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Impacts of biofuel-based land-use change on water quality and sustainability in a Kansas watershed

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ABSTRACT

The growth in ethanol production in the United States has sparked interest in potential land-use change and the associated environmental impacts that may occur in order to accommodate the increasing demand for grain feedstocks. In this study water quality and sustainability indicators are used to evaluate the impacts of land-use change to increase corn and grain sorghum acreage for biofuel production in the Perry Lake watershed in northeast Kansas. Water quality indicators include sediment loads per converted land acreage and the relative increase of total nitrogen, total phosphorus and sediment loads compared to the baseline conditions. Sustainability indicators include land-use, water use, and nutrient use efficiencies. Hay, Conservation Reserve Program (CRP), and winter wheat were selected as targeted land-uses for conversion to biofuel feedstocks. The Soil and Water Assessment Tool (SWAT) was used to evaluate 6 different scenarios, each at 10 land-use change increments, for a total of 60 simulations. Results demonstrate that increased corn production generates significantly greater sediment loads than increased grain sorghum production and larger relative increases in nutrient loads. Expansion of corn or grain sorghum cropland by replacing hay or CRP land-uses resulted in the highest sediment loads and relative increases in nutrient loads. Expansion of corn or grain sorghum by replacing winter wheat cropland produced the lowest relative changes in nutrient and sediment loads and therefore may be a more sustainable land-use change. Corn had a higher yield potential per km^2 compared to grain sorghum, resulting in better land, nutrient and water use efficiencies.

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1. Introduction

As of 2013 there were nearly 200 operating biorefineries in the United States producing an estimated 13.3 billion gallons of ethanol per year. This is approximately twice the amount of ethanol produced before the passage of the 2007 Energy Independence and Security Act (Renewable Fuels Association, 2014). The National Renewable Fuel Standard Program projects steady growth of renewable fuel production for the next several years (EPA, 2015). The growth in ethanol and other renewable fuel production has sparked interest in potential land-use change (LUC) that may result from increasing demand for grain and the associated water quality and environmental impacts.

Many LUC studies have focused on environmental changes in the Upper Midwest states, such as Iowa, Illinois, and Indiana, where the biofuel market is the strongest (Hendricks et al., 2014; Secchi et al., 2011a,b). These studies by Secchi and others highlight the potential increase in sediment and nutrient non-point source pollution that may occur due to rising corn prices. Other studies have examined the impacts of corn and switchgrass production in North and South Dakota (Wu et al., 2012), corn stover removal in Indiana (Cibin et al., 2011), biofuel feedstock rotations in Michigan (Love and Nejadhashemi, 2011), increased corn production in the Mississippi-Atchafalaya River Basin (Donner and Kucharik, 2008), and advanced cellulosic feedstock production in the Arkansas-White-Red river drainage basin (Jager et al., 2014). In general, these studies show that increased row-crop production for biofuel feedstocks results in increased non-point source nutrient pollution, but that replacing row-crop land-use with perennial feedstocks for cellulosic biofuel production shows the potential for improved water quality conditions. Overall, corn and switchgrass production have both been extensively studied in relation to water quality impacts (Jager et al.,

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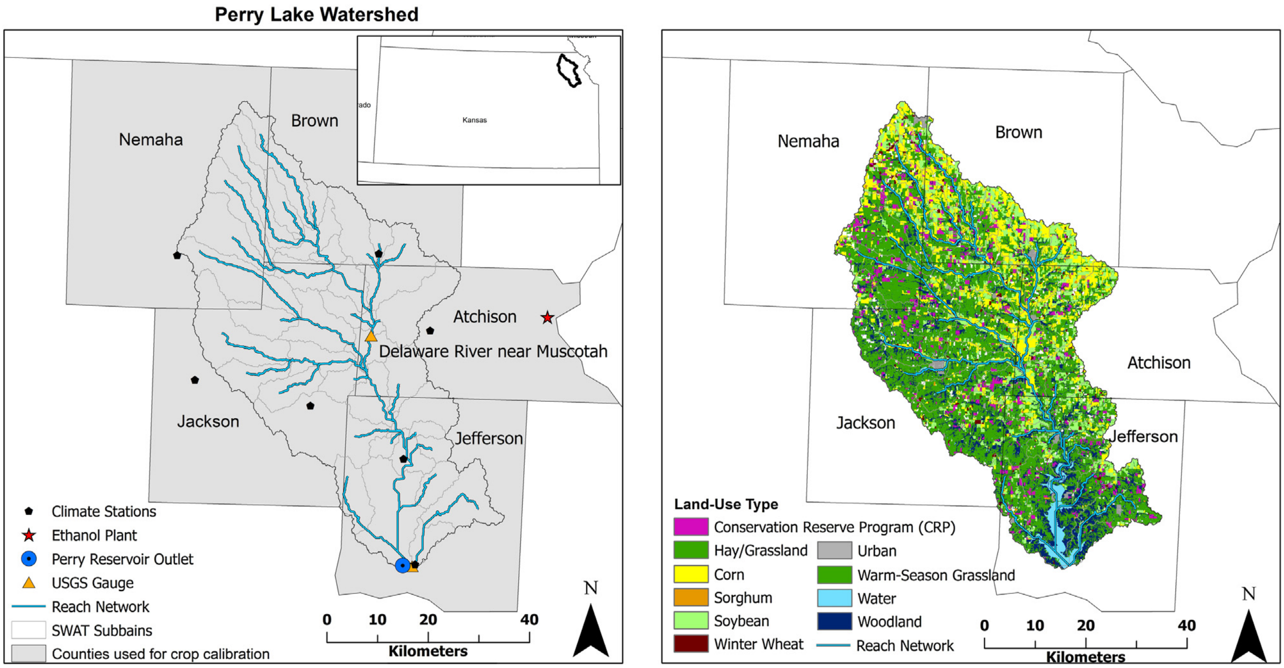

Fig. 1. Location of Perry Lake watershed and important features, including: nearby ethanol plant, weather stations used for simulation climate data, stream gauge used for flow calibration, counties used for crop calibration, SWAT-generated reach network, subbasins, and dominant land-use within watershed.

Table 1
Perry Lake watershed characteristics.

Watershed Size	2924 km^2
Reservoir Size	44.5 km^2
Ecoregions	Central Irregular Plains and the Western Corn Belt Plains
Dominant Land-use	Hay
Dominant Crop Type	Corn-Soybean Rotation
Mean Annual Precipitation	890–980 mm
Percent of land irrigated	<0.05% (0.17% of cropland)
Dominant Slope Class	>5%
Dominant Hydrologic Soil Group	Group D (High runoff potential)

2014; Secchi et al., 2011a,b; Wu et al., 2012). However, to our knowledge, there are few studies that examine the water quality impacts of increased grain sorghum production, which is a relevant biofuel feedstock in Kansas and other Great Plains states (Love and Nejadhashemi, 2011).

Grain sorghum is a drought tolerant C-4 grass, and typically does well in dry areas without irrigation. As such, sorghum may be more water efficient than other biofuel feedstocks. One study reported that forage sorghum (i.e. grain sorghum) produced biomass yields similar to corn using 33% less water (Rooney et al., 2007). Kansas is an ideal location to study the impacts of grain sorghum LUC as the state is responsible for 42% of the national grain sorghum production, making it the nation's largest producer (Kansas Department of Agriculture, 2014). Current ethanol production in Kansas uses a mixture of corn and grain sorghum, with an often 50-50 mixture at biorefineries, but some have reported mixtures with up to 80% sorghum (Jessen, 2010). Grain sorghum ethanol was approved by the United States Environmental Protection Agency (USEPA) as a renewable fuel under the Renewable Fuel Standards guidelines. Approximately 30% of grain sorghum produced in the US is utilized for ethanol production, contributing about two percent to the total domestic ethanol production (Cai et al., 2013). Ethanol yield from sorghum grain is comparable to corn grain, but corn has a slightly higher conversion rate (Ohrel et al., 2010; Wang et al., 2008).

