Aerial view of the Lower Fox River, WI [1].

Anthropogenic Contamination of the Lower Fox River, WI

An Analysis of Total Phosphorous, Total Suspended Solids, and Polychlorinated Biphenyls

GIS in Water Resources, Fall 2012, Final Report

Prepared by: Alyssa Offutt

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Abstract

The Lower Fox River watershed of northeastern Wisconsin faces high anthropogenic contaminant loadings of total phosphorus, total suspended solids, and polychlorinated biphenyls (PCBs). The objective of this investigation is to determine the magnitude of these contaminant loads, to geospatially locate the pollutant loadings, and to correlate the watershed history and current land use with the pollutant distribution. These tasks were completed with the use of ArcGIS. Through analysis, it was demonstrated that PCBs remain present within the Lower Fox River at high concentrations while also transporting downstream and into Green Bay. The required reduction of total phosphorus and total suspended solids were also displayed, and the high quantity of reduction required in addition to the concentrations at the mouth of the Lower Fox River serve to reiterate the PCB analysis. It can be concluded that there is a large need for remediation and reduction within the Lower Fox River watershed as well as within Green Bay and the Great Lakes basin. This investigation further proved the continual impact of anthropogenic contamination and the need to understand such contamination in order to alleviate water quality degradation.

Introduction

The Lower Fox River Watershed

The Lower Fox River watershed of northeastern Wisconsin encompasses a 641 mi^2 portion of the state between the outlet from Lake Winnebago, the DePere Dam, until drainage into Green Bay and then Lake Michigan [2]. Supporting an estimated population of 404,000 within the watershed boundary, the Lower Fox River basin is comprised of large urban and industrial areas including the cities of Green Bay and Appleton, WI which account for nearly 35% of the watershed's land use [3,4]. Agricultural land is also prevalent in the region and covers 50% of the watershed, while natural areas account for the remaining 15% of the land and provide for the recreational use of the river basin [4].

Figure 1. The Lower Fox River watershed is located in the northeast portion of Wisconsin and dischargees into Green Bay.

The Lower Fox River itself stretches for 39 miles and serves as a drainage for eighteen counties and forty watersheds in a 6,250 mi^2 area of Wisconsin [5]. Along the river there are twelve dams and seventeen locks which moderate the river flow and concentrate sediment from downstream transport [6]. The Lower Fox River can be seen highlighted within the extent of the watershed in Figure 2.

While the river has served as a source of recreation, water supply, and industry, it has also been historically plagued with water quality degradation. The sources of this poor water quality include high total phosphorus loading, high total suspended solids loading, and most notably, a high concentration of *polychlorinated biphenyls* (PCBs). Each of these pollutants has a distinctive impact on the river. Total phosphorus causes eutrophication and hypereutrophication of water bodies which, in combination with suspended solids, degrades aquatic environments by lowering dissolved oxygen concentrations and impeding light infiltration that is necessary for biota survival. PCBs, on the other hand, serve as persistent organic pollutants of 209 different chemical species. These species include endocrine disruptors and probable carcinogens which partition easily into sediment and bioaccumlate [7]. Due to their adverse health impacts and slow degradation, PCBs are listed within the US Environmental Protection Agency's (EPA's) 10% most toxic chemicals.) [7]. While total phosphorus and suspended solids are relevant in the assessment of anthropogenic pollutants, it is the presence and toxicity of PCBs which make the Lower Fox River unique in the study of watershed contamination and its impact within the Great Lakes Basin.

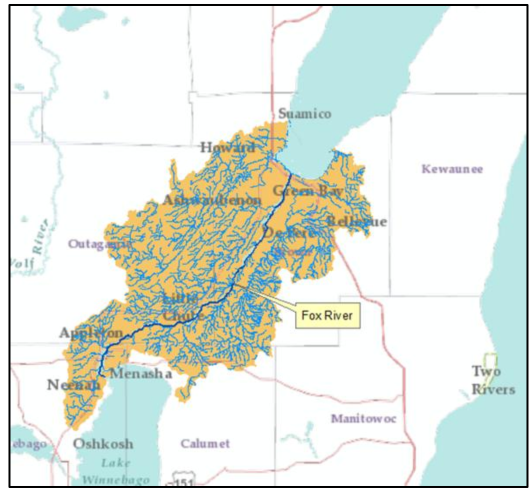

Figure 2. The Lower Fox River can be seen with its watershed outlined in orange.

History of Anthropogenic Contamination

In order to analyze the extent of the anthropogenic contamination, it is important to understand the history which caused the degraded water quality. In the case of the Lower Fox River, it is especially relevant to understand the introduction of PCBs into the watershed as this has been the driving force of studies and remediation. Much of this contaminant history is based on the industrial development within the region, specifically the development of the paper industry.

Paper mills began to establish along the banks of the Lower Fox River in the 1840s where they could utilize the steady flow of the river, as tempered by Lake Winnebago, as well as the straw resources of the region [8]. Over time, the paper industry flourished, and the Lower Fox River became the highest concentration of paper mills in the world, with 24 mills along the 39 mile stretch of stream [9]. Within this time period, the Lower Fox River basin also urbanized and saw the development of the timber industry. The logging activities, in combination with changing land use through city growth and agriculture, caused erosion throughout the watershed which significantly increased the sediment and nutrient loads [4]. Thus, the early 1990s saw an increase in both total phosphorus and total suspended solids in water bodies throughout the entire basin.

PCBs were first introduced into the river in 1954 when two paper companies, Appleton Paper Company and NCR Corporation, began to produce PCB-coated carbonless copy paper [8]. This copy paper used PCBs as solvents within the paper ink, and the PCBs in turn partitioned into the waste and byproducts from the manufacturing of this copy paper [10]. This waste was then discharged directly into the Lower Fox River or was recycled by five additional companies serving as secondary fiber mills [10]. However, these mills similarly produced waste streams that contained PCBs, and thus became additional point sources of PCB loading. Between the years of 1957-1997, the Wisconsin Department of Natural Resources (WDNR) estimates that over 660,000 lbs of PCBs were discharged into the Lower Fox River, with the discharge peaking from 1969-1970 [10,8]. Appleton Paper Company and NCR Corporation began to phase out the use of PCBs in 1971 and 1972 in response to studies conducted by the WDNR concerning the sources of the chemicals. However, the recycling of fibers containing PCBs continued into the 2000s, which accounts for continual PCB discharges of smaller magnitudes into the river [10].

This approximate twenty year period of high PCB discharges impacted a region greater than the Lower Fox River. The WDNR estimates that 70% of the PCB loading in Lake Michigan can be attributed to seven companies along the Lower Fox River [8]. The locations of these seven mills can be seen in Figure 3. Secondary sources of discharge include the City of Appleton Wastewater Treatment Plant and the Neenha-Menasha Publicly Owned Treatment Works which treated overflow, bypasses, and effluent discharges from the paper companies [10]. The location of these secondary point sources can also be seen in Figure 3.

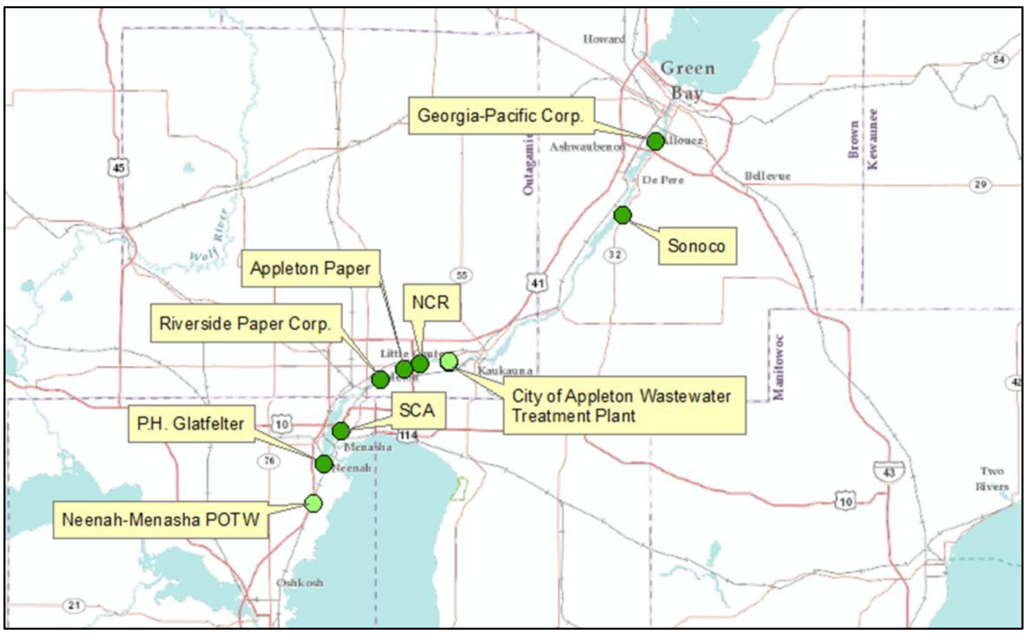

Figure 3. The seven paper mills which provided 70% of the PCB loading to Lake Michigan are picture here in dark green. The two wastewater treatment plants, and secondary sources, are located in light green.

