Assessing sediment yield for selected watersheds in the Laurentian Great Lakes Basin under future agricultural scenarios

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Abstract

In the Laurentian Great Lakes Basin (GLB), corn acreage has been expanding since 2005 in response to high demand for corn as an ethanol feedstock. This study integrated remote sensing-derived products and the Soil and Water Assessment Tool (SWAT) within a GIS modeling environment to assess the impacts of cropland change on the sediment yield within four selected watersheds in the GLB. The SWAT models were calibrated over a six year period (2000–2005), and predicted stream flows were validated. The R^2 values were 0.76, 0.80, 0.72, and 0.81 for the St. Joseph River, St. Mary's, the Peshtigo River, and the Cattaraugus Creek Watersheds, respectively. The corresponding *E* (Nash and Sutcliffe model efficiency coefficient) values ranged from 0.24 to 0.79. The average annual sediment yields (tons/ha/yr) ranged from 0.12 to 4.44 for the baseline (2000−2008) condition. Sediment yields were predicted to increase for possible future cropland change scenarios. The first scenario was to convert all "other" agricultural row crop types (i.e., sorghum) to corn fields and switch the current/baseline crop rotation into continuous corn. The average annual sediment yields increased 7−42% for different watersheds. The second scenario was to further expand the corn planting to hay/pasture fields. The average annual sediment yields increased 33–127% compared to the baseline conditions.

1. INTRODUCTION

The US Midwest has experienced significant changes in agricultural cropping patterns (*i.e.,* area and rotation pattern changes) since 2005. Ongoing agricultural land use change is likely to be partly due to rising corn prices and subsidies implemented by the US government to encourage corn ethanol production. The US Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS) reported that corn acreage in 2007 reached the highest level (37.9 million ha) since 1944. The expanding corn acreage is often related to the decrease of other agriculture crops (*i.e*., soybean and winter wheat) and pasture land (Westcott, 2007; Keeney and Hertel, 2009). Remote sensing-based crop rotation study indicated that traditional crop rotation (*i.e.,* corn-soybean) is being replaced by continuous corn plantings (Stern *et al*., 2008; Lunetta *et al*., 2010; Secchi *et al*., 2011) across the Great Lakes Basin (GLB). Shifts toward more intensive corn production may cause a number of negative environmental consequences with respect to water quality, soil fertility, biodiversity, and overall ecosystem sustainability (Pimentel and Patzek, 2005; Searchinger *et al*., 2008). For instance, Donner and Kucharik (2008) have raised concerns of corn-based ethanol production with respect to the goal of reducing nitrogen export by the Mississippi River.

Many remote sensing cropland mapping efforts have produced crop type distributions using a variety of remote sensor imagery, mapping schemes, and image classification algorithms. For example, NASS generated the cropland data layer (CDL) products using Advanced Wide Field Sensor (AWiFS) imagery (Johnson, 2008). The Moderate Resolution Imaging Spectroradiometer (MODIS) data also show high potential for mapping individual crop types (Chang *et al*., 2007; Wardlow *et al.,* 2007; Shao *et al*., 2010). Most of the above remote sensing efforts focused on characterizing cropland distributions and monitoring change. The impacts of agricultural change on water quality, soil erosion, and biodiversity are still poorly understood.

The integration of land-cover change and watershed modeling provides a useful framework to assess the environmental consequences of agricultural land use change. Tong and Chen (2002) quantified the relative impacts of land-uses on surface water quality. They identified agricultural and impervious urban lands as the major source areas for nitrogen and phosphorus loadings to a watershed within the Little Miami River Basin, Ohio. For the Little Eagle Creek watershed in Indiana, Bhaduri *et al*. (2000) reported that about 80% of the annual runoff increase was due to the expanding impervious surface. Fohrer *et al*. (2001) calibrated and validated SWAT (Soil and Water Assessment Tool) models for four watersheds and found that the impact of land-cover change on the annual water balance was small due to compensating effects in complex catchments. Tang *et al*. (2005) integrated a land-use change model and a web-based environmental impact model to assess the changes in runoff and nutrient loadings due to urbanization. Distributed watershed models are increasingly used to assess the impacts of land use change on hydrologic responses (Miller *et al*., 2002; Naef *et al*., 2002), sediment loadings (Allan *et al*., 1997; Tong and Chen, 2002), nutrient loadings (Allan *et. al*., 1997; Weller *et al*., 2003; Lunetta *et al*., 2005), and in-stream habitat structure (Allan *et al*., 1997).

1.1 Study Objectives

The overall goal of this research was to examine how agricultural land use change affects sediment yields for selected watersheds in the Great Lakes Basin (GLB). The GLB is a region that has undergone significant changes in cropping patterns since 2005 (Lunetta *et al*., 2010). The currently expanding corn acreage in the GLB might increase sediment and nutrient loadings to the GLB streams, affecting the sensitive GLB ecosystem (GLC, 2007). We are interested in how the spatial distributions of corn planting affect sediment yields. Such information will enable conservation organizations and government agencies to better understand the consequences of environmental and energy policies in agricultural and forested landscapes. The specific research procedures of this paper included the following: (a) implement SWAT models for the selected watersheds to estimate baseline sediment yields using current land-use; and (b) predict sediment yields for simulated future agricultural land use conditions.

