THE IMPACTS OF LAND USE AND LAND COVER CHANGE ON WATER QUALITY IN THE BIG SIOUX RIVER: 2007-2016

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science 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 candidate are necessarily the conclusions of the major department.

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ACRONYMS

ArcGIS – Trademark name of ESRI GIS Software

AWiFS - Advanced Wide Field Sensors

BMPs – Best Management Practices

BSR – Big Sioux River

CDL – Cropland Data Layer

CRP – Conservation Reserve Program

CWA – Clean Water Act

CWSRF – Clean Water State Revolving Fund

DEM – Digital Elevation Model

DENR – Department of Natural Resources

DMC – Disaster Monitoring Constellation

DMWW – Des Moines Water Works

EDWDD – East Dakota Water Development District

EISA – Energy Independence and Security Act

EPA – Environmental Protection Agency (U.S.)

EROS – Earth Resources Observation and Science Center

ESRI - Environmental Systems Research Institute

ETM+ - Enhanced Thematic Mapper Plus

FMI – Finnish Meteorological Institute

GIS – Geographic Information Systems

GPS – Global Positioning System

HUC - Hydrological Unit Code

IPCC – Intergovernmental Panel on Climate Change

IRS-P6 - Indian Remote Sensing RESOURCESAT-1

LCC – Land Cover Change

Mg/L – Milligram per Liter

MK – Man-Kendall

MPCA – Minnesota Pollution Control Agency

NASS – National Agricultural Statistical Service

NPDES – National Pollution Discharge Elimination System

SD – South Dakota

SDDA - South Dakota Department of Agriculture

SDSU – South Dakota State University

SWD – Surface Water Discharge

TM - Thematic Mapper

UK2 - Ultra Kit (Type 2) sensors

USDA – U.S. Department of Agriculture

USGS – U.S. Geological Survey

UTM – Universal Transverse Mercator

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ABSTRACT

THE IMPACTS OF LAND USE AND LAND COVER CHANGE ON WATER QUALITY IN THE BIG SIOUX RIVER: 2007 – 2016

DINESH SHRESTHA

2019

Between 2006 and 2012, conversion of 485,000 acres of grassland to cropland in eastern South Dakota was reported. In 2012, the Big Sioux River (BSR) running through most of eastern South Dakota was listed among the dirtiest rivers in the nation. This rating convinced state authorities to study trends of land cover changes in the BSR watershed and its association with BSR water quality with respect to increases in nitrate levels. This research i) quantifies spatial and temporal changes in the land cover types within the BSR watershed, and ii) identifies any correlation between these changes and changes in BSR nitrate levels. It uses the Cropland Data Layer (CDL) to characterize and determine rates of Land Cover Changes (LCC), and the non-parametric Mann-Kendall test to identify statistically significant increasing and decreasing LCC trends within the BSR watershed. Similarly, nitrate data collected from 11 gauging stations operating in the BSR watershed were analyzed using the Mann-Kendall test to identify any trends. For all the land cover classes and gauging stations that were identified as statistically significant, a Sen's Slope estimate was used to estimate their magnitudes. Only Corn/Soybean and Grassland acreage displayed a significant increasing and decreasing trends, respectively whereas remaining classes including Other Crops, Water, and Developed didn't show any trends and were considered as classes having "No Trend".

Similarly, out of 11 gauging stations, one station (SD Codington K06) showed a significant increasing trend, one station (MN Pipestone 099) showed a decreasing trend and remaining other stations didn't show any trends and were considered as gauging stations having "No Trend". In general, there was insufficient evidence to conclusively link changes in Corn/Soybean LCC to changes in nitrate levels. The results of this research suggest that changes should be made to gauging station locations and sampling frequency, particularly on smaller tributary rivers and streams within the watershed.

Keywords: the Big Sioux River basin, water quality, Nitrates, Mann-Kendall test, Sen Slope estimator, NASS CDL dataset, land use/land cover, East Dakota Water Development District (EDWDD)

CHAPTER 1: INTRODUCTION

1.1 Background

Corn requires very large quantities of soil nitrogen for its growth, development, and reproduction (Alexander et al. 2008). Nitrogen in the soil is obtained from atmospheric nitrogen and is fixed into the soil by legumes such as alfalfa and soybeans (Alexander et al. 2008; Clay et al. 2014). Since corn has a shallow root system, it cannot easily absorb nitrogen (Leaver 1991; Hudson 1994; Malcolm and Aillery 2009). Natural fixation of nitrogen in soil is a slow process and farmers are sometimes required to add synthesized fertilizer containing sufficient quantities of nitrogen to corn to increase its uptake (Malcolm and Aillery 2009). Unfortunately, corn utilizes only 30% - 50% of applied nitrogen fertilizer (Cassman 1999; Smil 1999), and the remaining nitrogen leaches into local water systems during rainfall events (Vitousek et al. 2009).

After the Environmental Protection Agency (EPA) banned methyl tertiary butyl ether (MTBE) in 2000 and recommended ethanol as a substitute fuel additive (Gruchow 2007), the acreage devoted to corn production significantly increased in parts of the U.S. This happened because corn is the most important component in ethanol production (Wright and Wimberly 2013; Clay et al. 2014; Reitsma et al. 2015). The increase in corn acreage resulted in additional total nitrogen fertilizer use, which led to a significant increase in free nitrogen leaching into local water supplies (Alexander et al. 2008; Clay et al. 2014).

Nitrogen leaching into waterways increases the concentration of nitrates in the water. Elevated nitrate levels in a human population’s water supply may lead to the onset of medical conditions such as methemoglobinemia (“blue baby syndrome”) in children, and thyroid and bladder cancer in adults (Yu and Chen 1996; Schlesinger and Emily 1997; Iowa Environmental Council 2016). In addition to the deterioration in human health caused by excess consumption of nitrates, increased nitrogen leaching can lead to disturbances to the equilibrium of an aquatic ecosystem (Paul 2016), such as eutrophication (algal blooms) in rivers and hypoxic zones in coastal waters.

To prevent deterioration of human health and the local aquatic ecosystem, it is therefore important to reduce nitrogen leaching. This reduction can be achieved with the implementation of advanced fertilizer management techniques such as crop rotation (alternating planting of corn with the planting of legumes to restore soil nitrogen levels), and determination of an appropriate application regimen with respect to timing and optimal nitrogen quantity given local soil conditions (Malcolm and Aillery 2009). With proper fertilizer management, corn yields can also be significantly increased, resulting in improvement to the local economy.

1.2 Problem Statement

Reitsma et al. (2015) estimated that 485,000 acres of grassland were converted to cropland throughout eastern South Dakota between 2006 and 2012. Most of the region is drained by the Big Sioux River (BSR) watershed. During this time, the East Dakota Water Development District (EDWDD) reported increasing nitrate levels in the BSR (eastdakota.org 2016). In 2012, the *Rapid City Journal* published an Associated Press article ranking the BSR as one of the “dirtiest” rivers in the U.S (Associated Press 2012). Some studies claim that point sources, such as municipal sewage runoff, are causing increased pollution in the BSR. Other studies, however, claim other sources are polluting the river, such as nitrogen leaching stimulated by the increased grassland-to-cropland conversion and application of synthetic fertilizers. Therefore, it is important to identify trends in land cover changes (LCC) in the BSR watershed and to determine whether a causal relationship exists for the observed trend in BSR nitrate levels. Elevated nitrate levels in the BSR are of great concern, especially since the BSR flows through Sioux Falls and other communities in the region where a significant percentage of the state's population is concentrated.

1.3 Objectives

The objectives of the research presented in this work were the following:

1. Identify and characterize LCC trend(s) in the BSR watershed:
    - How much grassland was converted to acreage for corn and soybeans between 2007 and 2016?
    - How much existing corn and/or soybean acreage was restored to grassland during this same period?
2. Identify and characterize the temporal and spatial trends of BSR nitrate levels:
    - How much did BSR nitrate levels change between 2007 and 2016?
    - Which portions of the BSR exhibited the most changes?
3. Determine whether the change in levels represents a consistent trend.
    - Determine whether any relationship identified between LCC and changes in BSR nitrate levels is causal.