In this study, water quality and sustainability indicators are used to evaluate and compare the impacts of LUC with increased corn and grain sorghum acreage for biofuel production in the Perry Lake watershed in northeastern Kansas. Kansas is located in the periphery of the Corn Belt and the dominant region of US ethanol production, but is still ranked 9th among US states for total ethanol production (504 million gallons/year) and 7th for the total number of biorefineries (12 + 2 under construction) (Renewable Fuels Association, 2014). Whereas some areas within the Corn Belt may soon be saturated with respect to ethanol biorefineries and available corn grain, Kansas remains an area with potential for expansion of ethanol production – especially with grain sorghum as a feedstock (Wang et al., 2008). However, an understanding of the water quality impacts associated with land-use changes is needed. Perry Lake is a regionally important reservoir with sedimentation and eutrophication problems (Bosworth, 2011; Juracek, 2015). Further development of the watershed may increase sediment and nutrient loads, which will impede watershed planning goals to reduce sediment and nutrient loads by ~70% (Bosworth, 2011). Therefore the goals of this study are two-fold: (1) to evaluate the water quality impacts of biofuel-based land-use scenarios in Kansas, and (2) to compare the environmental sustainability indicators and water quality impacts of corn and grain sorghum to determine the more environmentally sustainable biofuel crop in northeast Kansas.

2. Methods

2.1. Study sites

The Perry Lake watershed is located in northeastern Kansas within the Central Irregular Plains (14.5%) and the Western Corn Belt Plains (85.5%) Level III Ecoregions. The drainage area is approximately 2924 km^2 and is utilized mostly for agricultural pur-

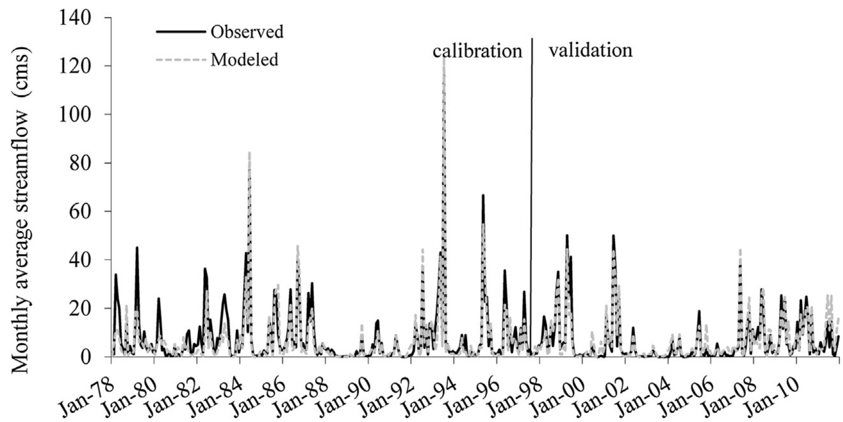

Fig. 2. Comparison of observed vs. simulated monthly streamflow for both calibration and validation time periods at the USGS gauge station at Delaware River near Muscotah.

poses with very little irrigated crop land (0.17% of cropland). Hay (cool-season grassland) and rangeland (warm-season grassland) represent, respectively, 32% and 15% of the watershed, with corn and soybeans together representing 27% of the watershed (Fig. 1 and Table 1). Soils in the watershed are mostly (77%) fine—textured (silt and clay) with moderately high to high runoff potential (soil groups C and D). Dominant soil groups are Pawnee clay (30.5%), Grundy silt clay (30%), and Kennebec silt (16.1%). Annual average precipitation ranges from 890 to 980 mm (Juracek and Ziegler, 2009). The major water bodies in the watershed are the Delaware River, which drains into Perry Lake, a 44.5 km^2 man-made reservoir operated by the Army Corp of Engineers, which then releases water into the Kansas River. There is one ethanol plant, MGP Ingredients, with 25 million gallons per year (MGY) capacity, located near the Perry Lake watershed.

2.2. The SWAT model

SWAT is a continuous-time, spatially-distributed simulator of the hydrologic cycle and agricultural pollutants. Watersheds are divided into subbasins based on the reach network and then further divided into hydrologic response units (HRUs), which represent unique combinations of land-use, soil, and slope (Arnold et al., 1998). Major model inputs include climate conditions, soil properties, topography, plant growth, and land management. Simulation outputs of the SWAT model include HRU-level crop yield, evapotranspiration, and water use, as well as subbasin flow and loads of nutrients and sediment (Gassman et al., 2007; Ficklin et al., 2009). SWAT estimates surface runoff using the modified SCS curve number method and erosion and sediment yield with the Modified Universal Soil Loss Equation (MUSLE). Nutrient cycles are based off of those in the Erosion-Productivity Impact Calculator (EPIC), and in-stream nutrient processes are simulated using equations from the QUAL2E model (Neitsch et al., 2011). The SWAT model has been used worldwide to study a variety of environmental, hydrologic, and agricultural practices, and has been successfully applied in several Kansas watersheds (Daggupati et al., 2011; Glavan et al., 2015; Jager et al., 2014; Love and Nejadhashemi, 2011; Nelson et al., 2006). In this study the LUC scenarios were applied through the land use updater tool (.LUC) within ArcSWAT version 2010-beta (Pai and Saraswat, 2011).

2.2.1. Model input development

A 30-m digital elevation model (DEM) from the U.S. Geological Survey (USGS) was used to delineate and characterize sub-watersheds and channel network reaches. A total of 38 sub-watersheds were delineated for the Perry Lake watershed. HRUs were defined using 30-m DEM-derived slope, STATSGO soil polygons from the National Resources Conservation Service, and a 2005 land use land cover map developed from the Kansas Applied Remote Sensing Program (KARS). Without any thresholds a total of 3,879HRUS were established. Point sources were placed in the watershed based on sub-watershed location and data provided from the Kansas Department of Health and Environment (KDHE) via open records request. Daily maximum and minimum temperature and precipitation inputs for the 1975–2011 time period were derived from the National Climatic Data Center Global Historical Climatology Network (NCDC-GHCN) for a total of 8 stations within the watershed.

Table 2
Fertilizer application amounts and dates for cropland.

Crop land	Fertilizer application date	Elemental nitrogen amount (kg/ha)	Elemental phosphorus amount (kg/ha)
Corn	5/1	170	45
Grain sorghum	5/23	121	32
Soybeans	5/18	0	23
Winter wheat	9/30 + 1/10	32/64	28/0

Table 3
Plant and Harvest dates for corn, grain sorghum, soybeans, and winter wheat.

Crop	Plant	Harvest
Corn	4/30	10/10
Grain sorghum	5/20	10/15
Soybeans	5/15	10/10
Winter wheat	9/30	6/20

To develop management inputs, US Department of Agriculture (USDA) Cropland Data Layer maps over the time period 2006–2010 from the USDA Data Gateway were used to establish typical crop rotations in each watershed. Other management inputs, including approximate fertilization rates (Table 2), planting and harvesting dates (Table 3), and tillage practices, were developed with guidance from Dr. Nathan Nelson, Kansas State University agronomy professor, and recommended extension literature (Leikam et al., 2003). Fertilizer application rates of nitrogen (lb ac^{-1} yr^{-1}) and P_2O_5 (lb ac^{-1} yr^{-1}) were estimated using recommended rates per acre corresponding to a bushel yield goal, with soil organic matter assumed to be 2.5% (Leikam et al., 2003). County-level yield averages from 2005 to 2010 were calculated from the National Agricultural Statistics Service (NASS) data available online, with a 10% factor of safety, which were then used to determine nutrient application rates for both irrigated and non-irrigated corn, soybeans, sorghum, and winter wheat. Within SWAT 30% of the fertilizer was applied to the top 10 mm of soil. Herbicides and pesticides were

