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Identifying and Mitigating Potential Nutrient and Sediment Hot Spots under a Future Scenario in the Missouri River Basin

Energy Systems Division

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ACRONYMS AND ABBREVIATIONS

ARS	Agricultural Research Service
ARRB	Arkansas Red River Basin
AWRRB	Arkansas White and Red River Basin (same as ARRB, sometimes used by ORNL)
BETO	Bioenergy Technologies Office (DOE)
BMP	best management practice
CDL	cropland data layer
CT	conventional tillage
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EPA	U.S. Environmental Protection Agency
HRU	hydrological response unit
HTP	Hypoxia Task Force
HUC-8	8-digit hydrologic unit code
IngN	inorganic nitrogen
IngP	inorganic phosphorus
LMoRB	Lower Missouri River Basin
LMRB	Lower Mississippi River Basin
MDT	million dry ton(s)
MoRB	Missouri River Basin
NASS	National Agricultural Statistic Service
NCDC	National Climate Data Center
NH_4^+	ammonium ion
NH_4-N	ammonia-nitrogen
NID	National Inventory of Dams
NO_2-N	nitrite-nitrogen
NO_3	nitrate
NO_3-N	nitrate-nitrogen
NSE	Nashe-Sutcliffe (model) Efficiency
NT	no-till, no tillage
ORB	Ohio River Basin
OrgN	organic nitrogen
OrgP	organic phosphorus

PBIAS	percent bias
RF1	EPA Stream Network Data
RMSE	root mean square error
RSR	ratio of RMSE to standard deviation
RT	reduced-till, reduced tillage
SD	standard deviation
SolP	soluble phosphorus
STATSGO	State Soil Geographic Database
SWAT	Soil and Water Assessment Tool
SWG	switchgrass
TN	total nitrogen, includes OrgN, NO_3, and NH_4
TP	total phosphorus, includes OrgP and IngP
TRB	Tennessee River Basin
TSS	total suspended sediment
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UMoRB	Upper Missouri River Basin
UMRB	Upper Mississippi River Basin

IDENTIFYING AND MITIGATING POTENTIAL NUTRIENT AND SEDIMENT HOT SPOTS UNDER A FUTURE SCENARIO IN THE MISSOURI RIVER BASIN

by

May Wu and Zhonglong Zhang

ABSTRACT

Using the Soil and Water Assessment Tool (SWAT) for large-scale watershed modeling could be useful for evaluating the quality of the water in regions that are dominated by nonpoint sources in order to identify potential "hot spots" for which mitigating strategies could be further developed. An analysis of water quality under future scenarios in which changes in land use would be made to accommodate increased biofuel production was developed for the Missouri River Basin (MoRB) based on a SWAT model application. The analysis covered major agricultural crops and biofuel feedstock in the MoRB, including pasture land, hay, corn, soybeans, wheat, and switchgrass. The analysis examined, at multiple temporal and spatial scales, how nitrate, organic nitrogen, and total nitrogen; phosphorus, organic phosphorus, inorganic phosphorus, and total phosphorus; suspended sediments; and water flow (water yield) would respond to the shifts in land use that would occur under proposed future scenarios. The analysis was conducted at three geospatial scales: (1) large tributary basin scale (two: Upper MoRB and Lower MoRB); (2) regional watershed scale (seven: Upper Missouri River, Middle Missouri River, Middle Lower Missouri River, Lower Missouri River, Yellowstone River, Platte River, and Kansas River); and (3) eight-digit hydrologic unit (HUC-8) subbasin scale (307 subbasins). Results showed that subbasin-level variations were substantial. Nitrogen loadings decreased across the entire Upper MoRB, and they increased in several subbasins in the Lower MoRB. Most nitrate reductions occurred in lateral flow. Also at the subbasin level, phosphorus in organic, sediment, and soluble forms was reduced by 35%, 45%, and 65%, respectively. Suspended sediments increased in 68% of the subbasins. The water yield decreased in 62% of the subbasins. In the Kansas River watershed, the water quality improved significantly with regard to every nitrogen and phosphorus compound. The improvement was clearly attributable to the conversion of a large amount of land to switchgrass. The Middle Lower Missouri River and Lower Missouri River were identified as hot regions. Further analysis identified four subbasins (10240002, 10230007, 10290402, and 10300200) as being the most vulnerable in terms of sediment, nitrogen, and phosphorus loadings. Overall, results suggest that increasing the amount of switchgrass acreage in the hot spots should be considered to mitigate the nutrient loads. The study provides an analytical method to support stakeholders in making informed decisions that balance biofuel production and water sustainability.

PART A: OVERALL PROJECT PLAN, GOALS, AND SUMMARY OF RESULTS

A.1 INTRODUCTION

The Bioenergy Technologies Office (BETO) in the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) set a goal of developing the resources, technologies, and systems needed to grow the biofuel industry in a way that would be economically feasible, socially responsible, and environmentally sustainable (DOE 2014). Environmental sustainability emphasizes maintaining the ecological services provided by natural resources, including air quality, soil productivity, water availability, and water quality. Water use and water quality are key factors that are intrinsically linked to bioenergy production across the supply chain. The uses of water resources change in response to changes in land cover and land use and can be affected by climate change. Therefore, it is critical to assess the use and availability of water resources, quantify the impacts from increased production of bioenergy feedstock on water quality, and identify region-specific factors and options that relate to meeting regulatory requirements for environmental sustainability. The results of this effort could then be applied to help mitigate undesirable environmental consequences and strengthen energy security.

It is anticipated that the feedstock required to achieve the rapid growth of the domestic biofuels industry will come from perennial grass, agricultural residue, conventional feedstock, forest wood residue, and other emerging feedstock (DOE 2011). A significant portion of that feedstock could be grown in the Mississippi River Basin (MRB) (Figure A-1). The MRB has six tributary basins: (1) Upper Mississippi River Basin (UMRB), (2) Missouri River Basin (MoRB), (3) Ohio River Basin (ORB), (4) Tennessee River Basin (TRB), (5) Arkansas Red River Basin (ARRB), and (6) Lower Mississippi River Basin (LMRB). At present, the MRB, with its six tributary basins, produces more than 90% of the biofuels and biofuel feedstock in the United States. In the future, it is expected to play a central role in the development of cellulosic biomass, which could displace 30% of the current petroleum oil supply. Land use affects watershed responses in a multitude of ways. It controls the infiltration rates, amount of runoff generated, and amounts of evaporation and transpiration, thus affecting the pathways that water takes across the landscape. It also has a significant impact on surface water quality with regard to the types of contaminants that might be present and their quantities. Historically, the MRB has also been recognized as the major source of nutrients (nitrogen and phosphorus) that flow into the Gulf of Mexico (Hunsaker and Levine 1995, Johnson and Gage 1997; Alexander and Smith 2006; Harmel et al. 2006). Moreover, agricultural production is a major contributor to seasonal hypoxia and associated loss of marine diversity in the Gulf of Mexico (Alexander et al. 2008). The increase in biofuel feedstock production, expected to reach 36 billion gal by 2022, could accelerate eutrophication, erosion in the soil, and decreases in aquatic biodiversity (Donner and Kucharik 2008).

Given the importance of the MRB and its role in large-scale biofuel feedstock production, the need to understand the interactions among biofuel feedstock production, landscape and land cover, hydrology, and water quality at both a river-basin scale and a watershed scale at various spatial resolutions is urgent. The simulation of changes in water quality in response to future production scenarios could result in valuable region-specific information. Such data are needed to support decision making at an early stage of biofuel industry development, in the development of feedstock, selection of technologies, and planning of management strategies, so these decisions can lead to a water-sustainable bioenergy industry.

FIGURE A-1 Mississippi River Basin and Its Six Tributary Basins: Upper Mississippi River Basin (UMRB), Missouri River Basin (MoRB), Ohio River Basin (ORB), Tennessee River Basin (TRB), Arkansas Red River Basin (ARRB), and Lower Mississippi River Basin (LMRB).

A.2 SCOPE

The main objective of this work is to quantify relationships between increased biofuel production, land conversion, and water quality to serve as a basis for aquatic biodiversity analysis and modeling. A geospatial watershed model, the Soil and Water Assessment Tool (SWAT; see http://swat.tamu.edu/), is the key tool being used to link landscape changes associated with increased bioenergy production and their impacts on water quality. The goals of the project discussed in this report are to (1) develop large-scale watershed models for the major tributary river basins of the MRB that have high concentrations of biofuel feedstock or a high potential for biofuel feedstock production and (2) conduct an assessment of historical baselines, and (3) estimate changes in water quality (sediment and nutrient loadings) and water flow associated with increased biofuel feedstock production to meet projected targets set by the U.S. Congress.

A.3 PROJECT BACKGROUND

With the support of the BETO in DOE/EERE, a multi-institute watershed simulation effort that focuses on the tributaries of the MRB was initiated in 2009. In fiscal year 2011, a plan for this joint effort by Argonne National Laboratory and Oak Ridge National Laboratory (Argonne and ORNL 2011) to develop hydrologic watershed models for the MRB's six tributary basins (UMRB, MoRB, ORB, TRB, ARRB, and LMRB) was established. In this joint work, researchers in Argonne and ORNL use SWAT, a physically based watershed model developed by the U.S. Department of Agriculture's (USDA's) Agricultural Research Service (ARS) that is in the public domain, to identify major nonpoint sources, predict riverine sediment and nutrient exports, and track their delivery to the Mississippi River. To date, Argonne and ORNL have completed the development of a suite of base SWAT models at U.S. Geological Survey (USGS) eight-digit hydrologic unit code (HUC-8) scale for five tributary basins; three (UMRB, ORB, MoRB) were developed by Argonne, and two (TRB and ARRB) were developed by ORNL. (ORNL's work for ARRB also includes White River, so it is referred to as AWRRB, for Arkansas White and Red River Basin). The base models were calibrated and validated against historical climate, hydrologic, and water quality data. Water quality components (nitrogen, phosphorus, and suspended sediments) and the water yield were simulated at both the tributary basin outlet level and subbasin level. A selected future production scenario was applied to these base models, and additional future scenarios were simulated to examine the impact of various land uses on water quality. SWAT modeling results for the UMRB, MoRB, ORB, TRB, and AWRRB were published in several peer-reviewed journals and national laboratory reports (Baskaran et al. 2013, 2010; Demissie et al. 2013, 2012; Schweizer and Jager 2011; Jager et al. 2015; Wang et al. 2014; Wu et al. 2012; Zhang and Wu 2013).

In 2013–2014, a SWAT model for MoRB was developed by establishing two separate large tributary basin models: the Upper MoRB model and Lower MoRB model (Figure A-2) based on historic land use (Figure A-3). Each model was calibrated and then validated with 20 years of data on measured stream flow and water quality collected from 20 USGS stream flow gage stations (Zhang and Wu 2013). The model's performance ranged from satisfactory to very good for both the calibration and validation periods. The two SWAT models for MoRB were integrated, and the results were analyzed. Model outputs on the riverine suspended sediment and nutrient loads indicated a need to increase the amount and types of monitoring data and to refine the models. Further analysis revealed considerable variations in the loads and yields of total suspended sediment (TSS), total nitrogen (TN), and total phosphorus (TP) among the major tributaries of the MoRB (by two, six, and seven regional watersheds) and its 307 subbasins. Further analysis was conducted at the seven regional watersheds characterized in Figure A-4 and Table A-1. The largest TN and TP loads were in the Lower Missouri River watershed and Middle Missouri River watershed, because of their own inputs and the cumulative effects from upstream. These two watersheds contribute 28.4% and 29.1% of TN, 18.6% and 38.7% of TP, for Lower Missouri River and Middle Missouri River, respectively. The work provides a historical baseline of water quality and water quantity in the MoRB at the basin outlet, regional watersheds, and its subbasins. It set a foundation for future scenario assessments.

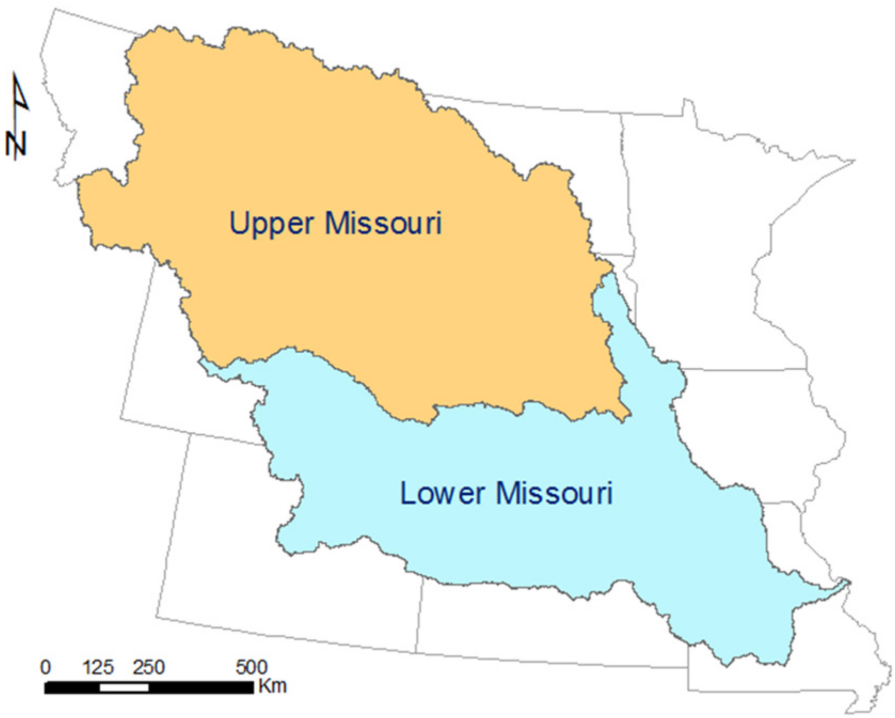

FIGURE A-2 System Boundaries of Upper MoRB and Lower MoRB in SWAT Models

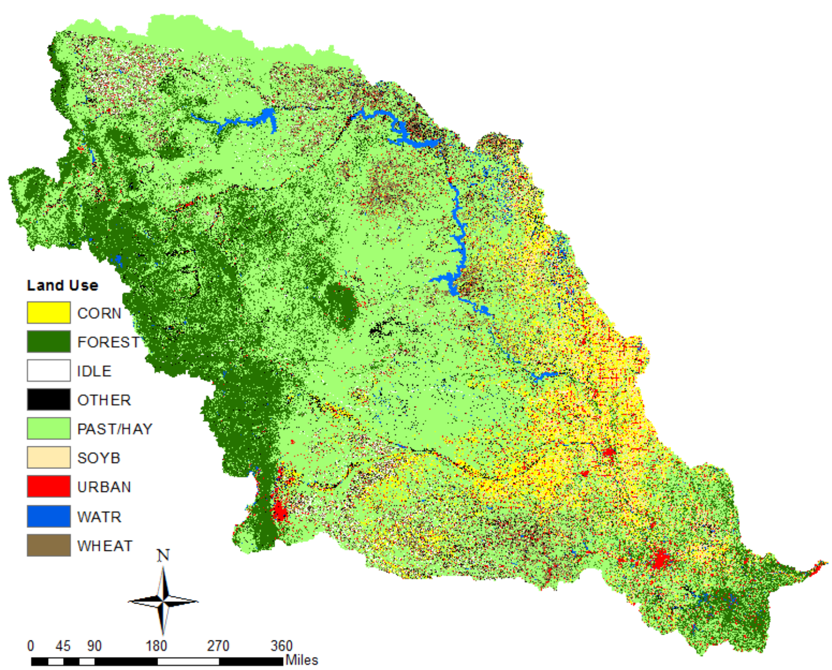

FIGURE A-3 Current Land Use and Land Cover in the Missouri River Basin

A.4 DESCRIPTION OF THIS WORK

In 2014, the project team began to study the impact of future biomass production by implementing a future land use and cover scenario and analyzing associated water quality changes. The U.S. Department of Energy (DOE 2011) estimated that nearly 8.9 million ha of cropland and 16.6 million ha of pasture land and hay land might shift to energy crops, with an additional 140−270 million dry tons (MDT) of corn stover being harvested from most no-till (NT) and reduced-till (RT) corn farms by 2022 in the MoRB. Such widespread changes in land use and crop residue management would likely affect sediment and nitrogen and phosphorus loading. Although land use changes are common and widespread, it is often difficult to quantify these changes exactly and assess them because of the heterogeneity of the land surface and the difficulty of characterizing diverse land uses and their features. In the work discussed here, impacts of land use changes and management practices on sediment and nutrient loading and water quality in the MoRB were characterized by using calibrated baseline MoRB SWAT models.

This report documents the implementation of a future scenario (DOE 2011) on the MoRB by using the SWAT base models and the resultant spatial and temporal analysis of riverine suspended sediment and nutrient loads. This study was intended to examine the effect of agricultural land use changes on nutrients (nitrogen and phosphorus), suspended sediments, and flow in the MoRB. The future scenario considers converting a portion of the following three types of land - low-productivity land, marginal land, and idle land - for bioenergy production by growing conventional and cellulosic feedstock in MoRB by 2022 (Figure A-5). The team further evaluated the spread and the extent of the changes in water quality in response to a shift in land cover and land use by conducting a multi-scale geospatial and temporal analysis. Simulated outputs were analyzed at four, six, and seven regional watersheds and at durations of time ranging from monthly to annually. The water quality analysis was performed at a chemical constituent level to examine the interactions among water chemistry, soil property, and land cover and use. To evaluate water chemistry, organic nitrogen, nitrate, TN, organic phosphorus, soluble phosphorus, TP, and SS were examined for their concentration and watershed loadings at HUC-8 level. Based on the results, the study identified HUC-8 subbasins that potentially to be the most vulnerable to a change in land use or land cover in terms of water quality. Furthermore, the study quantified the potential benefits of land use and land cover change in terms of water quality, especially when land was converted to grow switchgrass. The positive impact of this approach can be considered as a mitigation strategy to improve water quality at the watershed scale while producing non-food cellulosic biofuels.