1.4 Hypothesis

This research hypothesizes a significant positive correlation between the increase in corn acreage and the observed increase in BSR nitrate levels.

1.5 Significance of Thesis

Nitrates and other pollution in the BSR watershed can contribute to the creation of hypoxic zones in the Gulf of Mexico, as the BSR empties into the Missouri River and it empties into the Mississippi river (Alexander et al. 2000; Rabalais et al. 2002; Scavia and Donnelly 2007; Strauss, Grossman, and DiMarco 2012), potentially impacting fishing and other industries dependent on a healthy aquatic ecosystem. In addition, the adverse health effects of excess nitrate consumption could affect a significant percentage of the U.S. population that lives along these waterways. The full degree to which BSR nitrate pollution contributes to these issues, however, has yet to be studied.

1.6 Thesis Organization

This thesis is organized as follows. The background, thesis statement, hypothesis, and objectives of the study are presented in Chapter 1. Chapter 2 gives a literature review on the impacts of LCC on water quality. Chapter 3 presents the data and methods used in the thesis research including descriptions of various LCC scenarios applicable to the contiguous U.S, the National Agricultural Statistics Service (NASS) Cropland Data Layer (CDL), the Mann-Kendall (MK) nonparametric hypothesis test, Sen's slope estimator, and linear regression models. Chapter 4 reports the results obtained for objectives 1 and 2. Chapter 5 presents a discussion on objectives 1 and 2 and justifies objective 3. Finally, Chapter 6 summarizes the thesis research and lists potential future research directions.

CHAPTER 2: LITERATURE REVIEW

2.1 Historical Land Use and Land Cover Change Analysis (to 2000)

The U.S. has a long history of land management practices, dating back a century or more. During the Dust Bowl in the 1930s, farmland management began to focus on soil conservation practices and the adoption of advanced tillage and irrigation technologies (Chin 2012; Clay et al. 2014; Reitsma et al. 2015), with the goals of i) conserving fertile topsoil; and ii) supporting higher yields per acre (Napton and Graesser 2011). Traditional corn growing practices of using manure as a natural fertilizer or planting legumes to increase soil nitrogen levels (Perry, Robbins and Barnes 1988) were largely stopped in favor of using synthetic fertilizers, pesticides, and herbicides to increase yields during mid nineteenth (Malcolm, Aillery, and Weinberg 2009; Clay et al. 2014; Reitsma et al. 2015).

During the 1950s, the Federal Agriculture Act of 1956 (also known as the Soil Bank Program) was enacted (Stubbs 2014). Under this program, landowners who voluntarily retired their land from farming received payments from the federal government (Helms 1985). The purposes of this program were to reduce production of basic crops, maintain farm income, and conserve soil (Helms 1985). However, the program as initially enacted lasted only three crop seasons.

Throughout the 1960s and in the 1970s, concerns were raised about the effects of existing land management practices on water quality and potential threats to wildlife habitats. The Clean Water Act (1972) focused on improving non-point runoff management practices on farms (National Water Quality Monitoring Council, 2007). The Endangered Species Act (1973) focused on protecting wildlife habitats from the effects of urban and rural “sprawl” (Kayden 2000; Nolon 2006, 824, 834, 846). The Water Pollution Control Amendments of 1972 (PL 92-500) and the Clean Water Act of 1977 (PL 95-217) extended the 1972 act, authorizing state and federal water quality programs (Vladimir 2004; WHO 2015; Knobeloch et al. 2000; Iowa Environmental Council 2016) intended to restore and maintain the chemical, physical and biological integrity of the nation's waters.

In 1985, the U.S. Department of Agriculture developed the Conservation Reserve Program (CRP), which authorized adoption of cost-sharing and land rental with the goals of reducing land erosion, improving water quality through restoration of wetlands and field buffers, reducing fertilizer use, and increasing wildlife habitat (Napton and Graesser 2008; Grossman and Gary 2012; Stubbs 2014). Under this program, the federal government leased the land for 10 years and the farmers received annual payments. (Stubbs 2014). The program intended to remove environmentally sensitive cropland from production and facilitate its conversion to more diverse vegetative cover, such as native bunchgrasses and grasslands, riparian buffers, filter and buffer strips, windbreak and shade trees, and grassed waterways (Napton and Graesser 2008; Grossman and Gary 2012; Stubbs 2014; Hellerstein 2015).

Beginning in 1996, however, the focus on environmental protection began to shift in favor of economic interests. The crop insurance program, which had initially discouraged farmers from converting wheat acreage to corn (Claassen et al. 2011; Morgan 2008) was ended. Disaster relief programs, which provided financial and technical assistance to help conserve agricultural lands (Wright and Wimberly 2013,

4135) were enacted that increased incentives to discontinue CRP enrollment and replant crops, particularly corn.

From the 1970s to 2000, despite the efforts of the CRP, significant amounts of natural grassland in the U.S. were converted for cropland use (Napton and Graesser 2011; Waisanen 2003, 1). Much of the conversion occurred (Waisanen 2003; Clay et al. 2014; Wright and Wimberly 2013; Reitsma et al. 2015) in the Western Corn Belt Plains (WCBP) and North Glaciated Plains (NGP) ecoregions (Omernik 1987; Omernik 1995; Waisanen 2003). In the WCBP ecoregion (located in Iowa, Minnesota, Kansas, Nebraska, and eastern parts of North and South Dakota), land use changes were mainly characterized by conversion of pastureland and grassland to production of wheat (1,037,843 acres), corn (506,566 acres), and soybeans (177,916 acres) (Waisanen 2003, 1). Similarly, in the NGP ecoregion (located in western North and South Dakota, western Nebraska, and parts of eastern Montana), almost 7.7 million acres of cattle rangeland were converted to cultivated crop production between 1997 and 2007 (Claassen et al. 2011). This basically led to westward expansion of corn cropland in WCBP ecoregion which impacted the land use and land cover in the eastern South Dakota.

2.2 Historical Land Use and Land Cover Change Analysis in South Dakota (2000 - 2015)

In 2000, the EPA under the Energy Independence Act, banned the use of methyl tertiary butyl ether (MTBE) as a gasoline additive and recommended the substitution of ethanol (United States Environmental Protection Agency 2003; Gruchow 2007; Napton and Graesser 2011). In 2007, the EPA formally mandated its use. As the Energy Independence Act required the county to produce energy on its own, and corn being a good source for ethanol, the more emphasis was given to corn production (Napton and Graesser 2011). This mandate, and the establishment of federal subsidies for corn and ethanol production, resulted in the construction of 18 new bioethanol plants in eastern South Dakota alone. The plants stimulated demand for corn, leading to higher corn prices (Koplow and Earth Track Inc. 2006; Gruchow 2007; Westcott 2007; Napton and Graesser 2011, 8; Clay et al. 2014; Reitsma et al. 2015) and a significant increase in grassland-to-cropland conversion. An ethanol plant in South Dakota typically requires approximately 4 to 5 million bushels of corn per year depending upon the number of markets within a 150-mile radius of the plant (McNew and Griffith 2005).

Interestingly, studies show that in both ecoregions, grassland conversion between 2006 and 2011 was concentrated in North Dakota and South Dakota; both states possess large grassland acreage generally suitable for crop production (Napton and Graesser 2011; Wright and Wimberly 2013; Olimb 2013). Wright and Wimberly (2013) reported that South Dakota alone lost 1.8 million acres of grassland to cropland. Focusing on acreage located east of the Missouri River, Reitsma et al. (2015) estimated the conversion of approximately 239,000 acres in northeastern South Dakota, 163,000 acres in east-central South Dakota, and 83,000 acres in southeast South Dakota. This amounts to approximately 485,000 acres or 33% of the total grassland-to-cropland conversion in the state.

