Sediment and Total Phosphorous Contributors in Rock River Watershed

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ABSTRACT

Total phosphorous (TP) and total suspended sediment (TSS) pollution is a problem in the US Midwest and is of particular concern in the Great Lakes region where many water bodies are already eutrophic. Increases in monoculture corn planting to feed ethanol based biofuel production could exacerbate these already stressed water bodies. In this study we expand on the previous studies relating landscape variables such as land cover, soil type and slope with changes in pollutant concentrations and loading in the Great Lakes region.

The Rock River watershed in Wisconsin, USA was chosen due to its diverse land use, numerous lakes and reservoirs susceptible to TSS and TP pollution, and the availability of long-term streamflow, TSS and TP data. Eight independent subwatersheds in the Rock River watershed were identified using United States Geological Survey (USGS) monitoring sites that monitor flow, TSS and TP. For each subwatershed, we calculated land use, soil type, and terrain slope metrics or variables. TSS and TP from the different subwatersheds were compared using Analysis of Variance (ANOVA), and associations and relationships between landscape metrics and water quality (TSS and TP) were evaluated using the Partial Least Square (PLS) regression. Results show that of urban land use and agricultural land growing corn rotated with non-leguminous crops are associated with TSS and TP in streams. This indicates that increasing the amount of corn rotated with non-leguminous crops within a subwatershed could increase degradation of water quality. Results showed that increase in corn-soybean rotation acreage within the watershed is associated with reduction in stream's TSS and TP. Results also show that forest and water bodies were associated with reduction in TSS and TP. Based on our results we recommend adoption of the Low Impact Development (LID) approach in urban dominated subwatersheds. This approach attempts to replicate the pre-development hydrological regime by reducing the ratio of impervious area to natural cover wherever possible, as well as recycling or treating stormwater runoff using filter strips, ponds and wetlands. In agriculturally dominated subwatersheds, we recommend increasing corn-soybean rotation, keeping corn on areas with gentle slope and soils with lower erodibility.

Key Words*:* Land use, PLS, Rock River watershed, TP, TSS

1. INTRODUCTION

Water bodies around the world are threatened by increases in upstream nutrients and sediment runoff as they influence sources of drinking water, aquatic species, and other ecologic functions of streams and lakes (Haycock and Muscutt, 1995; Verhoeven et al., 2006). Phosphorus, a primary nutrient, and sediment accelerate eutrophication and increase turbidity in water bodies. They could originate from anthropogenic activities such as agriculture, urban dwelling, cattle, natural decay of organic matter and natural erosion (Tong and Chen, 2002). The recent US policy to increase generation of ethanol biofuels from 13 billion gallons (bgals) in 2010 to 36 bgals in 2022 (Congress, 2007; Schnepf, 2011) could cause an environmental challenge due to the potential loss of conservation reserve program lands and corn-soybean rotations to monoculture corn to meet the demands of energy. The majority of these agricultural -based biofuels are mainly generated from corn grown in US Midwest (Simpson et al., 2008).

Watershed scale studies on the potential effect of land use changes will have on water quality are essential to controlling water pollution. Various studies have linked stream pollutants to land use variables using process-based hydrological models (Jha et al., 2010; Kirsch et al., 2002; Ullrich and Volk, 2009) or statistical methods (Lenat and Crawford, 1994; Liu et al., 2009; Lopez et al., 2008; Mehaffey et al., 2005; Nash et al., 2009). Process based hydrologic models have been successfully used to characterize watershed processes and sources of stream pollutants; however these models require detailed input data, which may not be available for some areas. For instance, Kirsch et al. (2002) showed the difficulty of calibrating a SWAT model for Rock River basin in Wisconsin, due to limited data for numerous lakes, reservoirs and dams in the basin. Using statistical regression methods, agricultural land was found to be a major contributor to nutrients in Oregon, New York, and the Missouri-Arkansas Ozark region

(Lopez et al., 2008; Mehaffey et al., 2005; Nash et al., 2009). In addition, Liu et al. (2009) found that urban and agricultural lands contribute many pollutants (such as TP, bacteria, metals, low dissolved oxygen, alkalinity and conductivity) to Wisconsin streams using similar statistical methods. In contrast, lowest stream pollution was attributed to the presence of forests and wetlands in the above studies. Lenat and Crawford (1994) also found that urban land use is the highest contributor to sediment when they collected water samples from three watersheds with different dominant land uses (forest, urban, agricultural) in the Piedmont ecoregion of North Carolina.

While various studies demonstrated a statistical relationship between land use metrics and water quality, there are few studies that examined contributions of specific types of cropping practices on pollutant loadings to streams and reservoirs. The objective of our study was to determine the influence of landscape characteristics on water quality measures of TSS and TP using statistical models in lieu of more data-intensive process models. Understanding how changes in land use (for instance, the type of crop planted in watersheds having different soils and terrain) might influence TSS and TP in streams would greatly improve water quality predictions in response to changes in cropping practices within a watershed, thereby helping stakeholders make informed decisions about land use planning. The results of this study could help: (1) in setting priorities in watershed management, and (2) to demonstrate a method applicable to cases with limited monitored data, and data with different temporal scales.

2. MATERIALS AND METHODS

2.1. Study area description

The Rock River watershed is located within the formerly glaciated portion of south central and eastern Wisconsin and covers an area of approximately 9,708 square kilometers. The watershed is subdivided into the Upper and Lower Rock River watersheds. The northern part of the watershed includes a cluster of lakes and marshes along the Rock River. These marshes include Theresa and Horicon, located upstream of Sinissippi Lake. The south part includes the Beloit marsh. The southwestern border includes most of Madison city and a cluster of lakes along the Yahara River, including the Mendota and Monoma lakes. The east contains another cluster of lakes, including the larger Oconomowoc Lake. The most dominant geologic features are the extensive drumlin fields in Dodge County and portions of Dane, Columbia, and Jefferson counties. It has roughly 6,265 river kilometers, of which about 3,089 kilometers are classified as perennial. There are approximately 443 lakes and impoundments in the watershed, covering approximately 23,400 hectares. The dominant land use in the basin is agriculture, with crops ranging from continuous corn and corn–soybean rotations in the south to a mix of dairy, feeder operations, and cash crops in the north (Kirsch et al., 2002). Soils in the watershed varied from very deep, excessively drained soils formed in sandy drift on outwash plain (Plainfield series) to very deep, very poorly drained soils formed in herbaceous organic materials more than 130 cm thick in depressions on lake plains (Houghton). Major soil series include Kidder (Fine-loamy, mixed, active, mesic Typic Hapludalfs), Hochheim (Fine-loamy, mixed, active, mesic Typic Argiudolls), Fox (Fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Hapludalfs), Plano (Fine-silty, mixed, superactive, mesic Typic Argiudolls), and Pella (Fine-silty, mixed, superactive, mesic Typic Endoaquolls). The first three soil series (Kidder, Hochheim and

Fox) are characterized as well-drained soils with moderately high to high permeability, Plano is somewhat poorly drained and Pella is poorly drained with low permeability. The study area is depicted in figure 1.

