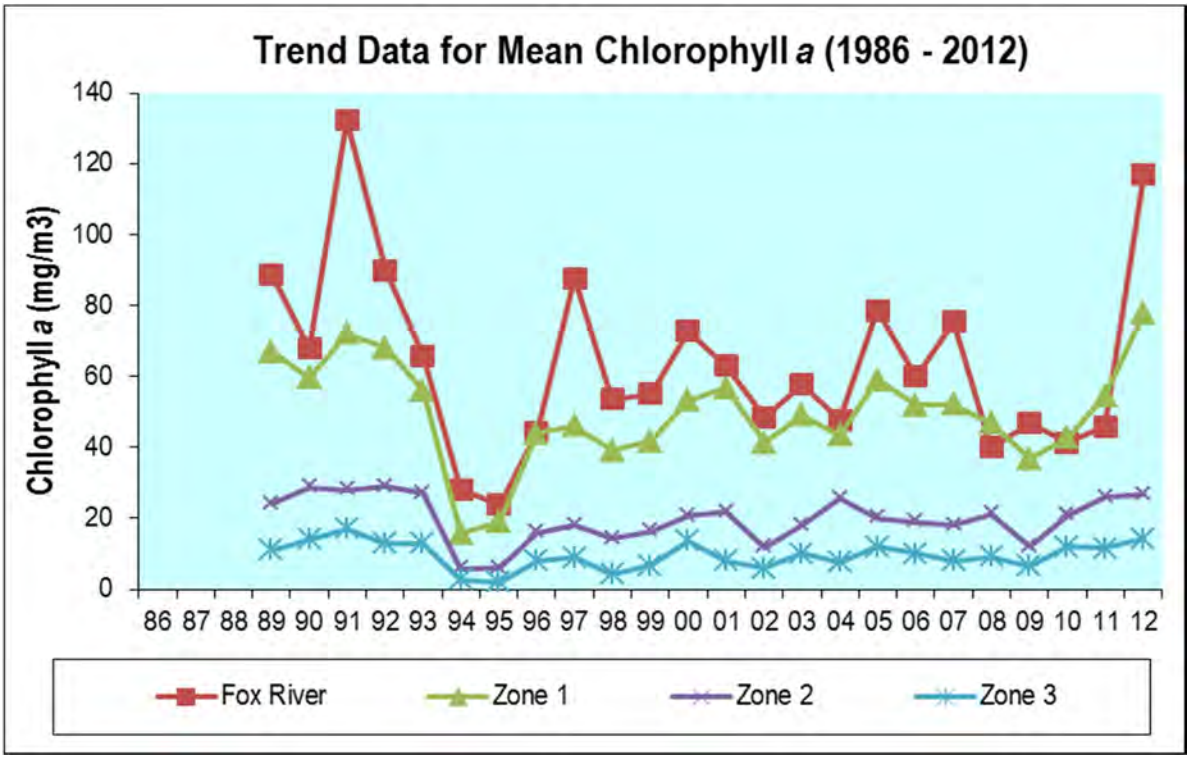

Figure 7. Long-term mean chlorophyll *a* concentrations by zone (1986 – 2012).

Total Suspended Solids

Figure 8 presents TSS data for all survey dates during 2012, while Figure 9 presents TSS long-term trend data for the period 1986 – 2012.

TSS was identified along with phosphorus in the WDNR'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.

Review of Figure 8 shows that TSS concentrations were generally higher as compared to data from 2011, particularly for the river and Zone 1 stations. Concentrations for the East and Fox Rivers and Zone 1 began to rise in early July and continued to climb until mid – September, similar to the trend observed for chlorophyll *a*. Overall, the 2012 seasonal average values were higher for the river and Zone 1 stations than were observed in 2011. These observations correspond to below average Fox River flow for the June through September period (Figure 10).

Review of Figure 9 shows the increase of annual average TSS values from the rivers and Zone 1, with only minor increases seen in Zones 2 and 3. The 2012 seasonal average TSS concentrations for the mid bay region (Zone 3) stations were essentially identical to the 2011 results. It would appear that even with increased TSS loading from the Fox River, the removal of suspended solids (presumably the result of settling) as that water mass moves north reduces the water column concentration to 5 mg/L or less in the vicinity of Zone 3.