The factors that impacted the grassland-to-cropland conversion are discussed below:

2.2.1 Economic Development:

The three critical factors influencing agricultural profitability are (i) the yield per acre; (ii) the price per bushel received for the crop; and (iii) the total cost of production (Janssen et al. 2013; Wright and Wimberly 2013; Clay et al. 2014; Reitsma et al. 2015). Reitsma et al. (2015) state that between 2006 and 2012, corn prices increased by 192%, from U.S $2.28 per bushel to U.S $6.68 per bushel (National Agricultural Statistics Service 2014). During the same period, soybean prices increased by 148%. The increasing demands for corn and escalating profits from cropland resulted in a 53% drop in the profitability of cattle farming from 2002 to 2008 (Mousel 2010). During the same period, the yield per acre and total cost of production also increased. The increase in agricultural profitability is associated with an increase in grassland-to-cropland conversion.

2.2.2 Government Policies:

Government policies can simultaneously encourage and/or discourage land-use change (Reitsma et al. 2015). Under the CRP program during the 1980s, the government encouraged landowners to convert erosion-prone cropland to native grassland by providing rental payments. However, the government’s mandated substitution of ethanol for MBTE and increasing profits from converted cropland switched the interest of many landowners towards active farming. As a result, the enrollment of cropland in the CRP has been steadily decreasing since 2006 (Nickerson et al. 2012; Janssen et al. 2013, Reitsma et al. 2015). Between 2007 and 2014, the amount of CRP-enrolled land in South Dakota alone decreased from approximately 1.5 million acres to approximately 699,000 acres (Farm Service Agency 2015). Similar levels of decrease occurred in neighboring

North Dakota and Montana. Higher cropland rental rates and greater overall profitability in cropland likely encouraged farmers to devote more of their land to crop cultivation (Mann 2010; Janssen et al. 2013). Additionally, other government programs such as federal crop insurance (Claassen et al. 2011), inheritance laws and property tax assessments, and disaster relief programs (Wright and Wimberly 2013, 4135) greatly influenced the grassland-to-cropland conversion.

2.2.3 The Collapse of the Rotational Sequence:

Alfalfa, a legume, was commonly planted in rotation with corn (Sainju et al. 2009; Reitsma et al. 2015). It benefited corn production by improving weed control and soil health and reducing disease pressure, but only when planted for four successive growing seasons or more. However, the increased profitability from corn cropland provided landowners incentives to reduce alfalfa planting to fewer than four seasons, essentially eliminating the rotation sequence (Lubowski et al. 2008; National Agricultural Statistics Service 2014). This reduction in alfalfa planting necessitated the use of synthetic fertilizers and pesticides/herbicides to maintain overall soil nitrogen levels and soil health.

2.2.4 Technology Improvements:

Improvements in technology have played a vital role in grassland conversion to cropland in the U.S. (Clay et al. 2014). The use of heavy equipment led to reduced labor costs while contributing to increased total production (Gruchow 2007; Du and Hayes 2008).

Globally, grassland-to-cropland conversion maybe driven by the need to feed an increasing population (Seré, Henning, and Jan 1995). Significant conversion of native forests, shrublands, and grasslands to cropland occurred, beginning in the late nineteenth century (DeFries et al. 1999; Raun et al. 1999; Clay et al. 2014; Chaplin-Kramer et al. 2016). The intense land use changes affected local, regional, and global ecosystems and associated environmental processes (Gilbert 1987; DeFries et al. 2004; Huntington 2006; Ellis and Pontius 2007; Turner et al. 2007; Lambin and Meyfroidt 2011; Sleeter et al. 2013). In countries including Ethiopia, (Fowler and Rockstram 2001), Turkey (Evrendilek et al. 2004), and Brazil (Müller et al. 2004; California Electric Transportation Coalition 2013; Strassburg et al. 2014), the loss of fertile topsoil was reported because of grassland-to-cropland conversion.

With the excessive use of fertilizers, these changes account for lower soil carbon levels (Bowman et al. 1990; Gebhart et al. 1994; Unger 2001; Guo and Gifford 2002), sediment run-off (Gangolli 1994; Fargione et al. 2009), diminished water quality (Wu et al. 1999; Schilling and Zhang 2004; Reitsma et al. 2008; Chaplin-Kramer et al. 2016), climate change through emission of the greenhouse gas nitric oxide (N_20) (Davidson et al. 2012; Reimer et al. 2017, 1), and a loss of biodiversity (Herschy 1998; Kalkhoff et al. 2001; Townsend et al. 2003, 240; Goulart, Salles, and Saito 2009; Ward et al. 2009, 352; Davidson 2012, 1).

2.3 Land Use and Land Cover Change and Water Quality

Historically, when farmers added natural substances such as manure or grew legumes to add nitrogen to the soil (Perry, Robbins and Barnes 1988), nitrogen leaching into nearby water supplies was minimal. Low-impact technologies such as crop rotation, tillage conservation practices, and irrigation also minimized nitrogen leaching and conserved fertile topsoil, increased production, and supported higher yields per acre

(Napton and Graesser 2011; Chin 2012; Clay et al. 2014; Reitsma et al. 2015). With the use of nitrogen-based and other synthetic fertilizers, leaching of soil nitrogen significantly increased (Malcolm, Aillery, and Weinberg 2009; Clay et al. 2014; Reitsma et al. 2015).

Nitrogen contamination in water has an adverse economic effect. For example, algal blooms in the Gulf of Mexico resulted in millions of dollars of damage to the tourism and fishing industries (Downing et al. 1999). Similarly, the Des Moines Water Works spends between $4,000 and $7,000 **per day** to remove nitrates that accumulate in the lower river basin (Des Moines Water Works Lawsuit Questions 2016, 12). In addition, it can lead to a loss in biodiversity, modification in vegetation, and reduced crop productivity, which can weaken industries dependent on a healthy natural ecosystem (Townsend et al. 2003, 240; Ward et al. 2009, 352; Fargione et al. 2009; Davidson 2012, 1).

Nitrogen leaching into a river system or other water body results in diminished water quality. Li et al. (2009) found that the levels of aquatic vegetation in the Han River in central China were significantly (negatively) correlated with water quality. Similarly, Alexander et al. (2008) stated that corn and soybean production alone contributed 52% and 25% of the total nitrogen and phosphorous contamination, respectively, in the Upper Mississippi River Basin. Moreover, excessive nitrogen in water leads to eutrophication of surface water and formation of coastal dead zones (for example, Black Sea, Adriatic Sea, and Chesapeake Bay) (Smith et al. 1999; Petreson, and Brakebill 1999; Alexander 2000; Rabalais et al. 2002; Jha et al. 2007; Scavia and Kristina 2007; Chin 2012, 3; Davidson et al. 2012; Strauss 2012; Reimer et al. 2017, 1).

Grassland-to-corn acreage conversion is associated with nitrogen leaching because (1) unlike grassland and non-corn acreage, corn requires extensive fertilizer and pesticide application; and (2) corn has a shallower root system that cannot efficiently uptake nitrogen (Leaver 1991; Hudson 1994; Malcolm and Aillery 2009). Corn utilizes only 30-50% of applied nitrogen fertilizer (Cassman 1999; Smil 1999); the remaining nitrogen leaches into water systems during rainfall events that saturate the soil (Vitousek et al. 2009). In addition to soil moisture, other properties affecting the degree of nitrogen leaching are soil aeration, soil texture, soil drainage, the degree of slope to the land, soil and ambient air temperature, soil salt content (Rose, Chichester, and Phillips 1983; Ditxler and Tugel 2002), and the amount of free nitrogen (Perry, Robbins and Barnes 1988). The free nitrogen forms water-soluble nitrate compounds (Gangolli 1994; Perry, Robbins, and Barnes 1988); any excess not utilized by the growing plants is available for leaching (Smil 1999; Ditxler and Tugel 2002).

