SWAT Model Application for Assessing Recent Crop Expansion Impacts on Missouri River Basin Water Quality

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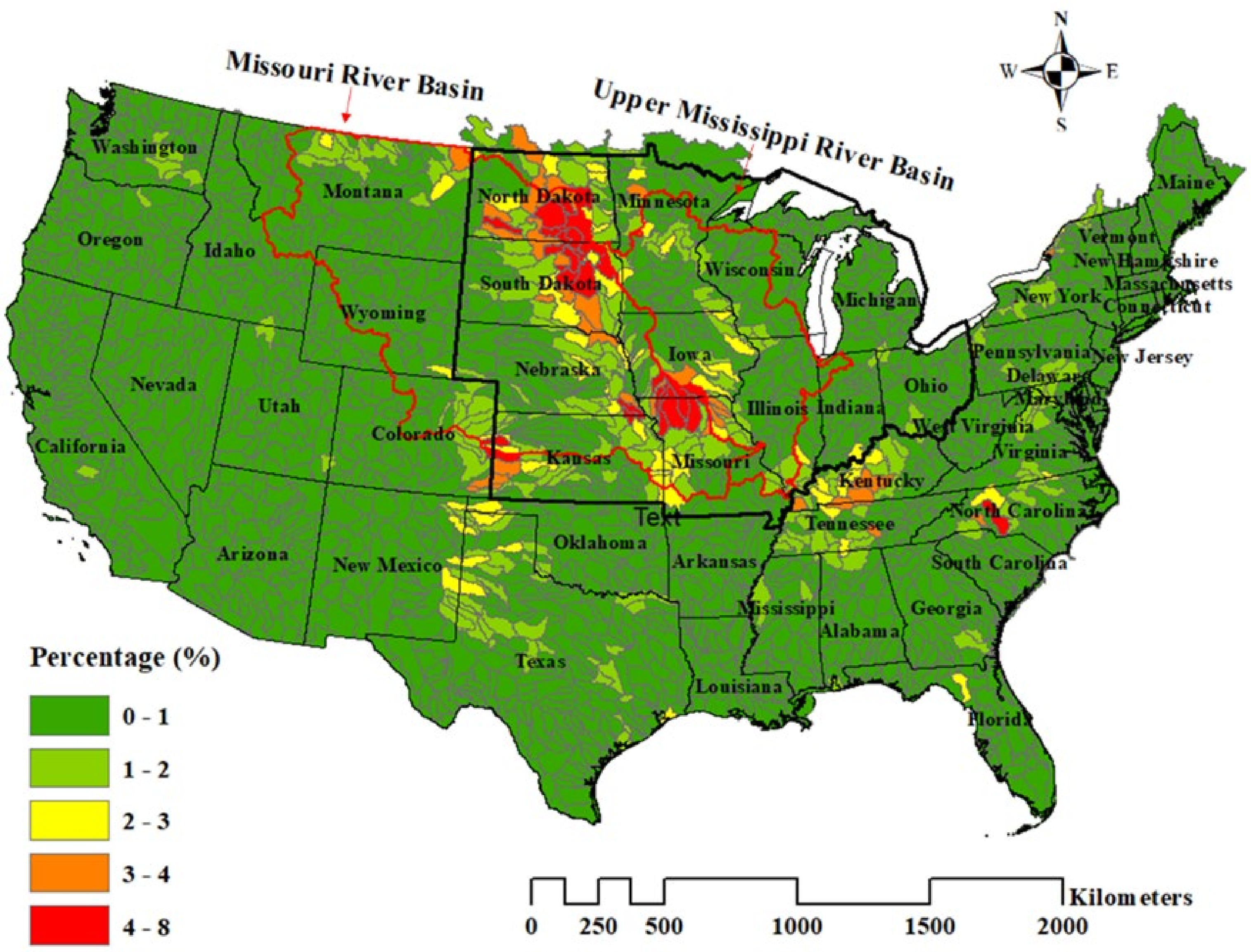
Background Information

- Increased demand for biofuels and changes to commodity markets resulted in increased corn and soybean production.
- US Midwest is the hotspot of cropland expansion (Lark et al., 2018).
- Increased corn soybean production raises increased concern for water quality, lake eutrophication, and hypoxia of the northern Gulf of Mexico (GOM) (NSTC, 2000; USEPA, 2014; Alexander et al., 2008; Rabalais et al., 2001).
- Nutrient losses from Midwest corn/soybean cropland have been identified as one of the major sources of nutrient in streams and to the Gulf of Mexico.