FIGURE A-4 Locations of the Seven Regional Watersheds of the MoRB and Their Outlets to the Missouri River (Red circles represent outlets of regional watersheds)

TABLE A-1 Characteristics of the Seven Regional Watersheds Analyzed by the Two SWAT Models for MoRB

No.	Regional Watershed	Watershed Outlet Location	Watershed Area (km^2)	Drainage Area (km^2)
1	Yellowstone River	Yellowstone River near Sydney, MT	181,376	181,376
2	Upper Missouri River	Missouri River near Culbertson, MT	239,946	239,946
3	Middle Missouri River	Missouri River at Pierre, SD	206,064	627,385
4	Middle Missouri River	Missouri River at Omaha, NE	206,127	833,512
5	Platte River	Platte River at Louisville, NE	221,527	221,527
6	Kansas River	Kansas River at Desoto, KS	155,623	155,623
7	Lower Missouri River	Missouri River at Hermann, MO	138,621	1,349,283

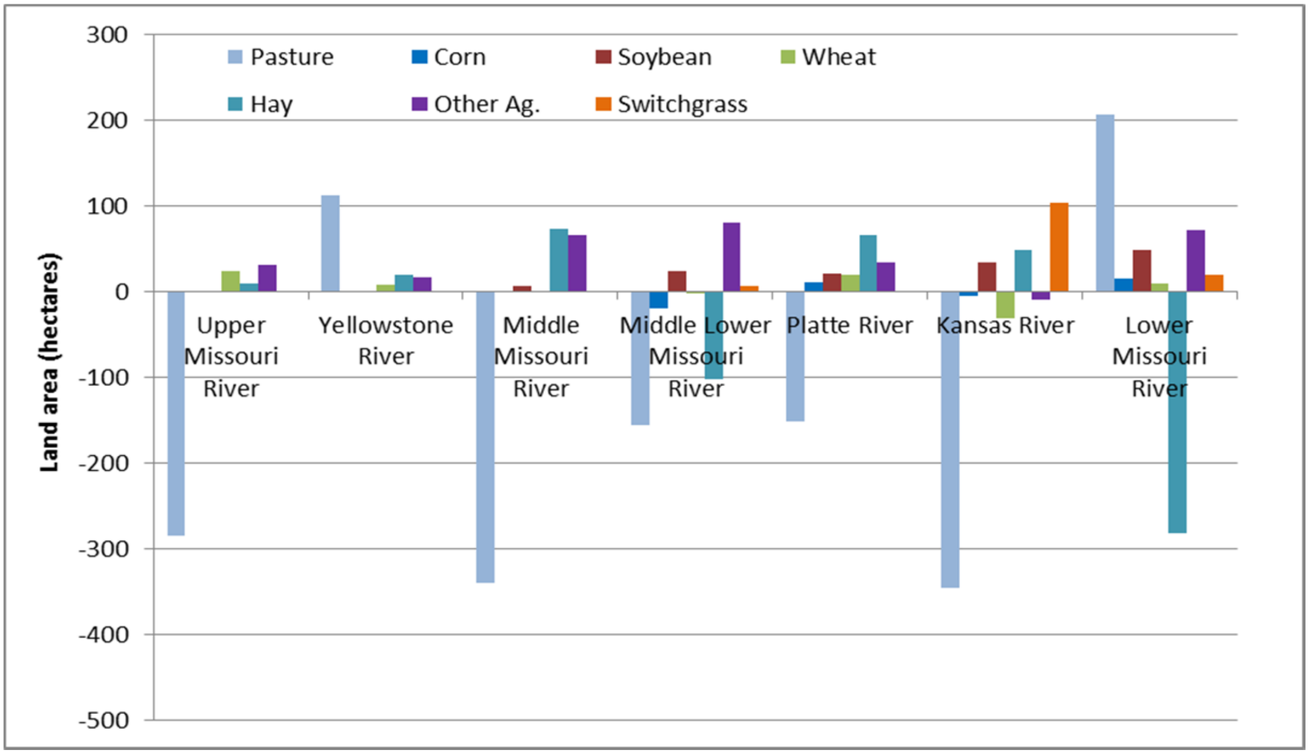

FIGURE A-5 Changes in Land Use and Land Cover under the Future Scenario Compared with the Baseline Values.

A.5 KEY FINDINGS

A.5.1 Nitrogen Loadings

Water quality could improve as the result of careful planning with regard to land use and land cover in the MoRB. The improvement could spread from 30% to 65% of the subbasins at the HUC-8 scale. Under a future bioenergy production scenario, in which the crop yield would increase by 1% annually from 2010 to 2022 and the cellulosic feedstock price would be $55 per dry ton, the amount of nitrate loadings could be reduced cross the entire UMoRB (Figure A-6, Table A-2), while it would increase in several subbasins in the LMoRB. Of the 307 subbasins in the MoRB, 127 (41%) of them would experience a reduction in nitrate loading. The extent of the changes in the nitrate loading was found to vary. Subbasins with increases in nitrate of from 5 to 28 kg N/ha accounted for 6.2% (19) of the 307 subbasins. Changes in the remaining 180 subbasins were relatively small, at 0 to <5 kg N/ha.

Three streams contribute to watershed nitrate loadings: surface runoff, lateral flow, and groundwater. Under the future scenario studied, nitrate in these streams would be reduced in 45% to 58% of the subbasins (139–177). Nitrate reduction was found most often in lateral flows (177 subbasins), less often in groundwater streams (169 subbasins), and least often in surface runoff (139 subbasins). Note that due to the nitrification and denitrification process in the soil microbial community, the nitrate intensity varied temporally across the subbasins. Therefore, the number of subbasins with the same level of changes in lateral flow, groundwater, and surface runoff might not necessarily “sum up” to the total nitrate loadings.

Organic nitrogen (OrgN) appears to be the major contributor to the total nitrogen (TN) in the river basin and played a dominant role in the increase in the TN loading. In places with high TN loadings, it is most likely that the OrgN is also high (Figure A-6, Table 1). With the land use and land cover in the future scenario, 13% of the subbasins (40) in MoRB would have an increase in OrgN, and a majority of these would be located in the subbasins with increased TN and nitrate levels (Figure A-6). The increase in OrgN and TN would mostly be concentrated in the Lower Missouri River watershed. This watershed receives cumulative inputs from all six of the upstream regional watersheds.

A.5.2 Phosphorus and Suspended Sediments

Results show a substantial decrease in phosphorus loadings. Organic, sediment, and soluble phosphorus would be reduced in 35%, 45%, and 65%, respectively, of the subbasins (Table A-1). In the subbasins where phosphorus loadings increased, the increase would be below 5 kg/ha, and no subbasins would have an increase of more than 5 kg/ha (Figure A-6). Results for suspended sediments are mixed. TSS decreased in 32% of the subbasins and slightly increased in 68% of the subbasins. In 9% of the MoRB subbasins — all in Lower Missouri River watershed — TSS could increase by at least 5 dry metric tons/ha (Figure A-7). Water yield would likely decrease in 62% (190) of the total subbasins.

TABLE A-2 Number of Subbasins in MoRB That Experienced Changes in Nutrient Loadings under the Future Scenario

	Number of HUC-8 Subbasins[b,c]										
Change in Loadings[a]	Total NO_3	Lat NO_3	GW NO_3	Sur NO_3	OrgN	TN	SolP	SedP	OrgP	TP	TSS
≤0	127 (41%)	177 (58%)	169 (55%)	139 (45%)	102 (33%)	92 (30%)	200 (65%)	128 (42%)	108 (35%)	114 (37%)	99 (32%)
> 0 to <5	180	130	138	168	205	215	107	179	199	193	208
≥5	19 (6%)	0	10 (3%)	0	40 (13%)	50 (16%)	0	0	0	0	29 (9%)

[a] Loadings for N and P are in units of kg/ha; loadings for TSS are in dry metric tons/ha.

[b] NO_3 = nitrate, Lat = lateral flow, GW = groundwater, Sur = surface runoff, OrgN = organic nitrogen, TN = total nitrogen, SolP = soluble phosphorus, SedP = sediment phosphorus, OrgP = organic phosphorus, TP = total phosphorus, TSS = total suspended sediment.

[c] Value in parentheses represents percent of subbasins in the MoRB. There are a total of 307 subbasins.

A.5.3 Hot Spots in Regional Watersheds

Geographically, the Kansas River watershed benefited most under the future land use change scenario. The water quality improved significantly for every nitrogen and phosphorus compound simulated by SWAT (Figure A-8) in the watershed, including a reduction of more than 40 million kg of nitrate and nearly 100 million kg of TN per year. As indicated in Figure A-5, the Kansas River watershed experienced a land conversion (100 ha) to switchgrass (SWG) that was the largest in scale among all seven regions, in addition to an increase in soybeans and hay and a decrease in wheat, corn, pasture land, and other crops. SWG has been demonstrated to effectively intercept nutrients in runoff and in soil. Therefore, it is not surprising to see such dramatic improvement, even when the region lost a sizable amount of pasture land (Figure A-5). By incorporating swithchgrass into land use and land cover change, the overall water quality of regional watersheds in the LMoRB can be improved, as was demonstrated in the Kansas River watershed.

In contrast, the Middle Lower Missouri River and Lower Missouri River watersheds would face challenges, especially in dealing with an increase in nitrogen (i.e., nitrate, organic nitrogen, and total nitrogen) (Figure A-8). In the Middle Lower Missouri River watershed, land use was changed from pasture and hay to grain crops (Figure A-5). As one might expect, the change would result in an increased loss of nutrients (Figure A-8). In the Lower Missouri River watershed, despite a large reduction in corn and an increase in pasture, nitrogen loadings would

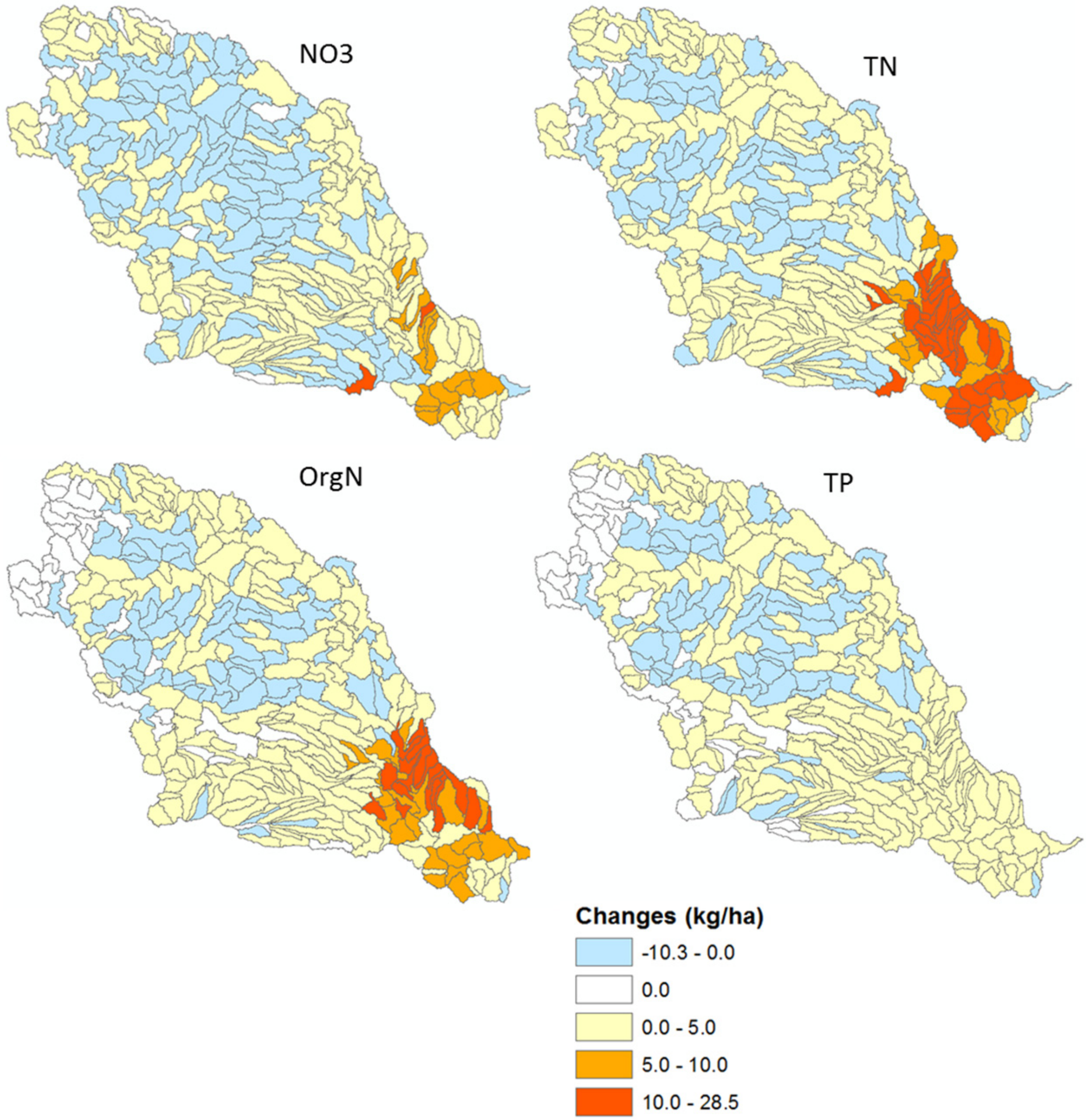

FIGURE A-6 Geographic Representation of Changes in Nitrate, Organic Nitrogen, Total Nitrogen, and Total Phosphorus at the HUC-8 Subbasins in the MoRB under the Future Land Use and Cover Scenario Compared with the Baseline Values (Negative value means a decrease; positive value means an increase.)

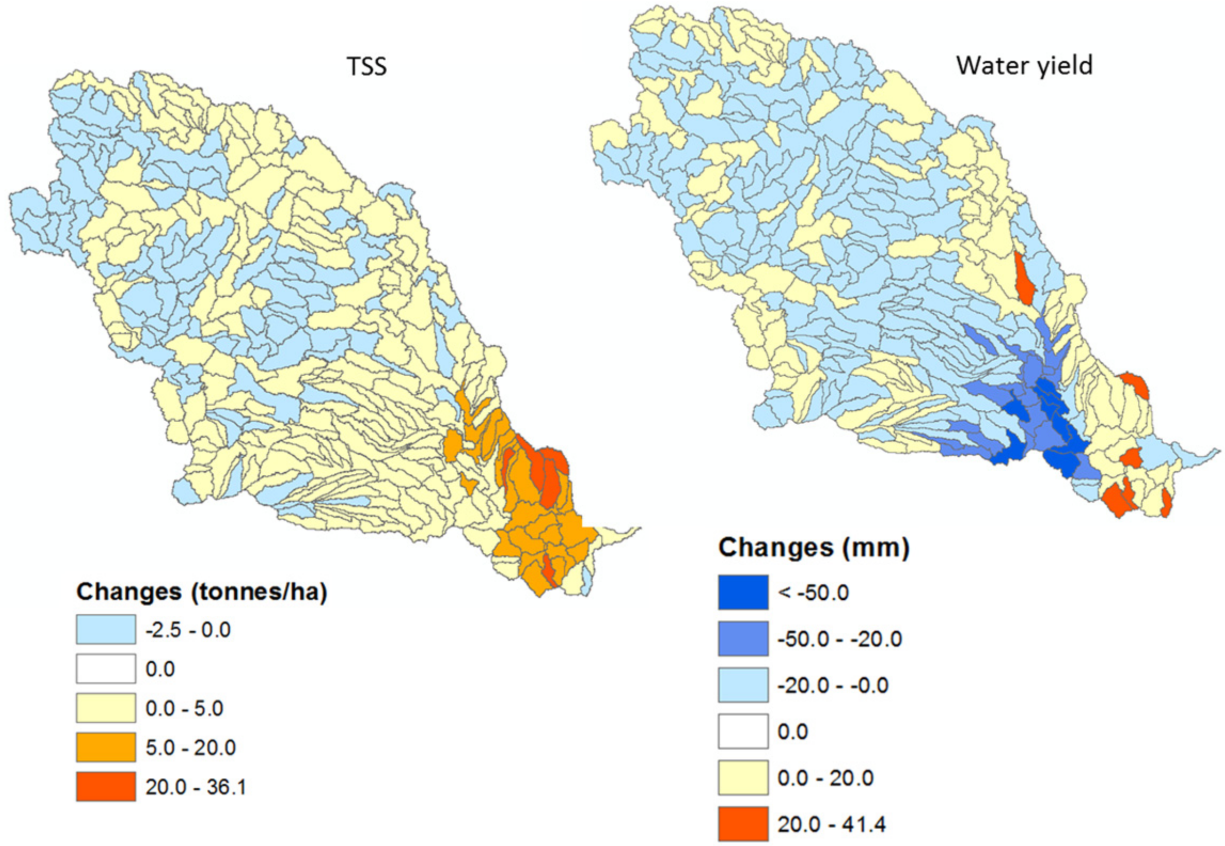

FIGURE A-7 Geographic Distributions of Changes in TSS and Water Yield at the HUC-8 Subbasin Scale in the MoRB under the Future Land Use and Land Cover Scenario Compared with the Baseline Values (Negative value means a decrease; positive value means an increase.)

increase. Switchgrass acreages in both regional watersheds were small — only a fraction of that in the Kansas River watershed. Therefore, a valuable option can be to mitigate nutrient and soil loss in these two regional watersheds by converting an increased proportion of land to SWG.

It is noticeable that TSS, organic phosphate (OrgP), inorganic phosphate (IngP), and total phosphorus (TP) loadings were decreased from the Middle Lower Missouri River watershed to Lower Missouri River watershed. Since the outlet of Lower Missouri River watershed is the outlet of the MoRB to the main stem of the Mississippi River, results represent a minimal impact of future scenario on the phosphorus and TSS loadings exported to the Mississippi River Basin.

Iowa and Missouri appeared to be the states with the highest nitrogen loadings; they contributed to a significant portion of the nutrients loading into the Missouri River. The most vulnerable subbasin at the HUC-8 level appears to be 102400002, to which loadings of sediments, organic nitrogen, total nitrogen, and phosphorus (total organic and water soluble) are ranked the highest. It is followed by Subbasin 10230007. Both of them are in western Iowa in the Middle Lower Missouri River watershed (Figure A-9). There is little overlap in the watersheds between a high nitrate loading and other water quality constituents. Residing in Missouri,

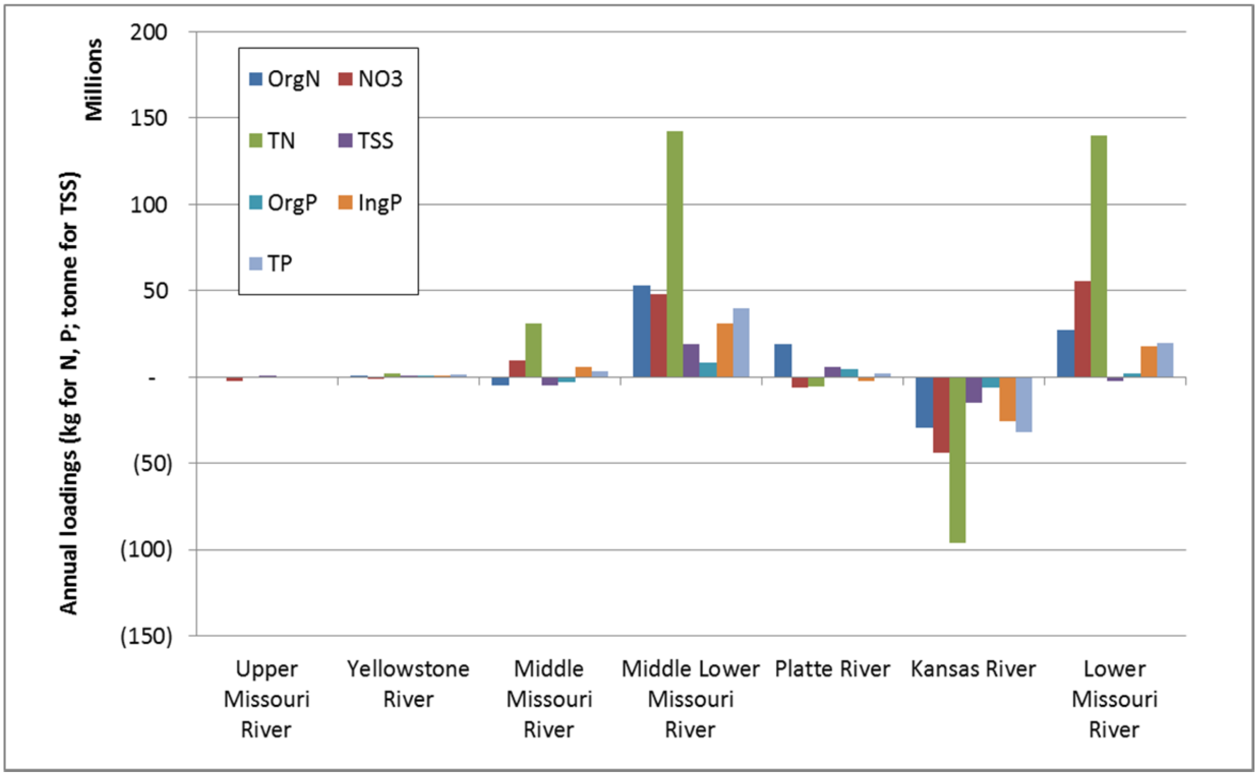

FIGURE A-8 Summary of Changes in Nitrogen and Phosphorus at Seven Regional Watersheds in the MoRB under the Future Land Use and Cover Scenario Compared with Baseline Values (The seven regional watersheds are shown in Figure A-4 and Table A-1)

subbasins 10300200 and 10290102 ranked at the top in nitrate loading. However, these two subbasins were not in the list of the top 10 for TN (in Iowa, Figure A-9), because the TN loadings in the MoRB is mostly influenced by the loadings of organic nitrogen, rather than nitrate. Finally, the change in land use and land cover under the future scenario did not cause a shift of the relative loading ranking among the subbasins in the MoRB.