Methods intended to reduce nitrogen leaching are available. These include management of the timing and rate of fertilizer application, and management of irrigation. However, these methods are affected by unpredictable weather fluctuations (Perry, Robbins and Barnes 1988; Leaver 1991; Hudson 1994; Malcolm and Aillery 2009; Chin 2012; Davidson et al. 2012; Clay et al. 2014; Reitsma et al. 2015; Reimer et al. 2017).

2.4 Land Use and Land Cover Change and Water Quality in the Big Sioux River Watershed

In 2012, the Big Sioux River (BSR) was listed as the 13th dirtiest river in the nation (Associated Press 2012). The main causes of contamination within the BSR basin were fecal coliform bacterial contamination, total suspended solids, and nitrogen/phosphorous nutrient runoff (Priner 2016). In Sioux Falls, the city wastewater treatment plant and John Morrell were identified as the two major point sources (Associated Press 2012). The presence of nitrogen in other parts of the basin results primarily from runoff from livestock operations, wet weather discharges and storm sewers within municipal areas, nutrient runoff from nearby croplands, and inflow from tributaries (Dieterman and Charles 1998; Priner 2016). Nationally, runoff carrying the sediments and nutrients from agricultural land is the major non-point source of pollution (Corwin 1999).

Currently, various water authorities including the USGS, the South Dakota DENR, the East Dakota Water Development District, the South Dakota Association of Conservation Districts, and the Sioux Falls Downtown River Greenway Project are involved in efforts to clean up the BSR (Associated Press 2012). Part of the cleanup process involves identification of pollution sources and mitigating their causes (Associated Press 2012). In addition, the South Dakota Nonpoint Source Pollution Management Program focuses primarily on control of nonpoint source pollution through Best Management Practices (BMPs) and holistic resource management plans—manage the land, grazing animals, and water in better ways (Priner 2016).

High nitrate concentration in water systems is a major concern to the general public and various water resource authorities, as removing nitrates from water is expensive but does not necessarily resolve the issue (Iowa Department of Natural Resources and South Dakota Department of Environment and Natural Resources 2007; Kreiling 2016; Iowa Environmental Council 2016). As mentioned earlier, the Des

Moines Water Works (DMWW) spends between $4,000 and $7,000 per day on the removal of nitrate compounds accumulating in the lower Des Moines river basin (Des Moines Water Works Lawsuit Questions 2016, 12). On March 16, 2015, the Board of Water Works Trustees of Des Moines filed suit, demanding that upstream farmers not pollute the water, or else contribute to the cost of water denitrification (Des Moines Water Works Lawsuit Questions 2016, 15). Fearing similar lawsuits, public water authorities in South Dakota, including the EDWDD became concerned about the possible consequences of elevated nitrate levels in the BSR.

The pollution in the BSR could be associated with the significant grassland-to-cropland conversion in the BSR watershed. It is likely that nitrogen leached from the cropland in the basin remains in the BSR River. The presence of nitrogen in water as nitrate may cause several human health issues to the population that consume BSR water. The full degree to which BSR nitrate pollution contributes to these issues, however, has yet to be studied.

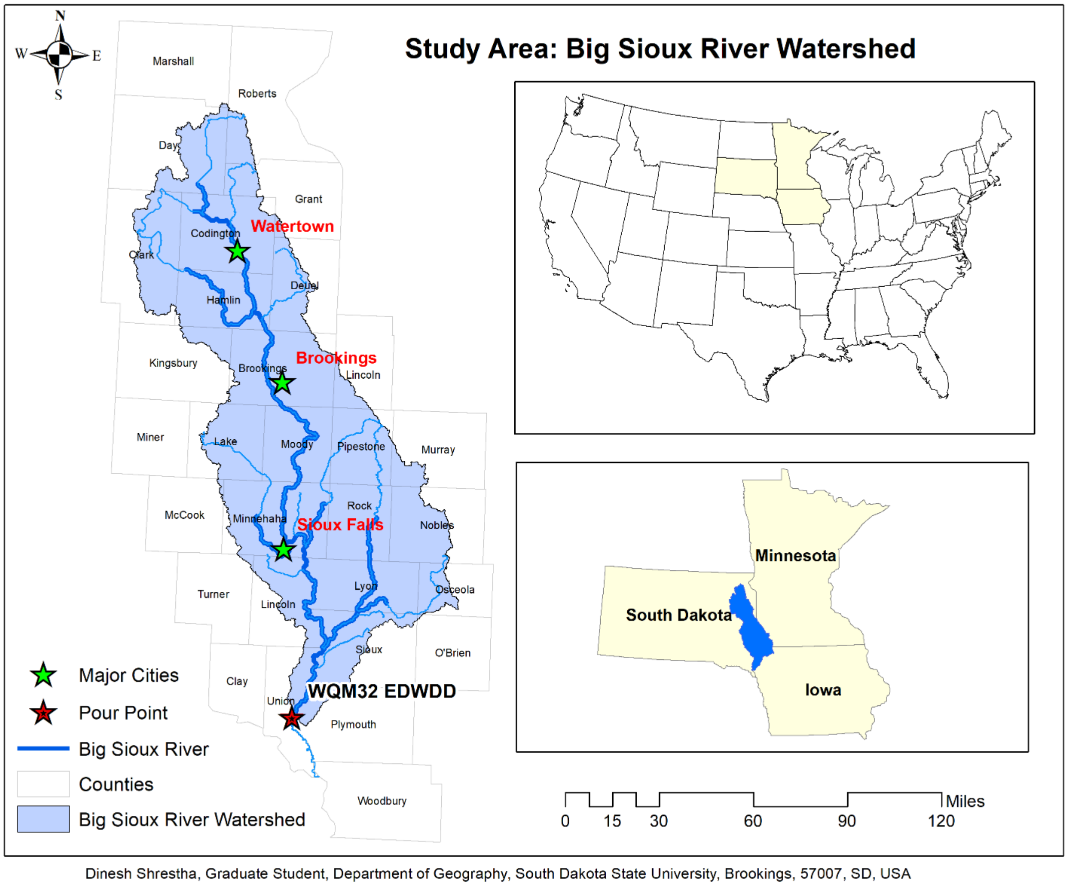
CHAPTER 3: DATA AND METHODS

As stated in Chapter 1, the objectives of this research are to quantify the spatial and temporal changes in the land cover types within the BSR watershed and associate these changes with BSR nitrate levels. In this chapter LCC trends in the BSR watershed and temporal and spatial trends relating to BSR nitrate levels are identified and characterized. In addition, analyses are performed in an attempt to determine whether identified relationships between LCC and BSR nitrate levels are causal or only correlative in nature.

3.1 Geographic Location of Study Area

Map 1 shows a representation of the BSR watershed and provides a detailed description of its geographic location. Flowing south for approximately 420 miles from Roberts County in South Dakota until its confluence with the Missouri River in Sioux City, Iowa, it drains an area of approximately 6,000 square miles of eastern South Dakota and an additional 3,000 square miles of Minnesota and Iowa (Priner 2016, 75; Rothrock 1943; eastdakota.org 2016).

The BSR watershed is South Dakota's most heavily populated region, containing several of the state's largest cities, including Watertown, Brookings, and Sioux Falls (Priner 2016, 75; Associated Press 2012). With fertile soils, relatively abundant precipitation, and easy access to irrigation, agriculture is the primary source of income for the people living in the region; its five most valuable agricultural products are cattle, corn, soybeans, wheat, and hogs (Reitsma et al. 2015, 2363). In addition, the region also contains the majority of South Dakota's light manufacturing, food processing, and wholesale industries. Generally, nitrate pollution in the BSR comes from a point source, such as municipal waste treatment units or ethanol plants.



Map 1: Study Area - The Big Sioux River Watershed that drains majority of eastern South Dakota and parts of Minnesota and Iowa.