FIGURE 1

2.2. Data acquisition

There are seventeen USGS monitoring sites within the watershed that measured stream flow and water quality on a daily basis. The drainage area around these USGS sites includes nested subwatersheds, i.e., some basins are situated within larger basins. To comply with the assumption of independence of watersheds (observations) for regression analysis, nested subwatersheds were not included in this analysis. Only 8 non-nested subwatersheds were identified. Six subwatersheds have TP data (loading and concentration) while eight have TSS data (loading and concentration). Figure 1 shows the location of these sites and Table 1 shows available monitored data by time period. The drainage area around these USGS sites was delineated using ArcGIS 10 (ESRI, 2011).

The land use distribution for each subwatershed was determined by overlaying the land use map in which the 2001 National Land Cover Database (NLCD) was expanded by using the USDA National Agriculture Statistical Survey (NASS) Cropland Data Layer (CDL) (Mehaffey et al., 2011). CDL data collected for years of 2004 to 2007 were used to expand the "single cultivated crops" land-use within the NLCD into multiple cropping types and crop rotation information. The majority of subwatersheds (six) have agricultural (corn-soybean rotation, corn and other crops) as the dominant land use. Two subwatersheds have urban as the dominant land use.

A soil type layer was added using the State Soil Geographic (STATSGO) map from United States Department of Agriculture-National Resources Conservation Cervices (USDA-NRCS, 2009). Land (Terrain) slope was calculated using ArcMap (ArcGIS10). The distribution (percent of total watershed area) of land use, soil type, slope and point sources determined for each subwatershed are summarized in tables 2-6. These distributions formed predictors for each watershed. A list of all predictors is shown in table 7. Soil properties; texture, saturated hydraulic conductivity (Ksat), and erodibility from USDA-NRCS universal soil loss equation (USLE_K) are included in Table 4. The number of point sources of pollution (Concentrated Animal Feeding Operations (CAFOs), Municipal Waste Water Treatment Plants (WWTP), Industrial WWTPs) for each subwatershed were obtained from the total maximum daily loading (TMDL) for total phosphorus and total suspended solids in the Rock River Basin report (The CADMUS group Inc., 2011). Major CAFOs, with at least a thousand animal units, were considered because Wisconsin surveys and requests permit application to only those major CAFOs.

For monitored data, since USGS sites do not have measured data in exactly the same time periods, TSS and TP load and concentration of each month were calculated by averaging multiple years' monthly TSS and TP. Daily weather data (1980-2008) from three weather stations inside the watershed were obtained from National Oceanic and Atmospheric Administration-National Climatic Data Center (NOAA-NCDC).

TABLE 1

TABLE 2

TABLE 3

TABLE 4

TABLE 5

TABLE 6

TABLE 7

2.3. TSS and TP time series

Monthly TP and TSS loading and concentration time series were generated from monitored data and used to visually compare response from different subwatersheds. Monthly average precipitation time series were overlaid to the TP and TSS time series to visualize the influence (lagging, leading and synchronization of peaks) of precipitation on water quality in each subwatershed. A comparison between precipitation relationship to TSS and TP expressed either in loading (tons/ha or kg/ha) or concentration (mg/l) was also conducted.

2.4. Statistical analyses

Two types of statistical analyses were performed. The first, analysis of variance (ANOVA), was performed to compare TP and TSS between different subwatersheds. The second analysis was partial least square (PLS) to determine landscape metrics (predictors) associated with variation in TP and TSS from different subwatersheds.

2.4.1 Analysis Of Variance (ANOVA)

Before analyzing the relationship between predictors and response (TP, TSS), ANOVA was performed to determine the differences in monthly TSS and TP between subwatersheds and time periods. ANOVA was also used to find whether monthly precipitation from three NOAA weather sites in the watersheds are different. A General Linear Model (GLM) with the least-square means option was used for multiple comparisons of means (Proc GLM; SAS® 1998). The response variable (TSS or TP) was transformed (natural log) to meet the GLM assumptions of linearity in relationships, normality (Shapiro-Wilks test; $P > 0.05$) and homoscedasticity of residuals.

2.4.2 Partial Least Square (PLS)

The PLS statistical method was used to find the relationship and association between measured water constituents (TSS and TP) and landscape characteristics; land use, soil, topography, and point source pollutants. To further identify the impact of different land uses, including different crops, on water quality, PLS analysis was also performed on measured water constituents (TSS and TP) and land use. Measured water constituent (response: Y) and landscape metrics (predictors: X) form two matrices, in which responses were treated as dependent variables and predictors as independent variables. Small sample size, large number of predictors and presence of collinearity between predictors will not allow using standard multivariate regression (Yeniay and Goktas, 2002). Cases that have this issue are handled well by the partial least square analyses (PLS). PLS regression builds components from X that are relevant for the response variables (Abdi, 2010; Nash and Chaloud, 2002). It extracts orthogonal factors called latent variables by simultaneous decomposition of X and Y with the constraint that these latent variables explain as much as possible of the covariance between X and Y. It is followed by a regression step where the decomposition of X is used to predict Y (Helland, 1988; Höskuldsson, 1988). Predictor coefficients (magnitude and direction) from the PLS regression can be examined to define their role and influence on responses. The positive and negative sign of the coefficient indicate the direction of influence predictors have on TSS and TP (i.e, increase or decrease). The magnitude of the coefficient indicates the weight and degree to which the predictor influenced the response.

3. RESULTS AND DISCUSSION

3.1 TSS, TP, and Precipitation

While the pattern of increases and decreases in monthly TSS (tons/ha) and TP (kg/ha) loadings were similar between USGS monitoring sites the overall amounts and response to precipitation events varied (figure 2 and 3). Measured TSS and TP loadings also shows that there are time periods when TSS and TP peaks coincide (or are aligned) with precipitation (PCP) peaks (for instance, between February and November 1993), and there are times when there is a lag between TSS, TP, and PCP peaks (Between November 1996 and August 1997). There are also time periods when PCP peaks did not generate TSS and TP peaks (August 1994 to February 1996). The differences in response to PCP events between time periods suggests that while PCP has a large influence on TSS and TP, there are other factors such as land cover, soils, terrain slope and anthropogenic activities that are influencing TSS and TP.

