Phosphorus and Sediment Runoff Loss: Management Challenges and Implications in a Northeast Wisconsin Agricultural Watershed

by

Martin D. Jacobson

A thesis submitted in partial fulfillment of
the requirements for the Degree of

MASTER OF SCIENCE
in
ENVIRONMENTAL SCIENCE AND POLICY

University of Wisconsin-Green Bay

August 2012

Approved:

____
Kevin Fermanich, Major Professor

____
Andrew E. Kersten
Associate Provost for Academic Affairs and Director of Graduate Studies

Committee Members:
Paul Baumgart
David Dolan
Patrick Robinson

ACKNOWLEDGEMENTS

This project would not have been completed without the help of many individuals and agencies.

I would like to thank Kevin Fermanich and Paul Baumgart for their expertise and guidance in all aspects of this project from start to finish. I would also like to thank my committee members Dave Dolan and Patrick Robinson for their insightful input.

The list below contains the many individuals and agencies that provided assistance in one way or another.

Brown County Land Conservation Department
Calumet Land Conservation Department
Green Bay Metropolitan Sewage District
Outagamie Land Conservation Department
United States Geological Survey
Wisconsin Department of Natural Resources – Green Bay and Oshkosh offices
Matthew Abrahamzon
Dan Feldman
Joe Schoenebeck
Laura Ward Good
Paul Kaarakka

ABSTRACT

PHOSPHORUS AND SEDIMENT RUNOFF LOSS: MANAGEMENT CHALLENGES AND IMPLICATIONS IN A NORTHEAST WISCONSIN AGRICULTURAL WATERSHED

MARTIN D. JACOBSON

The Lower Fox River and Lower Green Bay are impaired by sediment and phosphorus and in 2012 a TMDL was approved for this area. TMDL modeling suggested that Plum Creek was the highest sediment and phosphorus yielding watershed in the TMDL area. This study was undertaken to characterize sediment and phosphorus loss from Plum Creek and to increase understanding of how land characteristics and agricultural practices influence these losses.

Event flow and low flow total suspended solids (TSS), total phosphorus (TP) and dissolved phosphorus (DP) data were collected from October 2010 through April 2012 at a fixed-location, automated monitoring station established in 2010. In addition, event grab samples were collected near peak flow at 17 multi-field catchments (15 to 212 ha) in Plum Creek Watershed. Data from a subset of these catchments were used to assess SnapPlus and the Wisconsin Phosphorus Index management tools.

Across all flow conditions, Plum Creek median TSS, TP and DP concentrations were 149 mg/L, 0.60 mg/L and 0.24 mg/L, respectively. Plum Creek TSS, TP and DP study period concentrations and water year 2011 yields were higher than those from Baird Creek during the same periods. Water year 2011 Plum Creek TSS, TP and DP yields were greater than those from five other agricultural watersheds in the Lower Fox River Basin during water years 2004-2006.

Across four multi-field catchment runoff events, median suspended sediment (SSC), TP and DP concentrations were 218 mg/L, 1.03 mg/L and 0.33 mg/L, respectively. Median DP fraction was 35%. Area-weighted SnapPlus sediment loss and phosphorus index values were compared to SSC and P concentrations in MFC runoff. Field management input data, including crop rotation, nutrient applications, and tillage practices were collected from nutrient management plans. SnapPlus predictions were poorly correlated with measured sediment and P concentrations. Insufficient SnapPlus input accuracy likely played a role in the poor correlations. SnapPlus and the P index, as they are currently used, will not improve Plum Creek water quality.

Key words: agriculture, phosphorus, sediment, BMP, WI P Index, SnapPlus

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

BMP	Best management practices
DP	Dissolved phosphorus
GBMSD	Green Bay Metropolitan Sewage District
LFR	Lower Fox River
LFRB	Lower Fox River Basin
NMP	Nutrient management plan
NRCS	Natural Resource Conservation Service
P	Phosphorus
PP	Particulate phosphorus
SSC	Suspended sediment concentration
TP	Total phosphorus
TSS	Total suspended solids
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WDNR	Wisconsin Department of Natural Resources
WI PI	Wisconsin Phosphorus-Index
WY	Water year

CHAPTER 1 - INTRODUCTION

Lower Fox River Basin

The Fox-Wolf River Basin (Figure 1.1) drains approximately 16,500 km^2 of northeast Wisconsin. Major rivers include the Upper Fox and Wolf Rivers, which flow into Lake Winnebago near Oshkosh, and the Lower Fox River, which flows out of Lake Winnebago near the cities of Neenah/Menasha and flows northeast 24 km into Green Bay. The Lower Fox River Basin (LFRB) drains 1,654 km^2, 50% of which is agricultural land. The LFRB is heavily urbanized and industrialized, especially along the main channel of the Lower Fox River (WDNR 2011).

In 2005, the United States Environmental Protection Agency (US EPA) and the Wisconsin Department of Natural Resources (WDNR) began discussing the development of a total maximum daily load (TMDL) plan for the LFR and Lower Green Bay (Scheberle and Cooper 2008) and in May 2012, a TMDL was approved. The TMDL contains 27 segments of 14 different waters in the basin that are impaired by excessive phosphorus and/or suspended sediment (WDNR 2012).

Plum Creek Watershed

One of the Lower Fox River tributaries included in the TMDL is Plum Creek (Figure 1.2). The watershed spans approximately 9,200 hectares (92 km^2) and includes portions of Brown, Calumet, and Outagamie counties. Plum Creek originates in the Forest Junction area and flows north to Wrightstown, where it empties into the Lower Fox River. The watershed is predominantly agricultural and can be divided into the main branch (63% of the area) and west branch subwatersheds (37% of the area). To meet TMDL allocations, reductions of 70% and 77% are needed for sediment and phosphorus, respectively (WDNR 2012).

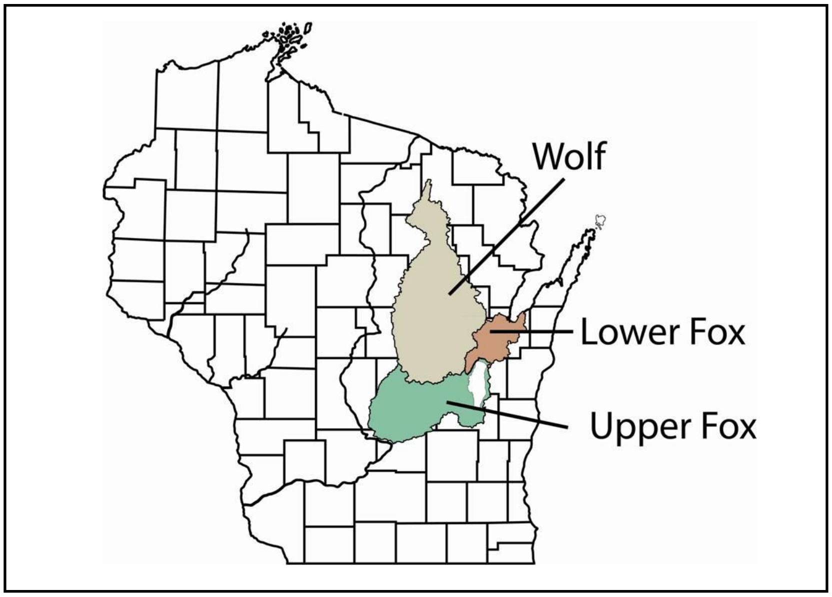

Figure 1.1. Map showing subwatersheds of the Fox-Wolf River Basin (FWWA 2011).

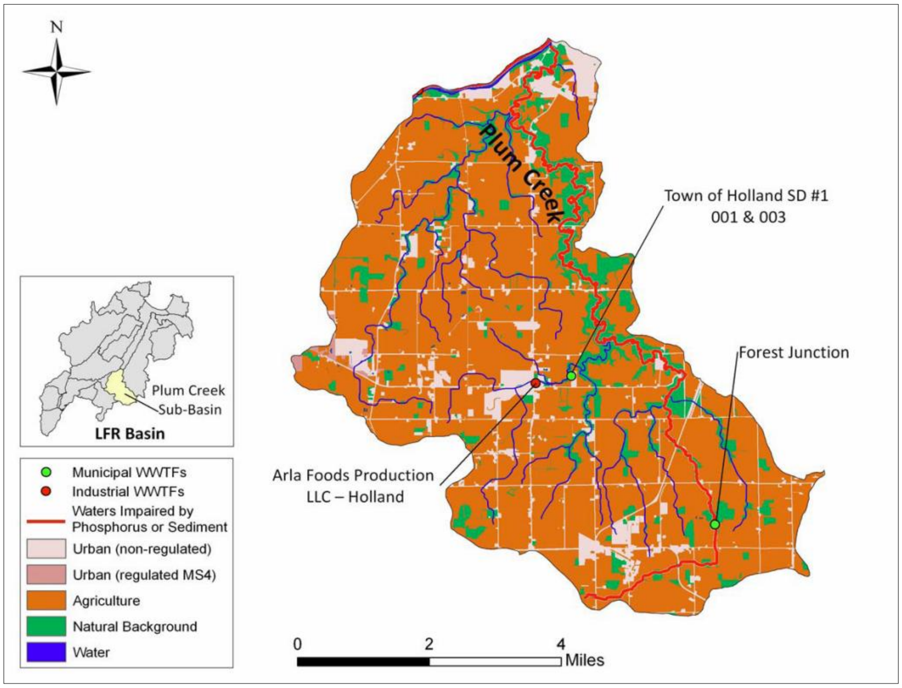

Figure 1.2. Map showing Plum Creek watershed land use and point sources (WDNR 2010).

Literature Review

Phosphorus

Phosphorus (P) is an important agricultural nutrient for crop and animal production (Hedley and Sharpley 1998). P has more biological functions than any other nutrient (Beede and Davidson 1999), being a component of DNA, cell membranes, and Adenosine Triphosphate (ATP), which is the molecule responsible for storing and providing energy. In plants, P increases seed production, grain yield, stalk strength, root growth, and disease resistance (Norfleet 1998). Despite its beneficial role in food production, excessive P levels can negatively affect humans and associated aquatic life and human uses.

Runoff from agricultural fields can deliver large amounts of P to surface waters, where, under natural conditions, it is frequently a limiting nutrient. This P enrichment causes prolific aquatic plant and algae growth and subsequent eutrophication of receiving surface waters (Corell 1998). Bacterial decomposition of the large amounts of biomass produced in eutrophic systems consumes oxygen and causes hypoxic conditions. Chronic hypoxia can shift fish community structure towards low oxygen tolerant species (Dauer 1993), reduce fish fecundity and growth or cause death (Brungs 1971).

Prolific algal growth negatively affects aquatic systems in other ways as well. Algae reduce water clarity, causing a reduction of submerged aquatic vegetation (SAV) (Crosbie and Chow-Fraser 1999). SAV provides food, oxygen, and habitat for many organisms (Diehl and Kornjow 1998). SAV increases water clarity by reducing turbulence and accompanying sediment resuspension (Gregg and Rose 1982; Madsen and Warncke 1983; Madsen et al 2001). Reduced water clarity can shift fish species composition in lakes from desirable species (i.e. sport fish) to less desirable fish (Egertson and Downing 2004) by inhibiting the hunting success of sight-oriented feeders (Bruton 1985).

Eutrophication can negatively affect human communities and individuals as well. Algal blooms can be unsightly, produce unpleasant odors, and be a health hazard. Cyanobacteria, a species commonly present in eutrophic waters, produce neurotoxins and hepatotoxins. These toxins can cause a loss of muscle control and liver damage, respectively (Carmichael 2001). Toxic algae and nuisance algae can decrease the overall aesthetic value of a lake and therefore property values adjacent to it (Pretty et al., 2003). Dodds et al. (2009) estimated annual economic costs associated with anthropogenic eutrophication in U.S. freshwaters on recreation ($1 billion), waterfront property value ($0.3-2.8 million), recovery of threatened and endangered species ($44 million), and drinking water ($813 million).

Sediment

Sediment can also negatively affect aquatic and human communities. Suspended sediment reduces water clarity, thereby producing the same negative effects discussed above with eutrophication. Studies have shown that suspended sediment can reduce fish survival by decreasing reproductive success (Burkhead and Jelks 2001; Sutherland 2007) and foraging success (Zamor and Grossman 2007; Sweka and Hartman 2001). Suspended sediment also absorbs sunlight, thereby raising water temperature; a problem for temperature-sensitive organisms. In addition, sediment accumulation can reduce habitat for bottom-dwelling invertebrates. The resulting shift in the invertebrate community can negatively affect growth and survival of juvenile fish (Suttle et al., 2004).

Suspended sediment and any potential attached toxins require higher levels of treatment, increasing costs to water treatment facilities (Tegtmeier and Duffy 2004). Sediment can also accumulate in reservoirs, depriving communities of maximum flood protection, electricity production, and recreational opportunities (Freeman 1982; Vaughan and Rusell 1982). Dredging the accumulated sediment is costly and disposing of the dredged material is problematic (Morris and Fan 1998).

Agriculture and Phosphorus

Trends in the Wisconsin dairy industry show that average herd size is increasing. From 1997 to 2007, the number of Wisconsin dairy farms with greater than 100 head of cattle increased from 15 to 78 (420% increase) (USDA NASS 2012). The result is an increase in animal density in at the locations of these large operations. Greater animal density increases manure concentrations on the landscape, leaving landowners and operators with an insufficient land base for manure application (Sanford et al. 2009). This situation leads to over-application of manure on fields, increasing soil P levels and the potential for P loss. The following sections will discuss source and transport factors that influence P and sediment loss from agricultural watersheds.

Phosphorus Forms, Sources and Transport

Without adequate soil P concentrations, crops fail to produce maximum yields (Johnston 2005). However, excess P can be an expensive problem for downstream human and natural communities when it enters surface waters. The potential for P to enter surface waters is determined by source factors and transport factors. Source factors such as soil P levels and manure, biosolids and fertilizer application methods and timing, dictate the amount of P available for transport. Transport factors, including erosion, surface runoff, and the distance from edge-of-field to the stream, in turn determine P transport from land to surface water (Sharpley et al. 2001a). Together, source and transport factors determine the total amount and relative proportion of phosphorus forms that are lost from a field to surface water (Sharpley et al. 2001b). The three phosphorus loss mechanisms (physical, chemical, and acute) are described in more detail below (Haygarth and Jarvis 1999).

Loss Mechanisms

The driving force behind sediment and P loss is runoff events caused by snowmelt and precipitation. Many studies suggest that surface runoff caused by these events accounts for the vast majority of phosphorus loss from watersheds (Graczyk et al. 2011; Heathwaite and Dils 2000). Sharpley et al. (2008) found that storm flow accounted for only 32% of annual flow but accounted for 80% of phosphorus loads from an agricultural watershed. The same study also found that P loss increased as storm size increased, most likely because larger storms cause larger amounts of surface runoff and soil erosion.

The primary physical P loss mechanism is soil erosion. P lost in this manner is attached to soil particles and is termed particulate P (PP) (Haygarth and Sharpley 2000). This study defines PP as P unable to pass through a 0.45μm filter. Rainfall and surface runoff detach PP from surrounding soil, making it available for transport. Erosion preferentially detaches and transports smaller particles, which have higher P concentration than larger particles (Sinaj et al., 1997). This phenomenon, known as the enrichment ratio, is a measure of the disproportionate P distribution among different sized soil particles (Sharpley 1980; Sharpley 1985), and is dependent on physical (e.g. surface area to volume ratio) and chemical properties (e.g. high P retention capacity of clays) of soil particles. Finer soils, those with higher clay content, have higher enrichment ratios (Sharpley 1985).

The primary chemical P loss mechanism is dissolution or solubilization. P lost in this manner is termed dissolved phosphorus (DP). This chemical loss mechanism occurs in a set of desorption-dissolution-extraction reactions that take place between soil P and water (Sharpley 1985). A higher surface soil P concentration allows for greater water-soil interaction, thereby increasing the likelihood of solubilization and therefore the P available for loss (McDowell et al. 2001). Water extracts P from other sources as well, such as crop residues (Schreiber and McDowell 1985), and recently applied manure and fertilizer applications. As the time between manure application and runoff increases, the risk for P loss decreases (Sharpley 1997; Westerman et al. 1983).

The third mechanism, acute, differs from the other two conceptually. Whereas physical and chemical P loss involves the transport of P from the soil P pool, acute loss involves the transport of recently applied P fertilizers and manures by runoff (Haygarth and Sharpley 2000).

Dissolved P forms can be classified in terms of filtration methods and chemical reactions (Haygarth et al. 1998). The portion of the sample that passes through a filter, commonly 0.45 µm, is termed total dissolved P (TDP). TDP that reacts in the molybdate blue reaction is termed dissolved or soluble reactive P (SRP) and consists primarily, although not exclusively, of orthophosphorus (PO_4^-) (Haygarth and Sharpley 2000). SRP is readily available for plant and algae uptake (Reynolds and Davies 2001).

Managing Phosphorus Loss

Loss Reduction

Natural Resources Conservation Service (NRCS) Nutrient management (acre) Code 590 requires that producers prepare a nutrient management plan (NMP) for all fields receiving fertilizer and manure amendments. NMPs are nutrient budgets for individual fields, with the 590 standard defining their purpose as “managing the amount, source, placement, form, and timing of the application of nutrients and soil amendments” (NRCS 2005). These plans attempt to create balanced nutrient budgets for individual fields with the goal of reducing soil and nutrient loss to surface water and groundwater (NRCS

2005). Because the U.S. Environmental Protection Agency recognizes P as the largest source of surface water quality problems, NMPs are P-based, a shift from the traditional practice of basing application rates on nitrogen levels (Haygarth et al. 1998). In Wisconsin, producers can choose to manage a field's P budget by limiting P applications based on either soil test P (STP) or a P index (NRCS 2005).

Soil Test Phosphorus

Agronomic soil P testing measures the amount of P available to plants and was originally developed to optimize crop growth. Samples are typically taken at plow depth, which is 5-30 cm depending on tillage type (Sharpley et al. 2006). STP is not necessarily a complete assessment of the risk of P loss to surface waters because it does not account for the processes that control loss risk, soil erosion and surface runoff potential (Kleinman et al. 2000). A field with high STP may not pose much of a threat for P loss because of low susceptibility to erosion and surface runoff (Sharpley and Tunney 2000). Although a reasonably accurate predictor of P loss, soil test values often under predict P loss when manure or fertilizer has been recently applied (Sharpley et al. 2001b). To be a reliable option for P management, scientists have revised STP recommendations to consider threats to surface water quality along with recommendations aimed at meeting agronomic needs (Sims and Sharpley 1998).

Phosphorus Index

Using a P index is another strategy for managing P at the field scale. The NRCS developed the P index as a way to assess the risk of P loss in surface runoff from fields

(Lemunyon and Gilbert 1993) with the assumption that certain fields pose greater risks (Gburek and Sharpley 1998) and therefore should not receive equal applications of fertilizer and manure. Included in the P index calculations are STP, rate and timing of fertilizer and manure applications, and susceptibility to soil erosion and surface runoff. The majority of U.S. states use the P index approach to manage phosphorus (Sharpley et al. 2003).

Loss Reduction Practices

Landowners and managers can implement best management practices (BMPs) to reduce P and sediment loss. One BMP that focuses on controlling the source of P is nutrient management. This strategy manages P inputs, such as mineral fertilizer and manure applications, at the farm or field scale (Sharpley et al. 2006) to ensure that soil P concentrations meet crop requirements while reducing the risk of P loss to surface waters (Sharpley et al. 2001b). Dietary P content is a major factor in the P content of manure. Eliminating excess dietary P intake and increasing animal P uptake efficiency, done by supplementing feed with P in more digestible forms, are two strategies to reduce P inputs to fields through manure applications (Sharpley et al 2001). These strategies are important in areas with high animal concentrations. These areas have large quantities of manure to dispose of, but may have limited land on which to apply it and limited resources to address the cost of transporting manure to fields that require P inputs. This scenario causes elevated soil P in fields closest to manure sources. An option to reduce transportation costs, allowing producers to apply manure to a larger land area, is to reduce its weight by composting it on site (Eghball et al. 1997).

Another set of BMPs reduce P transport by controlling erosion and surface runoff and include practices such as conservation tillage, contour tillage, cover crops, grass waterways and buffers strips. Buffer strips are areas of perennial vegetation bordering surface waters and control agricultural runoff in several ways (Schultz et al. 2000). The roughness of a buffer's permanent vegetation slows surface runoff, causing the deposition of particles and associated PP before entering surface waters (Correll, 1997; Dillaha, et al. 1997). Increased infiltration rates caused by slower runoff velocities allow buffer strips to reduce DP loads entering surface waters as well. The root systems of buffer strip plants also increase infiltration (Lee et al. 2000). Once in the soil, plants can assimilate P, in this way acting as a P sink (Uusi-Kamppa et al., 1997). However, when plants are not actively assimilating P, buffer strips can act as a P source (Graneli, 1990; Mander et al., 1991). To reduce this P loss, studies advise periodic harvesting of buffer strip biomass (Lee et al., 2000; Stutter et al., 2009). Because of the relatively high levels of organic matter found in buffer strips, these soils harbor large microbe populations, which, like plants, act as a P sink through assimilation (Schultz et al. 2000). Other BMPs, such as conservation tillage and cover crops, reduce agricultural runoff through essentially the same mechanisms as buffer strips, by protecting soil particles and increasing surface roughness.

Research Objectives

Problem Statement

TMDL models suggest that Plum Creek P and sediment yields are the highest in the LFRB and that agriculture is the largest source (WDNR 2012). To meet TMDL water quality goals, P and sediment loads from Plum Creek watershed must be reduced drastically (>70%) (WDNR 2012). In this thesis I attempt to answer the following questions:

1. Plum Creek watershed P and sediment loss
    a. How much P and sediment does Plum Creek contribute to the Lower Fox River?
    b. How do Plum Creek and West Plum Creek water quality compare?
    c. How does Plum Creek water quality compare to that of other agricultural watersheds in the Lower Fox River Basin?
2. Multi-field catchment P and sediment loss
    a. What are the characteristic of multi-field catchment runoff in Plum Creek watershed?
    b. How is STP related to P and sediment concentrations in runoff at the multi-field catchment scale?
    c. How do watershed characteristics (slope, land use and management practices) influence P and sediment concentrations in runoff at the multi-field catchment scale?
3. Wisconsin P-Index assessment
    a. Can the nutrient management tools, SnapPlus and the Wisconsin Phosphorus Index, be used as reliable P and sediment loss predictors in Plum Creek watershed?
4. Point source P contribution
    a. What is the significance of a point source cheese production facility to in-stream P concentrations in Plum Creek?
5. Policy Questions
    a. Can the current Wisconsin P-Index standard of 6 achieve water quality goals?
    b. What are the challenges associated with the current approach of P management?

Study Limitations

This project, like all stream flow and water quality sampling projects, was heavily dependent on the amount, intensity and timing of precipitation events. The amount and intensity of rainfall can significantly alter concentrations and loads of water quality parameters. Samples from only four runoff event samples were collected from the multi-field catchments during the study period. This small number of events limited the statistical analysis that could be performed on the data. In addition, limited availability and confidence in the quality of nutrient management plans reduced the number of multi-field catchments included in the analysis with SnapPlus.

Document Organization

The remainder of this document is divided into four chapters. Chapter 2 characterizes Plum Creek water quality and compares it to other Lower Fox River Basin streams over various time periods. Chapter 3 characterizes multi-field catchment water quality and assesses SnapPlus and the Wisconsin Phosphorus Index. Chapter 4 examines the P contributions of a point source in Plum Creek watershed. Chapter 5 summarizes research findings, discusses the implications of this study and examines the future of the watershed.

CHAPTER 2 –PLUM CREEK WATER QUALITY

Introduction

Phosphorus (P) and sediment, primarily from agriculture, negatively affect water quality in the LFR and its tributaries. P has caused proliferation of algae and a reduction in beneficial submerged aquatic vegetation in the waters of the Lower Fox River and Lower Green Bay (WDNR, 1993). Hypoxic conditions, a result of algal decomposition, have caused fish kills in the river and bay. Additionally, communities must dredge sediment deposits that impede navigation of bay and river waters, a costly operation. Dredging can also release toxins into water from contaminated sediments (WDNR 1993).

