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MODELING STREAMFLOW AND WATER QUALITY IMPACTS OF GRASSLAND ESTABLISHMENT, CONVERSION, AND MANAGEMENT IN SKUNK CREEK WATERSHED

BY

JIYEONG HONG

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Agricultural and Biosystems Engineering

South Dakota State University

2017

MODELING STREAMFLOW AND WATER QUALITY IMPACTS OF GRASSLAND ESTABLISHMENT, CONVERSION, AND MANAGEMENT IN SKUNK CREEK WATERSHED

JIYEONG HONG

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science in Agricultural and Biosystems Engineering degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidates are necessarily the conclusions of the major department.

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Disclaimer

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ABSTRACT

MODELING STREAMFLOW AND WATER QUALITY IMPACTS OF GRASSLAND ESTABLISHMENT, CONVERSION, AND MANAGEMENT IN SKUNK CREEK WATERSHED

JIYEONG HONG

2017

Grassland is a valuable natural resource with many environmental benefits, which include erosion control, wildlife habitat promotion, water quality protection, and flood prevention. Conversion of grassland to cultivated cropland has been linked to environmental quality concerns. The goal of this study was to model the impacts of grassland establishment, depletion, and management on hydrology and water quality in Skunk Creek watershed in eastern South Dakota. The specific objectives are to quantify the impacts of grassland conversion and selected management regimes on streamflow and water quality, and explore the optimum grassland establishment location within a watershed to achieve water quality benefits. The Soil and Water Assessment Tool (SWAT) was used to evaluate "what if" scenarios to simulate streamflow, sediment, nitrate, and dissolved phosphorus loads at the outlet of the study watershed. Cropland Data Layer for the year 2011 was used as the existing land use condition, and 19 years of historical climate dataset (1996-2014) was used to create SWAT models for scenario simulations.

Results indicate that grassland conversion to cropland and heavy grazing will likely result in water quality degradation in this watershed, while the best location for

grassland establishment to attain water quality benefits within a watershed depends on the nutrient of interest and cropping systems. Grassland conversion to cropland scenarios resulted in 7% of increase in streamflow and sediment loading, 9% increase in dissolved phosphorus loading, and 25% decrease in nitrate loading. Grass-crop rotation shows increase in streamflow, and sediment loads by 12% and 19%, respectively, 13% decrease in nitrate loads, and a decrease in dissolved phosphorus loading. Grass-crop rotation scenarios with long-term grassland establishment resulted in 18% reduction in nitrate loads and less than 1% increase in dissolved phosphorus loads.

Based on the simulations, heavy grazing reduced streamflow, sediment, and dissolved phosphorus, and nitrate loading by 7%, 8%, 2%, and 6%, while moderate grazing reduced streamflow, sediment, and dissolved phosphorus, and nitrate loading by 6%, 6%, 3%, and 6% compared to the baseline scenario. Heavy grazing (grazing on 100% of grassland) affected streamflow, sediment, and dissolved phosphorus loading by -1%, 2%, and 0.23% while nitrate loading remained similar compared to moderate grazing (grazing on 50% of grazing).

The results of grassland establishment at downstream, midstream, and upstream areas of the watershed showed that the optimum locations for implementing grass cover in a watershed to attain water quality benefits varied depending on the nutrient and crop examined. Downstream, midstream, and upstream are respectively the optimum locations for reducing dissolved phosphorus, sediment, and nitrate loads in this watershed.

CHAPTER 1: INTRODUCTION

1.1 Background

The distribution, quantity, and quality of water resources in a watershed are generally affected by natural and human activities (Bennett et al., 2001; Gburek & Folmar, 1999; Helmer et al., 1989). Natural phenomena that affect watershed hydrology include precipitation and watershed characteristics, while human activities include land use alteration such as agricultural expansion, forestry, urbanization, and industrialization (Gburek & Folmar, 1999; LeBlanc et al., 1997; Taebi & Droste, 2004). Research has linked increased streamflow to climate change at various geographic locations (Iglesias et al., 2007; Mimikou et al., 2000; Yu et al., 2002). Intensive farming and urbanization change infiltration and surface runoff characteristics, which in turn affect groundwater recharge, water and sediment yield, and evapotranspiration (Chen et al., 2009; Lee & Bang, 2000; Qin et al., 2013).

In the Upper Midwest and Northern Great Plains, grassland conversion to cultivated cropland is common and mainly driven by demand for biofuel feedstocks such as corn-based ethanol and significant increase of crop prices (Claassen, 2011; Fargione et al., 2009; Wright & Wimberly, 2013). Between 2006 and 2011, many areas in the western Corn Belt experienced 1 to 5% annual conversion of grassland to corn and soybean production systems (Wright & Wimberly, 2013). Grassland conversion can be detrimental to downstream hydrology and water quality.

1.2 Problem Statement

Grassland has many environmental benefits, including reduction of runoff and flooding, control of soil erosion, preservation of biodiversity, and water quality improvement (Lehmann & Hediger, 2004; Vandever & Allen, 2015; Wu et al., 2008). For example, grassland has been credited for surface runoff and flood reduction (Gao & Li, 2015; Lüscher, 2004; Moriasi et al., 2008). Retaining grassland near waterways is an effective strategy to reduce runoff volume and peak flow rates as well as sediment yield (Hjelmfelt & Wang, 1999; Qi et al., 2005). While the ecological and economic impacts of grassland depletion has been extensively studied and well documented in the Great Plains region (Clay et al., 2014; Reitsma et al., 2014; Reitsma et al., 2015), there is a scarcity of information on hydrologic and water quality impacts of grassland conversion to cultivated croplands.

1.3 Objectives

The goal of this study was to quantitatively analyze the effects of grassland depletion and management on hydrology and water quality in Skunk Creek watershed in eastern South Dakota. The specific objectives were to:

1. Quantify the impacts of grassland conversion and selected management regimes on streamflow and water quality; and
2. Explore the optimum grassland establishment location within a watershed to achieve water quality benefits.

1.4 Significance of Thesis

Given the rapid conversion of grassland to cropland during the past few decades (Wright & Wimberly, 2013), this study would provide useful information to support sustainable conversion and management of perennial grasses in South Dakota.

CHAPTER 2: LITERATURE REVIEW

2.1 Land Use Conversion

Land use conversion is a major factor that impacts hydrological processes and water quality in a watershed (Harbor, 1994; Hunt et al., 2014; Quinn et al., 1997; Scanlon et al., 2005). Land use and land cover (LULC) are mainly driven by human activities for food and recently for biofuel production (de Souza Ferreira Filho & Horridge, 2017; García-Hernández et al., 2017; Liu et al., 2005).

2.1.1 Conversion of Grassland to Agricultural Land

Over the past few decades, cropland has displaced grassland in the Northern Great Plains (Claassen, 2011). The land use change is mainly driven by production of bioenergy crops and the global population increase (Wright & Wimberly, 2013). In South Dakota, 1,840,000 acres of grassland were converted to other land uses between 2006 and 2012 (Reitsma et al., 2014; Wright & Wimberly, 2013) (Figure 2.1).

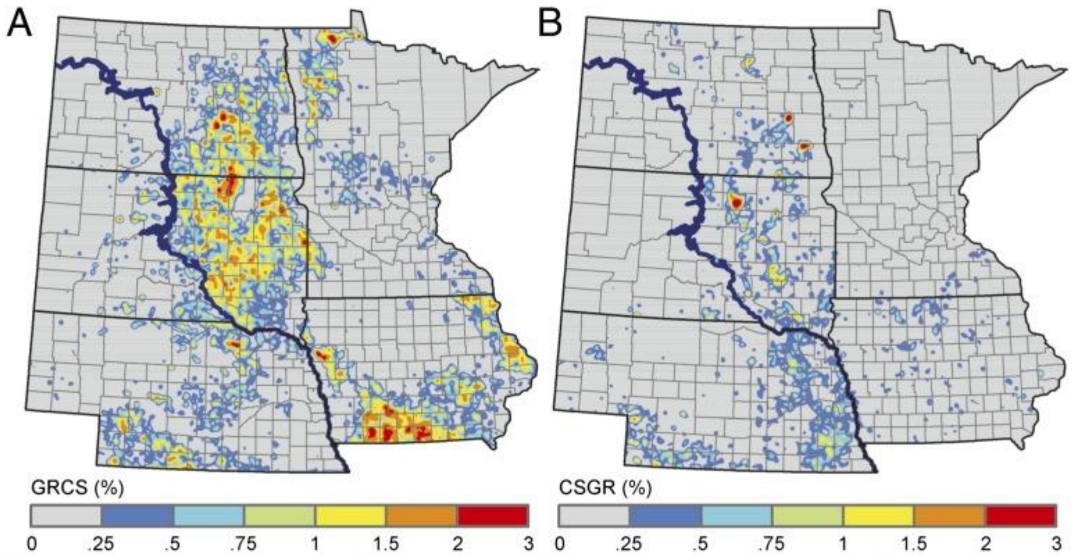


Figure 2.1 (A) Absolute change from grassland in 2006 to corn or soybeans in 2011, (B) Absolute change rate from corn or soybeans in 2006 to grassland in 2011 (Wright & Wimberly, 2013)

2.1.2 Conversion of Agricultural Land to Grassland

Although expansion of cropland is the common land use conversion, restoration of grassland through conservation reserve practices has captured interest of producers in the region (Donald et al., 2001; Drum et al., 2015; Stubbs, 2014). Promoted by the Conservation Reserve Program (CRP), grassland increased to 14.9 million ha in 2007 in the Prairie Pothole Region (Congress, 2008). In the James River Basin in the Dakotas, the CRP initiative has the goal of establishing 100,000 acres in 10-15 year contracts from November 2009 (USDA, 2009). Conversion of cropland to grassland would support conservation of ecosystem services (Karlen et al., 1998; Reynolds et al., 1994; Ribaudo, 1989).

2.2 Grassland Conversion Impacts on Hydrology and Water Quality

Depletion of grassland can lead to frequent floods (Wagner et al., 2009), because grassland increases infiltration rate compared to crop producing areas (Yi et al., 2013). A modeling study revealed that grassland reduces surface runoff and increases streamflow during dry seasons (Qiu et al., 2011). Studies showed that retaining grassland near waterway areas is an effective strategy to reduce runoff volume and peak rate as well as sediment yield (Hjelmfelt & Wang, 1999; Qi et al., 2005). However, other researchers showed that streamflow decreases due to land use conversion from grassland to cropland with application of the Variable Infiltration Capacity (VIC) model in the Great Lakes region (Mao & Cherkauer, 2009).