1.2 Study Area

The GLB covers an area of 764,568 km^2 and includes both the United States and Canada. The US portion of the GLB includes all or part of eight states and the Canadian portion includes part of the Province of Ontario. The GLB is one of the most industrialized regions in the world. For the last 30-years, rapid land use change, especially urban growth and residential sprawl, has raised many issues and concerns with respect to the sustainability of the GLB's ecosystems (USEPA, 2008). The US EPA reported a decrease of 9.5% in agricultural land within the U.S. portion of GLB from 1981–1992 (USEPA, 1997). A majority of these agricultural lands was converted to urban use. During 1992–2001, there was an additional 2.3% decrease for both agricultural and forested lands, also substantially attributed to urban development (Wolter *et al*., 2006). In the Canadian portion of the GLB, Statistics Canada (1998) estimated that 18% of agricultural land was converted to urban from 1976–1996. Impacts of land-cover conversions on the Basin's water quality, biodiversity, and ecosystem sustainability have been a focus of attention (Crosbie and Chow-Fraser, 1999; Detenbeck *et al*., 1999; EC and USEPA, 2003). Under current national and state energy policy, farmers in the region are altering agricultural land-use strategies. For example, the corn acreage in the GLB increased approximately 21% from 2006–2007, mainly at the cost of soybean and winter wheat acreage (Lunetta *et al*., 2010). Corn-related crop rotation change (*i.e*., continuous corn plantings) was also evident (Lunetta *et al*., 2010). Recent changes to agricultural practices in the GLB are complicating the study of nonpoint source pollution (NPS).

1.3 Watershed Assessment and the SWAT Model

A variety of hydrologic and water quality models have been used to assess the impacts of land use changes (Bhaduri *et al*., 2000; Fohrer *et al*., 2001; Weller *et al.,* 2003; Tang *et al*., 2005).   For example, Weller *et al.* (2003) developed an empirical linear model to predict water quality using the proportion of cropland and developed land as independent variables. Bhaduri *et al.* (2000) integrated GIS with an NPS pollution model to assess the long-term runoff and NPS pollution. Tang *et al.* (2005) implemented the Long-Term Hydrologic Impact Assessment (LTHIA) model (Harbor, 1994), to estimate the impacts of land use changes on surface runoff and NPS pollution. Empirical water quality models have advantages in data preparation as the input data are readily available and the model can be routinely used for operational applications.

Recently, distributed watershed models have been increasingly used to assess hydrologic responses to different land-cover changes. Additionally, process-based watershed models can be very useful for improving the understanding of interactions between land-use change, water balance, and water quality issues. The SWAT model is a physically-based, continuous time-step model (Arnold *et al*., 1998; Neitsch *et al*., 2002).   The model was developed by USDA-Agricultural Research Service (ARS) to assess the impact of agricultural management practices on water balance, sediment, and nutrient loadings for non-gauged watersheds. The SWAT model has been widely used in both US and international sites. Borah and Bera (2004) provided an overview of SWAT applications for 17 case studies. Most SWAT models were calibrated and validated at monthly intervals. Good results were achieved for both small (Warner Creek, 3.46 km^2) and large watersheds (Upper Mississippi River Basin, 491,700 km^2). The daily estimations from SWAT are generally considered less accurate compared to monthly estimations (Borah and Bera, 2004). A thoroughly review of SWAT model is also provided by Gassman (2007).

One of the main drawbacks for the application of SWAT is its significant data requirements. Primary SWAT input data include a land-cover, digital elevation model (DEM), soil map, daily precipitation and temperature, and detailed agricultural management information (land-use). The SWAT model's calibration and validation procedures require additional datasets such as stream flow, sediment, and nutrient loadings. Due to limited data availability, thorough model calibration and validation were not possible for many applications (Stonefelt *et al*., 2000). However, recent advances in remote sensing and GIS have resulted in improved data availability, and continuous software development (*i.e*., ArcSWAT) has made the SWAT toolbox more user-friendly. As a result, it is expected that SWAT will be widely used for future watershed assessments, particularly those linking land-cover and water quality.

2. METHODS

2.1 Watershed Selection

The US portion of the GLB consists of 157 USGS 8-digit hydrologic units or watersheds. Only 15 of the 157 watersheds have relatively large portions of agricultural land (*i.e.,* >15%). Within these 15 watersheds, we selected four for SWAT model assessment: the St. Joseph River watershed in the Lower Peninsula of MI and northwestern portion of IN, St. Mary's watershed near the OH-IN border, the Peshtigo River watershed in Northern WI, and the Cattaraugus Creek

Watershed in Western NY (Table 1). These four watersheds are located in four different ecoregions (Eastern Corn Belt Plains, Southern Michigan/Northern Indiana Drift Plains, Northern Lakes and Forests, and Northern Allegheny Plateau, respectively). Each ecoregion has different climate, soil, and land use conditions (Figure 1). The area of the watersheds ranged from 1,430 to 12,132 km^2. The percentage of agricultural land ranged from 14–84%. The large variation of agricultural proportions allows us to evaluate the impacts of agricultural land use change on sediment yields. It should be noted that the St. Joseph River watershed is substantially larger than the other three. To better compare across watersheds, we selected a subset of the St. Joseph River watershed (Dry Run Creek) for the SWAT implementation.

2.2 SWAT Input Data

The 30 m DEM was obtained from the US Geological Survey (USGS) Seamless Data Distribution System. The Soil Survey Geographic (SSURGO) data were obtained from the US Natural Resources Conservation Service (NRCS). The climate data, including daily precipitation and daily temperature, were obtained from the USDA-ARS (Agricultural Research Service). The USDA-ARS climate data were developed using data from the National Oceanic and Atmospheric Administration (NOAA). The USDA-ARS climate data were already processed using the standard SWAT model input formats, so they can be readily incorporated for SWAT application.

SWAT model is designed to parameterize and analyze a wide range of land use and crop management information (*i.e.*, crop rotation, planting data, tillage, and fertilizer application). However, it is often difficult to obtain detailed agricultural land use and crop management information, especially when multiple watersheds or large study areas are involved (Borah and Bera, 2004). We used the 2001 National Land Cover Dataset (NLCD) as the primary land use and land cover data. Within the 2001 NLCD row crop areas, the USDA-NASS Cropland Data Layer (CDL) was used for the supplement crop rotation construction. For the St. Joseph River watershed and a large portion of the St. Mary's watershed, annual CDL data are available since 2000. Three dominant crop rotation patterns (*i.e*., corn-soybean, soybean-corn, continuous corn) were identified (Table 2). For the Peshtigo watershed, there is yearly CDL data since 2003. Continuous corn and corn-alfalfa rotations were the most common crop rotation practices. For the Cattaraugus Creek, there was no corresponding CDL coverage. A combination of continuous corn and corn-alfalfa rotation was assumed for the study watershed. These baseline crop rotation patterns were implemented through permutations within SWAT model (Gassman *et al*., 2003).