In 2005, the United States Environmental Protection Agency (US EPA) and the Wisconsin Department of Natural Resources (WDNR) began discussing the development of a total maximum daily load (TMDL) plan for the LFR and Lower Green Bay (Scheberle and Cooper 2008). A TMDL is the maximum load of pollutant that a water body can receive and still meet water quality standards. The LFR and Lower Green Bay TMDL was approved in May 2012. The TMDL contains 27 segments of 14 different waters in the basin that are impaired by excessive P and/or suspended sediment (WDNR 2012).

In the recently approved Lower Fox River TMDL, the summer median total P (TP) concentration is not to exceed 0.10 mg/L in the main stem of the LFR and the summer median total suspended solids (TSS) concentration is not to exceed 18 mg/L at the outlet of the Lower Fox River. Summer median TP concentration is not to exceed 0.075 mg/L in LFR tributaries, including Plum Creek. In addition to concentration limits, the TMDL allocates TP and TSS loads to each sub-basin in the LFRB.

Plum Creek watershed spans 9,200 hectares, and agriculture is the dominant land use. The watershed is contained within Brown, Calumet and Outagamie counties (Figure 2.1). The creek empties into the Lower Fox River in Wrightstown. Its soils are categorized as hydro-group C, meaning that infiltration rates are low and surface runoff is high. An interesting geologic feature of the watershed is an upland ridge with thin soils underlain by the Fort Atkinson Formation of the Maquoketa Group. The Plum watershed can be divided into the main branch (63% of the area) and the west branch (37% of the area). The Fort Atkinson Formation ridge defines the upper elevation boundary between the main branch and west branch sub-watersheds (Figure 2.1).

TMDL models suggest that Plum Creek is the highest P and TSS yielding watershed in the LFRB (WDNR 2012). The TMDL sets annual loads at 3,266 kg (7,200 lb) and 1,588 metric tons (3.5 million lb) of TP and TSS, respectively. Property owners and watershed managers in Plum Creek would need to reduce TP by 77% and TSS by 70% to meet TMDL goals (WDNR 2012).

This chapter characterizes Plum Creek water quality and compares Plum Creek to Baird Creek and several other agricultural streams in the LFRB for various time periods. This chapter also examines the relationship between watershed characteristics and water quality differences among LFRB tributary streams.

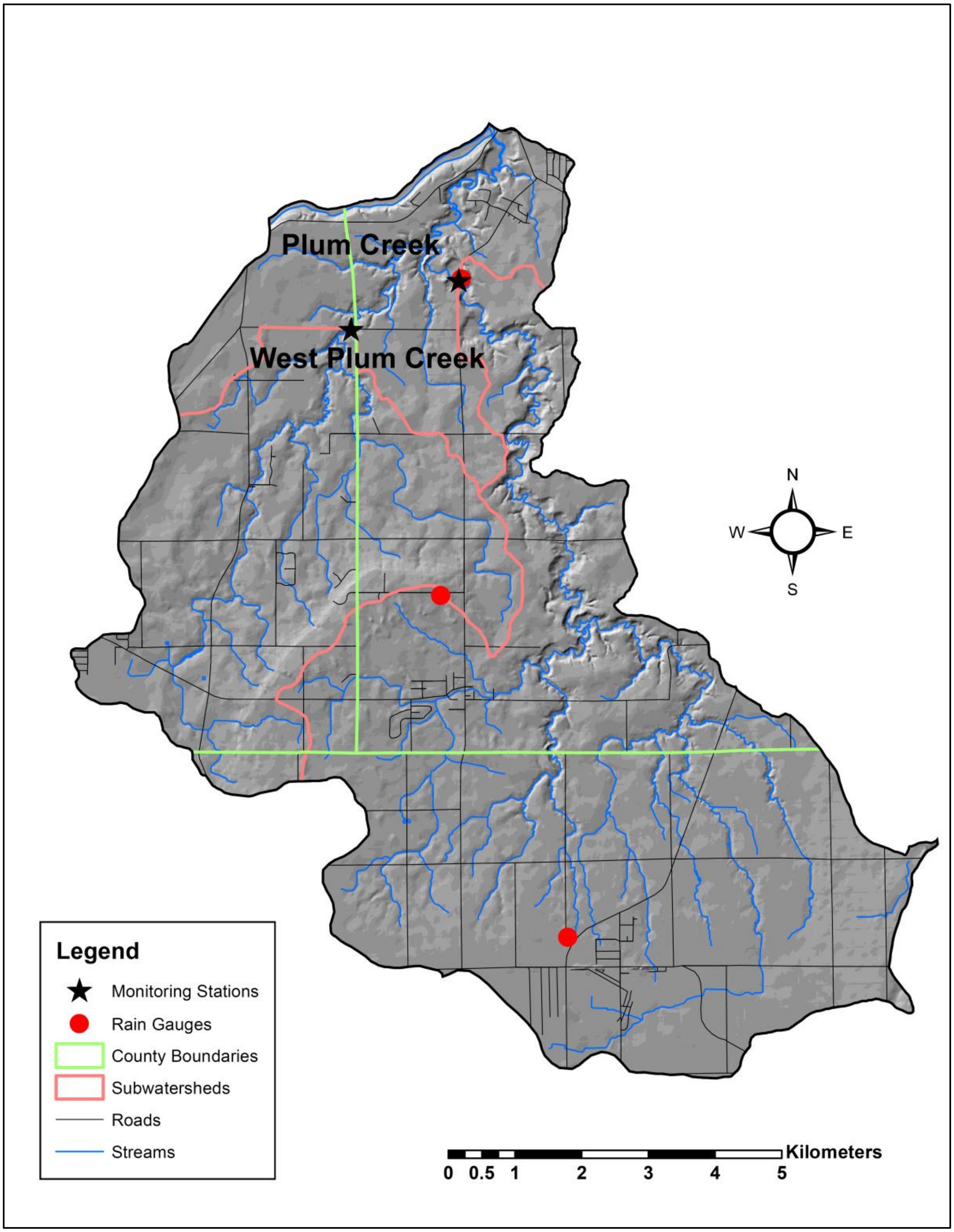

Figure 2.1. Map of Plum Creek watershed showing the main Plum Creek and west Plum Creek monitoring stations and rain gauges.

Methods

Water Quality

A cooperatively-operated United States Geological Survey (USGS) monitoring station was installed on the main branch of Plum Creek (Figure 2.1) in October of 2010 (USGS 04084911). It is located at the stream's intersection with County Road D, south of Wrightstown, Brown County (Figure 2.1). The station consists of a refrigerated automated sampler (ISCO, model 2700R), a gas bubble water level measuring system, rain gauge and a datalogger (Campbell Scientific CR1000) and cellular modem. Data from a similarly outfitted, operated, and automated USGS monitoring station (USGS 040851325) at Superior Road on Baird Creek in Green Bay was used for comparison purposes in this study (Graczyk et al., 2011).

A University of Wisconsin-Green Bay (UWGB) operated monitoring station was installed on the west branch of Plum Creek (Figure 2.1) in October 2010. This West Plum Creek station was located at the stream's intersection with New Road, Outagamie County (Figure 2.1). The West Plum Creek station consisted of a pressure transducer (Campbell Scientific PDCR) and datalogger (Campbell Scientific CR10X) that were used to measure stream height at five second intervals and record ten minute average stream height.

Sample Collection

Event and low flow samples were collected at the Plum Creek and Baird Creek USGS stations and at the West Plum Creek station during the October 2010 through April 2012 study period. Changes in stream gauge height triggered the automated station to collect representative, discrete samples throughout the rising and falling limbs of the hydrograph. The automated sampler collected samples in 1L polyethylene ISCO bottles. Event samples were collected manually from West Plum Creek near time of peak flow according to USGS methods (Shelton 1994). Low flow samples were manually collected at all three sites on a bi-weekly basis using the equal width increment (EWI) method or via grab sampling during extremely low flow conditions. The EWI method consists of dividing a stream into equal vertical segments that are approximately 5% of the total width of the stream and raising and lowering a DH-48 depth integrated wading sampler through the center of each vertical segment (Thornton et al. 1999).

Sample Analysis

All samples were taken to the UWGB laboratory and processed according to USGS established protocols (Shelton 1994). Samples were divided into separate bottles for analysis of TP, total dissolved phosphorus (DP), and TSS using a teflon cone splitter. DP samples were passed through a 0.45μm filter to remove particulate matter. TP and DP samples were preserved with 3:1 sulfuric acid to increase storage and then refrigerated at < 4°C until transported to Green Bay Metropolitan Sewage District (GBMSD) for analysis. The GBMSD laboratory analyzed samples for TSS using Standard Method 2540 D (Clesceri et al. 1998). The US EPA Automated Block Digester Method 365.4 was used to analyze TP and DP samples (US EPA 1983).

Load Calculations

Phosphorus and TSS loads from the portion of the watershed upstream of the main

Plum Creek monitoring station (59% of the total watershed area) were estimated by the USGS using the Graphical Constituent Loading Analysis System (GCLAS), a software program that relates continuous discharge and instantaneous concentrations from discrete samples (Blanchard and Miller 2004). Continuous discharge was estimated by relating discrete discharge measurements to continuous stage measurements.

There were 20 samples analyzed for DP in WY 2011. This small number of DP samples did not allow for GCLAS load calculations. Therefore, continuous DP concentrations were determined from a regression model developed from TSS, TP, and DP concentrations for the entire study period and applied to each five or 15-minute output from GCLAS. The continuous DP concentrations were combined with flow to estimate DP loads. Load calculations for the Baird Creek station were performed using the same procedures.

The USDA ARS Soil and Water Assessment Tool (SWAT), originally developed by Arnold and Williams (Neitsch et al. 2002) was used to extrapolate USGS station loads to the entire watershed. This was done by multiplying 2011 USGS station loads by the ratio of the long-term SWAT simulated loads for the entire watershed to long-term SWAT simulated loads at the USGS station.

Precipitation

Rain gauges were located at the main station on County Road D, on Crestview Road and on Cemetery Road in Plum Creek watershed during the study period (Figure 2.1). An average of the three rain gauges was used to obtain a daily total for Plum Creek watershed. Precipitation from the Green Bay National Weather Service station located at the Green Bay Austin Straubel International Airport was substituted when no data were recorded from any of the three Plum Creek watershed rain gauges. This substitution occurred mostly during frozen precipitation periods. A similar approach was taken with data from two rain gauges located within the Baird Creek watershed, which was compared to Plum Creek.

Environmental Characteristics

Characteristics such as slope, soil type and land use/land cover can influence water quality. These characteristics were analyzed for agricultural land in Plum Creek watershed and five neighboring watersheds. Slope was derived from a 10 m Digital Elevation Model (DEM) from the WDNR (USGS 2009). Soil types of each watershed were obtained from Soil Survey Geographic (SSURGO) Database (USDA NRCS). Land use/land cover characteristics were derived by overlaying wetland features from WISCLAND (WDNR 1998) onto 2011 National Agricultural Statistics Service Cropland Data Layer (NASS CDL) (USDA 2012).

Statistical Analysis

The concentrations of TSS, TP and DP and the DP fraction (portion of TP in the dissolved form) were examined for Plum Creek, West Plum Creek and Baird Creek for various time periods. The data values were found to be positively skewed and a natural log transformation was used for statistical analysis. The effect of flow was investigated by classifying samples as event flow or low flow. Samples were classified based on visual inspection of hydrographs. All statistical analyses were performed using SAS 9.2

computer software (SAS Institute, Cary NC).

The mean natural logs of concentration data were compared. Concentration differences between sites were determined using the PROC TTEST procedure in SAS. Plum Creek and Baird Creek low flow samples were paired by sampling date as were Plum Creek and West Plum Creek low flow samples.

A multiple regression equation for the natural log of DP was developed using PROC REG and applied to calculate DP loads. To correct for the transformation bias, the mean square error was multiplied by 0.5 (Cohn et al. 1989).

Results and Discussion

During the 19 month study period, 181 samples from the main Plum Creek monitoring station were analyzed for TSS and TP. Thirty three Plum Creek TP samples were analyzed for DP (Appendix A). At Baird Creek during the study period, 175 samples were analyzed for TSS and TP. Thirty four Baird Creek TP samples were analyzed for DP (Appendix A). At West Plum Creek during the study period, 19 samples were analyzed for TSS and TP. Fifteen West Plum Creek TP samples were analyzed for DP (Appendix A).

Precipitation

Precipitation totals in Plum Creek watershed were 833 mm and 1,186 mm during WY 2011 and the study period, respectively. Precipitation totals in Baird Creek watershed were 884 mm and 1,218 mm during WY 2011 and the study period, respectively. Precipitation in Plum Creek watershed exceeded the National Weather Service 30 year average by 12% during WY 2011 and the study period. Precipitation in Baird Creek watershed exceeded the National Weather Service 30 year average by 19% and 15% during WY 2011 and the study period, respectively.

In Plum Creek watershed, monthly departures from the average precipitation were not evenly distributed throughout the study period (Table 2.1). November 2010 and August 2011were far below average and April 2011, June 2011 and November 2012 were far above average. Precipitation timing and amount influenced the effect that potential runoff events had on stream flow and therefore sample collection. For example, 48% of Plum Creek event flow samples were collected in just two of the 19 study-period months (April and June 2011). Thirty one percent of the study period samples were collected in June 2011.

Table 2.1. Summary of monthly precipitation for Plum Creek and Baird Creek watersheds from October 2010 – April 2012. Data obtained from Plum Creek watershed rain gauges and the Green Bay National Weather Service (NWS) station at Green Bay.

	Plum Creek		Baird Creek		
Month	**Watershed average (mm)**	**Departure from 30 yr average**	**Watershed average (mm)**	**Departure from 30 yr average**	**Green Bay NWS 30-year average**
Oct.	46.7	-15%	50.7	-8%	55.1
Nov.	22.4	-61%	32.9	-43%	57.7
Dec.	48.0	34%	48.0	34%	35.8
Jan.	31.2	2%	31.2	2%	30.6
Feb.	34.0	33%	34.0	33%	25.6
Mar.	81.5	56%	78.2	50%	52.3
Apr.	135.7	109%	165.1	154%	65.0
May	66.0	-6%	61.3	-12%	69.9
June	125.4	44%	126.6	45%	87.1
July	85.0	-3%	109.6	25%	87.4
Aug.	48.2	-50%	47.1	-51%	95.8
Sept.	109.1	38%	99.3	26%	79.0
WY 2011 Total	**833.3**	12%	**884.2**	19%	**741.3**
Oct.	26.7	-52%	37.6	-32%	55.1
Nov.	95.4	65%	88.3	53%	57.7
Dec.	32.9	-8%	32.5	-9%	35.8
Jan.	35.6	16%	35.6	16%	30.6
Feb.	28.4	11%	28.4	11%	25.6
Mar.	62.3	19%	57.7	10%	52.3
Apr.	72.1	11%	54.2	-17%	65.0
Study Period Total	**1186.7**	12%	**1218.4**	15%	**1063.4**

Concentration Comparisons

Event flow concentration comparisons were made between Baird Creek and Plum Creek during the study period. Event flow comparisons between Plum Creek and West Plum Creek were not performed due to the limited number of event samples from West Plum Creek. Low flow concentration comparisons were made between Baird Creek and Plum Creek and between Plum Creek and West Plum Creek.

Total Suspended Solids

Plum Creek mean natural log TSS concentrations were significantly greater than Baird Creek for event flow, low flow and combined flow conditions (all samples) ($p < 0.05$; Table 2.2 and Figure 2.2). Seventy five percent of all Plum Creek TSS samples were greater than 46 mg/L compared to 16 mg/L for Baird Creek. Maximum TSS concentrations from Plum Creek and Baird Creek samples were 5,790 mg/L and 2,180 mg/L, respectively (Figure 2.2 and Appendix A). Plum Creek and West Plum Creek mean natural log TSS concentrations (Table 2.3 and Figure 2.3) did not differ during low flow conditions ($p = 0.15$).

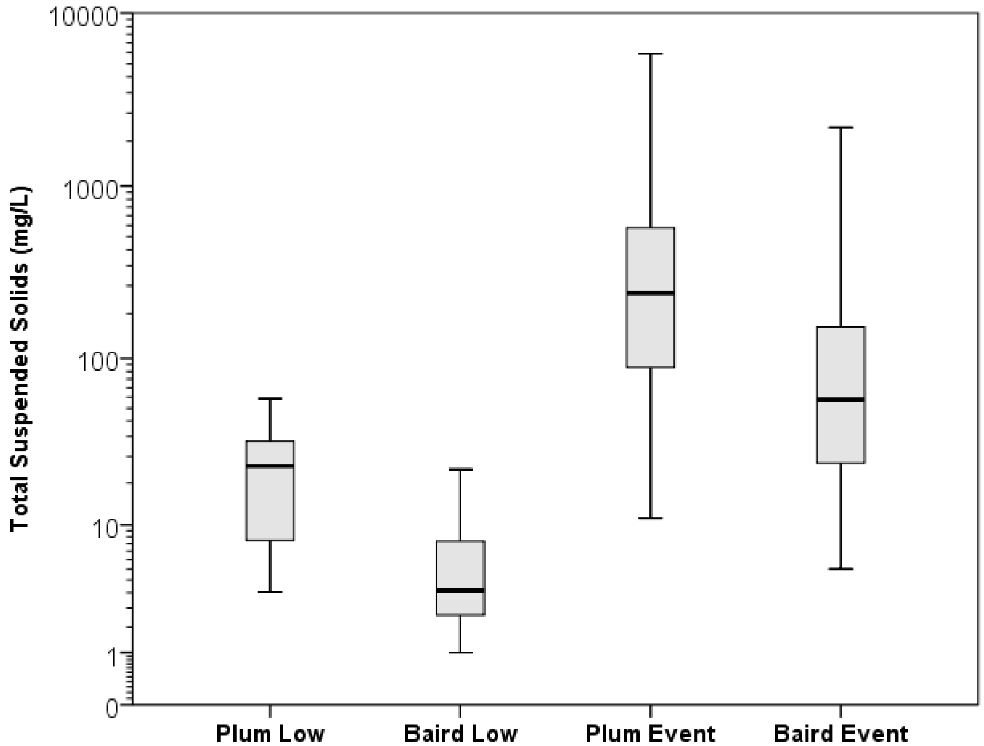

Figure 2.2. Event flow and low flow total suspended solids concentration for Baird Creek at Superior Rd and Plum Creek at County Road D during the study period. Plum Creek low flow and event flow concentrations are significantly greater than Baird Creek. Boxes and bars represent the interquartile range and median respectively. Whiskers represent the largest sample values that are not considered outliers.

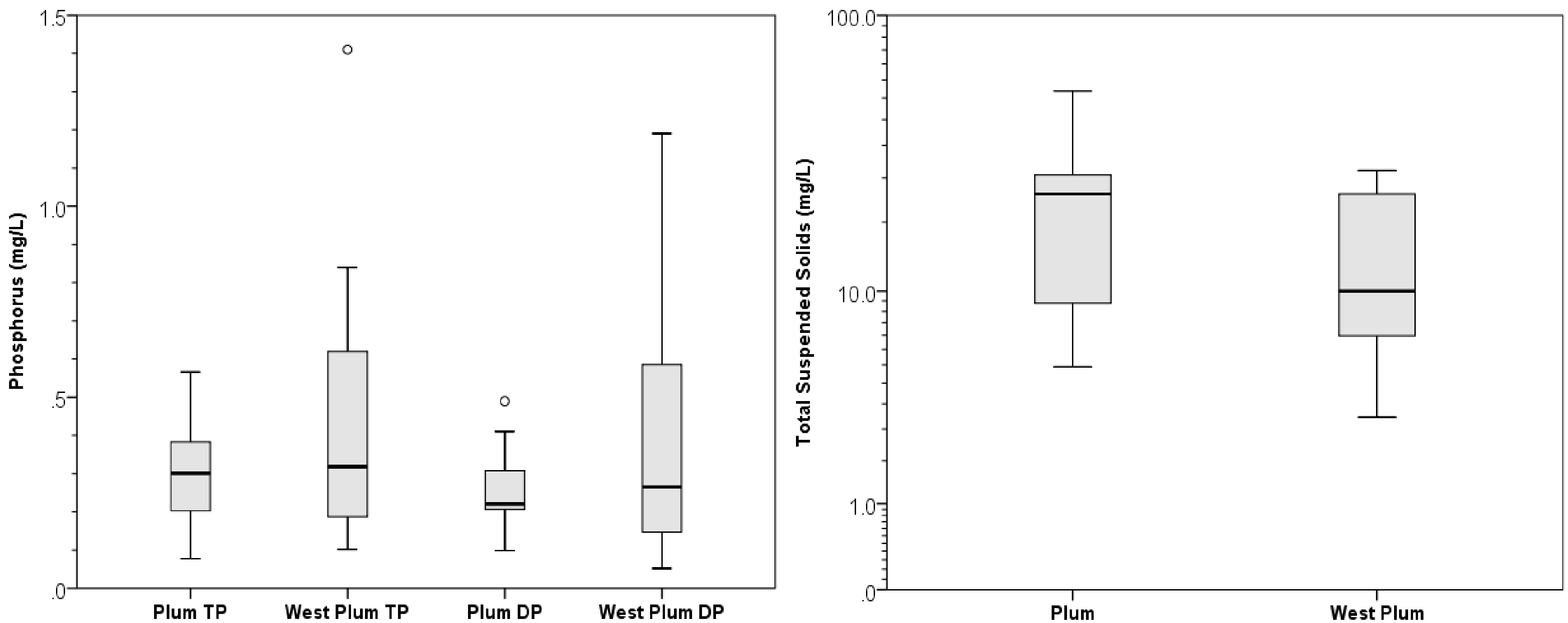

Figure 2.3. Paired low flow total phosphorus and dissolved phosphorus concentration (A) and total suspended solids concentration (B) for Plum Creek at County D and West Plum Creek at New Road during the study period. Plum Creek and West Plum Creek concentrations did not differ. Boxes and bars represent the interquartile range and median respectively. Whiskers represent the largest sample values that are not considered outliers. Outliers (1.5 box lengths from the end of the box) are represented as circles.

Total Phosphorus

Plum Creek mean natural log TP concentrations were significantly greater than Baird Creek for event flow, low flow and combined flow conditions ($p < 0.05$; Table 2.2 and Figure 2.4). Plum Creek and West Plum Creek mean natural log TP concentrations (Table 2.3 and Figure 2.3) were not significantly different during low flow conditions ($p = 0.44$). Seventy five percent of all Plum Creek TP samples were greater than 0.41 mg/L compared to 0.18 mg/L for Baird Creek. Baird Creek did, however, have a higher maximum TP concentration with 6.35 mg/L. The maximum TP concentration for Plum Creek was 5.64 mg/L (Figure 2.4 and Appendix A).

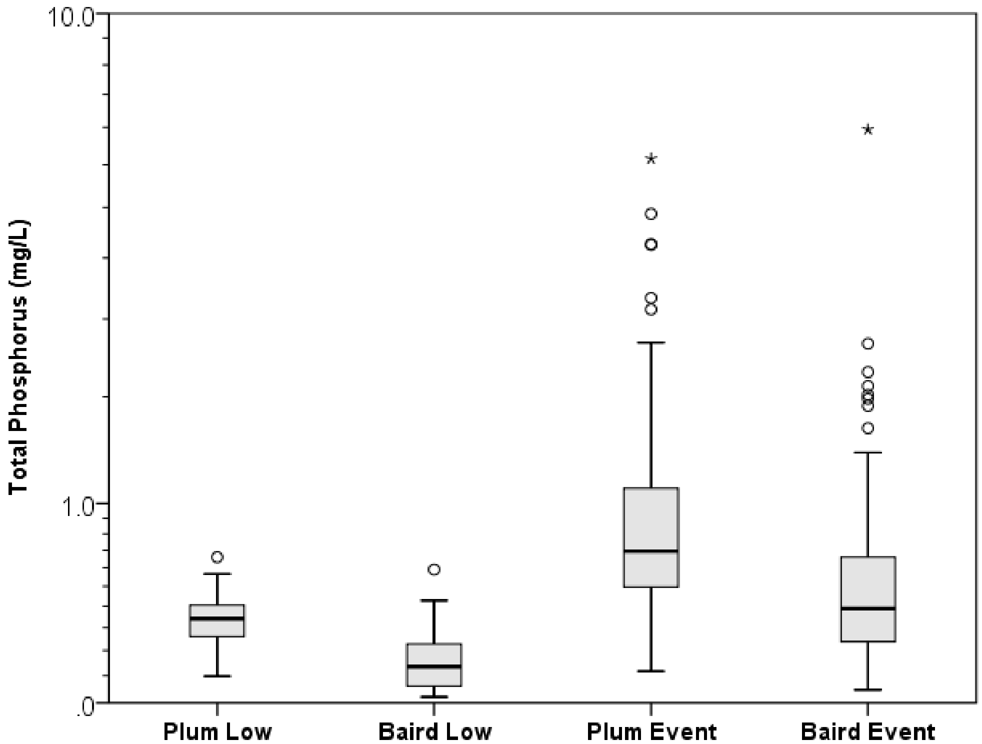

Figure 2.4. Event flow and low flow total phosphorus concentration for Baird Creek at Superior Road and Plum Creek at County Road D during the study period. Plum Creek low flow and event flow concentrations are significantly greater than Baird Creek. Plum and Baird low flow samples are paired. Boxes and bars represent the interquartile range and median respectively. Whiskers represent the largest sample values that are not considered outliers. Outliers (1.5 box lengths from the end of the box) are represented as circles, and extreme outliers (3 box lengths from the end of the box) are represented as asterisks.