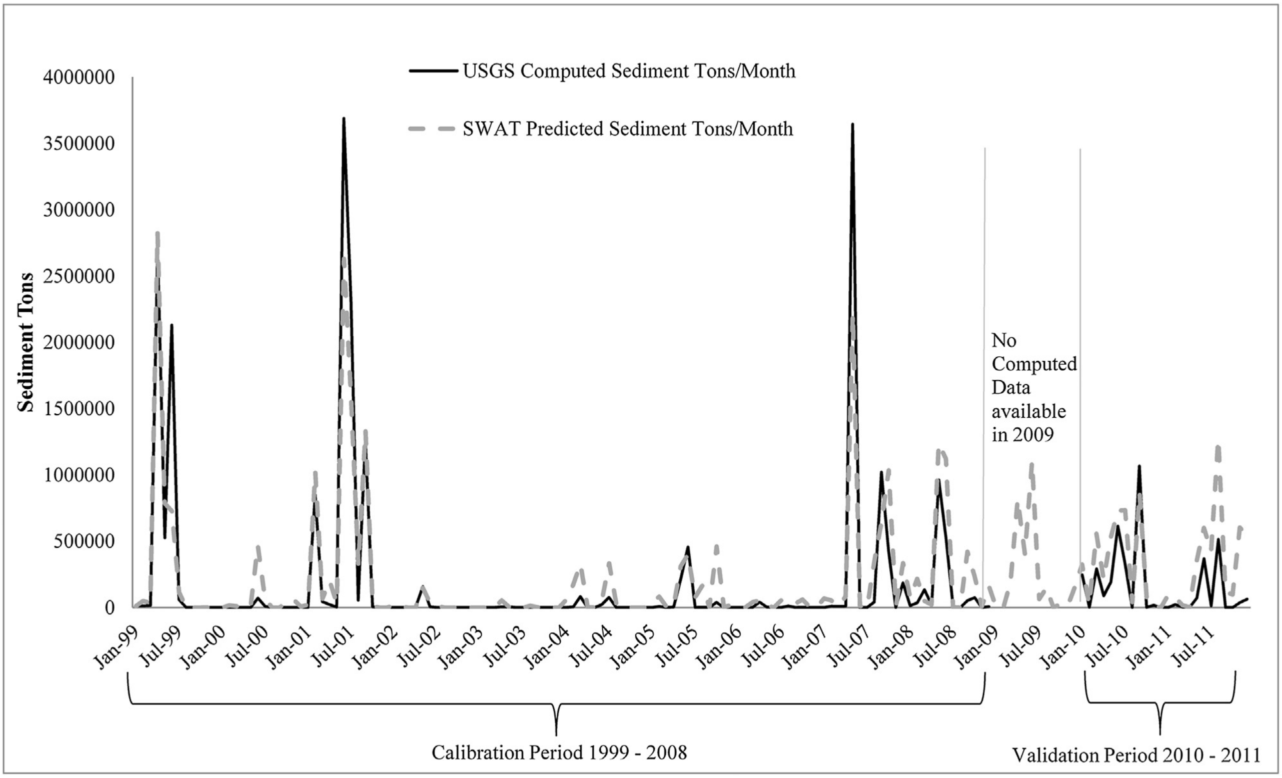

Fig. 3. Comparison of computed vs. simulated monthly sediment load for both calibration and validation time periods at the USGS gauge station at Delaware River near Muscotah.

not applied in the simulations. Time-based management was used instead of the default method and potential evapotranspiration was calculated using the Penman/Monteith method.

2.2.2. Model calibration and validation

Two statistics were used to evaluate model performance during the calibration and validation stages: Nash-Sutcliffe efficiency (NSE) and percent bias (PBIAS) (Moriasi et al., 2007). The acceptable range for each statistic varies based on the timescale and model component, see Moriasi et al. (2007) and Douglas-Mankin et al. (2010) for more detailed information. The model was run from 1975 to 2011, which included three warmup years from 1975 to 1977, 19 years for flow calibration from 1978 to 1996, and 15 years for flow validation from 1997 to 2011. Flow was calibrated and validated using the United States Geological Survey (USGS) streamflow gauge at Delaware River near Muscotah (USGS 06890100). Crop yield was calibrated with data from Jackson and Brown counties and validated with data from Nemaha, Atchison and Jefferson counties from 1996 to 2009 from the National Agricultural Statistics Service (NASS). A multi-step manual calibration procedure was used for flow and crop yield. Based on literature and experience with the SWAT-model in this region, nine parameters for flow and four parameters for crop yield were selected for calibration (Zhang et al., 2009; Schmalz and Fohrer, 2009; Cibin et al., 2010). Model parameters were adjusted until daily model output fell within 10% of average measured values and satisfactory statistics were reached (for flow NSE >0.65). A description of all calibration parameters and the final value used in the model simulations can be found in Table 4 and more detail can be found in Sinnathamby (2014).

Sediment load was calibrated using daily computed data for the Delaware River near Muscotah stream gauge location provided by the USGS Kansas Real-Time Water Quality online database (United States Geological Survey, 2013). Daily predicted data

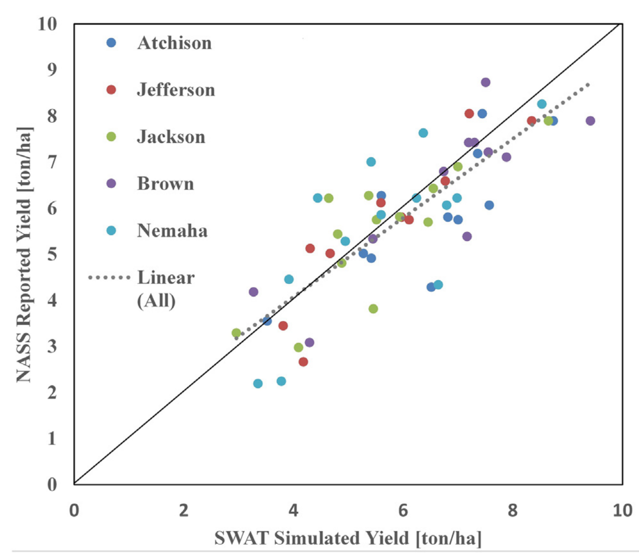

Fig. 4. Comparison of NASS-reported vs. simulated corn yield [ton/ha] for 5 counties within the Perry Lake watershed; each county is represented as a different color and dotted line indicates linear regression best-fit line for all data (n = 58), r2 = 0.67, y = 0.858x + 0.64.

was developed by the USGS using suspended sediment samples (n = 181) and daily streamflow measurements that were collected between the years 2000–2002 to develop a regression equation to predict suspended sediment values based on streamflow measurements ($\log_{10}SSC = 1.270 + 0.257\log_{10}Q + 0.116(\log_{10}Q)^2$; $r^2 = 0.68$ and mean square error = 0.260 in log units; SSC: suspended sediment concentration in mg/L and Q: discharge in cubic feet per second) (Putnam and Pope, 2003). Suspended sediment was con-

Table 4
Perry Lake watershed flow, crop and sediment calibration parameters.

Parameters	Description	Initial value	Final value
Flow			
ICN	Daily curve number calculation method	Antecedent soil moisture condition	Plant evapotranspiration
CNCOEF	Plant ET CN Coefficient	1	1.3
CN2	SCS runoff curve number	35–98	−5%
ESCO	Plant evaporation compensation factor	0.95	0.6
SURLAG	Surface runoff lag coefficient	4	1
ALPHA_BF	Baseflow alpha factor (days)	0.048	0.10
GW_DELAY	Groundwater delay (days)	31	0
RCHRG_DP	Aquifer fraction coef.	0.05	0
CANMX	Maximum canopy storage	0	Agriculture 3 Forests 8 Urban 1.5
Crop			
BIO_E	Biomass-energy ratio		
	Corn	39	35
	Soybean	25	20
HVSTI	Harvest index		
	Corn	0.50	0.46
	Soybean	0.31	0.31
WYHI	Lower limit of harvest index		
	Corn	0.3	0.35
	Soybean	0.01	0.20
LAI	Leaf area index		
	Corn	5	5
	Soybean	3	2
Sediment			
SPCON	Linear parameter for channel sediment routing	0.0001	0.008
SPEXP	Exponent parameter for channel sediment routing	1.0	1.43
CH_COV2	Channel erodibility factor	0	0.62
USLE_P	USLE support practice factor	1	0.86
CH_N(2)	Manning's value	0.014	0.05

verted to sediment load using measured streamflow, which was then compared to the SWAT-predicted sediment load. The USGS-developed database is the most continuous record of suspended sediment data and provides the closest estimate of suspended sediment concentrations within the watershed.

The SWAT-CUP SUFI2 program was used to conduct sediment calibration. The process was iterative with only the most sensitive parameters being used to perform the final calibration. Several thousand iterations were performed that identified SPCON, SPEXP, CH_COV2, USLE_P and CH_N as the most sensitive parameters affecting sediment load and indicated the recommended range for further refinement of calibration. A final 500 iterations were performed with the reduced tested range, which provided the final values for the five parameters (Table 4). The sensitivity of channel-process parameters matches previous studies conducted in Perry Lake watershed that demonstrated that channel-bank sediment sources are dominant for Perry Lake and in the downstream portion of the watershed (Juracek and Ziegler, 2009).