Tillage practice data were obtained from the Conservation Technology Information Center (CTIC). Percentages of tillage practices for corn, soybean, and other major crop types are available through CTIC website (http://www.ctic.purdue.edu/CTIC/CRM.html). For this study, the 2004 tillage practice information (*i.e*., no-till, conventional tillage) for corn and soybean were derived for all counties that intersect the watersheds. Within each county, the dominant tillage practice for corn and soybeans were identified and incorporated into the SWAT model. Table 2 shows the primary crop rotations and tillage practices used for different watersheds.

2.3 SWAT Calibration and Validation

We used ArcSWAT to model water and sediment yields (Winchell *et al*., 2007). The USGS National Hydrology Dataset (1:100,000 scale) was directly overlaid on the DEM in the watershed delineation procedure to ensure that the stream locations were correctly identified. A threshold value (1,000 ha) was used to defined the minimum drainage area required to form a stream branch. The outlet for each watershed was manually selected. The watershed delineation generated a range of GIS layers (*i.e*., sub-basin, reach) and detailed reports with respect to the topographic aspect of the watershed. For the hydrologic response unit (HRU) definition, we used threshold values of 5%, 10%, and 5% for land-cover, soil, and slope class percentages, respectively. These threshold values were used to remove minor land use and soil types, so a simplified HRU definition could be achieved (FitzHugh and Mackay, 2000). Daily precipitation, daily minimum temperature, and daily maximum temperature were derived from the USDA-ARS climate data for the period January 1999 to December 2008. For the selected four watersheds, all available weather stations within a watershed or in close proximity were used as the input. This allowed a better spatial representation for precipitation and temperature data. We used the SWAT default dataset for wind, solar radiation, and relative humidity variables.

We focused on water balance and stream flow calibration for the SWAT model since hydrology is the driving force regulating sediment yields. For all four selected GLB watersheds, the USGS stream flow observation historical data records were available. We obtained data from January 1999 to December 2008 at gauge stations for Elkhart River at Goshen, IN (4100500), St. Mary's River near Fort Wayne, IN (4182000), Peshtigo River at Peshtigo, WI (4069500), and Cattaraugus Creek at Gowanda, NY (4213500). For these four selected watersheds, calendar year 1999 was used for the SWAT model warm up period, stream flow calibration was conducted from years 2000 to 2005, and model validations were conducted for 2006 to 2008. We followed the recommended SWAT Manual for stream flow calibration (Neitsch *et al*., 2002). The first calibration step was to compare the average annual observed stream flow and SWAT simulated results. In this procedure, it is often required to estimate the fractions of base-flow and surface runoff from observed data. The base flow filter program was used to estimate the ratio of surface runoff to baseflow (Arnold and Allen, 1999). The SWAT outputs were required to match the surface runoff and baseflow derived from the observation data.

The curve number (CN2) parameter was used to increase or decrease the SWAT estimated surface runoff. The soil evaporation compensation factor (ESCO) was also adjusted if the curve number alone did not generate good estimates. The parameters for the base-flow calibration included Alpha_BF (base-flow recession constant), GW_Revap (ground water "revap" coefficient), Revapmn (water level in shallow aquifer), and Rchrg_Dp (aquifer percolation coefficient). The annual stream flow calibration procedures were repeated until satisfactory results were achieved (*i.e.*, within 5% difference). We assumed that the monthly variations would be acceptable if the annual stream flow calibration was successful. However, the initial comparison for the monthly stream flow data showed relatively large scattering. Additional SWAT parameters such as SFTMP (snowfall temperature), SMTMP (Snow melt base temperature), SURLAG (surface runoff lag coefficient), N (Manning's coefficient), and TIMP (snow pack temperature lag factor) were also adjusted to improve the SWAT model performance. We targeted an R^2 value of 0.7 as the threshold value for monthly stream flow calibration.

The SWAT predicted stream flow was assessed for the validation period (2006–2008) for monthly intervals. The two most commonly used quantitative measures, the linear regression coefficient of determination (R^2) and the Nash and Sutcliffe model efficiency coefficient (E), were calculated. Detailed calibration and validation for the sediment yields were not feasible due to the limited availability of observation data. For overall comparison purposes, we reviewed the literature for similar watershed studies in the GLB. The SWAT sediment yields were calibrated based on the annual average values.

2.4 Future Land-Cover Scenarios

The SWAT calibration models were used to assess the sediment yields for two simulated future land-cover scenarios. The first scenario was to convert all "other" agricultural row crop types (*i.e.*, sorghum) to corn fields and switch the current/baseline crop rotation into continuous corn. The second scenario was to further expand the corn planting to hay/pasture field. The tillage practices remained to be the same as those of the baseline condition. Although these assumed agricultural scenarios are likely unrealistic, our intention was to assess the boundary conditions under these extreme scenarios. We replaced the current or baseline land-use data with the future land use data, while other SWAT model inputs and parameters were held at the baseline condition. The sediment yields for the future land use scenarios were then compared to the baseline sediment yields.

3. RESULTS and DISCUSSION

3.1 SWAT Stream Flows

Independent SWAT models were developed for each of the watersheds. Simple land-cover distribution analysis using the NLCD showed that the dominant cover type for the St. Joseph River and St. Mary's watersheds was agricultural row crops (> 50%). The Peshtigo River and the Cattaraugus Creek watersheds were forest-dominated (> 50%), although row crops accounted for approximately 15–20% for both watersheds. For all four watersheds, urban development occupies relatively small portion of the total area (4–8%). The SWAT watershed delineation procedure created total numbers of 57, 101, 147, and 74 sub-basins for the St. Joseph River, St. Mary's, the Peshtigo River, and the Cattaraugus Creek Watersheds, respectively. The combination of land-cover and soil types further delineated 1,094, 1,557, 2,000, 2,766 HRUs for these four watersheds, respectively. The HRUs are the basic processing units in the SWAT model.