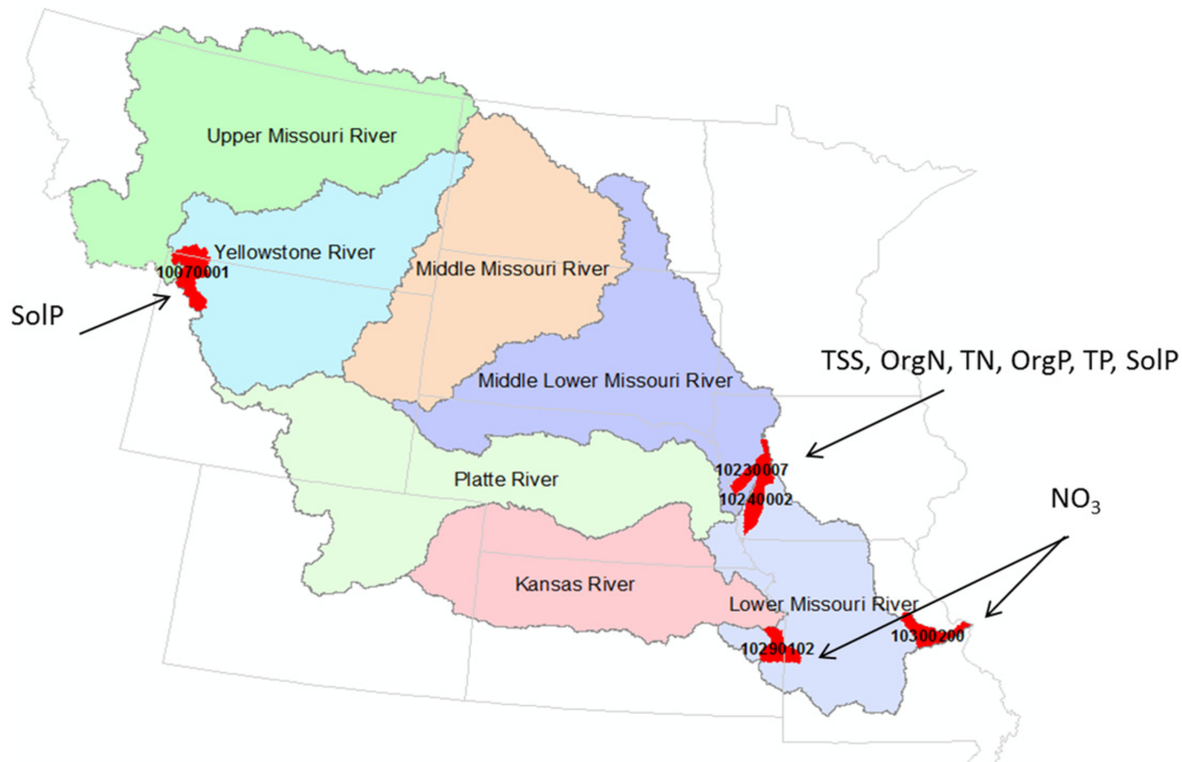

FIGURE A-9 Locations of the Hot Spots for Nitrogen and Phosphorus Sediments at the HUC-8 Subbasins in the MoRB.

A.6 CONCLUSIONS AND RECOMMENDATIONS

It was demonstrated that the conversion of land to grow SWG resulted in an excellent improvement in water quality. Incorporating SWG into 100 ha of land in the Kansas River watershed was able to significantly reduce the nutrient loss and sediment loss across all of the chemical compounds evaluated (orgN, nitrate, TN, orgP, ingP, TP, and TSS). The loss of TN could be reduced by up to 100 million kg. However, the water yield (available water) in the watershed could decrease as the demand for evapotranspiration increased due to changes of land cover. Organic nitrogen and nitrate are the key nutrients in the MoRB.

Under the historical baseline and the future scenario, the Middle-Lower Missouri River and Lower Missouri River watersheds are confronting risks associated with an increase in nitrogen (in all forms).The high level of nutrients in the two watersheds is the result of a combination of land use changes involving small grains, corn, pasture land, and soybeans and the cumulative loadings received by the watersheds from upstream. The impact appears to be persistent and pronounced, even with a large reduction in the corn acreage in the Lower Missouri River watershed. The study identified four subbasins with the highest nutrient and sediment loss (10230007, 10240002, 10290102, and 10300200). These hot spots could be mitigated by adopting land use and land cover designs at scales similar to those used for the Kansas River watershed.

A future study will focus on developing and evaluating integrated agriculture and biomass landscape with BMPs implementation to compare the trade-offs between curb nutrient and sediment loss in the hot spots areas, agriculture production, and feedstock production.

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PART B: MODELING THE SPATIAL AND TEMPORAL VARIATIONS IN SEDIMENT, NITROGEN, AND PHOSPHORUS LOADINGS IN THE MISSOURI RIVER BASIN UNDER HISTORICAL AND PROJECTED LAND USE SCENARIOS

B.1 INTRODUCTION

The Missouri River Basin (MoRB) is the largest of the water resource regions that make up the Mississippi River Basin (MRB). More than 160 stream reaches, lakes, reservoirs, and points in the MoRB were reported to the U.S. Environmental Protection Agency (EPA) as having nutrient-related impairment on the 303(d) lists in 2006 (EPA 2013). Nutrient-related issues within the MoRB are important to state resource managers tasked with developing nutrient criteria, total maximum daily loads, and nutrient reduction strategies. In addition, resource managers require precise estimates of sediment and nutrient loads to receiving waters to monitor compliance with water quality standards. The Missouri River had the largest sediment loads of any large river in the United States and contributed nearly one-half the sediment delivered to the Gulf of Mexico by the Mississippi River (Meade 1995). In addition, nutrient loads from the MoRB and other major river basins of the Mississippi River have been linked to hypoxic conditions in the northern Gulf of Mexico (Rabalais et al. 2002; Donner and Scavia 2007; Scavia and Donnelly 2007; Turner et al. 2008). The hypoxic zone in the Gulf is one of the largest in the world, and its size is related to the fluxes of nutrient exports from the Mississippi River (Rabalais et al. 2002).

In 2008, led by the EPA's Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, the Hypoxia Task Force (HTF) began to develop a plan for reducing nutrient exports by the Mississippi and Atchafalaya Rivers. It was suggested that nitrogen exports might need to be reduced by up to 55% to achieve the hypoxia-reduction goal because of the annual climate-driven variability in nitrogen flux and the annual variability in ocean dynamics (Donner and Scavia 2007; Scavia and Donnelly 2007). The HTF set a goal for a 50% reduction in nutrient losses in the watersheds of the 12 MRB states (EPA 2008). A five-year reassessment in 2013 showed that results in achieving this goal were promising in several states (EPA 2013). The ability to estimate the stream flow and the sediment and nutrient loading at any point on a river throughout the MoRB could provide additional valuable information for quantifying the effects of water resource management.

Two baseline Soil and Water Assessment Tool (SWAT) models were developed and calibrated for the MoRB (Zhang and Wu 2013). The baseline models could perform a long-term, detailed analysis of riverine sediment, nitrogen, and phosphorus loading in the MoRB. This work was aimed to further investigate spatial and temporal variations of sediment, nitrogen, and phosphorus loading under current conditions and under projected land use changes.

B.2 BASELINE SWAT MODELS

B.2.1 SWAT Models

The MoRB covers about 1,502,000 km^2 and includes parts of 10 states and Canada. The whole basin is divided by the U.S. Geological Survey (USGS) into 307 eight-digit hydrologic unit codes (HUC-8s). The HUC-8s within the basin are shown in Figure B-1. The main stem of the Missouri River flows 3,768 km from Three Forks, Montana, to its confluence with the Mississippi River near St. Louis, Missouri, which eventually flows to the Gulf of Mexico. The Missouri River's largest tributaries based on runoff are the Yellowstone River in Montana and Wyoming; the Platte River in Wyoming, Colorado, and Nebraska; and the Kansas-Republican/Smoky Hill River and Osage River in Kansas and Missouri. Each of these tributaries drains an area that is more than 26,000 km^2 and has an average discharge that is more than140 m^3/s.

FIGURE B-1 Overview of the Missouri River Basin

Two baseline SWAT models were developed for the MoRB. One model simulated the Upper Missouri River Basin (UMoRB), which covers a drainage area of approximately 786,364 km^2. This model is called the UMoRB SWAT model henceforth. The other model simulated the Lower Missouri River Basin (LMoRB), covering a drainage area of approximately 562,936 km^2. This model is called the LMoRB SWAT model henceforth. The UMoRB outlet is assumed to be at Sioux City, Iowa (Figure B-1). The UMoRB was configured with 163 subbasins (HUC-8), and the LMoRB included 144 subbasins. Baseline land uses were determined on the basis of 2007 cropland data layers (CDLs) and crops grown over the four years from 2007 through 2010. A total of 14,539 and 8,811 hydrological response units (HRUs) were created in the UMoRB and LMoRB SWAT models, respectively. Both SWAT models were executed for a total simulation period of 20 years (1990–2009). The numbers of model calibration sites for the MoRB were 19 for stream flows, 9 for total TSS, and 6 for TN and TP. The overall statistical indices for the model calibration period for all gage stations varied from 0.47 to 0.82 for R^2, from 0.30 to 0.82 for NSE (Nash-Sutcliffe [model] efficiency), and from 4.71 to 81.07 for RMSE (root mean square error). The indices for the validation period varied from 0.55 to 0.84 for R^2, from 0.46 to 0.84 for NSE, and from 4.17 to 96.87 for RMSE. The values for NSE, percent bias (PBIAS), and the ratio of RMSE to the standard deviation of measured data (RSR) were mostly "good" with a few exceptions, according to criteria summarized in Moriasi et al. (2007). Modeling performance statistics and a visual comparison revealed that the baseline SWAT models were effective in capturing watershed hydrology and that they could predict sediment and nutrient loading in the MoRB. Detailed descriptions of the baseline UMoRB and LMoRB SWAT models can be found in Zhang and Wu (2013).

B.2.2 Spatial Variations in Sediment, Nitrogen, and Phosphorus Annual Loadings at HUC-8 Scale

Baseline MoRB SWAT models were used to quantify spatial and temporal variations in sediment, nitrogen, and phosphorus loadings. Spatial variations were characterized based on annual averaged loadings at the subbasin level. Each subbasin load or yield reflects the amount of sediment, nitrogen, and phosphorus that is exported from the subbasin and comes into a reach. Annual subbasin loads are presented in terms of the 2006–2008 year averages, representing a baseline, since the cropping patterns and practices for the this period were applied in baseline SWAT models. The spatial distribution of sediment, nitrogen, and phosphorus loadings is best suited for identifying and ranking the areas based on their relative contributions to the TSS, TN, and TP loadings.

Sediment (TSS), organic nitrogen (OrgN), nitrate (NO_3), total nitrogen (TN), organic phosphorus (OrgP), soluble phosphorus (SolP), and total phosphorus (TP) yields from each subbasin were estimated from baseline MoRB SWAT models. An annual data analysis is presented in Table B-1. Large SDs indicate that the yields were highly skewed. The highest annual yield of TSS was discharged from HUC-8 No. 10240002. Annual yields of TSS (>10 tons/ha) were primarily from subbasins in intense agricultural areas of the basin. The highest annual yields of TN and TP were also from HUC-8 No. 10240002. Overall nutrient loads were much higher in the lower portion of the basin (LMoRB) than in the UMoRB. Annual yields (>20 kg of N/ha and >10 kg-of P/ha) were primarily discharged from subbasins dominated by the large corn acreage of the LMoRB. Spatial distributions of annual OrgN, NO_3, TN, TSS, OrgP, and SolP yields across subbasins in the MoRB are shown in Figure B-2.

TABLE B-1 Statistics for Modeled Sediment, Nitrogen, and Phosphorus Loadings from Subbasins

Statistics	TSS (dry metric tons/ha)	OrgN (kg/ha)	NO_3 (kg/ha)	TN (kg/ha)	OrgP (kg/ha)	SolP (kg/ha)	TP (kg/ha)
Mean	3.70	6.44	2.16	8.60	0.83	0.07	1.88
Median	1.05	2.49	0.36	3.18	0.30	0.01	0.68
Standard deviation	6.86	10.26	4.33	12.8	0.13	0.13	2.98
Maximum	53.59	68.28	39.41	78.43	9.51	1.17	19.01

All 307 of the subbasins in the MoRB were ranked by their delivered loads (Table B-2). There was a gradual decrease from the highest contributing subbasin to the lowest; however, there was a relatively large decrease after the first 20 highest subbasins. Subbasins with higher N and P yields were mostly in Iowa, Missouri, Nebraska, and Kansas. The top four contributing states delivered a significant part of their nitrogen and phosphorus loadings into the Missouri River. Subbasins with higher sediment yields were spread out over the LMoRB. The major contributors of nitrogen and phosphorous were in areas generally dominated by agricultural croplands.

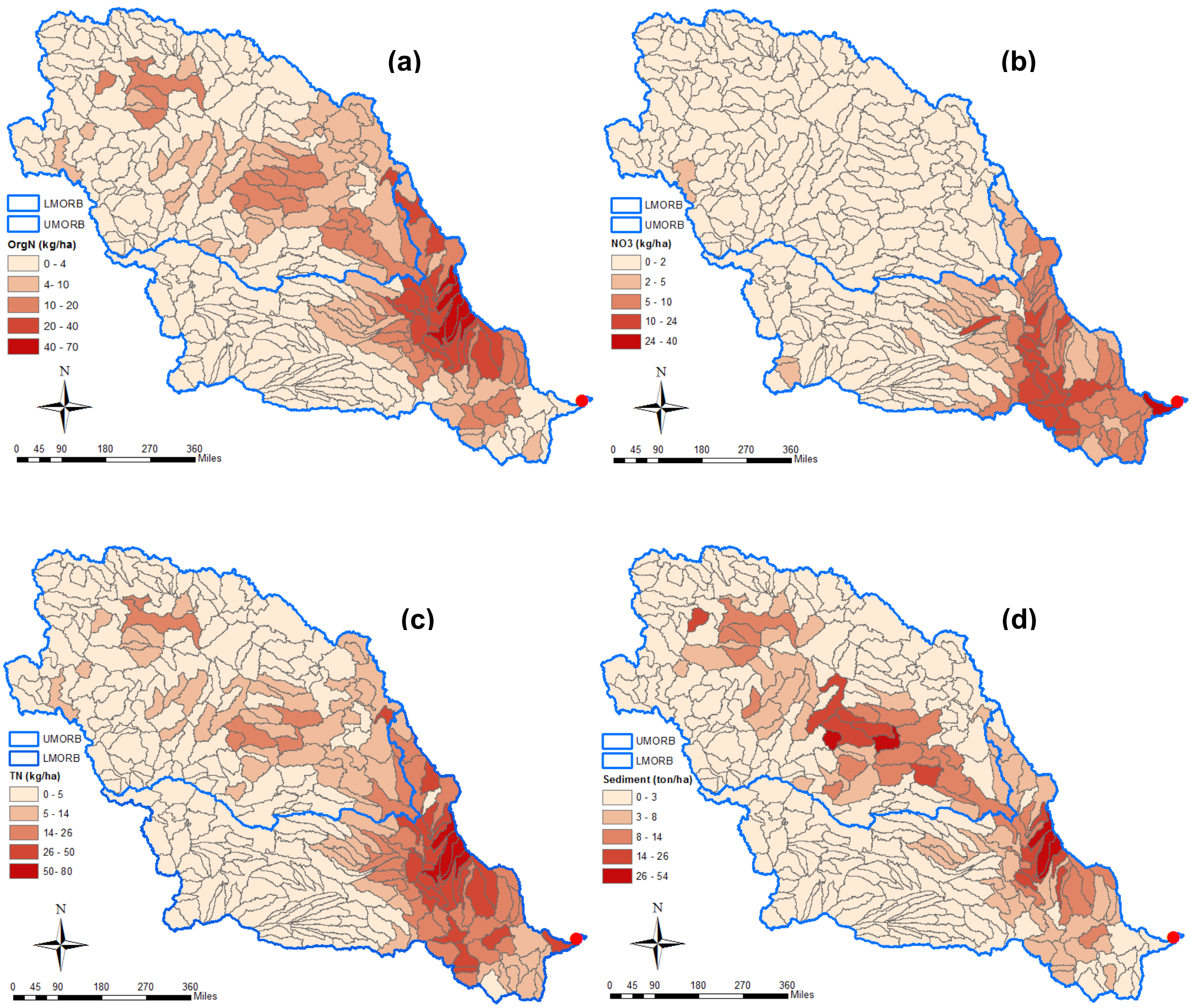


FIGURE B-2 Spatial Distributions of Annual (a) OrgN, (b) NO_3, (c) TN, (d) TSS, (e) OrgP, (f) SolP, and (g) TP Yields (Loadings generated within an HUC-8 Subbasin)

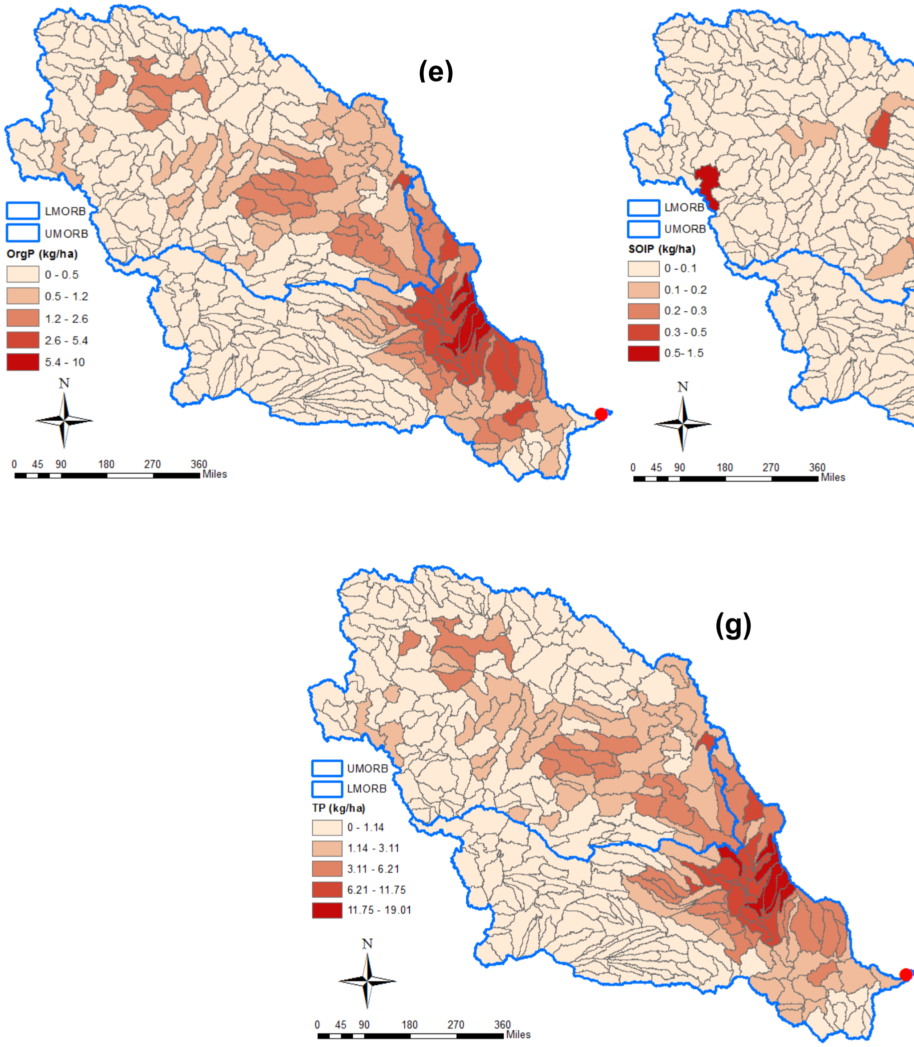


FIGURE B-2 (Cont.)