Nutrient load calibration was not possible in these watersheds due to lack of data. The only available nutrient data within the watershed was in an upstream reach taken once every other month, but accompanying flow data was not available. Other estimates of watershed loads have been developed through similar watershed models and have the same degree of uncertainty as estimates in this study. For this reason, analysis of simulation results focus on sediment loads and crop sustainability indicators. Nutrient results are presented as a percent change from the baseline scenario and as a plot of additional fertilizer added within the scenarios.

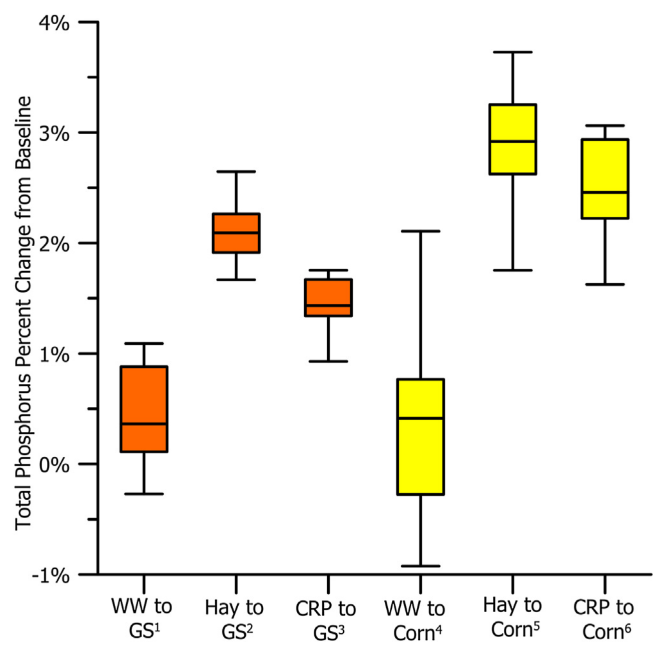

Fig. 5. Box plots showing the percent difference from baseline of total phosphorus export over the study period (2000–2011) in the Perry Lake watershed. Land area changed in each scenario was 112 km^2, 212.7 km^2, 311 km^2, 412 km^2, 59 km^2, 611 km^2. (WW: Winter Wheat, GS: Grain Sorghum, CRP: Conservation Reserve Program).

2.3. Land-use scenarios

Land-use scenarios consider both expansion of cropland into non-cultivated land, as well as intensification of production on cultivated land. There were six scenarios simulated: two representing cropland expansion and four representing cropland intensification. In the expansion scenarios, corn and grain sorghum replaced conservation reserve program (CRP) land-use. In the intensification scenarios corn and grain sorghum-based rotations replaced either winter wheat or hay land-uses. Winter wheat land-use was

Table 5
Study design matrix demonstrating the range of biofuel feedstock land-use transitions studied in each watershed; each range was broken into 10 simulations to study how impacts vary within the range.

Original Land-use	Additional area in grain sorghum	Additional area in corn
Winter Wheat	2.4–24 km^2	1.7–17 km^2
Hay	13–127 km^2	9.3–93 km^2
CRP	5.4–54 km^2	3.6–36 km^2

selected for analysis because it is not utilized as a biofuel crop, yet is a dominant crop in the Kansas landscape. Hay/pasture (furthermore referred to as "hay") and CRP have been indicated as targeted land-uses for conversion to biofuel feedstock crops, such as corn and soybean, in the Western Corn Belt due to projected higher profit returns from rising commodity prices (Wright and Wimberly, 2013). It is also expected that many land owners may not re-enroll CRP land due to high crop prices in recent years; however, this trend may not be seen if crop prices decline (Hellerstein and Malcolm, 2011; Secchi et al., 2011b). There is a total of 59 km^2 CRP land-use in the Perry Lake watershed that is set to expire between 2015 and 2025 as determined by geospatial analysis.

All corn land-use is represented by a corn-soy rotation, as this is the realistic land management practice in this watershed. Continuous sorghum and continuous winter wheat are also represented crop management. Baseline land-use areas are 34.8 km^2 winter wheat, 945 km^2 hay, 144 km^2 Conservation Reserve Program (CRP), 9 km^2 grain sorghum, and 400 km^2 corn. Each of the 6 scenarios were simulated at 10 different land-use change increments, resulting in 60 different simulations (see Table 5). The LUC tool is only able to convert an HRU from its original land-use type to a land-use type that is located in an adjacent HRU. Therefore, greater change could be simulated with the more dominant crops from the 2005 land-use patterns, which is one drawback to using this tool.

2.4. Water quality indicators

Total phosphorus, total nitrogen, and sediment loads were used as indicators of water quality impacts from LUC scenarios. Loads were determined at the subbasin outlets closest to the inlets of the reservoir and averaged over 12 years from 2000 to 2011 for each scenario. A baseline load was determined by calculating average total phosphorus (TP), total nitrogen (TN), and sediment loads from the 2000–2011 period before any land-use modifications. Baseline values were then subtracted from all scenario-generated TP, TN, and sediment loads to determine the difference from baseline conditions.

2.5. Sustainability indicators

Sustainability indicators were used to account for nutrient, land, and water resources used to grow biofuel feedstocks and to serve as metrics that can be compared across crop types and watersheds. Water resource use is accounted for by the water use efficiency (WUE; kg/m^3) indicator, which is calculated by taking the ratio of grain yield (Y; g/m^2) to crop evapotranspiration (ET; mm) (Tolk and Howell, 2003). Only non-irrigated cropland was simulated and analyzed in the LUC scenarios. As such, the WUE values varied mostly with the weather conditions of the two watersheds that dictated crop evapotranspiration. The average and standard deviation of WUE values are reported for both corn and grain sorghum for each watershed, as the values did not vary between scenarios. Nutrient resource use is represented by the nutrient use efficiency (NUE) indicator for nitrogen (NUE-N) and for phosphorus (NUE-P), which are calculated by dividing the grain yield (kg) by the amount of nitrogen (N; kg) and phosphorus (P; kg) applied as fertilizer (Good et al., 2004). Nitrogen and phosphorus application rates were determined based on recommended rates per acre for a specific bushel yield goal using county average yields from 2005 to 2011 from the National Agricultural Statistics Service (Leikam et al., 2003). Spatial land-use impact, or land-use efficiency (LUE; km^2/L) is accounted for by the ratio of land area changed (km^2) to the liters of ethanol produced. An estimate of ethanol production was calculated using values from the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG), which estimates an ethanol yield of 2.71 gallons per bushel of corn (using a dry milling process) and 2.38 gallons per bushel of grain sorghum (Ohrel et al., 2010). In all cases, indicators were calculated using average values for the entire watershed from 2000 to 2011. Other factors necessary to grow, harvest, or process the biofuel crop are not included in this analysis.

Table 6
Model evaluation statistics from comparison of observed vs. simulated average daily, monthly, and annual flow during calibration (1978–1996) and validation (1997–2011) time periods for the Delaware River NR Muscota USGS gauge.

Time Step	Scenarios	NSE	PBIAS
Daily	Calibration	0.65	5.68
	Validation	0.74	0.13
Monthly	Calibration	0.84	−15.6
	Validation	0.84	7.46
Annual	Calibration	0.80	−3.75
	Validation	0.79	7.46

Table 7
Model evaluation statistics from comparison of computed vs. simulated monthly sediment load during calibration (1999–2008), validation (2010–2011), and entire record time periods for the Delaware River NR Muscota USGS gauge.

Time Step	Scenarios	NSE	PBIAS
Monthly	Calibration	0.83	−20.0
	Validation 2010 (2011)	0.62 (−0.19)	43.5
	Entire Record	0.79	23.7

3. Results and discussion

3.1. Calibration and validation

Calibration and validation statistics are presented for streamflow and sediment load at the Delaware River near Muscotah and crop yield in the Nemaha, Jackson, Jefferson, Atchison, and Brown counties. A summary of calibration and validation statistics for annual, monthly, and daily streamflow, and monthly sediment yield are provided in Tables 6 and 7, respectively. Crop calibration and validation statistics are provided in Table 8.