The base flow filter program estimated that baseflow contributed about 40–60% of total stream flow for the four watersheds. For example, the baseflow of St. Mary's watershed contributed about 40% of total flow. For the calibration period (2000–2005), the average observed annual baseflow and surface runoff were 178 mm/yr and 267 mm/yr, respectively. It should be noted that these values were averaged over the entire watershed. Using the default parameters, the SWAT model predicted 102 mm/yr and 303 mm/yr for baseflow and surface runoff, respectively. It appeared that the SWAT overestimated surface runoff values while underestimating the baseflow. We slightly reduced (-0.5%) the curve number (CN2) to decrease the surface runoff. We also adjusted GW_REVAP (0.02) and REVAPMN (10) to increase the base-flow. The SWAT predicted new values of 155 mm/yr and 244 mm/yr for base flow and surface runoff, respectively. The SWAT predicted monthly stream flows were then compared with the observed values resulting in a $R^2 = 0.68$. To achieve the targeted threshold value ($R^2 = 0.70$), we tested adjusting a number of SWAT parameters. Literature review of SWAT applications and EPA internal reports (Ambrosio *et al*., 2007) were particularly useful for identifying the most commonly used parameters and corresponding values. For the St. Mary's watershed, SFTMP (1.1), SMTMP (3.5), and SURLAG (0.5) appeared to have the highest impacts on the SWAT model performance. The calibration of these parameters was conducted in an iterative manner until acceptable calibration results were achieved. For example, the default SURLAG value is four days. We adjusted the SURLAG value in the range of 0.5–6. We found that the time of concentration of 0.5-day produced the best results. Manning's coefficient for the tributary channel was adjusted from 0.014 to 0.05 (Neitsch *et al*., 2002). The R^2 values increased to 0.83 after the model calibration. This value was much higher than the recommended threshold ($R^2 = 0.5$) by Gassman (2008) and Nair (2010).

The same calibration procedures were conducted for the other three watersheds. Table 3 shows the common parameters adjusted in the calibration. All parameters required iterative testing to achieve the satisfactory calibration results. Overall, the calibration of stream flow achieved R^2 values of 0.71, 0.83, 0.69, and 0.67 for the St. Joseph River, St. Mary's, the Peshtigo River, and the Cattaraugus Creek Watersheds, respectively. The corresponding *E* statistics had a wider range of variation (0.41–0.82) than the R^2 values (0.67–0.83). The *E* values for two watersheds were higher than general threshold value ($E > 0.5$) suggested for the SWAT model calibration (Nair 2010).

The stream flow outputs from SWAT were validated independently (2006–2008). Table 4 shows the statistics for both the calibration and validation periods. A relatively low E value (< 0.3) was achieved for the Peshtigo watershed. SWAT model largely overestimated stream flow during the spring months (*i.e.*, April and May). High spatial variability of precipitation during spring months and lack of representative rainfall station might be reasons for the relatively poor model performance (Srinivasan *et al.*, 1998). We developed cross-plots (2006–2008) to compare the predicted monthly stream flow and observed values (Figure 2). For all four watersheds, the scatter plots suggested that the SWAT model predicted stream flows matched the USGS observed values reasonably well. The SWAT model performed better for medium flows at monthly intervals. The main problem was the relatively large scattering for the low stream flow values. For the St. Joseph River, St. Mary's, and the Cattaraugus Creek Watersheds, the SWAT model overestimated low flows during the summer months (*i.e.,* July to September). This result was consisted with those reported in similar SWAT model applications. The overestimation of base-flow between rainstorms might contribute to the effects (Van Liew *et al.*, 2007). It should be noted that no detailed agricultural management information was used as SWAT input, but different agricultural practices are likely to affect the water balance (Green *et al.*, 2006).

3.2 Sediment Yields

For the selected watersheds, there were no long-term observation data for the calibration of sediment yields. Using the default SWAT parameters, the annual sediment yields (tons/ha/yr) for the St. Mary's watershed (2000–2008) were 2.13. For the same watershed, Whiting (2003) reported the annual sediment yields of 0.60 tons/ha/year. Overestimation of sediment yields have also been reported elsewhere (Chen and Mackay, 2004; Ghidey *et al.*, 2007). One of the main reasons is that SWAT typically uses multiple HRUs for each sub-basin; the sum of the runoff energy from the HRUs does not provide accurate information for transport processes (Chen and Mackay, 2004). Although the hydrology is the driving force of sediment yields, there are many other factors (*i.e.,* support practices (P) factor, slope length factor, slope within HRUs, etc.) that may affect sediment yields. A common practice for the sediment yield calibration is to adjust the USLE_P factor or P factor. Generally, agricultural lands with a slope >5% are terraced (Neitsch *et al.*, 2002). We tested the USLE_P value of 0.5 for the SWAT model (Foster and Highfill, 1983). The slope length factor was also reduced to 30 m (Ambrosio *et al.*, 2007). By adjusting the USLE_P and slope length values, the average annual sediment yield (tons/ha/yr) for the St. Mary's watershed was reduced to 0.58. The newly estimated sediment yields were < 3.0% of the reference value. We used the same USLE_P value and slope length factor for all four watersheds due to limited availability of calibration data.