3.2 Overall Study Design

This study uses the National Agricultural Statistic Service (NASS) Cropland Data Layer (CDL) to characterize and determine the rates of LCC, and the non-parametric Mann-Kendall test to analyze increasing and decreasing trends of land-cover change in the BSR. Similarly, it used the nitrate data from the gauging stations in the BSR watershed to determine the nitrate trends in the BSR. Land-cover change trends and nitrate trends, represented by Sen's Slope estimation of their magnitudes, are determined in separate process flows. Finally, a linear model of nitrate concentration vs. percentage of land cover classes is constructed (Figure 1). These methods will be discussed in greater detail in Sections 3.3, 3.4 and 3.5.

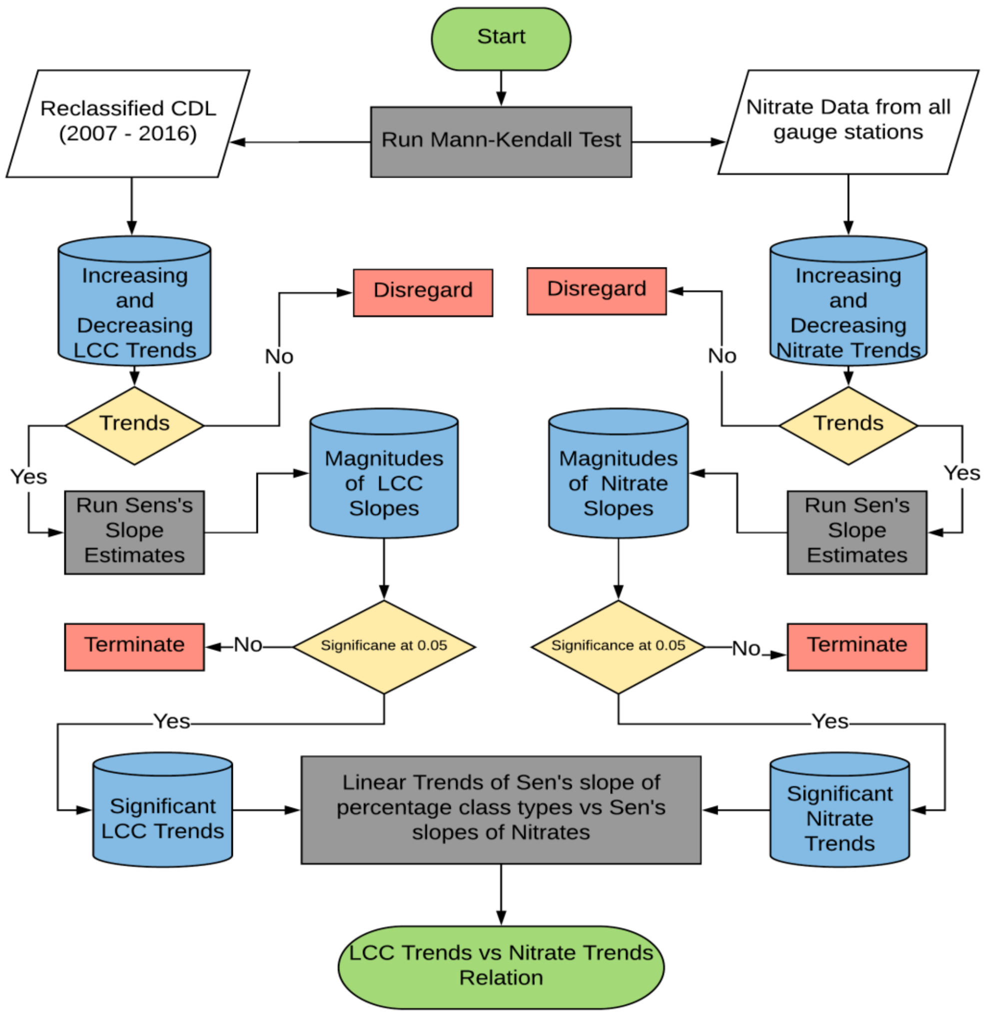


Figure 1: The Flowchart for Data Collection and Analysis

3.3 Land Cover Change Trend

The determination of land use and land cover change trends involve the following steps (Figure 2):

- Download the digital elevation model (DEM) raster file for the study area and delineate the watershed region.

- Download the CDL datasets from 2007 through 2016 and clip them to the extent of the study area.
- Resample all 56m CDLs to 30m and reclassify all the CDLs into five groups: Corn and Soybeans, Other Crops, Water, Developed, and Grassland.
- Calculate the area for each class type for the years 2007 through 2016
- Perform the Mann-Kendall test and generate Sen's slope estimates to identify potential land cover trends.

Steps 1 through 4 are discussed in this section. Step 5 is discussed later in this chapter.

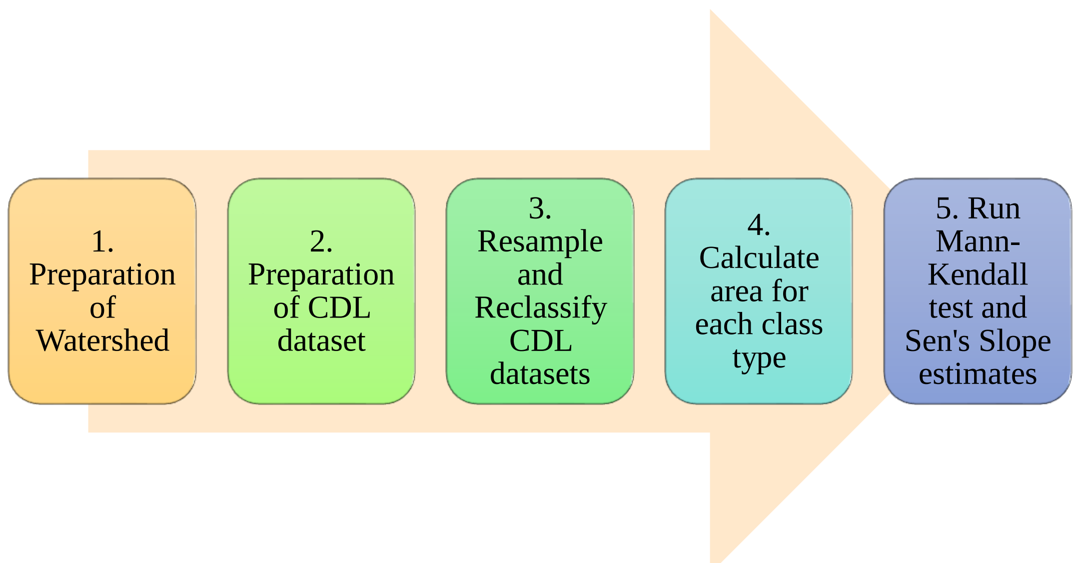


Figure 2: Methodology flowchart (LCC Trend)

3.1.1 Preparation of the Watershed

One arc-second Digital Elevation Model (DEM) images of eastern South Dakota, southwestern Minnesota, and northwestern Iowa were downloaded from the USGS National Map website (https://viewer.nationalmap.gov/basic/). These DEMs have a north-south ground spacing of approximately 30 meters and a latitude-dependent east/west ground spacing (Decision Innovation Solutions 2013). The individual DEM images were mosaicked into a single DEM image using the mosaic tool in ArcGIS.

The BSR watershed was delineated within the mosaicked DEM image using ArcGIS Model Builder as follows. First, depressions or "valleys" in the DEM images were filled in with the Fill tool. From the depression-less DEM image, the Flow Direction tool was used to determine the upward or downward direction of flow for each DEM pixel; once the flow directions were established, the corresponding stream order and flow length and accumulation were calculated. The Watershed tool was then used to establish the watershed region based on the flow direction, with the WQM32 EDWDD Gauging station, located near Richland, as a reference "pour" point. Figure 3 and Figure 4 illustrate the process flow as an algorithm and as a specific Model Builder processing flow, respectively. The resulting watershed map is shown in Map 2.