Two subwatersheds, 5427948 and 5427718, had the greatest overall responses to precipitation resulting in higher peaks in TSS and TP than other subwatersheds. These subwatersheds have percentages of agriculture land cover planted with corn and corn-other as greater than 25% of the watershed area, as well as urban areas as greater than 10% (Table 2). In addition, soil erodibility in these two subwatersheds is higher compared to other subwatersheds. Furthermore, in the case of subwatershed 5527948 its overall terrain has higher steeper slopes greater than 3% (Table 5). The effect of slope on TSS and TP was more pronounced than that of permeability; subwatershed 5527948 has higher steeper slopes (greater than 3%) than subwatershed 5527718 (Table 5), it has higher TSS and TP loadings than 5527718 (Figure 2 and 3) although the dominant soils in the subwatershed 5527948 are well drained comparing with subwatershed 5527718 which has predominantly soils somewhat poorly drained with lower saturated hydraulic conductivity (Table 4).

Subwatersheds 5425912 and 5431014, which have lower TSS and TP loadings, have lower percentages of urban, less erodible soils and gentler slopes. Subwatershed 5425912 has higher surface area of ponded water (Table 2). In spite of soils with low saturated hydraulic conductivity in Subwatershed 5431014, the terrain has gentler slopes (Table 5) which could reduce runoff, thus less TSS and TP loadings. In addition, this watershed did not have any major point sources which contribute to TP loading (Table 6).

Subwatersheds 5427965 and 5427970, which have higher steeper slopes greater than 3% as the subwatershed 5527948 (Table 5) and they also have soils with high erodibility, they did not have as high TSS and TP loadings as subwatersheds 5427948. The reason is that the subwatersheds 5427965 and 5427970 have low percentages of agriculture land cover planted with corn and corn-other (Table 2).

The land cover, soil nature, and slope determine the precipitation runoff relationship which determines runoff amount and the velocity of flow after precipitation. Vegetative cover, soil organic matter, and soil pores promote infiltration and evapotranspiration and, thus, reduce runoff and sediment transport. The reduced sediment transport results in lower attached P loss.

The correlation between TSS and TP has R^2 between 0.75 and 0.96 for a linear fit for the study area.

Terrains with steeper slopes experience increased runoff velocity and susceptibility to sediment particles detachment. However, other unmeasured factors can impact TSS and TP loadings, for instance anthropogenic soil disturbance can promote or hinder sediment and phosphorous loss. Removal of the vegetative cover and loosening the soil (e.g. tillage) can cause an increase in sediment detachment while best management practices (BMP) such as contour farming, interception structures and drainage ditches on hill slopes can reduce sediment and phosphorus loss.

FIGURE 2

FIGURE 3

3.2 Comparison of loading and concentration and their relationship with precipitation

TSS and TP measurement from the USGS can be expressed either in loading (kg/ha/month) or in concentration (mg/L). Since precipitation is the medium of pollutant transport, a correlation assessment between precipitation and, loading and concentration was done to check whether they could impact analyses differently. The correlation between TSS concentration and precipitation was higher than the correlation between TSS loading and precipitation. A total of 25% in TSS concentration variability was explained by precipitation while 18 % in TSS loading variability was explained by precipitation. A similar phenomenon was observed for TP, in that TP concentrations had better correlation with precipitation peaks than TP loads. Concentration is more affected by the degree of mixing while loading is more affected by travel time of water and inherently takes flow rate into account. For Rock River, loading could be more affected by systems along streams such as reservoirs, lakes and dams, than concentration. Thus, due to these differences, loading and concentration units were both used in statistical analyses.

3.3 ANOVA results

Prior to analyzing relationships between land characteristics and TSS /TP, ANOVA analysis was conducted to check whether TSS and TP from various subwatersheds are statistically different. TSS/TP differences among subwatersheds enable determination of sources of TSS and TP using landscape characteristics. Monthly TSS and TP measured at different USGS sites and NOAA- monitored precipitations at different parts of the watershed were compared using ANOVA also. The overall ANOVA-P value (<0.0001) from the comparison of TSS among monitoring sites and for different months was less than the reference alpha value ($P=0.05$), which indicates monthly TSS and TP loads from the independent subwatersheds (monitoring sites) and different months are significantly different. Multiple comparisons of means indicated that some subwatersheds have similarities in TSS and TP however; for example, no significant difference in TSS among sites 5427970, 5427965, 5427718 and 5427948 (Figure 4) were found, and there was no significant difference between sites 5431018, 5424000 and 5425912. For TP however, 5431018 was the only subwatershed that was significantly different from the rest.

The comparison among months of the year for all subwatersheds showed similarities between monthly TSS loading from February through August (Figure 5). This period's TSS was significantly different from the September through January period. Elevated TSS from February through August could be attributed to snow melt in February and early March, agricultural activities in April or May (such as tillage or planting), and increase in precipitation (Mbonimpa et al., 2012). Frozen streams due to low temperatures in the period of November through January also hinder TSS transport. For TP, when months that ANOVA found to have similarities in monthly TP loading are grouped, the group of September, October, and December was significantly different from the group of February to July, but has similarities with January, August and November. August's and November's TP loads were not significantly different from other groups. Overall months with high TSS and TP also received high precipitation, except February's and March's TP loads which were higher. This elevated amount of TP may be due to snow melt. Runoff generated by snow melt could promote transport of sediment and phosphorus. In addition, anthropogenic activities such as agricultural fertilization in April or May (Mbonimpa et al., 2012) may results in elevated TP loading. The similarities in trends between TSS and TP on Figure 5, lower amounts in January and higher amounts in June, could be attributed to phosphorus and soil particle interaction. Phosphorus is added to the soil either in mineral form through fertilization (as phosphate ion) or organic form (manure and decaying plant residue), the mineral (soluble) form is unstable and a large portion binds to ionic soil particles. The rest is taken by plant roots or immobilized into organic form by bacteria. Though a small portion of organic phosphorus is mineralized by bacteria, it is usually stable and insoluble, and transported together with sediment by water runoff.

ANOVA analysis of monthly precipitations found no significant differences between the watershed's three weather stations.

FIGURE 4

FIGURE 5

3.4 PLS results

The PLS regression results, depicted in Figures 6, 7 and 8 described how TSS and TP are associated with various landscape predictors. (Figure 8 shows water quality associations with only land use to check the PLS results for one type of landscape characteristic). Regression coefficients indicated that urban land use highly influences TSS and TP loadings. The results indicated that Rock River watershed agricultural lands in general were not associated with increase in TSS and TP, possibly due to mixed results from different crops. Agricultural lands planted with corn rotating with other crops (corn_other) were associated with an increase in TSS concentration, and TP load and concentration. TSS and TP lost from the "corn_other" lands could be attributed to agricultural operations such as planting, tillage, fertilization, harvesting, decaying organics and manure.