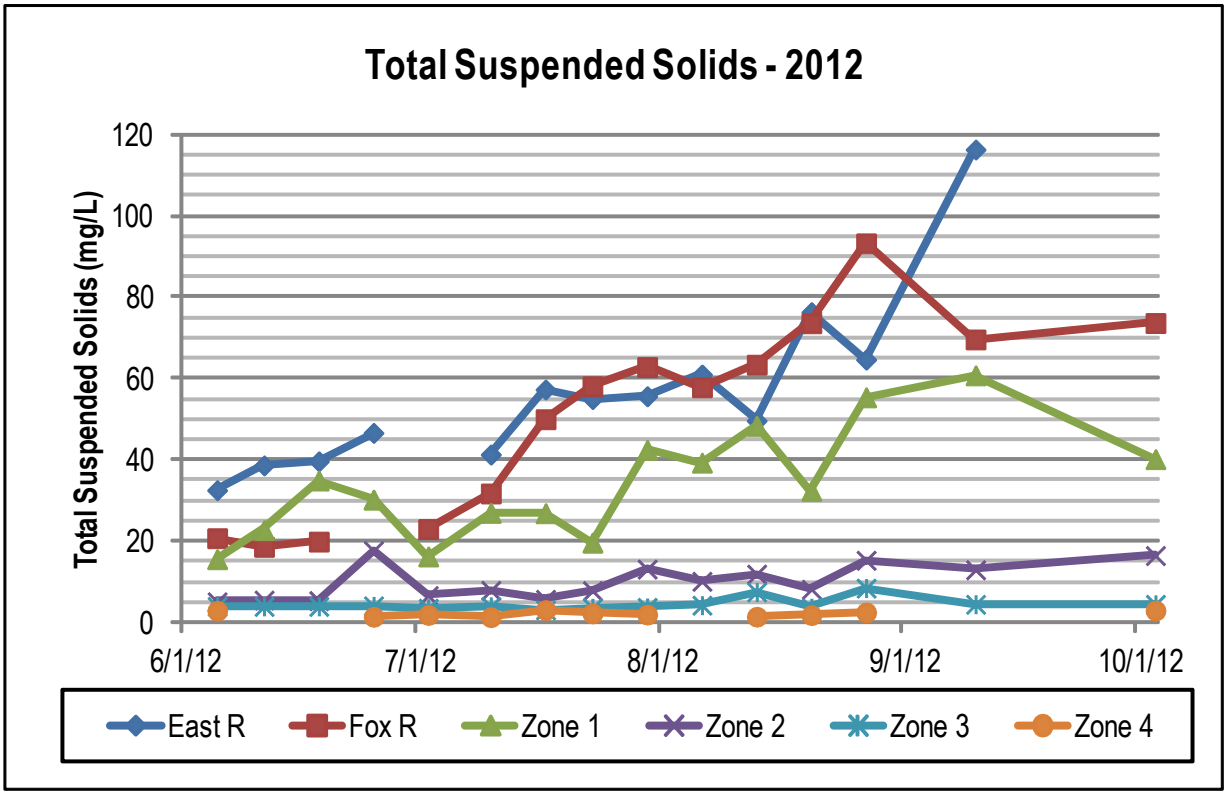

Figure 8. Mean TSS concentrations for all survey dates during 2012.

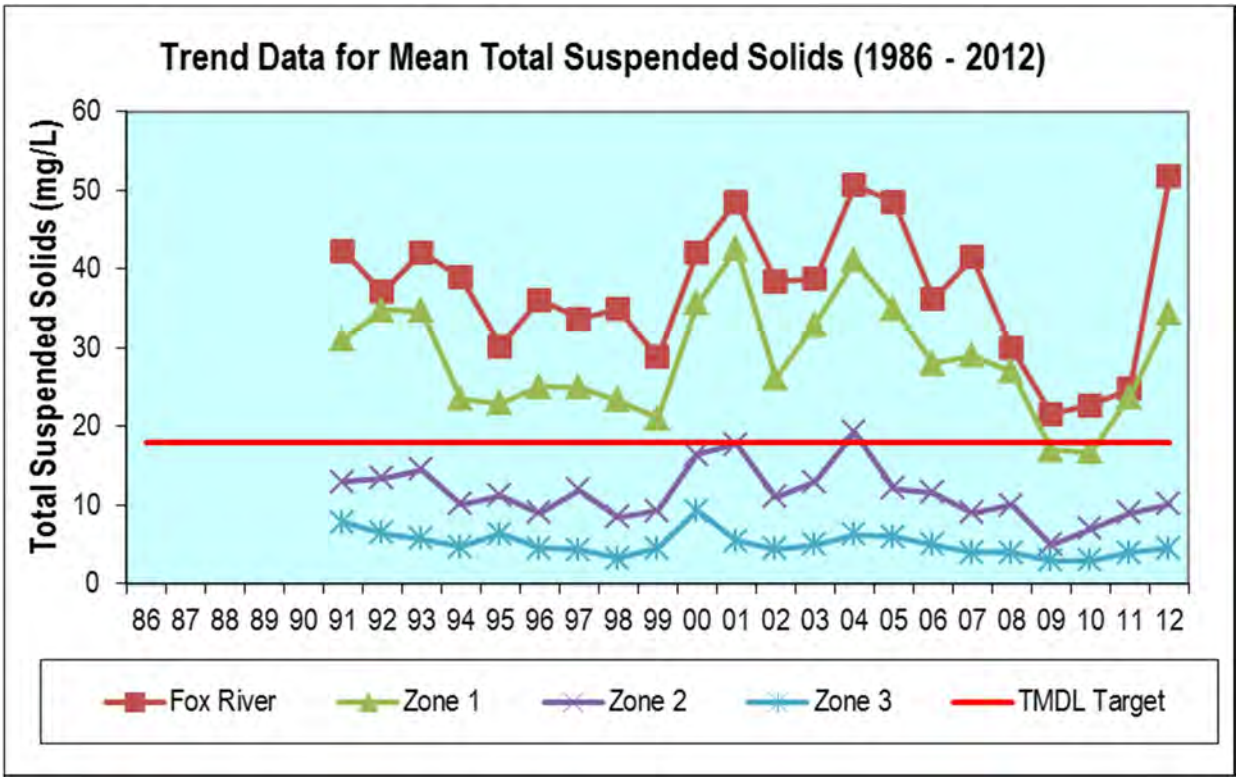

Figure 9. Long-term mean TSS concentrations by zone (1986- 2012).