TABLE B-2 Rankings of Sediment, Nitrogen, and Phosphorus Loadings from Subbasins

Ranking	HUC-8	TSS (dry metric tons/ha)	HUC-8	OrgN (kg/ha)	HUC-8	NO_3 (kg/ha)	HUC-8	TN (kg/ha)
1	10240002	53.586	10240002	68.284	10300200	39.40933	10240002	78.43166
2	10230007	44.076	10230007	67.51133	10270104	23.74733	10230007	75.685
3	10240003	41.494	10240003	59.88033	10290102	21.21333	10240003	70.10833
4	10120203	40.439	10240009	49.66567	10290103	19.28867	10240009	60.46634
5	10120112	31.62966	10240001	43.58666	10230006	18.157	10240001	56.42766
6	10240009	25.854	10230005	43.435	10300101	16.975	10230005	49.83433
7	10040102	25.04933	10220004	39.687	10240007	14.163	10230006	49.11133
8	10240001	20.563	10240006	35.00567	10240001	12.841	10240006	47.696
9	10240013	18.718	10240004	33.232	10290101	12.69167	10240004	44.72133
10	10110201	18.00567	10230004	31.208	10240006	12.69033	10220004	43.978
11	10120113	17.85133	10230006	30.95433	10240008	12.657	10300200	42.709
12	10230006	17.47833	10230001	30.54733	10240011	11.98967	10230001	39.97567
13	10240004	16.79133	10160005	30.16633	10240004	11.48933	10240008	38.06333
14	10240006	16.259	10240013	28.446	10270102	11.22167	10230004	38.03667
15	10230005	16.01067	10280101	25.524	10270103	10.895	10290102	33.989
16	10120202	15.69933	10280102	25.51133	10200103	10.88667	10240013	33.90633
17	10130304	15.45033	10240008	25.40633	10240009	10.80067	10240005	32.429
18	10140204	15.023	10200202	25.10733	10240003	10.228	10200202	31.15
19	10130305	14.291	10240005	23.94633	10240002	10.14767	10160005	30.87733
20	10120109	13.99767	10220003	23.54	10230001	9.428333	10240010	30.72

Ranking	HUC-8	OrgP (kg/ha)	HUC-8	SolP (kg/ha)	HUC-8	TP (kg/ha)
1	10240002	9.509	10070001	1.166667	10240002	19.01233
2	10230007	9.435666	10240002	0.526333	10230007	17.46
3	10240003	8.584666	10220004	0.522	10240003	17.31333
4	10240009	6.806333	10240003	0.507667	10220004	16.376
5	10230005	6.041667	10240004	0.451333	10230005	13.383
6	10240001	5.753333	10230006	0.397667	10240009	12.23633
7	10220004	5.402334	10280202	0.377333	10240001	12.199
8	10240006	4.529667	10170204	0.371333	10220003	11.74967
9	10240004	4.446334	10230005	0.369667	10230006	10.024
10	10230004	4.261	10110203	0.362333	10210009	9.605
11	10230006	4.115	10240009	0.358	10240006	9.522333
12	10230001	4.006333	10220003	0.354333	10230001	9.280667
13	10160005	3.739667	10230003	0.353	10240004	9.025333
14	10240013	3.431334	10230007	0.349333	10200202	8.91
15	10240008	3.388667	10300101	0.340667	10200201	8.725333
16	10280101	3.237667	10200202	0.335667	10200203	7.621667
17	10280102	3.235333	10230001	0.326	10240008	7.523333

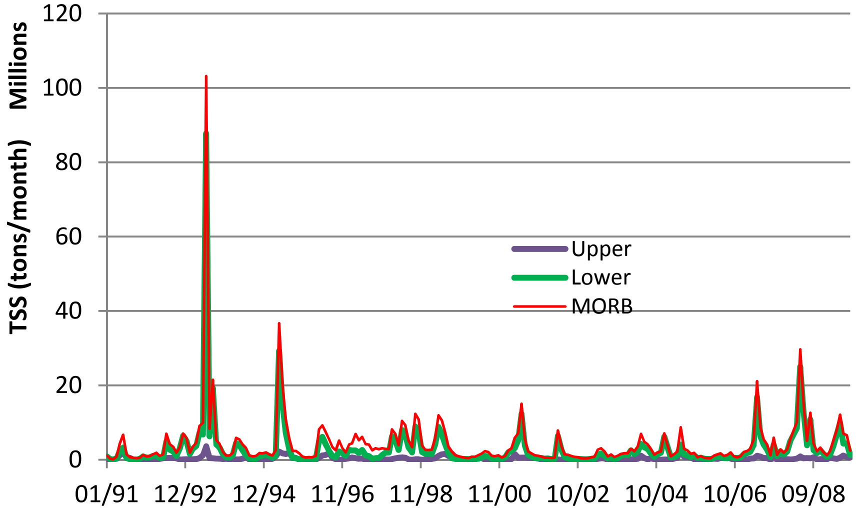
TABLE B-2 (Cont.)

Ranking	HUC-8	OrgP (kg/ha)	HUC-8	SolP (kg/ha)	HUC-8	TP (kg/ha)
18	10220003	3.188667	10240001	0.324667	10230004	7.413667
19	10200202	3.182667	10290102	0.319	10170204	7.054333
20	10240005	3.116333	10200103	0.316667	10240005	6.843667

B.2.3 Temporal Variations in Sediment, Nitrogen, and Phosphorus Loadings for Upper, Lower, and Entire Missouri River Basin

Temporal variations of sediment, nitrogen (OrgN, NH_4, NO_3), and phosphorus (OrgP, IngP) loadings and flow delivered from the UMoRB, LMoRB, and the entire MoRB are shown in Figure B-3. Sediment, nitrogen, and phosphorus loadings discharged from the LMoRB were much higher than those from the UMoRB. The LMoRB loads reflected the majority of sediment, nitrogen, and phosphorus delivered from the MoRB into the Mississippi River. The spatial distribution of sediment, nitrogen, and phosphorus yields at the subbasin level (Figure B-2) also indicates the same pattern.

In order to further investigate the temporal variations of sediment and nutrient loadings across the basin, the MoRB is divided into six watersheds — Upper Missouri River, Middle Missouri River, Yellowstone River, Platte River, Kansas River, and Lower Missouri River (Figure B-4). The Yellowstone, Platte, and Kansas Rivers are three major tributaries of the Missouri River. The entire MoRB is then represented by six regional watersheds. The drainage area of the Upper Mississippi River Basin (UMRB) covers the Yellowstone River, Upper Missouri River, and Middle Missouri River watersheds. The drainage area of the Lower Mississippi River Basin (LMRB) covers the Platte River, Kansas River, and Lower Missouri River watersheds. The characteristics for each major watershed are given in Table B-3.



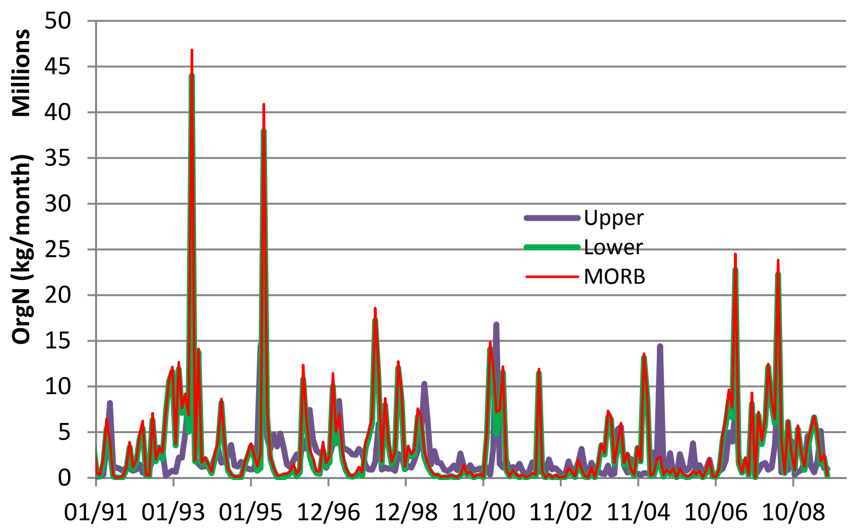
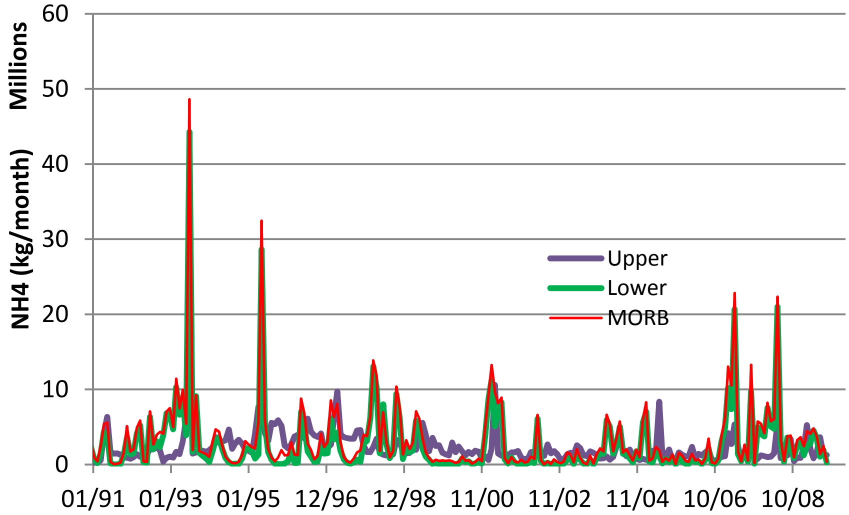
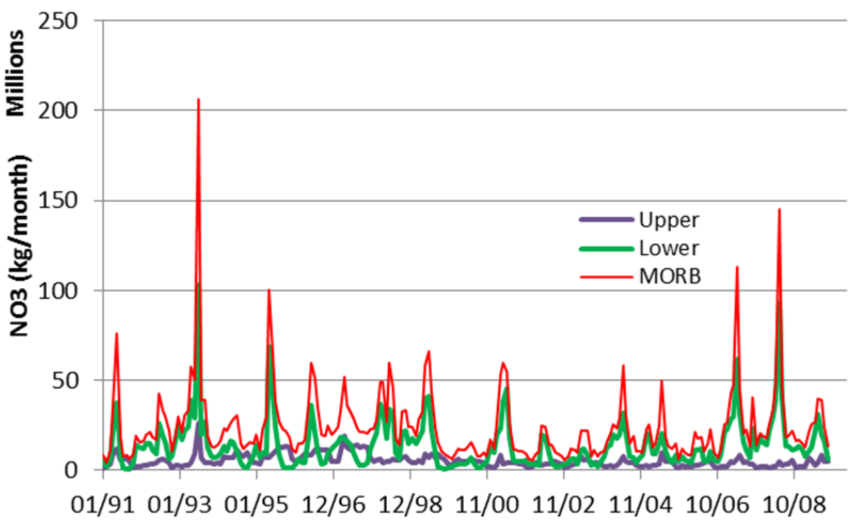


FIGURE B-3 Temporal Variations in Sediment (TSS), Nitrogen (OrgN, NO_3, NH_4), and Phosphorus (OrgP, IngP, TP) Loadings and Flow Delivered from the Upper, Lower, and Entire Missouri River Basin





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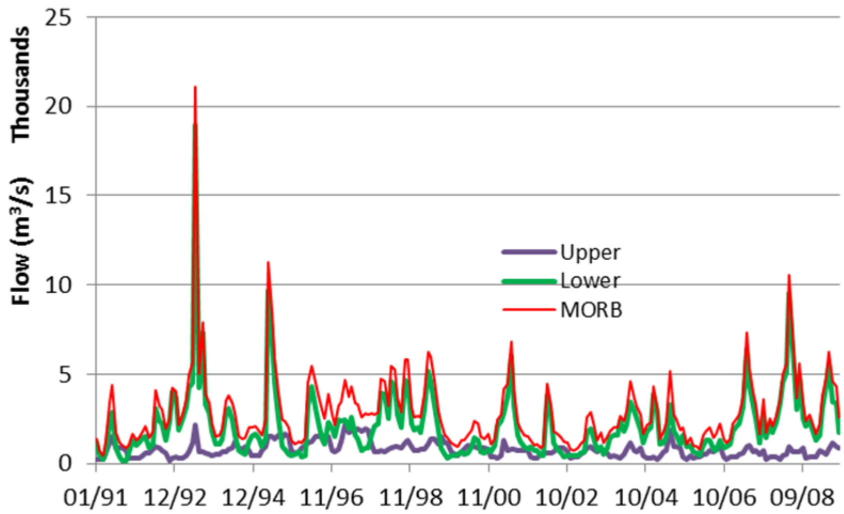

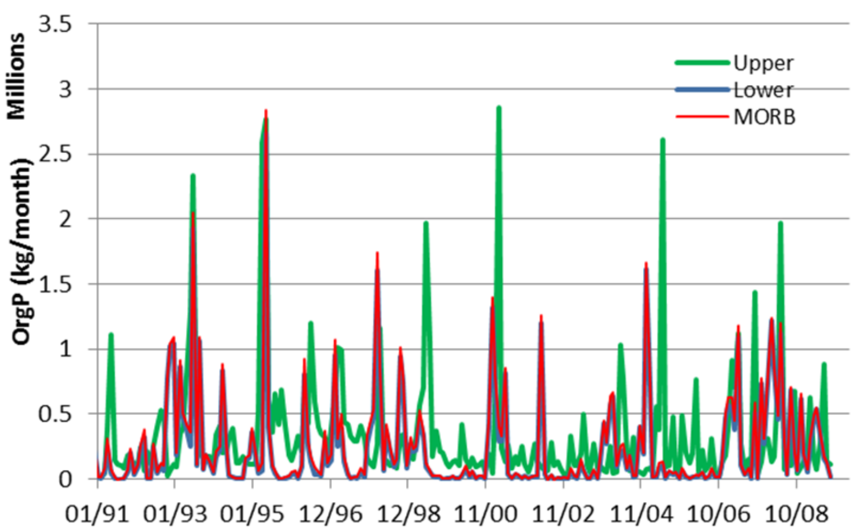

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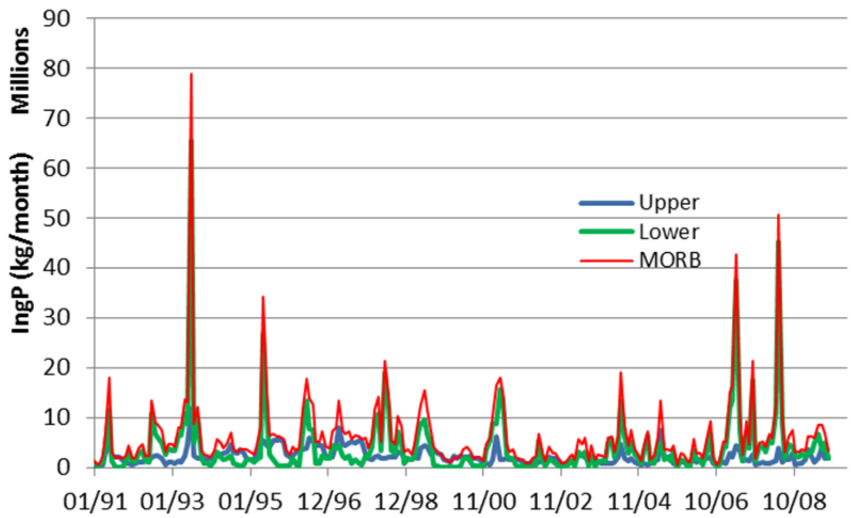

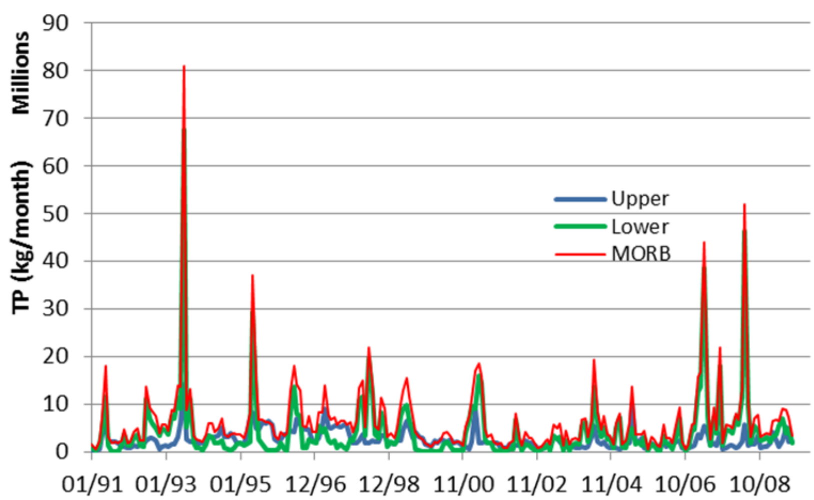

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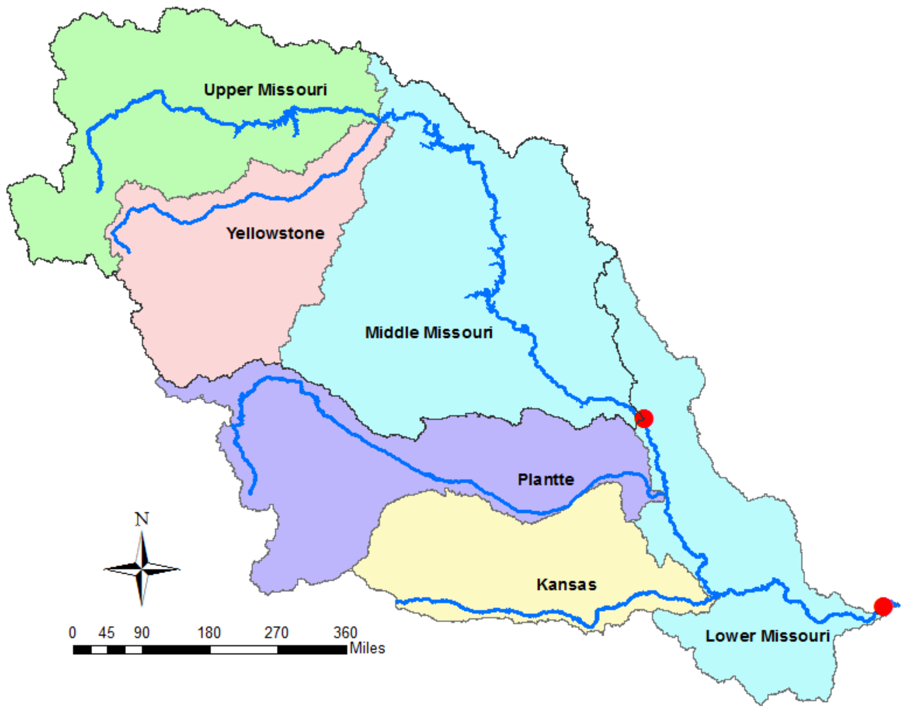
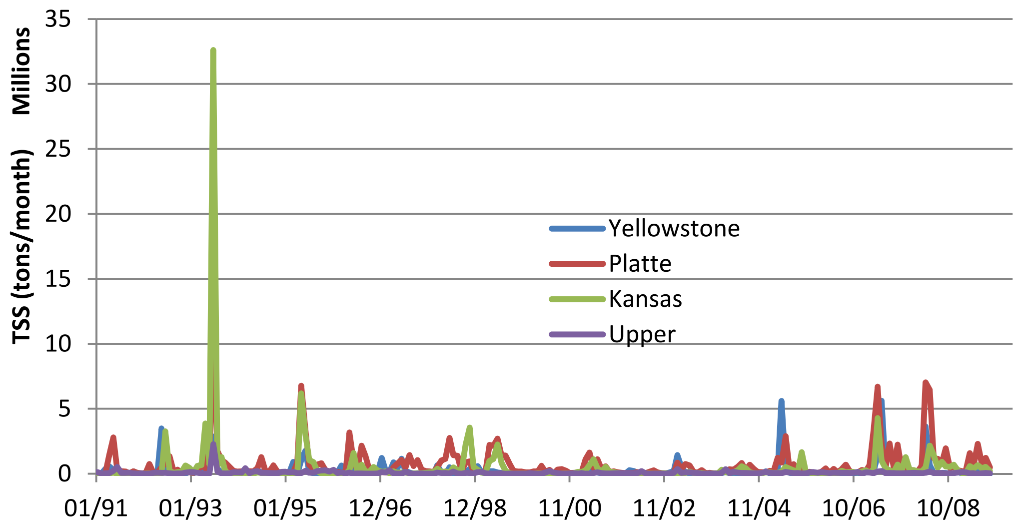