The average annual sediment yields (tons/ha/yr) were 0.56, 0.58, 0.12, and 4.44 for the St. Joseph River, St. Mary's, the Peshtigo River, and the Cattaraugus Creek watersheds, respectively. Figure 3 shows the average annual sediment yields at the sub-basin level for four selected watersheds. The Peshtigo River Watershed had the lowest overall sediment yields. A majority of sub-basins generated low sediment yields (< 0.12 tons/ha/yr). A few sub-basins located at the southwest area generated slightly higher sediment yields (0.4–0.8 tons/ha/yr). Limited agricultural lands were located in these sub-basins. The highest sediment yields were observed for the Cattaraugus Creek Watersheds. The sub-basins with high sediment yields (*i.e.*, > 3 tons/ha/year) matched well with the location of agricultural lands, especially areas with relatively high slope values. There were many steep valleys in the Cattaraugus Creek Watershed.

Two future cropland change scenarios were considered. The first scenario was to convert all "other" agricultural row crop types (*i.e.,* sorghum) to corn fields and switch the current/baseline crop rotation into continuous corn. The average annual sediment yields (tons/ha/yr) increased to 0.64, 0.62, 0.17, and 5.97 for the St. Joseph River, St. Mary's, the Peshtigo River, and the Cattaraugus Creek Watersheds, respectively. Compared to the baseline condition, the annual sediment yields increased 14%, 7%, 42%, and 34%. It should be noted that corn and soybean are the dominant row crops for the St. Joseph River and St. Mary's watersheds, thus the first scenario's impact is mostly due to the shift from corn soybean rotation to continuous corn. For the Peshtigo River and the Cattaraugus Creek Watersheds, the impacts are mainly due to the shift from corn-alfalfa rotation to continuous corn.

The second scenario was to further expand the corn planting to hay/pasture fields. Accordingly, the average annual sediment yields (tons/ha/yr) for the four watersheds increased to

1.27, 0.77, 0.20, and 7.67. The estimated annual sediment yields increased 33–127% compared to the baseline conditions. The large increase in sediment yields for St. Joseph watershed and Cattaraugus watershed were attributed to relatively large proportions of hay/pasture lands, which were converted as corn fields in the simulated scenario.

Figure 4 shows the comparison of sediment yields for the baseline and the two cropland change scenarios. The increase for the first cropland change scenario (7–42%) was considered as moderate compared to the second cropland change scenario (33–127%), because corn and soybeans were already the dominant row crop types in the selected watersheds and the impact was mostly due to the shift from other crop rotations to continuous corn. The large increase of sediment yields for the second cropland change scenario was expected because corn planting generally generates much higher rates of soil erosion than hay/pasture lands (Claassen *et al*., 2010). Figure 5 compares the spatial distributions of sediment yields at the sub-basin level. Visual interpretation of these two sediment yield maps for the Cattaraugus Creek Watershed suggested that the conversion of hay/pasture to corn planting substantially increased the sediment yields for almost all the sub-basins.

Currently, the conversion of pasture/hay field to corn planting is already happening in the Northern Plains (Claassen *et al*., 2010). In addition to the impacts on the sediment yields, these trends may cause a number of negative environmental consequences with respect to water quality, biodiversity, and overall ecosystem sustainability (Pimentel and Patzek, 2005). Future studies are needed to quantify the magnitude of impacts on these additional ecosystem components and processes. In this study, the comparison of the sediment yields was conducted using the same climatic conditions for all three land-use scenarios. The estimation of sediment yields for future land-use change can be complicated by different climate change scenarios. In addition, we only considered two possible agricultural land use change scenarios. Other change scenarios (*i.e*., urban growth) were not included in the assessment. It should be noted that the historical changes in crop lands in the GLB are much larger than those in the recent decade (USDA-NASS statistics). There is much less land in cropland now than there used to be (*i.e*., 1930s). The land-use change scenarios chosen in this study are arbitrary. More reasonable agricultural land-use change scenarios may need to be developed using literature from the economics and policy field, especially from studies that link economic/policy signals and agricultural land use change. In the future study, the SWAT model can be potentially used as an integrated system to assess the coupled climate and land use change impacts on sediment yields and water quality issues.

4. CONCLUSIONS

This study integrated remote sensing-derived products and the Soil and Water Assessment Tool (SWAT) model within a GIS modeling environment to assess the impacts of cropland change on the sediment yield within four selected watersheds in the GLB. The SWAT model was implemented for four selected watersheds in the GLB. We focused on SWAT model calibration and validation for stream flows. For three of the four selected watersheds, the SWAT predicted stream flows matched well with the USGS observation data. For the validation period of 2006–2008, the R^2 values were 0.76, 0.80, 0.72, and 0.81 for the St. Joseph River, St. Mary's, the Peshtigo River, and the Cattaraugus Creek Watersheds, respectively. The SWAT calibration process was further used to estimate sediment yields.

We considered two future agricultural scenarios compared to the current baseline condition, these included the conversion of all "other" row crop types to corn and the conversion of hay/pasture to corn. The average annual sediment yields (tons/ha/yr) for the current baseline condition ranged from 0.12–4.44. The average annual sediment yields increased 7–42% when all “other” row crop types were converted to corn and traditional crop rotations were removed. Further conversion of hay/pasture to corn generated annual sediment yields (tons/ha/yr) of 1.27, 0.77, 0.20, and 7.67 for the St. Joseph River, St. Mary's, the Peshtigo River, and the Cattaraugus Creek Watersheds, respectively. The predicted annual sediment yields increased 33–127% compared to the baseline conditions.

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Table 1. The four selected watersheds located within the GLB and associated land-use characteristics (Ag = agriculture, HUC = 8-digit).

Name	HUC Ids.	State	Area (km^2)	Ag (km^2)	%Ag
St. Joseph	4050001	MI,IN	12131.76	7097.36	68
St. Mary's.	4100004	IN,OH	2108.81	1649.50	84
Peshtigo	4030105	WI	3031.08	450.35	14
Cattaraugus	4120102	NY	1429.59	508.96	35

Table 2. The primary crop rotation and tillage practices applied for selected watersheds (c = corn, s = soybean, h = hay).