The use of grass as buffer zones can filter nitrogen (N), and phosphorus (P) (Heathwaite et al., 1998; Muscutt et al., 1993). Grassland has many water quality benefits that include control of soil erosion, preservation of biodiversity, and nutrient loading reduction (Lehmann & Hediger, 2004; Vandever & Allen, 2015; Wu et al., 2008). Grassland has been credited for surface runoff and flood reduction (Lüscher, 2004), leading to less sediment loading from grassland areas than cultivated cropland (Gao & Li, 2015; Moriasi et al., 2008). In Virginia, 18-month field experiments were conducted to assess the role of different size of grass filter strips on improving water quality (Mendez et al., 1999). The researchers found that 8.5 m filter reduced between 42 and 90%, and the 4.3 m filter reduced from 20 to 83% concentrations of total Kjeldahl nitrogen, ammonia nitrogen (NH_4^+-N), and nitrate nitrogen (NO_3-N). In the Delaware basin in northeast Kansas, SWAT model simulations showed 99, 55, 34, and 98% reduction of sediment, surface runoff, nitrate, and edge-of-field erosion with establishment of grass on all parcels of agricultural cropland within the watershed (Nelson et al., 2006). Furthermore, a reduction of instream phosphorus load and total nitrogen was predicted with turfgrass using SWAT (Stewart et al., 2006). In the Raccoon River watershed in Iowa, the role of grass under CRP in cropping areas was noticeable with reductions in sediment yield, nitrate and phosphorus loadings, while expansion of corn cropping systems increased streamflow, sediment yield, and nitrate and phosphorus loadings (Jha et al., 2007). With expansion of grass/pasture and reduction of cropland areas in the Skunk Creek watershed in South Dakota, not only was surface runoff decreased but sediment, nitrate, and total phosphorus loads were also reduced (Rajib et al., 2016).

2.3 Grassland Management Impacts on Hydrology and Water Quality

Management practices often used on grassland areas include mowing, grazing, fertilization, species diversity, legume introduction, and CRP (Babcock et al., 1996; Li et al., 2014; Oelmann et al., 2011; Parsons et al., 2013). Among grassland management practices, this study will focus on grazing. Heavy grazing can lead to changes in streamflow and nutrient loading into streams and rivers (Park et al., 2015). A study conducted in North Texas revealed that surface runoff is the primary contributor to streamflow increase under heavily continuous grazing while baseflow is the major contributor to streamflow under multi-paddock grazing by SWAT simulations (Park et al., 2017). Multi-paddock grazing can decrease high flow events, leading to reduction in flooding frequency (Park et al., 2017).

Research showed conflicting results regarding water quality issues about grazing management. Increased suspended solids and nitrate loads were not noticeable with grazing practices but bacteria densities increased in a Colorado front range stream (Gary et al., 1983). Other studies reported that grazing operations on grassland degrades water quality (Lyons et al., 2000; O'reagain et al., 2005; Owens et al., 1989). For example, intensive rotational grazing resulted in streambank erosion and fine substrate reduction in the channel compared to continuous grazing (Lyons et al., 2000). Heavily continuous (all-year round) grazing lead to increased organic nitrogen, total organic carbon, and sediment in streamflow in a North Appalachian watershed near Coshocton, Ohio (Owens et al., 1989). Similarly, summer rotational grazing and winter-feeding grazing increased sediment by 60% compared to summer rotational grazing only in Wisconsin (Lyons et al., 2000). In North Carolina, pollutant loads from grazed grassland fields slightly decreased with installation of off-stream water sources for cattle (Line et al., 2000). Regulating and managing the intensity of grazing practices can also lead to water quality improvement (Mosley et al., 1997; Sheffield et al., 1997). Research showed that intensive grazing may have negative impacts on water quality (Stout et al., 2000). Grazing regulations through strategies such as duration and intensity of' livestock grazing, animal distribution patterns, site suitability for grazing were shown to improve water quality and aquatic habitat (Clary & Webster, 1989; Dwyer et al., 1984). Park et al. (2015) reported 40% decrease in sediment loads with management of multi-paddock grazing.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Area

This study was conducted in Skunk Creek watershed in South Dakota (Figure 3.1), a subwatershed of the Big Sioux River watershed. The total area of the watershed is 1,605 km^2, which is mainly under agricultural land use (Figure 3.2). Major cultivated crops consist of 35% corn, 29% soybean of the watershed area (USDA-NRCS, 2016). Grassland is another major land use; about 14% of the watershed area (USDA-NRCS, 2016). Grassland is being converted to agricultural land use (approximately 3% between 1992 and 2001). Due to the demand for biofuel crop production, agriculture areas increased with decreased grassland area in this watershed (Paul et al., 2017; Rajib et al., 2016). This trend in grassland conversion in Skunk Creek is relatively consistent with grassland depletion in majority of watersheds in South Dakota based on data from 2006 to 2012 (Reitsma et al., 2014).

Dominant hydrologic soil group in this watershed is group B, which includes 10% to 20% clay content, and 50% to 90% sand with some loamy sand. Soils in group B have moderately low runoff potential when thoroughly wet with unimpeded water transmission capacity (NRCS, 2009).

Annual average precipitation in the watershed between 1996 and 2014 was 668mm. Annual average streamflow at the watershed outlet was 4m^3/sec. The maximum and minimum streamflow during the 1996-2014 period were 135m^3/sec and 0m^3/sec, excluding the period of 2001 to 2003. Average daily temperature in the watershed ranged from -29.8°C to 31.4°C between 1996 and 2014.

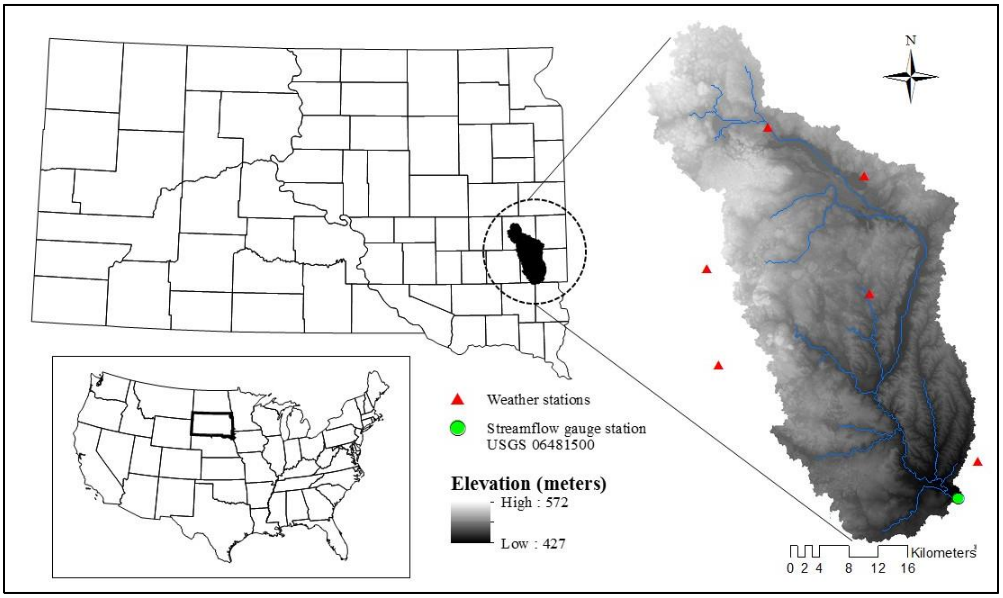


Figure 3.1 Location of Skunk Creek watershed in South Dakota, nearby rain gauge stations, and streamflow gauge station (USGS 06481500) at the outlet of the watershed

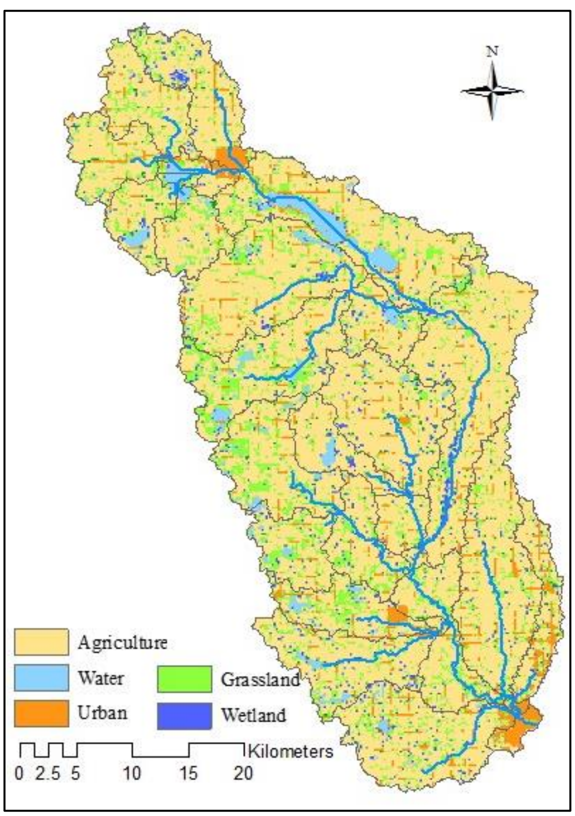


Figure 3.2 Major land uses in Skunk Creek watershed

3.2 SWAT Model

The Soil and Water Assessment Tool (SWAT) is a physically based and distributed parameter model designed to predict the long-term impact of land use management and climate on hydrology and water quality of a watershed (Arnold et al., 1998). The impact of agricultural land management practices such as planting, harvesting, fertilizing, and grazing on hydrology and water quality can be predicted. Digital Elevation Model (DEM) from the USGS National Elevation Dataset (USGS-NED, 2016) was used to delineate the watershed boundary with sub-watersheds which are further divided into HRUs. HRUs are basic units in hydrologic modeling and are homogeneous areas resulting from the combination of land use, soil, and slope (Arnold et al., 2010).

Components of SWAT include processes of surface runoff, percolation, lateral subsurface flow, groundwater flow, evapotranspiration, snow melt, transmission losses, ponds, weather including precipitation, air temperature, solar radiation, wind speed, and humidity for hydrological modeling (Arnold et al., 1998). Simulation of hydrology in SWAT is based on the water balance equation as follows (Neitsch et al., 2011):

$$SW_t = SW_o + \sum_{i=1}^{t}\left(P - Q_{surf} - ET - w_{seep} - Q_{gw}\right) \qquad (3.1)$$

where SW_t is the final soil water content on day t, SW_0 is initial soil water content, P is the precipitation, ET is the evapotranspiration, Q_{surf} is the surface runoff flow, Q_{gw} is the groundwater flow, and w_{seep} is the deep aquifer recharge. Accurate prediction of pollutant transport is driven by accurate prediction of water movement in the watershed. Nitrate and dissolved phosphorus are computed by using algorithms for transport and transformation such as mineralization, nitrification, denitrification, volatilization, sediment-bound phosphorus, phosphorus fixation by soil particles, and plant uptake (Green & Van Griensven, 2008).

SWAT has been widely used worldwide for different purposes (Gao & Li, 2015; Jha et al., 2007; Moriasi et al., 2008; Parajuli, 2007). For example, Paul et al. (2017) evaluated hydrological response of climate and land use changes in Bad River, Skunk Creek, and Upper Big Sioux River watersheds in South Dakota using SWAT model. It is evident that SWAT model performed well for their study since they obtained reasonable calibration and validation statistics as discussed by Moriasi et al. (2007). In addition, Paul (2016) was able to predict the outcome of future climate and land use change scenarios for the mentioned watersheds. SWAT model was also used for assessing water quality, including; sediment, nitrate and phosphorus in many studies. In the Raccoon River watershed in Iowa, Jha et al. (2007) showed that changes in land use scenarios can result in reduction of nutrients and sediments. The results of the study indicate that conversion of cropland into fallow land resulted in large reductions of sediment yields at the watershed outlet. The study of sediment-associated with Escherichia coli (E. coli) transport in the Little Cove Creek watershed using SWAT model in southern Pennsylvania Kim et al. (2010) revealed the capability of SWAT to model E. coli release despite the uncertainty of E. coli concentration in streambed sediment. However, modeling bacteria colonies with SWAT is still under development to improve model accuracy.