The combination of high total phosphorous, total suspended solids, and PCBs, in combination with the passing of environmental legislation prompted action to be taken in the region. In 1976, the WDNR put into place fish consumption advisories, many of which are still in effect [5]. In addition, upgrades of wastewater treatment plants in the 1980s visually reduced the loading of phosphorus and suspended solids in the watershed [12]. However it was the recognition of degraded water quality in the region that has allowed it to be designated and addressed. These designations remain relevant in the present time and thus must be considered and understood.

Current Watershed Contamination: Area of Concern

Due to the levels of PCB contamination in addition to the high phosphorus and suspended solids loading in the watershed, the Lower Fox River was designated as a Great Lakes Area of Concern by the International Joint Commission of Canada and the United States in the early 1980s [11]. This specific area, which is the region of highest contamination, can be seen in Figure 4. In addition, the entire 39 mile Lower Fox River and 20 mile section from the mouth of the river into Green Bay is addressed as a Zone of Contamination and included in the National Priority List of the US Environmental Protection Agency [10].

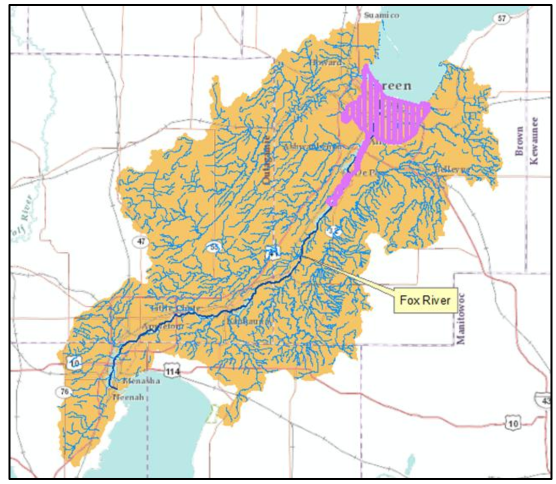

Figure 4. The Great Lakes Area of Concern within the Lower Fox River watershed is highlighted in purple.

Consideration of the beneficial use impairments served as background for labeling the region with these designations. The US and Canadian governments set fourteen beneficial use impairments that may affect a watershed. Within the Lower Fox River basin, eleven of these impairments are reported as present and two are suspected as seen in Table 1 [13]. Low dissolved oxygen, phosphorus, and PCBs are specifically linked as causes for a majority of these use impairments.

Table 1. The fourteen beneficial use impairments and their status within the Lower Fox River watershed.

Beneficial Use Impairments	Status in the Lower Fox River Watershed
Restrictions on fish and wildlife consumption	Present
Tainting of fish and wildlife flavor	Suspected
Degradation of fish and wildlife populations	Present
Fish tumors or other deformities	Suspected
Bird or animal deformities or reproductive problems	Present
Degradation of benthos	Present
Restrictions on dredging activities	Present
Eutrophication or undesirable algae	Present
Restrictions on drinking water, or taste and odor problems	Present
Beach closings	Present
Degradation of aesthetics	Present
Degradation of phytoplankton and zooplankton populations	Present
Loss of fish and wildlife habitat	Present
Added costs to agriculture or industry	Absent

In addition to the recognition of regions of degraded water quality, specific streams within the Lower Fox River watershed have been placed on the WDNR 303(d) list of impaired waterbodies. The problems of degraded habitat and low dissolved oxygen, which are criteria for placing the streams on this list, can be attributed to the anthropogenic pollutants of phosphorus, suspended solids, and PCBs. These streams can be seen in Figure 5 which shows the impaired waterbodies of the Lower Fox River watershed [4]. It can be noted that most of the major streams within the region are presented as impaired.

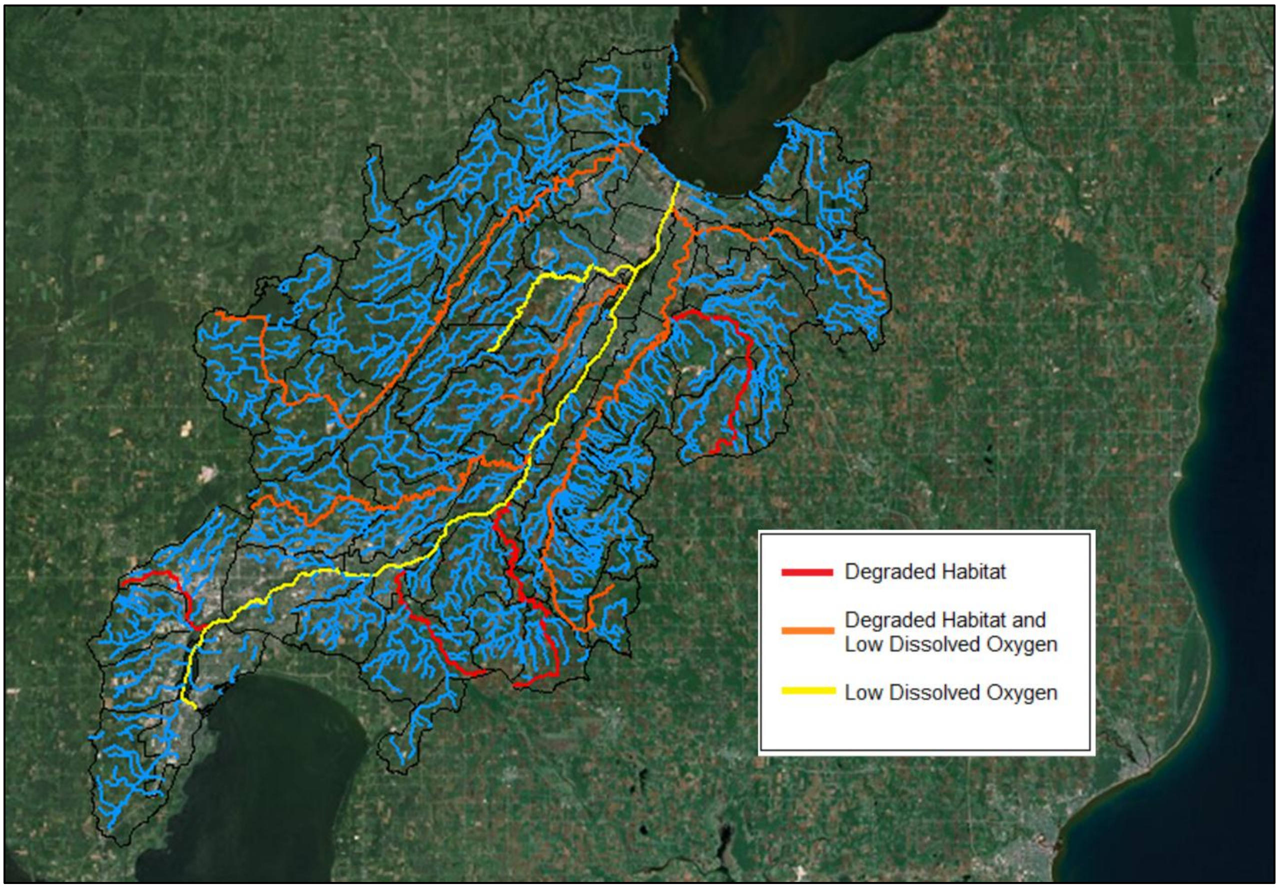

Figure 5. Waterbodies from the WDNR's 303(d) list that are impaired from low dissolved oxygen and degraded habitat can be seen within the watershed.

The designations given to the Lower Fox River watershed clearly present a recognition of high contaminant loading. Therefore, this project hopes to consider the magnitude of these pollutant loads, to consider their location, and to correlate watershed history with the current distribution in order to better understand anthropogenic contamination. To achieve these goals, ArcGIS will be used as a tool that can present and help analyze data.

Methods

Feature Basemap Construction

A feature basemap was constructed by use of an ESRI standard Reference basemap and overlaying this with flowline, waterbody, and reach features from the National Hydrography Dataset [14]. Both were imported using the GCS North American 1983 projection. Using the sub-watershed reach features and the watershed outline, the NHD data was clipped to the extent of the Lower Fox River watershed. This minimized processing time of ArcMap and allowed for a better focus within the specific region of interest. The combination of the Reference basemap and NHD streamlines served as the base for most of the map representations. However, in several cases, the ESRI standard World Imagery basemap was also used in order to better illustrate the data presented.

Many of the feature classes used in the contaminant analysis were also presented on a basemap which included the location of the paper mill discharge point sources. These locations were added to the basemap by use of orthoimagery, as xy coordinate data was difficult to find. The orthoimagery was completed by the overlaying of maps provided by the Fox River Watch, and was then used to provide approximate geographic coordinate of the point source locations [8].

Collection of Data

The contaminant data proved more difficult to find in desired formats. However, through searching through multiple mediums and analyzing publications, the contaminant data was extracted. The process of extraction is discussed in the *Data Preparation and Analysis* section, yet the source of the data is of equal importance.

The data for PCB contamination came from several sources. The data of discrete locations and PCB concentrations within Green Bay came from the final report of the Natural Resource Damage Assessment, *PCB Pathway Determination for the Lower Fox River/Green Bay* as prepared for the U.S. Fish and Wildlife Service, the U.S. Department of the Interior, and the U.S. Department of Justice [10]. The time series data of PCB concentrations at two USGS Gage locations was downloaded from the USGS National Water Information System of USGS Water-Quality Data [15]. It should be noted that only two gage stations within the watershed have water quality data, and thus are the two presented within this report. The data provided for the gage station was checked against and supported by the Lower Fox River watershed water quality data downloaded from USGS STORET [16]. The USGS STORET data, however, is not presented in this project as it added no additional relevant information.