Streamflow was simulated very well with 0.84 NSE for both monthly calibration and validation, 0.65 NSE for daily calibration, and 0.74 for daily validation. Percent bias was 5.7% for daily calibration and 0.13% for daily validation. Although there are some slight discrepancies in peak flow prediction, which can be noticed in the hydrograph (Fig. 2), for the most part it is clear that SWAT-predicted daily average flows follow the measured hydrograph. Sediment load calibration also showed promising statistics with a NSE monthly calibration value of 0.83 and −20% percent bias. Monthly validation for 2010 achieved a 0.62 NSE. It is clear in Fig. 3 that SWAT under predicts the sediment peaks; however, it is important to keep in mind that the "observed" sediment record is actually computed and therefore has uncertainty as well.

Crop calibration and validation (see Table 8) demonstrated that SWAT satisfactorily estimates corn yield in the Perry Lake watershed. Examining the overall period from 1996 to 2009 there is a positive bias in all counties ranging from 0.39–9.9%. Soybean calibration was limited due to fewer observed data in the study

Table 8
Comparison of NASS-reported and SWAT-modeled average crop yield from the 1996–2009 period in 5 counties within the Perry Lake watershed; percent bias (PBIAS) is reported for the corresponding time series (N = number of observations).

County	N	Average Crop yield 1996–2009 (t/ha)		PBIAS (%)
		NASS Reported	SWAT Modeled	
Corn				
Atchison	11	5.89	6.48	9.92
Brown	11	6.42	6.71	4.48
Jackson	13	5.49	5.56	1.36
Jefferson	10	5.65	5.69	0.83
Nemaha	13	5.54	5.61	1.35
Soybean				
Atchison	8	2.04	2.03	−0.39
Brown	4	2.11	1.88	−10.70
Jackson	6	2.13	2.08	−2.09
Jefferson	10	2.07	1.87	−9.85
Nemaha	6	2.29	1.90	−17.17

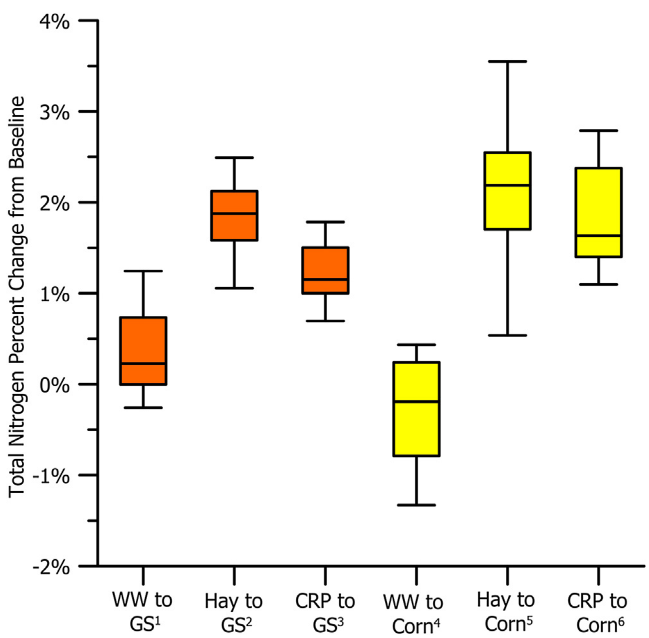

Fig. 6. Box plots showing the percent difference from baseline of total nitrogen export over the study period (2000–2011) in the Perry Lake watershed. Land area changed in each scenario was [1]12 km^2, [2]12.7 km^2, [3]11 km^2, [4]12 km^2, [5]9 km^2, [6]11 km^2. (WW: Winter Wheat, GS: Grain Sorghum, CRP: Conservation Reserve Program).

counties. In general soybean yield was under-predicted, on average, by 2–11%. Overall crop yield estimates seem to match fairly well on an annual basis with an r^2 value of 0.67 (n = 58) for simulated vs. reported crop yield from all years and counties (see Fig. 4). Sorghum yield was not calibrated for Perry watershed due to the lack of observed data.

3.2. Corn vs. grain sorghum

In general, corn-based scenarios produced higher water quality loads than grain sorghum-based scenarios (Figs. 5, 6, and 7). The corn land-use scenarios produced higher sediment loads per land area compared to the grain sorghum land-use scenarios and the difference was significant with a p-value < 0.001. Higher nutrient loads may be expected from increased corn acreage due to larger fertilizer applications compared to grain sorghum cropland (Fig. 8). However, these results vary slightly from a study comparing corn and grain sorghum LUC (Love and Nejadhashemi, 2011). In the Love and Nejadhashemi study, continuous production of grain sorghum

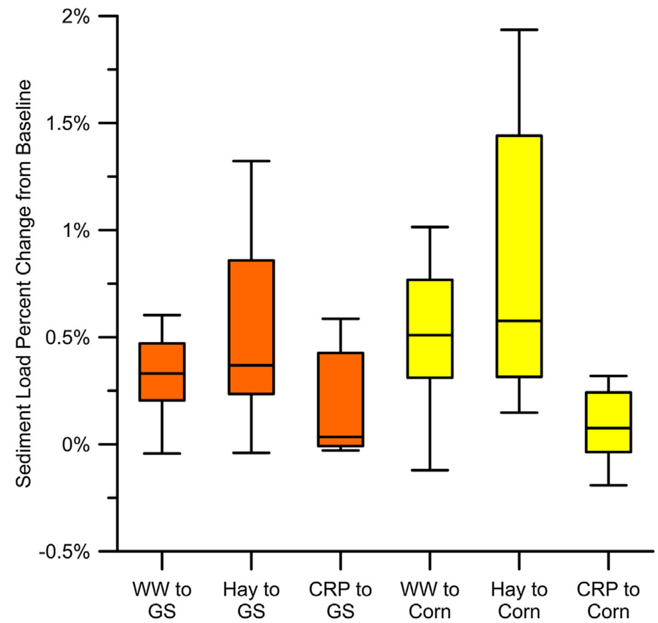

Fig. 7. Box plots showing the percent difference from baseline of sediment export over the study period (2000–2011) in the Perry Lake watershed. Land area changed in each scenario was 12 km^2, 12.7 km^2, 11 km^2, 12 km^2, 9 km^2, 11 km^2. (WW: Winter Wheat, GS: Grain Sorghum, CRP: Conservation Reserve Program).

resulted in higher median sediment and TP loads, but lower TN loads in comparison to continuous corn and corn-soy LUC in a Michigan watershed.

Sustainability indicators for both grain sorghum and corn are shown in Table 9. The SWAT model estimated average NUE-N and NUE-P values of 36 and 137 for grain sorghum (i.e.1 kg-N yielded 36 kg grain sorghum grain). Equivalently, an average of 27 kg-N and 7.2 kg-P are required to produce one metric ton of grain sorghum. For corn production average NUE-N and NUE-P values of 56 and 212 were estimated. Equally, about 17.5 kg nitrogen and 4.7 kg phosphorus are needed to produce one ton of corn grain. Therefore, corn has a higher NUE both in terms of nitrogen and phosphorus in the Perry Lake watershed. Corn LUE-yield, or grain yield per area, is also more than twice that of grain sorghum: 934–970 t/km^2 for corn compared to 433–452 t/km^2 for grain sorghum. Consequently, LUE-ethanol, or ethanol yield per km^2, is also more than double for corn (377,000–392,000 L/km^2) compared to grain sorghum (153,000–160,000 L/km^2). The range in estimates of ethanol production with all land-use simulations can be seen in Table 10. Average water use efficiency in the Perry Lake watershed was estimated to be 0.66 ± 0.22 kg/m^3 for grain sorghum and 1.49 ± 0.37 kg/m^3 for corn. Corn achieves about twice as much grain yield per m^3 water consumed in the Perry Lake watershed. The WUE results were somewhat unexpected as grain sorghum is considered a drought-tolerant plant and has been shown to produce greater biomass yield per water use, when compared to corn (Rooney et al., 2007). However, this study is focusing on grain yield and not overall biomass. Other studies indeed show that while corn has a higher max and threshold ET compared to grain sorghum, corn also has a higher yield to ET relationship (i.e. WUE) (Stone and Schlegel, 2006). It is important to note that the crops analyzed in the LUC scenarios were all simulated without irrigation. Overall, this study suggests that corn will most likely be favored over grain sorghum as a biofuel feedstock in the Perry Lake watershed, and similar watersheds, due to the higher yield potential and suitable climate to produce high corn yields without irrigation.