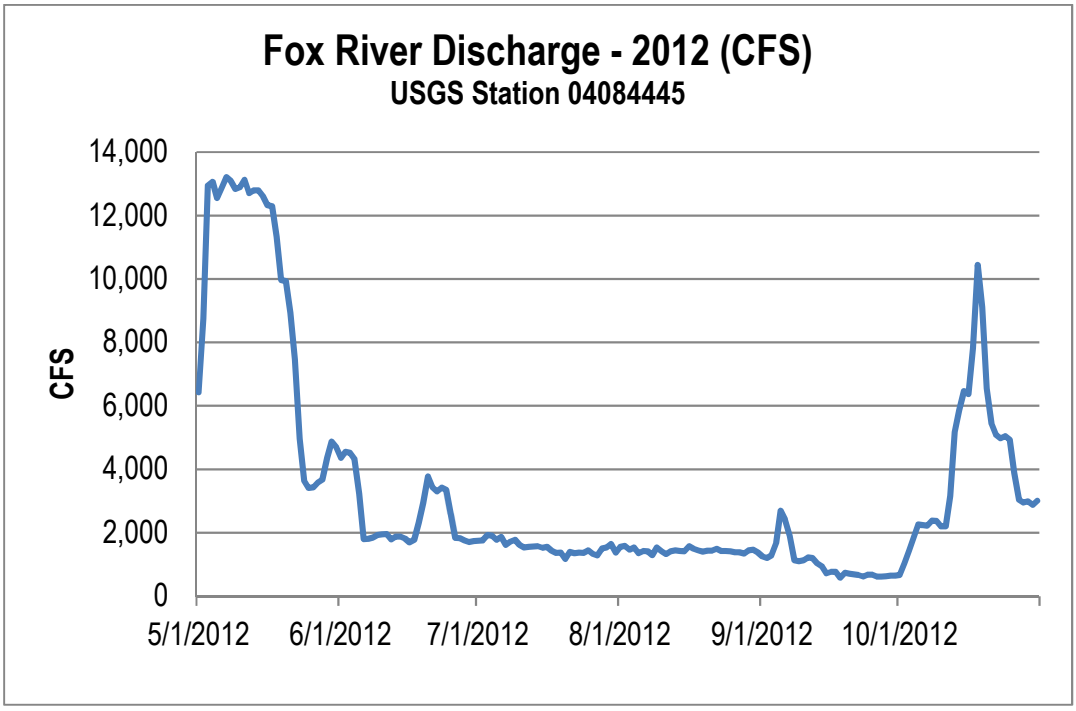

Figure 10. Lower Fox River discharge in CFS; April 1 – October 31, 2012.

Ammonia

Figure 11 presents ammonia data for all survey dates during 2012, while Figure 12 presents ammonia long-term trend data for the period 1986 – 2012.

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 fresh water 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 most ammonia concentrations for Zones 1 through 4 were low, i.e. near the detection limit. Concentrations for the East and Fox Rivers were much higher, though highly variable. Seasonal average values for the East and Fox Rivers were also much higher than were reported in 2011.

Review of Figure 12 shows the long-term variability for this parameter. The 2012 Fox River annual average shows a substantial increase as compared to 2011.

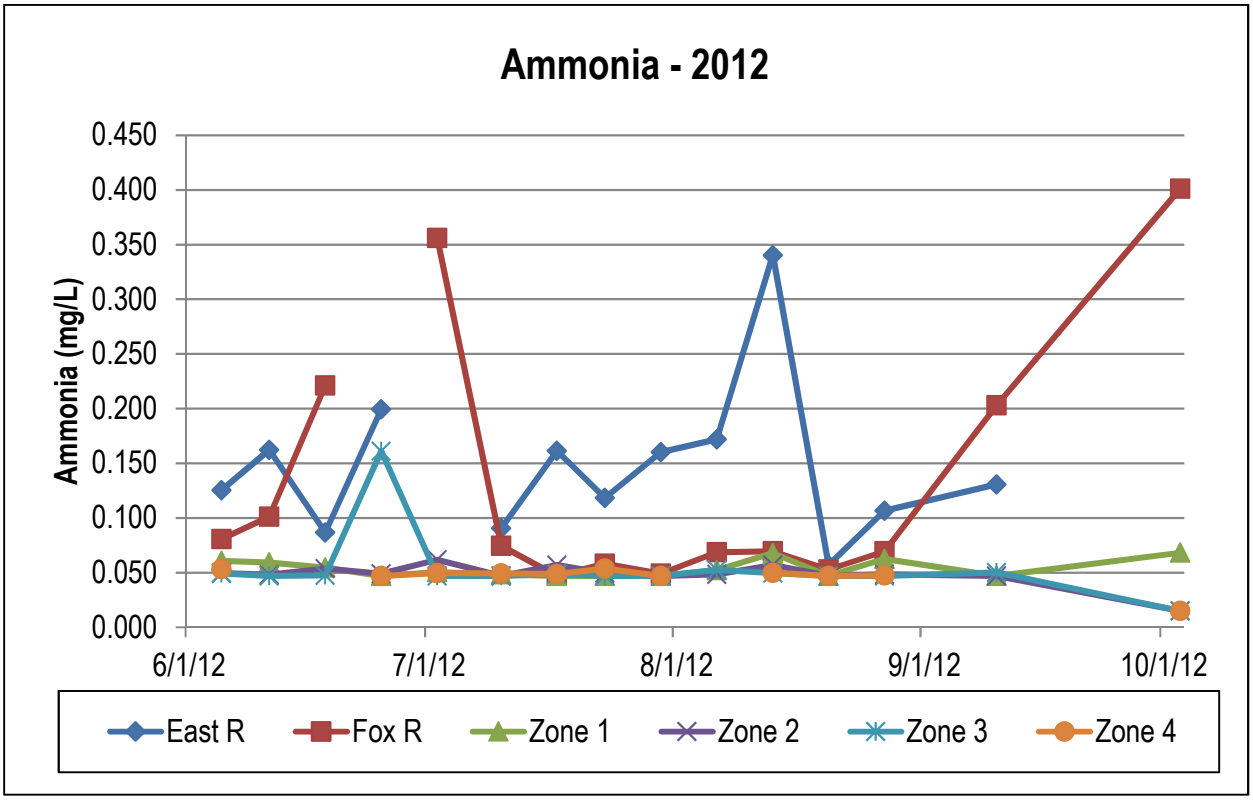

Figure 11. Mean ammonia concentrations for all survey dates during 2012.