The total phosphorus and total suspended solids data was comprised of information from a report prepared for the Wisconsin Department of Natural Resources, the Oneida Tribe of Indians of Wisconsin, and the US Environmental Protection Agency. This report, the *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* provided data of concentrations at sampling locations, as well as the baseline and total maximum daily load data for each subwatershed [4].

The location of the Area of Concern was determined from the US EPAs research on Region 5 Cleanup Sites of the Lower Fox River and Green Bay [11].

Data Preparation and Analysis

Since a portion of the data came from rather unconventional sources, specifically official reports, the data preparation was challenging and unique to the contaminant. For most data from the official reports, the data had to be copied either electronically or manually and adjusted in NotePad prior to importing into excel and then adding to ArcMap. However, as some of these files presented data in complicated formats, NotePad proved to be insufficient, and NotePad++ was downloaded and utilized.

The PCB data concentration data provided from *PCB Pathway Determination for the Lower Fox River/Green Bay* required the preparation described above, prior to adding the data onto ArcMap. In addition, while the report provided maps, there were no xy coordinates provided, and none that could be found with further research. Therefore, orthoimagery was again utilized to geospatially locate the sampling locations. These sampling locations were then checked against the descriptions of the sampling locations as provided in reports as well as the basemap in order to assure accuracy.

The PCB time series data from the USGS also provided specific challenges. The PCB concentrations were reported for each of the 209 congeners (chemical species of PCBs) within the dissolved form and solid form. Therefore, the cumulative of both categories had to be taken through processing the data. However, while the sampling data was taken from the maximum available range, 1986-2012, there were gaps in the sampling. For the gage station in Appleton, WI the only PCB data present was sampled between 1986-1990. In addition, between 1986-1989 only two or three congeners were sampled and a summation of this data would not be comparable to a sum of the 209 congeners as presented at other dates. Therefore, the data from before 1989 was disregarded. For the gage station in Green Bay, WI, the PCB data was recorded several times in 1994 and then from 2005-2006. This data was compared as it shows the concentrations over a twelve year range; however the data would be improved had there been data between 1994 and 2005 as this would demonstrate any variability. Finally, the USGS data preparation encountered some errors, as there is a slight overestimation to the summation of the data. This is due to the reporting of the PCB concentrations. Several of the samples were recorded as less than or equal to a given value. As this data could not be summed in this format, it was assumed that these data points were equal to the given value. The USGS data was imported with geospatial coordinates and these were projected onto the map with the GCS North American 1983 projection.

The total phosphorus and total suspended data from *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* similarly required processing through Notepad++ prior to importing into excel. While the data was presented in a simpler format, a column needed to be added to the data in order to link the WDNR nomenclature of streams with the NHD nomenclature. Through manual matching of subwatershed and reaches, an attribute field was added to the total phosphorus and total suspended solids attribute tables. This was then imported into ArcMap and joined with the NHD flowline feature class. This similar process was completed in order to match the stream impairments and stream pollutants. Finally, for the phosphorus and suspended solids data, the percent reduction was calculated and added as an attribute. This was completed by taking $Percent\ Reduction = \frac{Baseline\ Loading - TMDL}{Baseline\ Loading}$ for both total phosphorus and total suspended solids.

The location data for the Area of Concern was also difficult to find with xy coordinates, and thus the Area of Concern was located with orthoimagery and the creation of an Area of Concern feature class. This then served as a manner to compare locations to high concentrations.

Finally, after preparing and adding each of these data sets, the trends, concentrations, and locations of each anthropogenic pollutant could be analyzed and conclusions can be drawn.

Contaminant Analysis

PCB Loading

As paper mills severed as the source of PCBs along the Lower Fox River, it is important to consider the concentration of PCBs relative to the location of the point sources of paper mill discharge. Using average total PCB concentrations as sampled between 1989-1990, the PCB concentrations at five sampling locations along the river were determined [8,10]. These can be seen relative to the mill locations in Figure 6.

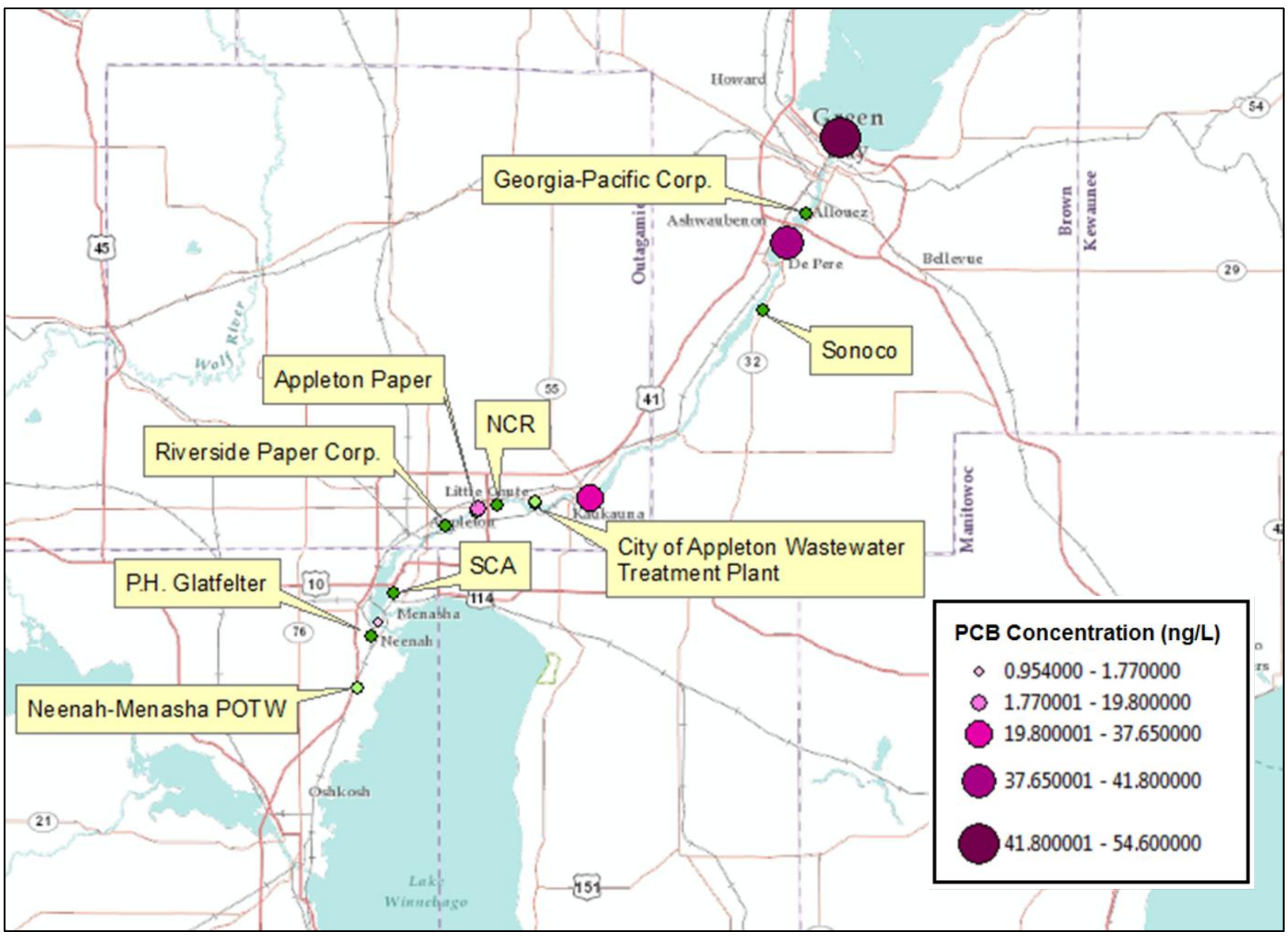

Figure 6. Average PCB concentrations (ng/L) and locations of the seven largest point discharges for PCBs.

From the figure it is clear that PCBs accumulate in increasing quantities as more paper mills are located upstream of the sampling locations. This suggests that the discharges of the mills are significant in the locations of the PCBs, and that some of the PCBs are transporting downstream and thus concentrating. This is especially relevant at the mouth of the Lower Fox River as this is the point of discharge into Green Bay and thus is the concentration of PCBs that is being introduced to the bay.

In order to understand the quantity of transport into the Great Lakes, as well as the need for remediation, it is also important to consider the time series data for each of these locations. To do so, the data for two USGS gage stations are considered. The location of these gage stations, one near the beginning of the Lower Fox River and one near the river's discharge, are shown in Figure 7. The PCB concentrations (in ng/L) are also demonstrated in Figure 8 for the USGS Gage Station 4084445 at Appleton WI and in Figure 9 for the USGS Gage Station 40815385 at Oil Tank Depot in Green Bay, WI.