Agricultural lands that have corn- soybean rotation and "soybean_other" were associated with reduction in TSS and TP. Soybean and other leguminous crops improve soil conditions and fixes nutrients required by corn (Yuan et al., 2011). It is a conservation method that reduces TSS and TP loadings to streams because of reduction in fertilizer and tillage needs. These results also show that converting corn-soybean rotation to continuous corn and other non-leguminous plants to generate ethanol biofuel could cause an adverse impact on water quality as shown in other studies (Mbonimpa et al., 2012; Yuan et al., 2009). Other previous studies also indicated that urban areas and land planted with corn are sources of TSS and TP in runoff (Landis et al., 2008; Lenat and Crawford, 1994). High TSS and TP loadings from urban areas could be attributed to the presence of a high percentage of impervious areas, flushing runoff, household organic wastes, household chemicals, construction activities, and fertilization of lawns.

TSS and TP loadings from urban and corn land use underscore the need for best management practices; urban runoff management should be practiced to reduce TSS and TP before it is discharged into water bodies. Urban runoff recycling, maximizing infiltration by reducing impervious areas, increasing grassland areas, treatment ponds and wetlands are some of best management practices (BMPs) included in Low Impact Development designs to replicate pre-development hydrological regimes. These BMPs were also recommended by Braune and Wood (1999) to reduce urban pollution.

Areas with steep slopes (slp_mt3; slope > 3%) and erodible soils such as WI115 and WI117 (STATSGO) were significantly associated with TSS and TP loadings. These areas, when combined with urban and corn-other lands, could potentially be the largest sources of TSS and TP pollution. These areas should be protected using conservation reserve program (CRP) and BMPs such as vegetative buffers as recommended in various studies (Mbonimpa et al., 2012; Yuan et al., 2009). Good land use management could also be practiced to reduce TSS and TP; for instance, urban and corn land uses should be placed on less steep and less erosive areas, far from streams and upstream of treatment ponds and wetlands.

Forests and water bodies were associated with high reduction in TSS and TP as shown by the PLS results (Figures 6, 7, and 8). Thus, riparian forests should be placed mainly on streams that drain sources of TSS and TP. We can also use these results to recommend intermediate water ponds to treat runoff before discharge into protected water bodies as suggested by previous studies (Chaubey et al., 2010; Liu et al., 2009).

Point source pollutants (Total_ps) in general were associated with reduction in TSS and TP. However, among these point sources industrial point sources (Ind_WWTF) were associated with increases in TSS and TP while municipal wastewater treatment facility outlets (Mun_WWTF) and concentrated animal feeding operations (CAFOs) were associated with reduction in TSS and TP. This could be due to the fact that municipal wastewater effluents have negligible TSS and TP after treatment while industrial wastewater has higher pollutant contents in discharging waters. Many factors can affect the pollutant loading from wastewater discharges; such as storms, time of the year, and type of facility. Secondly, Wisconsin regulations require that regulated CAFOs (1000 animals or more) have no discharge of pollutants to streams, unless caused by a catastrophic storm; a storm with 24-hour duration exceeding the 25-year recurrence frequency (CADMUS group Inc., 2011). Thus, CAFOs did not have positive association with TP although they are known to generate wastes containing TP.

Weak association between corn land use and TSS/TP (Figures 6-8) from PLS results could be caused by factors on which we did not have data; such as application of conservation measures and BMPs, and localized stream erosion or legacy phosphorus that make the receiving streams have higher TP and TSS than runoff from agricultural fields. Mixed positive and negative associations of wetlands with TSS and TP could be attributed to the fact that large parts of wetlands vary from dry grass lands during dry periods to water submerged during wet periods. For instance, cattle and deer have access to dry parts and can contribute TP and TSS to streams; wetlands are also known to reduce upstream nutrients due to uptake by wetland flora. In addition, there could errors involved in data collection and uncertainty in data used for statistical analysis. Furthermore, the PLS model showed that around 10 to 20% of variation in TP and TSS could not be explained by used predictors. This could be due to other factors not included as predictors because of difficulties in some data collection. Those factors could involve parameters related to water bodies, because main drainage streams in this study watershed pass through a chain of lakes, marshes and reservoirs, some with flow control structures such as dams.

The location of these water bodies with respect to other land uses also would affect the response at the outlet. The use of static land use and land cover maps might have also introduced errors because land use varies over time. It was also observed that two sites 5427965 and 5427970 with roughly homogeneous land use; their drainage areas are almost entirely constituted by urban land use (83 and 96%, respectively), reduced accuracy of prediction by the PLS model. Uncertainty in response and predictor data also affects regression results. For instance, response data could introduce errors because some response data from various monitoring sites were not collected during the same time periods.

Differences in PLS analysis results were also noticed between TSS/ TP concentration and loading. Concentration does not take into account streams flow rate even though it could be affected by it. Analysis with of TSS/TP concentration could be affected if subwatersheds receive precipitation with large differences in intensity and distribution. However, ANOVA indicated that precipitation did not differ significantly among the three weather stations in the watershed. PLS analysis with TSS/TP expressed in loading could be affected if subwatersheds have differences in the presence and location of hydraulic structures such as dams, reservoirs and other water flow obstructing systems. These structures hold water inside the watershed and could cause a lag in TSS and TP response at the outlets. Thus, TSS or TP readings for a certain month for some subwatersheds could be comparable to previous months' readings in other subwatersheds. These hydraulic systems could also accelerate deposition of sediment or dissolution or decomposition of phosphorus.

Also, the geographical position of different landscape features in the watershed could affect results. For instance, a wetland upstream of agriculture would not show improvement of water compared to wetlands located downstream of agricultural areas. Thus, if the position of landscape features is not included in regression as variables it could affect regression results. In addition, Rock River watersheds comprise many internal drained areas that sometimes do not contribute water to the watershed outlet (Kirsch et al., 2002). The position, number and the size of these areas and the hydraulic systems mentioned earlier should be included in regression as variables, but the information was difficult to collect to be included into the analyses.

FIGURE 6

FIGURE 7

FIGURE 8

4. CONCLUSIONS

The conclusions from this study are that urban land use and corn rotating with other crops, except legumes such as soybeans, were associated with TSS and TP loadings increases in the Rock River watershed. These loadings are also influenced by steep terrain (slopes higher than three percent) and soils with higher erodibility (WI115 and WI117). In watersheds dominated by urban land use the TSS and TP loadings could be attributed to urban impervious areas and household chemicals while in agricultural land use they could be attributed to tillage and fertilizers. Thus, potential future increases in biofuel generation from crops that do not improve soil conditions, and urbanization, may lead to increases in TSS and TP pollutants if best management practices (BMPs) to offset expected loads are not applied. In watersheds with high percentages of agriculture, TSS and TP loadings could be reduced if corn is rotated with soybeans. Additional BMPs, such as retention ponds and forest buffers also have the potential to significantly reduce TSS and TP. This study also found PLS to be a useful tool in determining the source of TSS and TP pollutants in watersheds, especially in absence of large monitored data. Future work may include refining the model by inclusion of more variables with significant influence on TSS and TP in streams, such as properties of reservoirs and hydraulic structures along streams. This process may increase the total variance explained by the final PLS model. In addition, future study may include proximity relationships of different land cover types to enhance the role of contributing predictors that improve understanding of TP and TSS pollution source and mitigation solutions.