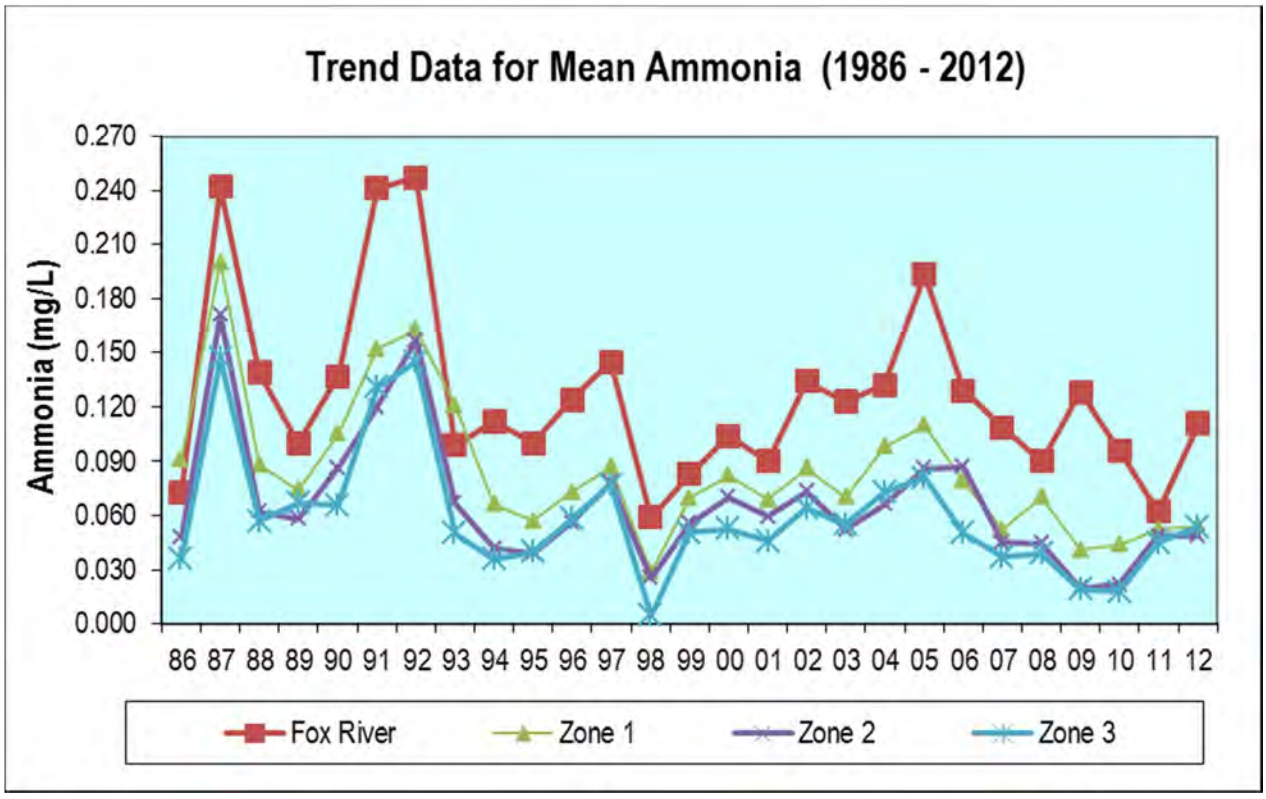

Figure 12. Long-term mean total ammonia concentrations by zone (1986 – 2012).

Chloride

Figure 13 presents chloride data for all survey dates during 2012, while Figure 14 presents chloride long-term trend data for the period 1986 – 2012.

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 receives large inputs of chloride. Concentrations in the East River during 2012 were almost identical to the 2011 survey results. Concentrations found in the Fox River were approximately 40% higher in 2012 as compared to 2011. Seasonal average concentrations in Zone 1 were slightly higher in 2012, while results for Zones 3 - 4 were essentially identical for both years.

Figure 14 shows no discernable long-term trend in chloride concentrations. Concentrations decrease as the Fox River plume is diluted with Green Bay water.

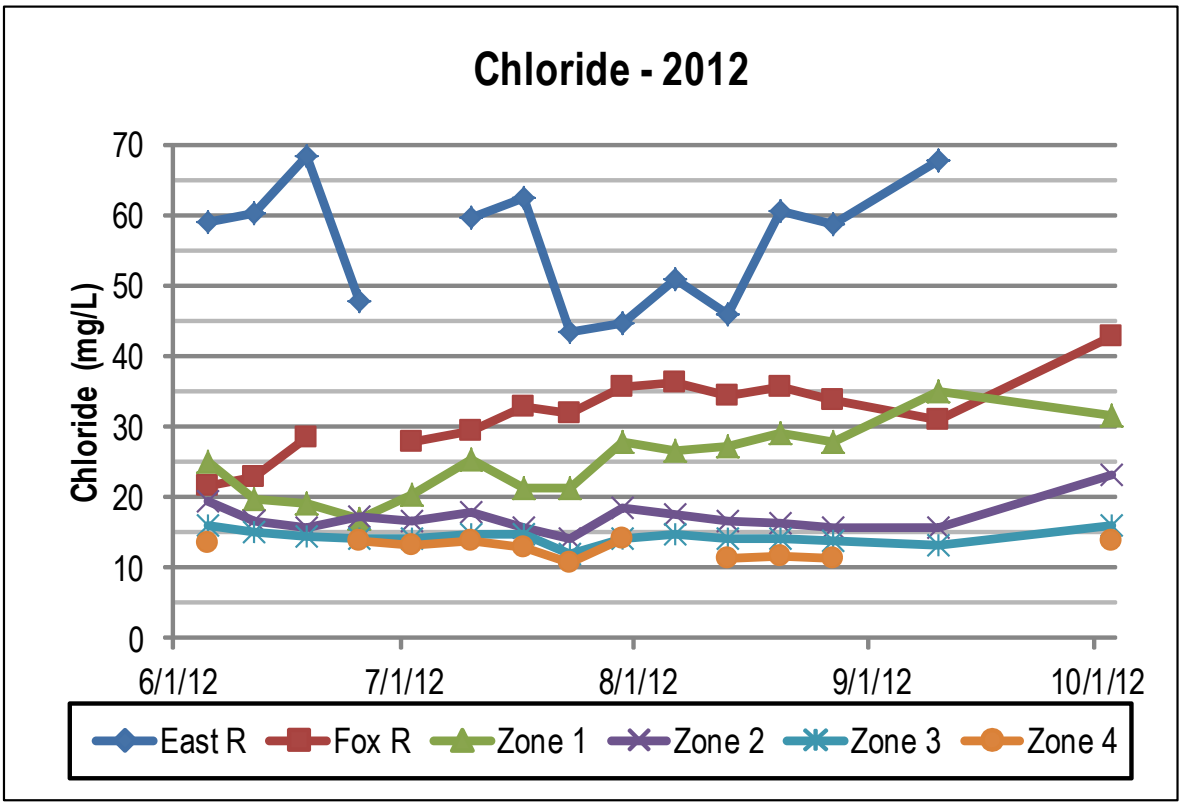

Figure 13. Mean chloride concentrations for all survey dates during 2012.