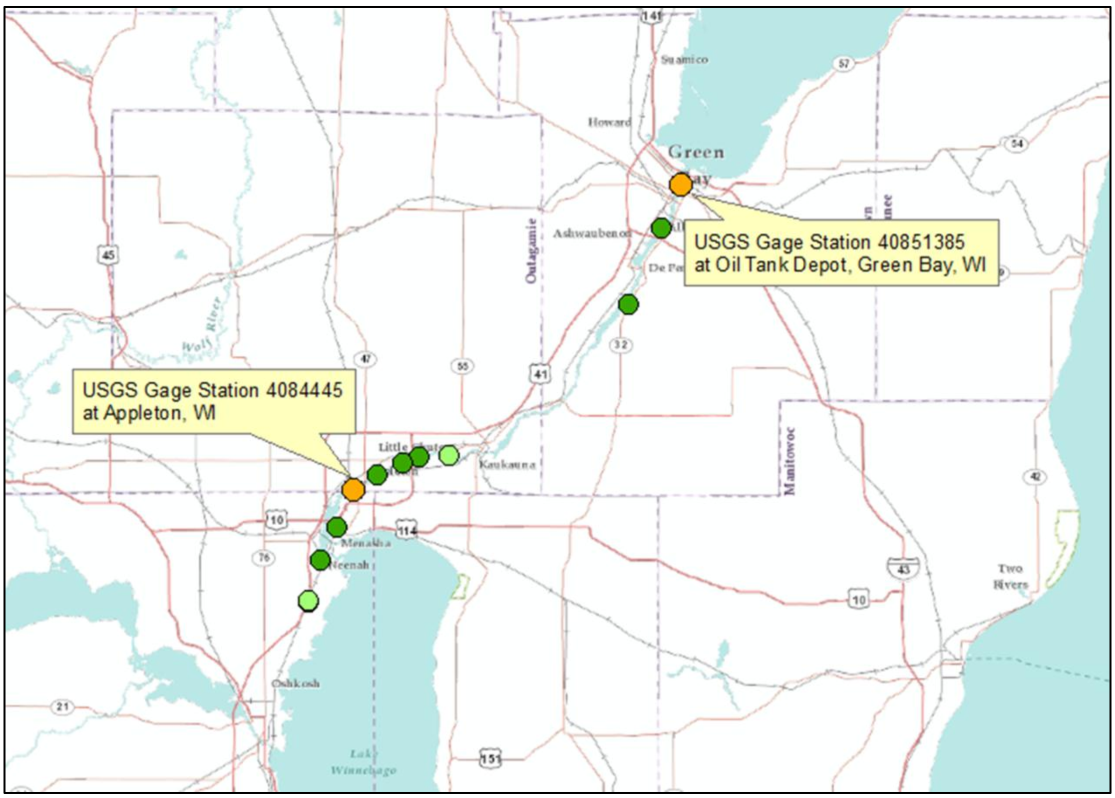

Figure 7. Location of USGS Gage Stations 4084445 and 40815385 which monitor water quality.

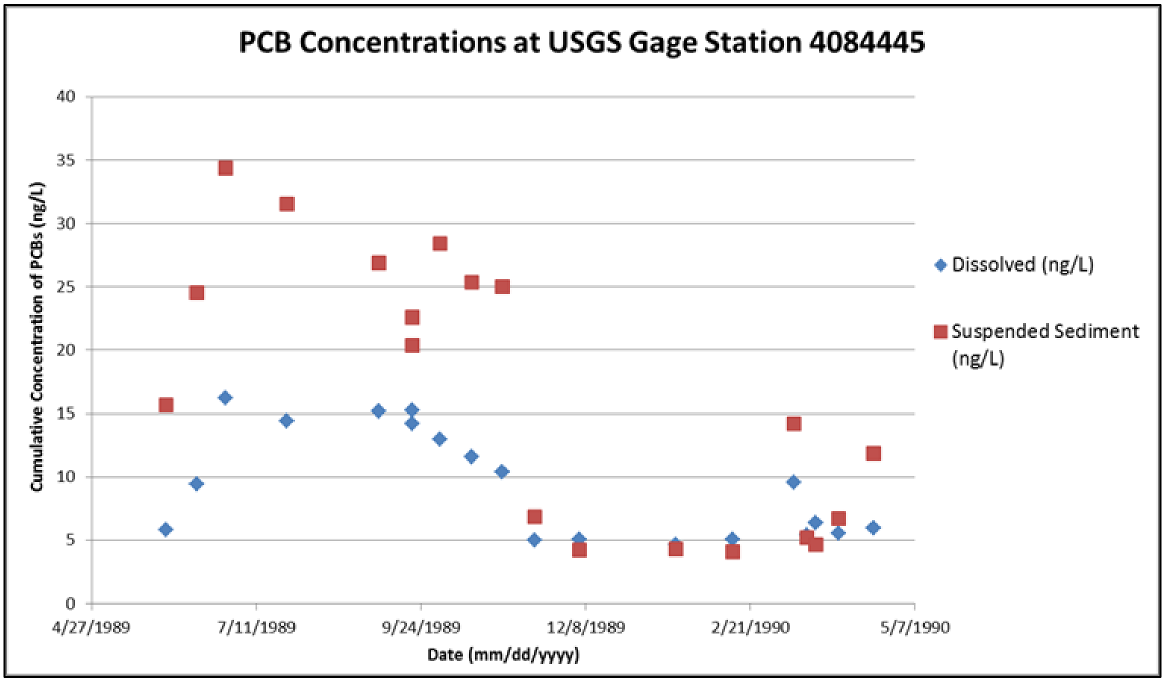

Figure 8. PCB concentrations over time for the USGS Gage Station 4084445 at Appleton, WI.

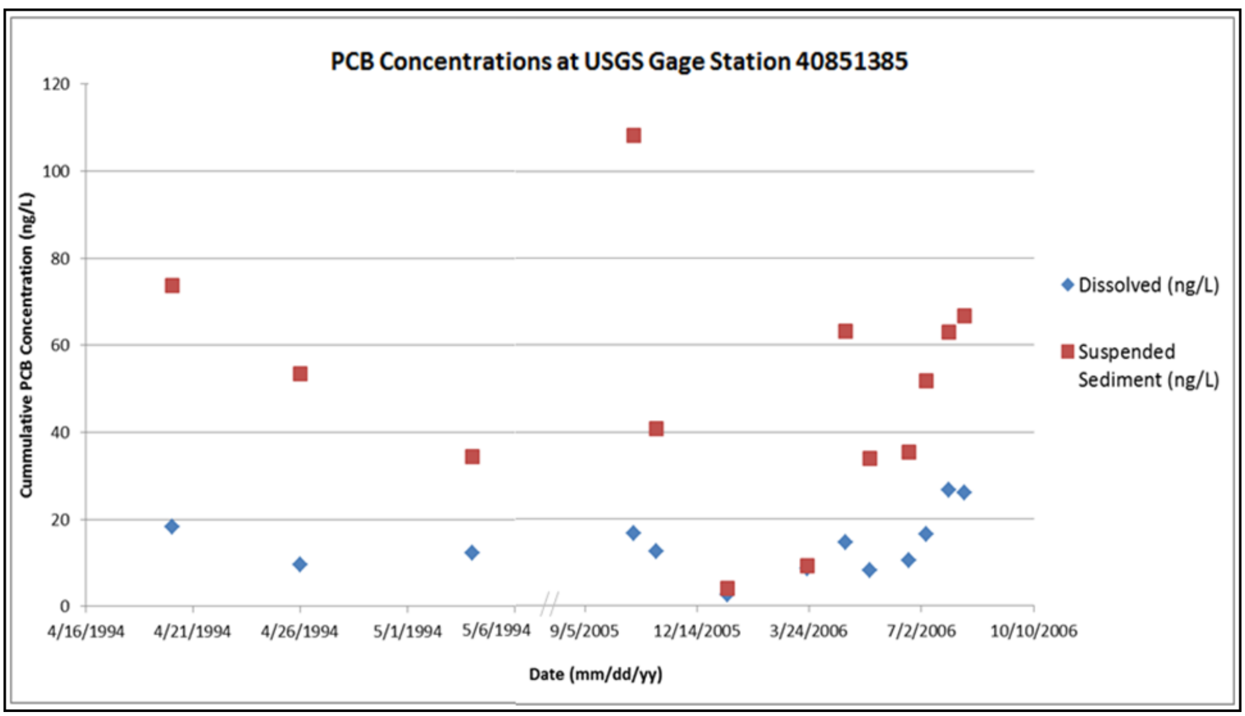

Figure 9. PCB concentrations over time for the USGS Gage Station 40815385 at Oil Tank Depot in Green Bay, WI.

These graphs show similar trends to those determined from the Figure 6. The gage station at Appleton, WI shows an overall trend of decreasing PCB concentrations. This suggests that PCBs generally transporting downstream from the gage location. However, considering that the samples of this data were taken approximately twenty years after the period of greatest PCB discharge, it can also be determined that not all PCBs are transporting and thus continue to pose a risk to that location by remaining and contaminating the sediment in this region. The gage station at Green Bay, WI, on the other hand, shows alternate trends. Over the greater sampling period, while there is noise in the data, the concentrations of the PCBs seem to remain constant. These concentrations are much greater than those seen at Appleton, WI. This reiterates that the transport of PCBs downstream is occurring and concentrating at the river's mouth prior to discharge and also demonstrates that PCBs are continuing to contaminate the region long after their introduction into the Lower Fox River. Both of these conclusions are supported by literature. It was determined that there is significant transport of PCBs within the river and high rates of sedimentation within the upper 10-15 cm of soil [17]. In addition, the US EPA estimates that PCB levels at the mouth of the Lower Fox River are 100 to 10,000 times greater than the safe levels set by the state [9]. The higher concentration of PCBs located at the mouth of the Lower Fox River also aligns with the Area of Concern as this region contains the highest risk and contaminant loading.