Land Use Changes from 2008 to 2016



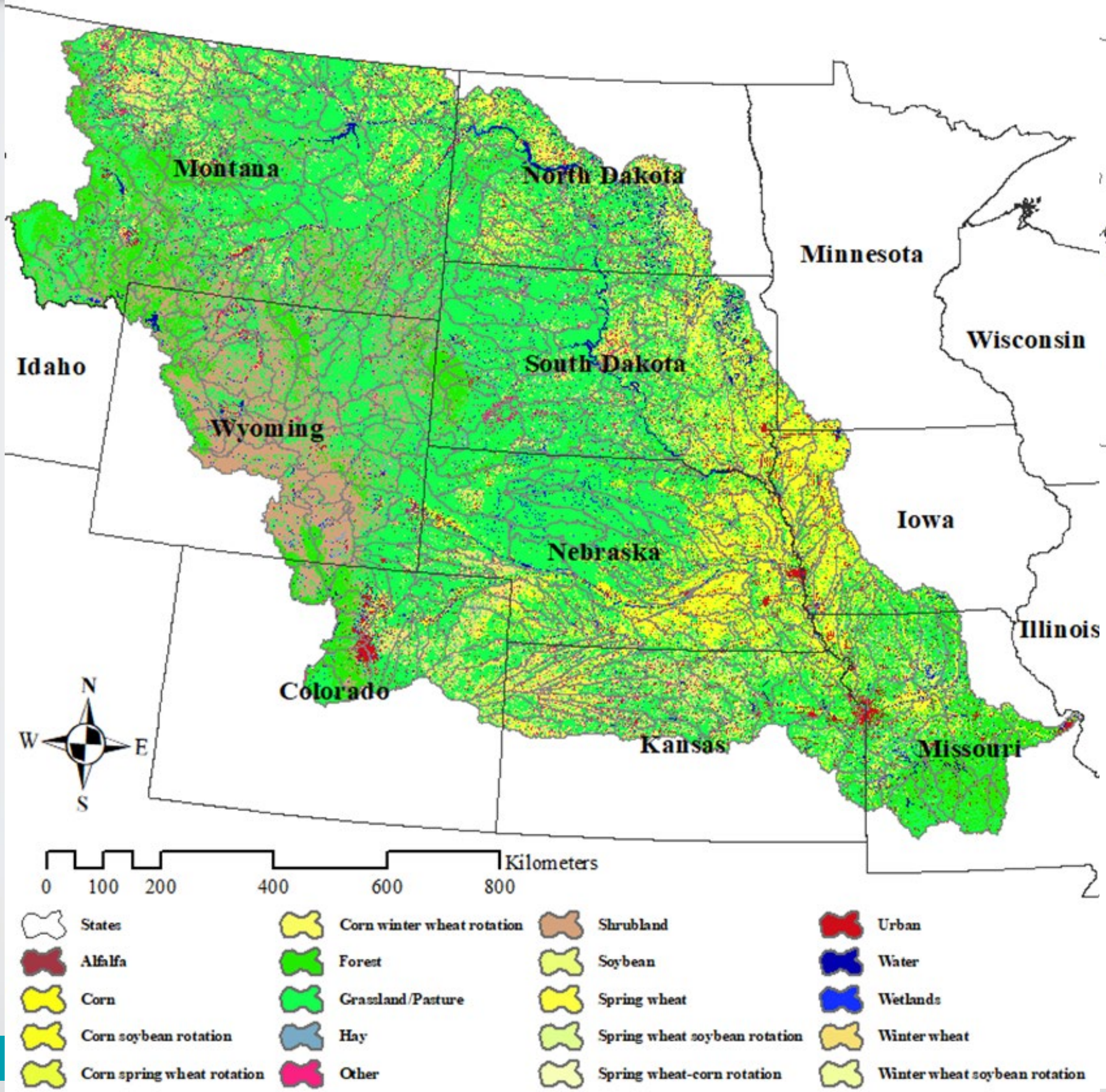
- Conversion to cropland--(i.e., crop expansion)--areas converted to crop production between 2008 and 2016.
- Major sources of new croplands are grassland (77%) and idle land (8%), cumulatively 85%.
- Main crops planted on newly expanded cropland: Corn (26%), Wheat (24.5%), Soybean(20.2%), and Alfalfa (6.9%), cumulatively 77%.

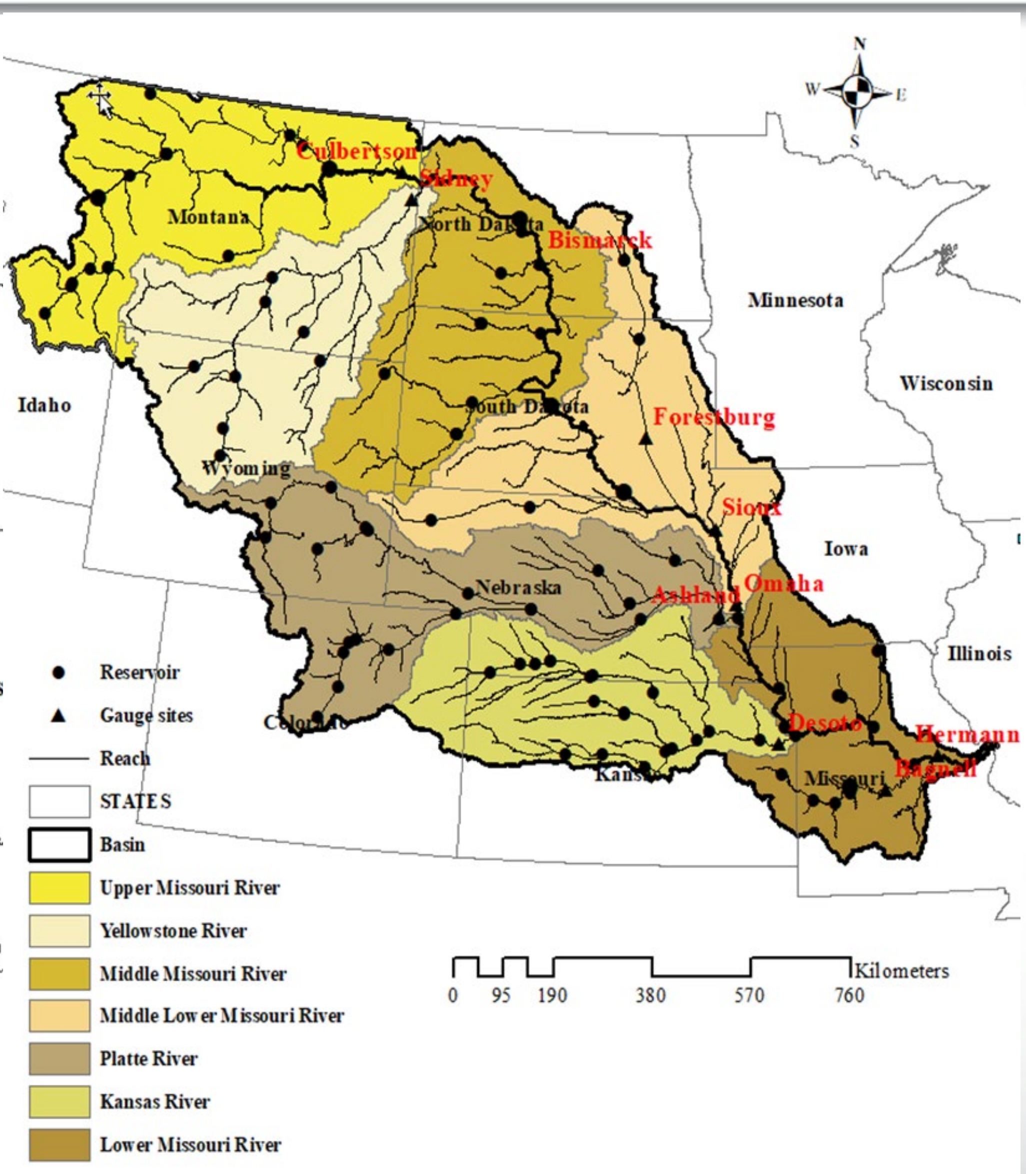
Lark, T. J., Bougie, M., Spawn, S., & Gibbs, H. K. (2018). Cropland expansion in the United States, 2008-2016, Online Website: http://www.gibbs-lab.com/US/(Lark et al., 2018)