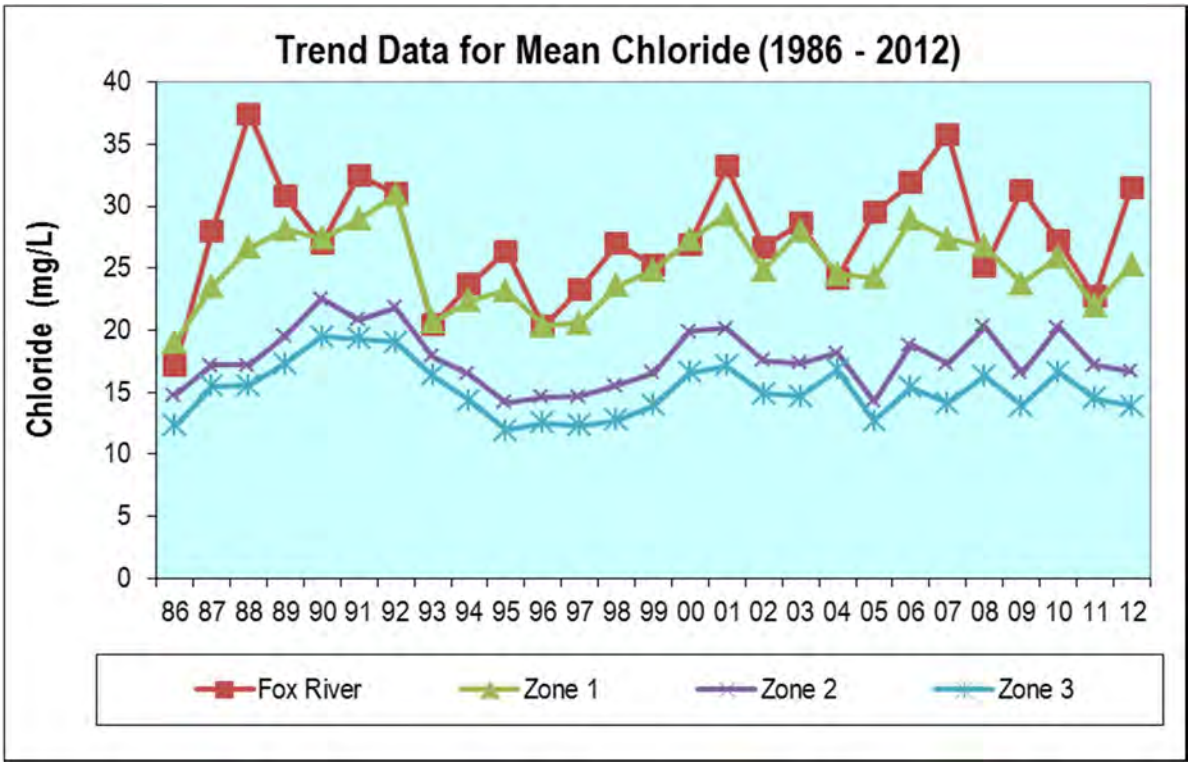

Figure 14. Long-term mean total chloride concentrations by zone (1986 – 2012).

Secchi Depth

Figure 15 presents Secchi depth data for all survey dates during 2012, while Figure 16 presents Secchi depth long-term trend data for the period 1986 – 2012.

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 2012 monitoring period to the 1.14 meter TMDL prediction.

Water clarity improves dramatically in stations north of the AOC, i.e. through Zones 2, 3 and 4. 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 cleaner 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.

Compared to 2011, observed 2012 Secchi depth values decreased in the Fox River, were about the same in Zone 1, and increased slightly in Zones 2 – 4 (Figure 15).

Review of Figure 16 shows that the secchi depth values for Zones 2 and 3 recovered somewhat after the dramatic decrease noted in 2011.