3.3 Input Data

In this study, a ‘baseline’ scenario was constructed with the existing land use condition of the study watershed for 19 years (1996-2014) to enable comparison to grassland conversion and management secenarios. The operation data requirements for SWAT are topography, land use, soil, and weather. For the baseline scenario, 30 m DEM data for Skunk Creek watershed were extracted from the USGS National Elevation Dataset (USGS-NED, 2016). Land use data of the Crop Data Layer 2011 (USDA-NASS, 2016), 1:250,000 scale State Soil Geographic (STATSGO) dataset included in SWAT2012 database were used. A total of 1,097 distinct HRUs and 31 sub-basins were discretized. SWAT weather data were created using continuous time-series of daily precipitation, daily maximum temperature, and daily minimum temperature for a period of 1994-2014. Observed steamflow data were obtained the Skunk Creek gauge station (USGS 06481500). The years 2001 to 2003 are excluded from the study period due to missing streamflow data. The climate data were obtained from the National Climate Data Center for five rain gauge stations in watershed (Figure 3.1). Practical land management operations in the watershed for corn, soybean, and alfalfa are shown in Table 3.1. Timing for planting, harvest, and kill were entered into “.mgt table” in SWAT. On corn growing areas, nitrogen and phosphorus fertilizers were applied. Phosphorus fertilizer was applied on soybean areas (Table 3.1). The frequency and amount of fertilizers were obtained from the relevant literature (Neupane & Kumar, 2015; Rajib et al., 2016).

Table 3.1 Land management operations in Skunk Creek watershed, South Dakota as used in this study

Corn		
Planting	5-May	
Fertilizer	Timing	Rate/Crop Year (kg/ha)
Urea	15-Apr	85
Monoammonium Phosphate	15-Apr	40
Harvest and Kill	5-Oct	
Soybean		
Planting	10-May	
Fertilizer	Timing	Rate/Crop Year (kg/ha)
Monoammonium Phosphate	9-May	40
Harvest and Kill	28-Sep	
Alfalfa *(Perennial)*		
Planting	1-Apr	
Harvest and Kill	10-Jul	

3.4 Calibration Validation

SWAT was executed for a total simulation period of 21 years, from 1994 to 2014. The first period of two years (1994 - 1995) was used as a warm up period, 10 years (2005 - 2014) as the calibration period, and five years (1996 - 2000) as the validation period. Calibration and validation were performed with daily streamflow, monthly sediment load, monthly dissolved phosphorus load, and monthly nitrate load using SWAT-CUP (Abbaspour, Vejdani, Haghighat, et al., 2007). SWAT-CUP was designed for calibration of SWAT models. The sensitivity of each parameter used for model calibration is shown in Figure 3.3.

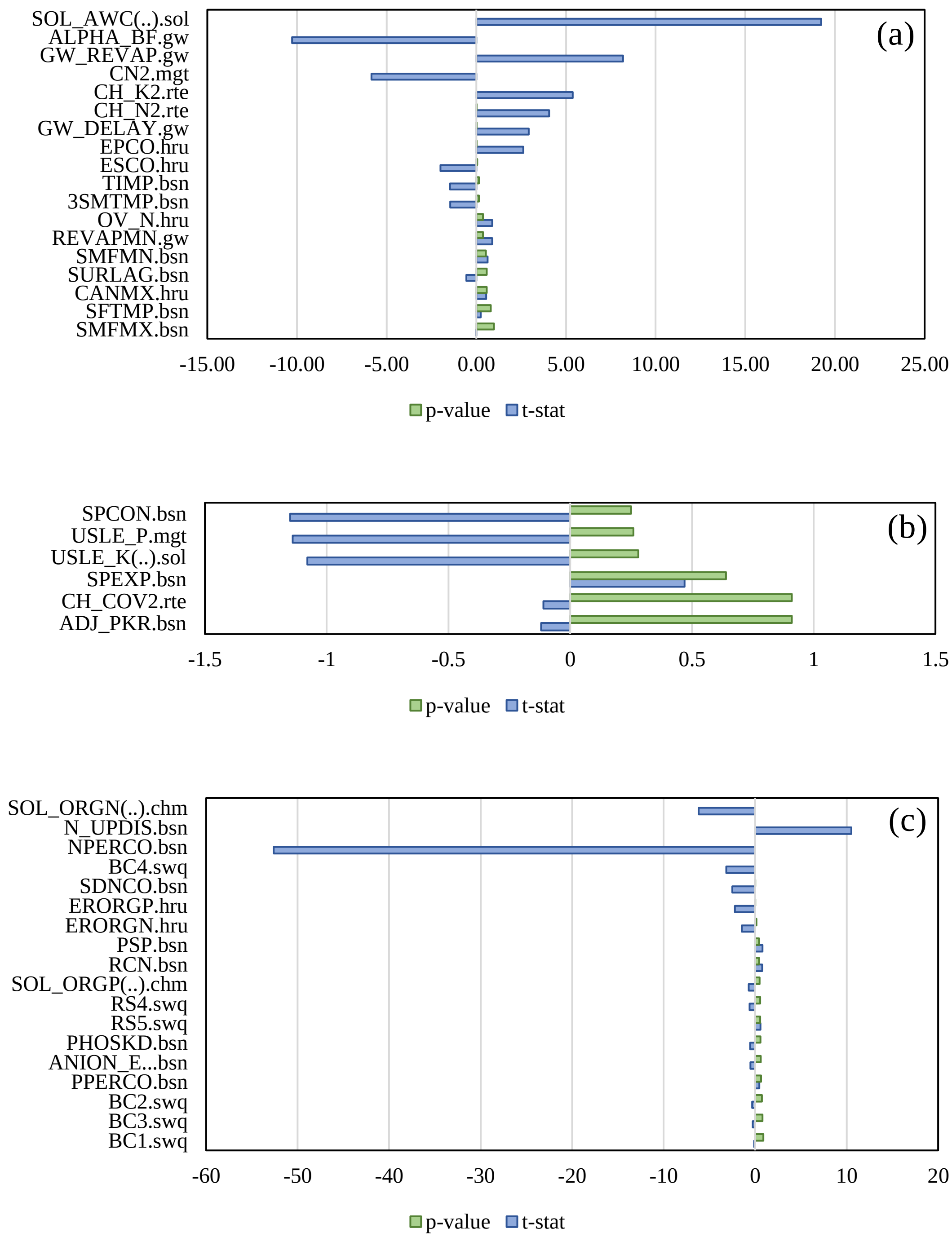


Figure 3.3 Sensitivity analysis of parameters used calibration of (a) streamflow, (b) sediment, and (c) dissolved phosphorus and nitrate based on output from SWAT-CUP. The length of the bar depicts the level of sensitivity of the parameter.

Daily observed streamflow data were obtained from the USGS streamflow gauge station (USGS 06481500). Observed pollutant concentration were obtained from STORET; http://www3.epa.gov/storet/). Due to the scarcity of nutrient concentration data, the load estimator (LOADEST) regression model (Runkel et al., 2004) was used to estimate continuous daily water quality constituent loads and used as observed loads for calibration and validation. LOADEST was designed to estimate water quality constituent loading with a time series of streamflow and measured pollutant concentrations (Runkel et al., 2004).

The Nash-Sutcliffe Efficiency (NSE), coefficient of determination (R^2), and percentage of bias (PBIAS) were used as objective functions to assess the agreement between simulated and observed streamflow, sediment, nitrate, and dissolved phosphorus loadings. NSE determines the relative magnitude of the residual variance ("noise") between the observed and simulated with an acceptable range of 0 to 1 (Moriasi et al., 2007). R^2 indicates the degree of collinearity between simulated and observed data with an acceptable range of 0 to 1. PBIAS measures the average deviation of the simulated data from the observed data (Gupta et al., 1999). The model simulation satisfactory ranges are generally NSE > 0.5, PBIAS < ±25% for streamflow, PBIAS < ±55% for sediment, and PBIAS <± 70% for nitrate and dissolved phosphorus loads (Moriasi et al., 2007). R^2 is considered satisfactory when the value > 0.5 (Van Liew et al., 2003).

Runoff, total sediment, nitrate, and dissolved phosphorus loadings at the outlet of Skunk Creek watershed at monthly and annual time steps were used in this study. As a standard approach, the model was first calibrated for hydrology, followed by sediment and dissolved phosphorus, and finally for nitrate. Model parameters that were selected for calibration, together with their ranges, and best fits are shown in Table 3.2.

Table 3.2 Parameters used for SWAT model calibration in this study

	Parameter	Definition	Initial range	Best estimate
Streamflow				
1	v__ALPHA_BF	Baseflow recession constant (days)	0.01-1	0.34
2	v__CH_N2	Main channel Manning's n	0.01-0.15	0.13
3	v__SMTMP	Snow melt base temperature (˚C)	0-5	1.23
4	v__SFTMP	Snowfall temperature (˚C)	0-10	2.36
5	v__SMFMX	Melt factor for snow on June 21 (mm H_2O/˚C-day)	0-10	2.62
6	v__GW_DELAY	Groundwater delay (days)	-10-10	-1.98
7	v__TIMP	Snow pack temperature lag factor	0-1	0.58
8	v__OV_N	Manning's n for overland flow	0.008-0.5	0.41
9	v__REVAPMN	Re-evaporation threshold (mm H_2O)	0.01-500	142.51
10	v__ESCO	Soil evaporation compensation factor	0-1	0.94
11	v__EPCO	Plant uptake compensation factor	0-1	0.65
12	v__CH_K2	Main channel hydraulic conductivity (mm/h)	5-100	87.49
13	v__SMFMN	Melt factor for snow on December 21 (mm H_2O /˚C-day)	0-10	6.28
14	v__SURLAG	Surface runoff lag coefficient (days)	0.05-24	23.08
15	v__GW_REVAP	Groundwater "revap" coefficient	0.01-0.2	0.14
16	a__CN2	Curve number (moisture condition II)	-20-20	-12.47
17	a__SOL_AWC	Available soil water capacity (mm/mm)	-15-15	5.05
18	v__CANMX	Maximum canopy storage (mm H_2O)	0.01-25	21.63
Sediment				
19	v__USLE_K	Soil erodibility factor	0.01-1	0.05
20	v__USLE_P	Support practice factor	0.001-1	0.24
21	v__ADJ_PKR	Peak rate adjustment for sediment routing in the trib.	0.5-1.5	1.25
22	v__SPEXP	Exponent factor for channel re-entrainment	1-2	1.90
23	v__SPCON	Maximum channel re-entrainment factor	0.0001-0.01	0.00
24	v__CH_COV2	Channel cover factor	0.01-0.5	0.06
Dissolved phosphorus				
25	v__PSP	Phosphorus availability index	0.01-0.7	0.23
26	v__PHOSKD	Soil partitioning coefficient (m3/Mg)	100-200	117.05

27	v__PPERCO	Phosphorus percolation coefficient (m3/Mg)	10-17.5	16.55
28	v__ERORGP	Phosphorus enrichment ratio	0.001-5	1.02
29	v__BC4	Rate constant for mineralization of organic P to dissolved P in reach (day-1)	0.01-0.7	0.55
30	v__RS5	Organic P settling rate in reach (day-1)	0.001-0.1	0.07
31	v__SOL_ORGP	Initial organic P concentration in soil (mg P/kg soil)	90-250	187.36
Nitrate				
32	v__RCN	Nitrogen in rain (mg/L)	0.001-10	3.56
33	v__NPERCO	Nitrate percolation coefficient	0.01-1	0.14
34	v__ANION_EXCL	Fraction of porosity from which anions are excluded	0.01-1	0.71
35	v__BC1	Rate constant for biological oxidation of NH_4 to NO_2 in reach (day-1)	0.1-1	0.47
36	v__BC2	Rate constant for biological oxidation of NO_2 to NO_3 in reach (day-1)	0.2-2	1.94
37	v__BC3	Rate constant for hydrolysis of N to NH_4 (day-1)	0.2-0.4	0.18
38	v__RS4	Organic N settling rate in reach (day-1)	0.001-0.1	0.20
39	v__ERORGN	Organic N enrichment ratio for sediment	0-5	1.05
40	v__N_UPDIS	Nitrogen uptake distribution parameter	1-100	68.84
41	a__SOL_ORGN	Initial organic N concentration in the soil layer (mg N/kg soil or ppm)	0.01-100	0.11
42	v__SDNCO	Denitrification threshold water content	0.8-1.4	1.29

‘v’ indicates that the original value was replaced by a value from the range; ‘a’ indicates that the original value was added to a value within the range (1+ given value within the range); and ‘r’ indicates that the original value was multiplied by a value from the range.