Table 2.2. Comparison of total suspended solids (TSS), total phosphorus (TP) and DP concentrations between Baird Creek (BA) and Plum Creek (PL) for various flow conditions during the study period (October 2010 – April 2012). Medians with different letters represent statistical significance at the 0.05 probability level.

	TSS (mg/L)		**TP (mg/L)**		**DP (mg/L)**		**DP Fraction (%)**	
	PL	**BA**	**PL**	**BA**	**PL**	**BA**	**PL**	**BA**
All Flow Conditions								
Median	149[a]	42[b]	0.60[a]	0.34[b]	0.24[a]	0.14[b]	38[a]	52[a]
No. of Samples	181	175	181	175	33	34	33	33
Low Flow Conditions – Data are Paired								
Median	23[a]	4[b]	0.34[a]	0.13[b]	0.22[a]	0.06[b]	71[a]	62[a]
No. of Samples	27	27	27	27	13	13	13	13
Event Flow Conditions								
Median	231[a]	58[b]	0.69[a]	0.39[b]	0.24[a]	0.17[b]	28[a]	44[b]
No. of Samples	153	146	153	146	19	20	19	20

Table 2.3. Comparison of total suspended solids (TSS), total phosphorus (TP) and DP concentrations between Plum Creek (PL) and West Plum Creek (WPL) for low flow conditions during the study period (October 2010 – April 2012). Medians with different letters represent statistical significance at the 0.05 probability level.

	TSS (mg/L)		**TP (mg/L)**		**DP (mg/L)**		**DP Fraction (%)**	
	PL	**WPL**	**PL**	**WPL**	**PL**	**WPL**	**PL**	**WPL**
Median	23[a]	10[a]	0.30[a]	0.32[a]	0.22[a]	0.27[a]	73[a]	78[a]
No. of Samples	13	13	11	11	11	11	11	11

Dissolved Phosphorus

Plum Creek DP concentrations were significantly greater than Baird Creek for event flow, low flow and combined flow conditions ($p < 0.05$; Table 2.2 and Figure 2.5). Seventy five percent of all Plum Creek TP samples were greater than 0.20 mg/L compared to 0.06 mg/L for Baird Creek. Maximum DP concentrations for Plum Creek and Baird Creek were approximately equal (Figure 2.5 and Appendix A.1). Plum Creek and West Plum Creek DP concentrations (Table 2.3 and Figure 2.3) were not statistically different during low flow conditions ($p = 0.21$).

Event flow DP fraction for Baird Creek (44%) was greater than Plum Creek (28%) ($p = 0.02$). For combined flow conditions, DP fraction for Baird Creek (52%) was greater than Plum Creek (38%) but the difference was not significant ($p = 0.22$; Table 2.2). Baird Creek and Plum Creek low flow DP fraction did not differ ($p = 0.39$). The greatest median DP fraction (78%) was observed for the 11 low flow samples collected from West Plum Creek (Table 2.3). The low flow DP fraction for Plum Creek was 71%, but it was not significantly less than that for West Plum Creek ($p = 0.35$).

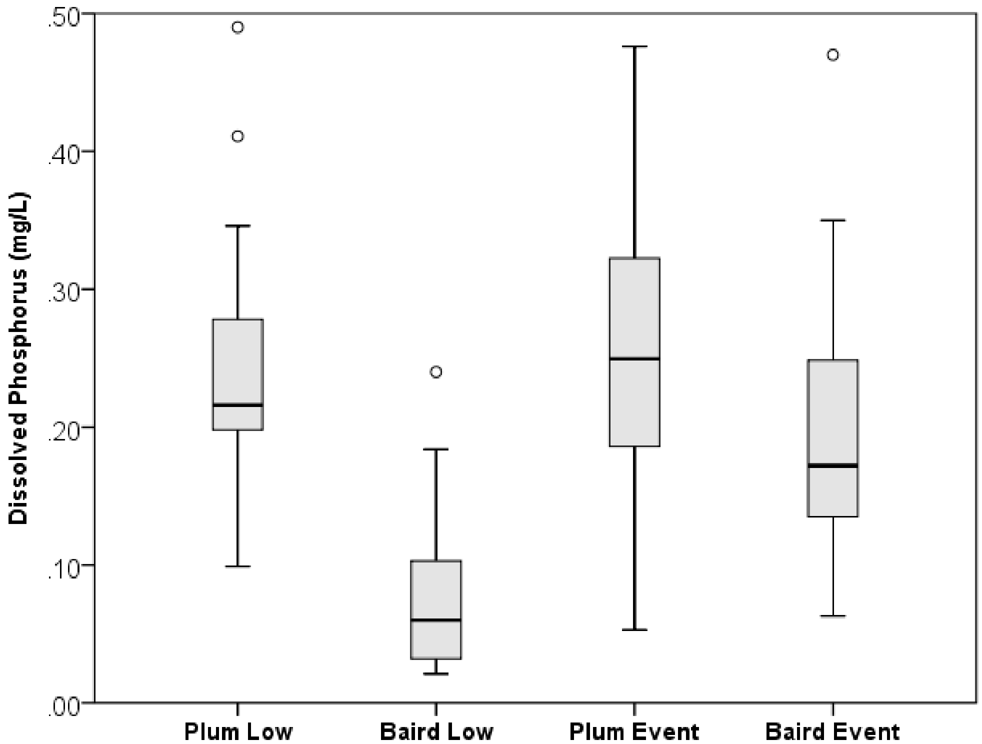

Figure 2.5. Event flow and low flow dissolved phosphorus concentration for Baird Creek at Superior Road and Plum Creek at County Road D during the study period. Plum Creek low flow and event flow concentrations are significantly greater than Baird Creek. Plum and Baird low flow samples are paired. Boxes and bars represent the interquartile range and median respectively. Whiskers represent the largest sample values that are not considered outliers. Outliers (1.5 box lengths from the end of the box) are represented as circles.

Linear Regression Predicted DP Concentrations

A linear regression analysis was performed on data from all flows across the entire study period to identify whether significant relationships existed between DP and other water quality variables such as TP, TSS, discharge (Q), and the ratio of TSS to TP (TSS/TP). Identification of significant relationships between DP and other variables may be useful in understanding and therefore reducing DP loss.

No significant relationships were found between DP and TSS, discharge or TSS/TP. In addition, no statistically significant relationship ($r^2 = 0.06$; n = 33) was found between the natural log of DP (lnDP) and the natural log of TP (lnTP) when flow conditions were combined (Figure 2.6). When separated by flow conditions, however, a significant relationship between low flow lnDP and lnTP was found ($r^2 = 0.78$; n = 13

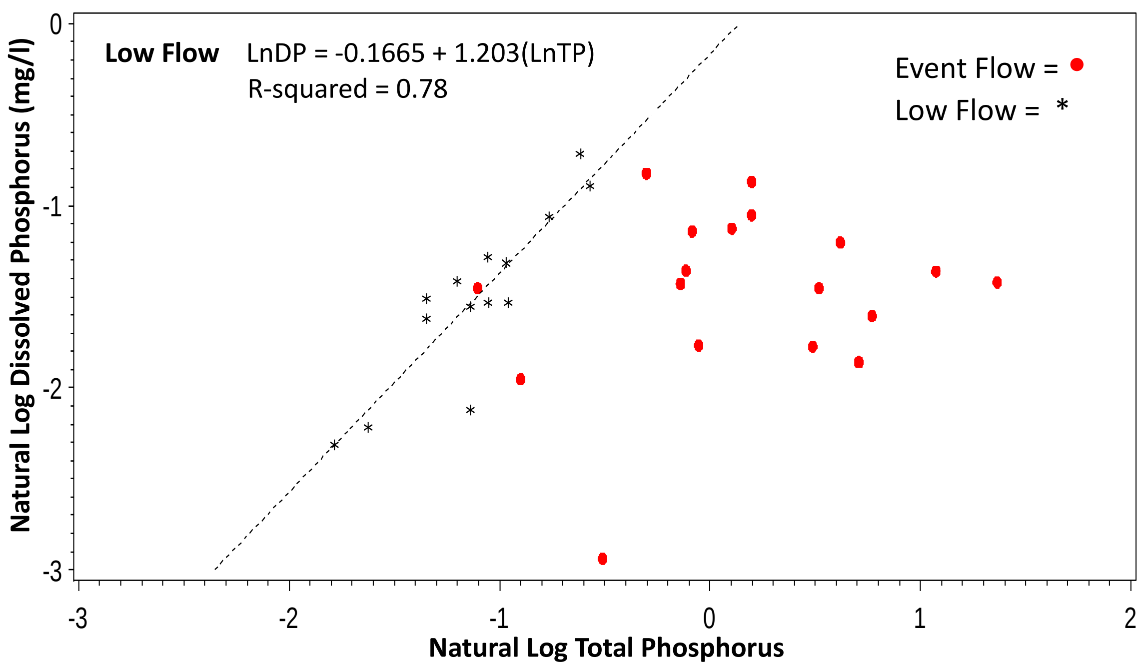

Figure 2.6. Natural log of dissolved phosphorus (LnDP) concentration vs. the natural log of total phosphorus (LnTP) concentration from all Plum Creek samples during the study period. Line depicts linear regression for low flow samples only.

Multiple Regression Analysis to Predict DP Concentrations and Loads

Because DP was only analyzed for a relatively small number of samples, a regression equation was needed to calculate the DP load for WY 2011. This was done by developing a multiple regression equation that predicted a DP concentration every five minutes. Data for the best fit model were derived from the entire study period through the end of April 2012, which included USGS-approved WY 2011 concentration and flow data, as well as estimated flows for WY 2012. The distribution of DP was positively skewed and was first natural log transformed to meet the normality assumption of multiple regressions. Variables that were incorporated into the model included the natural log of TP, the TSS to TP ratio and a seasonality component. The seasonality component consisted of two functions, sine and cosine, which were included as a means to account for seasonal differences in P concentrations (Helsel and Hirsch 1992). Seasonal differences of in-stream P concentrations may be due to biological activity (i.e. evapotranspiration), managed activities (i.e. nutrient applications) or the dominant source of water (i.e. groundwater versus surface runoff). TSS, discharge, discharge squared and the TP to TSS ratio were examined but not included in the best fit model. Figure 2.7 graphically displays the relationship between LnDP values and values predicted by the multiple regression equation. The best fit highest adjusted r-squared four variable model for predicting the natural log DP concentration was as follows:

$$\mathbf{LnDP = -0.3924 + 0.8046(LnTP) - 0.0023(TSS/TP) - 0.214(sin(day)) - 0.2209(cos(day))}$$

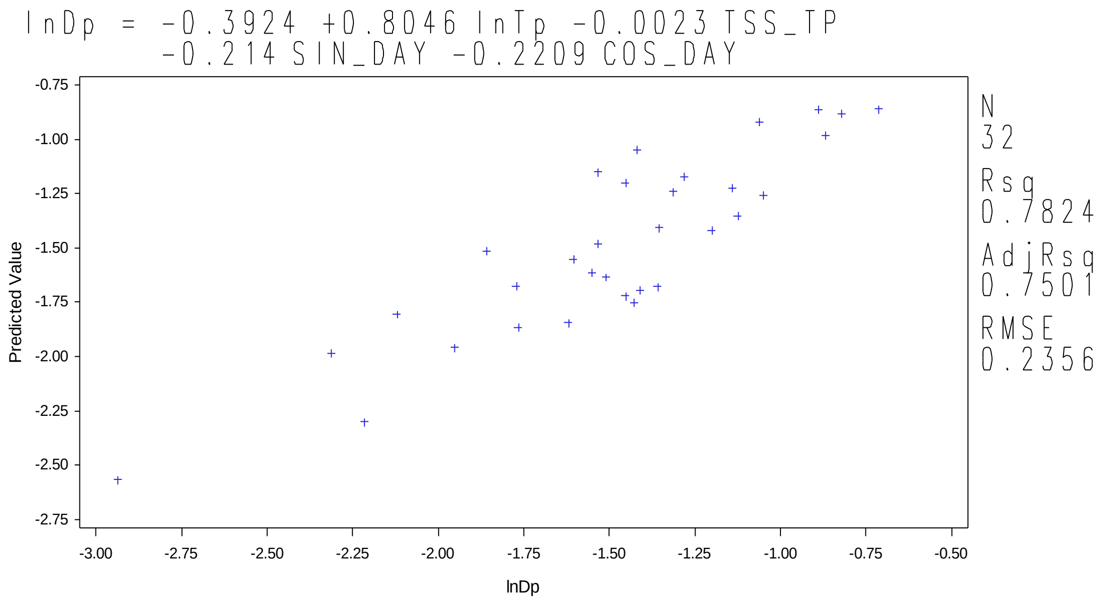

Figure 2.7. Plot of natural log of dissolved phosphorus (mg/L) against values predicted by the multiple regression model.

The multiple regression equation had an adjusted R-squared value of 0.75 (Figure 2.7). In other words, the equation explained 75% of the variation of DP across all flow conditions in Plum Creek during the study period. As expected, the natural log of DP increased as the natural log of TP increased and decreased as the ratio of TSS to TP increased. Relatively large TSS to TP values indicates a large in-stream TSS concentration, relative to TP concentration. The effect of this was noted in the linear regression analysis as no significant relationship was seen between DP and TP for event flow samples. Table 2.4 shows the probability values for the intercept and each variable in the model.

Table 2.4. Probability values for the intercept and variables of the multiple regression model used to predict dissolved phosphorus concentration.

Variable	Probability value
Intercept	0.0153
LnTP	<.0001
TSS/TP	<.0001
Sin(Day)	0.0018
Cos(Day)	0.0152

Load Comparisons – WY 2011

Constituent loads were computed for TSS and TP by the USGS. DP loads were calculated from predicted continuous DP concentrations and five minute discharge. Total load depends on watershed area; therefore its usefulness for making watershed comparisons is limited. Yield, or unit-area load, which accounts for watershed area, was used to compare Plum to other watersheds. WY 2011 flows, precipitation, and yields for Plum Creek and Baird Creek are given in Table 2.5. Plum Creek TSS, TP and DP yields at County D during WY 2011 were 1.08 t/ha, 2.54 kg/ha and 0.69 kg/ha, respectively (Table 2.6). Baird Creek TSS, TP and DP yields during WY 2011 were 0.24 t/ha, 1.01 kg/ha and 0.72 kg/ha, respectively (Table 2.6). WY 2011 TSS and TP yields from Plum Creek were approximately 530% and 250%, respectively, greater than from Baird Creek. However, Baird Creek had a greater flow-weighted DP fraction (71.1%) compared to in Plum Creek (26.7%).

Loads were extrapolated to the entire watershed using SWAT. Extrapolated WY 2011 loads for the whole Plum Creek watershed were 14,722 metric tons TSS, 26,701 kg TP and 7,279 kg DP.

Comparisons with Neighboring Agricultural Watersheds

The USGS, in cooperation with UWGB, analyzed water quality in five agricultural streams in the LFRB and Lower Green Bay watersheds during WYs 2004 to 2006 (Graczyk et al. 2011). Watersheds included in the study were Apple Creek, Ashwaubenon Creek, Baird Creek, Duck Creek and the East River. Combining all watersheds, average precipitation from rain gauges across water years 2004-2006 was 731 mm. Precipitation departures from the 30 year average at the Green Bay airport in WYs 2004, 2005 and 2006 were +7%, -2% and -9%, respectively (Graczyk et al. 2011). Differences in precipitation timing and intensities across water years did not allow for a statistical comparison between Graczyk et al. (2011) results and Plum Creek WY 2011 results. A qualitative comparison was made, however, between Plum Creek WY 2011 data and the water quality data presented by Graczyk et al. (2011).

When examining precipitation amounts, WY 2004 in Graczyk et al. (2011) was most similar to WY 2011 in the Plum Creek watershed. P and TSS yields were also much higher in WY 2004 than in either WY 2005 or 2006 in all five of the watersheds (Graczyk et al. 2011). As a group, the five watersheds exceeded the 30 year average precipitation total by 7%. Plum Creek watershed during 2011 had a departure from the 30 year average of +12%. For these reasons, Plum Creek yields during WY 2011 were compared to WY 2004 in Graczyk et al. (2011).

Plum Creek WY 2011 TSS (1.08 t/ha) and TP (2.54 kg/ha) yields exceeded those from any of the comparison watersheds (Table 2.5). During WY 2004, Apple Creek exhibited the highest TSS yield (0.93 t/ha), while Baird Creek exhibited the highest TP yield (2.34 kg/ha) and DP yield (1.22 kg/ha).

The distribution of loads from Plum Creek and the comparison watersheds was non-uniform throughout their respective water years. Eighty nine percent of the TSS load and 77% of the TP load from Plum Creek occurred during 14 days in March, April and June of 2011. The average for WYs 2004 to 2006 for the comparison watersheds ranged from 73% to 85% for TSS and 54% to 75% for TP (Graczyk et al. 2011). These data illustrate the disproportionate contributions of event flow to annual TSS and TP loads. Understanding the factors that influence event flow loads is important in reduction efforts and is the focus of Chapter 3.

Table 2.5. TSS, TP and DP yields, precipitation and flow in watersheds of six Lower Fox River monitoring sites for various water years.

Watershed	**Area (km^2)**	**WY**	**TSS (t/ha)**	**TP (kg/ha)**	**DP (kg/ha)**	**Precipitation (mm)**	**Flow (mm)**
Plum Creek	**54**	**2011**	**1.28**	**2.54**	**0.69**	**833**	**333**
Apple Creek	119	2004	0.93	1.89	0.67	741	318
Ashwaubenon Creek	52	2004	0.69	1.99	0.84	756	250
Baird Creek	54	2004	0.73	2.34	1.22	826	363
Baird Creek	54	2011	0.24	1.01	0.72	884	337
Duck Creek	280	2004	0.36	1.29	0.60	812	312
East River	376	2004	0.49	1.63	0.79	828	376

Environmental Characteristics

Comparing the environmental characteristics of Plum Creek with the neighboring watersheds may explain Plum Creek's high TSS and P yields and in-stream concentrations. Several factors were examined.

Analysis of 2011 land use/land cover of each monitoring site's watershed showed Plum Creek has a higher percentage of agricultural land (80%) than Apple Creek (66%), Baird Creek (76%), Duck Creek (70%) and the East River (63%) but not as much as Ashwaubenon Creek (84%) (Appendix B). Several studies have found a positive relationship between the percent of agricultural land in a watershed and in-stream TP concentrations (Robertson et al. 2006; Reckinger 2007; Graczyk et al. 2011).

Soil texture may also play a role. Reckinger (2007) found a positive relationship between soil clay content and in-stream TP concentrations. Clay content (21%) of Plum Creek watershed, however, is not as high as that found in Apple (26%) and Ashwaubenon Creeks (26%) (Graczyk et al. 2011).

Slope was also examined for the agricultural areas in the watersheds of each of the monitoring sites (Appendix B). The mean slope of agricultural land in Plum Creek watershed (3.7%) is higher than in Apple (2.6%), Ashwaubenon (1.7%), Baird (2.6%) and Duck Creek (3.1%) watersheds but not as high as in the East River watershed (4.1%). Steeper slopes increase the risk of sediment loss and subsequently P loss during runoff events.

Although any one of these factors may not explain Plum Creek's high yields, the combination of these and additional factors, such as management practices (tillage, manure applications, etc.) may provide an explanation.

Table 2.6. WY 2011 flow, TSS, TP and DP loads and the flow-weighted dissolved fraction of phosphorus at the Plum Creek and Baird Creek USGS monitoring stations.

Site	Area (ha)	Flow (mm)	TSS Load (metric ton)	TSS Yield (t/ha)	TP Load (kg)	TP Yield (kg/ha)	DP Load (kg)	DP Yield (kg/ha)	DP Fraction (%)
Plum Creek	**5,435**	**333**	**6,979**	**1.28**	**13,804**	**2.54**	**3,694**	**0.69**	**27.3**
Baird Creek	5,385	337	1,292	0.24	5,459	1.01	3,882	0.72	71.1

Conclusions

According to the LFRB TMDL, the Plum Creek watershed had the highest predicted TSS (Table 10, WDNR 2012) and TP (Table 9, WDNR 2012) yields of any watershed in the LFRB. These predictions were based on long-term simulations with a modified and locally validated version of SWAT. Results of this study show that Plum Creek does indeed have high TSS and TP yields. Plum Creek TSS and TP yields in WY 2011 were much higher than those from Baird Creek during WY 2011 and higher than those from Apple Creek, Ashwaubenon Creek, Baird Creek, Duck Creek and the East River during WYs 2004-2006.

Major reductions are needed to meet the water quality goals laid out in the TMDL. Plum Creek watershed's WY 2011 TSS (1,284 kg/ha) and TP (2.54 kg/ha) yields are many times greater than the yield goals of 175 kg/ha and 0.35 kg/ha stated in the TMDL (WDNR 2012). Furthermore, the low flow summer median TP concentration for Plum Creek (0.35 mg/L) was nearly five times the TMDL target concentration for tributaries of 0.075 mg/L. When combining all flow conditions, 99% of all Plum Creek samples during the study period were greater than 0.1 mg/L and 64% were greater than 0.5 mg/L.

Analysis of environmental characteristics did not provide an explanation for Plum Creek's high yields. Agricultural practices, such as tillage and manure applications, however, may provide some insight. Such factors are examined more in-depth in Chapter 3.

CHAPTER 3 – MULTI-FIELD CATCHMENT SCALE WATER QUATLITY AND EVALUATION OF THE WISCONSIN PHOSPHORUS INDEX AND SNAP-PLUS

Introduction

The US EPA recognizes agricultural runoff as a major source of water quality impairments (US EPA 1995). Nutrients and sediment are seen as two of the greatest causes of impairments (US EPA 2011). Agricultural runoff can contain elevated concentrations of P, a nutrient that can lead to surface water eutrophication (Correll 1998). Land application of P in the form of fertilizer and manure increases the potential of P loss in runoff (Daniel et al. 1998). Consequently, the Natural Resources Conservation Service (NRCS) requires all states to manage agricultural P under the NRCS 590 standard. Many states have responded by developing a P index, a tool that rates fields based on the P loss vulnerability (Sharpley 2003).

SnapPlus and the Wisconsin Phosphorus Index

The Wisconsin Phosphorus Index (WI PI) is a tool that Wisconsin producers can use to manage their P loss risk. Wisconsin producers can choose to manage P of individual fields via the Wisconsin Phosphorus Index (WI PI) or soil test P (STP). For those using the WI PI strategy, fields must have an average PI of 6 or lower for up to an 8 year rotation (NRCS 2005). Manure applications must be discontinued on fields exceeding this standard unless additional P is needed according to soil test recommendations (NRCS 2005).

The WI PI is a component of SnapPlus, a nutrient management software program designed to help producers prepare nutrient management plans (NMPs) in accordance with NRCS 590 (Kaarakka et al. 2011). SnapPlus calculates crop nutrient application recommendations, Revised Universal Soil Loss Equation 2 (RUSLE2)-based soil loss and edge-of-field PIs for single years and multiple-year rotations for individual fields. The PI is partitioned into particulate PI (PPI), soluble or dissolved PI (DPI), and an acute PI (Kaarakka et al. 2011).