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TABLES

Table1: USGS monitored data period

USGS site	Flow		Sediment		TP	
	start	End	start	End	start	End
5424000	Dec-97	Dec-00	Dec-97	Dec-00	Dec-97	Dec-00
	Oct-09	Oct-11	Oct-09	Sep-10	Oct-09	Sep-10
5425912	Mar-85	Oct-11	Sep-98	Sep-00	Sep-98	Sep-00
5427718	Feb-76	Oct-11	Mar-90	Sep-10	Mar-90	Sep-10
5427948	Jul-74	Oct-11	Jan-92	Sep-10	Jan-92	Sep-10
5427965	Feb-76	Oct-11	Oct-91	Sep-10	N/A	
5427970	Oct-73	Dec-83	Oct-73	Dec-83		
5431018	Oct-83	Sep-91	Oct-83	Sep-85	Oct-83	Sep-85
5431014	Oct-83	Sep-91	Oct-83	Sep-85	Oct-83	Sep-85
			Feb-93	Sep-95	Feb-93	Sep-95

Table 2: Land use distribution in selected drainage areas (in percent of drainage area)

Site	Drainage Area(ha)	Land use (% of total area)								
		Corn-soybean	Corn	Corn-other	Soybean-other	Other Crops	Wetlands	Urban	Water	Forest -other
5424000	46360.79	18.69	7.97	14.54	6.69	21.75	7.12	7.83	0.23	15.17
5425912	40662.81	18.32	13.06	9.85	4.44	28.89	6.95	5.51	5.53	7.44
5427718	9582.95	31.68	20.54	12.11	3.59	12.93	4.27	11.46	0.77	2.65
5427948	4423.7	11.04	11.76	14.38	4.61	20.44	7.25	26.10	0.19	4.24
5427965	852.11	0.01	0.23	0.04	0.10	3.41	4.87	83.04	0.20	8.10
5427970	815.85	0.00	0.03	0.00	0.00	0.47	0.74	96.31	0.44	2.01
5431018	1983.93	35.15	10.12	8.85	6.17	23.12	5.34	4.20	0.92	6.13
5431014	2320.63	51.64	14.66	7.27	2.04	6.67	10.14	2.97	0.56	4.05

Table 3: Soil types distribution (in percent of drainage area)

Site	Soil Type (% of total area)											
	WI069	WI091	WI115	WI116	WI117	WI118	WI120	WI122	WI124	WI125	WI126	WIW
5424000	0.00	0.00	6.44	82.26	0.00	0.00	7.83	0.00	0.31	3.16	0.00	0.00
5425912	0.22	0.08	0.00	0.00	21.99	4.84	8.05	0.00	0.00	12.26	48.05	4.51
5427718	0.00	0.00	8.59	0.00	21.14	70.27	0.00	0.00	0.00	0.00	0.00	0.00
5427948	0.00	0.00	53.04	0.00	44.47	2.49	0.00	0.00	0.00	0.00	0.00	0.00
5427965	0.00	0.00	25.79	0.00	74.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5427970	0.00	0.00	0.65	0.00	99.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5431018	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5431014	0.00	0.00	0.00	0.00	0.87	0.00	0.00	99.13	0.00	0.00	0.00	0.00

Table 4: Soil types and their erodibility, texture and hydraulic conductivity properties

Soil name	STATSGO code	Erodibility coefficient (USLE_K)	Texture (Layers)	Ksat (mm/hr)_top Layer
Plainfield	WI069	0.15	S-S-S	900
Lapeer	WI091	0.24	FSL-SL-SL	120
Fox	WI115	0.37	SIL-SICL-SCL-S	12
Hochheim	WI116	0.28	L-L-GR-SL	21
Kidder	WI117	0.37	SIL-SCL-SL	6
Plano	WI118	0.32	SIL-SICL-L-SIL	2.4
Lomira	WI120	0.37	SIL-SICL-SCL-SL	1.4
Pella	WI122	0.28	SIL-SICL-SICL-SICL	1.4
Varna	WI124	0.32	SIL-SICL-SICL	6.4
Houghton	WI125	0.1	MUCK-MUCK	110
Plano2	WI126	0.32	SIL-SICL-L-SIL	2.4
Water	WIW			

Meaning for texture abbreviations: S= Sand, FSL= Fine Sandy Loam, SCL=Sandy Clay Loam, SIL= Silt Loam, SICL= Silty Clay Loam, L= Loam, SL= Sandy Loam, GR= Gravelly, LS= Loamy Sand, MUCK= Muck.

Table 5: Slope distribution (in percent of drainage area)

Site	Slope (% of total area)	
	<3%	>=3%
5424000	48.73	51.27
5425912	69.83	30.17
5427718	61.52	38.48
5427948	37.70	62.30
5427965	34.40	65.60
5427970	36.29	63.71
5431018	77.11	22.89
5431014	94.30	5.70

Table 6: Number of point sources in selected drainage areas

Site	Major point sources (number)			
	CAFOs	Ind. WWTF	Mun. WWTF	TOTAL
5424000	3	1	5	9
5425912	1	0	2	3
5427718	2	0	1	3
5427948	1	1	0	2
5427965	0	0	0	0
5427970	0	1	0	1
5431018	0	0	0	0
5431014	0	0	0	0

Table 7: Summary of predictors

Predictors	**Abbreviation used in text**
Corn-soybean rotation	Corn_soybean
Monoculture corn	Corn
Corn mixed or rotating with other unspecified crops	Corn_other
Soybean mixed with other crops	Soybean_other
Other unspecified crops	Other_crops
Combined agricultural area	Agricultural
Urban	Urban
Wetlands	Wetlands
Water bodies	Water
Forests, Shrubs, Grass	Forest_other
Terrain with slopes lower than 3%	Slp_lt3
Terrain with slopes higher than 3%	Slp_mt3
Concentrated animal feeding operations	CAFOs
Industrial point source or industrial wastewater treatment facility outlet	Ind_WWTF
Municipal wastewater treatment facility outlet	Mun_WWTF
Total number of point sources	Total_ps
STATSGO soil types	WI069, WI091, WI115, WI116, WI117, WI118, WI120, WI122, WI124, WI125, WI126, WIW-water

