Quantifying Agricultural Contributions to Surface Water Quality Impairment in the Lower Wisconsin River Watershed

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Abstract

Fertilizers, sediments, and animal wastes from agricultural activities causes a host of problems for aquatic ecosystems across space and time. Due to the severe threat posed by agricultural activities to our water bodies and the biodiversity in our aquatic ecosystems, it becomes prudent to monitor the extent of water quality impairment caused by farm and livestock operations especially in watersheds that are characterized by heavy agricultural operation. This study utilized geospatial technologies of remote sensing, geographic information system (GIS), and spatial hydrologic water quality modeling to quantify the extent of agricultural footprint on nitrogen, phosphorus, and suspended sediment loading within the Lower Wisconsin River watershed. Results of the study demonstrated that total phosphorus, total nitrogen, and suspended sediment loads in the watershed reduced between 2000 and 2020 due to land management practices implemented over the study period.

Introduction

The recent National Water Quality Inventory report to congress listed agriculture as the number one source of contamination in rivers and streams, number three in lakes, and number two in estuaries and groundwater (USEPA 2017). Multiple studies have identified agricultural land use as a primary contributor to phosphorus, nitrogen, suspended sediments, and fecal coliform in surface waters (Tong and Chen 2002; Brezonik et al., 2007; Lui et al., 2009; Wilson and Weng 2010; Bu et al., 2011). Agricultural pollutants can lead to deterioration in water quality of which eutrophication is a key problem in lakes, coastal areas, and in some rivers with negative ramifications for aquatic ecosystem health. High nutrient concentrations in water does not only affect water quality but can negatively impact aquatic organisms that are integral to food chains and ecosystem functioning (Johnson et al. 2007). Suspended sediment is a huge problem in aquatic ecosystems in proximate location to croplands. Suspended sediments in rivers and lakes result in water clarity problems, increased turbidity, smoothing of river and lake beds, and other problems in aquatic ecosystems (Wilson and Weng 2011, Wilson 2015, Issaka and Ashraf 2017). Brezonik et al. (2007) reported a dramatic decline in water clarity when more than 80% of land use is allocated to cropland. Aside from the heavy influence of agriculture on the quality of inland water bodies and coastal environments, other factors such as climate, soil type, and topography should not be overlooked in water quality studies (Wilson and Weng, 2011; Wilson et al. 2018). To effectively quantify the role of agriculture on surface water quality, geospatial technologies of remote sensing and geographic information systems (GIS) must be employed (Li et al., 2008; Wilson 2015). Due to the complexity in quantifying agricultural influence on surface water quality and the associated ramifications for aquatic ecosystem health, it becomes expedient to investigate this phenomenon especially in the Lower Wisconsin River watershed with a heavy agricultural footprint.

Objectives

The overarching goal of this study is to assess the role of Land use/land cover (LULC) changes on surface water quality impairment in the Lower Wisconsin River watershed, an area dominated by agricultural activities. Specific objectives include 1) to develop LULC information for the study area at two timesteps – 2000, and 2020, and 2) to estimate total nitrogen, total phosphorus, and suspended sediments in the watershed between 2000 and 2020.

Methods

Study area

The Lower Wisconsin River watershed (LWRW) is situated in the southwestern portion of the State of Wisconsin. The LWRW spans 23,827 km^2 (5,887,7943 acres). The LWRW falls within 20 counties, including Dane County which houses the states capital city (Figure 1). Agriculture is the predominant economic activity in a large fraction of the LWRS; Marathon county alone has dedicated more than 490,628 acres of land to agriculture (Marathon County FPP). The average annual rainfall across the watershed is 34 inches, with snowfall averaging 47 inches in the winter months. The LWRW crosses through five major plant communities in Wisconsin, conifer-hardwood forests, pine savanna, oak savanna, southern-hardwood forests, and prairie. The elevation ranges from 1800 – 1200 ft in the northernmost segments of the watershed and 1200 – 600 ft in the central and southern portions of the watershed. Major socioeconomic activities in the region include agriculture, manufacturing, and tourism.

This study utilized the following dataset: Landsat satellite imagery, digital elevation model (DEM), soil survey geographic database (SSURGO), and climate data. LULC information was extracted from Landsat satellite images for the period 2000 and 2020. Advanced image classification techniques were applied to extract the relevant LULC types for the study area.