FIGURE B-4 Major Tributaries and Six Regional Watersheds in the Missouri River Basin

TABLE B-3 Summary of Six Regional Watersheds in the Missouri River Basin

No.	Watershed	Watershed Outlet Location	Watershed Area (ha)	Drainage Area (ha)
1	Yellowstone River	Yellowstone River near Sydney, MT	18,137,600	18,137,600
2	Upper Missouri River	Missouri River near Culbertson, MT	23,994,600	23,994,600
3	Middle Missouri River	Missouri River at Sioux City, IA	36,502,463	78,634,619
4	Platte River	Platte River at Louisville, NE	22,152,700	22,152,700
5	Kansas River	Kansas River at Desoto, KS	15,562,300	15,562,300
6	Lower Missouri River	Missouri River at Hermann, MO	18,578,665	134,928,300

In the MoRB shown in Figure B-4, the following four regional watersheds — Upper Missouri River, Yellowstone River, Platte River, and Kansas River watersheds — are directly discharged into the Missouri River. However, flow discharges and loads from the Middle Missouri River watershed and Lower Missouri River watershed represent accumulated values from the whole UMoRB and the entire MoRB, respectively. For three major tributaries and the Upper Missouri River (four watersheds), their loads from both SWAT models are presented as the loads in the river reach transported to the outlet after accounting for the effects of in-stream processes. The temporal variations in the sediment, nitrogen, and phosphorus loadings of these four watersheds are shown in Figure B-5. Loads of TSS, nitrogen (OrgN, NO_3, NH_4), and phosphorus (OrgP and IngP) in the major tributaries of the MoRB varied considerably over 20 years. The loads of nitrogen and phosphorus discharged from the Platte River and Kansas River watersheds were higher than those discharged from the Upper Missouri River and Yellowstone River watersheds, where inputs from all sources were low. The peak hydrographs of nitrogen and phosphorus occurred when there were storm events (for example, in 1993).



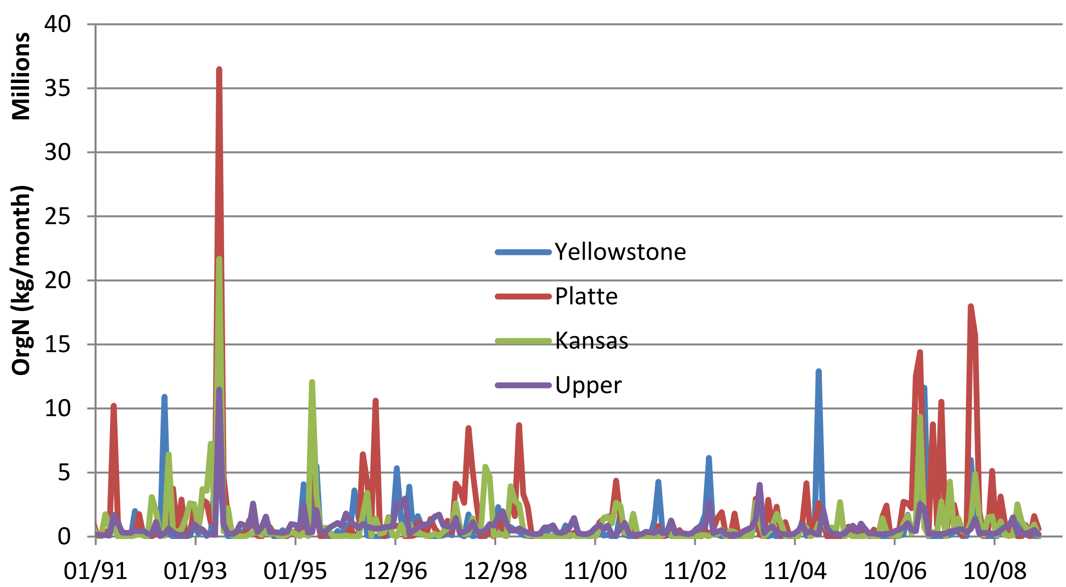
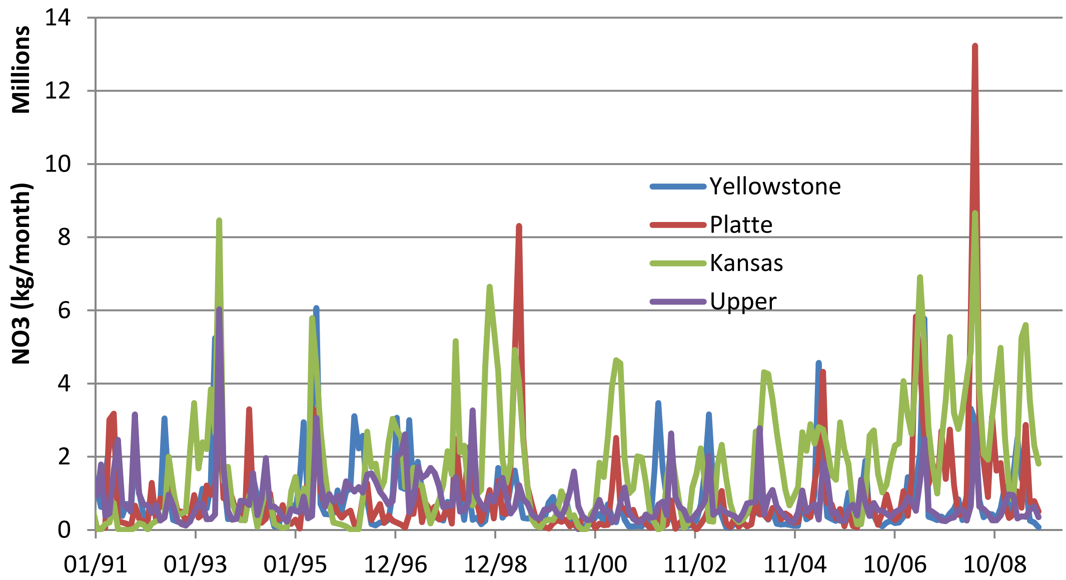


FIGURE B-5 Temporal Variations in Sediment (TSS), Nitrogen (OrgN, NO_3, NH_4), and Phosphorus (OrgP, IngP) Loadings Delivered from the Four Regional Watersheds That Discharge Directly into the Missouri River



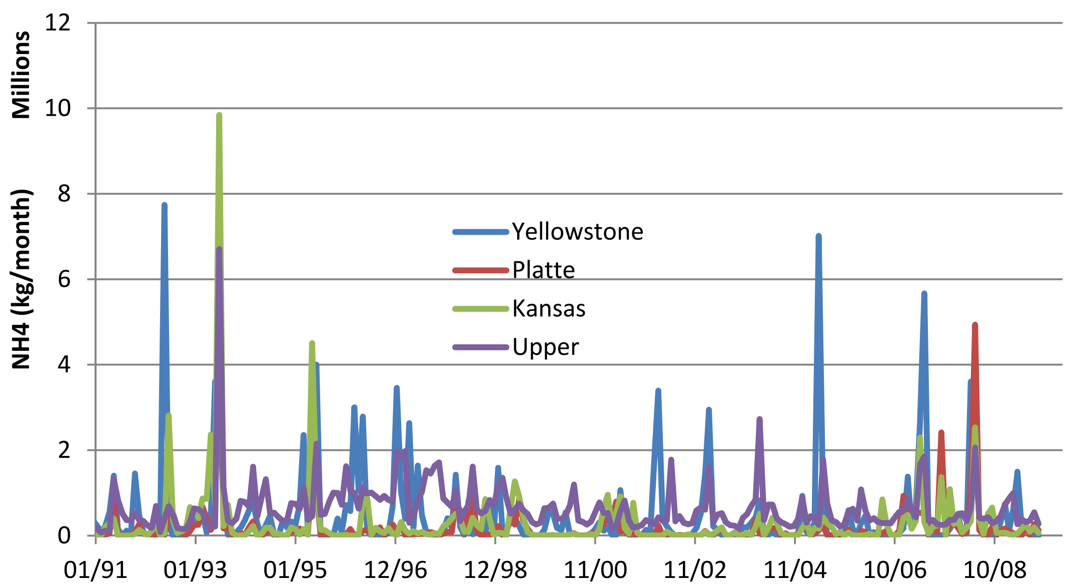
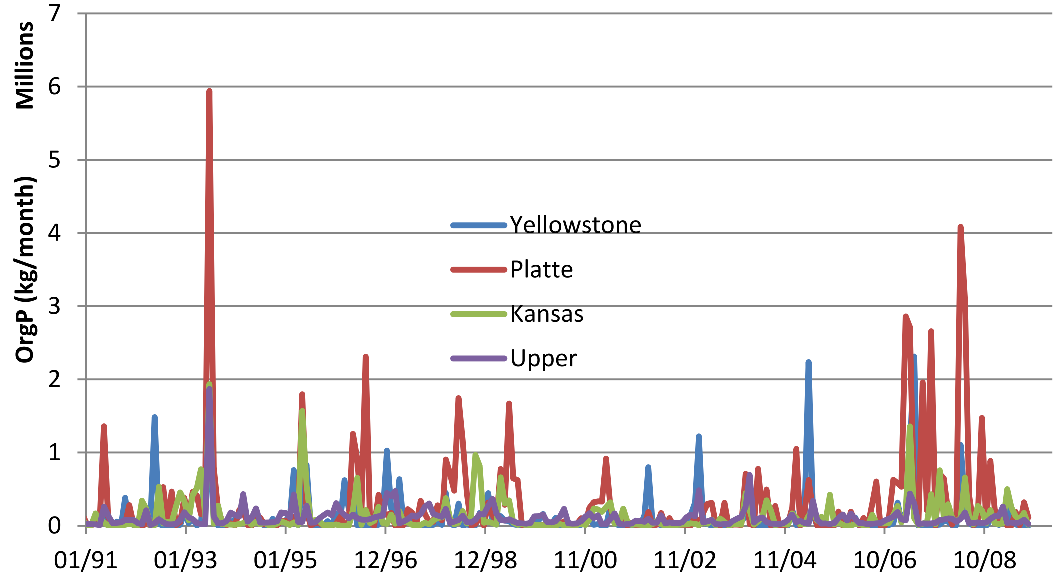


FIGURE B-5 (Cont.)



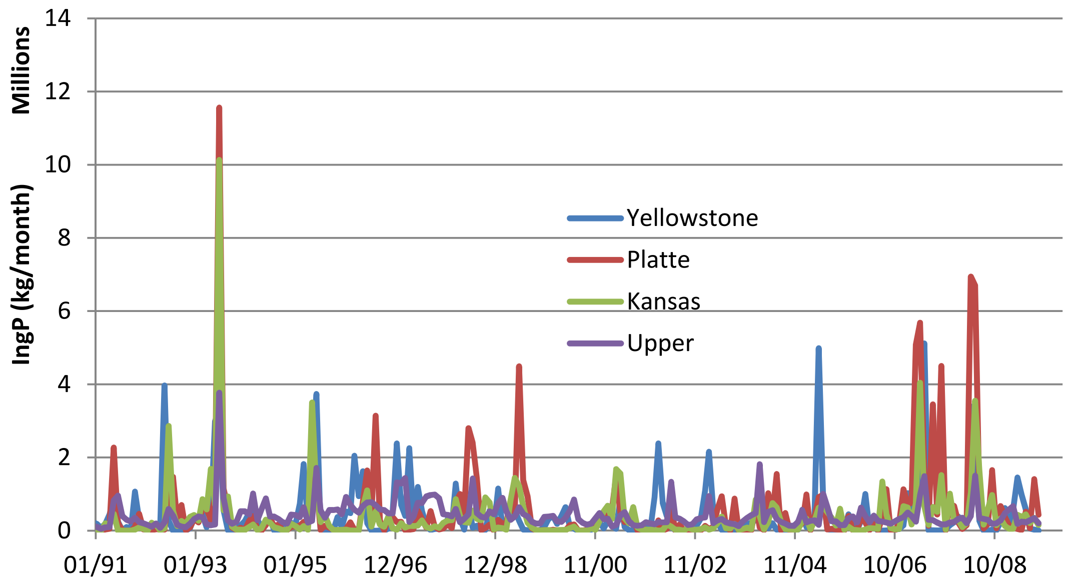


FIGURE B-5 (Cont.)

B.3 IMPACTS OF LAND USE CHANGE ON WATER QUALITY

B.3.1 Projected Land Use Change Scenario and SWAT Models

The baseline land use map for the MoRB is shown in Figure B-6. The dominant land cover in the MoRB is rangeland (51% of the area), most of which is grass and located in the western and central parts of the basin. Cultivated cropland accounts for about 25% of the area, the bulk of which is located in the eastern and southern parts of the basin. Corn and soybeans are the principal crops grown in the eastern portion of the basin, and wheat and other small grain crops are the principal crops grown in the western portion. Agriculture is vital to the economy of the region. The MoRB accounted for about 15% of all U.S. crop sales in 2007, totaling $22 billion (NRCS 2012). Forest accounts for 9% of the area, most of which is located in western and central Missouri. Permanent pasture and hay land represent only 6% of the area. Water, wetlands, horticultural land, and barren land account for about 4% of the area. Urban areas make up only a small part of the basin (3%) and are concentrated near large cities like Denver, Colorado; Omaha, Nebraska; and Kansas City, Missouri (NLCD 2006). The remaining 2% of the area belongs to Canada. Significant changes in land use have occurred in the MoRB over the last 10 years, including a major decrease in forests and an increase in row crops.

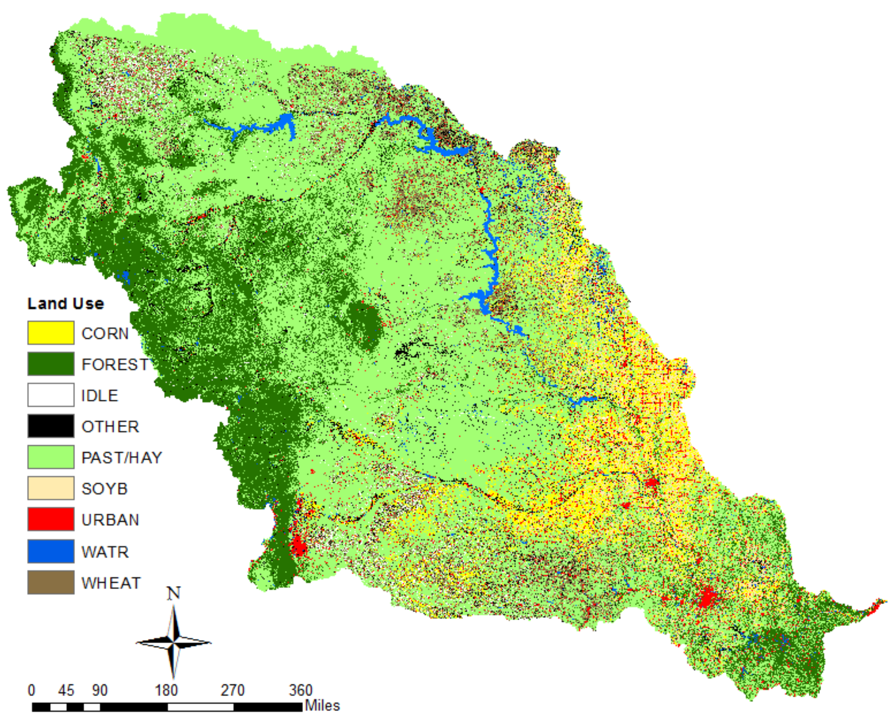


FIGURE B-6 Current Land Use and Land Cover in the Missouri River Basin

A projected land use change based on a relatively conservative feedstock production scenario developed by DOE (2011) was investigated in this study. The scenario assumes a cellulosic feedstock price of $50 per dry ton and an annual crop yield increase of 1%. Land uses projected under the scenario were available at the county level. Before incorporating land use changes into the MoRB SWAT models, projected county-level land uses were first aggregated into subbasins. Land use changes with regard to areas growing major crops between the future scenario and baseline scenario are shown in Figure B-7. The soybean and wheat land areas in the MoRB are expected to increase by about 130 and 23 ha, respectively, while corn acreage would remain about the same. The scenario assumes that switchgrass grows primarily on current pasture lands in the LMoRB. Land use changes involving four major crops at six regional watersheds are illustrated in Figure B-8. Once the baseline land uses at HRU levels are updated with projected land uses, SWAT allows crop rotation patterns to be defined on a yearly basis, with the timing of planting, harvesting, and killing operations being specified by the day and year or by heat units in the model.