Missouri River Basin (MORB)

- The MORB is one of the largest sources of nutrients to the Gulf of Mexico due to increased fertilizer runoff (Wu et al., 2012; Demissie et al., 2012).
- The highest rates of grassland conversion to cropland have occurred within this watershed, particularly along the western edge of the Corn Belt in the eastern Dakotas (Lark et al., 2018).
- The watershed covers approximately 1.3 million km^2 and includes 10 US states and part of Canada (which contains about 2% of the MORB's total area).
- The MORB is extremely diverse in many aspects as a large basin.

Missouri River Basin (MORB)





Objectives

- Quantify nutrient loading changes for the entire Missouri River Basin (MORB).
- Identify hot spots experiencing the greatest increase in nutrient loadings.
- Help better plan future biofuel targets as well as agricultural conservation practices.

Soil and Water Assessment Tool

- Soil and Water Assessment Tool (SWAT)— a GIS-based hydrologic and water quality modeling tool for watershed assessment and future scenario analysis.
- The model is a continuous, long-term simulation, watershed scale model.
- It was developed to simulate impacts of land use/land management changes as well as climate changes on water, sediment, and chemical loadings from large complex watersheds.

SWAT Setup and Calibration and Validation

- Model was setup using 2008/2009 Cropland Data Layer (CDL), available at https://nassgeodata.gmu.edu/CropScape/.
- HUC8s (304) were used as subbasin.
- For calibration, SWAT simulations were performed from 1992 to 2016 with first 5 years as warmup period. USGS data from 1997 to 2016 were used to calibrate the model.
- After model calibration, the SWAT model was rerun using weather data from 1970 to 1996 with the first 5 years as warmup period. USGS monitoring data from 1975 to 1996 were used to validate the model.

SWAT Model Validation

- Three widely used criteria were used to evaluate the model's performance: coefficient of determination (R^2), Nash-Sutcliff efficiency (NSE) coefficient, and percent bias (PBIAS).
- The R^2 value describes the variance in measured data explained by the model.
- The NSE is a normalized statistic indicating how well the observed and predicted data fit the 1:1 line (Nash and Sutcliffe, 1970).
- The PBIAS indicates the average tendency of the simulated data to be larger or smaller than the observed data.