3.5 Simulation Scenarios

Simulation scenarios consisted of grassland establishment, time static land use change (i.e. conversion of one land use type to another such as grassland to cropland), time variant land use change (i.e. rotational conversion for given years), and grassland management (see Table 3.3). Simulation scenarios were selected based on the trend of land use change in the region and interactions with various stakeholders in the state. To obtain the impacts of land use change, multiple “what if” scenarios were evaluated in this study. The time variant land use change input data for SWAT were created with the

SWAT Land Use Update Module (Pai & Saraswat, 2011). SWAT-LUU module was developed to integrate multiple land uses/land covers into one layer.

3.5.1 Time static land use change

The dramatic Excessive land use conversion in South Dakota.To quantify the impacts of grassland conversion on hydrology and water quality, 17 land use change scenarios were constructed by converting one land use type to another (i.e. grassland to cropland) for 19 years (1996-2014) as shown in Table 3.3.

3.5.2 Time variant land use change

To quantify the impacts of dynamic grassland conversion on hydrology and water quality, nine time variant land use change scenarios were constructed. The entire agricultural land area in the watershed was replaced by either corn, soybean, and grassland for defined rotational years over 19 years (1996-2014). For example, corn-soybean rotation (CSR; Table 3.3) rotates corn and soybean every year, starting with corn for 19 years. Corn 5 years and grassland 14 years scenario (C5G14) rotates corn the first five years and then grassland the remaining 14 years in replacement of the entire agricultural area in the watershed.

Table 3.3 Simulation scenarios constructed to evaluate the impact of grassland conversion

Scenarios	Existing	Replaced with	Notation
Time Static Land Use Change			
Baseline		Existing condition	Base
2	Soybean	Grass	SG
3	Corn	Grass	CG
4	Wheat	Grass	WG
5	Agricultural area	Grass	AG
6	Agricultural area	Corn	AC
7	Agricultural area	Soybean	AS
8	Agricultural area	Wheat	AW
9	Entire watershed except urban	Grass	EUG
10	Entire watershed except urban	Corn	EUC
11	Entire watershed except urban	Soybean	EUS
12	Entire watershed except urban	Wheat	EUW
13	Grass	Corn	GC
14	Grass	Soybean	GS
15	Grass	Wheat	GW
Time Variant Land Use Change			
16	Agricultural area	Corn-soybean rotation (19years)	CSR
17		Soybean-corn rotation (19years)	SCR
18		Corn (5years)-grass (14years)	C5G14
19		Soybean (5years)-grass (14years)	S5G14
20		Grass (5years)-corn (5years)-grass(9years)	G5C5G9
21		Corn-soybean rotation (10years)-grass (9years)	CSR10G9
22		Grass (10years)-corn-soybean rotation (9years)	G10CSR9
23		Soybean (5years)-grass (10years)-soybean(4years)	S5G10S4
24		Corn (5years)-grass (10years)-corn(4years)	C5G10C4
Management			
25	100% grassland	Grazing 212days in a year	100Gr
26	50% grassland	Grazing 212days in a year	50Gr
Grassland Establishment			

27	Entire Corn watershed	No establishment	CBASE
28		Grassland establishment on upstream	CUP
29		Grassland establishment on midstream	CMID
30		Grassland establishment on downstream	CDOWN
31	Entire soybean watershed	No establishment	SBASE
32		Grassland establishment on upstream	SUP
33		Grassland establishment on midstream	SMID
34		Grassland establishment on downstream	SDOWN

3.5.3 Grassland management practices

This study evaluated the impact of grazing on hydrology and water quality. Heavy grazing and moderate grazing corresponding respectively to 100% and 50% of grassland grazed over 212 days in each year were evaluated for 19 years (1996-2014). Grazing information was obtained and adjusted from relevant literature (Parajuli, 2007; Smart & Mousel, 2006) and shown in Table 3.4. Beef manure was selected with 7.5kg/ha/day of dry weight of biomass consumed daily, and 4.5kg/ha/day of dry weight of manure deposited daily (Parajuli, 2007; Smart & Mousel, 2006).

Table 3.4 Grazing operations simulated in this study

Parameter	Definition	SWAT input value
MANURE_ID	Manure identification code from fertilizer database	Beef-fresh manure
GRZ_DAYS	Number of consecutive days grazing takes place in the HRU	212
BIO_EAT	Dry weight of biomass consumed daily ((kg/ha)/day)	7.47
MANURE_KG	Dry weight of manure deposited daily ((kg/ha)/day)	4.52

3.5.4 Grassland establishment

In these scenarios, two baselines were constructed. For the first baseline scenario, the entire watershed was converted into corn except water and urban areas (corn-based baseline). The second baseline scenario adopted soybean instead of corn in the watershed (soybean-based baseline). The watershed was divided in three nearly equaled subwatersheds of 518.4km^2, 550.2km^2, and 534.1km^2, respectively, to enable establishment of grassland upstream, midstream, and downstream of within the watershed (Figure 3.4). Differences among the three areas are less than 6%.

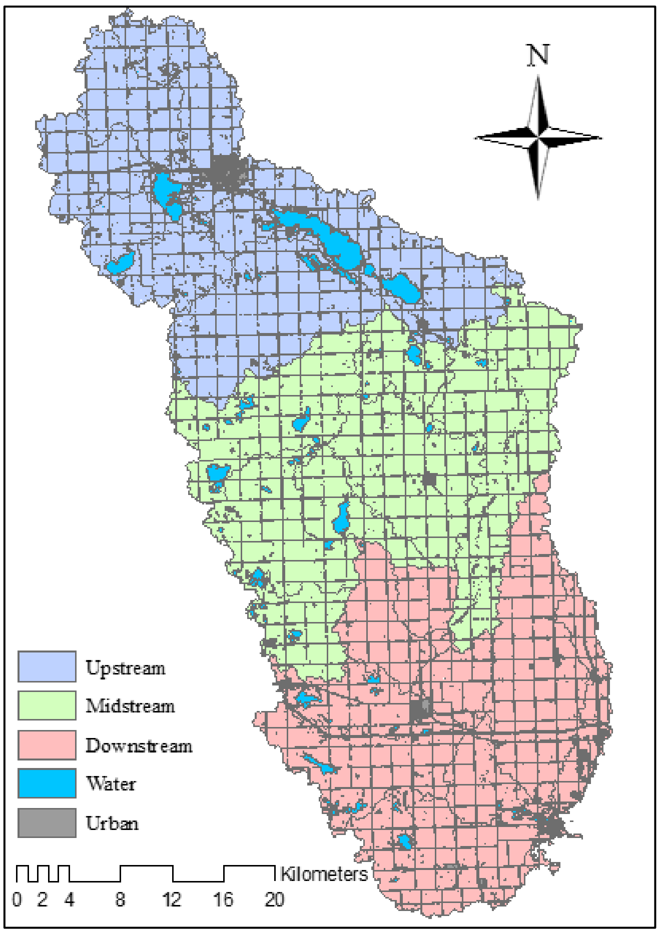


Figure 3.4 Map showing upstream, midstream, and downstream locations of grassland establishment

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Calibration and Validation of SWAT Model

The model was calibrated for daily streamflow, monthly sediment, monthly dissolved phosphorus, and monthly nitrate-nitrogen by using SWAT-CUP for a period of 1996-2014 (Abbaspour, Vejdani, & Haghighat, 2007). Due to the lack of daily nutrient load, Load Estimator (LOADEST) was used to estimate sediment, dissolved phosphorus, and nitrate loads at the outlet of the watershed (Runkel et al., 2004). LOADEST requires a time series data for streamflow and water quality constituent concentrations. The combination of all parameters used in the calibration process resulted into an acceptable model performance (Moriasi et al., 2007) (Table 4.1 and Figure 4.1). In general, NSE and R^2 are considered satisfactory when the values are greater than 0.5 (Moriasi et al., 2007; Van Liew et al., 2003).

Table 4.1 Calibration and validation results for streamflow, sediment, dissolved phosphorus, and nitrate in Skunk Creek watershed

		Calibration (2005-2014)			Validation (1996-2000)		
		R2	NSE	PBIAS	R2	NSE	PBIAS
Streamflow	Annual	0.7666	0.7396	-0.04	0.9014	0.8656	3.92
	Monthly	0.6237	0.6211	-4.24	0.7012	0.6521	3.92
	Daily	0.5729	0.5710	-4.14	0.5054	0.4977	3.90
Sediment	Annual	0.6942	0.6046	23.22	0.6488	0.5057	18.40
	Monthly	0.6142	0.5942	23.22	0.5329	0.4362	18.40
Dissolved phosphorus	Annual	0.7877	0.3482	47.68	0.7239	0.6004	18.03
	Monthly	0.5047	0.4090	47.68	0.5227	0.4320	18.03
Nitrate	Annual	0.9314	0.7041	27.76	0.8851	0.6197	-10.89
	Monthly	0.7253	0.6730	27.76	0.8145	0.4481	-10.89