As concluded, the transport of PCBs is significant, and is likely entering Green Bay. In fact, the US EPA estimates that over 160,000 lbs of sediment have been discharged into Green Bay and Lake Michigan [9]. To access the validity of this conclusion, the concentration data of PCBs over a year period is considered at discrete locations throughout Green Bay. The sampling at each month and the overall average concentrations are seen in Figure 10 [10]. It is clear from this figure that high concentrations of PCBs are present within Green Bay (with the upper limit being 103 ng/L). In addition, by knowing that water flows northeast out of the bay, it can be concluded that the PCB source within the bay is the Lower Fox River as there are diminishing concentrations as the flow is progresses.

The average PCB concentration of Green Bay as based on time variability can be seen in Figure 11 [10]. The peak average occurs in March which is likely attributed to the high stream flow derived from the snowmelt in Wisconsin. This additionally reiterates that transport from the Lower Fox River is significant, especially at this time of year. From considering the concentrations over time, it can also be concluded that the PCBs being introduced to Green Bay are remaining in the bay in significant quantities while some PCBs are likely transporting into Lake Michigan.

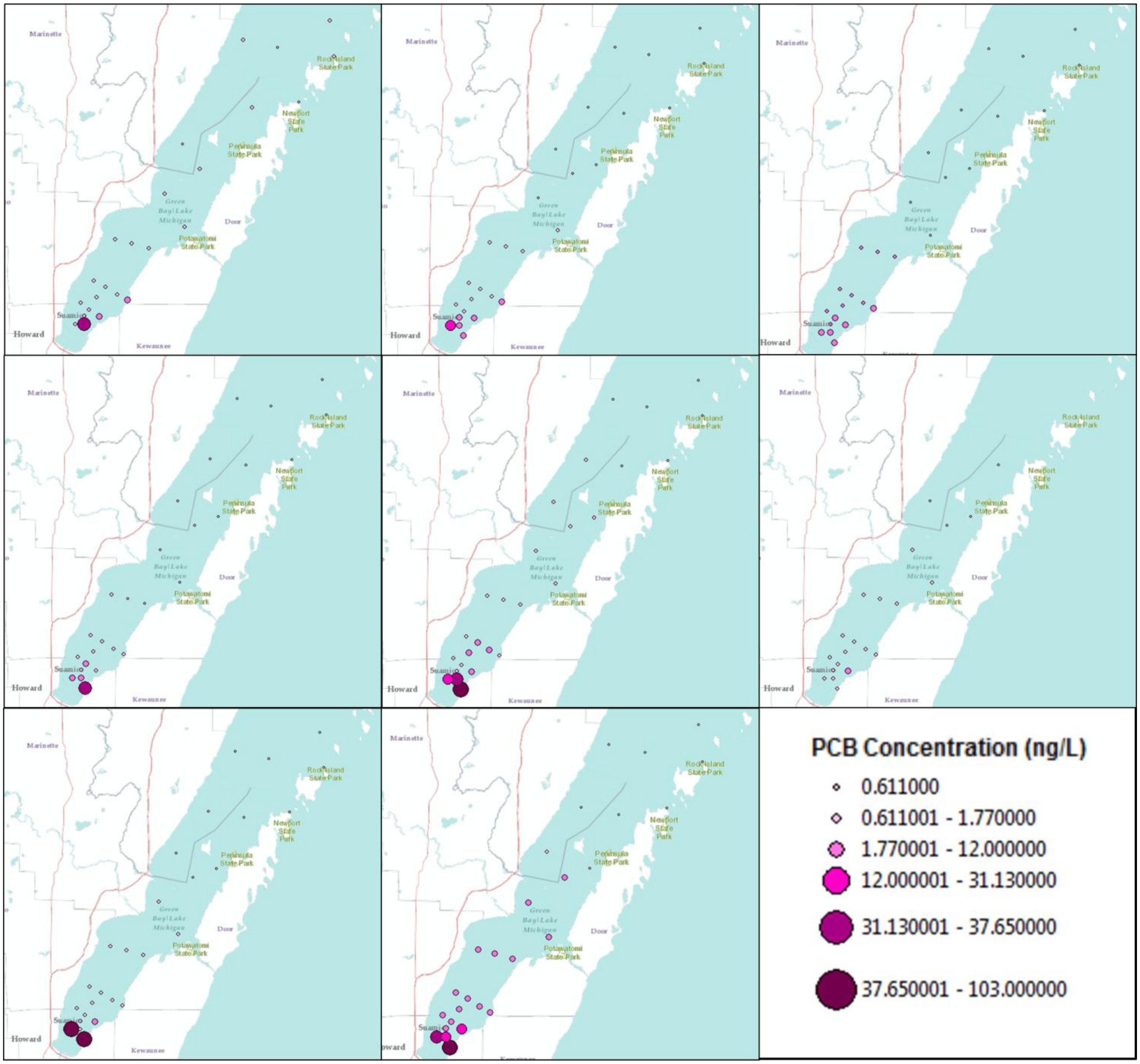

Figure 10. Concentrations of PCBs at sampling points in Green Bay. From left to right top to bottom, the sampling times include, May 1989, June 1989, July 1989, September 1989, October 1989, February 1990, April 1990, and the average over this entire range..

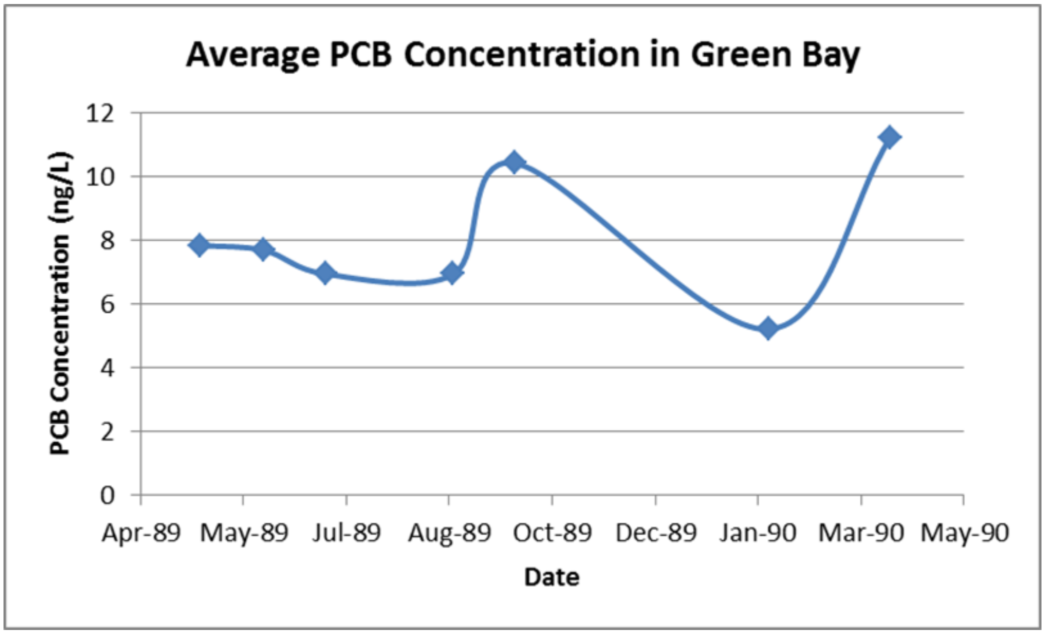

Figure 11. Seasonal average PCB concentration within the bay between May 1989 and April 1990.

Total Phosphorus and Total Suspend Solids Within the Watershed

While considering the impairment of water bodies for the 303(d) list, the WDNR also assessed the source of pollution which caused this impairment. Within the Lower Fox River watershed, the WDNR specifically considered which streams were polluted with total phosphorus, total suspended solids, or a combination of the two [4]. These streams can be seen in Figure 12. From the figure, it is clear that most of the major streams within the Lower Fox River watershed are polluted with either total phosphorus or total suspended solids. This is supported visually by the ESRI world imagery basemap, by which it is possible to see that phosphorus is entering Green Bay from the Lower Fox River, as the eutrophication (green in color) can be seen at the river’s mouth.