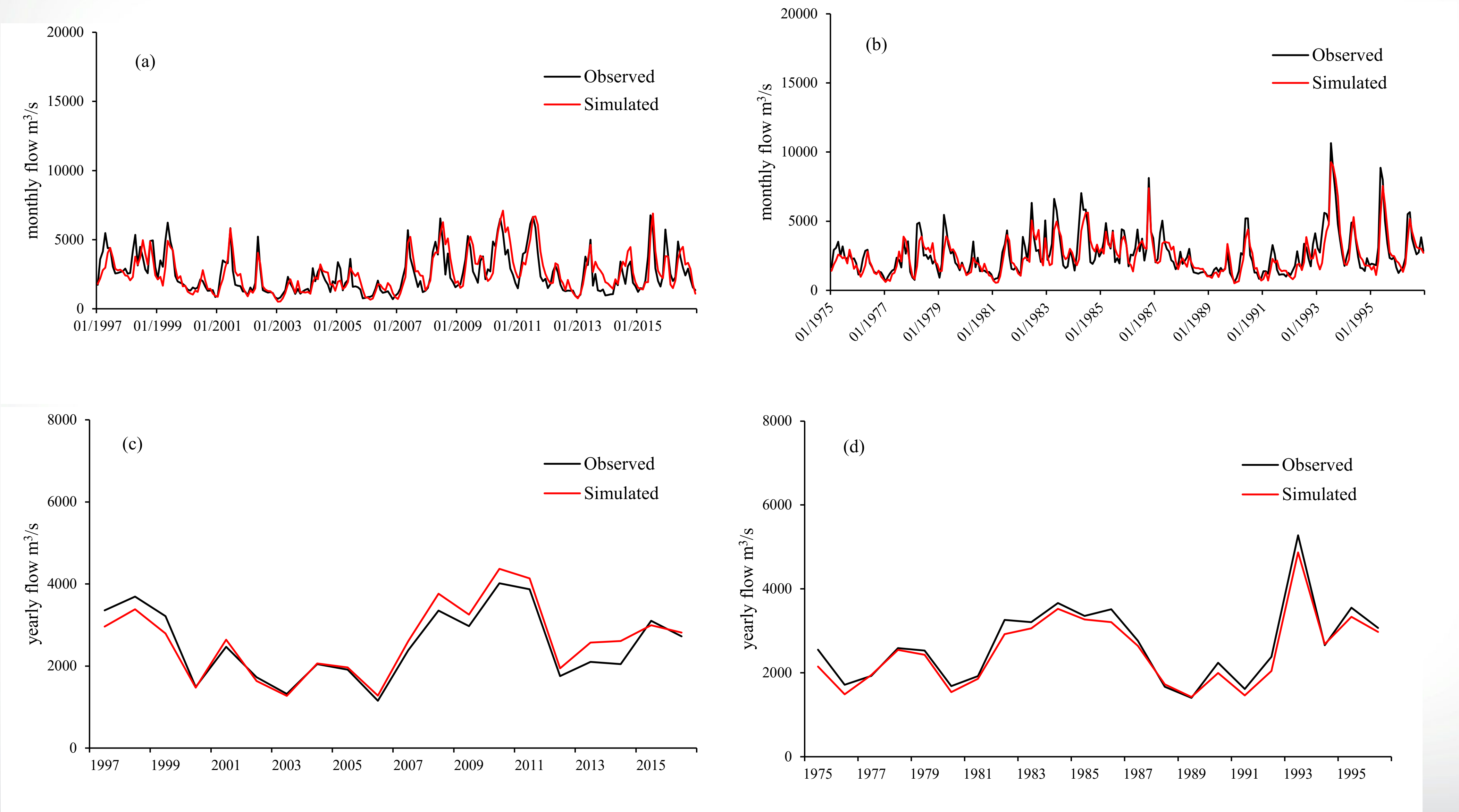
SWAT Calibration and Validation

- 10 USGS gauge stations were selected for model calibration and validation

Site Name	Site Number	Hydrologically Independent	Drainage (km^2)	Streamflow	Sediment	TN	TP
Culbertson	06185500	Yes	232731	1975-2019	-	-	-
Sidney	06329500	Yes	178966	1975-1990 2000-2019	1975-2019	1975-1990 2000-2019 (311)	1975-1990 2000-2019 (349)
Bismarck	06342500	No	482776	1975-2019	-	-	-
Forestburg	06477000	Yes	45617	1975-2019	-	-	-
Ashland	06801000	Yes	216524	1988-2019	-	-	-
Sioux	06486000	No	814814	1975-2019	1975-1976 1991-2019	-	-
Omaha	06610000	No	836049	1975-2019	1975-1976 1991-2019	-	-
Desoto	06892350	Yes	154768	1975-2019	-	1975-2019 (199)	1975-2019 (214)
Bagnell	06926000	Yes	36260	1975-2019	-	-	-
Hermann	06934500	No	1353270	1975-2019	-	1975-2019 (463)	1975-2019 (468)

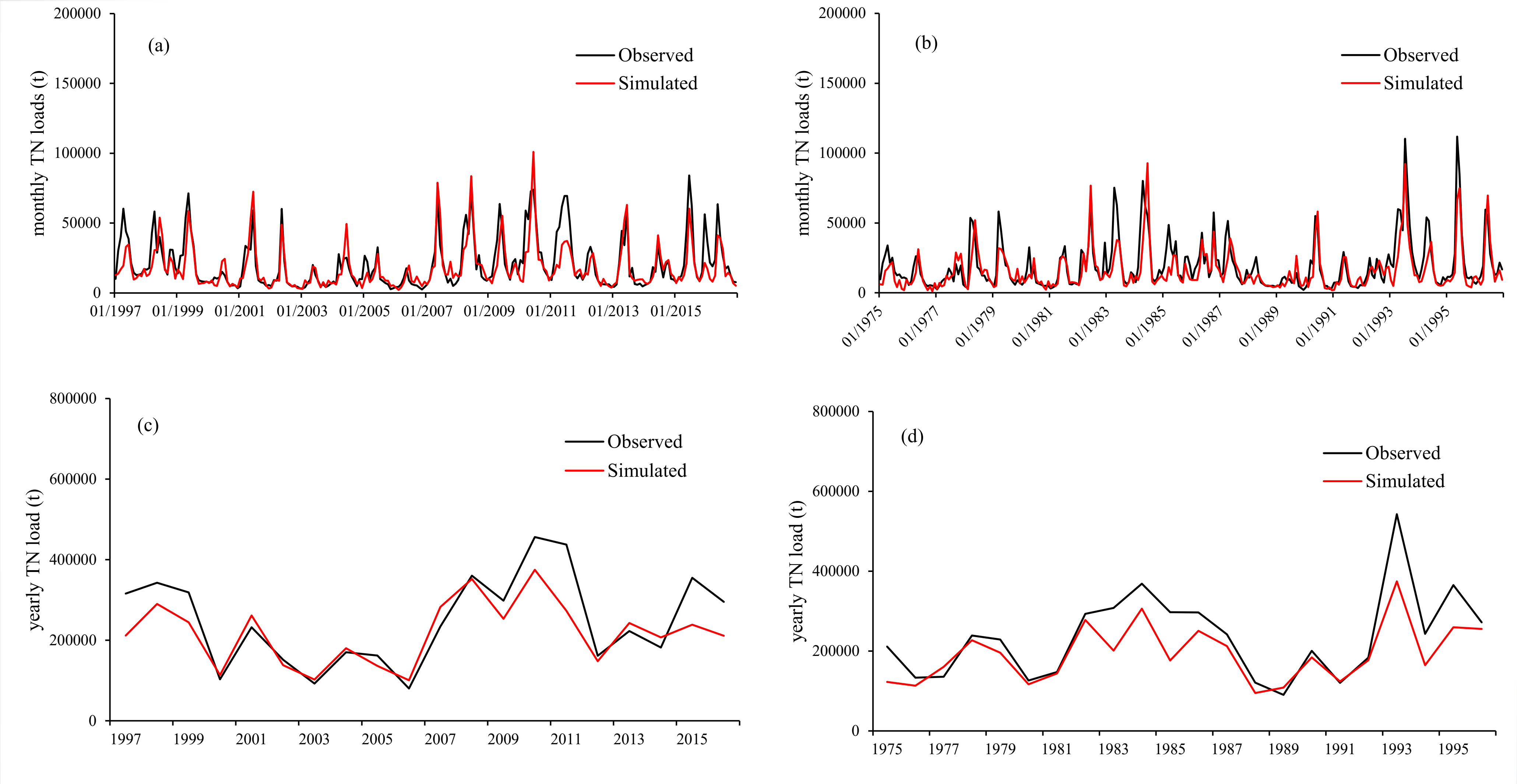
Comparisons of Simulated and Observed Annual and Monthly Streamflow at the Outlet