Tillage refers to the mechanical mixing of soil with an implement. It redistributes nutrients and plant residue throughout the shallow soil profile and can also serve to disrupt weeds or mix fertilizer into soil. Tillage operations vary spatially, changing as a result of farmer preferences, soil types, and the types of crops grown. For these reasons, it is important to account for the effects of tillage, especially in agricultural lands. Tillage management practices projected under the future scenario were also included in the MoRB SWAT models. Tillage systems include three types: (1) conservation tillage, (2) reduced tillage (RT), and (3) intensive or conventional (CT) tillage. Within SWAT, tillage affects the amount of surface residue left from decaying organic matter. Conservation tillage leaves at least one-third of the soil covered with crop residue after planting. Conservation tillage types include these: (a) no-till (NT)/strip-till, (b) ridge-till, and (c) mulch-till. NT leaves more than 50% residue, which means that in agricultural fields, residue from the previous crop is left on the surface, and the soil is not disturbed by tillage. RT leaves 15–30% residue on the soil surface after planting. RT and conservation tillage include practices that disturb less soil and involve less residue than do standard tillage practices, which leave fields bare. Mulch tillage and conservation tillage were lumped together and are referred to as RT in the MoRB SWAT models. CT involves full-width tillage, but there is less than 15% residue on the soil surface after planting. Projected county-level tillage data for the future scenario were first aggregated into subbasin levels. The distributions of tillage practices for corn and soybeans cultivated in the MoRB are presented in Figures B-9 and B-10. Different tillage implements mix the soil to different depths and have different mixing efficiencies. SWAT includes a database of common tillage implements and their mixing efficiencies.

The SWAT2009_LUC (land use cover) module developed by Pai and Saraswat (2011) was used to incorporate projected land use into baseline MoRB SWAT models. This function allows the user to change the area of one or several HRUs to reflect increases in the size of a specific land use. Although this does allow SWAT models to simulate changing land use, new HRUs are not allowed to be created in SWAT models.The projected land use changes and associated management practices were transferred into the HRUs and incorporated into the baseline MoRB SWAT models. The auto-fertilization feature in the SWAT model for nitrogen

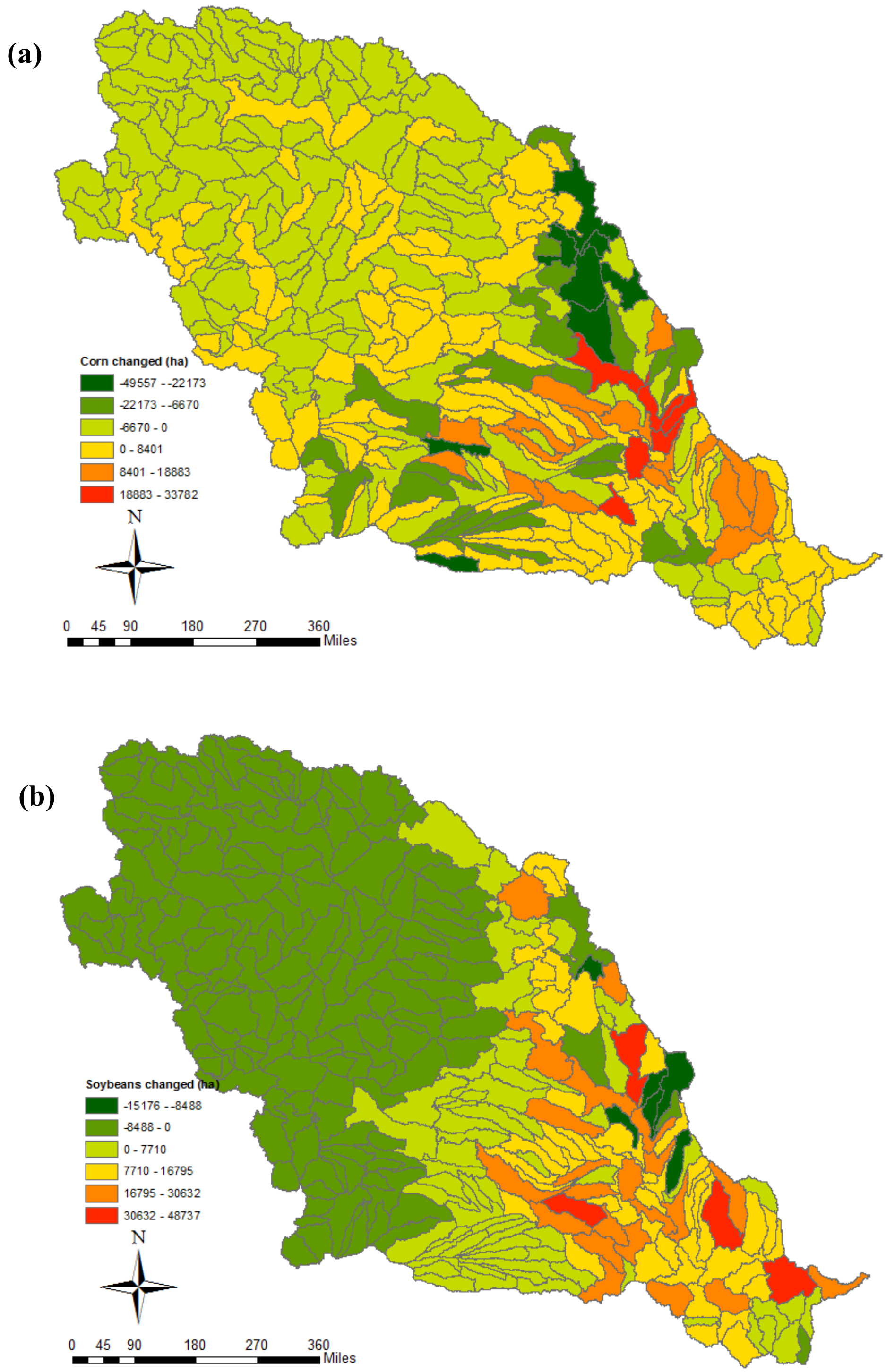


FIGURE B-7 Projected Land Use Changes in (a) Corn and (b) Soybean at the HUC-8 Subbasin

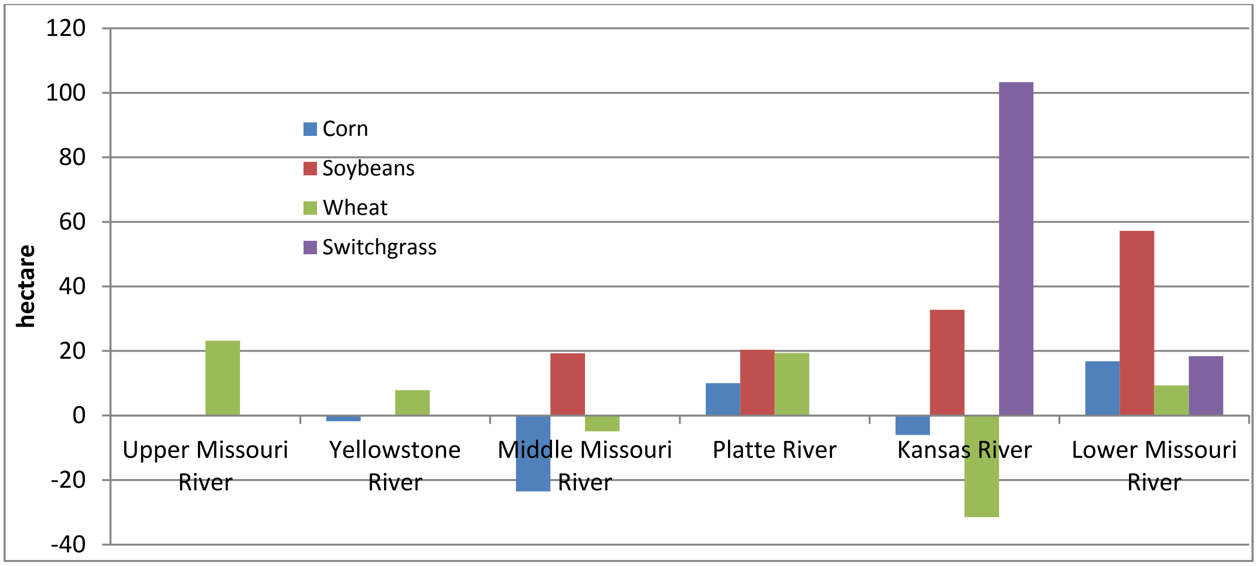


FIGURE B-8 Projected Land Use Changes Involving Four Major Crops at the Six Regional Watersheds in the Missouri River Basin

and phosphorus was applied to the future scenario. The auto-fertilization routine contains oversimplifications, in that producers are not able to easily determine nitrogen stress and efficiently apply uniform amounts of fertilizer over the entire extent of their fields. These simplifications are useful, however, since they allow the simulated crops to reach realistic levels of biomass. In the meantime, auto-fertilization may produce unrealistic nutrient loading for some watersheds.

The MoRB SWAT models implemented for the future scenario accounted for all spatially varying land use distributions and corresponding management changes by adjusting model inputs and parameters at the subbasin and HRU levels, as well as by improving the SWAT model database to represent spatially varying crop properties. The SWAT model simulations for the future scenario used the same 20-year climate data as the data used in the baseline model simulations. The MoRB SWAT models were reconfigured to quantify the spatial and temporal variations of future projected sediment, nitrogen, and phosphorus loadings in the MoRB.

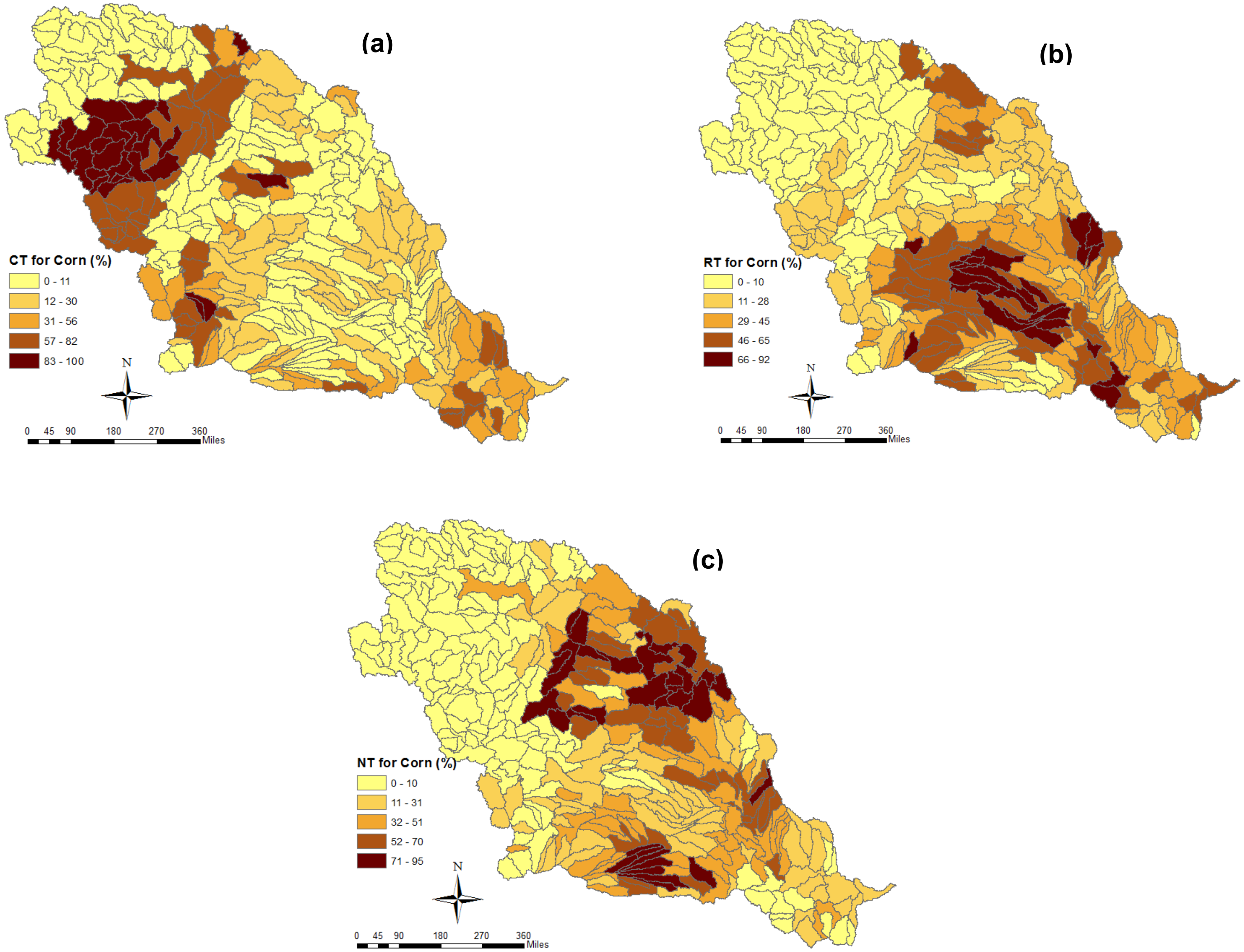


FIGURE B-9 Percent of Projected Tillage Practices Employing (a) CT, (b) RT, and (c) NT for Corn

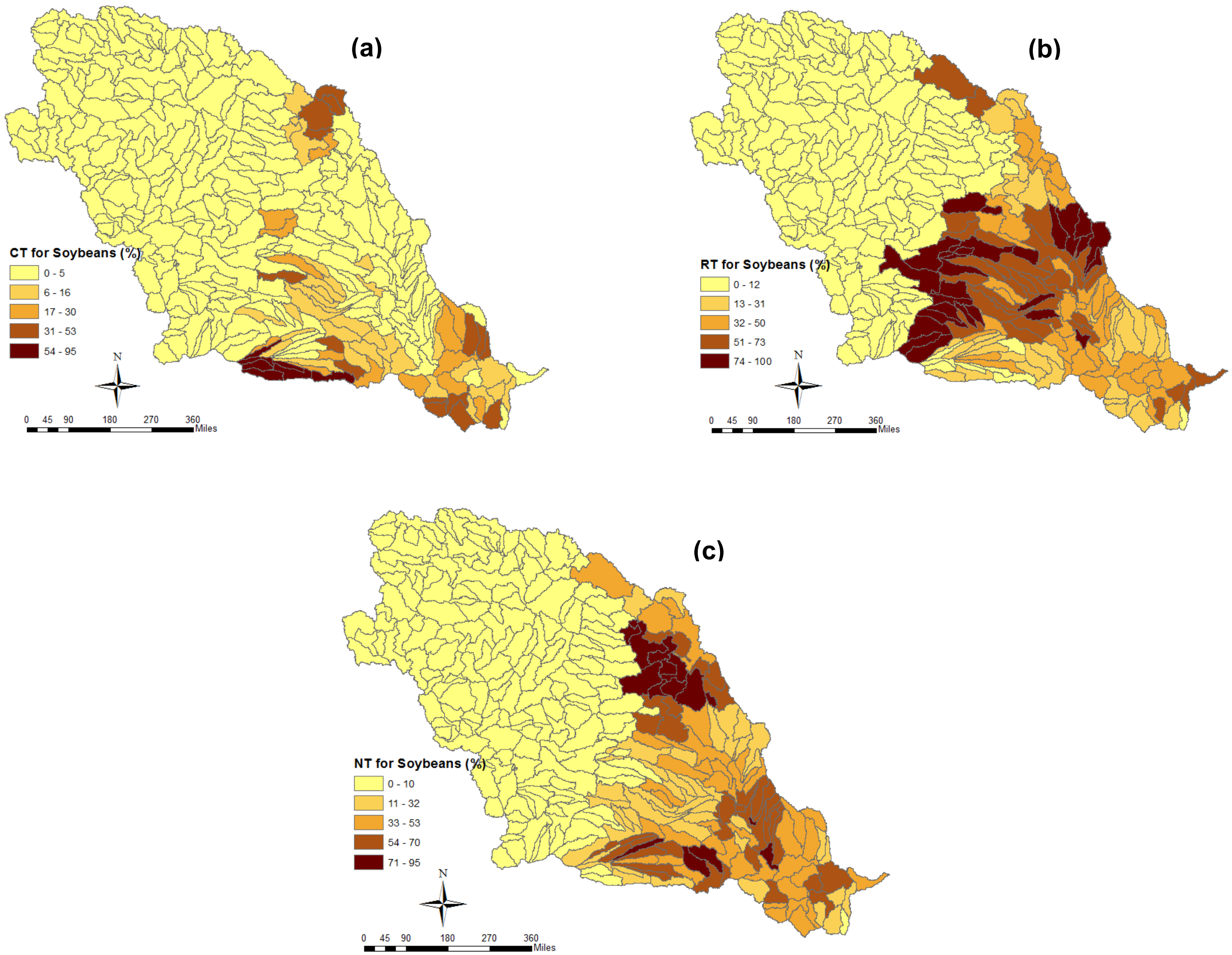


FIGURE B-10 Percent of Projected Tillage Practices Employing (a) CT, (b) RT, and (c) NT for Soybeans

B.3.2 Spatial Variations in Sediment, Nitrogen, and Phosphorus Loadings

SWAT-estimated sediment, OrgN, NO_3, TN, OrgP, SolP, and TP yields from each HUC-8 for the projected land-use-change scenario are shown in Figure B-11. Mean and median annual TSS yields were 5.19 and 1.38 tons/ha, respectively (SD = 9.08 ton/ha). Mean and median annual NO_3 yields were 2.87 and 0.38 kg/ha, respectively (SD = 5.34 kg/ha). Mean and median annual TN yields were 11.09 and 3.78 kg/ha, respectively (SD = 17.26 kg/ha). Mean and median annual SolP yields were 0.07 and 0.01 kg/ha, respectively (SD = 0.15 kg/ha). Mean and median annual TP yields were 2.21 and 0.85 kg/ha, respectively (SD = 3.44 kg/ha). Again, large SDs indicate that the yields are highly skewed. The highest annual yield of TSS was discharged from HUC-8 No. 10240002. The highest annual yields of TN and TP were also discharged from HUC-8 No. 10230007.

All 307 of the subbasins in the MoRB were ranked according to their projected loading (Table B-4). Subbasins with higher N and P yields were still located mostly in Iowa, Missouri, Nebraska, and Kansas. The top four contributing states delivered significant portions of their nitrogen and phosphorus loadings into the Missouri River. Subbasins with higher sediment yields were spread out over the lower part of the Missouri River. The major contributors of nitrogen and phosphorus were in areas that were generally dominated by agricultural croplands.