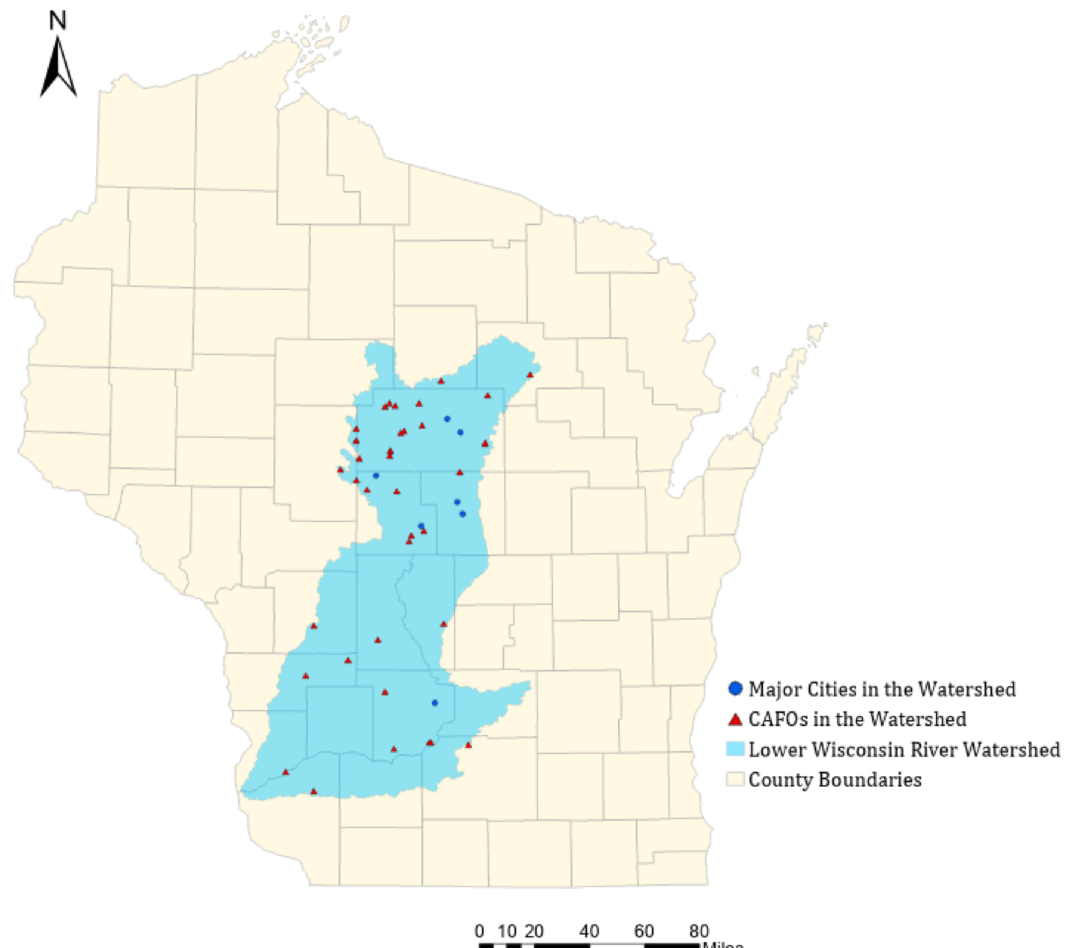

Figure 1: Lower Wisconsin River watershed, Wisconsin. CAFOs are concentrated animal farming operations. All CAFOs listed currently hold Wisconsin Pollutant Discharge Elimination System (WPDES) permits with the WDNR

Classification was completed using eCognition Developer. Objects were created using multiresolution segmentation and classified by using random forest classifier.

This study developed a total of six LULC classes which include water, urban, forest, agriculture, shrub, and wetlands by modifying the USGS Anderson Level 1 LULC classification scheme (Anderson et al., 1976). The classified images were then corrected for errors using ancillary data from the USGS National Land Cover Database. Subsequently, a spatial hydrologic-water quality model (the Soil and Water Assessment Tool- SWAT) was used to estimate pollutants at the sub-watershed scale within the LWRW.