	Crop rotation	Tillage	
		corn	soybean
St. Joseph	c-s, s-c, c-c	conventional and conservation	conservation
St. Mary's	c-s, s-c, c-c	conventional	conservation
Peshtigo	c-c-c, c-c-h, c-h-c, h-c-c, c-c-s	conservation	conservation
Cattaraugus	c-c-c, c-c-h, c-h-c, h-c-c, c-c-s	conventional	conventional

Table 3. Selected SWAT model calibration parameters used for the (* indicates SWAT default value). Note that only a subset of the SWAT parameters is listed.

SWAT Parameter	St. Joseph	St. Mary's	Peshtigo	Cattaraugus
Alpha_BF	0.02	0.05	0.06	0.20
CN2	-20%	-0.5%	-30%	*
ESCO	*	*	0.01	0.10
GW_Revap	0.20	0.02	0.20	0.20
Manning's coefficient	0.05	0.05	0.05	0.05
REVAPMN	0	*	0	*
SFTMP	1.1	1.1	1.1	1.1
SMTMP	3.5	3.5	4.0	3.0
SURLAG	1.0	0.5	0.5	0.5

Tables 4. The calibration and performance assessment values for SWAT model for the four GLB watersheds.

	Calibration (2000–2005)		Validation (2006–2008)	
	R^2	*E*	R^2	*E*
St. Joseph	0.71	0.41	0.76	0.66
St. Mary's.	0.83	0.82	0.80	0.79
Peshtigo	0.69	0.43	0.72	0.24
Cattaraugus	0.67	0.57	0.81	0.78

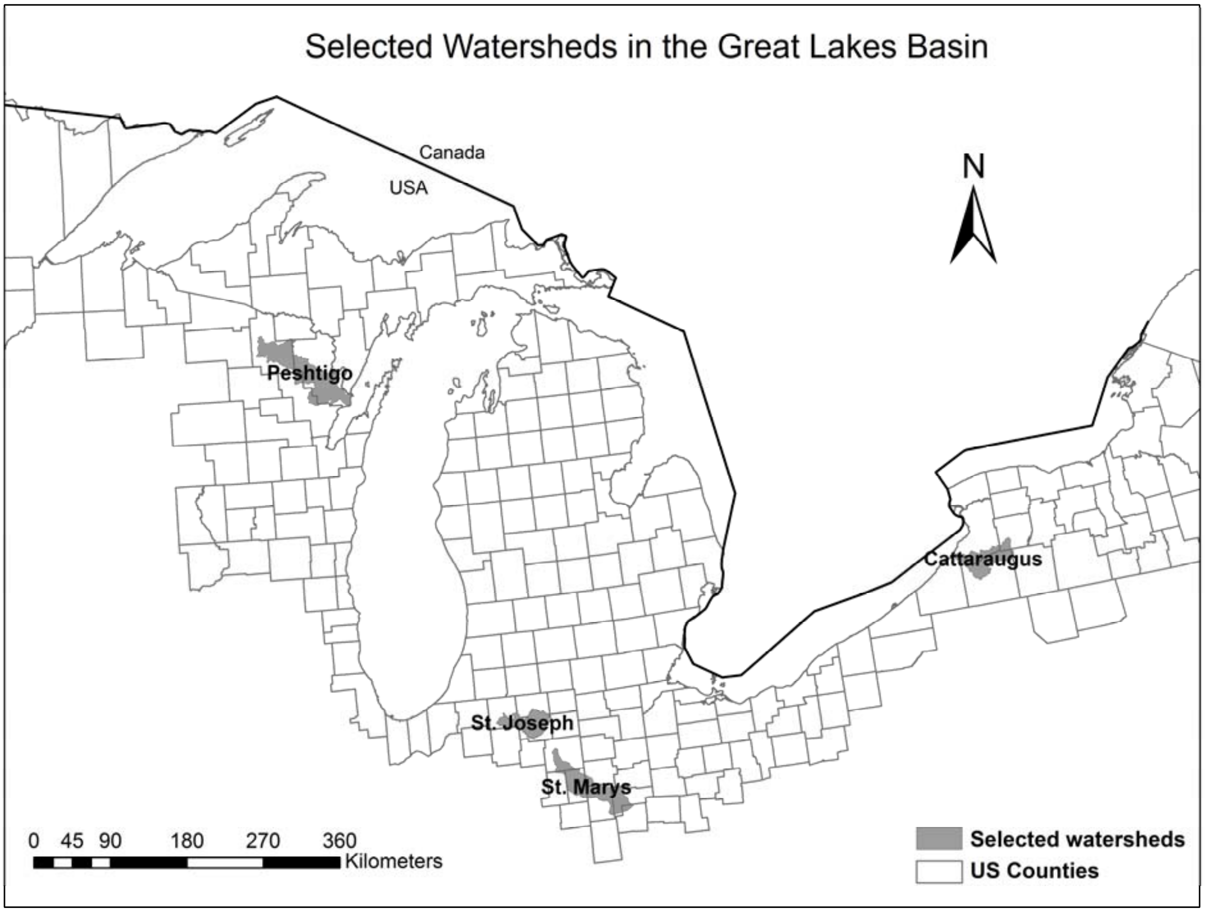

Figure 1. Location map highlighting the four selected watersheds in the Great Lakes Basin.