Table 9
Sustainability indicators for nutrient and land use resource requirements per ton of grain and per liter ethanol in Perry Lake watershed and Kanopolis Lake watershed (Units: NUE-N: kg-N/kg-grain, NUE-P: kg-P/kg-grain, LUE-Yield: tons/km^2, LUE-Ethanol: 1000L/km^2.

Starting Land-use	Ending Land-use	NUE-N (kg/kg)	NUE-P (kg/kg)	LUE-Yield (tons/km^2)	LUE-Ethanol (1000 L/km^2)
Winter Wheat	Grain Sorghum	36	136	446 ± 31	158 ± 11
Hay	Grain Sorghum	36	135	433 ± 4	153 ± 2
CRP	Grain Sorghum	37	140	452 ± 12	160 ± 4
Winter Wheat	Corn	56	211	954 ± 69	385 ± 28
Hay	Corn	55	208	934 ± 13	377 ± 5
CRP	Corn	58	218	970 ± 38	392 ± 15

Table 10
Increase in grain yield and subsequent ethanol production resulting from land-use scenarios substituting winter wheat, hay, and CRP for grain sorghum or corn in the Perry Lake watershed.

Starting Land-use	Ending Land-use	Area changed (km^2)	Grain Yield (t)	Ethanol Produced (L × 1000)
Winter Wheat	Grain Sorghum	2.4–24	1061–10,610	376–3762
Hay	Grain Sorghum	13–127	5507–55,070	1953–19,530
CRP	Grain Sorghum	5.4–54	2410–24,100	855–8546
Winter Wheat	Corn	1.7–17	1615–16,150	652–6522
Hay	Corn	9.3–93	8654–86,530	3494–34,940
CRP	Corn	3.6–36	3486–34,860	1408–14,080

3.3. Expansion vs. intensification of cropland

The water quality impacts differ between expanding cropland into CRP and intensifying production on current agricultural land (i.e. replacing winter wheat and hay with biofuel feedstock crops). In order to compare the various scenarios, results from scenarios with similar land-use change (9–13 km^2) will be reported here. When winter wheat land-use was replaced by 12 km^2 grain sorghum or corn, sediment loads increased an average of 0.26% and 0.43%, respectively, above the baseline sediment load of 2,340,000 t. TP loads increased an average of 0.51% and 0.36%, respectively, above the baseline TP load of 692,000 kg. The increase in sediment for both of these scenarios were statistically significant with a p-value <0.01. The increase in TP for both scenarios were also significantly different relative to the baseline ($p < 0.05$).

A simulated land-use change of 13 km^2 hay to grain sorghum resulted in a 0.35% increase in sediment load, a 1.5% increase in TN load, and a 1.9% increase in TP load above baseline levels. A simulated land-use change of 9 km^2 hay to corn (the most comparable land-use change increment) resulted in a 0.57% increase in sediment load, a 1.9% increase in TN load, and a 2.6% increase in TP load above baseline levels. All sediment, TN, and TP load increases from both corn and grain sorghum scenarios were statistically significant, relative to the baseline simulation with p-values <0.01. In all CRP land-use scenarios there was an increase in sediment, TP, and TN loads. The sediment load increased by 0.07%, TP increased by 1.4%, and TN increased by 1.1% above baseline values with an additional 11 km^2 in grain sorghum. With an additional 11 km^2 corn there was a 0.05% increase in sediment load, a 1.6% increase in TP load, and a 2.3% increase in TN load. All TN and TP load increases were statistically significant, relative to the baseline with p-values <0.001. Due to the lack of observed nutrient data needed to calibrate the nutrient simulation components, results are only reported as percentage increases above the baseline and care should be taken when evaluating these results.

Converting winter wheat land-cover to either corn or grain sorghum produced the lowest water quality changes (Figs. 5, 6, and 7). These results suggest that converting current cropland to a more intensive crop, such as corn or grain sorghum, may cause less water quality impacts than converting less intensive agricultural land-uses, such as hay or pasture. Other studies have also confirmed that conversion of current row crop land to biofuel feedstock provides the lowest water quality changes (as opposed to converting non-row crop land), and in some cases can result in a decrease in water quality outputs compared to the current baseline (Love and Nejadhashemi, 2011). For example, the Love and Nejadhashemi (2011) study found that a sorghum-soybean rotation had the potential to reduce nitrogen loads when grown on current row cropland.

Returning CRP land-use into production would also have greater environmental impacts beyond what can be analyzed in this study. CRP land sequesters carbon, maintains marginal land, provides habitat for birds and grassland species, and supports re-emerging grassland ecosystems (Wright and Wimberly, 2013). Tallgrass and mixed-grass prairies have been converted to agriculture at extremely high rates in the past, and remaining areas are critical for ecosystem conservation (Samson and Knopf, 1994). Interviews of Kansas farmers indicate that many farmers support the CRP program and see their participation as important for being a good steward to the land. However, some farmers indicated that they have already converted CRP land to cropland at the end of contracts, or have expressed interest in doing so (Brown et al., 2014; Gray and Gibson, 2013). Farmers cite income potential of grain production and land scarcity as reasons for converting CRP to cultivated land. Therefore, it is challenging to predict the amount of CRP land that may be converted back to agriculture, as personal values and economic factors both play a large role in land-use decision-making.

Intensification scenarios also pose additional problems that are not quantified in this study, such as the direct and indirect effects of replacing food-related crops with crops dedicated to the biofuel market. Kansas is consistently the number one or two producer of winter wheat in the United States, representing about 14% of the market (Kansas Department of Agriculture, 2014). Replacing winter wheat with biofuel feedstocks could interfere with the commodity market for wheat, causing a rise in food prices. Similarly, hay production is used to support the cattle industry, especially in Eastern Kansas. Therefore, substituting either of these crops at a large scale may have consequences for agricultural production for human consumption. The food vs. fuel issue is central to the biofuel debate, including the concern for rising food prices as food crops are diverted to fuel production (Cassman and Liska, 2007; Tilman et al., 2009). Specifically, there have been concerns about increasing greenhouse gas emissions, biodiversity loss, and water quality degradation due to cropland expansion for food crops if biofuel feedstocks are grown on currently utilized fertile land (Searchinger et al., 2008; Wright and Wimberly, 2013).

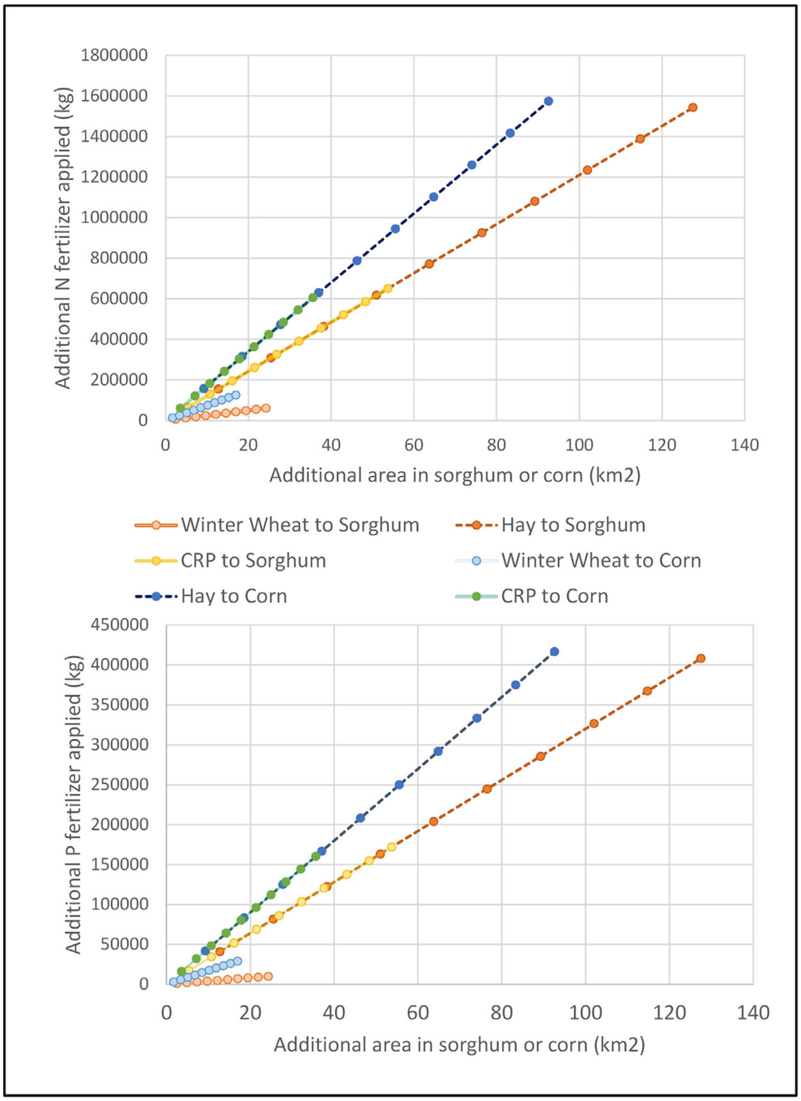

Fig. 8. Additional fertilizer applied in all scenarios (nitrogen on top and phosphorus below); each data point represents an iteration with a different land-use increment.