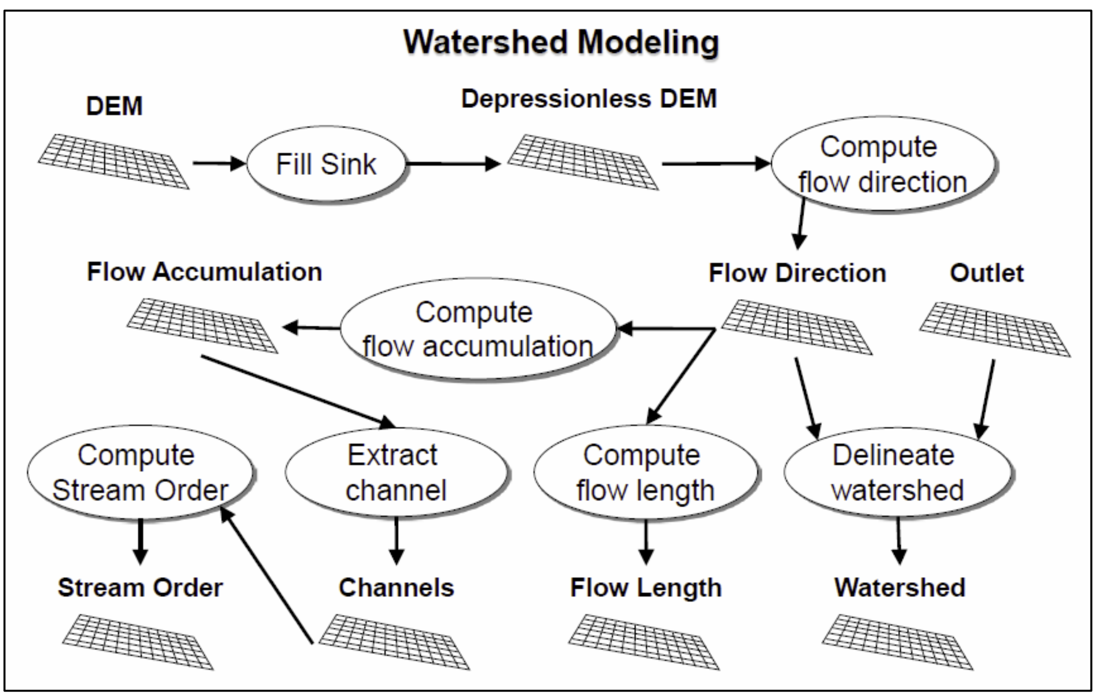


Figure 3: Watershed Modeling Process

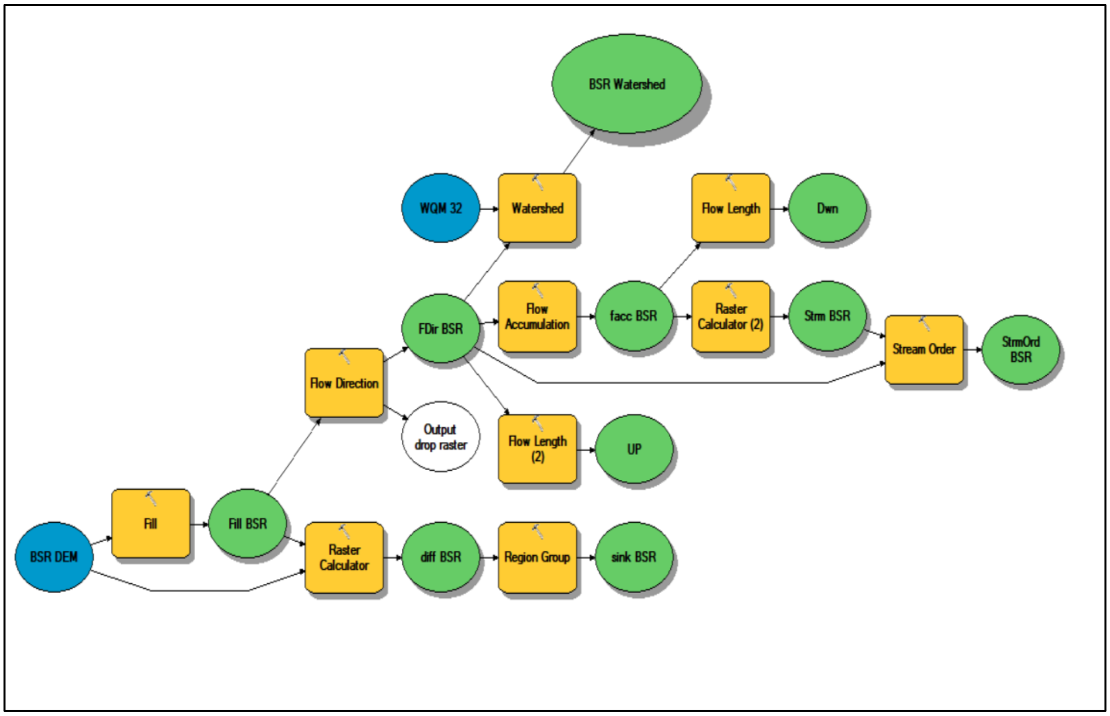


Figure 4: Watershed Delineation Process (ArcGIS Model Builder).

Map 2: Delineation of BSR Watershed. Gauging Station WQM32 EDWDD was used as pour point for the watershed delineation.

3.3.2 Preparation of the CDL Dataset

The National Agriculture Statistics Service (NASS) Cropland Data Layers (CDL) dataset is used for agricultural policy decision making (Fernandez-Cornejo and Caswell 2006; Maitima et al. 2009; Chang et al. 2007; Hatfield et al. 2010; Schrag 2011; Han et al. 2012; Li et al. 2012; Bandaru et al. 2013; Wright and Wimberly 2013; Decision Innovation Solutions 2013; Johnston 2013; Johnson 2013; Mueller and Harris 2013; Clay et al. 2014; IPCC 2014; Elliot et al. 2014; Lee et al. 2014; Liska et al. 2014; Reitsma et al. 2015). In agricultural analyses, CDL datasets are typically used in descriptive studies, which characterize recent land use changes; they are also used in predictive studies, which attempt to understand and predict the effects of changes in land use (Lark et al. 2017).

Fredrick (2017) used 2002 - 2010 CDL data to study the impact of land use and land cover change on stream water quality in the Reedy Fork-Buffalo creek watershed in North Carolina. In 2012, Venteris et al. used 2010 CDL data to study land availability and price in the coterminous United States for conversion to algal biofuel production. Wright and Wimberly (2013) used the CDL to determine recent land use change in the Western Corn Belt Plains ecoregion. Similarly, Reitsma et al. (2014) used the CDL to estimate land use change in South Dakota between 2006 and 2012.

3.3.2.1 A Brief History of CDL

The CDL program began with the compilation of data for North Dakota in 1997 and expanded to cover the entire continental United States by 2008. The CDL datasets are derived from satellite data. Its spatial resolution is variable, depending on the state and the year when the data were initially generated. In 2006, the CDL had a 56 m resolution and its various land-use categories were based on remote sensing information provided by the Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), the Indian Remote Sensing RESOURCESAT-1 (IRS-P6), and Advanced Wide Field Sensors (AWiFS). In 2012, the CDL had a 30 m resolution and the categories were based on information from the Landsat 5 TM, Landsat 7 ETM+, Disaster Monitoring Constellation (DMC) DEIMOS-1, and Ultra Kit (Type 2) (UK2) sensors (Veregin, 2012).

The availability of the CDL also varies by the state and year, potentially limiting the temporal extent of a particular study. For example, this research work required CDL data from South Dakota, Minnesota, and Iowa. South Dakota and Minnesota have available data from 2007 to the present, but Iowa has available data from 2001 to the present. Consequently, the time period covered in this research could begin no earlier than 2007.

3.3.2.2 The Structure of CDL

CDL layers are available on an annual basis and provide (1) supplemental acreage estimates for the state's major commodities; and (2) crop-specific, geo-referenced digital output products. Statewide CDL metadata for each year is posted for 85 to 125 classes of land cover, including crops such as corn, wheat, soybeans, peas, and alfalfa (Decision Innovation Solutions 2013). The NASS has added new classes to the CDL every year; some classes present in the 2016 data layer are likely absent in earlier versions.