Distributed hydrologic flow model construction

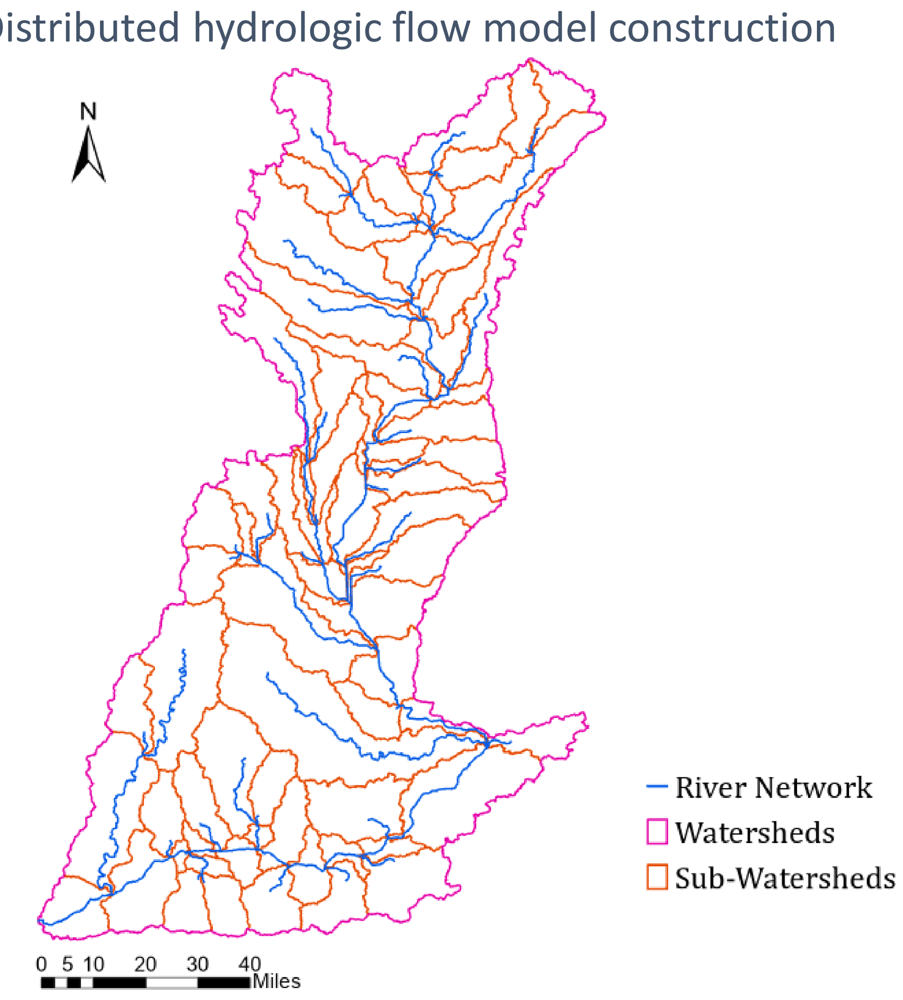

Figure 2: Simplified SWAT model for the Lower Wisconsin River basin

Results and discussion

Evaluation of the LULC changes between 2002 and 2020 revealed only slight increases in agricultural areas (2.4%) 23350 hectares. Urban areas also increased by about 6%, 7570 hectares. Forest cover, in contrast, demonstrated a loss of 0.5% (3769 hectares) as did wetlands, reduced by 1614 hectares (0.5%). Rangeland/shrub areas experienced the greatest decrease, dropping 61% (27405 hectares) from their distribution in 2000. The extent of suspended sediment load, total nitrogen and total phosphorus all showed some degree of reduction between 2000 and 2020. These positive changes could be the result of the conservation efforts of the WDNRs, USDA and the NRCS, including partnerships with farmers, landowners and municipalities across the watershed (WDNR 2020). Common conservation practices include streambank stabilization, no-till farming, cover crops, rotational grazing, nutrient management, and grassed waterways. There have already been measurable reductions in phosphorus up to 30,000 lbs in some areas (WDNR, 2020).