Monthly and yearly streamflow comparison between SWAT simulated and monitored at the Hermann station during calibration period 1997 to 2016 (a and c) and validation period 1975 to 1996 (b and d)



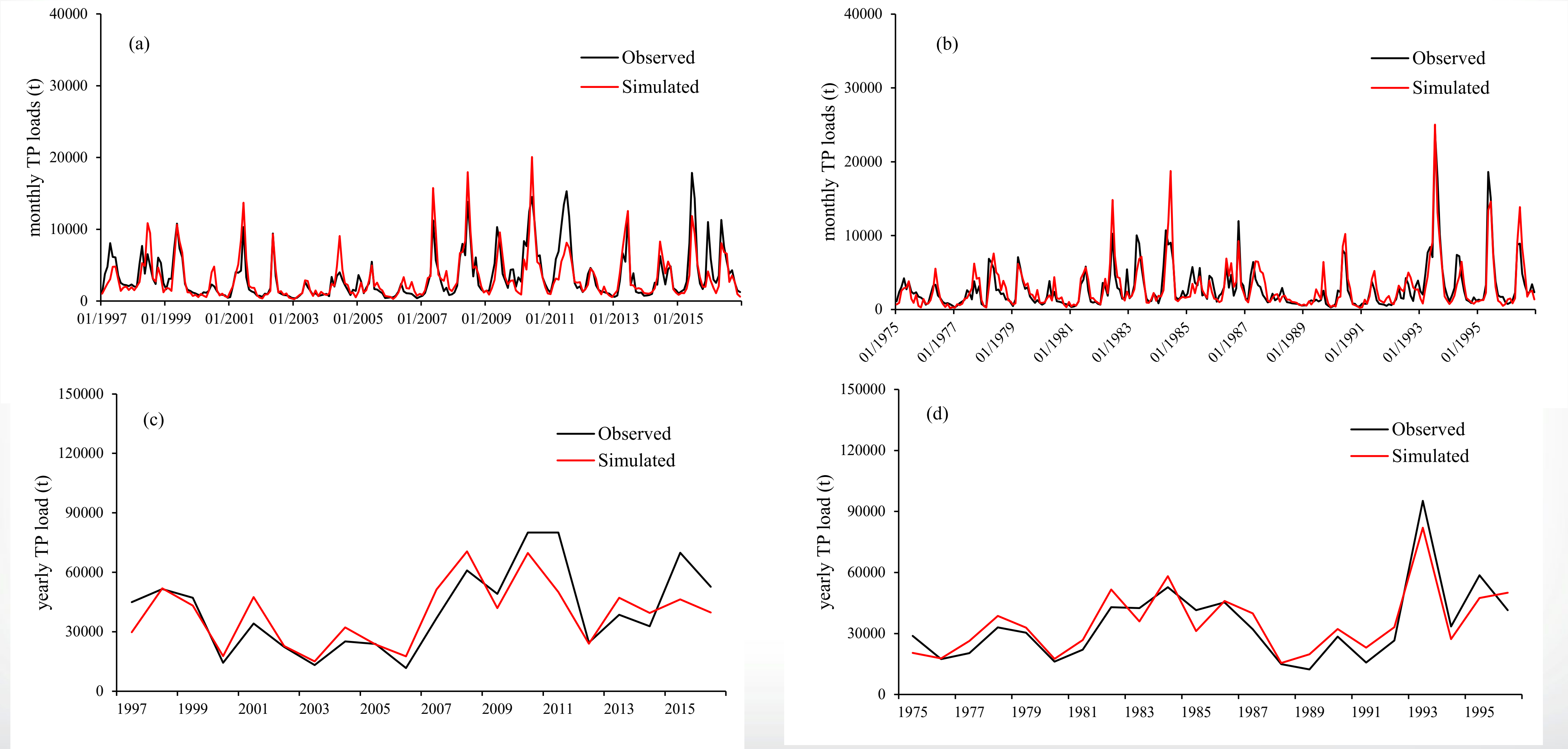
Comparisons of Simulated and Observed Annual and Monthly TN at the Outlet

Monthly and yearly TN comparison between SWAT simulated and monitored at the Hermann station during calibration period 1997 to 2016 (a and c) and validation period 1975 to 1996 (b and d)