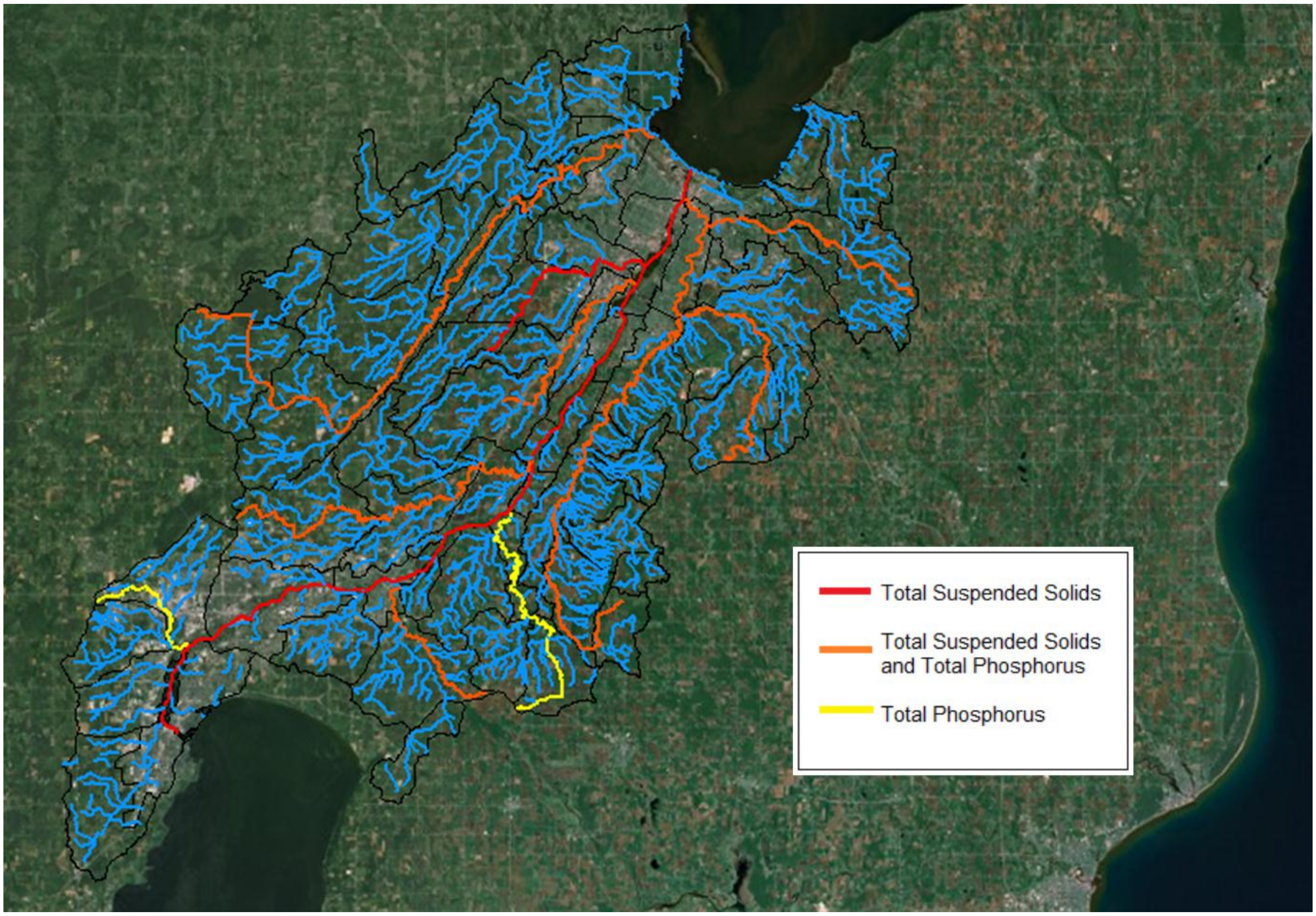

Figure 12. Streams polluted with total phosphorus and/or total suspended solids within the Lower Fox River basin.

Total Phosphorous Analysis

Besides visual depiction of phosphorus loading, the total phosphorus can be quantified by considering data from 2004-2006.This data is taken at five sampling locations throughout the watershed in addition to an average concentration throughout a section of Green Bay [4]. The concentrations at these locations can be seen in Figure 13 which shows the variability of concentration data with time. From the figure it can be determined that phosphorus load generally increases downstream, due to transport, and has an impact on the first portion of Green Bay. These increasing concentrations align with the Area of Concern. It is also important to note that all phosphorus concentrations within Figure 13 exceed the water quality targets that are set by the WDNR. For higher flow streams, the maximum target is 0.1 mg/L, while the target for low flowing streams is 0.075mg/L [4]. The determination of high versus low flowing streams is determined by the hydrologic parameter of the $Q_{7,10}$ [4].

In order to more closely observe the exceedance of phosphorus in the region, each subwatershed can be considered. To do so, the baseline phosphorus load of each sub-watershed, or the loading attributed to each sub-watershed is considered. These baseline values of total phosphorus in lbs/year from 2006 data can be seen in Figure 14 [4].

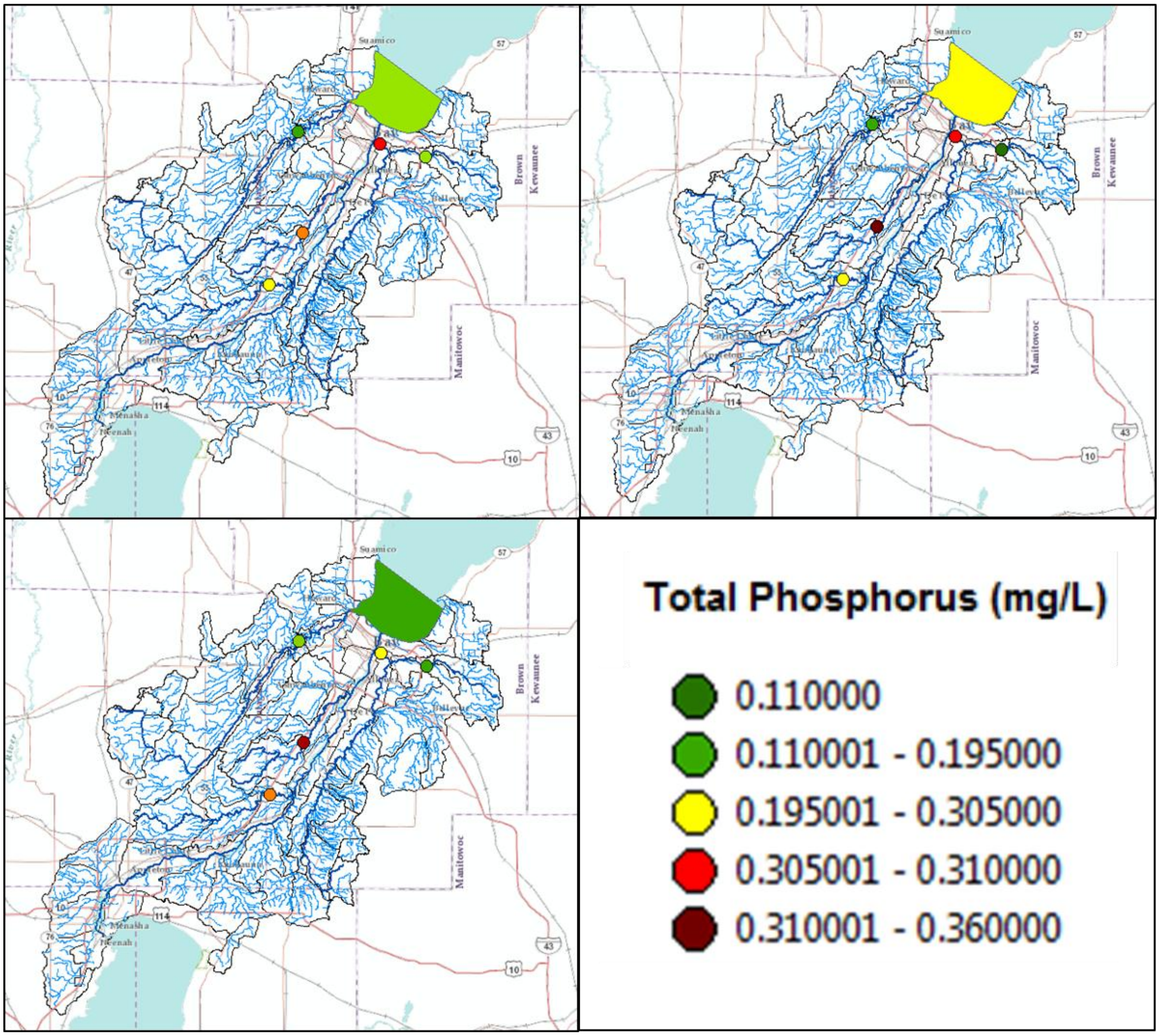

Figure 13. Phosphorus concentrations at sampling locations between the years of 2004-2006. Data presented from left to right top to bottom with the years 2004, 2005, and 2006 respectively.

The WDNR sets total maximum daily loads (TMDLs) which are the maximum quantity that should be discharged into the waterbody within the period of a day. The TMDLs for each subwatershed are based on water quality targets and streamflows [4]. Using the TMDL for each subwatershed, in combination with the baseline load, the percent reduction required for each watershed is calculated. These values can be seen linked to each subwatershed in Figure 15. It is interesting to note that the required reduction ranges from between 35.5% to 77.2%. This demonstrates that the current total phosphorus loads in each watershed are very high and that significant effort will be required in order to achieve these reductions.