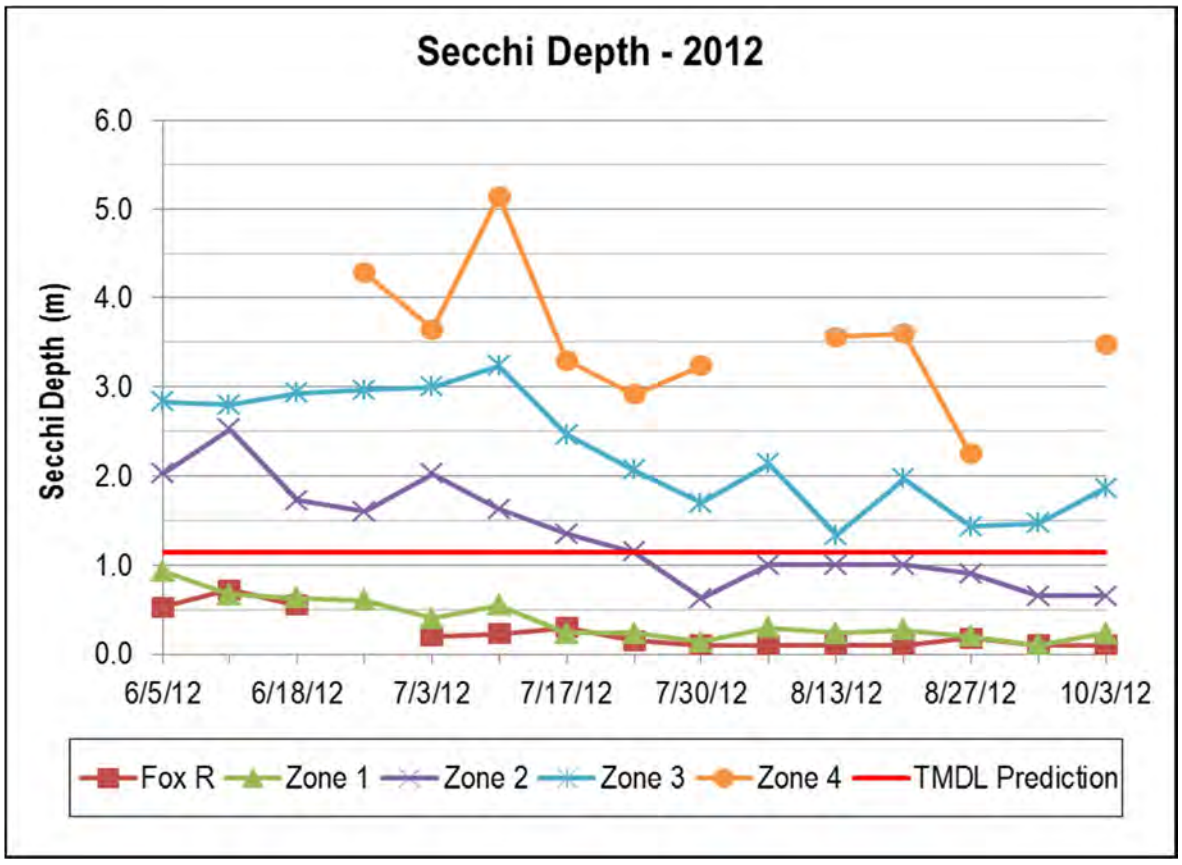

Figure 15. Mean Secchi depth values for all survey dates during 2012.

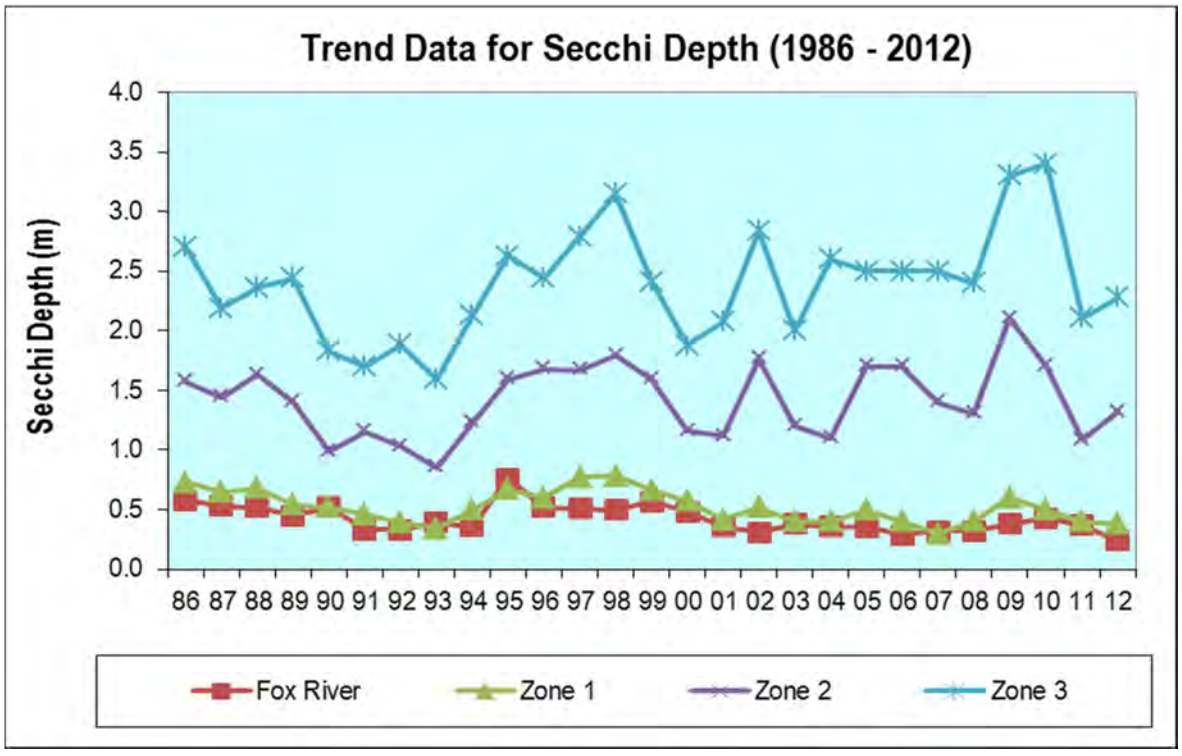

Figure 16. Long-term mean Secchi depth values by zone (1986 – 2012).

Grant Participation

Acquisition of the new workboat in 2011 expanded opportunities for collaboration with other Green Bay area researchers, including the option of adding GBMSD as co-investigator in the principle investigator's grant application. GBMSD collaborated in four research efforts during 2012 that resulted in approximately $43,520 of revenue. These studies included:

- "Green Bay Hypoxia: Biogeochemical Dynamics, Watershed Inputs and Climate Change." University of Wisconsin – Milwaukee. Principle Investigator – Dr. Val Klump.
- "Harmful Algal Bloom Mapping for the Great Lakes." Michigan Technological University. Principle Investigator – Dr. Robert Shuckman.
- "Frequency and Severity of Harmful Algal Blooms of Cyanobacteria and Cyanotoxin (Microcystin) in the Green Bay Area of Concern." Joint effort between GBMSD and WDNR. Principle Investigator – Tracy Valenta.
- Support for UW – Madison graduate student Bryan Althouse conducting research in Green Bay.

