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Sediment and total phosphorous contributors in Rock River watershed

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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 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.

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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

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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 9708 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 6265 river kilometers, of which about 3089 km are classified as perennial. There are approximately 443 lakes and impoundments in the watershed, covering approximately 234 square kilometers. 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 Fig. 1.

2.2. Data acquisition

There are seventeen USGS monitoring sites within the watershed that measured streamflow 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). Fig. 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 2004–2007 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).

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