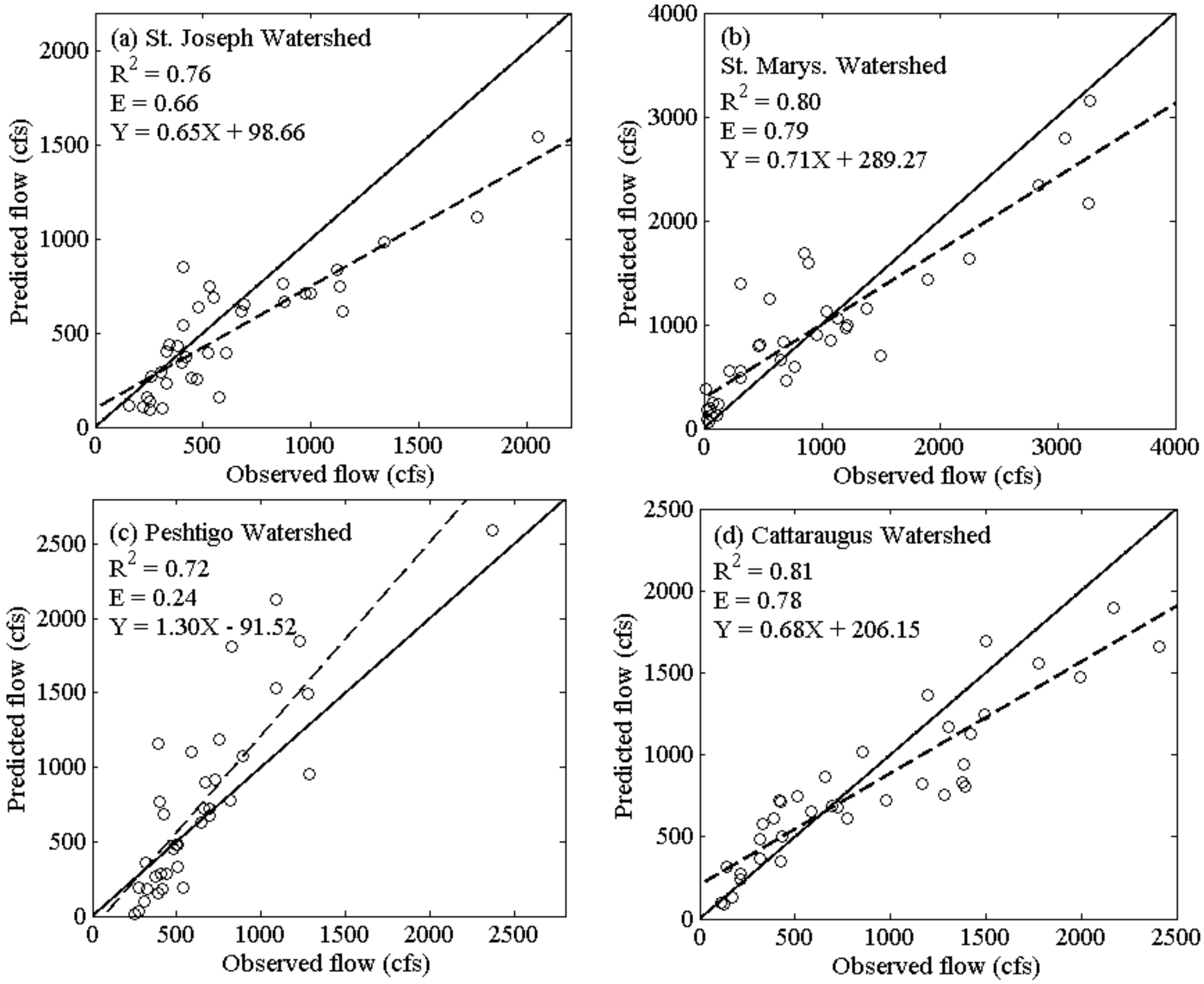

Figure 2. Comparisons of stream flow estimates from SWAT model versus the USGS observation data (2006-2008) for (a) St. Joseph River, (b) St. Mary's, (c) Peshtigo River, and (d) Cattaraugus Creek watershed.

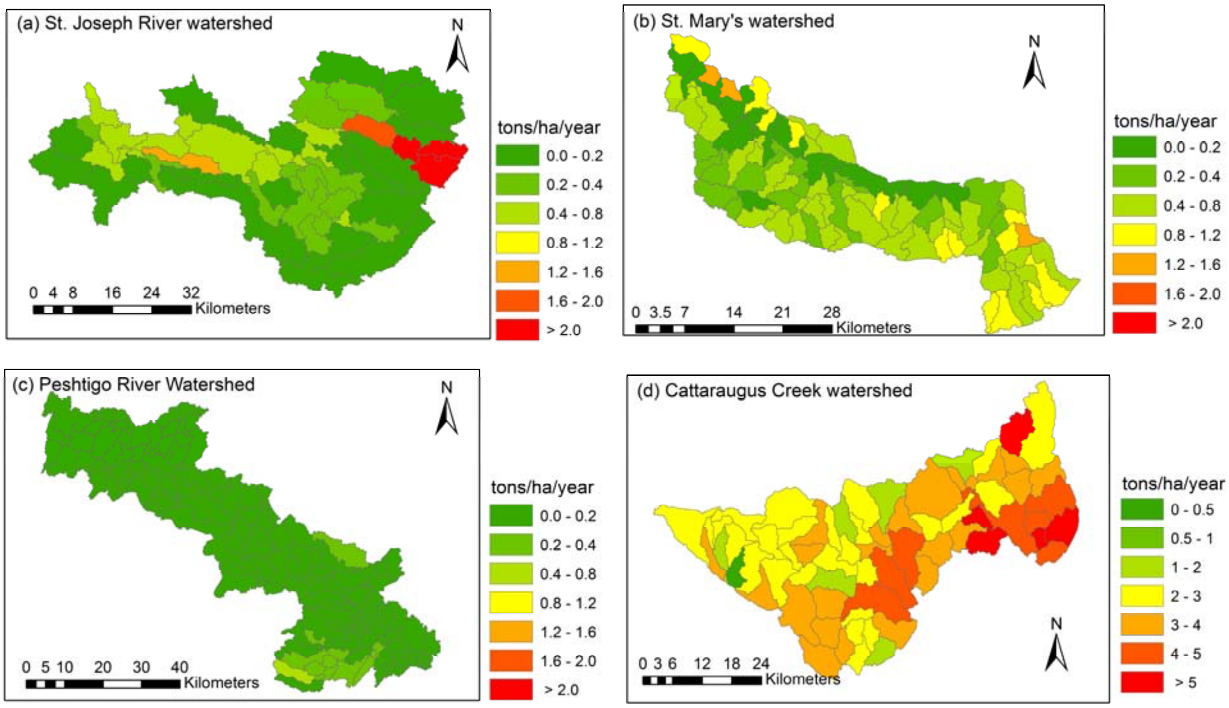

Figure 3. Average annual sediment yields from SWAT model (2000–2008) for (a) St. Joseph River, (b) St. Mary's, (c) Peshtigo River, and (d) Cattaraugus Creek watersheds.