WI PI equations are based on runoff monitoring data from multiple sites in Wisconsin (Good et al. 2010). The WI PI calculates the PPI by multiplying the mass of each particle size class by estimated surface soil TP concentrations and then summing the mass of each class. Surface soil TP is the total P in the surface soil adjusted for the total P added from fertilizer and manure (Good et al. 2010).

RUSLE2 takes into account soil type, climate, slope length and steepness, crop management, and conservation practices present. The WI PI calculates DP loads separately for frozen and non-frozen periods by multiplying surface runoff volume by soluble phosphorus concentrations in runoff. Unlike PP and DP, which represent losses for an average weather year, acute P loss values represent worst-case scenarios. The WI PI incorporates fertilizer and manure application losses from non-frozen ground and manure application losses from frozen ground into the acute loss value. To derive a final P index value, SnapPlus multiplies the sum of all P loss categories (PP, DP, and acute) by a delivery ratio, which is a function of length and steepness of the overland flow path to a receiving body of water.

Good et al. (In Press) found a strong relationship ($r^2 = 0.87$) between PI and measured annual P runoff loads from 86 field years when measured runoff and erosion were used in the PI calculations. When not adjusted for runoff or erosion, however, the relationship between PI and P runoff load relationship was much weaker ($r^2 = 0.24$). Good and Bundy (2005) also found a strong relationship ($r^2 = 0.79$) between PI and measured P runoff loads. PI calculations were based on inputs derived from research level crop management data.

Reckinger (2007) compared the PI to measured runoff P concentrations near peak flow during five events from 11 source areas. The study's source areas range in size from 15 ha to 224 ha. PI inputs were based on NMPs that producers submitted to the WDNR and county offices. Reckinger (2007) did not find a significant relationship between PI and measured runoff TP concentrations but did find a significant relationship ($r = 0.81$) between DPI and runoff DP concentrations.

This chapter characterizes P and sediment concentrations measured at the multi-field catchment (MFC) scale and compares these observed concentrations to NMP-derived SnapPlus P and sediment loss predictions in Plum Creek Watershed. The chapter also takes an in-depth look at three of the MFCs. These case studies examine in greater depth the effects of land use and practices on P and sediment runoff concentrations.

Methods

Water Quality

Sample Collection

In March of 2011, 17 MFC monitoring sites were selected in Plum Creek watershed

(Figure 3.1). These MFC sites were selected because they were predominately agricultural, of adequate size for sufficient discharge and had significant NMP coverage. Table 3.1 shows the areas and NMP coverage of each of the 17 MFCs. The contributing area of each MFC sampling site was delineated using contour maps and LIDAR data in ArcGIS 10. Boundaries of farm fields all or partially within MFCs were digitized based on maps included in NMPs.

MFC runoff samples were manually collected near peak flow of four spatially uniform precipitation events. The relative time of peak flow occurrence was expected to approximately correspond to MFC area. The order in which MFCs were sampled was based on this assumption. Uniform precipitation across the entire watershed was essential for valid MFC water quality comparisons. Uniformity of precipitation was determined by visual examination of NWS total storm precipitation radar images. All MFC monitoring sites were located at road crossings. Tape-down measurements were taken from fixed reference points established at each sampling site to ensure that samples were taken at approximately peak flow. Results of previous studies suggest that peak flow grab sample concentrations correlate closely with event mean concentrations (Reckinger 2007).

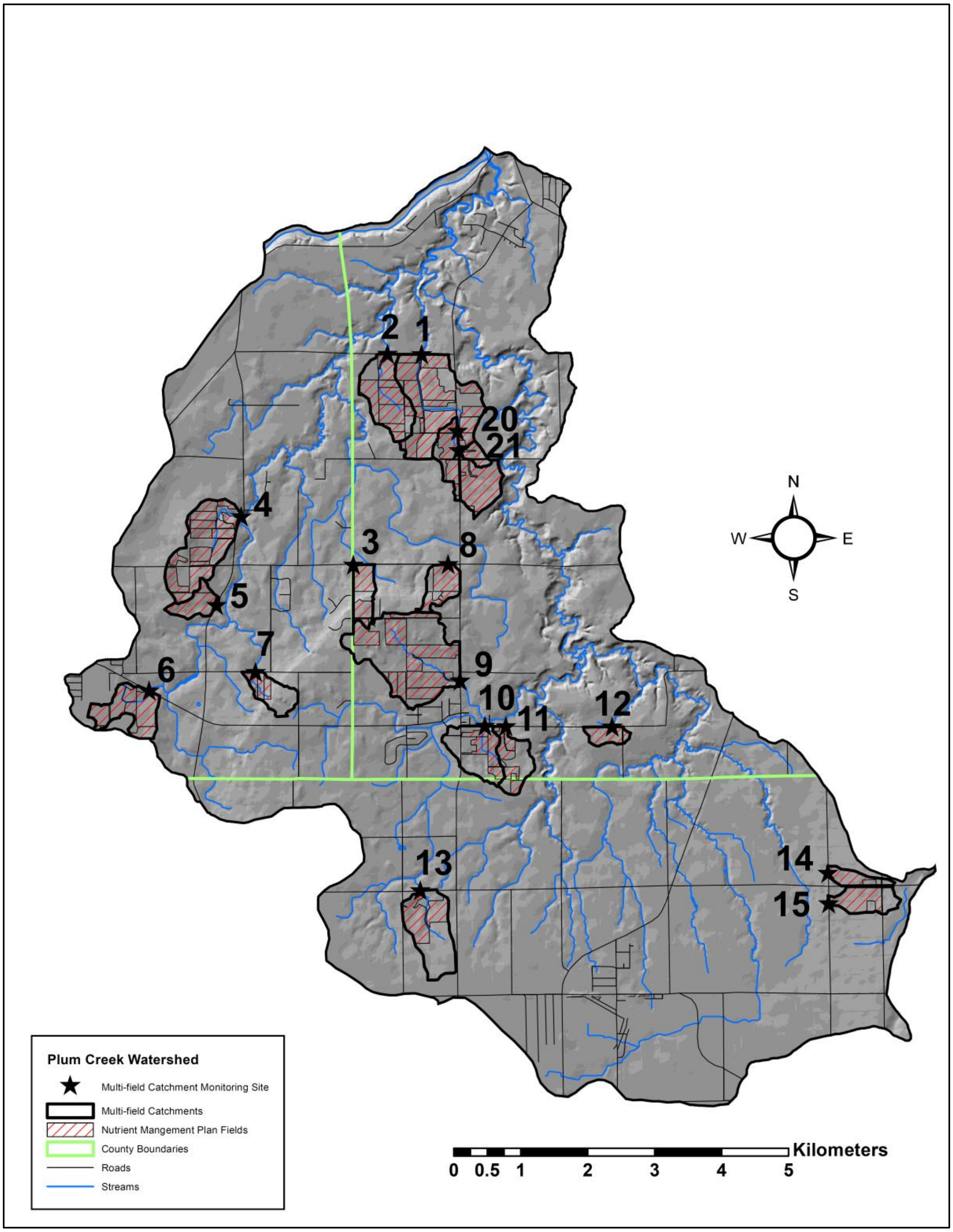

Figure 3.1. Map of Plum Creek watershed showing multi-field catchments, sampling sites and nutrient management plan fields.

Sample Analysis

All MFC samples were transported to the University of Wisconsin-Green Bay (UWGB) laboratory and processed according to USGS established protocols (Shelton 1994) (See Chapter 2). MFC samples were analyzed for TP and DP at UWGB labs using QuikChem Method 10-115-01-2-B. MFC samples were analyzed for suspended sediment concentration (SSC) using standard methods (USFS 2002).

Table 3.1. Area and nutrient management plan (NMP) coverage for crop years 2011 and 2012 of 17 multi-field catchment (MFC) monitoring sites in Plum Creek watershed.

MFC	Area (ha)	Ag Area (ha)	Ag Area (%)	NMP Coverage (%) Crop Year 2011	NMP Coverage (%) Crop Year 2012
1	212.3	181.4	85	72	67
2	66.0	62.1	94	88*	88*
3	26.6	22.1	83	93*	93*
4	97.0	74.8	77	96*	91*
5	21.0	21.3	97	100*	13
6	50.6	46.1	91	100*	54*
7	29.0	21.5	74	72*	72*
8	28.7	26.9	94	55*	55*
9	162.8	139.2	85	56*	56*
10	53.9	36.8	68	57*	57*
11	37.5	30.4	81	58*	58*
12	15.3	13.5	88	94*	94*
13	72.3	68.8	95	45	45
14	16.6	12.8	77	100	100
15	33.4	28.7	86	80	80
20	79.5	70.2	88	39	30
21	40.5	38.9	96	0	0

*Selected MFCs with >50% NMP coverage used in water quality comparisons.

SnapPlus Assessment

SnapPlus Inputs and Outputs

Sound SnapPlus P and sediment loss predictions require accurate inputs. Input data for SnapPlus includes field area, dominate soil type, field slope and length, below field slope to water, distance to water, STP, nutrient applications, crop type, yield goals and tillage practices. Typically producers provide a professional crop consultant with field data and the consultant develops a NMP for the producers. The consultant uses this field data to compute WI PI values for individual fields.

In this study, NMP data was obtained from the WDNR and Brown, Calumet and Outagamie County conservation departments. NMP data for 74 fields in 2011 and 70 fields in 2012, partially or entirely within the MFCs, were entered into SnapPlus (version 1.132.8). All SnapPlus inputs used to calculate PI and soil loss values were based on information reported in NMPs. Field slope and length were based on dominant soil type. P and sediment loss values were calculated over a three year rotation period (2010 - 2012). Annual P and sediment loss values for crop years 2011 and 2012 were extracted from SnapPlus and used to calculate area-weighted PI and soil loss values for each MFC. A crop year is the period of time between harvest of the previous crop and harvest of the current crop.

Reliable and up-to-date data could not be obtained for all fields within each MFC. MFCs with less than 50% NMP coverage of agricultural land were not included in statistical analyses with water quality results because it was assumed such MFCs were not adequately characterized. Eleven of the 17 catchments met this criterion in crop year 2011 and ten did in crop year 2012 (Table 3.1).

Area-weighted MFC SnapPlus Output Values

For MFCs with greater than 50% NMP coverage of agricultural land, area-weighted PI, STP and soil loss estimate values were calculated for crop years 2011 and 2012. The area of each field, calculated in ArcGIS, was used to weight annual PI, STP and soil loss values for each field with NMP data. Non-NMP agricultural fields within the MFCs were assigned the same area-weighted SnapPlus outputs that were calculated for NMP fields in their respective MFC. Non-agricultural land within the MFCs was assigned a PI of 0.2 and a soil loss estimate of 0.1 ton/a (0.225 t/ha). The non-agriculture PI estimate was based on a SnapPlus simulation of permanent grassland with no nutrient applications during a three year rotation. The soil loss estimate was based on Good et al. (2011) which estimated soil loss from un-grazed pastures to be <0.1 ton/a (0.225 t/ha). Overall area-weighted PI, STP and soil loss value for these selected MFCs for each crop year were compared to SSC, TP, PP, and DP concentrations and the fraction of DP measured during four runoff events during the study period.

Residue Surveys

Road-side surveys were performed shortly after MFC sampling events to assess the amount of surface residue on fields within the MFCs. Surveys were performed in May 2011, November 2011 and May 2012 by evaluating surface residue from the road for each field. Residue was ranked on a scale from one to six (Table 3.2). A value of six represented full residue or cover (alfalfa, pasture, etc.) and a value of one represented no residue. Area-weighted residue values were calculated for each MFC and compared to water quality and SnapPlus outputs. MFCs with less than 50% residue survey coverage were not used in comparisons.

Table 3.2. Estimated residue cover percentages associated with categories used in residue surveys in Plum Creek watershed following multi-field catchment runoff events.

Value	Description	Residue Cover
1	Zero	0-5%
2	Low	5-15%
3	Low/moderate	15-30%
4	Moderate	30-50%
5	High	>50%
6	Alfalfa, hay, etc.	Full

Statistical Analysis

Concentrations of suspended sediment, TP and DP were compared among the four runoff events using PROC GLM in SAS. The data values were found to be positively skewed and a natural log transformation was used for statistical analysis.

To assess the relationship between SnapPlus ratings and runoff water quality, a correlation was performed on the ranks of the MFC concentrations from crop years 2011 and 2012 to the area-weighted SnapPlus outputs. The significance of each correlation was determined using the Spearman option in PROC CORR of SAS 9.2. Probability values (p) of less than 0.05 were considered to be statistically significant.

Limitations and Challenges

Obtaining complete NMP data from certain producers proved to be challenging. In some instances, assumptions were made for unknown SnapPlus inputs (soil pH, soil organic matter, soil potassium, yield goals, field slope, distance to water, etc.). When crop rotation data was unavailable, NASS CDL data was used to identify crops.

Results and Discussion

Water Quality

Sampling Events

MFC event samples were collected from four events (Table 3.3) during the study period. Event 1 (April 16, 2011) and event 2 (April 26, 2011) occurred during crop year 2011 and event 3 (November 9, 2011) and event 4 (May 6, 2012) occurred during crop year 2012. Sixteen MFCs were sampled during event 1 and 17 MFCs were sampled in events 2, 3 and 4. One-day and seven-day precipitation and peak flow at the main Plum Creek station varied widely among the four events (Table 3.3). A significant snowfall event occurred between events 1 and 2 and was a contributing factor to the high peak flow observed for event 2. Although event 3 had the highest "day of event" precipitation and second highest "7-day" precipitation, it had the lowest peak flow. This is due to October 2011 receiving only 26.7 mm (1.1 in) of rain. It is important to note that all events occurred when row-cropped agricultural fields were vulnerable to erosion. The three spring events (events 1, 2 and 4) occurred when row crop fields were either prepared for planting or were already planted and had little to no surface residue. The fall event (event 3) occurred when crops had been harvested and the field, in many cases, had received manure and had been tilled.

Table 3.3. Plum Creek watershed precipitation and flow during four multi-field catchment sampling events. Precipitation totals are an average of the three Plum Creek watershed rain gauges. Event runoff, peak stream heights and peak flows were from the Plum Creek USGS station at County D.

Event	Date	Precip. Day of Event (mm)	Precip. 7-Day (mm)	Plum Creek Estimated event runoff* (mm)	Plum Creek Peak Height† (m)	Plum Creek Peak Flow (m^3/s)
1	4/16/2011	17.3	49.7	17.6	1.9	11.1
2	4/26/2011	24.4	32.4	18.9	2.1	17.0
3	11/9/2011	34.0	58.3	16.2	1.5	6.7
4	5/6/2012	20.8	94.0	8.2	1.7	9.0

*Area-weighted runoff estimates are based on subtracting the flow prior to the event from the total recorded flow for each day of the event. Runoff from events 3 and 4 are estimates based on preliminary WY 2012 data from the USGS.
† Stream height (stage) prior to event 1, 2, 3 and 4 were 0.8, 0.9, 0.8, and 0.9 m, respectively.

Water Quality Characteristics

MFC runoff samples exhibited very high P and sediment concentrations. Across all events, median MFC runoff concentrations of SSC, TP and DP were 218 mg/L, 1.03 mg/L and 0.33 mg/L, respectively. For comparison, median MFC runoff concentrations in Apple Creek, a neighboring agricultural watershed, during 2004 were 0.46 mg/L and 0.19 mg/L for TP and DP, respectively (Reckinger 2007). The lowest TP concentration measured in Plum Creek watershed MFC runoff across all events was 0.38 mg/L. Statistical analysis showed that TP was significantly correlated with both SSC ($p = <0.0001$) and DP ($p = <0.0001$).

When comparing among the four events, TP and SSC concentrations were similar but DP concentrations for event 3 were significantly higher than for events 1, 2 and 4. Event 3 was the only event that occurred in the fall, the most common time of year for manure applications. This is a likely cause for the higher DP concentrations in event 3 compared to the other events. Table 3.4 shows the summary statistics for the four separate events and Table 3.5 shows summary data for the combined events. Complete results of the four MFC sampling events can be found in Appendix C.

Table 3.4. Summary statistics for SSC, TP and DP concentrations for each of the four MFC runoff events*.

	SSC (mg/L)				TP (mg/L)				DP (mg/L)				DP Fraction (%)			
Event	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Minimum	35	29	13	26	0.58	0.54	0.57	0.38	0.15	0.05	0.28	0.09	11	4	21	16
25 Percentile	93	127	59	142	0.77	0.91	1.03	0.62	0.22	0.12	0.44	0.22	27	13	36	24
Mean	246	356	330	278	0.96	1.20	1.51	1.01	0.36	0.28	0.80	0.32	39	25	52	32
Median	**122**	**267**	**131**	**278**	**0.89**	**1.07**	**1.15**	**0.99**	**0.33**	**0.27**	**0.57**	**0.28**	**41**	**24**	**58**	**34**
75 Percentile	282	525	483	328	1.03	1.36	1.57	1.21	0.47	0.34	0.81	0.36	48	36	66	39
Maximum	1272	878	1283	640	2.14	2.88	3.83	1.79	0.72	0.75	3.00	0.66	69	54	86	55
No. of Samples	16	17	17	17	16	17	17	17	16	17	17	17	16	17	17	17

*Event dates: 16 April 2011 (1), 26 April 2011 (2), 9 November 2011 (3) and 6 May 2011 (4).

Table 3.5. Combined Summary statistics for SSC, TP and DP concentrations for MFC runoff events.

	SSC (mg/L)	TP (mg/L)	DP (mg/L)	DP Fraction (%)
Minimum	13	0.38	0.05	4
25 Percentile	92	0.80	0.23	24
Mean	303	1.17	0.44	37
Median	**218**	**1.03**	**0.33**	**35**
75 Percentile	469	1.31	0.51	47
Maximum	1272	3.83	3.00	86
No. of Samples	67	67	67	67

Multi-field Catchment Characteristics

The total area of the 17 MFCs was 1,044 ha. For crop years 2011 and 2012, respectively, 572 ha and 519 ha had NMP data. Land use/land cover (LULC) was analyzed for crop year 2011 using NASS CDL data. Plum Creek watershed had approximately 12% more agricultural land in corn and soybeans than the combined MFC area (Figure 3.2). In addition, Plum Creek watershed above the main monitoring station at County D had approximately 13% more land in corn and soybeans than the combined MFC area. Given that corn and soybeans are intensive crops in terms of tillage there is a greater risk of soil and P loss in the greater Plum Creek watershed compared to the monitored MFCs. Therefore the observed sediment and P concentrations from the MFCs are likely a conservative estimate of runoff concentrations within the Plum Creek watershed as a whole.

STP values, acquired from NMPs, for fields within MFCs were analyzed and classified based on University of Wisconsin Extension STP recommendations for corn grown on Plum Creek watershed soils. STP values of 16-20 ppm are optimal for corn in Plum Creek watershed soils while values over 30 ppm are considered excessively high (Laboski et al. 2006) (Figure 3.3). The area-weighted STP value for all MFC area was 42 ppm. 68% of the MFC area with NMPs had excessively high STP with 22% having STP values greater than 50 ppm.

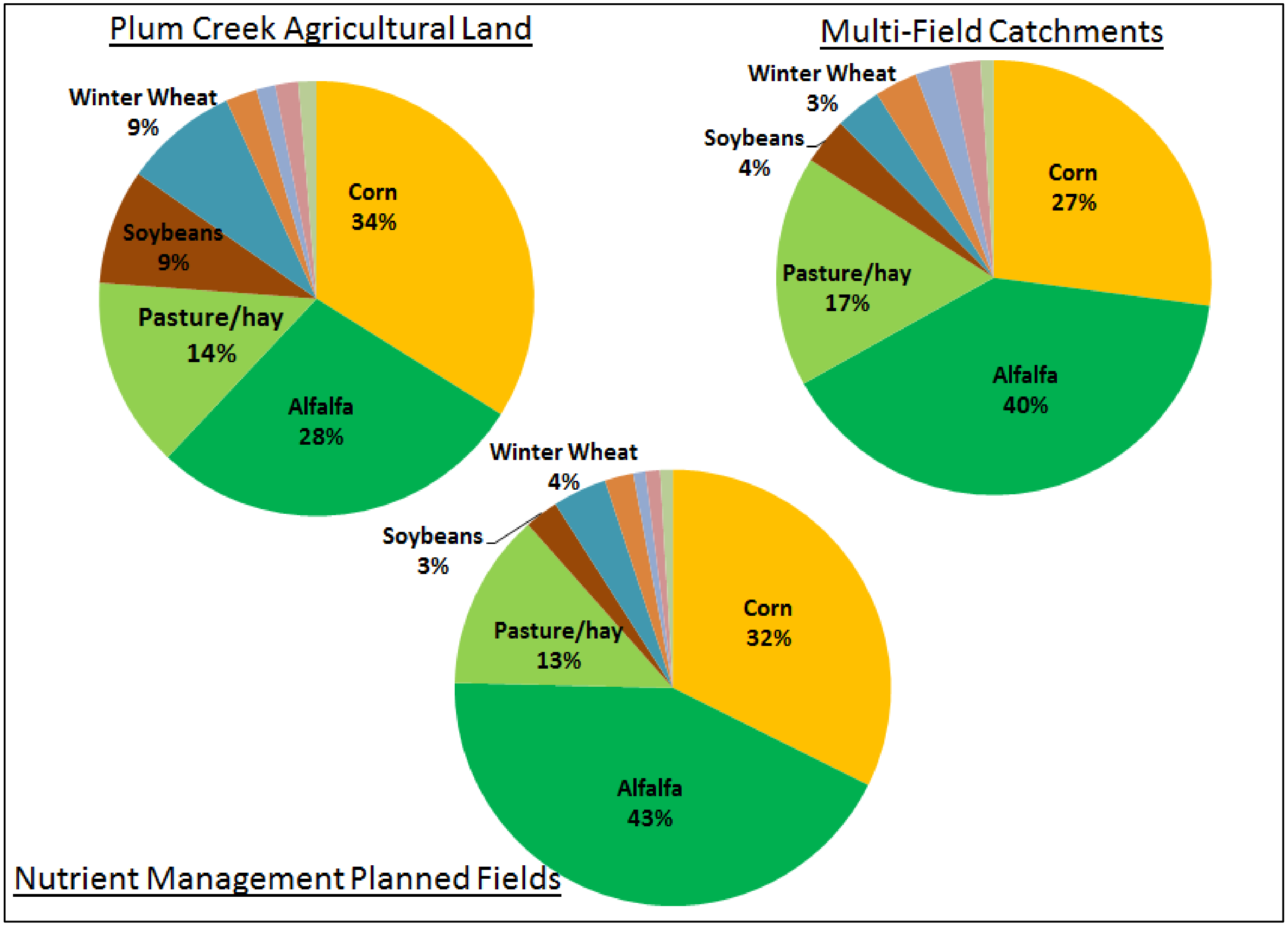

Figure 3.2. 2011 Land use/land cover percentages for all Plum Creek watershed agricultural land area, entire MFC area, and for nutrient management planned fields within the MFCs. Source: GIS analysis of NASS CDL (USDA NASS,2012).