3.3.2.3 The Accuracies of CDL

Because CDL datasets are produced with the intent of mapping annual land cover change, certain precautions should be taken with their use (Lark et al. 2017). These precautions are mentioned in the metadata layer documentation and relate to ensuring an analyst uses the data applicable to either a data producer or data user perspective. The metadata layer for each class contains the following information (Noe 2015; Fredrick 2017; Clay et al. 2014).

- estimates of **producer accuracy** (the overall accuracy with respect to the dataset producer)
- the **user accuracy** (the accuracy with respect to a data user who needs to know how often a given map class will be represented on the ground)
- the **omission error** (the rate at which sites were erroneously omitted from the correct class in the map)
- the **commission error** (the rate at which sites are correctly classified as "reference sites" but were erroneously omitted from the correct class in the classified map)
- the **Kappa Coefficient** (a measure used to evaluate the accuracy of a classification)

Clay et al. (2014) estimated the overall producer accuracy of the 2012 South Dakota CDL at approximately 83.3%. The estimated producer accuracies for cropland classification ranged from approximately 65.2% in southwestern South Dakota to approximately 96.6% in east central South Dakota. Similarly, the estimated producer accuracies for grassland classification ranged from approximately 48.8% in southeastern South Dakota to approximately 98.6% in northwestern South Dakota. At the state level, the estimated producer accuracy for cropland classification increased from approximately 83.3% in 2006 to approximately 89.7% in 2012, while the estimated producer accuracy for grassland classification also improved slightly, from approximately 87% in 2006 to approximately 90.8% in 2012 (Clay et al. 2014).

The overall user accuracy for all classifications in the 2012 South Dakota CDL was approximately 90%. There appears to be very little available information relating to estimated user accuracies for specific classifications in the previous CDL datasets. While the CDL may accurately estimate the change in cropland and grassland area for a given state relative to the NASS data, producer and/or user accuracies of "impervious" or developed land classifications are not guaranteed at any level (Noe 2015; Fredrick 2017). This uncertainty prompted Frederick's use of aerial photographs to estimate impervious land classification, and the CDL to estimate agricultural and forest land classification.

3.3.3 Resample and Reclassify CDL Dataset

As CDLs of varying spatial resolution were used for this research, it was decided to perform the analysis at one "common" spatial resolution. Consequently, it was necessary to resample the pre-2009 CDL data from 56 m spatial resolution to 30 m resolution (Noe 2015). The nearest neighbor resampling method was used to generate the resampled data since it is a relatively straightforward and quick resampling method suitable for discrete data such as land-use classifications. This resampling method preserves the spatial extent of the original raster scan at the potential cost of changing the pixel size (ESRI 2018). The maximum spatial error in this resampling method is one-half the pixel size, which for this type of research is considered an acceptable level of error.

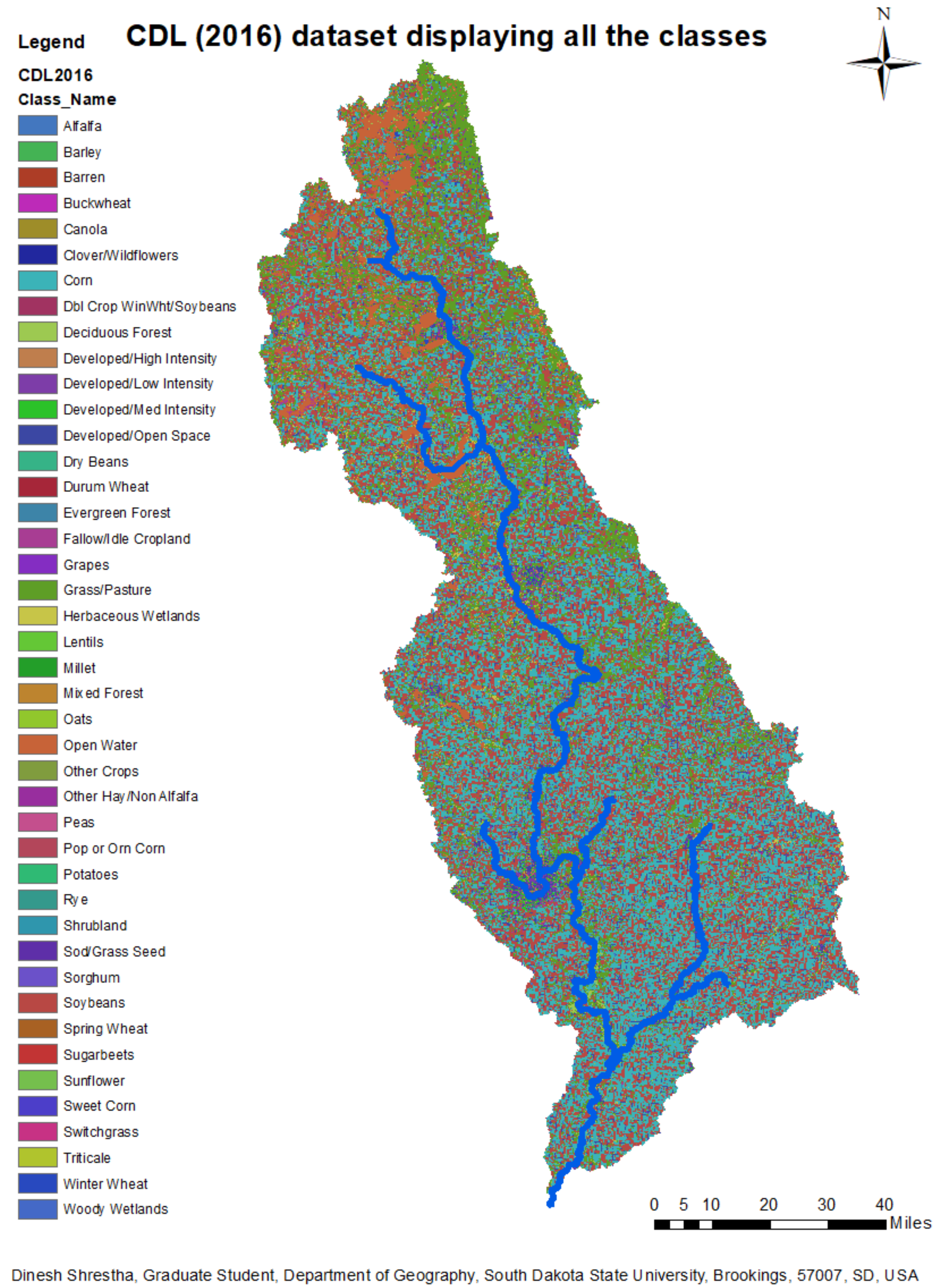
Map 3 represents a 2016 CDL dataset with its original set of classes at 30 m spatial resolution. An analysis of an original dataset of this type can be prohibitively time-consuming and resource intensive to process. As a result, it is generally recommended to generate a reduced set of broader “common” classes prior to any analysis (Noe 2015; Fredrick 2017). Reclassification is required for the case that the classes in some CDL layers are absent in others. In addition, reclassification can reduce errors when resolving spectrally similar land cover classes (Lark et al. 2017; Johnson 2013). This process can be performed from within ArcGIS.

Table 1 presents the reclassification guideline used in this research. Based on the analysis of the trends in corn and soybeans, all classes relating to corn or soybeans, such as “Sweet Corn”, were reclassified into a broader “Corn and Soybeans” class. All classes relating to land cover other than water bodies, such as grassland and pasture, were reclassified into a broader “Grassland” class. All classes relating to other crops, such as wheat, sunflower, alfalfa, oats, and hay, were reclassified into a broader “Other Crops” class. Similarly, water body classes such as rivers, lakes, open water, and wetlands were reclassified into a broader “Water” class. Finally, classes representing human activity such as buildings, roads, and parks were reclassified into a “Developed” class. Map 4 is the resulting reclassification map for the CDL 2016 dataset. Similar reclassification maps for the CDL datasets from 2007 through 2015 are shown in Appendix F.