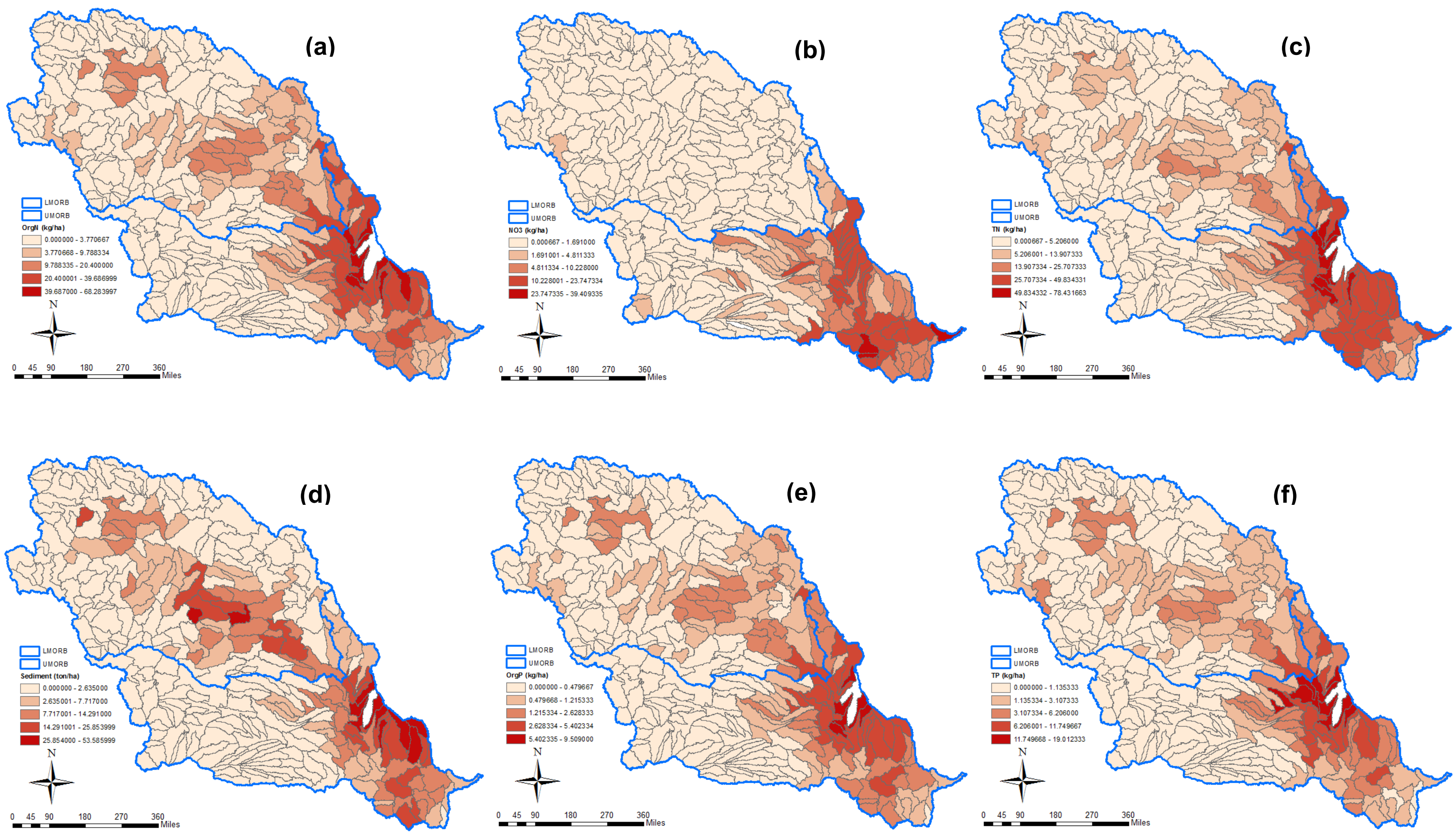


FIGURE B-11 Spatial Distributions of Annual (a) OrgN, (b) NO_3, (c) TN, (d) TSS, (e) OrgP, and (f) SolP Yields under the Future Scenario (Loadings generated within an HUC-8 Subbasin)

TABLE B-4 Rankings of Projected Sediment, Nitrogen, and Phosphorus Loadings from Subbasins

Ranking	HUC-8	TSS (dry metric tons/ha)	HUC-8	OrgN (kg/ha)	HUC-8	NO_3 (kg/ha)	HUC-8	TN (kg/ha)
1	10240002	63.816	10230007	91.45567	10300200	29.06867	10230007	104.1857
2	10230007	47.39633	10240002	79.52934	10290102	27.157	10240002	94.65134
3	10280102	46.52834	10240003	74.37967	10290103	25.54833	10240003	91.017
4	10240003	46.514	10240009	65.59933	10240009	21.96833	10240009	87.56767
5	10280201	41.128	10230005	63.43233	10300101	21.91867	10240001	78.31533
6	10120203	41.12567	10240001	59.063	10230006	20.505	10230005	75.45533
7	10240009	40.64733	10230006	47.92733	10240001	19.25233	10230006	68.43233
8	10240013	40.15567	10240013	46.72267	10270104	18.66867	10240006	63.227
9	10120112	30.793	10240006	46.49933	10240011	18.63367	10240013	59.62867
10	10230006	29.072	10230001	44.57733	10240008	17.41833	10230001	58.42966
11	10280103	28.403	10280102	40.64067	10240004	17.322	10240004	57.05333
12	10240001	26.44267	10240004	39.73133	10260008	16.76367	10240008	52.572
13	10240012	25.49167	10230004	37.79567	10240006	16.72767	10230004	49.943
14	10290107	24.841	10220004	37.45	10240003	16.63733	10280102	46.65867
15	10040102	22.575	10200203	37.089	10290101	16.53967	10240010	46.13934
16	10300104	22.039	10240008	35.15367	10240007	16.28167	10290102	45.40233
17	10230005	20.595	10280101	33.204	10300103	15.88767	10200203	43.393
18	10240006	20.041	10200202	33.134	10240002	15.122	10240005	43.071
19	10240004	19.924	10220003	33.06933	10290108	14.21967	10220004	42.06833
20	10230001	19.48967	10240010	32.868	10300104	14.15467	10300104	41.959

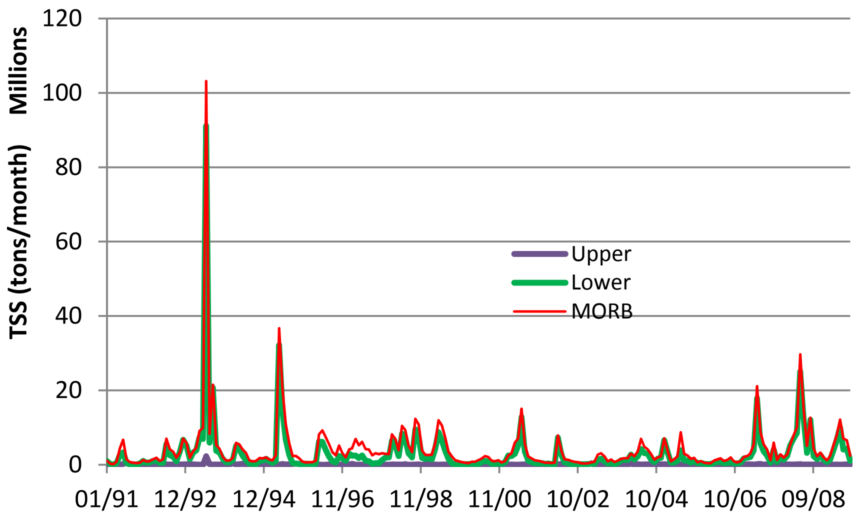
Ranking	HUC-8	OrgP (kg/ha)	HUC-8	SolP (kg/ha)	HUC-8	TP (kg/ha)
1	10240002	9.509	10070001	1.166667	10240002	19.01233
2	10230007	9.435666	10240002	0.526333	10230007	17.46
3	10240003	8.584666	10220004	0.522	10240003	17.31333
4	10240009	6.806333	10240003	0.507667	10220004	16.376
5	10230005	6.041667	10240004	0.451333	10230005	13.383
6	10240001	5.753333	10230006	0.397667	10240009	12.23633
7	10220004	5.402334	10280202	0.377333	10240001	12.199
8	10240006	4.529667	10170204	0.371333	10220003	11.74967
9	10240004	4.446334	10230005	0.369667	10230006	10.024
10	10230004	4.261	10110203	0.362333	10210009	9.605
11	10230006	4.115	10240009	0.358	10240006	9.522333
12	10230001	4.006333	10220003	0.354333	10230001	9.280667
13	10160005	3.739667	10230003	0.353	10240004	9.025333
14	10240013	3.431334	10230007	0.349333	10200202	8.91
15	10240008	3.388667	10300101	0.340667	10200201	8.725333
16	10280101	3.237667	10200202	0.335667	10200203	7.621667

TABLE B-4 (Cont.)

Ranking	HUC-8	OrgP (kg/ha)	HUC-8	SolP (kg/ha)	HUC-8	TP (kg/ha)
17	10280102	3.235333	10230001	0.326	10240008	7.523333
18	10220003	3.188667	10240001	0.324667	10230004	7.413667
19	10200202	3.182667	10290102	0.319	10170204	7.054333
20	10240005	3.116333	10200103	0.316667	10240005	6.843667

B.3.3 Temporal Variations in Sediment, Nitrogen, and Phosphorus Loadings

Under the land use change scenario, temporal variations in sediment, nitrogen (OrgN, NH_4, NO_3), and phosphorus (OrgP, IngP) loadings delivered from the UMoRB, LMoRB, and entire MoRB are shown in Figure B-12.



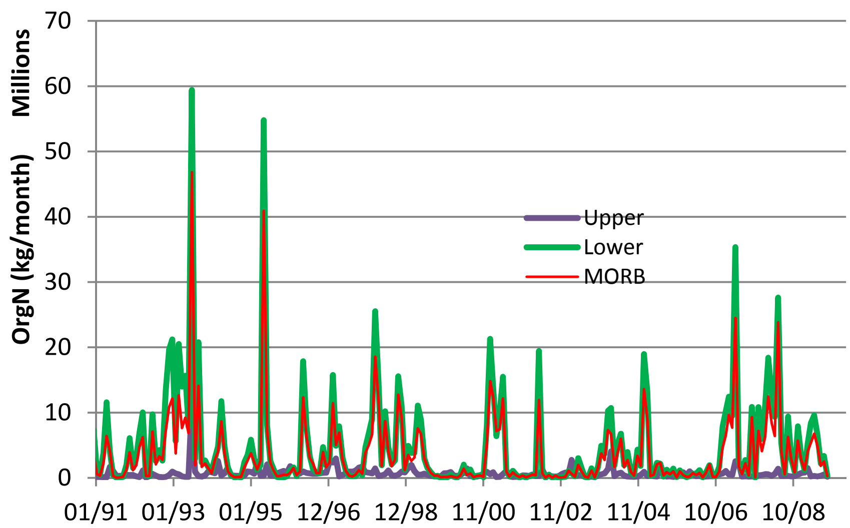
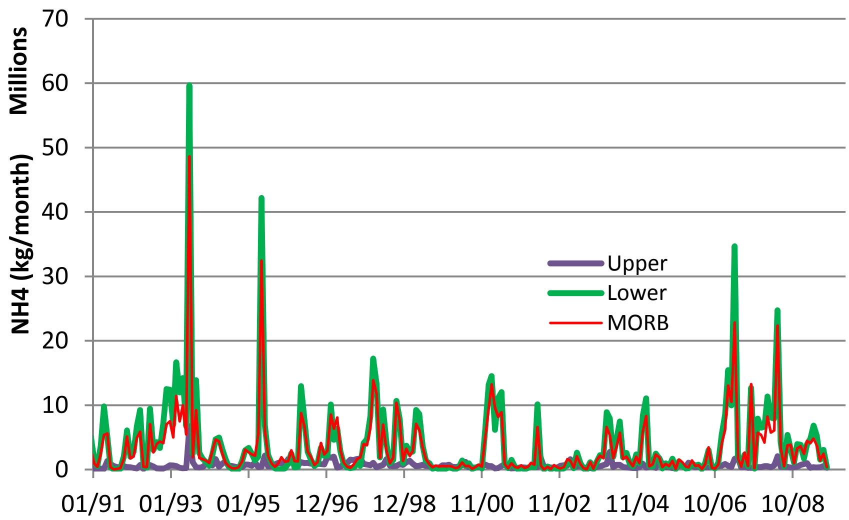


FIGURE B-12 Temporal Variations in Sediment (TSS), Nitrogen (OrgN, NH_4, NO_3), and Phosphorus (OrgP, IngP) Loadings from the Upper, Lower, and Entire Missouri River Basin under the Scenario



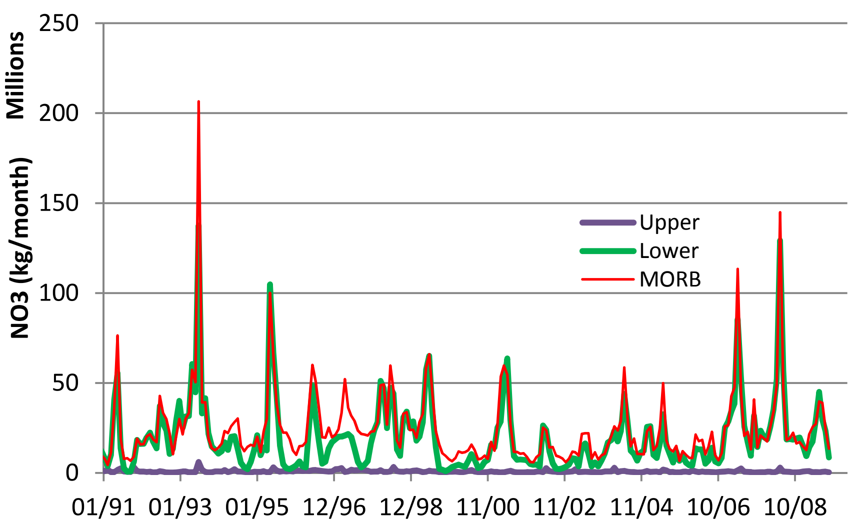
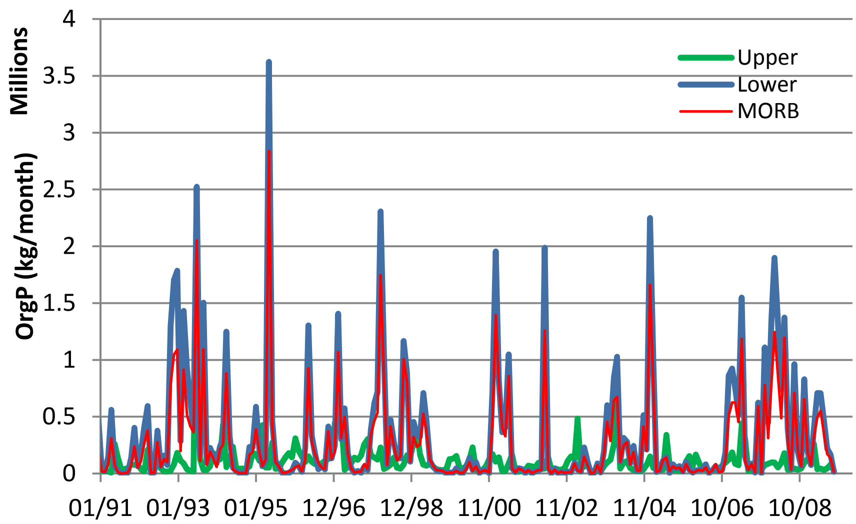


FIGURE B-12 (Cont.)



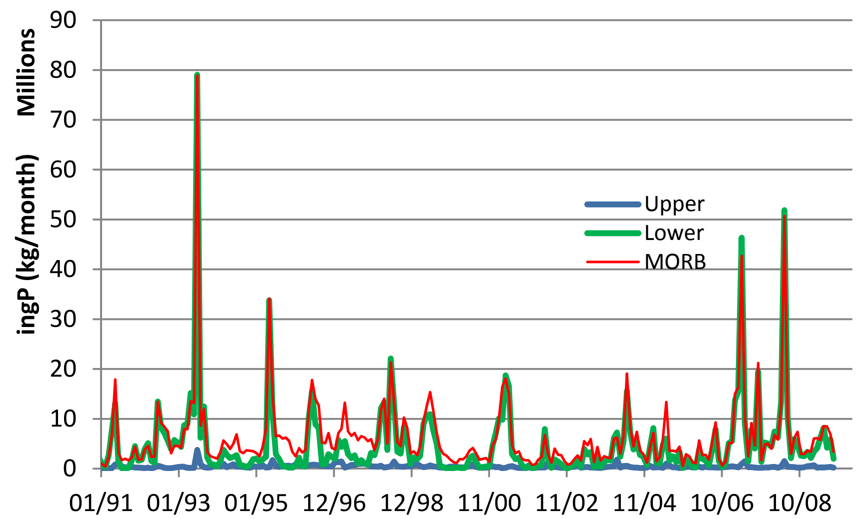
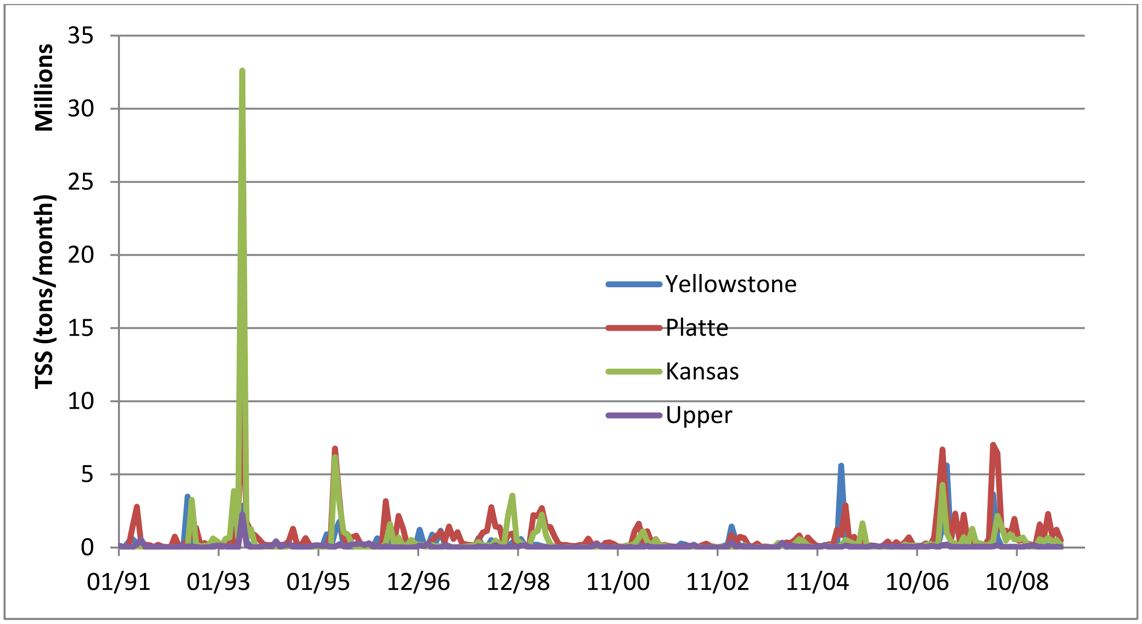


FIGURE B-12 (Cont.)

The temporal variations in sediment, nitrogen, and phosphorus loadings from four regional watersheds are shown in Figure B-13.