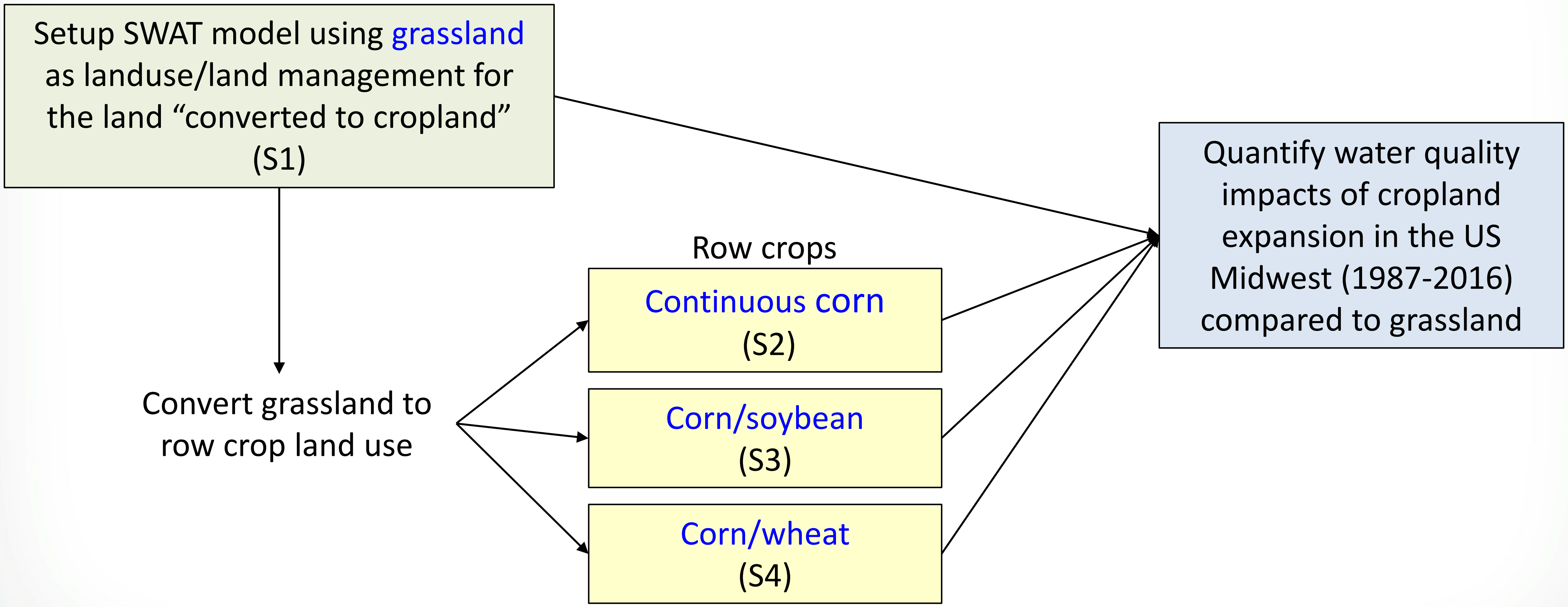


Comparisons of Simulated and Observed Annual and Monthly TP at the Outlet

Monthly and yearly TP comparison between SWAT simulated and monitored at the Hermann station during calibration period 1997 to 2016 (a and c) and validation period 1975 to 1996 (b and d)