3.4. Additional water quality considerations

Based on bathymetric surveys, the Perry reservoir has lost 19% of multipurpose pool water storage capacity due to sedimentation (Juracek, 2015). Sediment removal is costly and can cause further environmental damage due to the invasive nature of the process and the challenge of properly disposing removed sediment (DeNoyelles and Jakubauskas, 2008). Current sediment loads need to be reduced by 28% to keep Perry Lake on track to reach the desired 100-year design life for sediment storage (Bosworth, 2011).

In addition, all designated uses in Perry Lake are impaired by eutrophication caused by nonpoint source nutrient pollution, and both lakes are under total maximum daily load (TMDL) plans in order to improve water quality conditions (Kansas Department of Health and Environment, 2015, 2004). The nitrogen load needs to be reduced by 70% (388,000 kg/year) and the phosphorus load also needs to be reduced by 71% (80,000 kg/year) in order to meet the Perry Lake TMDLs. Targeted BMPs to reach water quality goals are primarily focused on reducing non-point source inputs from cropland, livestock, and streambank erosion (Bosworth, 2011). It is clear that water quality improvement is necessary and unfortunately it will not be achieved without substantial investment from both landowners and government agencies. This study concurs with literature suggesting that increasing production of ethanol feedstocks will cause increased sediment, nitrogen, and phosphorus loads transferred downstream (Secchi et al., 2011a,b; Hendricks et al., 2014). Therefore, increased development of biofuel feedstocks that would further degrade watershed water quality should be carefully considered in light of water quality goals.

5. Conclusions

It is difficult to know for certain how land-use patterns will respond to future grain and fuel prices, land scarcity, government regulations, and farmers' decisions. The literature suggests that both expanding and intensifying production of agricultural land for biofuel feedstock development is highly possible, and in fact already occurring in Kansas (Brown et al., 2014). However, until now, there was not a study that explored the impacts of such land-use change (LUC) in Kansas. This study contributes to the discussion of environmental impacts of biofuel-based LUC by comparing impacts of change with corn and grain sorghum crops. Grain sorghum is a common feedstock for biofuel production in the central plains; however, the water quality impacts have not been studied as heavily as those related to corn LUC. In addition, this study expands on previous approaches by integrating water quality analysis with sustainability indicators to develop a richer assessment of the trade-offs and benefits of landscape change for biofuel feedstock development.

In this study, the SWAT model was used to simulate grain sorghum and corn production on current winter wheat, hay, and Conservation Reserve Program (CRP) land-uses in two Kansas watersheds. The overall results indicate that increasing the amount of grain sorghum or corn land use would both cause increases in nutrient export, but corn would increase nutrient loads significantly more than grain sorghum land-use. However, corn's higher water quality impacts are offset by the increased yield per land area; corn yield per km^2 is twice as high as grain sorghum yield (see Table 9). The higher yield and higher conversion rate from grain to ethanol make it possible to produce more than twice the ethanol with corn than grain sorghum with the same amount of land. Based on these results, corn appears to be a more efficient biofuel crop in northeastern Kansas. In addition, changes in water quality loads are lower when converting current winter wheat cropland. These results suggest that intensification of current row-crop agricultural land may be a more environmentally sustainable option for increasing biofuel feedstock production that converting non-row crop land.

Overall, the land-use simulations explored in this study can help aid decision-making by providing guidance on expected yield from various crops, as well as potential environmental degradation that may occur from enhanced feedstock development. Simulations need to occur at various scales in order to aid decision-making from federal to state levels. This study provides a Kansas perspective and may be helpful in considering environmental impacts of biofuel development in other Great Plains ecoregions as well. However, there are several limitations due to the modeling approach. First, the lack of observed nutrient data at relevant spatial and temporal scales adds uncertainty to the nutrient load results. Sediment loads were modeled with good accuracy, which increases the confidence that sediment-bound nutrients may be simulated well. In consideration of lack of nutrient calibration, nutrient results were only compared against the baseline model simulation to show a percent change in results. As such, nutrient results cannot be evaluated with a great deal of hard statistics, but instead are evaluated for relative trends.

Another uncertainty is the location where land-use change will occur. This study did not use a LUC model to delineate new land-use patterns, but instead land-uses were redistributed internally within the model using the Land-Use Updater Tool. The location of LUC could influence the amount of erosion and nutrient export from the landscape, as well as the quantity of loads transported to the downstream reservoir. Another important consideration is that BMPs were not modeled in this study. However, there is potential for biofuel feedstock development to coincide with BMP development, and this could offset some of the negative water quality impacts. Future research should focus on coupling LUC scenarios with BMP development, which would require a different LUC allocation approach other than the one used in this study. Future work should also examine the relationships between land-use change and water quality loads in other parts of the US with different dominant land-use patterns and hydrology. More spatially diverse studies will allow for a comprehensive analysis of where biofuel feedstock development is most sustainable with respect to water resources. Such information will be helpful to guide national and local renewable fuel policies to either provide economic incentives to encourage development or restrictions to curb excessive land-use change and resulting water quality problems.