FIGURES

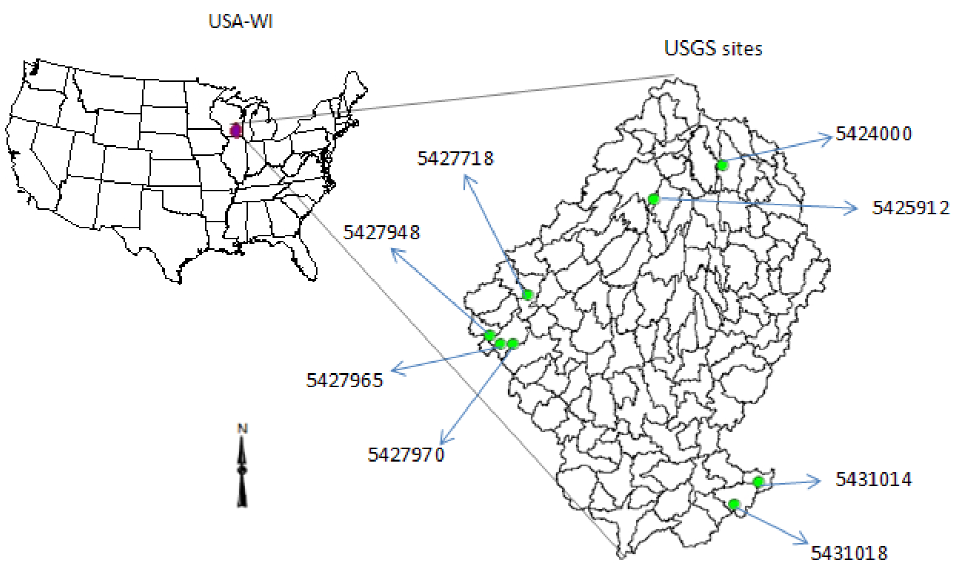

Figure 1**:** Location of USGS monitoring sites in Rock River Watershed

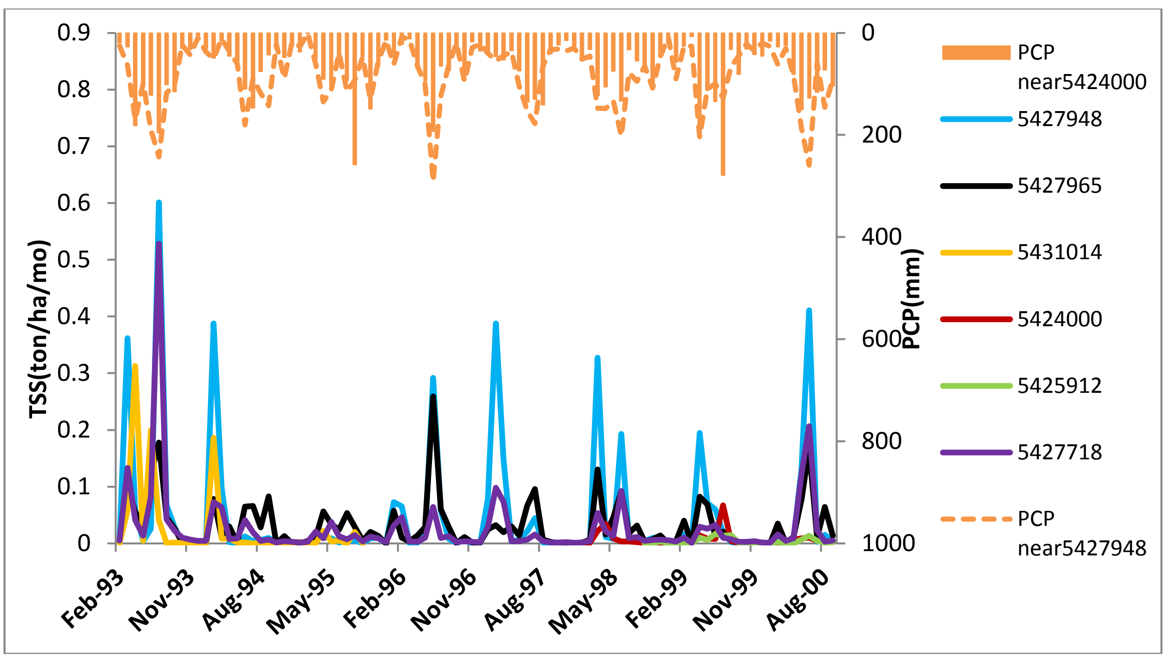

Figure 2: Comparison of monthly TSS load (ton/ha) from different subwatersheds (Only 4 have the data for the same period (overlapping time) 6 have some data for period from 1993-2000).

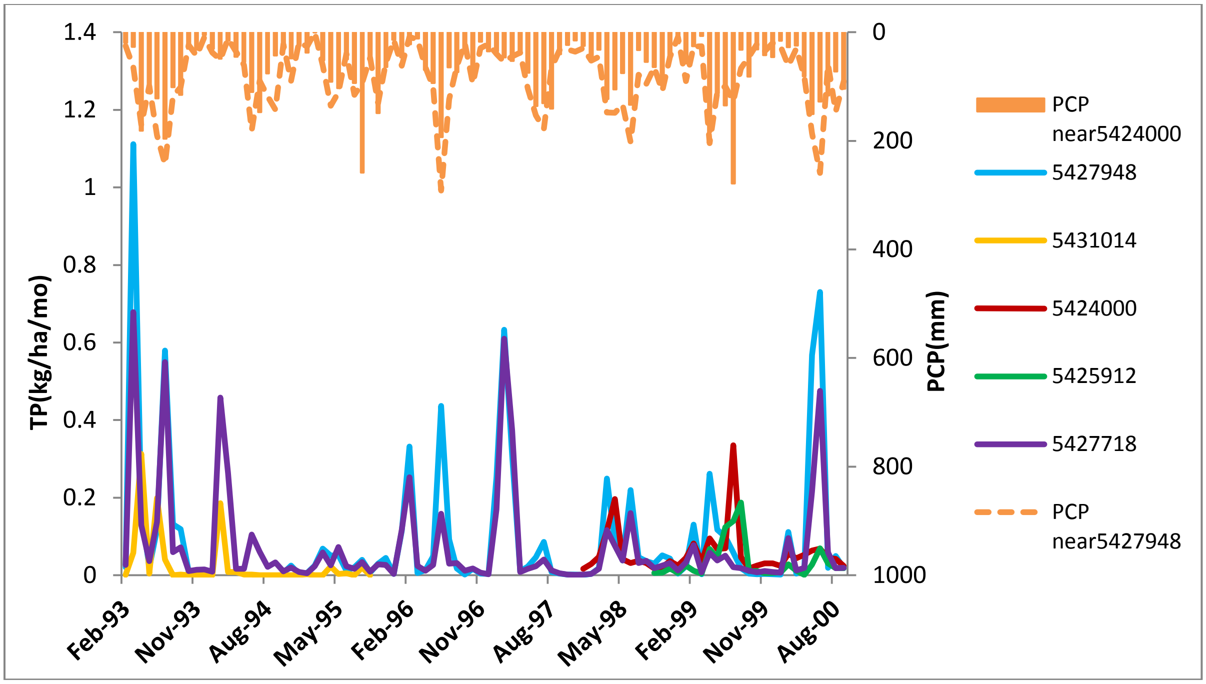

Figure 3: Comparison of monthly TP load (kg/ha) from different subwatersheds (Only five sites have data in the same period and two sites do not have TP data).