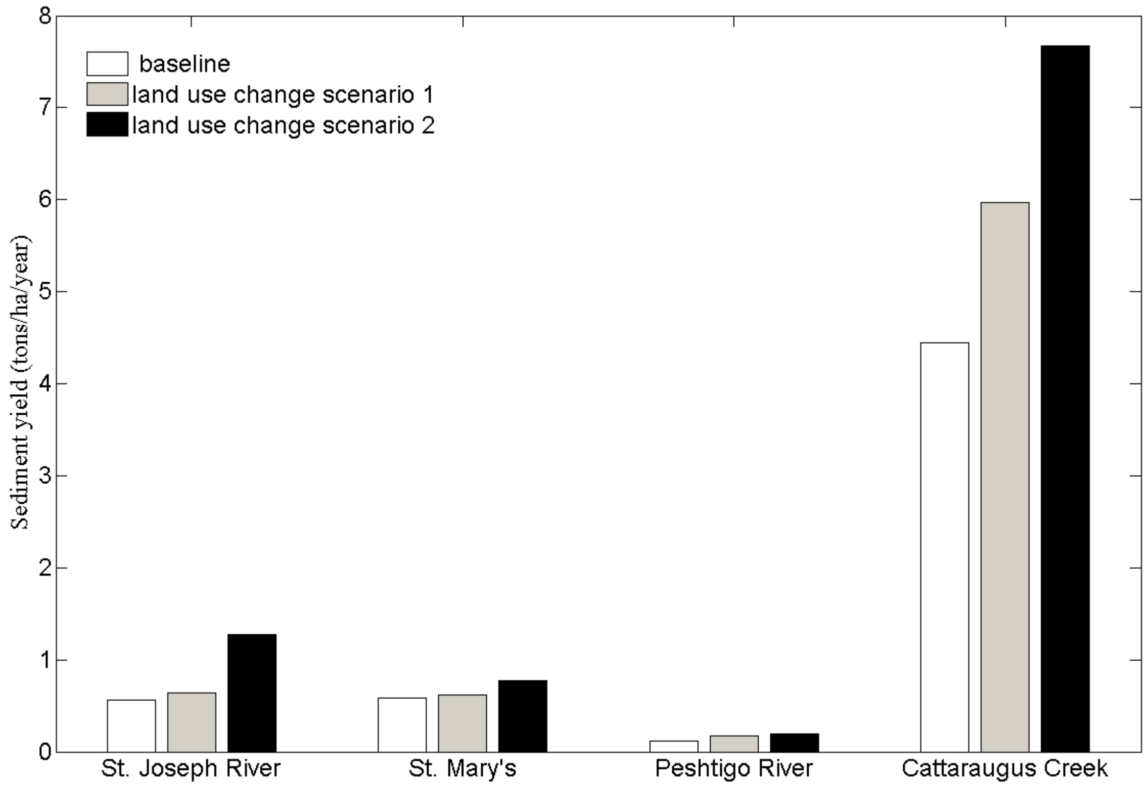

Figure 4. Comparisons of estimated average annual sediment yields corresponding to three land-use scenarios. The current baseline condition is included as reference. In the first land use change scenario, all other agricultural row crop types (*i.e.,* winter wheat) were converted to corn fields. The second scenario was to further expand the corn plantation to hay/pasture fields.

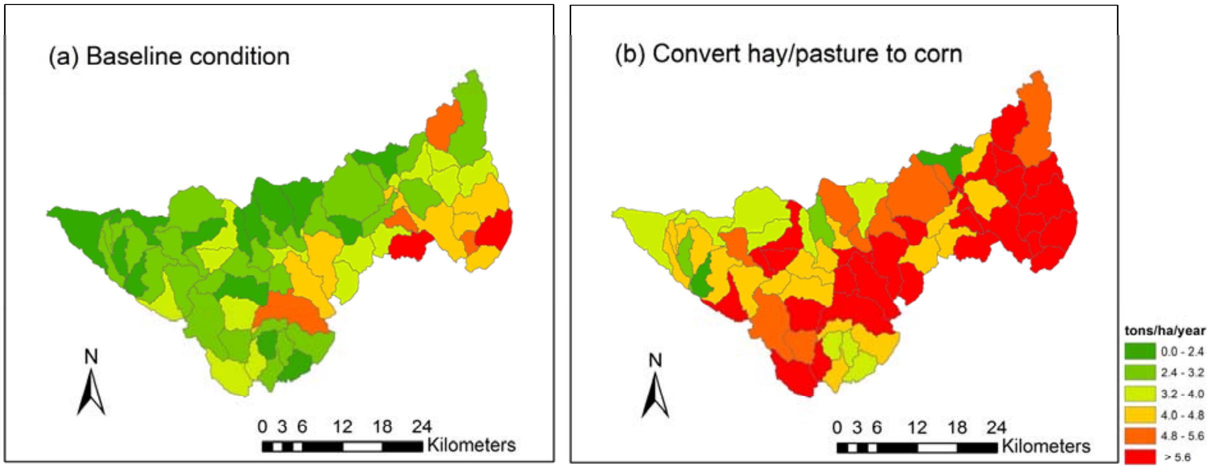

Figure 5. Average annual sediment yields from SWAT model for (a) baseline condition and (b) convert hay/pasture to corn field.