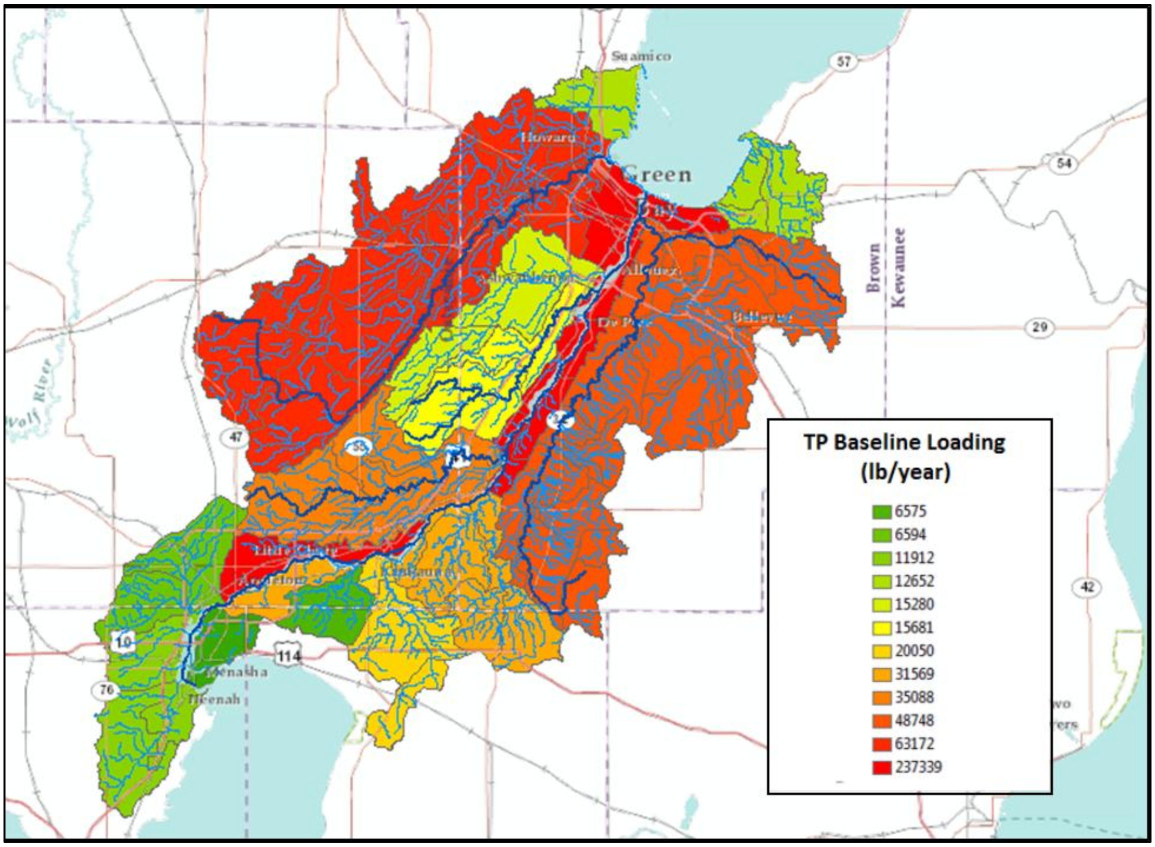

Figure 14. Background phosphorus loading for each sub-watershed within the Lower Fox River watershed [4].

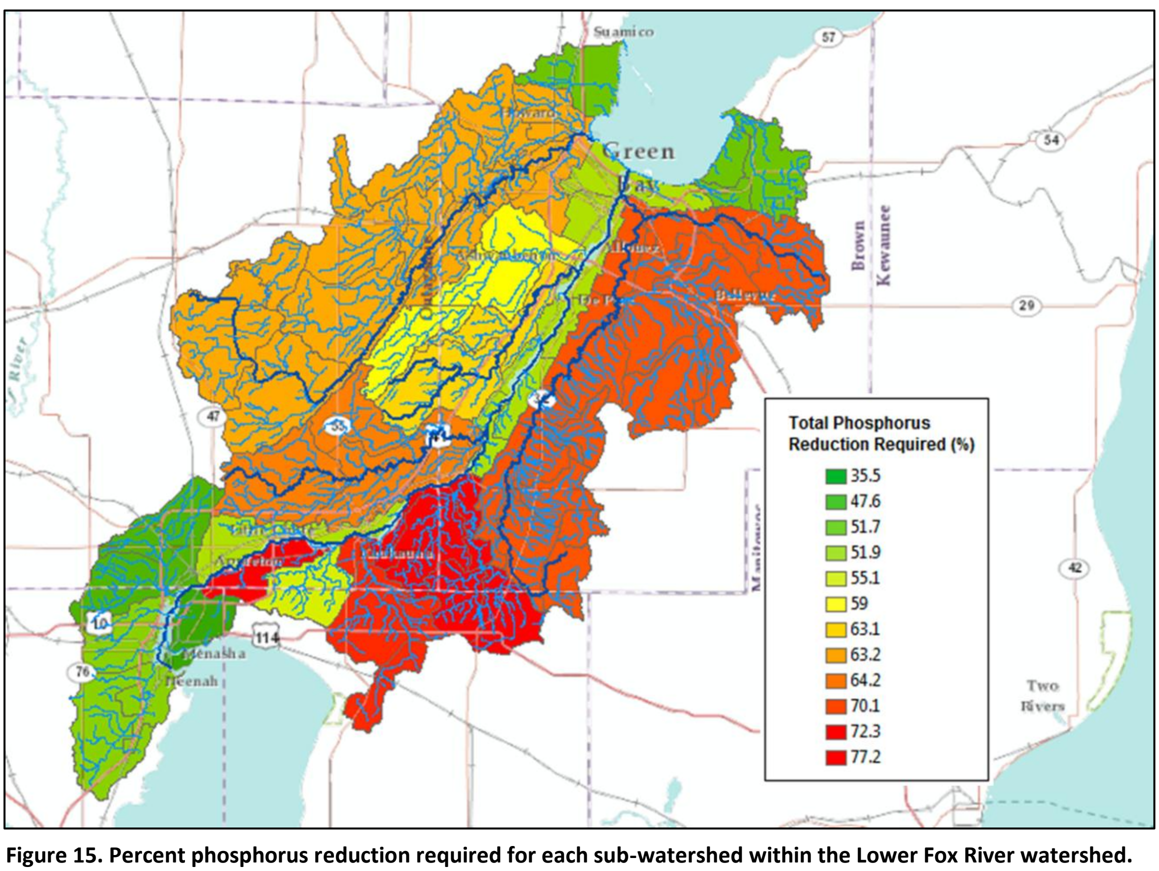

Figure 15. Percent phosphorus reduction required for each sub-watershed within the Lower Fox River watershed.

Finally, as this study focuses on anthropogenic contamination, it is important to determine the source of these phosphorus loads to be certain that the high concentrations are not from background levels. Figure 16 shows the sources of the average phosphorus loading within the Lower Fox River watershed. It can be seen that only 1% of the load is from natural background levels, as determined by the natural area land use. Therefore, the majority of this loading is coming from anthropogenic sources, specifically agriculture and wastewater treatment facilities. This not only proves the significance of anthropogenic contamination but helps to target reduction actions to these major total phosphorous outputs.

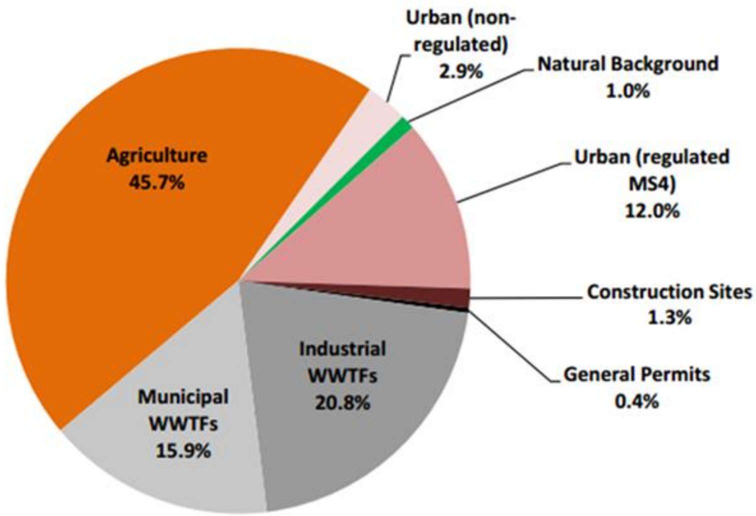

Figure 16. Percent contribution of total phosphorus into the Lower Fox River watershed [4].

Total Suspended Solids Analysis

Although less suspended solids data is available, the loading of total suspended solids can be analyzed in a manner similar to that of total phosphorus. In order to determine the origins of the total suspended solids loading, the baseline loads of total suspended solids can be determined for each watershed [4]. These baseline values of total suspended solids in lbs/year, from 2006 data, can be seen in Figure 17. It can be noted that although the units are not comparable, the WDNR water quality target is 18mg/L for total suspended solids.