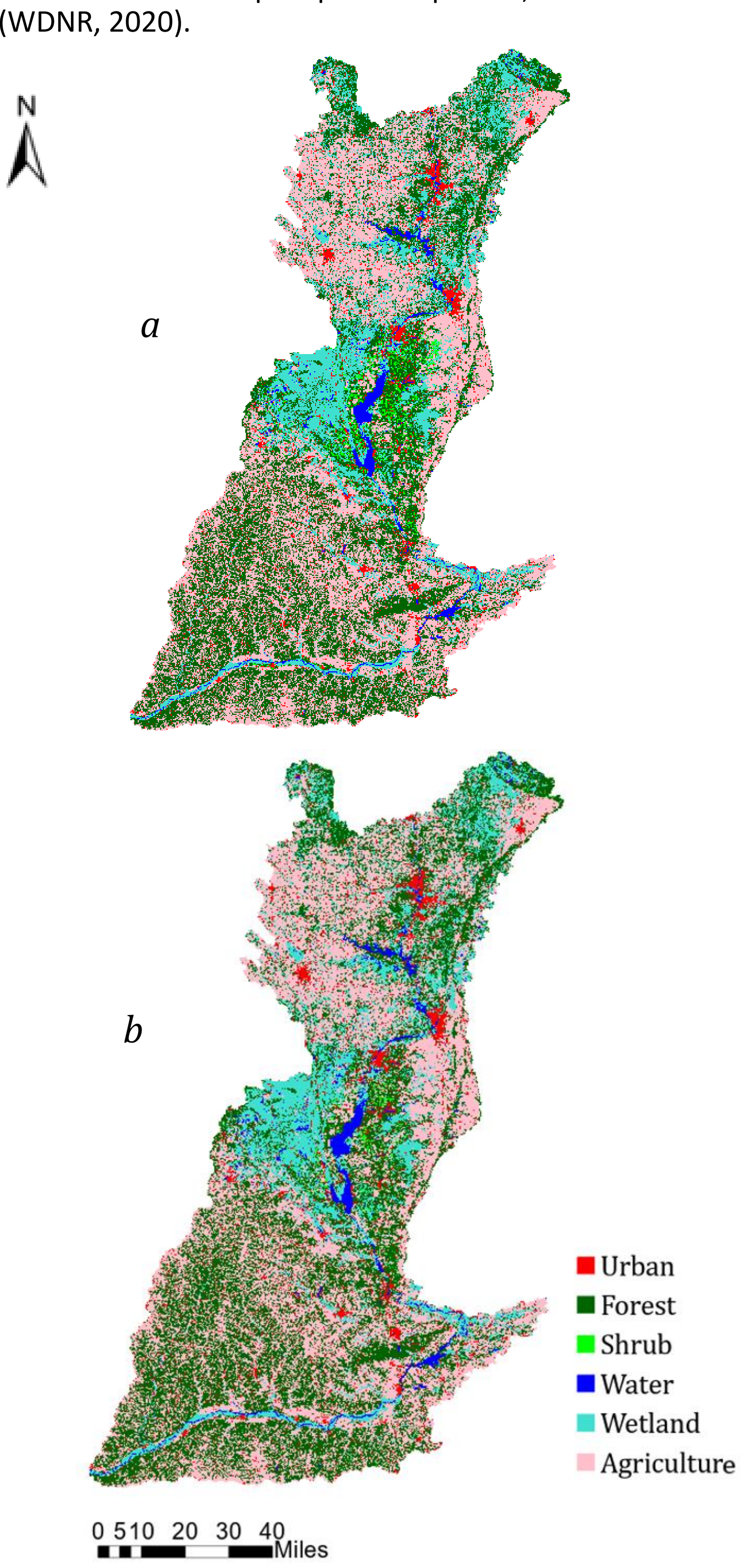

Figure 3: Land use/land cover maps for 2000 (*a*) and 2020 (*b*)

Percent Change in LULC		
Classification	Change in Hectares	Percent Change
Urban	7570	5.8%
Forest	-3769	-0.5%
Shrub	-27405	-62.5%
Water	1869	3.6%
Wetlands	-1614	-0.5%
Agriculture	23350	2.4%

Table 1. Changes in LULC type between 2000 and 2020

Notwithstanding the general improvement of nutrient in the LWRW, the areas with the highest nutrient loads in 2000 remained the same in 2020, indicating that farm management in those sub-watersheds remained relatively unchanged over the 20-year assessment period. Another potential reason for the higher nutrient loads in those sub-watersheds in the Southern segment of the LWRW is their more varied topography compared to the northern segments due to differences in recent glaciation effects. Greater topographic range can result in higher rates of runoff and nutrient wash-off from agricultural and urban areas, as indicated in Figure 4. Between total nitrogen, total phosphorus and sediment output, sediment was the only factor that changed significantly over the study period, with the average sediment output dropping by about 11 tons. The greatest sediment reduction in a subbasin was 267 tons, and the largest increase was 52 tons. This could be due to improved buffering systems put in place near waterways in areas of urban development, farming, mining, and other activities. According to the United States Drought Monitor between the years 2016 and 2020 there have been very few droughts (most classified as 'abnormally dry' or 'moderate drought') when compared to the years 2000 to 2016, which could have encouraged the growth of vegetation, offering the watershed protection from runoff during high rainfall events. Wildfires, mass wasting, precipitation events, stream power and other naturally occurring elements also play a role in sediment output.