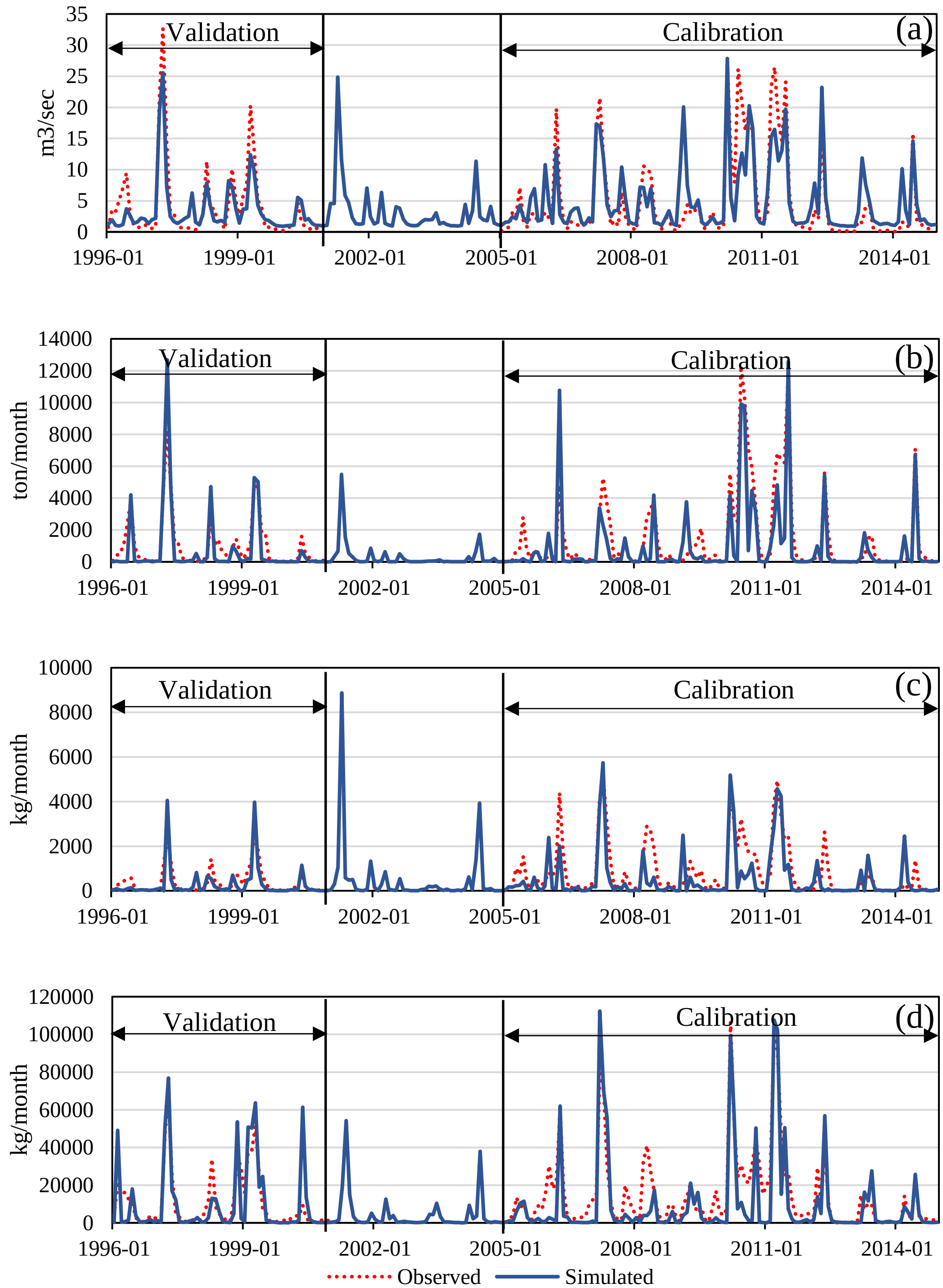


Figure 4.1 Comparison of observed and simulated (a) streamflow, (b) sediment, (c) dissolved phosphorus, and (d) nitrate loads during the calibration (2005 to 2014) and validation (1996 to 2000) periods

4.2 Simulation Scenarios

4.2.1 Baseline Scenario

The calibrated SWAT model was used for the baseline scenario (i.e. 1996 to 2014). Annual precipitation ranged from 441mm to 973mm with an average of 669mm during the study period. Observed annual streamflow varied from 1.0m^3/sec to 12.9 m^3/sec with an average of 4.3m^3/sec excluding 2001 to 2003, when there were missing data (Figure 4.2). The simulated annual streamflow ranged from 1.54 to 9.18m^3/sec with an average of 4.20m^3/sec through the period of 1996 to 2014. Annual sediment loads ranged from 2.31 to 212.39kg/ha, with an average of 59.62kg/ha. Annual dissolved phosphorus load ranged from 0.004 to 0.101kg/ha with an average of 0.035kg/ha, and annual nitrate load ranged from 0.18 to 1.86kg/ha with an average of 0.70kg/ha (Figure 4.3 and Figure 4.4).

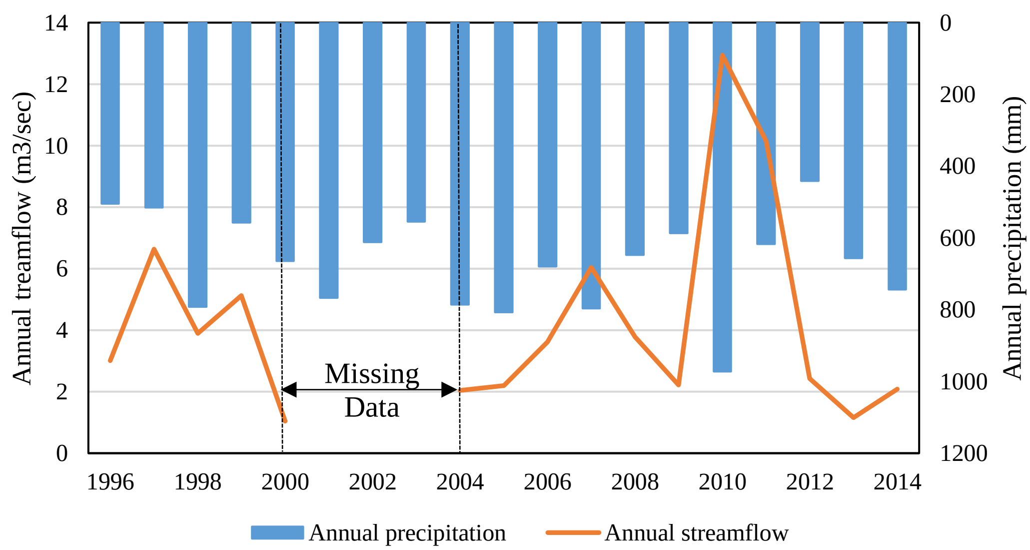


Figure 4.2 Annual streamflow and precipitation for the baseline condition (1996-2014) in Skunk Creek watershed.

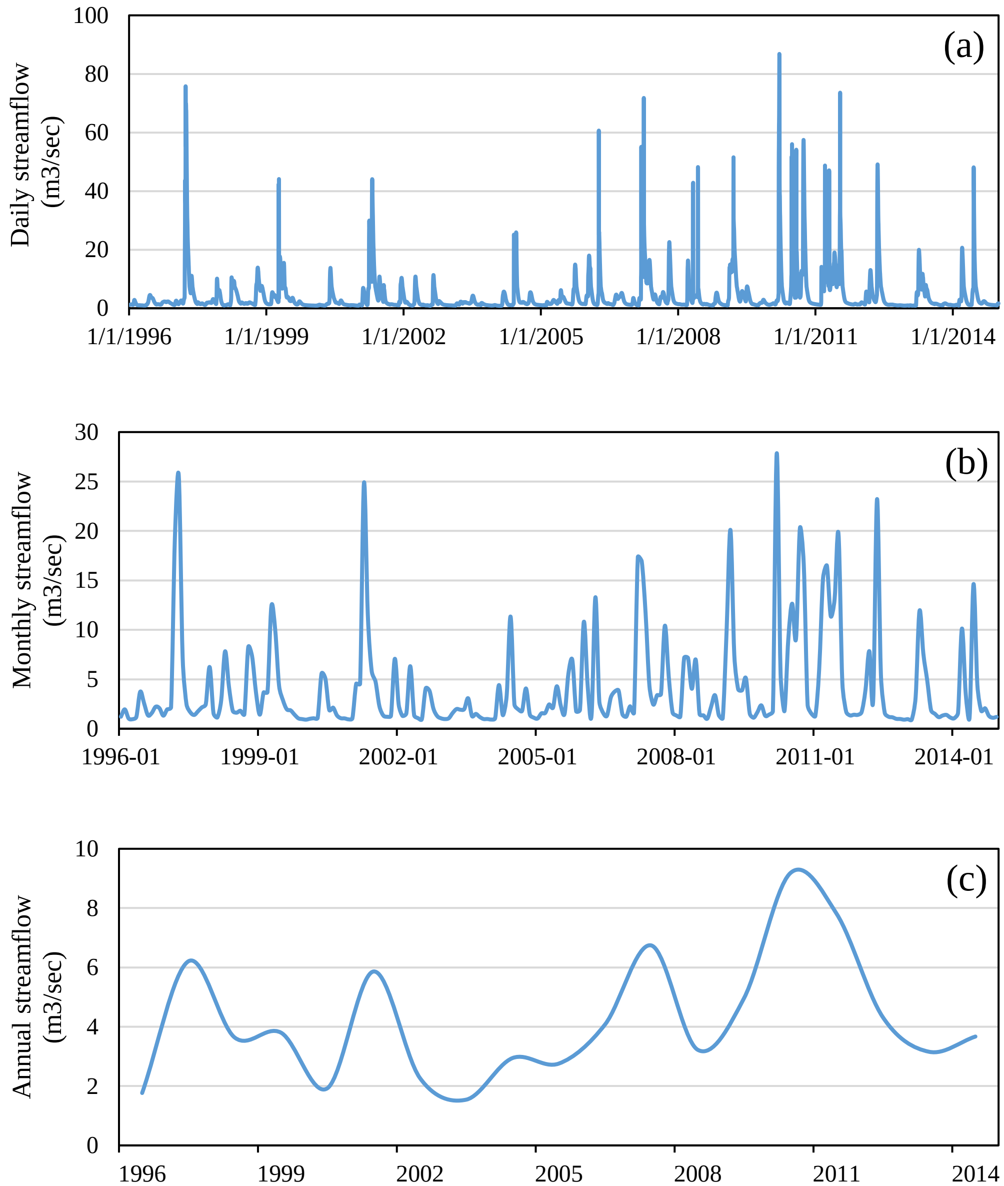


Figure 4.3 Simulated (a) daily streamflow, (b) monthly streamflow, and (c) annual streamflow for the baseline scenario

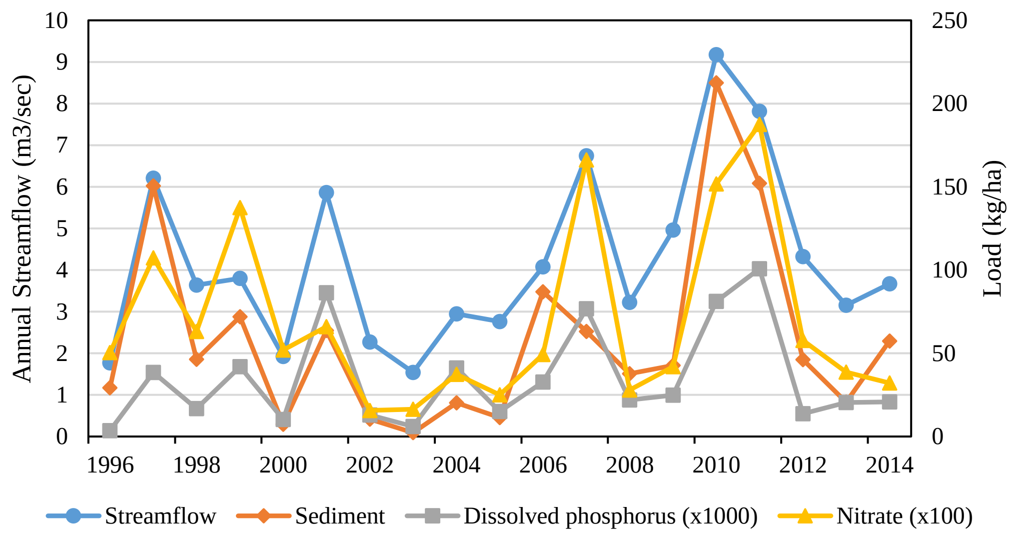


Figure 4.4 Simulated streamflow, sediment, dissolved phosphorus, and nitrate loads for the baseline scenario (1996-2014) in Skunk Creek watershed

4.2.2 Time Static Land Use Change Scenarios

The results from the time static land use change scenarios are shown in Figure 4.5. Average annual streamflow ranged from 3.70 to 4.93m^3/sec with an average of 4.26m^3/sec. Average streamflow in grassland scenarios are higher than the baseline scenario. Unlike grassland scenarios, some of cultivated lands (especially soybean) have lower average streamflow than the baseline scenario (Figure 4.5a). Increased trend in streamflow with cropland conversion to grassland were comparable to the findings from the Jinghe River catchment in China, where Qiu et al. (2011) reported that an increase in streamflow was the result of higher soil water content, decreased evapotranspiration, and surface runoff in grassland areas compared to cropland areas.