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References

Arnold, J.G., Srinivasan, R., Muttiah, R.S., William, J.R., 1998. Large area hydrologic modeler and assessment part I: model development. J. Am. Water Resour. Asooc. 34, 73–89.
Bosworth, M., 2011. Delaware River WRAPS—9 Element Watershed Plan Summary (Accessed at: http://www.kdheks.gov/nps/wraps/Delaware_Plan&summary.pdf. Date accessed 17.12.15.).
Brown, J.C., Hanley, E., Bergtold, J., Caldas, M., Barve, V., Peterson, D., Callihan, R., Gibson, J., Gray, B., Hendricks, N., 2014. Ethanol plant location and intensification vs extensification of corn cropping in Kansas. Appl. Geogr. 53, 141–148.
Cai, H., Dunn, J.B., Wang, Z., Han, J., Wang, M.W., 2013. Life-cycle energy use and greenhouse gas emissions of production of bioethanol from sorghum in the United States. Biotechnol. Biofuels 6 (1), 1–15.
Cassman, K.G., Liska, A.J., 2007. Food and fuel for all: realistic or foolish? Biofuel Bioprod. Biorefining 1 (1), 18–23.
Cibin, R., Sudheer, K.P., Chaubey, I., 2010. Sensitivity and identifiability of stream flow generation paremeters of the SWAT model. Hydrol. Process. 24, 1133–1148.
Cibin, R., Chaubey, I., Engel, B., 2011. Simulated watershed scale impacts of corn stover removal for biofuel on hydrology and water quality. Hydrol. Process. 26 (11), 1629–1641.
Daggupati, P., Douglas-Mankin, K., Sheshukov, A., Barnes, P., Devlin, D., 2011. Field-level targeting using SWAT: mapping output from HRUs to fields and assessing limitations of GIS input data. Trans. ASABE 54 (2), 501–514.
DeNoyelles, F., Jakubauskas, M., 2008. Current state, trend, and spatial variability of sediment in kansas reservoirs. In: Sedimentation in Kansas Reservoirs: Causes and Solutions. Kansas Agricultural Experimental Station, pp. 143.
Donner, S.D., Kucharik, C.J., 2008. Corn-based ethanol production compromises goal of reduciing nitrogen export by the Mississippi River. PNAS 105 (11), 4513–4518.
Douglas-Mankin, K., Srinivasan, R., Arnold, J., 2010. Soil and water assessment tool (SWAT) model: current developments and applications. Trans. ASABE 53 (5), 1557–1568.
Environmental Protection Agency, 2015. Final Renewable Fuel Standards for 2014, 2015, and 2016, and Biomass-Based Diesel Volume for 2017, Accessed at: http://www.epa.gov/renewable-fuel-standard-program/final-renewable-fuel-standards-2014-2015-and-2016-and-biomass-based. Date accessed: 1.7.16.
Ficklin, D.L., Luo, Y., Luedeling, E., Zhang, M., 2009. Climate change sensitivity assessment of a highly agricultural watershed using SWAT. J. Hydrol. 374 (1–2), 16–29.
Gassman, P.W., Reyes, M.R., Green, C.H., Arnold, J.G., 2007. The Soil and Water Assessment Tool: historical development, applications, and future research directions. Trans. ASABE 50 (4), 1211–1250.
Glavan, M., Pintar, M., Urbanc, J., 2015. Spatial varation of crop rotations and their impacts on provisioning ecosystem services on the river Drava alluvial plain. Sustainability Water Qual. Ecol. 5, 31–48.
Good, A.G., Shrawat, A.K., Muench, D.G., 2004. Can less yield more? Is reducing nutrient input into the environment compatible with maintaining crop production? Trends Plant Sci. 9 (12), 597–605.
Gray, B.J., Gibson, J.W., 2013. Actor–Networks, farmer decisions, and identity. Cult. Agric. Food Environ. 35 (2), 82–101.
Hellerstein, D.R., Malcolm, S.A., 2011. The Influence of Rising Commodity Prices on the Conservation Reserve Program. ERR-110. US Department of Agriculture, Economic Research Service, US Department of Agriculture.
Hendricks, N.P., Sinnathamby, S., Douglas-Mankin, K., Smith, A., Sumner, D.A., Earnhart, D.H., 2014. The environmental effects of crop price increases: nitrogen losses in the US Corn Belt. J. Enviorn. Econ. Manage. 68 (3), 507–526.
Jager, H.I., Baskaran, L.M., Schweizer, P.E., Turhollow, A.F., Brandt, C.C., Srinivasan, R., 2014. Forecasting changes in water quality in rivers associated with growing biofuels in the Arkansas-White-Red river drainage USA. GCB Bioenergy 7 (4), 774–784.
Jessen, H., 2010. Sorghum Surges. Ethanol Producer Magazine, February 9, 2010. Accessed at: http://www.ethanolproducer.com/articles/6338/sorghum-surges.
Juracek, K.E., Ziegler, A., 2009. Estimation of sediment sources using selected chemical tracers in the Perry lake basin, Kansas, USA. Int. J. Sediment Res. 24 (1), 108–125.
Juracek, K.E., 2015. The aging of america's reservoirs: in-reservoir and downstream physical changes and habitat implications. J. Am. Water Resour. Assoc. 51 (1), 168–184.
Kansas Department of Agriculture, 2014. Kansas Farm Facts, 59, Accessed at: http://agriculture.ks.gov/docs/default-source/ag-marketing/kansas-farm-facts-september-15-2014c08bcf002e6262e1aa5bff0000620720.pdf?sfvrsn=0. Date accessed: 4.12.15.

Kansas Department of Health and Environment, 2004. Smoky Hill/Saline River Basin Total Maximum Daily Load, Accessed at: http://www.kdheks.gov/tmdl/ss/KanopolisE.pdf. Date accessed: 17.12.15.).
Kansas Department of Health and Environment, 2015. Kansas Lower Republication Total Maximum Daily Load, Accessed at: http://ofmpub.epa.gov/waters10/attains_impaired_waters.show_tmdl_document?p_tmdl_doc_blobs_id=76348. Date accessed: 17.12.2015.
Leikam, D., Lamond, R., Mengel, D., 2003. Soil Test Interpretations and Fertilizer Recommendations. Kansas State University, Manhattan, Kansas.
Love, B.J., Nejadhashemi, A.P., 2011. Water quality impact assessment of large-scale biofuel crops expansion in agricultural regions of Michigan. Biomass Bioenergy 35 (5), 2200–2216.
Moriasi, D., Arnold, J., Van Liew, M., Bingner, R., Harmel, R., Veith, T., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans. ASABE 50 (3), 885–900.
Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., 2011. Soil and Water Assessment Tool Theoretical Documentation Version. Grassland, Soil and Water Research Laboratory—Agricultural Research Service, pp. 618.
Nelson, R.G., Neitsch II, J.C., Langemeier, M.R., 2006. Environmental and economic analysis of switchgrass production for water quality improvement in northeast Kansas. J. Environ. Manage. 79 (4), 336–347.
Ohrel, S.B., Beach, R.H., Adams, D., Alig, R., Baker, J., Latta, G.S., McCarl, B.A., Rose, S.K., White, E., 2010. Model Documentation for the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG). U.S. Environmental Protection Agency, Climate Change Divison, Washington, DC.
Pai, N., Saraswat, D., 2011. SWAT 2009 _LUC: a tool to activate the land use change module in SWAT 2009. Trans. ASABE 54 (5), 1649–1658.
Putnam, J.E., Pope, L.M., 2003. Trends in Suspended-sediment Concentration at Selected Stream Sites in Kansas, 1970–2002. US Department of the Interior US Geological Survey.
Renewable Fuels Association, 2014. Falling Walls & Rising Tides: 2014 Ethanol Industry Outlook. Renewable Fuels Association, Washington DC.
Rooney, W.L., Blumenthal, J., Bean, B., Mullet, J.E., 2007. Designing sorghum as a dedicated bioenergy feedstock. Biofuels Bioprod. Biorefining 1 (2), 147–157.
Samson, F., Knopf, F., 1994. Prairie conservation in North America. Bioscience 44 (6), 418–421.
Schmalz, B., Fohrer, N., 2009. Comparing model sensitivities of different landscapes using the ecohydrological SWAT model. Adv. Geosci. 21, 91–98.
Searchinger, T., Heimlich, R., Houghton, R.A., Dong, F., Elobeid, A., Fabiosa, J., Tokgoz, S., Hayes, D., Yu, T.H., 2008. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. Science 319 (5867), 1238–1240.
Secchi, S., Gassman, P.W., Jha, M., Kurkalova, L., Kling, C.L., 2011a. Potential water quality changes due to corn expansion in the Upper Mississippi River Basin. Ecol. Appl. 21 (4), 1068–1084.
Secchi, S., Kurkalova, L., Gassman, P.W., Hart, C., 2011b. Land use change in a biofuels hotspot: the case of Iowa, USA. Biomass Bioenergy 35 (6), 2391–2400.
Sinnathamby, S., 2014. Modeling Tools for Ecohydrological Characterization. (Doctoral Dissertation), Retrieved from K-Rex. Accessable at: http://hdl.handle.net/2097/18702. Date accessed: 12.11.15.
Stone, L.R., Schlegel, A.J., 2006. Crop water use in limited-irrigation environments. In: Proc. 2006 Central Plains Irrigation Conf., Colby, KS.
Tilman, D., Socolow, R., Foley, J.A., Hill, J., Larson, E., Lynd, L., Pacala, S., Reilly, J., Searchinger, T., Somerville, C., 2009. Beneficial biofuels—the food, energy, and environment trilemma. Science 325 (5938), 270.
Tolk, J.A., Howell, T.A., 2003. Water use efficiencies of grain sorghum grown in three USA southern Great Plains soils. Agric. Water Manage. 59 (2), 97–111.
United States Geological Survey, 2013. Kansas Real-Time Water Quality (accessed 20.06.11).
Wang, D., Bean, S., McLaren, J., Seib, P., Madl, R., Tuinstra, M., Shi, Y., Lenz, M., Wu, X., Zhao, R., 2008. Grain sorghum is a viable feedstock for ethanol production. J. Ind. Microbiol. Biot. 35 (5), 313–320.
Wright, C.K., Wimberly, M.C., 2013. Recent land use change in the Western Corn Belt threatens grasslands and wetlands. PNAS 110 (10), 4134–4139.
Wu, Y., Liu, S., Li, Z., 2012. Identifying potential areas for biofuel production and evaluating the environmental effects: a case study of the James River Basin in the Midwestern United States. GCB Bioenergy 4 (6), 875–888.
Zhang, X., Srinivasan, R., Van Liew, M., 2009. Multi-site calibration of the SWAT model for hydrologic modeling. Trans. ASABE 51 (6), 2039–2049.