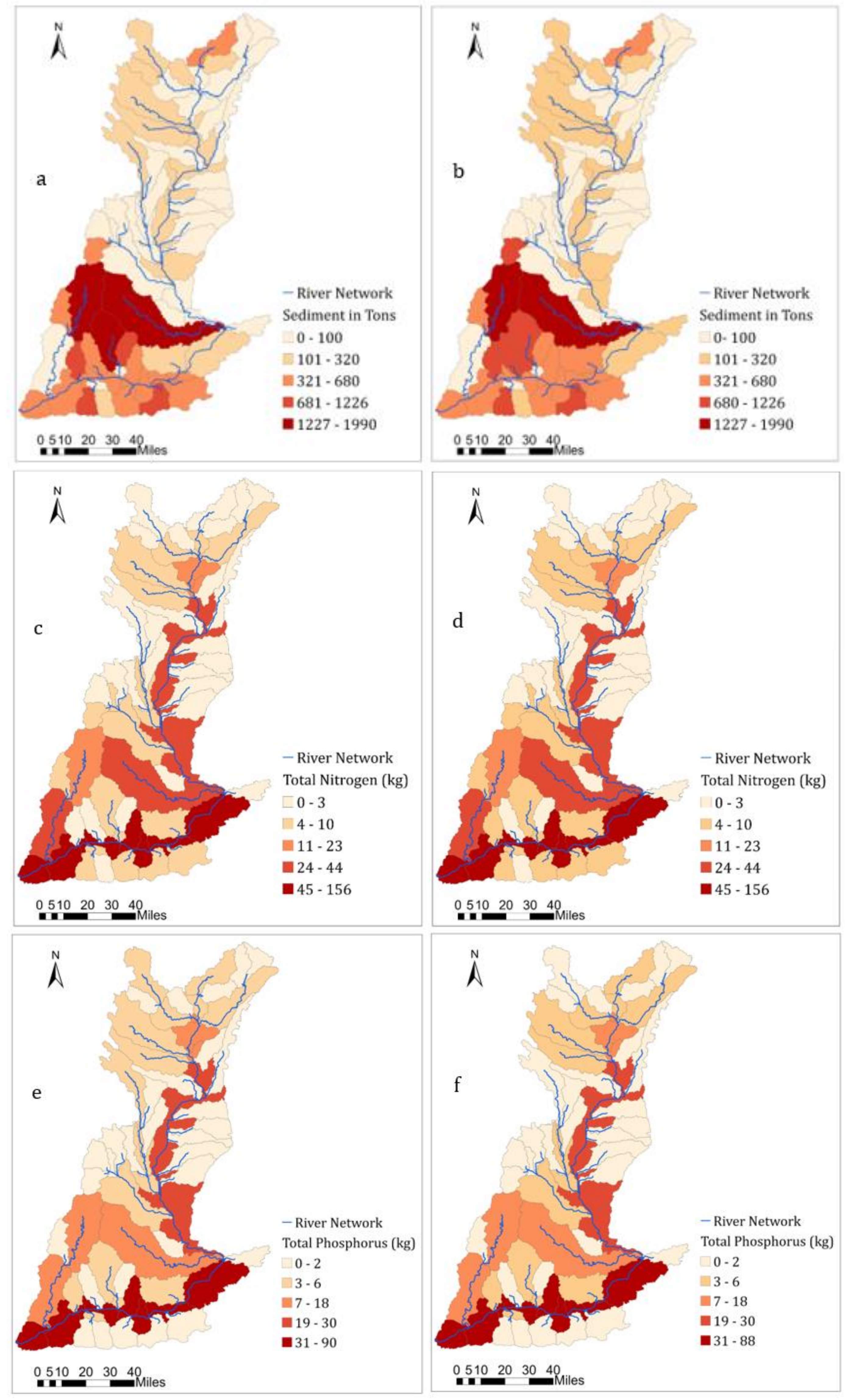

Figure 4: Average annual sediment in tons a) 2000 b)2020. Average annual total nitrogen (kg) c) 2000 d) 2020. Average annual total phosphorus (kg) e) 2000 f) 2020

Conclusions

Between 2000 and 2020, the LWRW underwent relatively low growth in urban areas and agricultural landscape. Forest cover, shrubland, and wetlands experienced overall declines. Despite these changes, the water quality regarding suspended sediments, total nitrogen and phosphorus generally improved. This can be attributed to the land management practices implemented in the watershed over the study period. A major limitation of this study is that the SWAT model was not calibrated and validated. This would have jeopardized the generation of accurate real-world results. Additional research needs to be done on this topic to better understand the role of changes in LULC and climate on the central and lower Wisconsin river watersheds.

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