Results obtained from the time static land use scenarios were similar for sediment and streamflow (Figure 4.5a, Figure 4.5b). Average annual sediment load ranged from 38.14 to 68.95kg/ha with an average of 57.68kg/ha. Average annual sediment load in scenarios where all agricultural land or entire watershed area except urban areas were replaced by grassland resulted in higher than the baseline scenario. Changing all agricultural land to corn showed higher sediment loads compared to the baseline scenario (Figure 4.5b). Scenarios that converted all agricultural land, entire watershed excluding urban, and grass into soybean or wheat have lower average annual sediment load than the baseline scenario. Generally, streamflow and sediment showed similar trends, because sediment transport is mostly dictated by discharge in the streams and rivers (Colby, 1956).

Grassland establishment led to reduced dissolved phosphorus and nitrate loads in streamflow (Figure 4.5c, Figure 4.5d). Average annual dissolved phosphorus loads ranged from 0.022 to 0.063kg/ha with an average of 0.041kg/ha, and average annual nitrate loads ranged from 0.45 to 0.85kg/ha with an average of 0.64kg/ha. Average annual dissolved phosphorus load is lower for scenarios that contain grassland than scenarios with cultivated cropland. In addition, grassland scenarios result in decreased nitrate load in comparison to cultivated cropland scenarios. Other researchers have also reported reduction in nitrate and phosphorus loads with grassland establishment (Blanco-Canqui et al., 2004; Mendez et al., 1999).

Average annual ET ranged from 464 to 517mm with an average of 491mm (Figure 4.6). Grassland conversion to cropland resulted in higher average annual ET than the baseline scenario whereas the scenarios that converted agricultural land to grassland have lower average annual ET than the baseline scenario. Other studies also reported similar results (Guo & Mo, 2007; Stan et al., 2014). The variation in ET between grassland and crop fields can be explained by differences in leaf area index, rainfall interception, canopy resistance, and plant-available water capacity (Zhang et al., 2001).

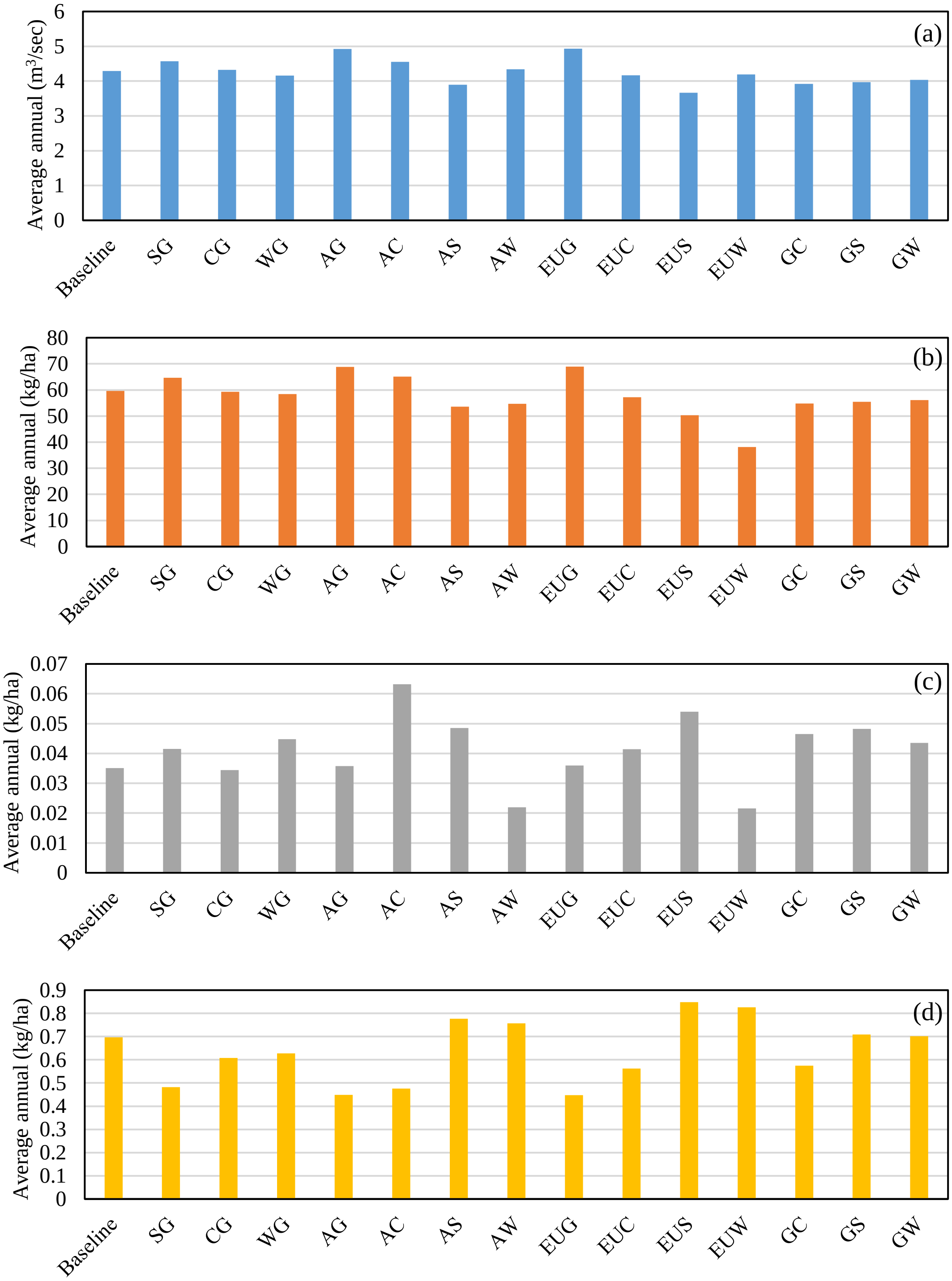


Figure 4.5 (a) Streamflow, (b) sediment, (c) dissolved phosphorus, and (d) nitrate loads for simulated time static land use change scenarios in Skunk Creek watershed over 1996-2014 period

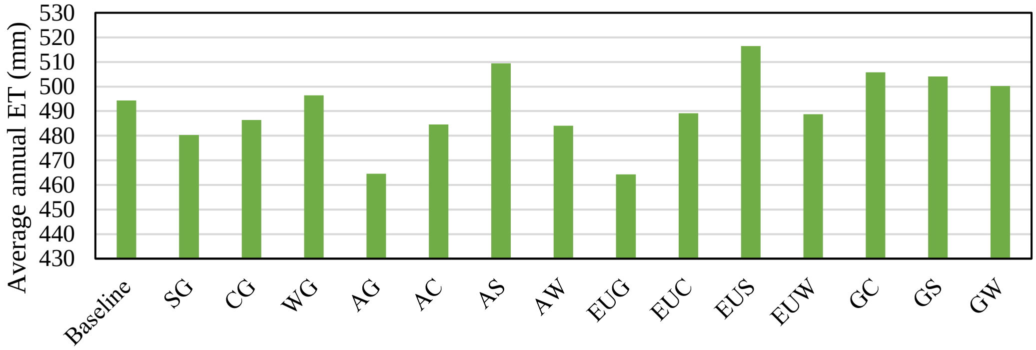


Figure 4.6 Annual average ET for simulated time static land use change scenarios in Skunk Creek watershed over 1996-2014 period

4.2.3 Time Variant Land Use Change Scenarios

Streamflow, sediment, dissolved phosphorus, and nitrate loads of the dynamic land use scenarios are shown in Figure 4.7. Average annual streamflow ranged from 4.32 to 4.95m^3/sec with an average of 4.71m^3/sec for all time variant land use change scenarios (Figure 4.7a). Average annual sediment loads ranged from 61.46 to 76.39kg/ha with an average of 70.92kg/ha (Figure 4.7b). Average annual dissolved phosphorus loads ranged from 0.034 to 0.037kg/ha with an average of 0.036kg/ha, and average annual nitrate loads ranged from 0.53 to 0.71kg/ha with an average of 0.60kg/ha for time variant land use change scenarios (Figure 4.7c, Figure 4.7d). The scenarios with continuous rotation of crops only (e.g. corn-soybean-corn-soybean, and so on) showed less streamflow and sediment loads and increased dissolved phosphorus and nitrate loads compared to other scenarios that contain grassland establishment, which resulted in increased streamflow and sediment loading, and slightly increased dissolved phosphorus and decreased nitrate loads.

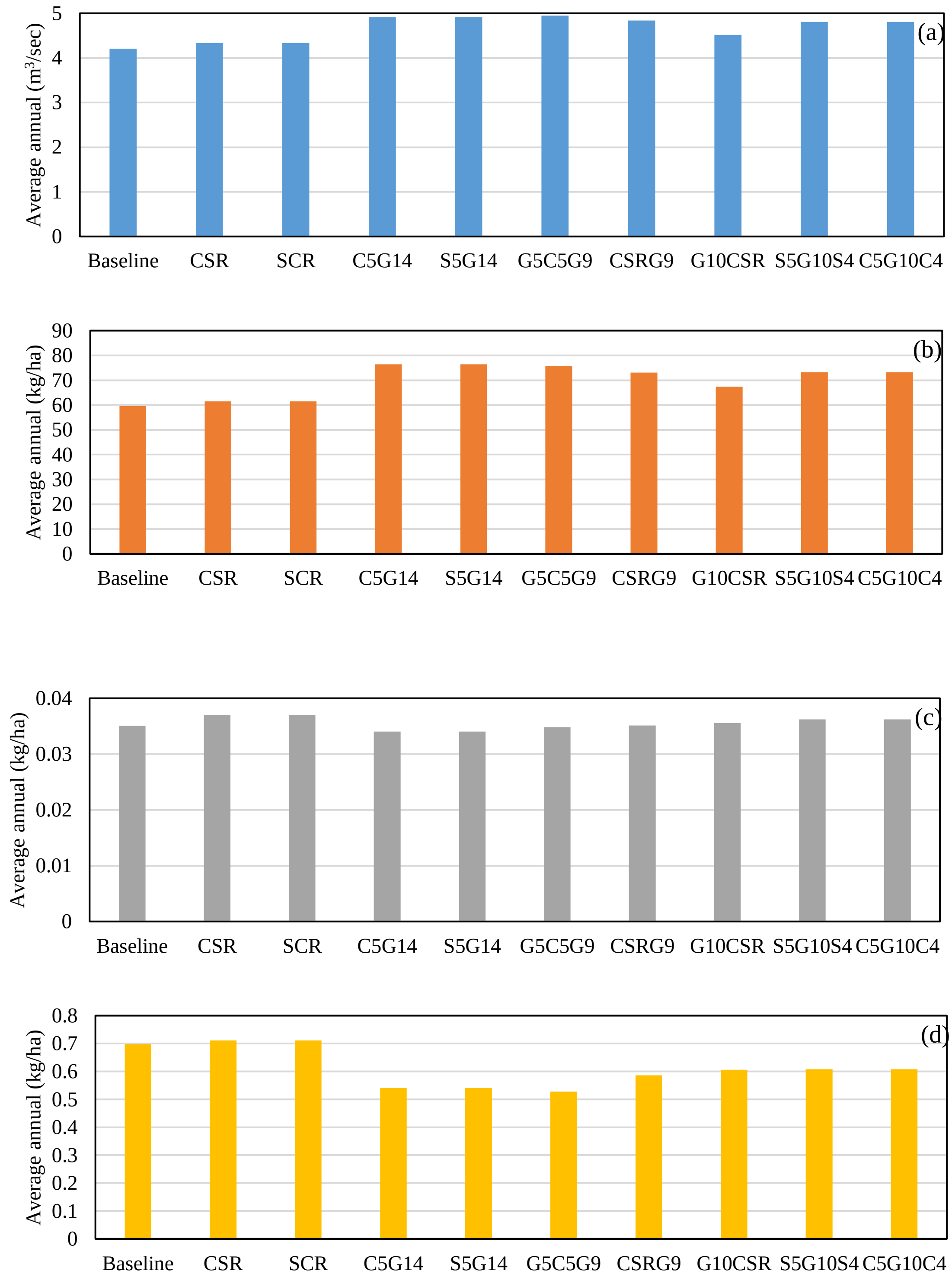


Figure 4.7 (a) Streamflow, (b) sediment, (c) dissolved phosphorus, and (d) nitrate loads for simulated time variant land use change scenarios in Skunk Creek watershed over 1996-2014 period