Simulations for 1981 to 2016, first 6 years as warmup period

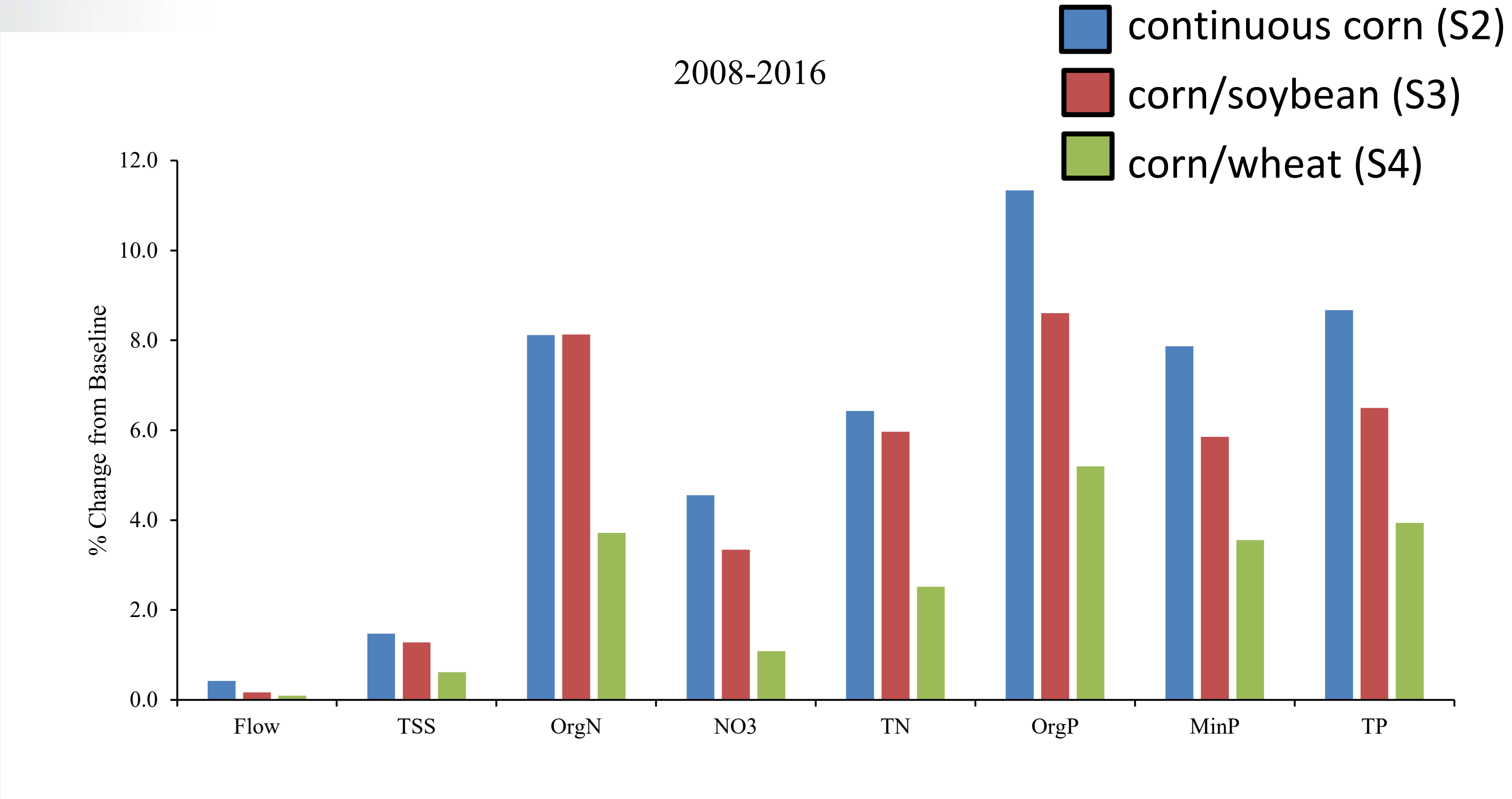


Results of S1 (baseline) from 40-yr simulation (1987-2016); Statistics of simulated annual average sediment, nitrogen, and phosphorus yields for the 304 HUC8s in the entire MORB

Statistics	TSS (t/ha)	OrgN (kg/ha)	NO_3 (kg/ha)	TN (kg/ha)	OrgP (kg/ha)	Min P (kg/ha)	SolP (kg/ha)	TP (kg/ha)
Mean	2.03	3.26	1.00	4.26	0.34	0.52	0.04	0.91
Median	0.4	1.1	0.3	1.5	0.1	0.2	0.0	0.3
Standard deviation	4.2	6.0	1.8	7.6	0.6	0.9	0.1	1.6
Maximum	37.3	36.7	9.7	42.0	3.8	6.7	0.9	10.7