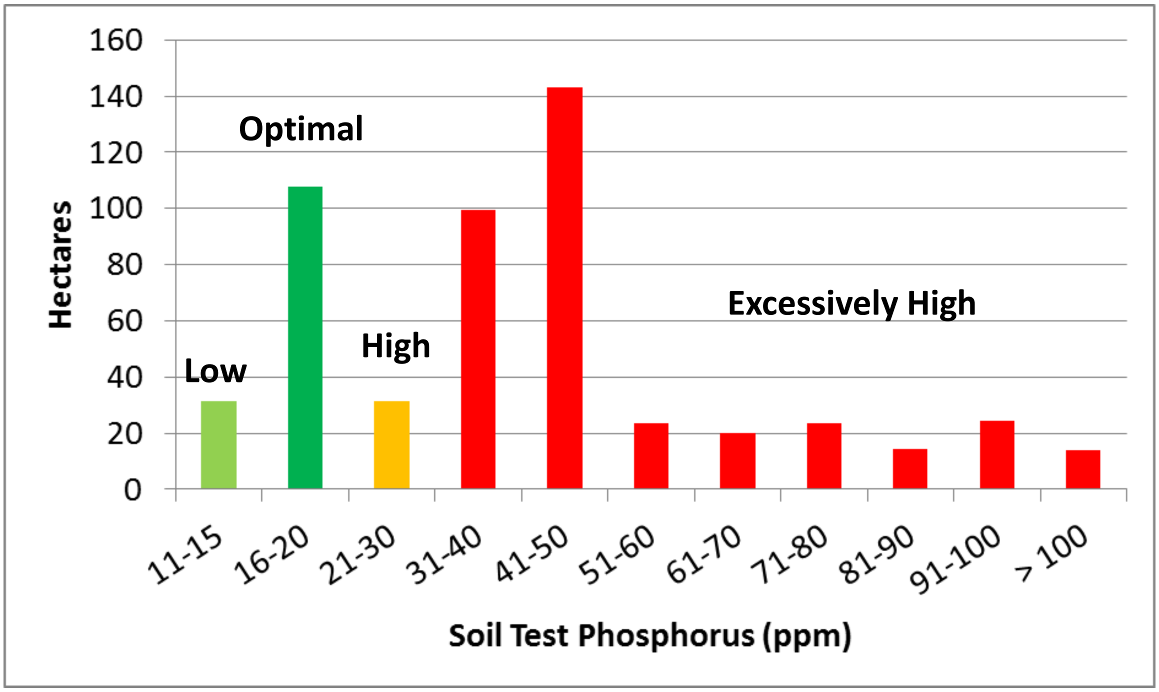

Figure 3.3. Distribution of soil test phosphorus values for fields within multi-field catchments in Plum Creek watershed. Also shown are University of Wisconsin Extension soil test phosphorus crop recommendation levels for corn.

Area-weighted STP values were included in a correlation analysis with measured mean MFC runoff concentrations. There was no significant correlation between STP and either DP ($p = 0.42$) (Figure 3.4) or TP concentrations ($p = 0.91$) (not shown). These results are in contrast with Reckinger (2007), who found a strong relationship between runoff DP concentration and area-weighted STP ($r = 0.91$) in Apple Creek MFCs.

Agronomic STP is P that is available to crops and therefore is not the most effective means to identify the risk of agricultural P to water quality (Kleinman et al. 2000). This being said, research has showed a relationship between STP and runoff DP (Andraski and Bundy 2003; Reckinger 2007; Sharpley et al. 2001c).

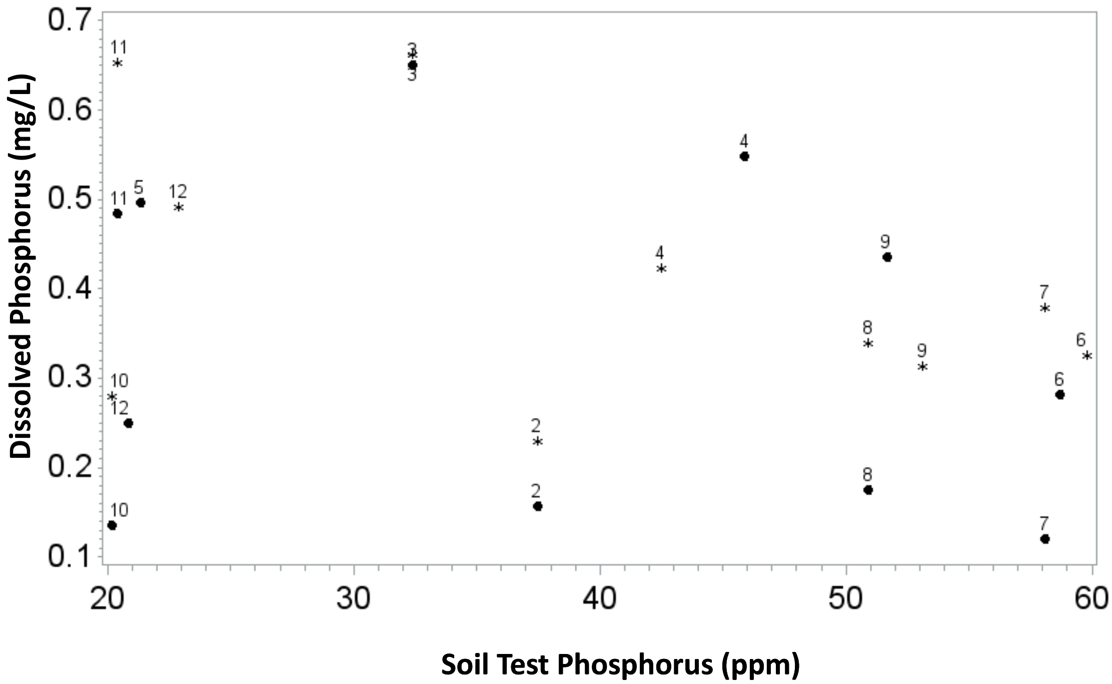

Figure 3.4. Relationship between event runoff total phosphorus concentration and area-weighted soil test phosphorus in selected multi-field catchments. Dots are the mean of crop year 2011 event concentrations and asterisks are the mean of crop year 2012 concentrations. Spearman correlation r = -0.18 (p = 0.42).

Case Studies

Three case studies were chosen to examine the influence that agricultural practices can have on water quality at the MFC scale. The measured water quality parameters in runoff from three MFCs (5, 8 and 12) differed markedly between spring 2011 and fall 2011 events and were therefore examined in greater depth in an attempt to explain the cause of such differences.

MFC 5

SSC concentrations in the two spring 2011 events (1 and 2) were 55 mg/L and 29 mg/L, respectively. Whereas, SSC concentration in the fall 2011 event (3) was 1,165 mg/L nearly 20 times greater than the spring concentrations (Figure 3.5). TP concentrations were also much lower in the spring events relative to the fall event (Appendix C; Figure 3.6). A large part of this extreme change in SSC, and therefore TP concentrations was likely a result of a change in surface residue/cover. In spring 2011, cover was moderate to high and consisted of minimally tilled alfalfa. The fall 2011 event occurred after tillage and the field had very little surface residue/cover.

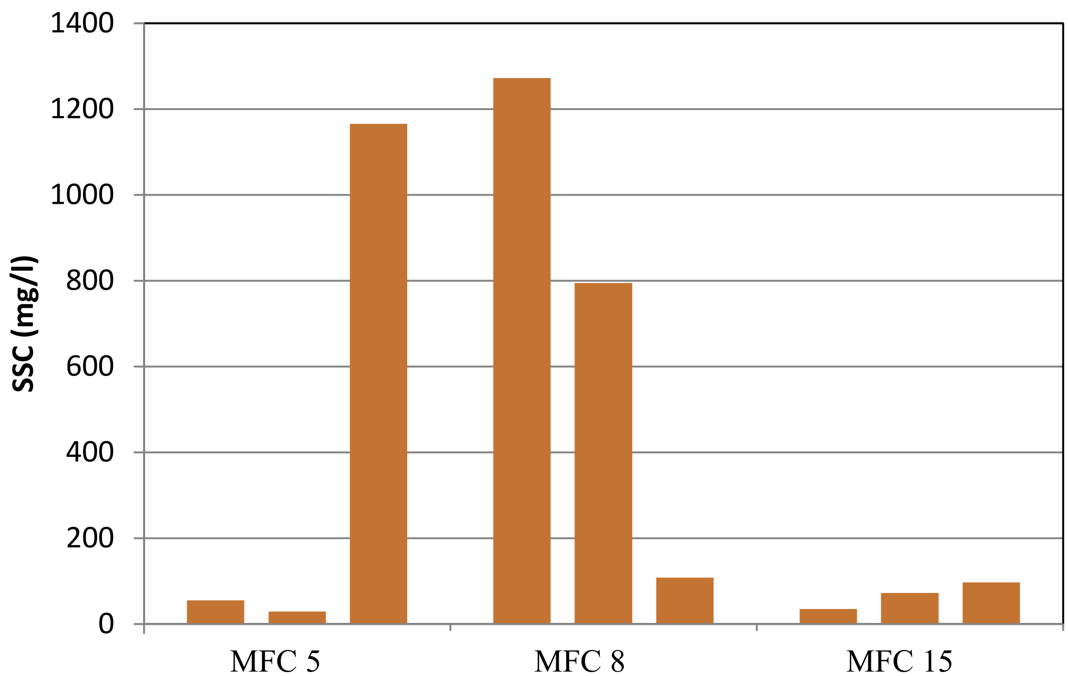

Figure 3.5. Suspended sediment concentrations (SSC) in multi-field catchment runoff for events 1, 2 and 3. Events 1, 2 and 3 occurred on 16 April 2011, 26 April 2011 and 9 November 2011. Note the large differences between events 1 and 2 and event 3 for MFCs 5 and 8 but not for MFC 15.

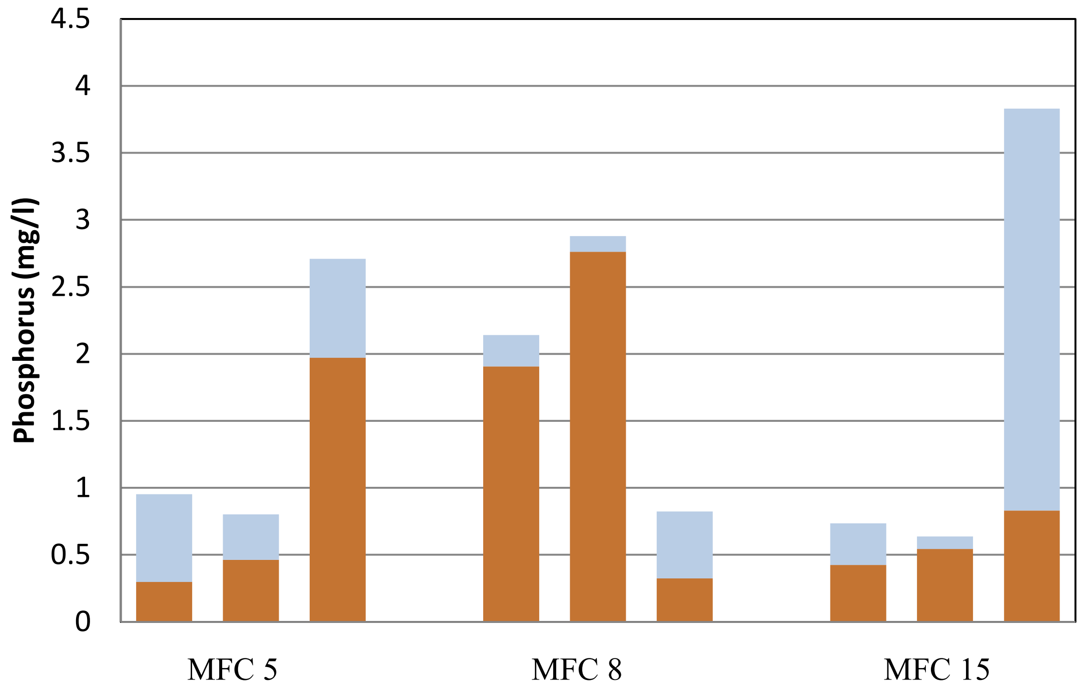

Figure 3.6. Particulate (brown portion of bars) and dissolved phosphorus (blue portion of bars) concentrations in multi-field catchment runoff for events 1, 2 and 3. Events 1, 2 and 3 occurred on 16 April 2011, 26 April 2011 and 9 November 2011. Note the large differences between events 1 and 2 and event 3.

MFC 8

SSC concentrations in the two spring 2011 events (1 and 2) were very large (1,272 mg/L and 795 mg/L, respectively). In contrast, SSC concentration in the fall 2011 event (3) was only 108 mg/L. Consistent with SSC, TP concentrations were much higher in the spring events than in the fall event (Appendix C; Figure 3.5; Figure 3.6). As with MFC 5, surface residue conditions can explain the difference in spring versus fall SSC and TP concentrations. In spring 2011, the field was prepared for planting and surface residue was minimal. Prior to the fall 2011 event, corn grain had been harvested leaving the soil surface nearly 100% covered by plant residue in the form of corn stubble (stalks and leaves). Gaynor and Findlay (1995) showed that conservation tillage (more than 30% crop residue; Unger 1990) in southwestern Ontario clay loam soils reduced average soil loss by 49% when compared to conventional tillage.

MFC 15

The case of MFC 15 differs from MFC 5 and 8 in that surface residue/cover was the same for both spring and fall 2011 events. The catchment was in alfalfa throughout 2011 and as a result SSC concentrations did not differ among spring and fall 2011 events (Appendix C; Figure 3.5). In addition, TP and PP concentrations did not differ greatly among the first two events. DP concentration, however, was much higher in the fall 2011 event (Appendix C; Figure 3.6). DP concentrations in the two spring 2011 events were 0.31 mg/L and 0.09 mg/L. The DP concentration observed in the fall 2011 event was 3.00 mg/L. According to 2011 manure logs, manure applications occurred in June, July and August of 2011 to the dominant field (80% of area) within MFC 15. The manure was applied on top of alfalfa and was therefore not incorporated into the soil, leaving it to interact with rainfall and surface runoff. The easily solubilized P found in the manure likely contributed to the high DP concentration observed in the fall 2011 event. Another possible contributor to the high fall 2011 DP concentration that could be considered is P leaching from alfalfa. Simulated rainfall studies conducted by Roberson et al. (2006) found that alfalfa, following the effects of freezing and drying, contributed significantly to runoff P concentrations. In natural runoff studies, however, no significant P contributions from alfalfa were observed, which suggests that the primary reason may be the manure applications.

These case studies demonstrate the influence that type and timing of agricultural practices can have on water quality. As seen in MFCs 5 and 8, surface residue has a large influence on sediment and PP concentrations in runoff. By using less aggressive tillage regimes, sediment and PP loss can be greatly reduced. Similarly, improper manure management (i.e. surface applying before runoff events), as seen in MFC 15, can cause DP concentrations in runoff to increase.

SnapPlus and Wisconsin Phosphorus Index Assessment

As previously stated, eleven of the 17 MFCs in crop year 2011 and ten MFCs in crop year 2012 were used in the correlation analyses between SnapPlus outputs and water quality. For MFCs included in the correlation analyses, the average NMP coverage of agricultural land was 79% in crop year 2011 and 72% in crop year 2012.

Area-weighted SnapPlus PI values from MFCs with greater than 50% NMP coverage ranged from 0.1 to 5.5. DPI values ranged from 0.1 to 0.7 and PPI values ranged from 0.1 to 4.5. Reckinger (2007) observed a larger range of values for both the PI and DPI (PI values ranged from 2 to 11 and DPI values ranged from 0.1 to 1.3). This study's calculated PI values were not correlated with measured MFC runoff TP concentrations during either crop year ($p = 0.18$; Figure 3.7). This result agrees with a previous study in Apple Creek watershed MFCs (Reckinger 2007). Unlike Reckinger (2007), however, this study's MFC runoff DP concentrations were not correlated ($p = 0.89$) with DPI (Figure 3.8). There was no relationship between particulate P and PPI ($p=0.22$).

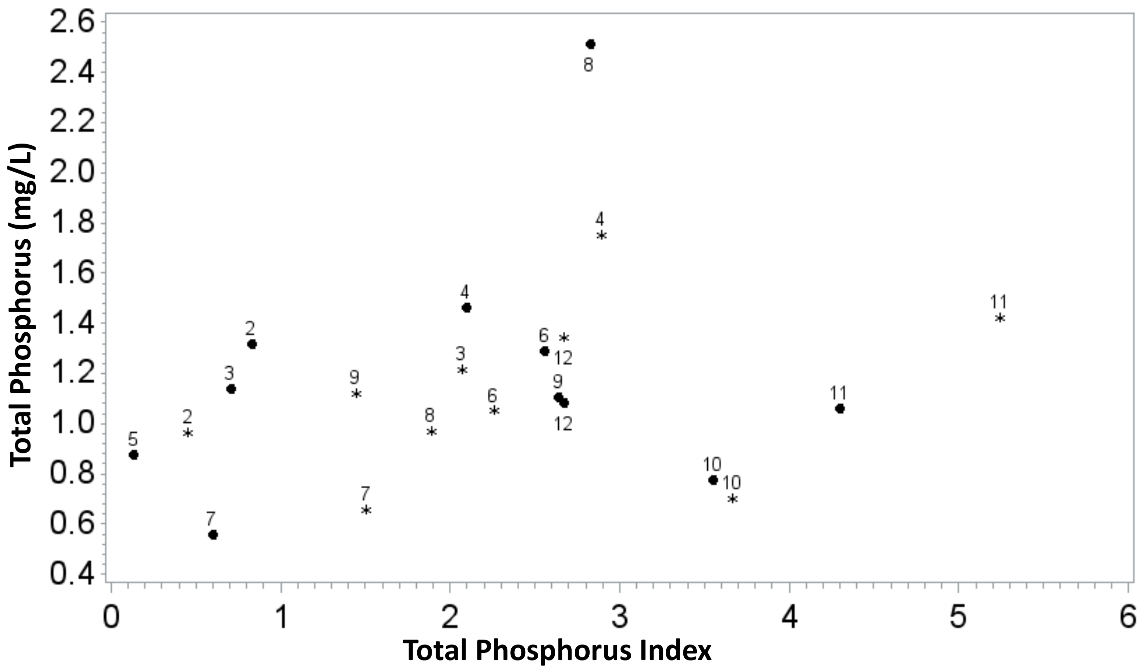

Figure 3.7. Relationship between MFC event runoff TP concentration and area-weighted Wisconsin Phosphorus Index in selected multi-field catchments. Dots are the mean of crop year 2011 event concentrations and asterisks are the mean of crop year 2012 concentrations. Spearman correlation r = 0.30 (p = 0.18).

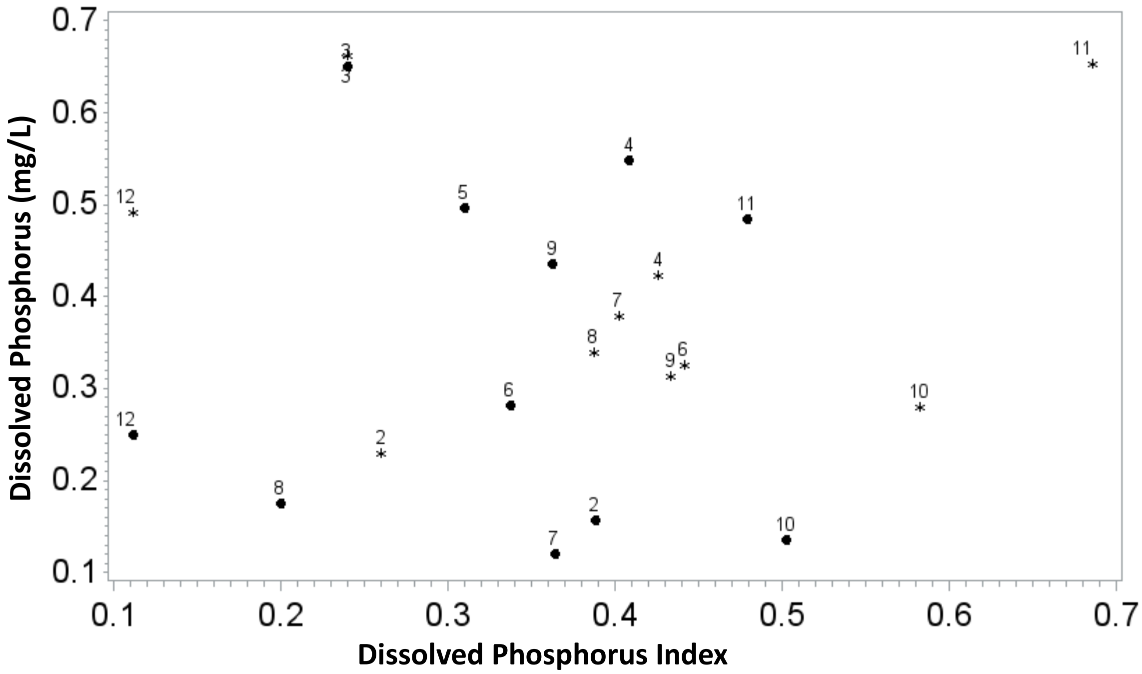

Figure 3.8. Relationship between MFC event runoff dissolved phosphorus concentration and the area-weighted dissolved portion of the Wisconsin Phosphorus Index in selected multi-field catchments. Dots are the mean of crop year 2011 event concentrations and asterisks are the mean of crop year 2012 concentrations. Spearman correlation r = -0.03 (p = 0.89).

In addition, SnapPlus sediment loss predictions were not correlated with measured MFC runoff sediment concentrations during crop years 2011 and 2012 ($p = 0.70$; Figure 3.9).

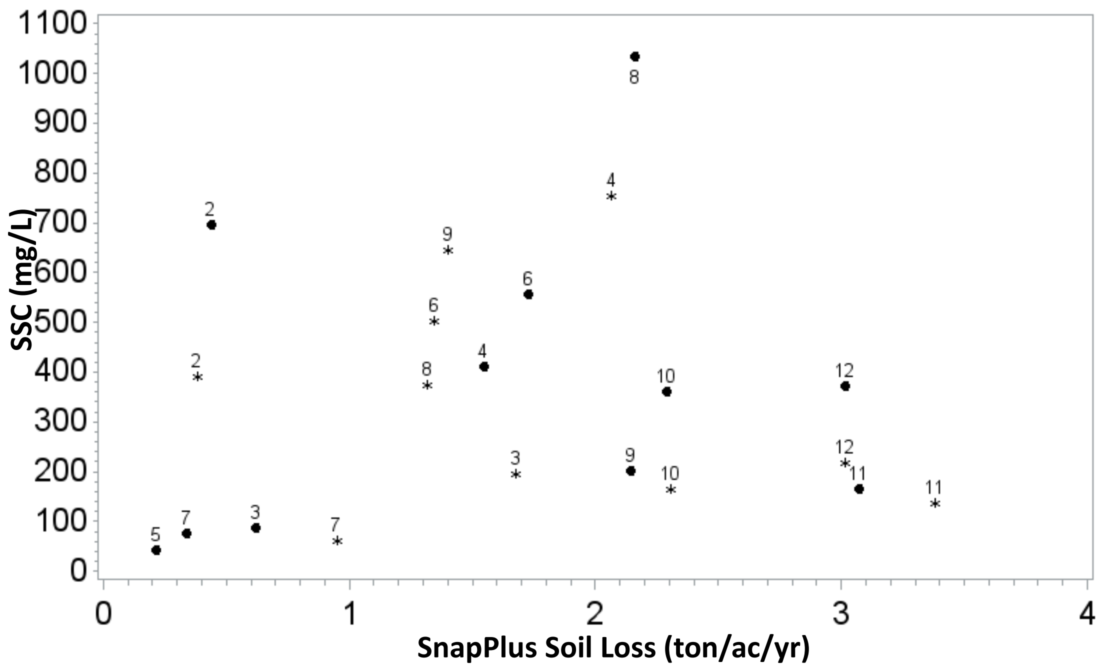

Figure 3.9. Relationship between MFC event runoff suspended sediment concentrations (SSC) and area-weighted soil loss estimates in selected multi-field catchments. Multiply soil loss by 0.405 to convert to ton/ha/yr. Red dots are the mean of crop year 2011 event concentrations and black dots are the mean of crop year 2012 concentrations. Spearman correlation $r = 0.09$ ($p = 0.70$).

Explanations for Poor SnapPlus Correlations

There are several possible explanations for the poor correlation between measured water quality and SnapPlus outputs. First of all, unlike this study, which measured runoff concentrations during 4 events over the course of just one year (April 16, 2011 to May 6, 2012), the PI component of SnapPlus estimates P runoff loads based on long-term weather patterns. Another possibility is that SnapPlus is not adequately parameterized for conditions in the Plum Creek watershed. Although SnapPlus is based on robust data sets from studies across Wisconsin (Good et al. 2010), it still may not be sufficiently able to capture the unique geomorphic and agronomic conditions of particular watersheds. Additionally, the limited range of area-weighted DPI values in this study (0.1 to 0.7), and the relatively low percent contribution to the total PI values may not have allowed for the detection of a relationship.