Average annual ET for time variant land use change scenarios ranged from 464.2 to 494.3mm with an average of 475.5mm (Figure 4.8). Crop rotational scenarios without grassland establishment showed higher average annual ET than long-term grassland establishment scenarios, suggesting less water losses through ET with grassland establishment. Similar to the results from the time static land use change scenarios, grassland in the time variant land use change has lower ET compared to cropland. This could also be explained by different leaf area index, rainfall interception, canopy resistance, and plant-available water capacity of grassland and cropland (Zhang et al., 2001).

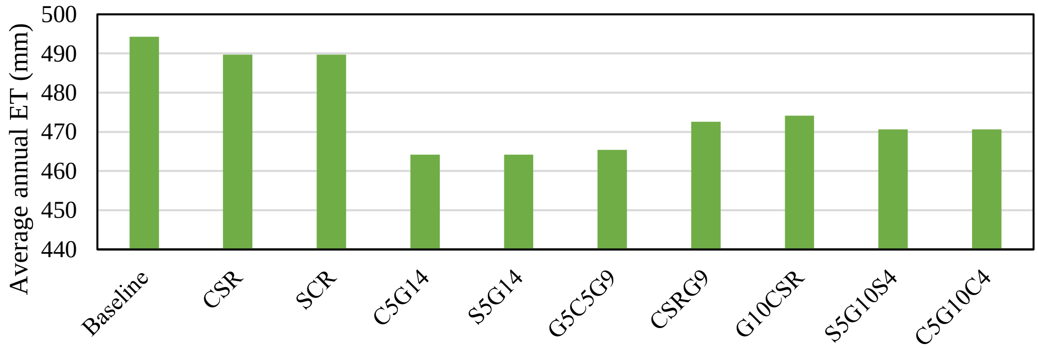


Figure 4.8 Annual average ET for simulated time variant land use change scenarios in Skunk Creek watershed over 1996-2014 period

4.2.4 Management Scenarios

The results for the comparison of grazing on 100% of grassland area and 50% of grassland area are shown in Figure 4.9. Average annual streamflow ranged from 3.90 to 3.94m^3/sec with an average of 3.92m^3/sec. Average annual sediment loads ranged from 54.79 to 55.75kg/ha with an average of 55.27kg/ha. Average annual dissolved phosphorus loads ranged from 0.031kg/ha to 0.032kg/ha with an average of 0.032kg/ha, and average annual nitrate loads ranged from 0.65 to 0.66kg/ha with an average of 0.66kg/ha.

Grazing simulation results show reduction in streamflow, sediment, and dissolved phosphorus, and nitrate loading by 7%, 8%, 2%, and 6% for heavy grazing, and streamflow, sediment, and dissolved phosphorus, and nitrate loading by 6%, 6%, 3%, and 6% for moderate grazing compared to the baseline scenario. The 50% grazing scenario has higher streamflow, sediment and dissolved phosphorus loads, whereas the simulation of 100% grazing on grassland resulted in less nitrate loads (Figure 4.7). Feces from cattle can enhance organic content build ups in the soil profile, leading to improved water holding capacity and infiltration (Hubbard et al., 2004). Heavy grazing, however, can create water quality concerns due to animal waste (Besser et al., 1993; Guan & Holley, 2003; Hubbard et al., 2004). In this study, 100% grazing scenario showed less streamflow, sediment, and dissolved phosphorus loads, while nitrate load increased compared to the 50% grazing.

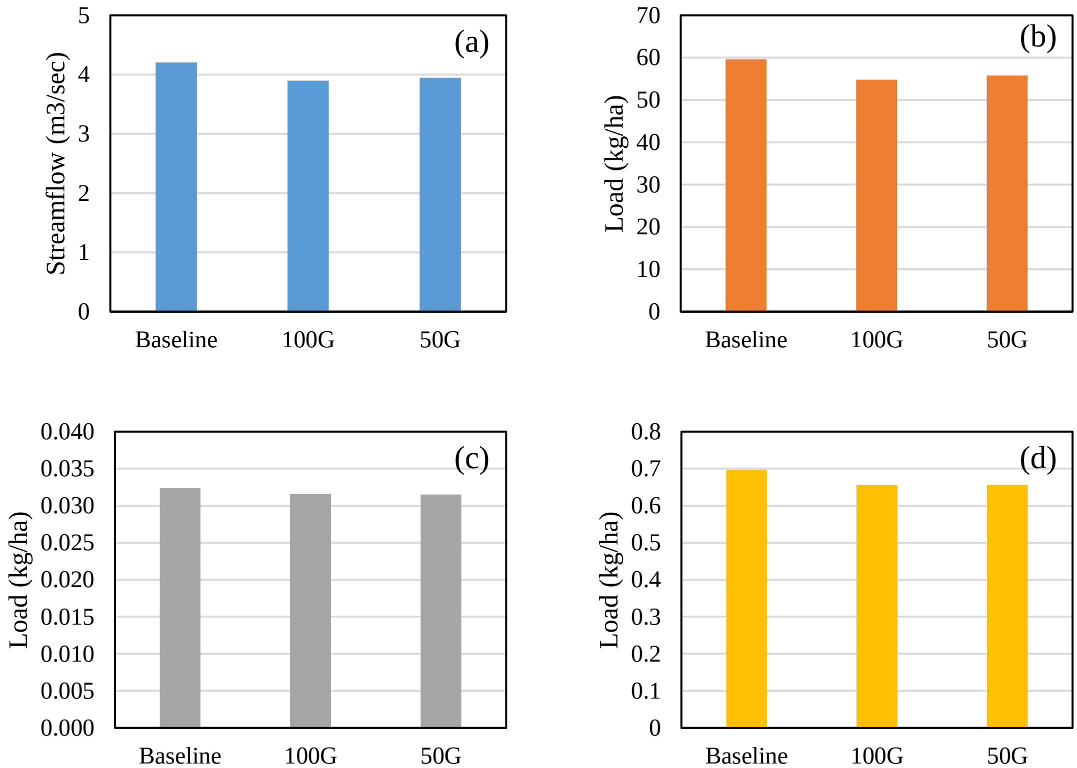


Figure 4.9 Streamflow, sediment, dissolved phosphorus, and nitrate for grassland management: (a) streamflow, (b) sediment, (c) dissolved phosphorus, and (d) nitrate loads in Skunk Creek watershed over 1996-2014 period

4.2.5 Grassland Establishment Scenarios

Results for the grassland establishment scenarios are shown in Figure 4.10 and Figure 4.11. The two baselines in this section consist of corn and soybean in the entire watershed, except in water and urban areas. For corn-based scenarios, the highest streamflow was simulated in upstream grassland establishment (4.4m^3/sec) and the lowest streamflow was simulated in downstream grassland establishment (4.33m^3/sec). Average annual sediment loads ranged from 60.8 to 61.7kg/ha with an average of

61.4kg/ha. Average annual dissolved phosphorus load ranged from 0.039 to 0.041kg/ha with an average of 0.040kg/ha, and average annual nitrate load ranged from 0.51 to 0.54kg/ha with an average of 0.52kg/ha.

For soybean-based scenarios, the highest average streamflow was simulated for upstream grassland establishment as 4.11m^3/sec and the lowest average streamflow was simulated for downstream grassland establishment as 3.90m^3/sec. Average annual sediment load ranged from 54.31 to 58.1kg/ha with an average of 55.9kg/ha. Average annual dissolved phosphorus load ranged from 0.048 to 0.054kg/ha with an average of 0.051kg/ha, and average annual nitrate load ranged from 0.70 to 0.76kg/ha with an average of 0.72kg/ha. Overall, grassland establishment in any part of the watershed showed water quality benefits although results were not consistent among scenarios. Grassland establishment in midstream showed the least amount of increase in sediment loading in both corn base and soybean base scenarios. Downstream grassland establishment was the most effective for dissolved phosphorus removal in both corn-based and soybean-based scenarios. Nitrate loads were less mostly in upstream grassland establishment scenario in corn scenario, and midstream in soybean scenario compared to the other locations in the watershed.

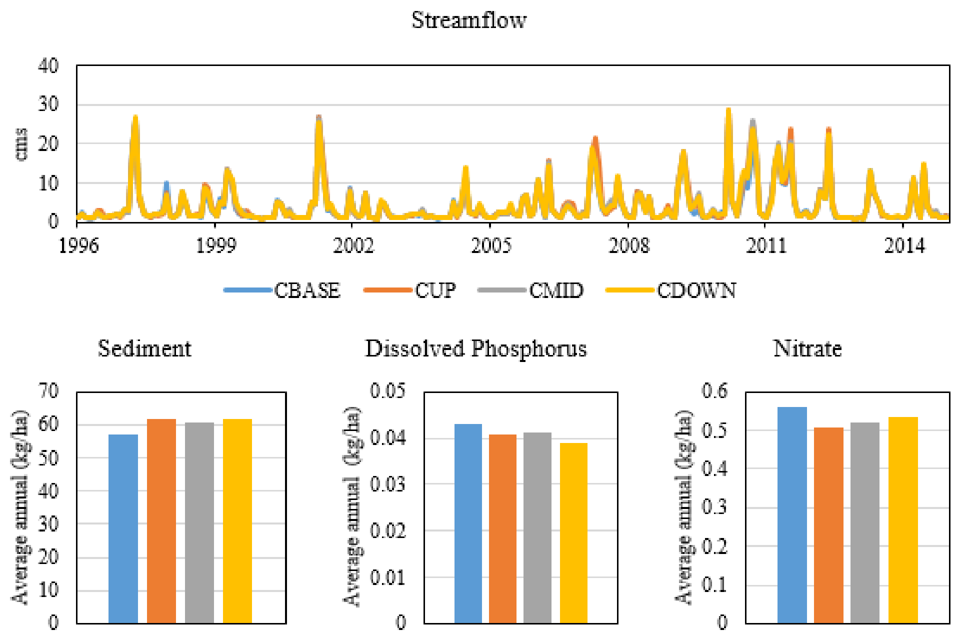


Figure 4.10 Streamflow, sediment, dissolved phosphorus, and nitrate loads for grassland establishment in corn base scenario in Skunk Creek watershed over 1996-2014 period