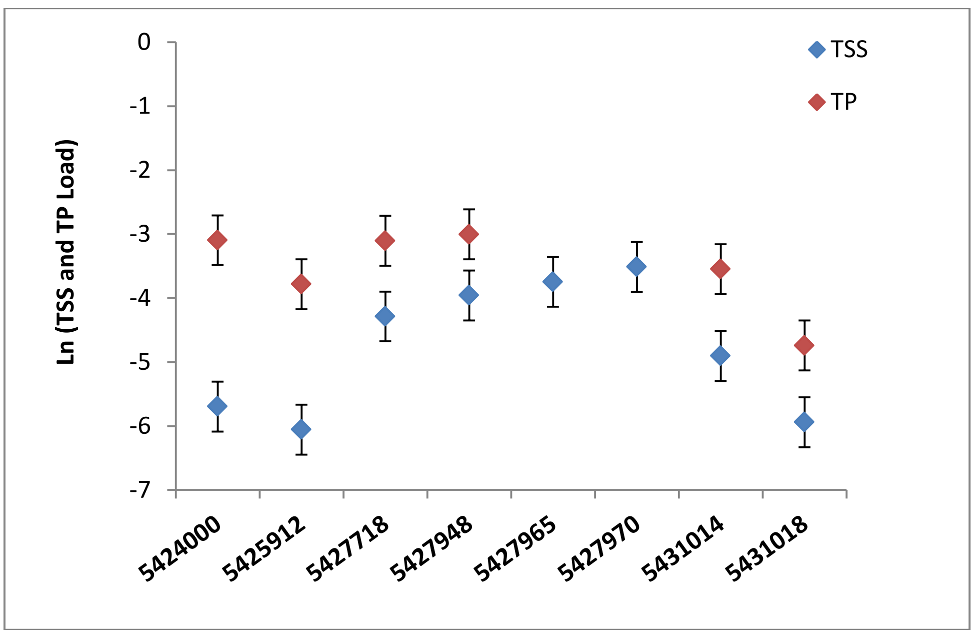

Figure 4: Overall mean and 95 % confidence interval of monthly TSS and TP from different subwatersheds.

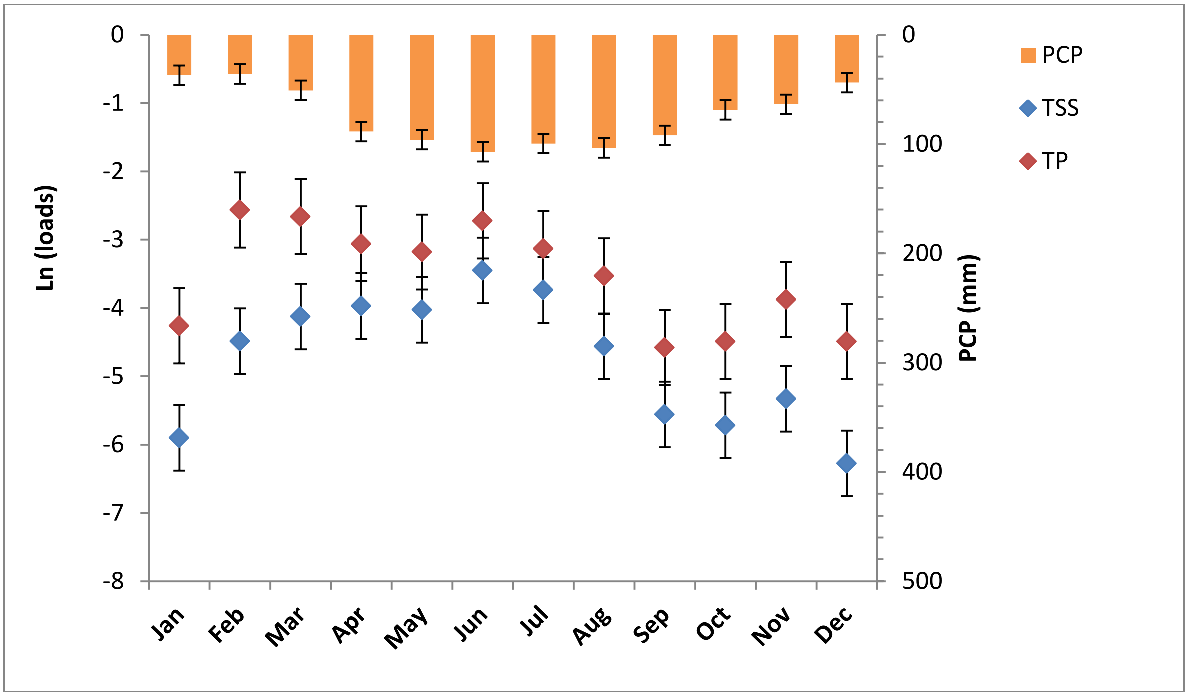

Figure 5: Mean and 95 % confidence interval of monthly TSS, TP, and rainfall (PCP) over all subwatersheds.