In this study we hypothesized that areas with larger PIs would have higher concentrations of event peak flow runoff P and vise-a-versa. However, peak flow runoff P and sediment concentrations are not directly comparable to SnapPlus' predicted annual P and sediment yields (mass per unit area: P in lb/acre/year and sediment in tons/acre/year). In an attempt to minimize this issue, correlations were estimated between the ranks, instead of between the values themselves, of measured water quality values and SnapPlus outputs. Still, loads and associated yields were not calculated for the MFCs, so direct unit-for-unit comparisons were not possible which can be problematic. The rank order of concentrations may be different than if yields were used. For example, when a crop like alfalfa is well underway in spring it has markedly influenced soil moisture via transpiration; in contrast, corn or soybean have just started to grow, so they have little impact on reducing soil moisture via transpiration. If a moderate runoff event occurs, the concentrations could be similar from the alfalfa field and corn or soybean fields, but the runoff volumes and associated yields should be markedly lower from the alfalfa field. Our concentration-based ranks may have been different if we had accounted for runoff volume and instead ranked yields. However, for the four events in our MFC study, runoff volumes measured at the USGS Plum Creek station were relatively high compared to the estimated average precipitation in the contributing area (Table 3.3); thereby implying that runoff from alfalfa fields was not minor during our observed events.

Another possible reason for poor correlation is that the sampling strategy was not able to collect comparable samples at each MFC. For example, if a sample for one MFC was collected before peak flow, it may not be comparable to another MFC sample collected at or after peak flow. Yet another possibility is that the areas with NMPs in each MFC weren't representative of the entire MFC. The NMP fields may not be representative because they do not constitute enough of the entire MFC area (50% NMP coverage was the criterion for a MFC to be included in the SnapPlus assessment). Non-agricultural land was assigned PI and soil loss values in an attempt to address this possible issue. Finally, a possible, and likely, explanation is that SnapPlus inputs did not accurately reflect actual practices occurring in the MFCs.

Tillage

Accurate inputs are important for obtaining reasonable estimates of P loss risk with SnapPlus. Based on personal observations, NMP data did not always reflect actual practices in the fields. For example, 48% of the MFC area during spring (following events 1, 2 and 4) residue surveys was rated as a 1 or 2 (0-15% residue cover) (Table 3.5). The most common SnapPlus tillage input was fall chisel no disk (chisel plow in the fall, no spring disking, spring field cultivation), which occurred on 69% of MFC area in crop year 2011 and on 55% in crop year 2012. The residue surveys suggest that actual tillage was more aggressive than SnapPlus inputs. This means that actual surface residue was lower than that being used in SnapPlus to calculate soil loss. Without accurate residue cover inputs, SnapPlus estimates of soil loss and therefore P loss would likely be inaccurate.

Crop type

Residue cover is also influenced by crop type. For example, the risk for soil loss from an alfalfa field is much less than from a field being prepared (tilled, disked and cultivated) for corn or soybeans. Such discrepancies between NMP crops and actual crops were observed. During crop year 2011, NMPs did not match NASS CDL analysis for 9 of the 78 MFC fields. The most common error was that fields planned as corn were actually alfalfa, or vice versa. Inaccurate crop type, as with tillage, may explain why SnapPlus was poorly correlated with measured water quality.

Manure Applications

Discrepancies between actual and planned manure applications could be playing a role in the poor SnapPlus correlations as well. A study by Cabot and Novak (2005) found that manure management discrepancies had a larger effect on PI values than did STP and other field factors. A University of Wisconsin–Extension agent stated that producers often complete NMPs after the fall manure application, as updated soil tests (or manure tests) may not be available to guide application rates. This can result in an unintentional over-application or under-application of nutrients once test results from the lab are included in SnapPlus. Another potential error occurs when the test results are received after the plan is written in the winter of the current crop year, which is after fall manure is applied. A producer could then modify actual manure application rate inputs to SnapPlus to be in compliance with the PI, but many do not take the time to update the plan. The agent also stated that double applications of manure to fields probably occasionally occur, although this problem is becoming less common (Kevin Erb, UW-Extension, Personal Communication).

Field Slope

Differences between actual field slopes and SnapPlus field slopes may have also played a role in the poor SnapPlus correlations. The field slope reported in NMPs and input to SnapPlus was the default slope of the dominant soil type within a field. Of the MFC area included in SnapPlus, 84% had a SnapPlus slope of 4% and 0% had slopes higher than 4%. The average area-weighted SnapPlus slope for the MFCs in crop year 2011 was 3.1% and in crop year 2012 was 3.7%. The actual average slope, derived from a 10m Digital Elevation Model (DEM), was 2.4%. It appears that default, soil type slopes in SnapPlus resulted in an underestimate of the actual slope of many catchments. Five of the eleven MFCs in the crop year 2011 SnapPlus comparisons and four of the ten MFCs in the crop year 2012 SnapPlus comparisons had an average slope of greater than 4%. Figure 3.10 shows the SnapPlus slope versus DEM-derived slope for 77 fields within the MFCs.

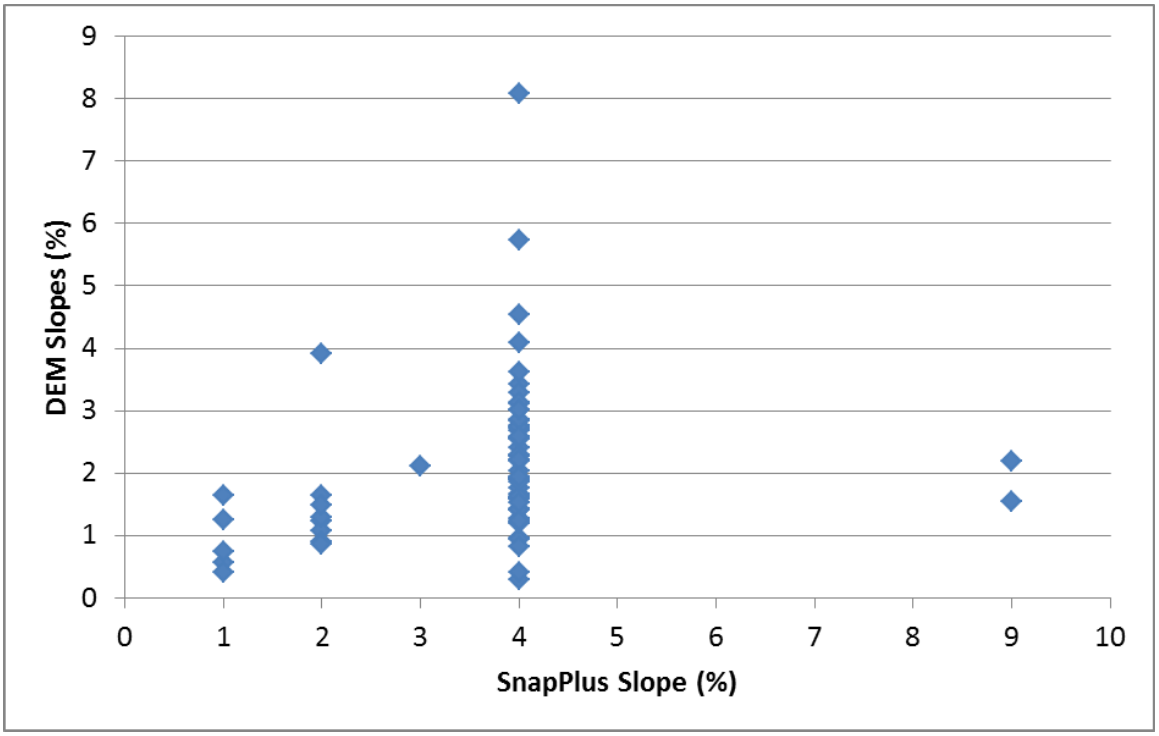

Figure 3.10. Digital elevation model-derived slopes and slopes used in SnapPlus for 77 fields within the multi-field catchments.

Other Possible Factors

Two factors, ephemeral gully erosion and runoff from barnyards, could have also affected the relationship between MFC concentrations and SnapPlus predictions. Ephemeral gully erosion, a possible source of sediment loss, is not included in RUSLE2 calculations (USDA ARS 2008) but was observed within the MFCs during runoff events. Likewise, barnyards are not included in PI calculations but are present in several of the MFCs and could have been additional sources of P loss.

In summary, limitations and inaccuracies of producer-supplied NMP-based SnapPlus inputs, even for individual fields, may have resulted in inaccurate SnapPlus P and sediment loss estimates. Therefore it is not surprising that the SnapPlus model estimates did not consistently predict relative water quality at the MFC scale in this project.

Algorithms in SnapPlus were developed from highly accurate input data (obtained from direct observations and measurements), a level of accuracy that could not be obtained in this study.

Phosphorus Index and Policy

Results of this study suggest that the current WI PI standard of 6 will not achieve water quality goals in Plum Creek. Figures 3.11 and 3.12 show the distribution of NMP-based PI values within the MFC area during crop years 2011 and 2012, respectively. Only 2% of crop year 2011 and 3% of crop year 2012 fields had TPI values greater than 6. TPI is the sum of DPI and PPI and is more precise than PI. The area-weighted MFC TPI was 1.88 for crop year 2011 and 2.06 for crop year 2012. The measured total phosphorus yield at the USGS station was 2.27 lb/acre (2.54 kg/ha) in WY2011. The watershed yield units (lb/ac) are roughly equivalent to the WI PI (Good et al. 2010).

These statistics, combined with measured MFC runoff water quality data (Appendix C), and the water quality data collected at the USGS Plum Creek station (Tables 2.2 and 2.5), suggest that a much lower PI goal is needed to improve water quality in Plum Creek and the Lower Fox River, and achieve the phosphorus targets set forth in the TMDL.

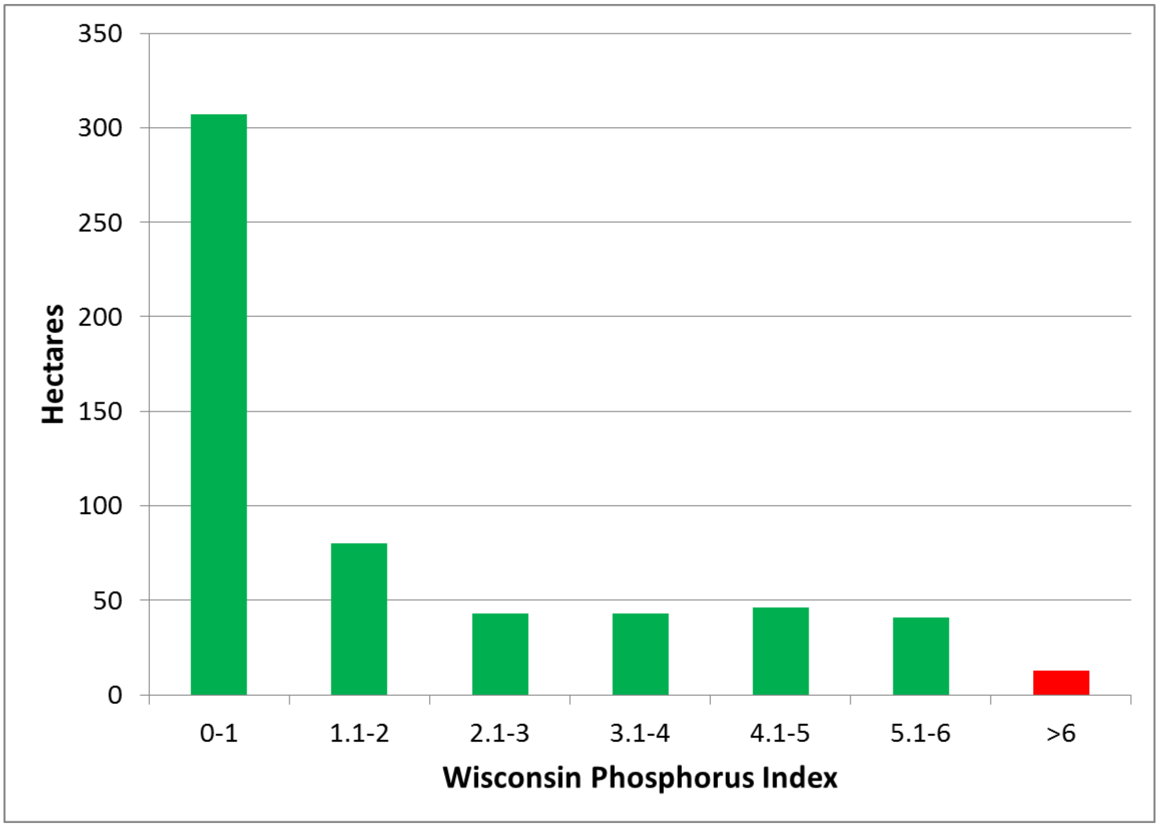

Figure 3.11. Distribution of Wisconsin Phosphorus Index values within multi-field catchment areas during crop year 2011.

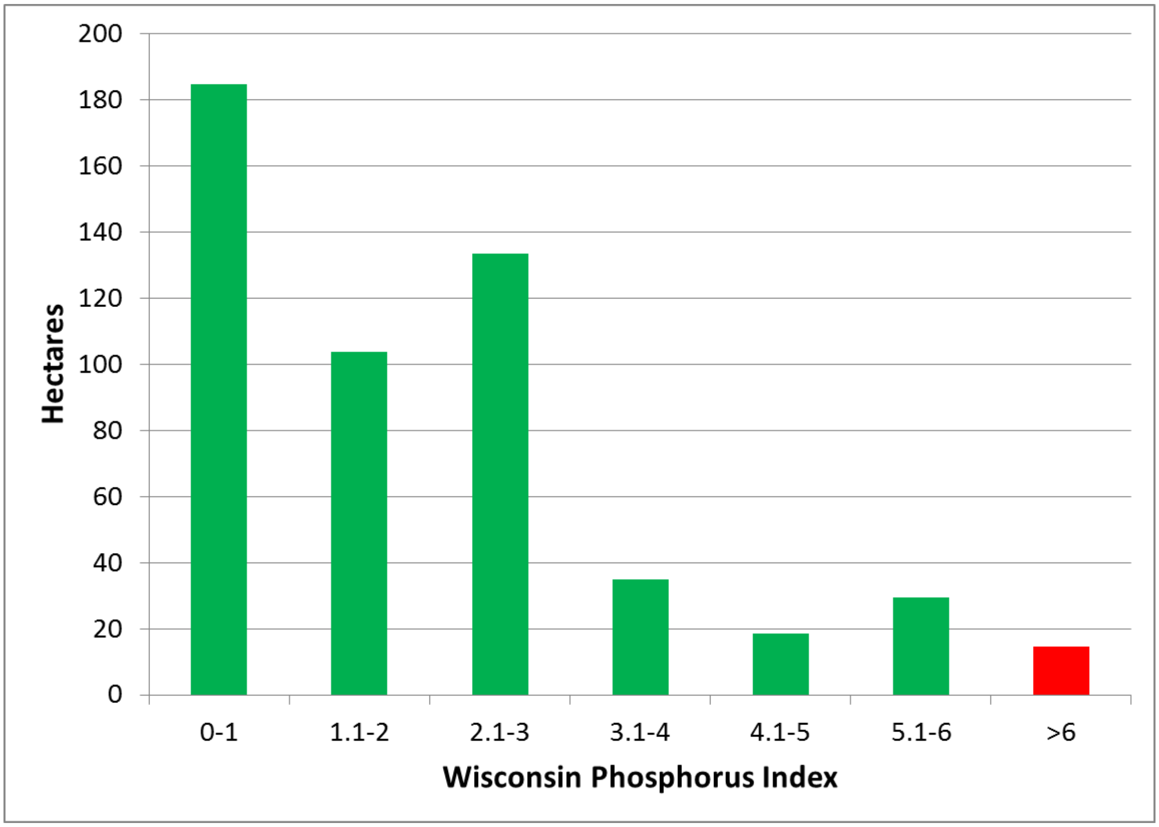

Figure 3.12. Distribution of Wisconsin Phosphorus Index values within multi-field catchment areas during crop year 2012.

Conclusions

Results of this study show that P and sediment concentrations in MFC runoff are very high (Appendix C). Across four sampling events, maximum SSC, TP and DP concentrations were 1,272 mg/L, 3.83 mg/L and 3.00 mg/L, respectively. Median values were 218 mg/L, 1.03 mg/L and 0.33 mg/L, respectively. Minimum values were 13 mg/L, 0.38 mg/L and 0.05 mg/L, respectively. The TMDL's summer median TP goal for Lower Fox tributaries is 0.075 mg/L (WDNR 2012). Although event concentrations are not directly comparable, the particulate phosphorus associated with runoff events accumulates in stream substrates and may elevate low flow phosphorus concentrations.

Across all four sample events, minimum, median and maximum particulate phosphorus concentrations were 0.09 mg/L, 0.52 mg/L and 2.76 mg/L, respectively.

MFC runoff TP concentrations were correlated with DP and SSC concentrations but not with STP. Rankings of MFCs according to runoff P and SSC concentrations were not correlated with NMP-based SnapPlus PI or sediment loss rankings. Insufficient accuracy of SnapPlus inputs is a possible reason for the poor correlation. Finally, analysis of MFC PI values show that the vast majority of fields within the MFCs met the NRCS PI standard of 6, yet Plum Creek watershed's WY 2011 TP yield of 2.54 kg/ha is many times above the yield goal of 0.35 kg/ha stated in the TMDL (WDNR 2012). Furthermore, the summer 2011 TP low flow concentration in Plum Creek was 0.35 mg/L, nearly five times the target concentration of 0.075 mg/L (WDNR 2012). The magnitude of the disparity between the calculated PI and observed impaired state of water quality in Plum Creek suggests that a much lower PI goal is needed to meet water quality goals.

CHAPTER 4 – PHOSPHORUS CONTRIBUTIONS FROM A POINT SOURCE IN PLUM CREEK WATERSHED

Introduction

Nonpoint sources, such as agriculture, are not the only sources of water pollution in Plum Creek Watershed. Point sources of P are present within the watershed as well. A point source is any discrete, readily identified source of pollution such as a pipe, ditch, etc. Examples include outfall from industrial facilities and wastewater treatment plants. The WDNR regulates municipal and industrial sources' pollutant loads to surface water or groundwater through the Wisconsin Pollutant Discharge Elimination System Permit Program (WDNR 2010). There is one permitted industrial point source facility and two permitted municipal point source facilities in the Plum Creek watershed (WDNR 2012).

This chapter compares P concentrations of sampling sites upstream and downstream from an industrial point source discharging directly into Plum Creek. In addition, TP and DP loads from the point source were estimated.

Methods

Sample Collection and Analysis

Eight low flow grab samples were collected upstream and downstream of a point source in Plum Creek watershed from May to November 2011. Samples were processed and analyzed according to standard methods (See Chapter 2). Samples were analyzed at UW-Green Bay for SSC, TP and DP (See Chapter 3).

Load Calculations

Measured concentrations were combined with daily flow data in Plum Creek and effluent volume from the point source to calculate loads for each of the eight sample dates. Annual TP and DP loads were calculated from the mean daily loads. Point source daily flow data for 2011 were obtained from the WDNR (Schmidt WDNR).

Statistical Analysis

A paired t-test was performed on the data, using PROC TTEST in SAS 9.2 to determine if the differences between upstream and downstream TP and DP concentrations were significantly different than zero.

Results and Discussion

Concentrations

Upstream and downstream TP values were 0.24 mg/L and 0.44 mg/L, respectively (Figure 4.1). Upstream and downstream DP values were 0.19 mg/L and 0.35 mg/L, respectively. Results of the paired t-tests showed the difference between upstream and downstream TP ($p = 0.0056$) and DP ($p = 0.0015$) were significant. SSC concentrations did not vary much and ranged from 0 mg/L to 7.5 mg/L.

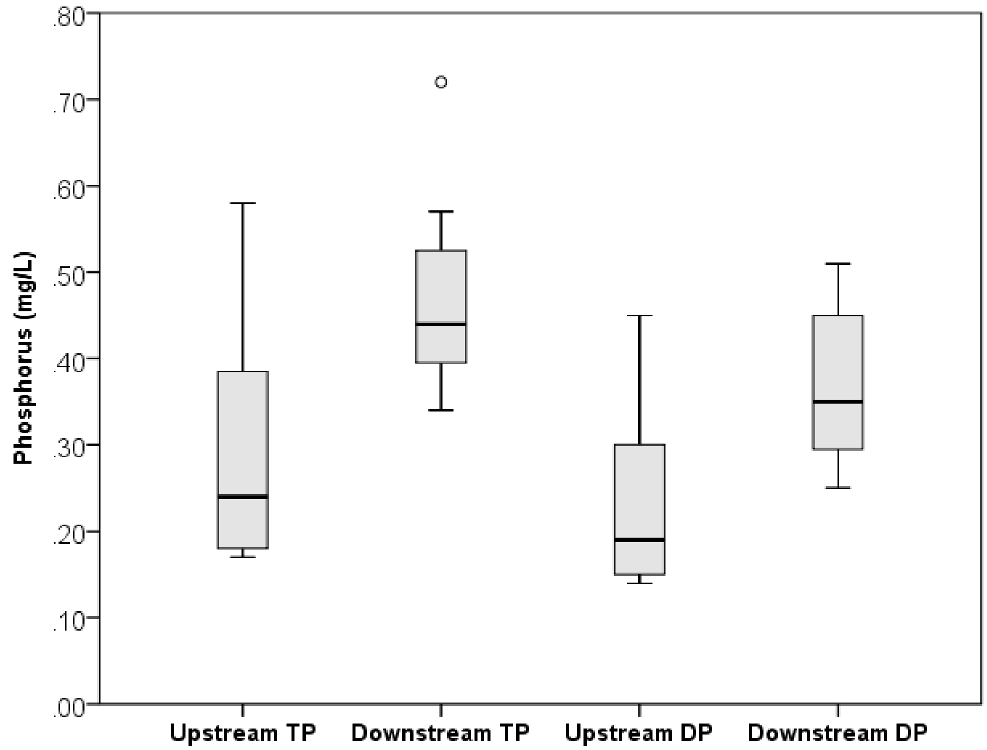

Figure 4.1. TP and DP concentrations upstream and downstream of a point source in the Plum Creek watershed. Upstream TP and DP concentrations are significantly greater than downstream concentrations. Boxes and bars represent the interquartile range and median respectively. Whiskers represent the largest unbooked sample values. Outliers (1.5 box lengths from the end of the box) are represented as circles.

Loads

Calculated annual loads of TP and DP from the point source in 2011 were 57 kg and 54 kg. DP load constituted 94% of the annual TP load. These match reasonably well with reported loads from 2008 (65 kg) (Schmidt WDNR). Based on this study's calculations, this point source is already meeting its TMDL allocation (WDNR 2012).

Based on these load estimates, the point source's TP contribution to Plum Creek was 0.2% of the WY 2011 total load. The DP contribution was only 0.7% of the WY

2011 total load.

Conclusions

The difference between upstream (0.24 mg/L) and downstream (0.44 mg/L) TP concentrations were significant ($p = 0.016$). Similarly, the difference between upstream (0.19 mg/L) and downstream (0.25 mg/L) DP concentrations were also significant ($p = 0.078$).

Less than 1% of the total annual P load in Plum Creek is contributed by this point source. Much of the P load contribution from nonpoint sources in Plum Creek watershed occurs during relatively few days (<20 days in WY2011) during the year when significant runoff eventst occur. During these times of high flow, point source contributions are negligible. During low flow periods, however, point sources have a measurable impact on Plum Creek water quality. Furthermore, almost all of the point source's discharged P (94% of the load) is in soluble forms, making it much more available for biological activity. This study showed that the point source had a measureable impact on water quality during low flow conditions. Although, point sources impact water quality in Plum Creek, reducing nonpoint source P loads from agriculture should be the number one priority for P load reduction efforts in the watershed.

CHAPTER 5 – PROJECT SUMMARY

This project was undertaken to more closely examine the water quality and land use characteristics of Plum Creek watershed, a high-yielding agricultural watershed in the Lower Fox River Basin. This chapter will summarize the findings of chapters 2, 3 and 4 by answering the questions stated in chapter 1.

Summary of Project Results

Chapter 2: Plum Creek Water Quality Characteristics and Comparisons

A cooperatively-operated United States Geological Survey (USGS) monitoring station was installed on the main branch of Plum Creek at County Road D in October of 2010. A similar monitoring station was located on Baird Creek at Superior Road and was used for comparison. A UW-Green Bay-operated monitoring station was installed on the west branch of Plum Creek (West Plum) in October 2010.