Summary of Findings from 2012 Monitoring

Notable water quality observations during the 2012 sampling year are as follows:

- Fourteen routine water quality surveys were performed on the lower Green Bay, Fox River, and East River. Eleven surveys were performed on the mid Bay. Two surveys included analysis for heavy metals and organic trace contaminants.
- Concentrations of TP throughout the study area were higher in 2012 as compared to 2011. TP concentrations in the Fox River stations always exceeded the TMDL target goal of 0.100 mg/L. The goal was met in Zone 1 in May and June, but then exceeded the target for the rest of the monitoring season. The seasonal average TP concentration for the Fox River stations was the highest observed since the AWQMP began in 1986.
- Chlorophyll *a* concentrations in the Fox River and Zone 1 were dramatically higher in 2012 as compared to 2011.
- TSS concentrations were generally higher as compared to data from 2011, particularly for the river and Zone 1 stations. Concentrations for the East and Fox Rivers and Zone 1 began to rise dramatically in early July and continued to climb until mid – September, similar to the trend observed for chlorophyll *a*. Fox River flows during the AWQMP period were below average.

- Input from the Fox and East Rivers continues to be the major source of phosphorus and suspended solids to Green Bay.
- Chloride concentrations in the East River during 2012 were almost identical to the 2011 survey results, whereas concentrations found in the Fox River were approximately 40% higher in 2012 as compared to 2011.
- Secchi depth values for the AOC were well below (i.e. did not meet) the TMDL target goal of 1.14 meters. Secchi depth values for Zones 2 and 3 recovered somewhat in 2012 after the dramatic decrease noted in 2011.
- Acquisition of the *Bay Guardian* allowed for collaboration with outside researchers, which resulted in approximately $43,520 in grant revenue for GBMSD.

Expansion of the AWQMP to the mid Bay (Zone 4) since 2011 has generated important information about the interaction between lower and mid Bay waters. The utility of this information will only increase in future years.

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, University of Wisconsin – Madison 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.

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APPENDIX A

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 2012 field season for all of the 23 stations monitored from June 5, 2012 through October 3, 2012. Some of the minimum values for nutrients reflect the analytical detection limit for the parameter.

Sampling Location	Parameter	N	Average	Maximum	Minimum	Standard Deviation
East River	Ammonia (mg/L)	39	0.144	0.579	0.047	0.111
Fox River	Ammonia (mg/L)	98	0.111	0.462	0.047	0.106
Bay Zone 1	Ammonia (mg/L)	70	0.054	0.165	0.015	0.024
Bay Zone 2	Ammonia (mg/L)	90	0.049	0.136	0.015	0.015
Bay Zone 3	Ammonia (mg/L)	58	0.054	0.504	0.015	0.061
Bay Zone 4	Ammonia (mg/L)	132	0.046	0.090	0.015	0.012
East River	Nitrate (mg/L)	39	0.453	3.029	0.002	0.685
Fox River	Nitrate (mg/L)	98	0.082	0.585	0.002	0.143
Bay Zone 1	Nitrate (mg/L)	70	0.053	0.555	0.002	0.110
Bay Zone 2	Nitrate (mg/L)	90	0.031	0.300	0.002	0.074
Bay Zone 3	Nitrate (mg/L)	58	0.045	0.300	0.002	0.081
Bay Zone 4	Nitrate (mg/L)	132	0.137	0.308	0.002	0.110
East River	Nitrite (mg/L)	39	0.033	0.107	0.005	0.027
Fox River	Nitrite (mg/L)	98	0.015	0.050	0.004	0.010
Bay Zone 1	Nitrite (mg/L)	70	0.010	0.050	0.001	0.012
Bay Zone 2	Nitrite (mg/L)	90	0.007	0.050	0.001	0.012
Bay Zone 3	Nitrite (mg/L)	58	0.007	0.050	0.001	0.012
Bay Zone 4	Nitrite (mg/L)	132	0.010	0.050	0.001	0.014
East River	Total Phosphorus (mg/L)	39	0.386	0.892	0.117	0.149
Fox River	Total Phosphorus (mg/L)	98	0.260	0.416	0.084	0.081
Bay Zone 1	Total Phosphorus (mg/L)	70	0.144	0.296	0.039	0.071
Bay Zone 2	Total Phosphorus (mg/L)	90	0.051	0.20	0.016	0.031
Bay Zone 3	Total Phosphorus (mg/L)	58	0.031	0.24	0.011	0.030
Bay Zone 4	Total Phosphorus (mg/L)	132	0.018	0.264	0.008	0.022
East River	Orthophosphorus (mg/L)	39	0.219	0.533	0.024	0.119
Fox River	Orthophosphorus (mg/L)	98	0.081	0.204	0.004	0.053
Bay Zone 1	Orthophosphorus (mg/L)	70	0.021	0.088	0.002	0.018
Bay Zone 2	Orthophosphorus (mg/L)	90	0.008	0.023	0.002	0.004
Bay Zone 3	Orthophosphorus (mg/L)	58	0.006	0.015	0.002	0.003
Bay Zone 4	Orthophosphorus (mg/L)	132	0.005	0.012	0.002	0.003
East River	Total Solids (mg/L)	39	565	860	288	136
Fox River	Total Solids (mg/L)	98	374	484	236	51
Bay Zone 1	Total Solids (mg/L)	70	315	420	236	49
Bay Zone 2	Total Solids (mg/L)	90	255	380	184	43
Bay Zone 3	Total Solids (mg/L)	58	237	324	176	41
Bay Zone 4	Total Solids (mg/L)	132	227	304	170	28