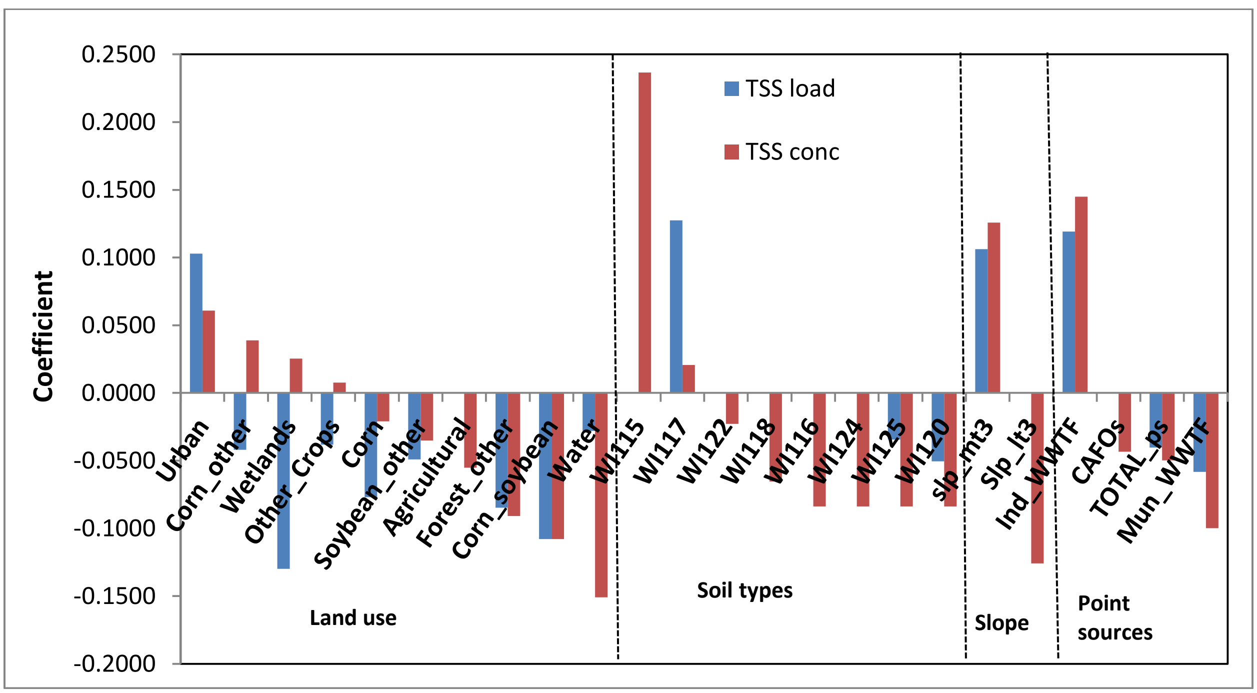

Figure 6: PLS regression coefficients of each predictor on TSS load and TSS concentration (a missing column means the predictor has zero coefficient).

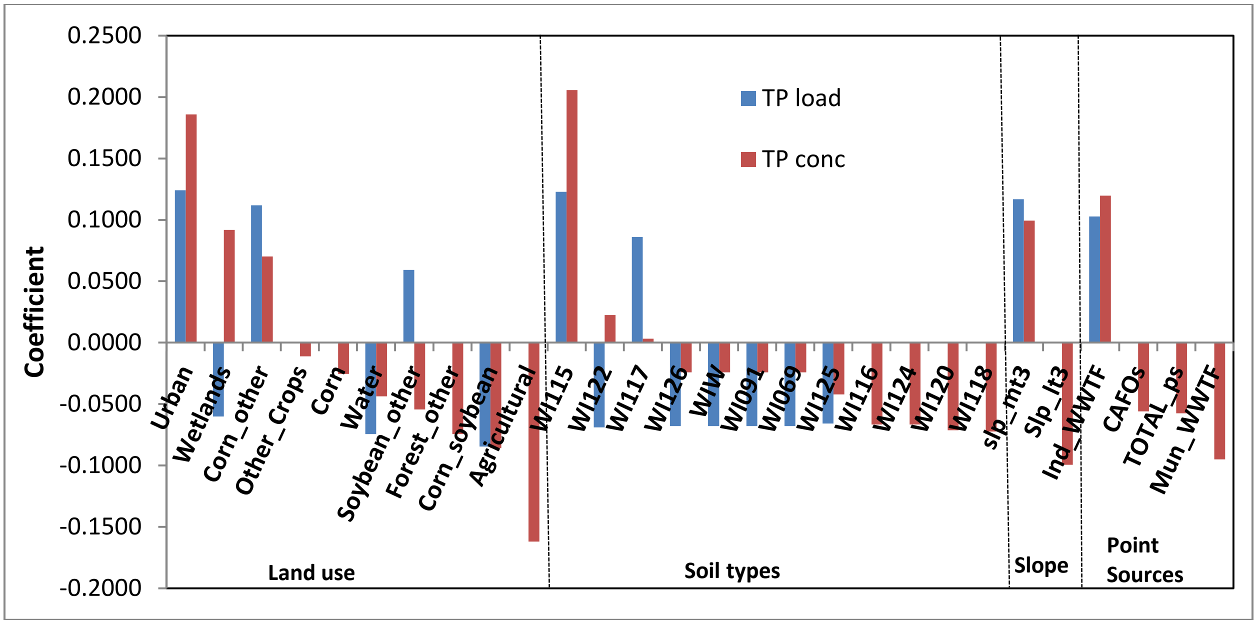

Figure 7: PLS regression coefficients of each predictor on TP load and TP concentration.

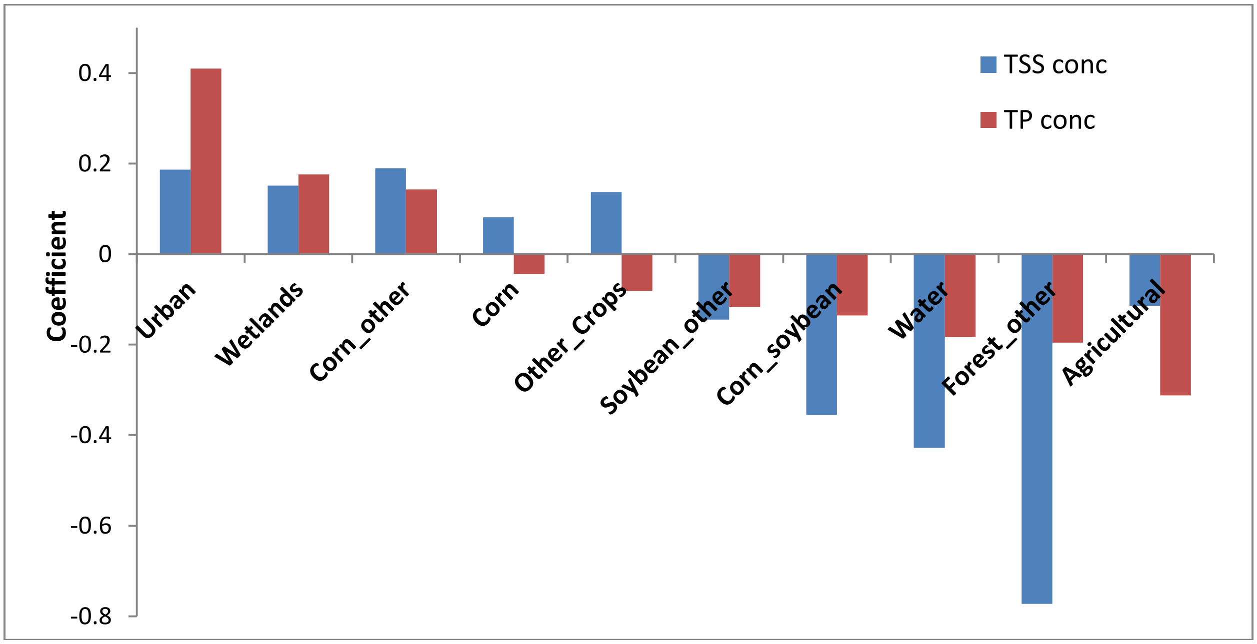

Figure 8: PLS regression coefficients of land cover predictors on TSS and TP concentrations.