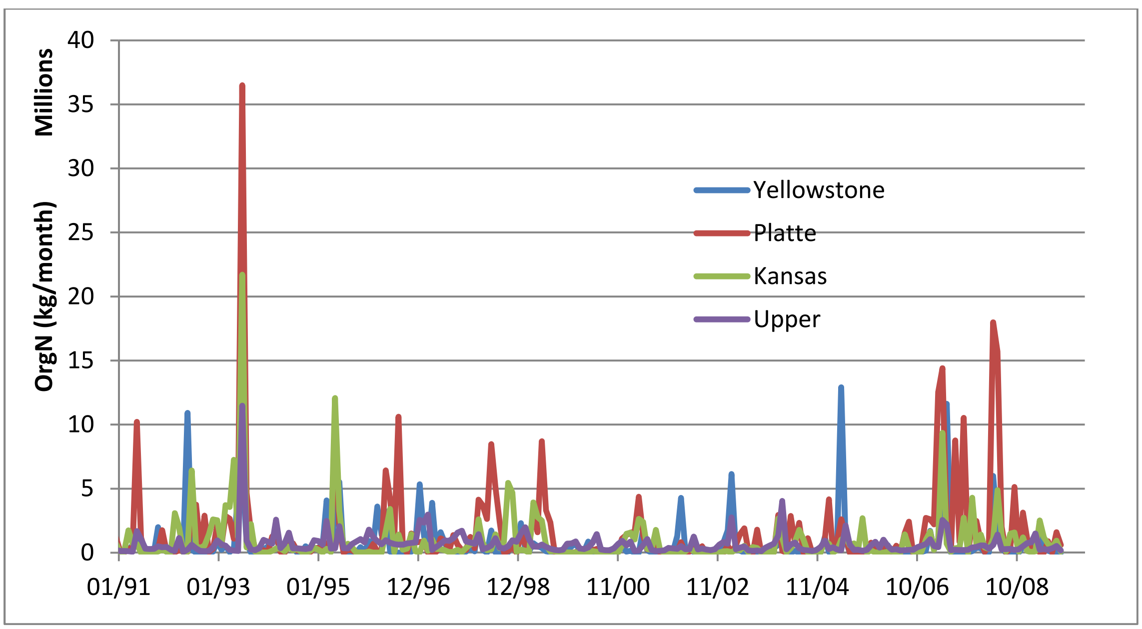
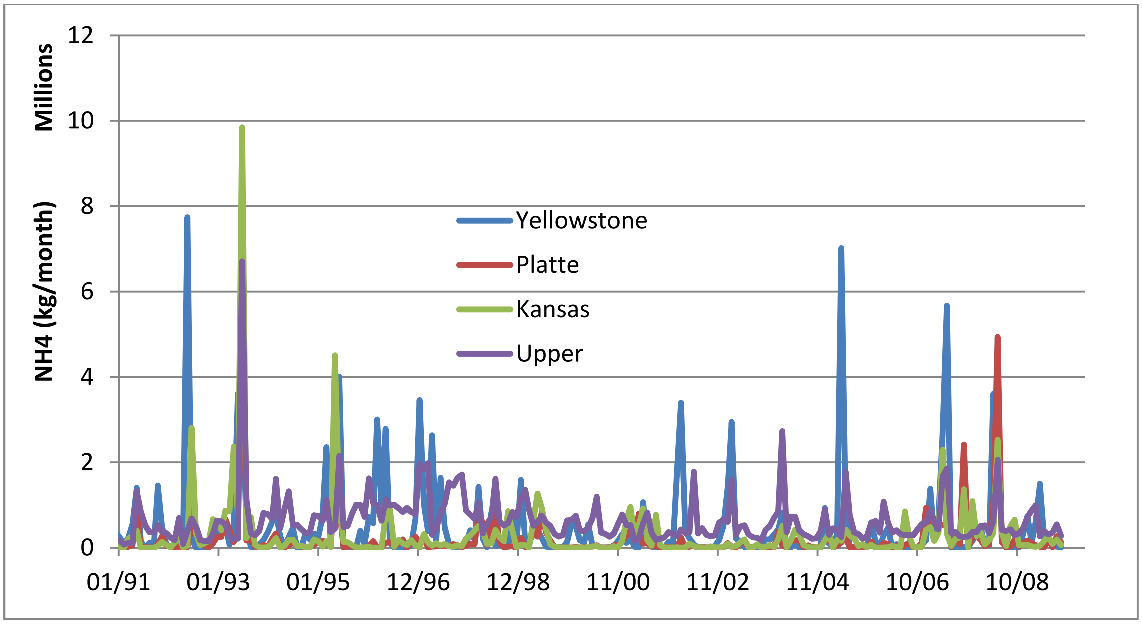


FIGURE B-13 Temporal Variations in Sediment (TSS), Nitrogen (OrgN, NH_4, NO_3), and Phosphorus (OrgP, IngP) Loadings from Four Regional Watersheds under the Future Scenario



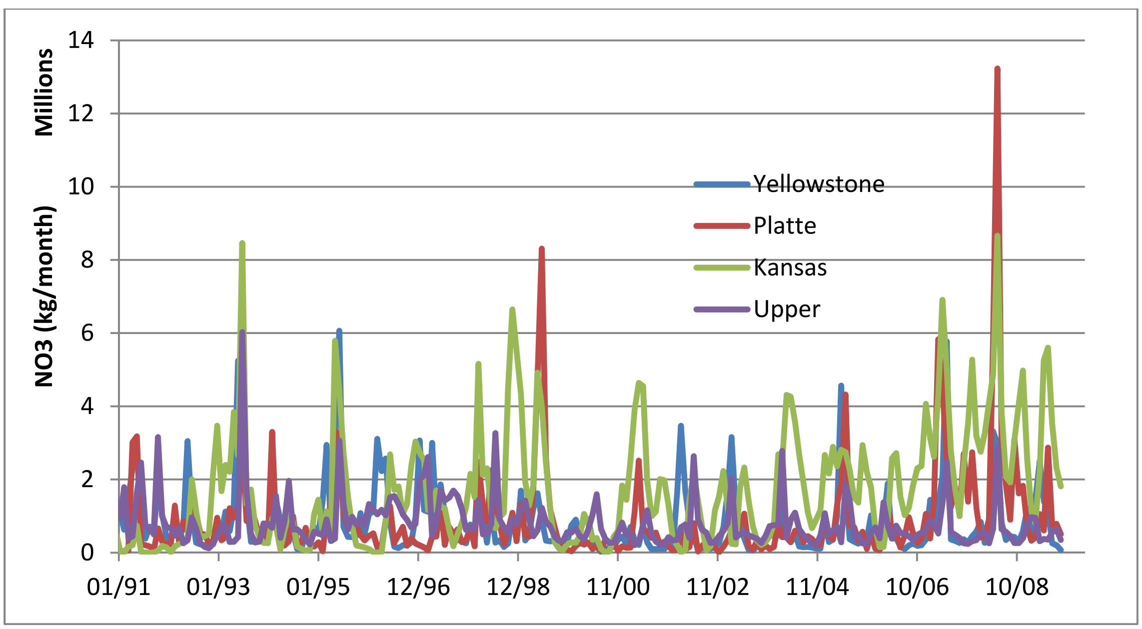
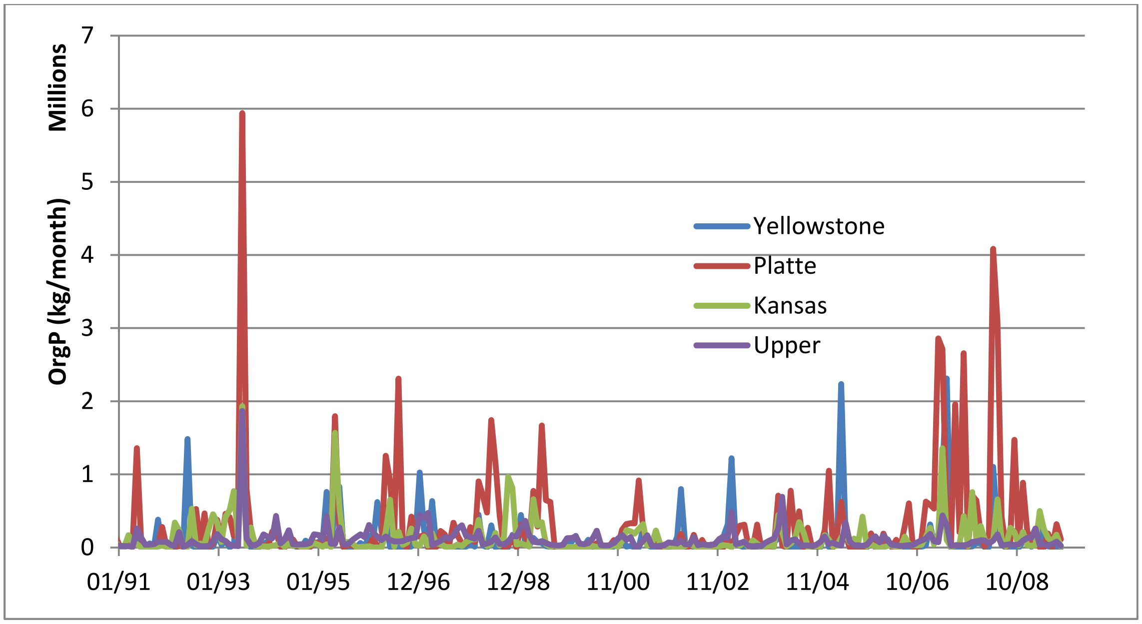


FIGURE B-13 (Cont.)



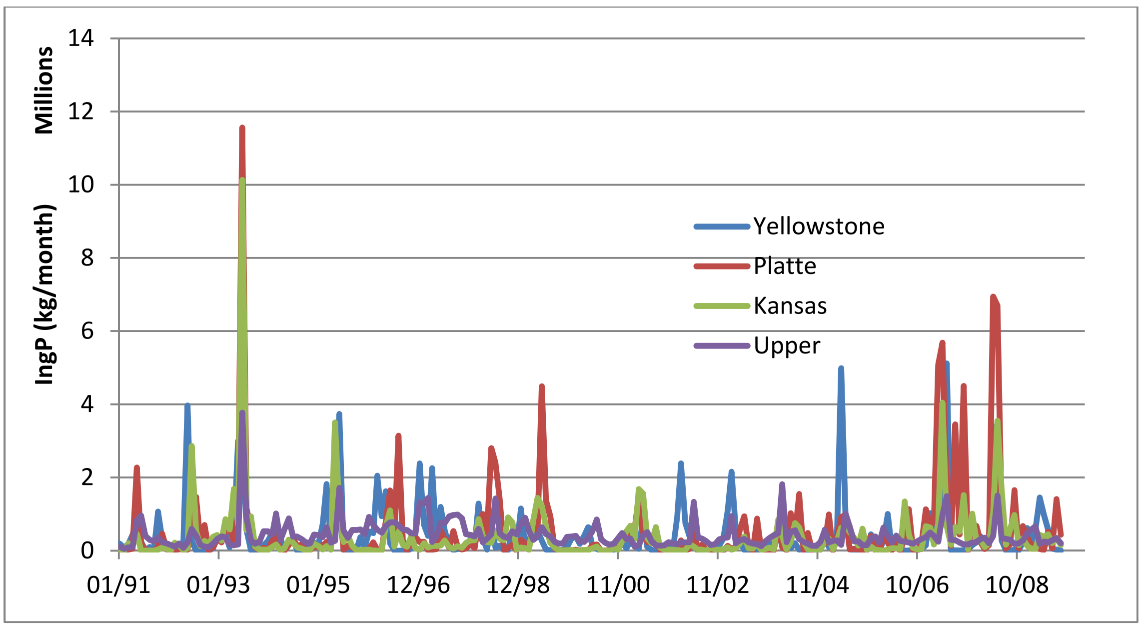


FIGURE B-13 (Cont.)

B.4 COMPARISON OF SEDIMENT, NITROGEN, AND PHOSPHORUS LOADINGS AND POTENTIAL WATER QUALITY IMPACTS

Based on the SWAT model analysis just discussed, sediment, nitrogen, and phosphorus loadings discharged from the LMoRB were much higher than the loadings from the UMoRB under both the baseline conditions and the future scenario. The LMoRB discharge loads reflected the majority of sediment, nitrogen, and phosphorus delivered from the Missouri River Basin into the Mississippi River. Therefore, the LMoRB was further investigated for potential water quality impacts in the MoRB, as discussed here. A comparison of time-series sediment, nitrogen, and phosphorus loadings under the baseline conditions with those under the projected scenario are shown in Figure B-14.

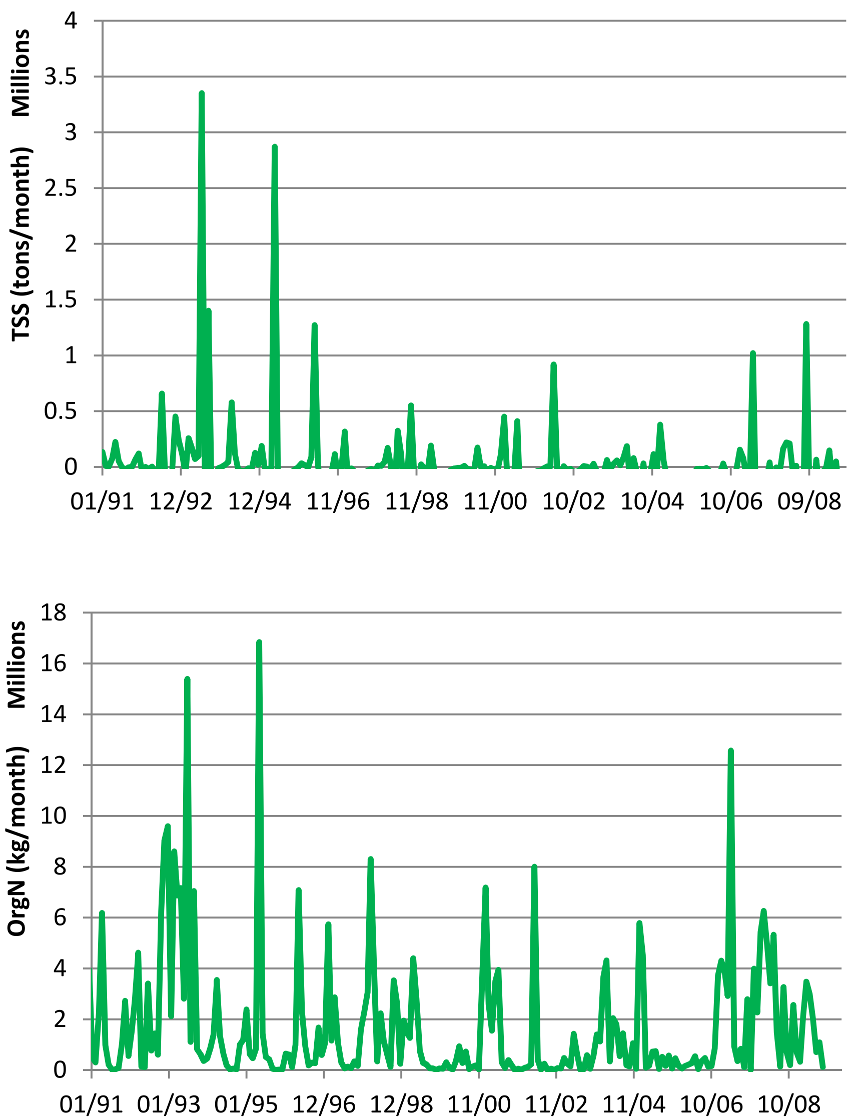
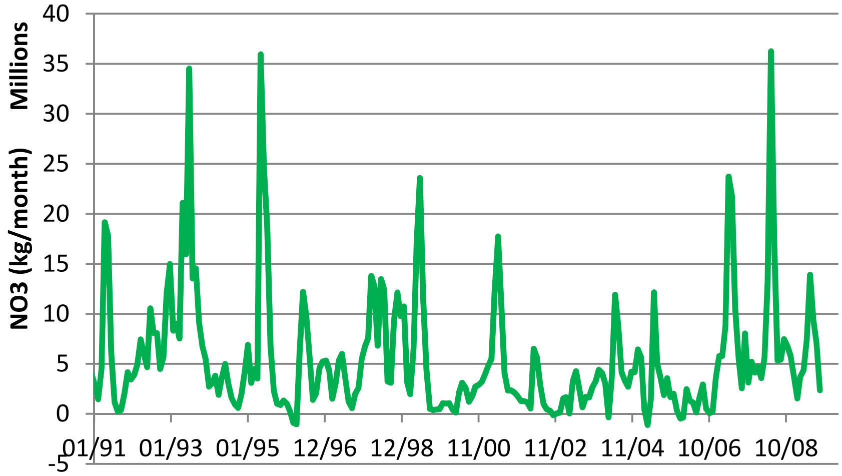


FIGURE B-14 Differences in Temporal Variations of Sediment (TSS), Nitrogen (OrgN, NO_3), and Phosphorus (OrgP, IngP) Loadings from the LMoRB



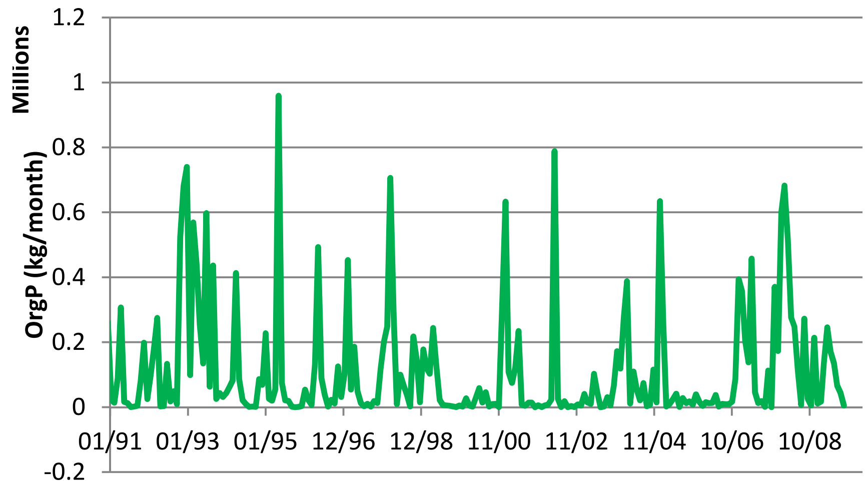


FIGURE B-14 (Cont.)

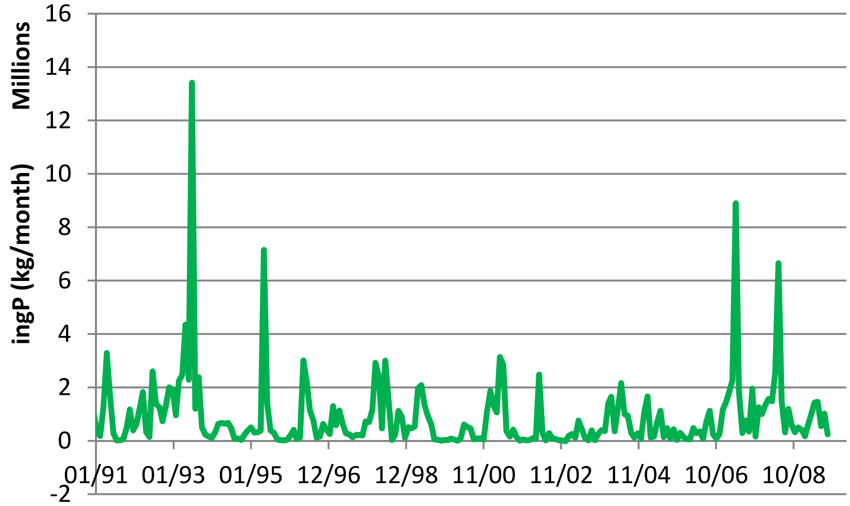


FIGURE B-14 (Cont.)

B.5 SUMMARY AND CONCLUSIONS

This study examines the effects of land use changes on sediment and nutrient loadings at various scales. Specifically, baseline MoRB SWAT models were used to quantify the magnitudes of sediment, nitrogen, and phosphorus loading responses to land use changes within the MoRB. This information was incorporated to set up a SWAT model for both the future scenario and current land uses. Regarding the impacts of land use changes, three scales were used: subbasin (HUC-8), regional watershed, and basin. At the subbasin scale, the sediment, nitrogen, and phosphorus loadings reflected the contribution of all fields in the subbasin to the river reach but did not include in-stream routing components. At the regional watershed scale, contributions from both subbasins and in-stream routing were included in the model results. Finally, at the basin scale, the overall results on the transport and fate of sediments and nutrients were considered.

At the basin scale, modest changes in major crops and sediment and nutrient loadings were detected. Significant increases in sediment and nutrient loadings in streamflow discharges were observed only when there were large storms. The MoRB SWAT models can be used to quantify the potential impacts of future projected changes in land use. Projected land use conversions in the MoRB could have modest impacts on sediment and nutrient exports from the basin. However, because of the important role that uncertainty analysis has in the decision-making process for renewable energy development and environmental sustainability, it is recommended that different sources of uncertainty be evaluated in order to increase confidence in the model results.

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