Sampling Location	Parameter	N	Average	Maximum	Minimum	Standard Deviation
East River	Total Volatile Solids (mg/L)	39	218	376	88	67
Fox River	Total Volatile Solids (mg/L)	98	159	256	72	37
Bay Zone 1	Total Volatile Solids (mg/L)	70	139	208	72	33
Bay Zone 2	Total Volatile Solids (mg/L)	90	110	172	32	28
Bay Zone 3	Total Volatile Solids (mg/L)	58	104	156	50	25
Bay Zone 4	Total Volatile Solids (mg/L)	132	109	176	50	28
East River	Total Suspended Solids (mg/L)	39	56.5	228	11	37.6
Fox River	Total Suspended Solids (mg/L)	97	51.8	132	9	25.2
Bay Zone 1	Total Suspended Solids (mg/L)	70	34.4	85	7	19.1
Bay Zone 2	Total Suspended Solids (mg/L)	90	10.2	34	3	6.5
Bay Zone 3	Total Suspended Solids (mg/L)	58	4.5	10	2	1.9
Bay Zone 4	Total Suspended Solids (mg/L)	132	2.2	8	1	1.2
East River	Total Suspended Volatile Solids (mg/L)	39	13.6	31	7	6.4
Fox River	Total Suspended Volatile Solids (mg/L)	98	21.3	45	7	10.1
Bay Zone 1	Total Suspended Volatile Solids (mg/L)	70	14.2	31	5	6.8
Bay Zone 2	Total Suspended Volatile Solids (mg/L)	90	5.7	12	2	2.4
Bay Zone 3	Total Suspended Volatile Solids (mg/L)	58	3.2	6	1	1.3
Bay Zone 4	Total Suspended Volatile Solids (mg/L)	132	1.5	4	1	0.7
East River	Chlorophyll *a* (mg/m3)	39	48.56	135	10	30.29
Fox River	Chlorophyll *a* (mg/m3)	98	117.12	221	29	49.53
Bay Zone 1	Chlorophyll *a* (mg/m3)	70	77.88	195	9.4	48.23
Bay Zone 2	Chlorophyll *a* (mg/m3)	90	26.71	80	2.8	17.83
Bay Zone 3	Chlorophyll *a* (mg/m3)	58	14.24	64	4.1	10.90
Bay Zone 4	Chlorophyll *a* (mg/m3)	132	5.42	28	1.5	4.06
East River	Chloride (mg/L)	39	56.08	94	23	17.88
Fox River	Chloride (mg/L)	98	31.48	43	19	5.64
Bay Zone 1	Chloride (mg/L)	70	25.27	43	15	6.65
Bay Zone 2	Chloride (mg/L)	90	17.14	39	13	3.21
Bay Zone 3	Chloride (mg/L)	58	14.33	17	11	1.23
Bay Zone 4	Chloride (mg/L)	132	12.73	15	9	1.51
East River	Turbidity (mg/L)	39	49.81	162	13.4	27.12
Fox River	Turbidity (mg/L)	98	49.86	91.7	7.1	25.33
Bay Zone 1	Turbidity (mg/L)	70	28.08	70.7	8.7	16.12
Bay Zone 2	Turbidity (mg/L)	90	7.95	30.5	1.4	5.58
Bay Zone 3	Turbidity (mg/L)	58	2.88	6.4	1.1	1.27
Bay Zone 4	Turbidity (mg/L)	132	2.08	6.7	0.6	1.04

Sampling Location	Parameter	N	Average	Maximum	Minimum	Standard Deviation
East River	Temperature (Cº)	86	21.3	25.7	17.0	2.72
Fox River	Temperature (Cº)	315	21.4	26.5	13.6	2.86
Bay Zone 1	Temperature (Cº)	237	19.8	25.3	11.9	3.13
Bay Zone 2	Temperature (Cº)	344	19.0	23.9	11.7	3.08
Bay Zone 3	Temperature (Cº)	341	18.4	23.5	8.7	3.23
Bay Zone 4	Temperature (Cº)	8705	17.3	26.0	8.5	5.18
East River	Dissolved Oxygen (mg/L)	85	6.75	14.7	2.7	2.61
Fox River	Dissolved Oxygen (mg/L)	312	9.05	16.6	4.8	2.47
Bay Zone 1	Dissolved Oxygen (mg/L)	237	9.56	15.7	4.4	2.27
Bay Zone 2	Dissolved Oxygen (mg/L)	341	9.58	14.0	1.0	1.86
Bay Zone 3	Dissolved Oxygen (mg/L)	340	9.81	14.7	3.9	1.72
Bay Zone 4	Dissolved Oxygen (mg/L)	8705	9.44	11.9	5.2	0.95
East River	Dissolved Oxygen %	85	76	163	31	28.14
Fox River	Dissolved Oxygen %	312	102	185	56	25.31
Bay Zone 1	Dissolved Oxygen %	237	104	168	47	22.61
Bay Zone 2	Dissolved Oxygen %	340	103	142	25	16.52
Bay Zone 3	Dissolved Oxygen %	340	104	158	43	16.03
Bay Zone 4	Dissolved Oxygen %	8705	99	138	48	15.63
East River	Specific Conductivity (umho/cm)	86	640	958	398	162.9
Fox River	Specific Conductivity (umho/cm)	315	416	529	296	35.2
Bay Zone 1	Specific Conductivity (umho/cm)	237	361	435	302	28.5
Bay Zone 2	Specific Conductivity (umho/cm)	344	320	381	281	23.1
Bay Zone 3	Specific Conductivity (umho/cm)	341	305	358	264	17.5
Bay Zone 4	Specific Conductivity (umho/cm)	8705	260	338	229	18.5
East River	pH (SU)	86	8.11	9.16	7.64	0.36
Fox River	pH (SU)	315	8.82	9.40	7.90	0.38
Bay Zone 1	pH (SU)	237	8.73	9.29	7.84	0.32
Bay Zone 2	pH (SU)	344	8.57	9.03	7.62	0.23
Bay Zone 3	pH (SU)	341	8.51	8.91	7.60	0.19
Bay Zone 4	pH (SU)	8704	8.28	8.91	7.28	0.38
East River	Secchi (m)					
Fox River	Secchi (m)	49	0.24	1.0	0.1	0.20
Bay Zone 1	Secchi (m)	41	0.40	1.1	0.1	0.32
Bay Zone 2	Secchi (m)	60	1.32	3.3	0.3	0.75
Bay Zone 3	Secchi (m)	43	2.24	3.6	0.9	0.78
Bay Zone 4	Secchi (m)	58	3.76	7.0	1.2	1.11