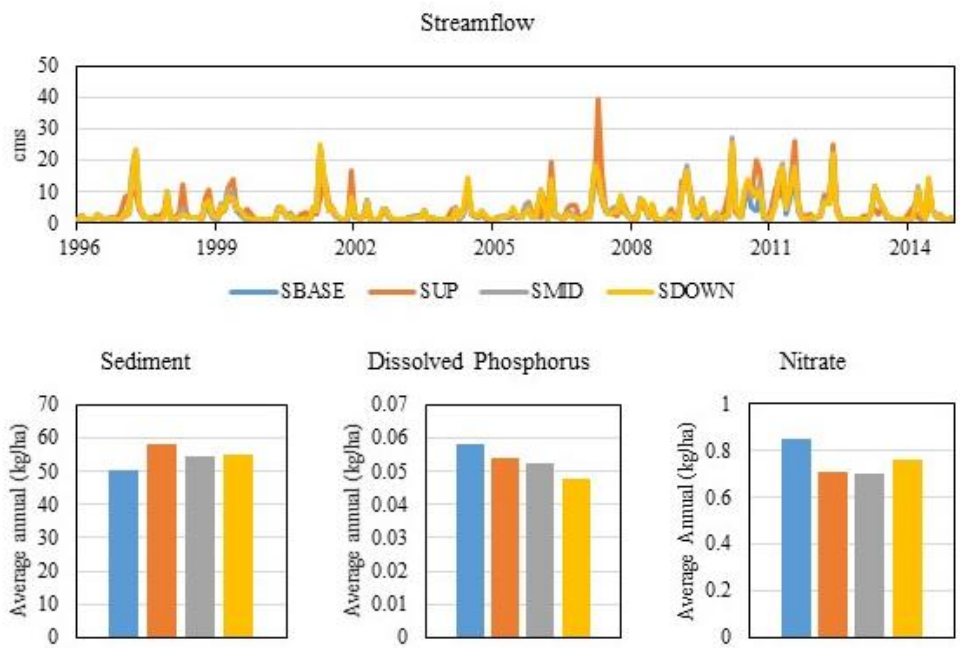
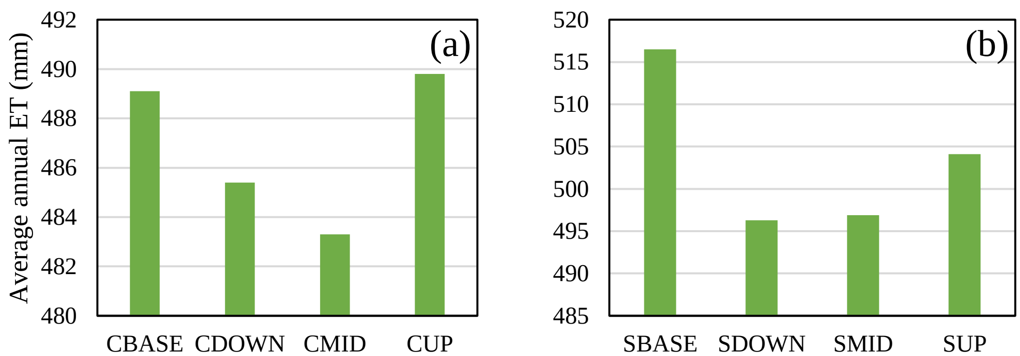


Figure 4.11 Streamflow, sediment, dissolved phosphorus, and nitrate loads for grassland establishment in soybean scenario in Skunk Creek watershed over 1996-2014 period

Average annual ET for corn-based grassland establishment scenarios ranged from 483 to 490mm with an average of 487mm (Figure 4.12). Average annual ET for soybean-based grassland establishment scenarios ranged from 496 to 517mm with an average of 503mm. In corn-based scenarios, grassland establishment at midstream area showed less average annual ET compared to corn-based baseline scenarios. Grassland establishment at midstream area in the corn-based scenarios showed less average annual ET compared to their baseline scenario. Grassland establishment at downstream area in the soybean-based scenarios showed less average annual ET compared to their baseline scenario.



CBASE: corn-based baseline, CDOWN: grassland establishment at downstream, CMID: grassland establishment at midstream, CUP: grassland establishment at upstream, SBASE: soybean-based baseline, SDOWN: grassland establishment at downstream, SMID: grassland establishment at midstream, and SUP: grassland establishment at upstream

Figure 4.12 Annual average ET for grassland establishment on (a) corn-based and (b) soybean-based scenarios over 1996-2014 period

4.3 Implications for agricultural water quality management

Phosphorus and nitrate are necessary elements for plant and animal growth; however they can cause pollution in water bodies when present in elevated concentrations (Davis et al., 2006; Ryther & Dunstan, 1971). Research showed that increase in agricultural production in the Midwest contribute to nutrient load increase leading to eutrophication and hypoxia problems (Rabalais et al., 2002). To prevent long-term eutrophication, phosphorus in freshwater is recommended to be below 0.5 mg/L (Dunne & Leopold, 1978), while nitrate must be less than 10 mg/L for drinking water to minimize environmental pollution and health issues (EPA, 2006; Fewtrell & Bartram, 2001). Also, several states in the nation provide sediment criteria values for an allowed daily maximum concentration ranging between 30 to 158 mg/L (Berry et al., 2003). In South Dakota, nitrate criteria for domestic water is also recommended to be under 10 mg/L and total suspended solid should be less than 30 mg/L for 30-day average (SD-DENR, 1997).

The results from this study provide useful information to improve water quality by establishing grassland into cropping systems. An increase in sediment erosion with grassland was observed while phosphorus and nitrate were reduced. Reduction of both phosphorus and nitrate are environmentally beneficial since they will minimize eutrophication and hypoxia in downstream waters. With long-term grassland establishment, water quality improvement could be achieved by lessening the negative effects of continuous cropping systems. Rotational land use of grassland and cropping areas decreased the accumulation of agricultural nutrients since grassland reduced nutrient loss in the scenarios simulated. Grassland establishment at different locations varied per nutrient but the downstream area was found to be the most effective area for phosphorus removal in both corn-dominant and soybean-dominant watersheds while grassland establishment at upstream area in corn-dominant watershed and midstream in soybean-dominant watershed are the most effective for nitrate removal. Sustainable crop production could be achieved without adverse effects on the environment when perennial grasses are incorporated in cropping practices at different locations throughout the watershed.

CHAPTER 5: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FUTURE WORK

5.1 Summary and Conclusions

In this study, SWAT was used to quantify the impacts of grassland conversion and selected management regimes on streamflow and water quality, and to explore the optimum grassland establishment location for achieving water quality benefits within a watershed. A total of 24 scenarios were created to evaluate the impacts of time static and time variant land use change for 19 years (1996-2014). Two scenarios were created to evaluate the impacts of heavy grazing (G100) and moderate grazing (G50) on grasslands, and eight scenarios with corn and soybean for the baseline scenarios were created to assess the impacts of grassland location on water quality. Simulation results indicate that grassland conversion and overgrazing will likely result in water quality degradation in this watershed, while the best location for grassland establishment to attain water quality benefits within a watershed depends on the nutrient of interest and cropping systems.

The specific conclusions from this study include:

- With the time static land use conversion, streamflow and sediment increased by 7% when cropping area was converted into grassland during the study period while streamflow and sediment decreased by 7% when grassland was changed to cropland. Streamflow changes range from -3% decrease to 15% increase, and changes in sediment loading range from -2% decrease to 16% increase with the conversion of crop areas to grassland. Grassland conversion into crop land showed reduction of 6 to 9% in streamflow, and from 6 to 8% in sediment.

Dissolved phosphorus and nitrate loads generally changed by 9 and -25% on average when cropping areas were converted into grassland. Changes in dissolved phosphorus and nitrate ranged from -2 to 28, and from -10% to -36% when cropland areas were converted to grassland. Conversion of grassland into cropland increased dissolved phosphorus loading from 24 to 38%, and nitrate from 1 to 2%, except grassland to corn scenario which resulted in 18% of nitrate reduction.

- Time variant land use change reveals that scenarios with long-term grassland establishment resulted in water quality benefits with 18% reduction in nitrate load while dissolved phosphorus load showed less than 1% increase on average. Sediment load increased by 19% in all scenarios with a range of 3% to 28%, while dissolved phosphorus and nitrate loads changed by -3% to 5% (1% on average), and -24% to 2% (-13% on average) compared to the baseline scenario.
- Simulation results reveal that streamflow, sediment, and dissolved phosphorus, and nitrate loadings were decreased by 7%, 8%, 2%, and 6% for heavy grazing, and 6%, 6%, 3%, and 6% for moderate grazing compared to the baseline scenario. Streamflow decreased by 1% and sediment load increased by 2% in heavy grazing (G100) compare to moderate grazing (G50). Heavy grazing (G100) showed higher loading (0.23% increase) of dissolved phosphorus than moderate grazing (G50), with heavy grazing having 0.032kg/ha/year and moderate grazing having 0.031kg/ha/year, while nitrate loading remained similar (approximately 0.65kg/ha/year) for both grazing intensities.

- With the corn-based scenarios, streamflow increased by 6 to 8% (7% on average). Sediment loads increased while dissolved phosphorus and nitrate loads decreased when grassland was established in upstream, midstream, and downstream of the watershed. Sediment loads increased by 8, 6, and 8% with grassland at upstream, midstream, and downstream compared to the baseline. Dissolved phosphorus decreased by 6, 4 and 10% with grassland established at upstream, midstream, and downstream, while nitrate loads were reduced by 10, 7 and 5%. With the soybean-based scenarios, streamflow increased by 9 to 15% (11% on average). Sediment loads increased while dissolved phosphorus and nitrate loads decreased when grassland was established in upstream, midstream, and downstream of the watershed. Sediment loads increased by 16, 8, and 10% with grassland at upstream, midstream, and downstream compared to the baseline. Dissolved phosphorus decreased by 8, 10 and 18% with grassland established at upstream, midstream, and downstream, while nitrate loads were reduced by 16, 17 and 10%.

- The optimum location for grassland establishment varies depending on the nutrient and crop examined. It appears that downstream area, upstream area, and midstream areas are optimum locations for grassland establishment for dissolved phosphorus, nitrate, and sediment reduction, respectively, in this watershed.

The results obtained in this study provide useful information on grassland establishment, conversion, management to support sustainable cropping practices.

5.2 Recommendations for Future Work

- In this study, only planting date, fertilizer application, and harvest/kill date were considered. For future studies, more detailed agricultural management practices (e.g. tillage systems) could be incorporated in the model to improve characterization of cropping systems in the study watershed.
- This study focused on streamflow, selected nutrients and sediment. Further studies can be extended to the impact of grassland conversion on other hydrologic processes (e.g. surface runoff, evapotranspiration) and water quality parameters such as bacterial pollution.
- Alterations of soil hydrologic properties (e.g. texture, structure) were not considered when modeling land use change scenarios. Accounting for changes in soil properties would improve accuracy of hydrologic and water quality assessment by alteration of soil characteristics including soil water content and percolation rate of land use change.

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