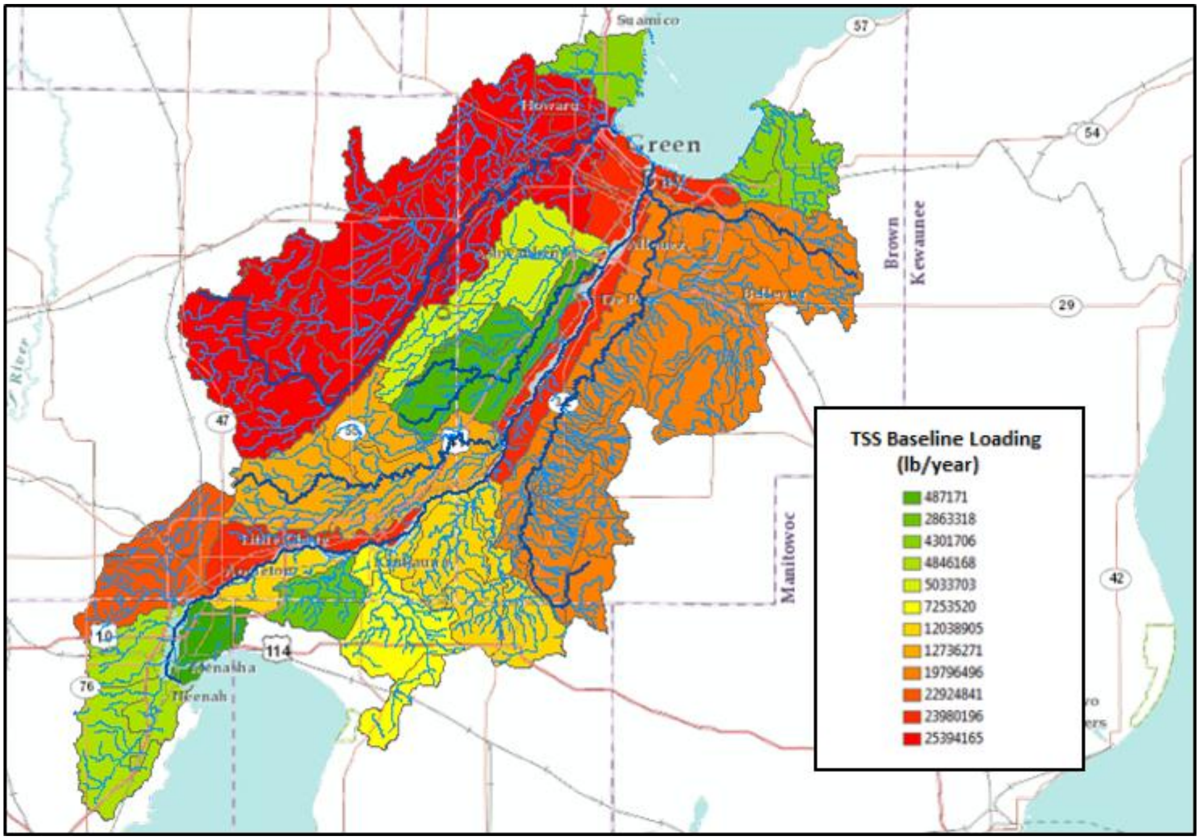

Figure 17. Background total suspended solids loading for each sub-watershed within the Lower Fox River watershed.

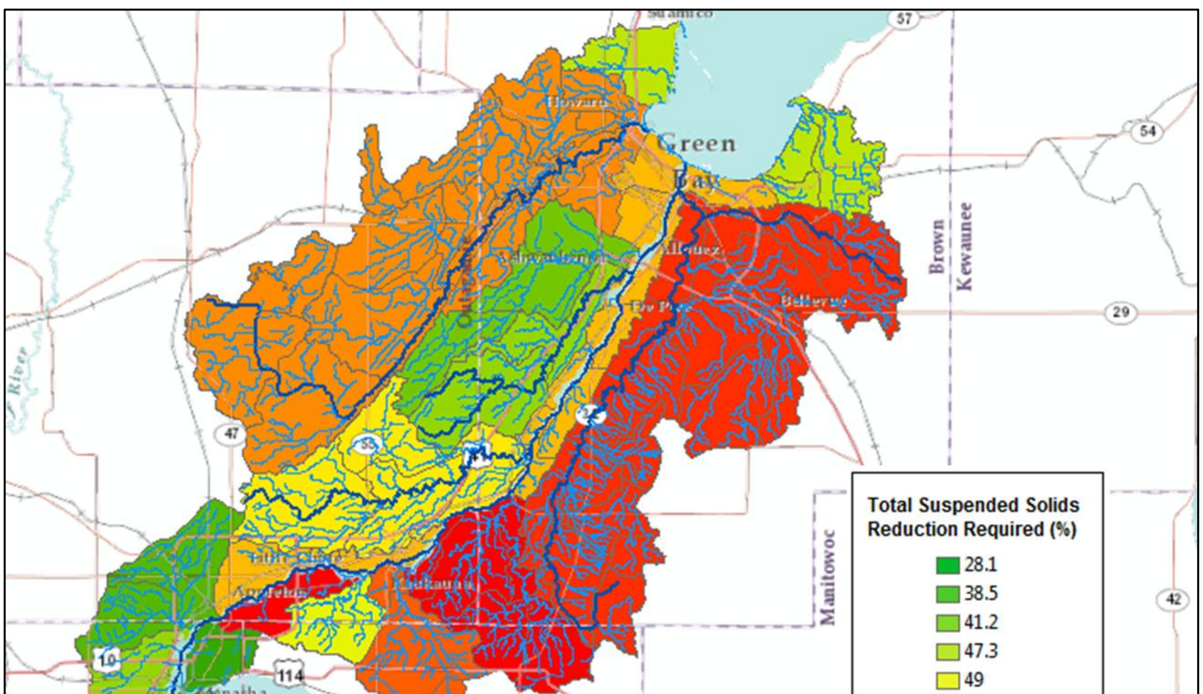

Figure 18. Percent suspended solids reduction required for each sub-watershed within the Lower Fox River watershed.

As based on the total maximum daily loads (TMDLs) of the region, the percent reduction required of total suspended solids can be calculated. The values of reduction required for each subwatershed are seen in Figure 18. For total suspended solids, the required reduction ranges from between 28.1% to 70.42%. This demonstrates that there is a large source of total suspended solid contamination, and that much effort will be required to reduce loading to the TMDL.

Finally, the source of the suspended solids must also be considered in order to prove that the loading is mainly anthropogenic. As seen in Figure 19, less than 1% of the total suspended solids are from natural background sources, whereas 65.7% of the loading comes from agriculture and 22.2% is contributed from urban areas. Therefore, agriculture and urban areas serve as a target for total suspended solids reduction while demonstrating the impact that anthropogenic land use holds on water quality.

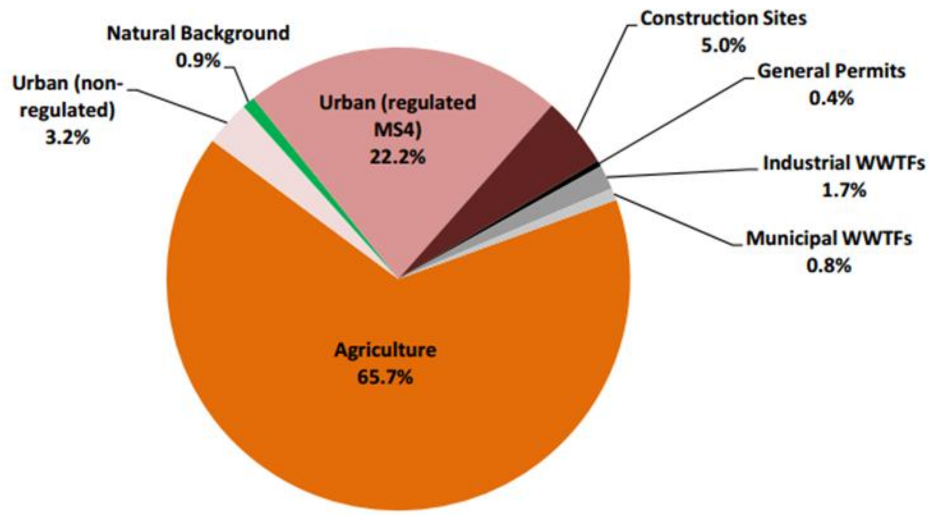

Figure 19. Percent contribution of total suspended solids into the Lower Fox River watershed [4].

Conclusion

From analysis of PCBs, total phosphorus, and total suspended solids, it is clear that all three contaminants exceed standard levels within the watershed and serve as prevalent anthropogenic contaminants which affect aquatic health. In addition to the concentrations within the Lower Fox River watersheds, these pollutants undergo transport and similarly impact Green Bay and thus Lake Michigan. The locations of the contaminants are strongly correlated with anthropogenic activities past and land use present, and demonstrate a strong need for remediation and reduction. Overall, these pollutants are most concentrated within the extent of the Great Lakes Area of Concern, and thus provide a focus for action to be taken.

The remediation need established throughout this project has been similarly concluded by both the Wisconsin Department of Natural Resources and the US Environmental Protection Agency. Both governmental organizations have worked to alleviate the contamination load in the Lower Fox River. Through litigation and legislation, funding was approved for the dredging of 660,000 yds^3 of PCB contaminated sediment by the end of 2012 [12]. As of present, 287,000 yds^3 have been successfully dredged [12]. In addition, the WDNR has set more strict water quality standards on the discharge of toxic substances in order to prevent similar contaminant loadings from occurring. The total phosphorus and total suspended solids have be decreasing in concentration since the 1970s due to reducing discharge limits on permits and encouraging several counties to adopt agricultural waste management programs [12]. However, while these actions are working to decreasing contaminant loading, it can be concluded that more action is required. This includes dredging which spans into Green Bay, as well as reduction of total phosphorus and suspended solids based on the excessive loads seen in 2006.

It can be concluded that with continual remediation and reduction strategies, the Lower Fox River basin will be able to alleviate the degradation that it has faced due to historic and current anthropogenic contaminant loads. It is by assessing the extent of contamination, the trends of this contamination, and the sources of the pollutants through the use of GIS, that the watershed contamination can be understood. With this information, the Lower Fox River watershed will progress towards its target water quality standards and have a beneficial use for both its ecological and human inhabitants.

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