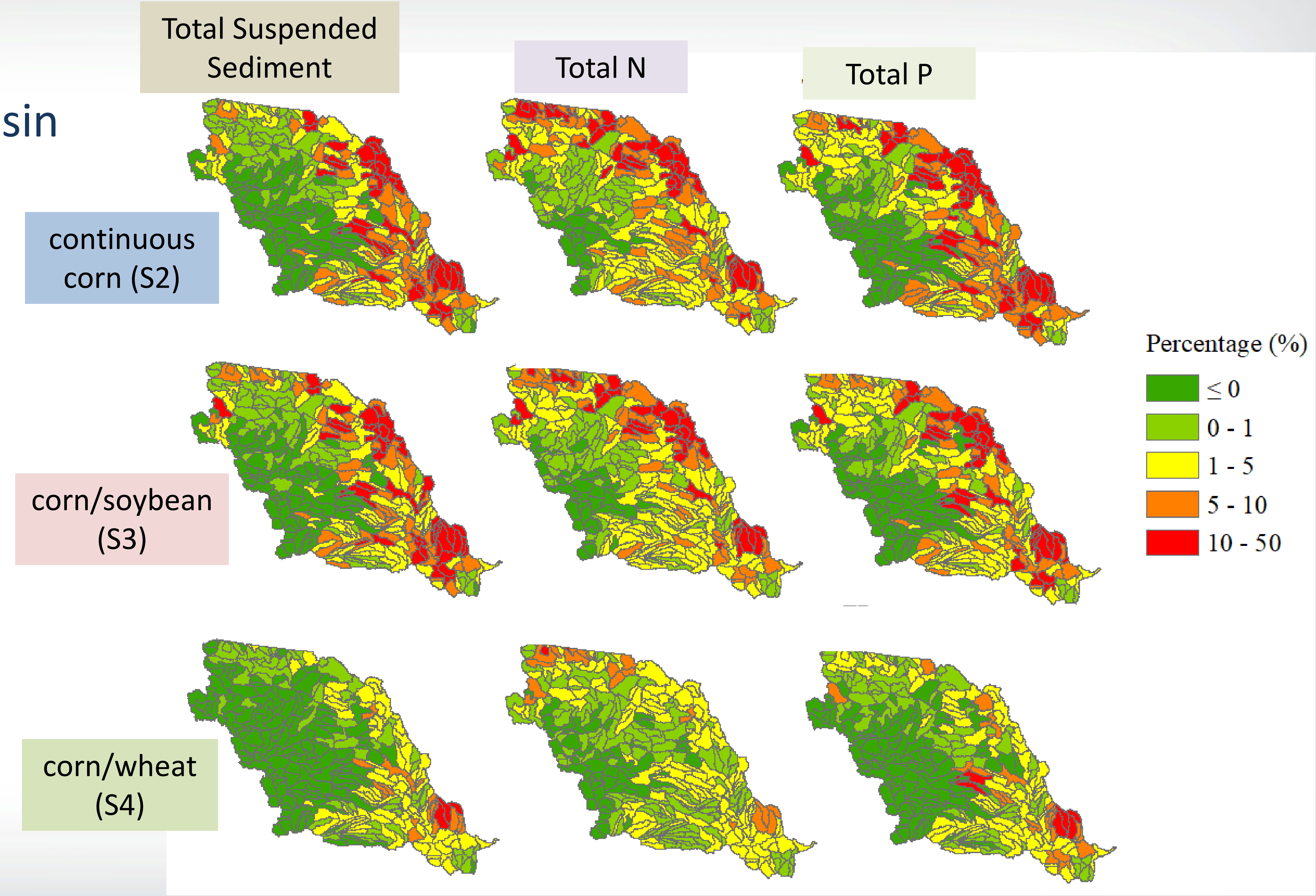
Results – Water Quality Impacts

Relative changes from conversion of 2008 to 2016

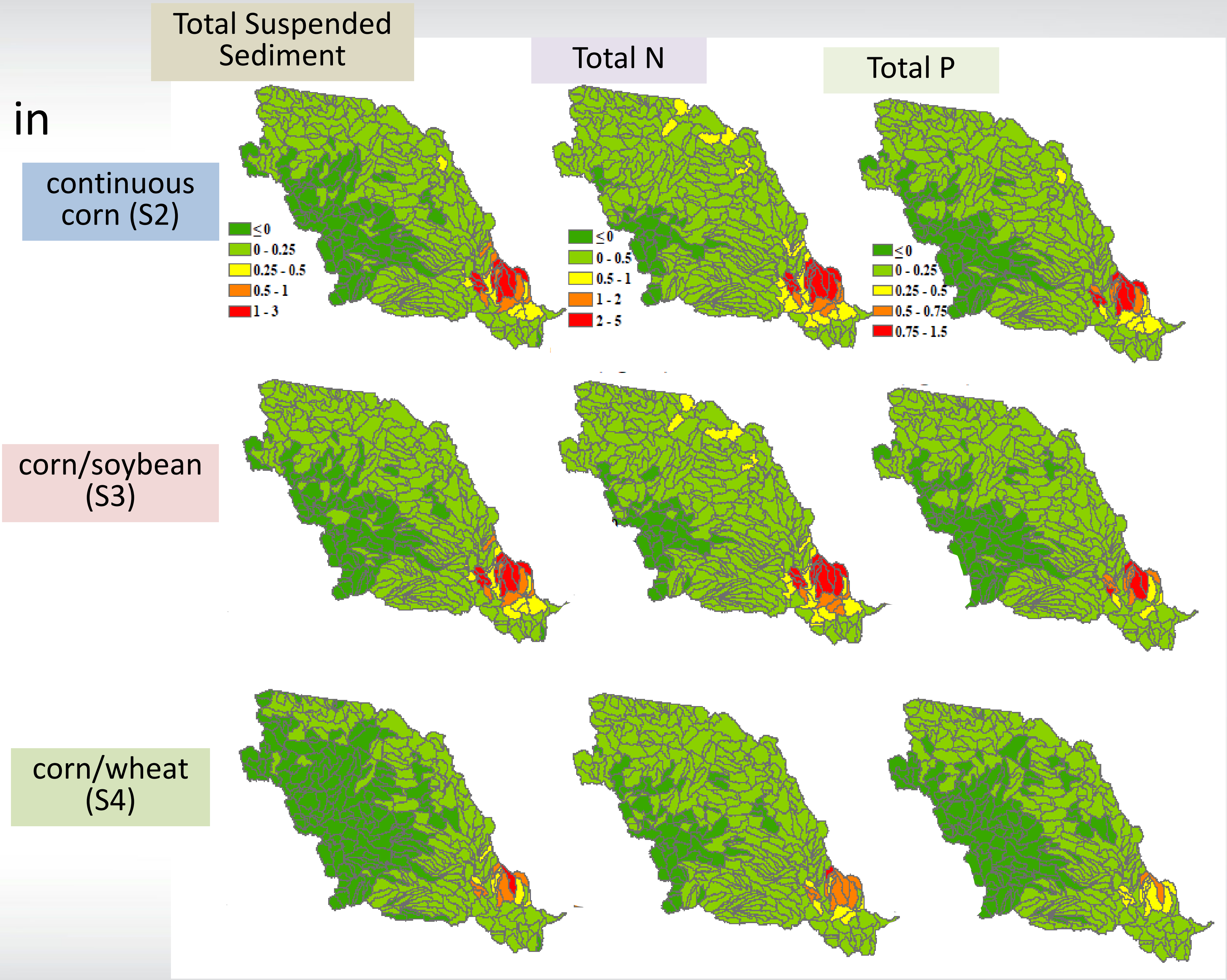


- Continuous corn (S2) has the most adverse effect on water quality compared with corn/soybean rotation and corn/wheat rotation.
- Sediment increased 2% from S1 to S2
- TN increased 6% from S1 to S2; dissolved N increased 5% from S1 to S2.
- TP increased 9% from S1 to S2; dissolved P increased 8% from S1 to S2.

Results – Percent Water Quality Changes at subbasin 2008-2016 after converting from grassland



Results – Water Quality Changes (%) in unit area



Spatial unit area changes of TSS, TN and TP from S1 to S2 (baseline vs. continuous corn), S1 to S3 (baseline vs. corn/soybean) and S1 to S4 (baseline vs. corn/wheat) for the period from 2008 to 2016

Summary and Conclusions

- Cropland expansion onto grasslands degraded water quality in the US Midwest
- The greatest percentage increases of TN and TP loading occurred in North Dakota and South Dakota, coinciding with the highest amount of grassland conversion
- Specific watersheds, or "hotspots," occurred in the lower MORB—especially in Iowa, Missouri, Nebraska, and Kansas—contributed the greatest amounts of TN and TP to basin-wide loads
- Results from SWAT simulations show that continuous corn (S2) has the most adverse effect on water quality compared with corn/soybean rotation and corn/wheat rotation.

Summary and Conclusions

- Sediment increased 1% from S1 to S2 from 2008 to 2012 (2% from 2008 to 2016).
- TN increased 4% from S1 to S2 (6% from 2008 to 2016); dissolved N increased 3% (5% for 2008 to 2016);
- TP increased 5% from S1 to S2 (9% from 2008 to 2016); dissolved P increased 4% from S1 to S2 (8% from 2008 to 2016).

Questions for Discussion

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