The objectives of Chapter 2 were to answer the following questions:

1. How much P and sediment does Plum Creek contribute to the Lower Fox River?
2. How do Plum Creek and West Plum Creek water quality compare?
3. How does Plum Creek water quality compare to that of other agricultural watersheds in the Lower Fox River Basin?

Objective 1

Sixty three percent of Plum Creek watershed was in the drainage area of the main monitoring station. Measured TSS, TP and DP loads at the main station during WY 2011, were 6,979 metric tons, 13,804 kg and 3,694 kg, respectively. WY 2011 yields from Plum Creek watershed were1.28 t/ha of TSS, 2.54 kg/ha of TP and 0.69 kg/ha of DP.

The DP fraction of the TP load in WY 2011 was 27.3%. Estimated TSS, TP and DP loads from the entire Plum Creek watershed were 14,722 metric tons, 26,701 kg and 7,279 kg, respectively.

Objective 2

Event flow sample data from West Plum Creek were too limited for comparison with Plum Creek event samples; therefore, only low flow samples were compared. Median TSS, TP and DP low flow concentrations in Plum Creek during the study period were 23 mg/L, 0.30 mg/L and 0.27 mg/L, respectively. Median TSS, TP and DP low flow concentrations in West Plum Creek during the study period were 10 mg/L, 0.32 mg/L and 0.27 mg/L, respectively. There were no significant differences in TSS, TP or DP low flow concentrations between Plum Creek and West Plum Creek.

Objective 3

Median TSS, TP and DP concentrations in Plum Creek across all flow conditions during the study period were 149 mg/L, 0.60 mg/L and 0.24 mg/L, respectively. Median TSS, TP and DP concentrations in Baird Creek across all flow conditions during the study period were 42 mg/L, 0.34 mg/L and 0.14 mg/L, respectively.

Study period Plum Creek TSS, TP and DP concentrations in all flow conditions were statistically greater than those from Baird Creek except for event flow DP concentrations, where the two streams were similar. WY 2011 Plum Creek loads and yields exceeded those from Baird Creek and appear to be greater than those from four neighboring agricultural watersheds during water years 2004 to 2006. The interaction of several factors may be causing these relatively high yields from Plum Creek watershed. Such factors include the high proportion of agricultural land, soil textures, slope and specific agricultural practices (tillage, manure applications, etc.).

Chapter 3: Multi-field Catchment Water Quality and SnapPlus Assessment

The Lower Fox River TMDL suggests that agriculture is the largest contributor of P and sediment to Plum Creek and the Lower Fox River. To better understand the influence of agricultural practices and land characteristics on P and sediment loss, runoff from 17 multi-field catchments (MFC) was sampled throughout the study period. These data were used to assess SnapPlus, a nutrient management planning software program.

The objectives of Chapter 3 were to answer the following questions:

1. What are the characteristic of multi-field catchment runoff in Plum Creek watershed?
2. How is STP related to P and sediment concentrations in runoff at the multi-field catchment scale?
3. How do watershed characteristics (slope, land use and management practices) influence P and sediment concentrations in runoff at the multi-field catchment scale?
4. Can the nutrient management tools, SnapPlus and the Wisconsin Phosphorus Index, be used as reliable P and sediment loss predictors in Plum Creek watershed?

Objective 1

Multi-field catchment runoff samples exhibited high sediment and phosphorus concentrations (Appendix C). Across four sampling events, maximum TSS, TP and DP concentrations were 1,272 mg/L, 3.83 mg/L and 3.00 mg/L, respectively. Median values were 218 mg/L, 1.03 mg/L and 0.33 mg/L, respectively. Minimum values were 13 mg/L, 0.38 mg/L and 0.05 mg/L, respectively. The TMDL's summer median TP goal for Lower Fox tributaries is 0.075 mg/L (WDNR 2012).

Objective 2

The area-weighted average STP concentration within the total MFC area was 41 ppm, classified as an excessively high value. Sixty eight percent of MFC area had excessively high STP concentrations. STP was not correlated with MFC runoff TP or DP concentrations.

Objective 3

Case studies of MFCs 5, 8 and 15 provided some insight into how watershed characteristics (slope, land use and management practices) influence P and sediment concentrations in runoff. In MFCs 5 and 8, surface residue changed dramatically between spring and fall of 2011. Consequently, sediment and TP concentrations changed dramatically. In MFC 15, surface residue remained unchanged over the same time period. Runoff DP concentration, however, increased greatly. Manure logs revealed that three unincorporated manure applications occurred from June to August of summer 2011. Manure is composed of easily soluble P that can exit fields in the form of DP during runoff events. Therefore, management changes can have a dramatic effect on P and sediment concentrations in runoff.

Objective 4

SnapPlus inputs are often obtained from nutrient management plans (NMPs) and include both land characteristics (soils, slope, soil test phosphorus concentrations, etc.) and land practices (tillage, crop rotation, fertilizer and manure applications, etc.). Based on these inputs SnapPlus calculates rotational average and annual Wisconsin Phosphorus Index (WI PI) and sediment loss values. To be in compliance with NRCS 590, producers choosing to manage P via the WI PI must not exceed a rotational average PI of 6.

SnapPlus inputs were obtained from NMPs that were gathered from the WDNR and county conservation departments. SnapPlus calculated PI and sediment loss values for individual fields within the 17 MFCs. Area-weighted PI and sediment loss values were then calculated and compared with measured MFC runoff P and sediment concentrations. PI and predicted sediment loss values were not correlated with MFC runoff P and sediment concentrations during 4 runoff events in crop years 2011 to 2012. The lack of correlation may be caused by several factors. The likely major cause is that SnapPlus inputs did not reflect actual practices.

Chapter 4: Phosphorus Contributions from a Point Source in Plum Creek Watershed

Although nonpoint sources of P are the major concern in Plum Creek watershed, point sources should still be evaluated. During the summer of 2011, samples were taken upstream and downstream of a point source discharging into Plum Creek.

The objective of chapter 4 was to answer the following question:

1. What is the significance of a point source cheese production facility to in-stream P concentrations in Plum Creek?

Objective 1

TP and DP concentrations downstream of the point source were significantly higher than concentrations upstream. Annual TP and DP loads from the point source were estimated at 57 kg and 54 kg, respectively. DP was 94% of annual P load. Although, the results of this chapter suggest that point sources have a measurable impact on water quality during low flow conditions, their annual load contribution is negligible (7% of Plum Creek watershed TMDL baseline P loads) compared to nonpoint sources (93% of Plum Creek watershed TMDL baseline P loads). Future P loading reduction efforts in Plum Creek must focus on agricultural nonpoint sources if water quality goals are to be achieved.

Implications of Research

This study confirms that Plum Creek contributes a disproportionately high amount of sediment and P to the Lower Fox River and it suggests that it may be the highest yielding watershed in the Lower Fox River Basin, as did TMDL models. Results suggest that for Plum Creek watershed to meet TMDL goals, greater than 70% reductions of both sediment and P loads are needed. Furthermore, the WY 2011 summer low flow median TP concentration in Plum Creek was 0.35 mg/L; greater than five times the goal stated in the TMDL.

Analysis at the MFC scale showed that SSC and P concentrations leaving fields in runoff are high and that these concentrations are influenced greatly by surface residue and manure management. Improved tillage, residue/cover, and manure management can therefore greatly reduce sediment and P loss in runoff.

Although measured water quality was poor, more than 95% of the area within the MFCs was at or below the PI standard of 6. In the eyes of the state and agricultural industry, producers within these MFCs are managing their fields in a way that sufficiently minimizes their impact on surface water quality. Regardless of whether or not the PI is accurately predicting water quality, the current approach of using the PI based upon existing standards to improve water quality will not achieve success in Plum Creek watershed.

Accuracy of SnapPlus outputs (the PI and soil loss predictions) could be improved, and therefore be a more effective tool for improving water quality, if SnapPlus inputs were more accurate. This study found that tillage and field slope values input into SnapPlus may not accurately reflect reality. Other inputs, including dominant critical soil type and manure application values, may also not be accurate. Improving the accuracy of inputs relies almost entirely on the producers and their consultants. Currently, producers submit NMPs to county conservation departments or in the case of permitted operations, the WDNR. Permitted operations are those with 1,000 or more animal units (roughly 700 milking cows) (WDNR 2010b). County and WDNR personnel review the NMPs and make sure fields meet the rotational PI average of 6. Funding and staff constraints, however, do not allow for physical inspections of all producers to check that what is entered into SnapPlus is in fact reality. Recently, however, the WDNR is beginning to enforce permitted operations' implementation of NMPs through on-site audits. As of March 2012, six permitted operations were audited by the WDNR. Only two of the six operations had fully implemented their NMP. These types of NMP compliance checks and audits have resulted in fines and other legal actions in Maryland's efforts to meet water quality goals for Chesapeake Bay by ensuring farms comply with nutrient management rules (Maryland Department of Agriculture, 2012).

Finally, results of this study place serious doubt on whether or not TMDL goals are realistic for Plum Creek. Allocated yields, calculated from the TMDL, to Plum Creek watershed agriculture are 0.18 metric ton/ha/yr (0.08 ton/ac/yr) for TSS and 0.25 kg/ha/yr (0.22 lb/ac/yr) for P. The latter is essentially a goal PI for agricultural land within the watershed. Only 101 ha (18% of NMP area) in crop year 2011 and 75 ha (15% of NMP area) in crop year 2012 had RUSLE2 soil loss values of 0.22 metric ton/ha/yr (0.1 ton/ac/yr) or less. Similarly, only 20 ha (3.5% of NMP area) in crop year 2011 and 36 ha (7% of NMP area) in crop year 2012 had total PI values of 0.2 or less. A hypothetical SnapPlus scenario in a typical Plum Creek field shows that a three year alfalfa rotation with no nutrient applications yields total PI values from 0.2 – 0.4 and a RUSLE2 soil loss value of 0.36 metric ton/ha/yr (0.16 ton/ac/yr). Another SnapPlus scenario shows that un-harvested, permanent grassland with no nutrient application yields a total PI of 0.2 and a RUSLE2 soil loss value of 0.09 metric ton/ha/yr (0.04 tons/ac/yr). These SnapPlus scenarios support the idea that to reach a PI of 0.2, drastic changes in land use and/or agricultural practices will need to occur.

The Future and Possible Solutions

Dairy production and the resulting demand on the finite land base is increasing in the Plum Creek watershed area. Between 1997 and 2007, the number of dairy cows in Brown, Calumet and Outagamie counties increased by 12% while the number of farms decreased by 44% (USDA NASS 2012). The amount of land devoted to agriculture in the three counties decreased by 4% between 2002 and 2007 (USDA 2007).

As of 2002, only 15-29% of dairy operations in these counties used pasture for milking cows (Taylor and Foltz 2006). These non-pastured dairy operations rely entirely on stored feed and often times confine cows for either feeding and/or housing. Stored feed consists of concentrates (i.e. grains) and forage (i.e. corn silage and alfalfa) (Linn et al. 2008). These confined, conventional dairy operations intensify land use in their vicinity due to the increased demand for land for spreading manure and harvesting forage. Harvested silage fields have little soil protection and are vulnerable to erosion. Fields receiving large volumes of manure have an increased risk of P loss. As land use intensifies in the region, improving water quality in the LFRB will become even more challenging.

This intense land use may be playing a role in Plum Creek's high sediment and P yields. Because 77% of Plum Creek's P is attached to particles such as sediment, reducing soil erosion must be a priority. Erosion can be addressed in a variety of ways ranging from simple conservation practices, to innovative policy tools, to drastic changes in land use. Absent drastic changes in land use, conservation practices that prevent soil erosion will need to be extensively implemented in Plum Creek watershed in order to improve water quality. Examples of conservation practices that can reduce sediment and P loss include cover crops (Sharpley and Smith 1991), conservation tillage (Gaynor and Findlay 1995) contour tillage (Potter et al. 2006) grassed waterways (Feiner and Auerswald 2003) and riparian buffer or filter strips (Lee et al. 2003).

These practices, however, are competing with rising corn prices. A major reason for this is 2005 and 2007 legislation that spurred the rapid growth of the ethanol industry (Carter et al. 2012). This caused an increased demand for corn among several industries (ethanol for fuel, livestock feed, food, etc.) and elevated corn prices. In fact, 38% of domestic corn in 2011 was used for fuel ethanol production (Carter et al. 2012). Some producers hoping to take advantage of high prices are farming land that was once considered too marginal to plant to crops and/or land enrolled in a conservation program (i.e. Conservation Reserve Program) or practice (i.e. grassed waterway or buffer strip). As conservation practices are displaced by agriculture, soil and water quality are reduced. We have observed this to be the case in Plum Creek watershed. Grassed waterways are being plowed through or were nonexistent to begin with and stream buffers are too narrow to be effective at filtering runoff.

One way to encourage conservation practice implementation is to use a market-based policy tool called a cap and trade system. Under such a system, polluters must own allowances of a pollutant in order to pollute. Polluters can earn credits by polluting at levels below their allowance. Market demand for credits is created by a cap, which is the maximum amount of pollutant that can be discharged by all the participants in the system (Ribaudo and Gottlieb 2011). Possible caps already exist via the LFRB TMDL and the Wisconsin state P standards. For example, GBMSD, a point source, must reduce the P concentration of their effluent from 0.2 mg/L to 0.1 mg/L. GBMSD would need to spend an estimated $223 million in capital and $2 million per year for operations and maintenance at their facility to achieve this reduction (GBMSD 2012). In a trading system, instead of spending money upgrading their facility, GBMSD could pay agricultural producers within the LFRB to implement conservation practices that would reduce P loading to the LFR. The latter strategy could achieve the desired P reduction at a much lower cost to GBMSD and its rate payers. Cap and trade systems do have problems, however. One major challenge is to determine the P-reducing ability of specific conservation practices. Without physical inspections to ensure conservation practices are installed and maintained properly, it is difficult to ensure the buyer of P credits that they are getting what they paid for.

Even though a cap and trade system shows potential to improve LFRB water quality, more drastic changes may be needed in the LFRB and Plum Creek watershed. An example of a drastic change is the conversion from conventional agriculture (confined dairy operations in the case of the LFRB) to alternative forms of agriculture. Alternative agriculture could take the form of management intensive grazing (MIG) dairy. In MIG systems, dairy cows obtain the majority of their forage from pasture and are moved to fresh pasture frequently at least once per week (Taylor and Foltz 2006). MIG systems have lower capital investments and reduced machinery and labor requirements and can be profitable. A study of Wisconsin dairy operations from 1993 to 2003 found that farmers of grazing dairies earned similar income with half as many cows, had less debt and were more satisfied with their quality of life than other dairy farmers (Taylor and Foltz 2006). Environmental benefits of MIG systems compared to conventional systems include increased soil protection (less sediment loss), increased soil organic matter, improved nutrient distribution, improved cow health and decreased dependence on fossil fuels that are essential to conventional dairy operations (field tillage, planting, harvesting, manure hauling, etc.) (USDA NRCS 2007). In a water quality modeling study, Baumgart (2005) estimated that by converting 40% of dairy farms to MIG systems in the LFRB, nonpoint sources of P exported to the bay of Green Bay would be reduced by >15%. These environmental benefits could in turn yield benefits for residents of the LFRB by potentially increasing property value along waterways, recreational opportunities and habitat for wildlife (Dodds et al. 2009). Moore et al. (2011) surveyed residents in 14 townships that bordered Green Bay and found that cumulatively they were willing to pay

$10 million annually to improve water clarity in the bay by 1.2 m (4 ft).

To encourage a switch from conventional to alternative agriculture, policies may need to be changed or enacted. For example, a policy could be enacted to limit the number of livestock per unit area. Another option would be to either increase subsidies for alternative agriculture, reduce subsidies to conventional agriculture, or eliminate all agricultural subsidies. Subsidies arose during the Great Depression as a way to alleviate farmer poverty. In Wisconsin, agriculture received $4.39 billion in commodity subsidies, $1.03 billion in crop insurance, $902 million in conservation subsidies and $352 million in disaster subsidies from 1995 to 2011. This totals $6.65 billion of taxpayer dollars during that period. Large, commercial farms receive 62% of all farm subsidies (EWG 2012). Furthermore, the US public spent on average 9.4% of their disposable income on food in 2010. In 1947 this value was 23.5% (USDA ERS 2012). The public will also need to consider whether they are willing to pay more for food in order to improve and/or maintain soil and water quality.

Future Research

The USGS station on County D Road is funded to continue monitoring until October 2013. At that point in time, three years of water quality data will have been collected from Plum Creek which will provide a better picture of annual sediment and P losses under multiple crop and weather conditions. During the study period, TSS and TP were highly correlated ($r2=0.88$) at the Plum Creek USGS monitoring station. Based on this relationship, the addition of a turbidity meter at West Plum Creek would allow for TSS and TP load calculations at the West Plum Creek monitoring station. This would be done by: estimating TSS and TP concentrations by applying regression equations that are based on continuous turbidity data and a limited number of event and low flow samples that are analyzed for TSS and TP; coupling the existing pressure transducer data with a larger stage/discharge dataset and subsequent stage/discharge relationship to obtain continuous flow measurements; and combining the concentration and flow data to produce daily loads. In addition, the MFC monitoring should be continued in an effort to obtain at least six to eight events at the monitoring sites established in this study. Ideally four events would be monitored within the same crop year so as to minimize field management variability within a site.

REFERENCES

Andraski, T.W. and L.G. Bundy. 2003. Relationship between phosphorus levels in soil and in runoff from corn production systems. J. Environ. Qual. 32:310-316.

Baumgart, Paul. 2005. Lower Green Bay and Lower Fox Tributary Modeling Report: Source Allocation of Suspended Sediment and Phosphorus Loads to Green Bay from the Lower Fox River Subbasin Using the Soil and Water Assessment Tool (SWAT). Oneida Tribe of Indians of Wisconsin and the Science and Technical Advisory Committee of the Green Bay Remedial Action Plan (RAP), Green Bay, WI.

Beede, D. K., and J. A. Davidson. 1999. Phosphorus: Nutritional management for Y2K and beyond. *In* Proceedings of Tri-State Dairy Nutrition Conference, Ft. Wayne, Indiana, April 20-21, 1999, 51-97. Columbus, OH: The Ohio State University.

Blanchard, S.F. and T. Miller. 2004. The Graphical Constituent Loading Analysis System (GCLAS) for computing discharges of suspended sediment and other water-quality constituents. US Geological Survey Office of Surface Water Technical Memorandum No. 2004.02.

Brown, C.E. 1966. Phosphate deposits in the basal beds of the Maquoketa Shale near Dubuque, Iowa. US Geological Survey Professional Paper 550b.

Brungs, W.A. 1971. Chronic effects of low dissolved oxygen concentrations on fathead minnow (Pimephales promelas). Journal of Fisheries Research Board of Canada 28:1119-1123.

Bruton, M.N. 1985. The effects of suspensoids on fish. Hydrobiologia 125:221-241.

Burkhead, N.M., and H.L. Jelks. 2001. Effect of suspended sediment on the reproductive success of the tricolor shiner, a crevice-spawning minnow. Transactions of the American Fisheries Society 130:959-968.

Cabot P.E. and P. Nowak. 2005. Planned versus actual outcomes as a result of animal feeding operation decisions for management phosphorus. J. Environ. Qual. 34:761-773.

Carmichael W.W. 2001. Health effects of toxin-producing cyanobacteria: the CyanoHABs. Human Ecological Risk Assessment. 7:1393-1047.

Clesceri, L.S., A.E. Greenberg, and A.D. Eaton. 1998. Standard methods for the examination of water and wastewater. 20th ed. American Public Health Association, Washington.

Cohn, T. A., L.L. Delong, E.J. Gilroy, R.M. Hirsch and D.K. Wells, D. K.1989. Estimating constituent loads. Water Resources Research 25: 937 – 942.

Correll, D.L. 1997. Buffer zones and water quality protection: General Principles. *In*

Buffer zones: their processes and potential in water quality protection, ed. N.E. Haycock, T.P. Burt, K.W.T. Goulding, and G. Pinay. Harpenden, Herts, UK: Quest Environmental.

Correll, D.L. 1998. The role of phosphorus in eutrophication of receiving waters: a review. Journal of Environmental Quality 27:261-266.

Crosbie, B. and P. Chow-Fraser. 1999. Percent land use in the watershed determines the water- and sediment-quality of 21 wetlands in the Great Lakes basin. Canadian Journal of Fisheries and Aquatic Sciences 56: 1781-1791.

Daniel, T., A.N. Sharpley, and J. Lemunyon, 1998. Agricultural Phosphorus and Eutrophication: a symposium overview. USDA Agricultural Research Service ARS-149.

Dauer, D.N. 1993. Biological criteria, environmental health and estuarine macrobenthic community structure. Marine Pollution Bulletin 26:249-257.

Dillaha, T.A., Inamdar, S.P., 1997. Buffer zones as sediment traps or sources. *In* Buffer Zones: their Processes and Potential in Water Protection, ed. Haycock, N.E., T.P. Burt, K.W.T. Goulding, G. Pinay. Harpenden, UK: Quest Environmental.

Dodds, W.K., W.W. Bouska, J.L. Eitzmann, T.J. Pilger, K.L. Pitts, A.J. Riley, J.T. Schloesser, and D.J. Thornbrugh. 2009. Eutrophication of U.S. freshwaters: analysis of potential economic damages. Environmental Science and Technology 43:12-19.

Egertson, C.J. and J.A. Downing. 2004. Relationship of fish catch and composition to water quality in a suite of agriculturally eutrophic lakes. Canadian Journal of Fisheries and Aquatic Science 61: 1784-1796.

Eghball, B., J.F. Power, J.E. Gilley, and J.W. Doran. 1997. Nutrient, carbon, and mass loss during composting of beef cattle feedlot manure. Journal of Environmental Quality 26:189-193.

Environmental Working Group (EWG). 2010. Farm income data debunks subsidy myths. Available from http://www.ewg.org/agmag/2010/05/farm-income-data-debunks-subsidy-myths/.

Environmental Working Group (EWG). 2012. Farm Subsidy Database. Available from: http://farm.ewg.org/region.php?fips=55000.

Feiner, P. and K. Auerswald. 2003. Effectiveness of grassed waterways in reducing runoff and sediment delivery from agricultural watersheds. Journal of Environmental Water Quality 32:927-936.

Fox Wolf Watershed Alliance. 2011. Available from: http://www.fwwa.org/.

Freeman, A.M. III. 1982. Air and water pollution control: a benefit-cost assessment. New York: John Wiley and Sons.

Gaynor, J.D. and W.I. Findlay. 1995. Soil and phosphorus loss from conservation and conventional tillage in corn production. Journal of Environmental Quality 24:734-741.

Gburek, W.J., and Sharpley, A.N. 1998. Hydrologic controls on phosphorus loss from upland agricultural watersheds. Journal of Environmental Quality 27:267-277.

Good, L.W., J. Panuska, and P. Vadas. 2010. Current calculations in the Wisconsin P index. Department of Soil Science. University of Wisconsin-Madison.

Good, L.W., P. Sutter, C. Diehl, K. Songer and K. Meyer. 2011. Watershed P index inventories: an example of runoff P loss risk distribution in two driftless area agricultural watersheds. Proceedings of the 2011 Wisconsin Crop Management Conference 50:136-138.

Good, L.W., P. Vadas, J.C. Panuska, C.A. Bonilla and W.E. Jokela. (In Press) Testing the Wisconsin phosphorus index with year-round, field-scale monitoring.

Graczyk, D.J., D.M. Robertson, P.D. Baumgart and K.J. Fermanich. 2011. Hydrology, phosphorus and suspended solids in five agricultural streams in the Lower Fox River and Green Bay watersheds, Wisconsin, Water Years 2004–2006. US Geological Survey Scientific Investigations Report 2011–5111.

Graneli, W. 1990. Standing crop and mineral content of reed, Phragmites australis, (Cav.) Trin. ex Steud., in Sweden—management of reed stands to maximize harvestable biomass.
Folia Geobot Phytotax 25:291–302

Green Bay Metropolitan Sewerage District (GBMSD). 2012. Phosphorus. Available from http://www.gbmsd.org/protect-the-environment/water-quality-research/indicators/phosphorus.

Gregg, W.W. and Rose, F.L. 1982. The effects of aquatic macrophytes on the stream micro-environment. Aquatic Botany 14, 309–324.

Haygarth, P.M., L. Hepworth and S.C. Jarvis. 1998. Forms of phosphorus transfer and hydrological pathways from soil under grazed grassland. European Journal of Soil Science 49: 65–72.

Haygarth, P.M. and A.N. Sharpley. 2000. Terminology for phosphorus transport. Journal of Environmental Quality 29:10-15.

Haygarth, P.M. and S.C. Jarvis. 1999. Transfer of phosphorus from agricultural soil. Advances in Agronomy 66:195-249.

Heathwaite, A.L. and R.M. Dils, 2000. Characterising phosphorus loss in surface and subsurface hydrological pathways. Science of the Total Environment 251-252:523-538.

Hedley, M.J., and A.N. Sharpley. 1998. Strategies for global nutrient cycling. *In* Long-term nutrient needs for New Zealand's primary industries: global supply, production requirements, and environmental constraints, ed. L. Currie, 70-95. The Fertilizer and Lime Research Center, Massey University, Palmerston North, New Zealand.

Helsel, D.R., and R.M. Hirsch. 1992. Statistical Methods in Water Resources. Amsterdam, Elsevier Publishers. 524 p.

Johnston, A.E. 2005. Phosphorus nutrition of arable crops. *In* Phosphorus: agriculture and the environment, ed. T. Sims and A. Sharpley. Agronomy monograph 46. Madison, Wisconsin: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

Kaarakka, P., L.W. Good, and J. Wolter. 2011. SNAP-Plus 1.132. University of Wisconsin, Madison. Available from http: //www.snapplus.net

Kleinman, P. J. A., R.B. Bryant, W.S. Reid, A.N. Sharpley, and D. Pimental. 2000. Using soil phosphorus behavior to identify environmental thresholds. Soil Science 165:943-950.

Laboski, C.A.M., J.B. Peters and L.G. Bundy. 2006. Nutrient application guidelines for field, vegetable and fruit crops in Wisconsin. University of Wisconsin Extension Bulletin A2809.

Lee, K.H., T.M. Isenhart, and R.C. Schultz. 2000. Multispecies riparian buffers trap sediment and nutrients during rainfall simulations. Journal of Environmental Quality 29:1200-12005.

Lee, K.H., T.M. Isenhart, and R.C. Schultz. 2003. Sediment and nutrient removal in an established multi-species riparian buffer. Journal of Soil and Water Conservation 58:1-8.

Lemunyon, J.L. and R.G. Gilbert. 1993. The concept and need for a phosphorus assessment tool. Journal of Production Agriculture 6:483-486.

Linn, J.G., M.F. Hutjens, R. Shaver, D.E. Otterby, W.T. Howard and L.H. Kilmer. 2008. Feeding the dairy herd. North Central Regional Extension Publication 346.

Madsen, J.D., P.A. Chambers, W.F. James, E.W. Koch and D.F. Westlake. 2001. The interactions between water movement, sediment dynamics and submersed macrophytes. Hydrobiologia 444:71-84.

Madsen T.V. and E. Warncke. 1983. Velocity of currents aroundand within submerged aquatic vegetation. Archives of Hydrobiology 97:389–394.

Mander, U., O. Matt, and U. Nugin. 1991. Perspectives of vegetated shoals, ponds, and ditches as extensive outdoor systems of wastewater treatment in Estonia. *In* Ecological Engineering for Wastewater Treatment, eds. C. Entnier and B. Guterstam. Bokskogen, Gothenburg.

Maryland Department of Agriculture. 2012. Recipe for a healthy Chesapeake Bay: Maryland Nutrient Management Program 2011 Annual Report.

McDowell, R.W., Sharpley, A.N., L.N. Condron, P.M. Haygarth and P.C. Brookes. 2001. Processes controlling soil phosphorus release to runoff and implications for agricultural management. Nutrient Cycling in Agroecosystems 59: 269-284.

Morris, G.L., and J. Fan. 1998. Reservoir sedimentation handbook: design and management of dams, reservoirs, and watersheds for sustainable uses. New York: McGraw-Hill.

Natural Resources Conservation Service (NRCS). 2005. Nutrient management (Acre) Code 590. Natural Resources Conservation Service, Conservation Practice Standard Publication. Madison, Wisconsin.

Neitsch S.L., J.G. Arnold, J.R. Kiniry, and J.R. Williams. 2002. Soil and Water Assessment Tool Theoretical Documentation, Version 2000. USDA, Grassland, Soil and Water Research Laboratory Agricultural Research Service, Blackland Research Center.

Norfleet, M.L. (ed.). 1998. Phosphorus in agriculture. Soil Quality Institute Technical Pamphlet No. 2. Soil Quality Institute.

Potter, S.R., S. Andrews, J.D. Atwood, R.L. Kellogg, J. Lemunyon, L. Norfleet and D. Oman. 2006. Model simulation of soil loss nutrient loss and change in soil organic carbon associated with crop production. US Department of Agriculture Natural Resources Conservation Service, Conservation Effects Assessment Project.

Pretty, J.N., C.F. Mason, D.B. Nedwell, R.E. Hine,, S. Leaf, R. Dils. 2003. Environmental costs of freshwater eutrophication in England and Wales. Environmental Science and Technology 37: 201–208.

Reckinger, N.A. 2007. Comparison of phosphorus forms at different spatial scales and assessment of an area-weighted p-index to multi-field watersheds. MS Thesis, University of Wisconsin-Green Bay.

Reynolds, C.S. and P.S. Davies. 2001. Sources and bioavailability of phosphorus fractions in freshwaters: a British perspective. Biological Reviews of the Cambridge Philosophical Society 76: 27-64.

Ribaudo, M.O., and J. Gottlieb. 2011. Point-Nonpoint trading – can it work? Journal of the American Water Resources Association. 47:5-14.

Roberson, T., L.G. Bundy and T.W. Andraski. 2006. Freezing and drying effects on potential plant contributions to phosphorus in runoff.

Robertson, D.M., D.J. Graczyk, P.J. Garrison, L. Wang, G. LaLiberte, and R. Bannerman. 2006. Nutrient concentrations and their relations to the biotic integrity of wadeable streams in Wisconsin. United States Geological Survey Professional Paper 1722. Reston, VA.

Sanford, G.R., J.L. Posner and G.L. Hadley. 2009. Economics of hauling dairy slurry and its value in Wisconsin corn grain systems. Journal of Agricultural, Food and Environmental Sciences 3:1–10.

Scheberle, D., and T. Cooper. 2008. Toward a TMDL for the Lower Fox River Basin: findings from facilitated stakeholder meetings and interview research. Report to the DNR. Green Bay, WI: University of Wisconsin-Green Bay.

Schmidt, J. Unpublished Data. Wisconsin Department of Natural Resources.

Schreiber, J. D., and L. L. McDowell. 1985. Leaching of nitrogen, phosphorus, and organic carbon from wheat straw residues: I. Rainfall intensity. Journal of Environmental Quality 14: 251-256.

Schultz R.C., J.P. Colletti, T.M. Isenhart, C.O. Marquez, W.W. Simpkins, and C.J. Ball. 2000. Riparian forest buffer practices. p. 189-281. *In* North America Agroforestry: An integrated science and practice, eds. H.E. Garrett et al., American Society of Agronomy, Madison, WI.

Sharpley, A.N. 1980. The enrichment of soil phosphorous in runoff sediments. Journal of Environmental Quality 9:521-526.

Sharpley, A.N. 1985. The selective erosion of plant nutrients in runoff. Soil Science Society of America Journal 49:1527-1534.

Sharpley, A.N. 1997. Rainfall frequency and nitrogen and phosphorus in runoff from soil amended with poultry litter. Journal of Environmental Quality 26:1127-1132.

Sharpley, A.N. 2003. Development of phosphorus indices for nutrient management planning strategies in the United States. Journal of Soil and Water Conservation 58:137-152.

Sharpley, A., D. Beegle, C. Bolster, L. Good, B. Joern, Q. Ketterings, J. Lory, R. Mikkelsen, D. Osmond, and P. Vadas. 2011. Revision of the 590 Nutrient Management Standard: SERA-17 recommendations. Southern Cooperative Series No. 412, Available from http://www.sera17.ext.vt.edu/Documents/590Recommends2011.pdf (verified 3 December 2011) Virginia Tech University.

Sharpley, A.N., T. Daniel, G. Gibson, L. Bundy, M. Cabrera, T. Sims, R. Stevens, J. Lemunyon, P. Kleinman, and R. Parry. 2006. Best management practices to minimize agricultural phosphorus impacts on water quality. U.S. Department of Agriculture, ARS-163. Washington DC.

Sharpley, A.N., P.J.A. Kleinman, and R.W. McDowell. 2001a. Innovative management of agricultural phosphorus to protect soil and water resources. Pasture Systems and Watershed Management Research Laboratory, University Park, PA, U.S.A. Communications in Soil Science and Plant Analysis 32:1071-1100.

Sharpley, A.N., R.W. McDowell, and P.J.A. Kleinman. 2001b. Phosphorus loss from land to water: integrating agricultural and environmental management. Plant and Soil 237:287-307.

Sharpley, A.N., R.W. McDowell, J.L. Weld and P.J.A. Kleinman. 2001c. Assessing site vulnerability to phosphorus loss in an agricultural watershed. Journal of Environmental Quality 30:2026-2036.

Sharpley, .A.N. and S.J. Smith. 1991. Effects of cover crops on surface water quality. *In* Cover crops for clean water, ed. W.L. Hargmve, Soil and Water Conservation Society, Ankeny, Iowa.

Sharpley, A. N., and H. Tunney. 2000. Phosphorus research strategies to meet agricultural and environmental challenges of the 21st century. Journal of Environmental Quality 29:176–181.

Shelton, L.R. 1994. Field guide for collecting and processing stream-water samples for the National Water Quality Assessment Program.

Sims, J.T., and Sharpley, A.N. 1998. Managing agricultural phosphorus for water quality protection: future challenges. *In* Soil Testing for Phosphorus: Environmental Uses and Implications, ed. J.T. Sims, 41–43. Southern Cooperative Series Bulletin No. 389, SERA-IEG 17. Newark, DE: University of Delaware.

Sinaj, S., E. Frossard, and J.C. Fardeau. 1997. Isotopically exchangeable phosphate in size fractioned and unfractioned soils. Soil Science Society of America Journal 61:14135-14139.

Sutherland, A.B. 2007. Effects of increased suspended sediment on the reproductive success of an upland crevice-spawning minnow. Transactions of the American Fisheries Society 136:416-422.

Suttle, K.B., M.E. Power, J.M. Levine, and C. McNeely. 2004. How fine sediment in riverbeds impairs growth and survival of juvenile salmonids. Ecological Applications 14:969-974.

Sweka, J.A., and K.J. Hartman. 2001. Influence of turbidity on brook trout reactive distance and foraging success. Transactions of the American Fisheries Society 130:138-146.

Taylor, J. and J. Foltz. 2006. Grazing in the dairy state: pasture use in the Wisconsin dairy industry, 1993 – 2003. University of Wisconsin Madison.

Tegtmeier, E.M., and M.D. Duffy. 2004. The external costs of agricultural production in the United States. International Journal of Agricultural Sustainability 2:1-20.

US Department of Agriculture Agricultural Research Service (USDA ARS). 2008. Draft science documentation, Revised Universal Soil Loss Equation Version 2. Available from http://www.ars.usda.gov/sp2UserFiles/Place/64080510/RUSLE/RUSLE2_Science_Doc.pdf,

US Department of Agriculture (USDA). 2007. 2007 Census of Agriculture. Available from http://www.agcensus.usda.gov/Publications/2007/Full_Report/usv1.pdf.

US Department of Agriculture Natural Resource Conservation Service (USDA NRCS), Soil Survey Staff. Soil Survey Geographic (SSURGO).

US Department of Agriculture Natural Resource Conservation Service (USDA NRCS). 2007. Profitable grazing based dairy systems. Technical Note No. 1.

US Department of Agriculture National Agricultural Statistics Service (USDA NASS). 2012. Quik Stats 2.0. Available from http://quickstats.nass.usda.gov/.

US Department of Agriculture Economic Research Service (USDA ERS). 2012. Available from http://www.ers.usda.gov/data-products/food-expenditures.aspx

US Department of Agriculture (USDA). 2012. 2011 Wisconsin Cropland Data Layer. United States Department of Agriculture, National Agricultural Statistics Service, Research and Development Division, Geospatial Information Branch, Spatial Analysis Research Section.

US Environmental Protection Agency (US EPA). 1995. National water quality inventory. 1994 Report to Congress. EPPA841-R-95-005.

US Environmental Protection Agency (US EPA). 2002. National water quality inventory 2000 report‖. EPA-841-R-02-001. Washington, DC.

US Environmental Protection Agency (US EPA). 2007. National water quality inventory: Report to congress, 2002 reporting cycle. US EPA Doc. 841-R-07–001. U.S. EPA, Washington, DC.

US Environmental Protection Agency (US EPA). 2011. National summary of impaired waters and TMDL information. Available from http://iaspub.epa.gov/waters10/attains_nation_cy.control?p_report_type=T. Accessed 10 April, 2011.

US Forest Service (USFS). 2002. Laboratory Procedures for Determining Suspended Sediment Concentration. Arcata, CA: Redwood Sciences Laboratory.

US Geological Survey (USGS). 2009. Elevation Grid of Wisconsin from 10-meter NED. United States Geological Survey.

Unger, P.W. 1990. Conservation tillage systems. Advances in Soil Science 13:27-68.
Vaughan, W.J., and C.S. Russell. 1982. Freshwater recreational fishing – the national benefits of water pollution control. Washington DC: RFF.

Uusi-Kammpa, J., E. Turtola, and T. Ylaranta. 1997. The interactions of buffer zones and phosphorus runoff. In Buffer Zones: Their Processes and Potential in Water Protection, eds. N.E. Haycock, T.P. Burt, K.W.T. Goulding and G. Pinay, Quest Environmental, Harpenden, UK.

Westerman, P.W., T.L. Donnely. and M.R. Overcash.1983. Erosion of soil and poultry manure—a laboratory study. Transactions of the American Society of Agricultural Engineers 26:1070-1078.

Wisconsin Department of Natural Resources (WDNR). 1993. Lower Green Bay Remedial Action Plan. 1993 Update for the Lower Green Bay and Fox River Area of Concern. Green Bay.

Wisconsin Department of Natural Resources (WDNR). 1998. WISCLAND land cover. Wisconsin Department of Natural Resources. Madison, WI.

Wisconsin Department of Natural Resources (WDNR). 2010. Wastewater Wisconsin Pollutant Discharge Elimination System (WPDES) Permit Program. Available from http://dnr.wi.gov/org/water/wm/ww/.

Wisconsin Department of Natural Resources (WDNR). 2010b. Concentrated animal feeding operations. Available from http://dnr.wi.gov/runoff/ag/cafo.htm

Wisconsin Department of Natural Resources. 2011. Lower Fox River Basin. Available from
http://dnr.wi.gov/water/basin/lowerfox/index.htm.

Wisconsin Department of Natural Resources (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. Wisconsin Department of Natural Resources. Madison, WI.

Zamor, R.M., and G.D. Grossman. 2007. Turbidity affects foraging success of drift-feeding rosyside dace. American Fisheries Society 136:167-176.

APPENDIX A: WATERSHED WATER QUALITY COMPARISONS

A.1. Comparison of median total suspended solids (TSS), total phosphorus (TP) and dissolved phosphorus (DP) concentrations between Baird Creek (BA) and Plum Creek (PL) for various flow conditions during the study period (October 2010 – April 2012). Medians with different letters represent statistical significance at the 0.05 probability level.

	TSS (mg/L)		TP (mg/L)		DP (mg/L)		DP Fraction (%)	
	BA	PL	BA	PL	BA	PL	BA	PL
All Flow Conditions								
Minimum	1	4	0.02	0.08	0.02	0.05	4	6
Mean	130	424	0.50	0.85	0.15	0.26	52	45
Median	**42[a]**	**149[b]**	**0.34[a]**	**0.60[b]**	**0.14[a]**	**0.24[b]**	**52[a]**	**38[a]**
Maximum	2180	5790	6.35	5.64	0.47	0.49	1	91
No. of Samples	175	181	175	181	34	33	33	33
Low Flow Conditions – Data are paired								
Minimum	1	4	0.02	0.10	0.02	0.10	6	38
Mean	6	22	0.17	0.34	0.08	0.25	64	68
Median	**4[a]**	**23[b]**	**0.13[a]**	**0.34[b]**	**0.06[a]**	**0.22[b]**	**62[a]**	**71[b]**
Maximum	22	58	0.59	0.66	0.24	0.49	1	91
No. of Samples	27	27	27	27	13	13	13	13
Event Flow Conditions								
Minimum	5	11	0.05	0.12	0.06	0.05	4	6
Mean	154	497	0.57	0.95	0.19	0.26	43	28
Median	**58[a]**	**231[b]**	**0.39[a]**	**0.69[b]**	**0.17[a]**	**0.24[b]**	**44[a]**	**28[a]**
Maximum	2180	5790	6.35	5.64	0.47	0.48	74	79
No. of Samples	146	153	146	153	20	19	19	19

A.2. Median total suspended solids (TSS), total phosphorus (TP) and dissolved phosphorus (DP) concentrations and comparison of low flow TSS, TP and DP concentrations between Plum Creek (PL) and West Plum Creek (WPL) for various flow conditions during the study period (October 2010 – April 2012). Medians with different letters represent statistical significance at the 0.05 probability level.

	TSS (mg/L)		**TP (mg/L)**		**DP (mg/L)**		**DP Fraction (%)**	
	PL	**PLW**	**PL**	**PLW**	**PL**	**PLW**	**PL**	**PLW**
All Flow Conditions								
Minimum	4	3	0.08	0.10	0.05	0.05	6	17
Mean	424	253	0.85	0.92	0.26	0.37	45	65
Median	149	23	0.60	0.62	0.24	0.27	38	74
Maximum	5790	1140	5.64	4.43	0.49	1.19	91	87
No. of Samples	181	19	181	19	33	15	33	16
Low Flow Conditions - Data are Paired								
Minimum	5	3	0.08	0.10	0.10	0.05	55	51
Mean	21	13	0.32	0.45	0.26	0.40	71	75
Median	**23**[a]	**10**[a]	**0.30**[a]	**0.32**[a]	**0.22**[a]	**0.27**[a]	**73**[a]	**78**[a]
Maximum	54	28	0.57	1.41	0.49	1.19	91	87
No. of Samples	13	13	13	13	11	11	11	11
Event Flow Conditions								
Minimum	11	355	0.12	0.80	0.05	0.23	6	17
Mean	497	773	0.95	1.95	0.26	0.35	27	24
Median	231	735	0.69	1.55	0.24	0.41	28	19
Maximum	5790	1140	5.64	4.43	0.48	0.42	79	34
No. of Samples	153	6	153	6	19	3	19	3

APPENDIX B: WATERSHED CHARACTERISTICS COMPARISON

B.1. 2011 Land use and land cover composition in the watersheds of six Lower Fox River Basin monitoring sites.

	Ag	Urban	Wetland	Forest	Grassland/shrubland	Water	Barren
Apple Creek	66%	26%	4%	4%	0%	0%	0%
Ashwaubenon Creek	84%	9%	2%	5%	0%	0%	0%
Baird Creek	76%	12%	10%	2%	0%	0%	0%
Duck Creek	70%	7%	13%	9%	0%	0%	0%
East River	63%	24%	5%	8%	0%	0%	1%
Plum Creek	**80%**	**9%**	**4%**	**6%**	**0%**	**1%**	**0%**

B.2. Mean overland slopes in the watersheds of six Lower Fox River Basin monitoring sites. Slopes are in percent.

Watershed	Cropland
Apple Creek	2.6
Ashwaubenon Creek	1.7
Baird Creek	2.6
Duck Creek	3.1
East River	4.1
Plum Creek	**3.7**

APPENDIX C: PLUM CREEK SAMPLING EVENTS

C.1. SSC, TP and DP concentrations in MFC runoff during event 1.

Event 1 – April 16, 2011					
Site	SSC (mg/L)	TP (mg/L)	DP (mg/L)	PP (mg/L)	DP Fraction
2	516	1.22	0.21	1.01	0.17
3	92	1.21	0.72	0.49	0.6
4	139	0.8	0.35	0.45	0.43
5	55	0.95	0.66	0.3	0.69
6	330	1.03	0.29	0.74	0.28
7	94	0.58	0.19	0.39	0.33
8	1272	2.14	0.23	1.91	0.11
9	130	0.96	0.45	0.5	0.47
10	234	0.59	0.15	0.44	0.25
11	115	1.01	0.49	0.52	0.49
12	218	0.8	0.26	0.55	0.32
13	41	0.8	0.5	0.3	0.62
14	469	1.04	0.42	0.62	0.4
15	35	0.74	0.31	0.42	0.42
20	96	0.83	0.39	0.44	0.47
21	98	0.68	0.16	0.53	0.23

C.2. SSC, TP and DP concentrations in MFC runoff during event 2.

Event 2 – April 26, 2011					
Site	SSC (mg/L)	TP (mg/L)	DP (mg/L)	PP (mg/L)	DP Fraction
1	183	0.92	0.26	0.67	0.28
2	878	1.42	0.1	1.32	0.07
3	85	1.07	0.58	0.49	0.54
4	686	2.13	0.75	1.38	0.35
5	29	0.8	0.34	0.46	0.42
6	781	1.55	0.27	1.28	0.18
7	58	0.45	0.05	0.4	0.11
8	795	2.88	0.12	2.76	0.04
9	274	1.25	0.42	0.83	0.34
10	485	0.96	0.12	0.84	0.13
11	218	1.11	0.48	0.63	0.43
12	525	1.36	0.24	1.12	0.18
13	127	0.71	0.3	0.42	0.42
14	460	0.91	0.27	0.63	0.3
15	72	0.64	0.09	0.54	0.15
20	267	1.27	0.3	0.97	0.24
21	134	0.92	0.08	0.84	0.09

C.3. SSC, TP and DP concentrations in MFC runoff during event 3.

Event 3 – November 9, 2011					
Site	SSC (mg/L)	TP (mg/L)	DP (mg/L)	PP (mg/L)	DP Fraction
1	131	1.29	0.57	0.72	0.44
2	483	1.31	0.3	1.01	0.23
3	45	1.11	0.81	0.3	0.73
4	1233	2.31	0.49	1.82	0.21
5	1165	2.71	0.74	1.97	0.27
6	414	1.15	0.42	0.73	0.37
7	47	0.78	0.46	0.32	0.59
8	108	0.82	0.5	0.33	0.61
9	795	1.03	0.44	0.59	0.42
10	59	0.57	0.28	0.29	0.49
11	48	1.06	0.67	0.39	0.64
12	210	1.04	0.33	0.72	0.31
13	87	2.95	2.12	0.83	0.72
14	148	1.57	1.03	0.54	0.66
15	96	3.83	3	0.83	0.78
20	535	1.39	0.81	0.58	0.58
21	13	0.69	0.59	0.1	0.86

C.4. SSC, TP and DP concentrations in MFC runoff during event 4
.

Event 4 – May 6, 2012					
Site	SSC (mg/L)	TP (mg/L)	DP (mg/L)	PP (mg/L)	DP Fraction
1	128	0.57	0.35	0.22	0.39
2	300	0.62	0.46	0.16	0.25
3	345	1.32	0.81	0.51	0.39
4	278	1.20	0.84	0.36	0.30
5	328	0.99	0.77	0.22	0.22
6	593	0.95	0.73	0.23	0.24
7	79	0.54	0.24	0.30	0.55
8	640	1.12	0.94	0.18	0.16
9	497	1.21	1.02	0.19	0.16
10	272	0.83	0.55	0.28	0.34
11	224	1.79	1.16	0.63	0.35
12	228	1.65	0.99	0.66	0.40
13	292	0.92	0.60	0.32	0.35
14	289	1.13	0.80	0.33	0.29
15	142	1.40	0.83	0.57	0.41
20	62	0.58	0.34	0.24	0.42
21	26	0.38	0.29	0.09	0.24