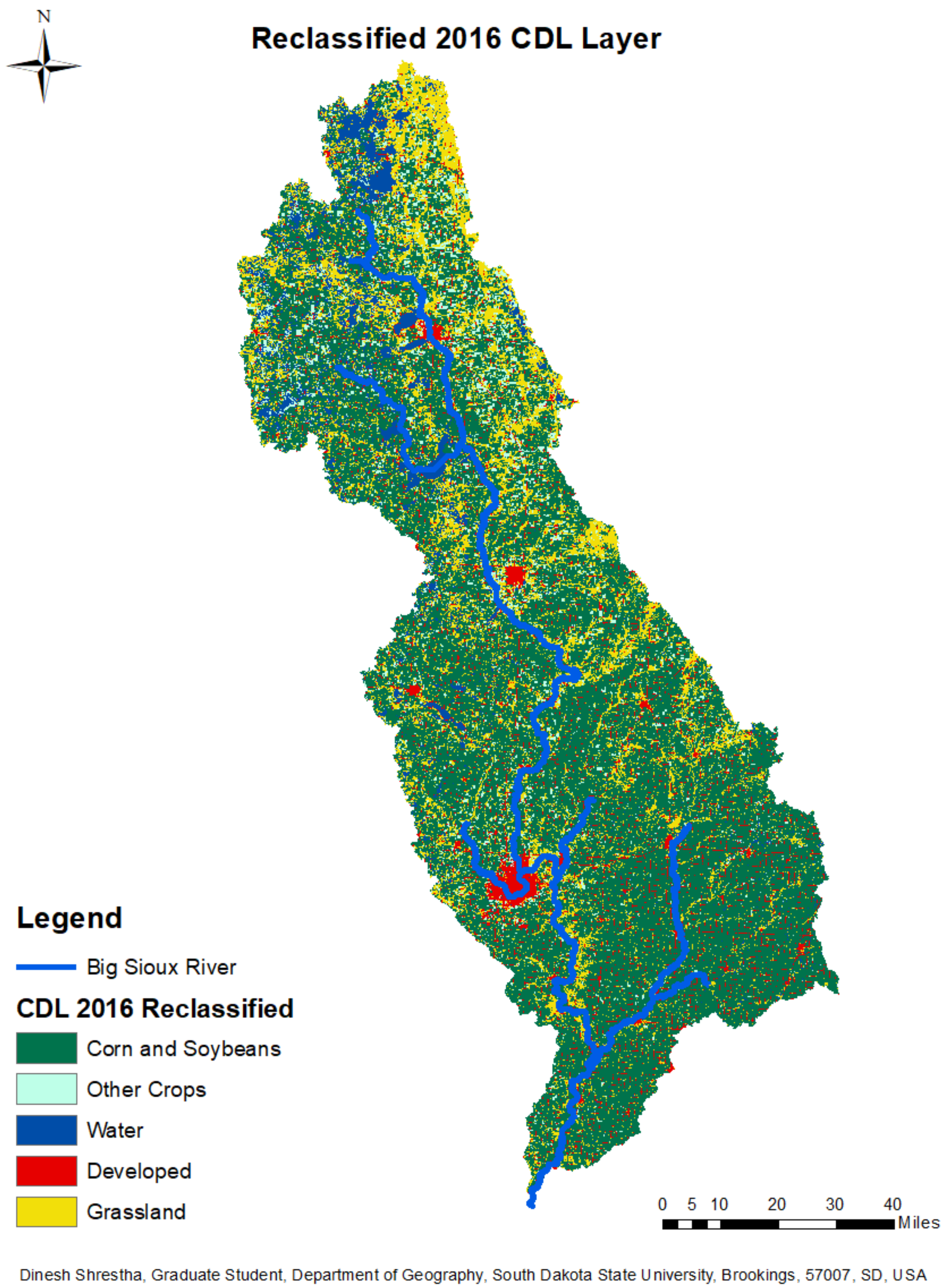
Table 1: Proposed Reclassification Guideline for NASS CDL Datasets

Classes	Categories
Corn and Soybeans	Corn and Soybeans, Sweet Corn, Pop Corn
Grassland	Forest, Switchgrass, Grass/Pasture, Shrubland, Barren
Other Crops	Wheat, Alfalfa, Sorghum, Oats, Millet, Pumpkin, Flaxseed, Potatoes, Barley, and other crops
Water	Rivers, Lakes, Open Water, Wetlands, and Woody Wetlands

Developed	Open space, Developed/Low Intensity, Developed/Medium Intensity, Developed/High Intensity, Developed/Open Space, Buildings, Roads, and Parks



Map 3: 2016 CDL Dataset Containing Original Set of Classes



Map 4: 2016 CDL Dataset Reduced to 5 Broader Classes.

3.3.4 Area Calculation for Reduced Set of Broader Classes

After reclassification of the 2007 – 2016 CDL datasets, the total coverage area for the BSR watershed region for each year was calculated with respect to the five broader classes. This was done by multiplying each pixel value in a given class by the corresponding pixel dimensions. When multiplied by the conversion factor 0.000247105 acres/m^2, one dataset pixel of 900m^2 is equal to approximately 1 acre. Therefore, multiplying this conversion factor by the total number of pixels in a given class yields the total covered area in acres for that class (Figure 5). Figure 6 shows the corresponding computation sequence in the ArcGIS Model-Builder.

Then, the pixels in each class in the 2007 CDL were compared to pixels in the same spatial locations in the 2016 CDL, and the percentage change in coverage for each class was determined. In particular, the pixels originally classified as “Grassland” in 2007 but converted to “Corn and Soybeans” in 2016 were identified.

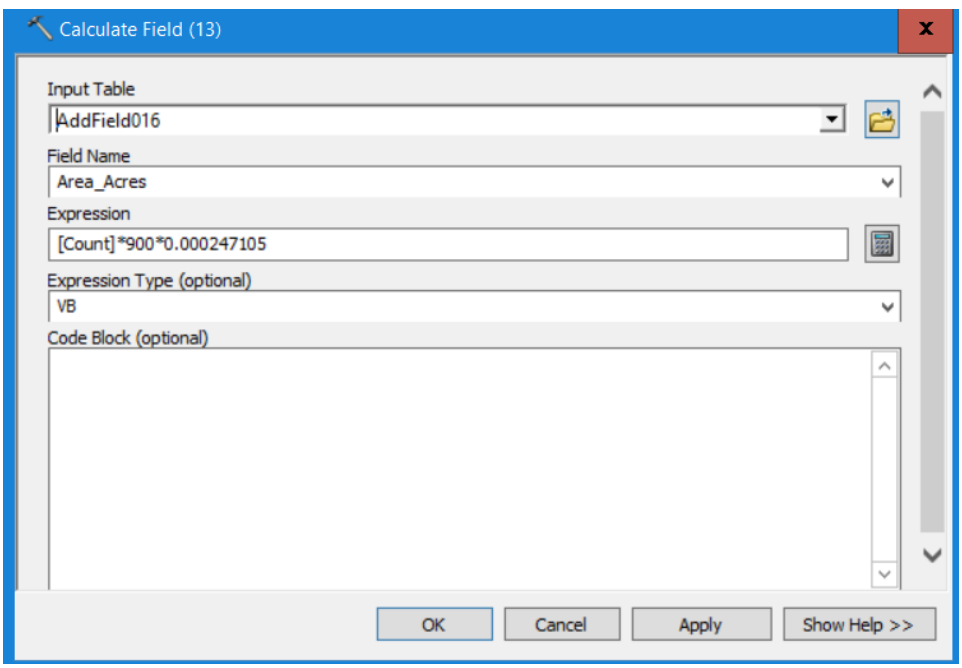


Figure 5: Area calculation of each class type using ArcGIS

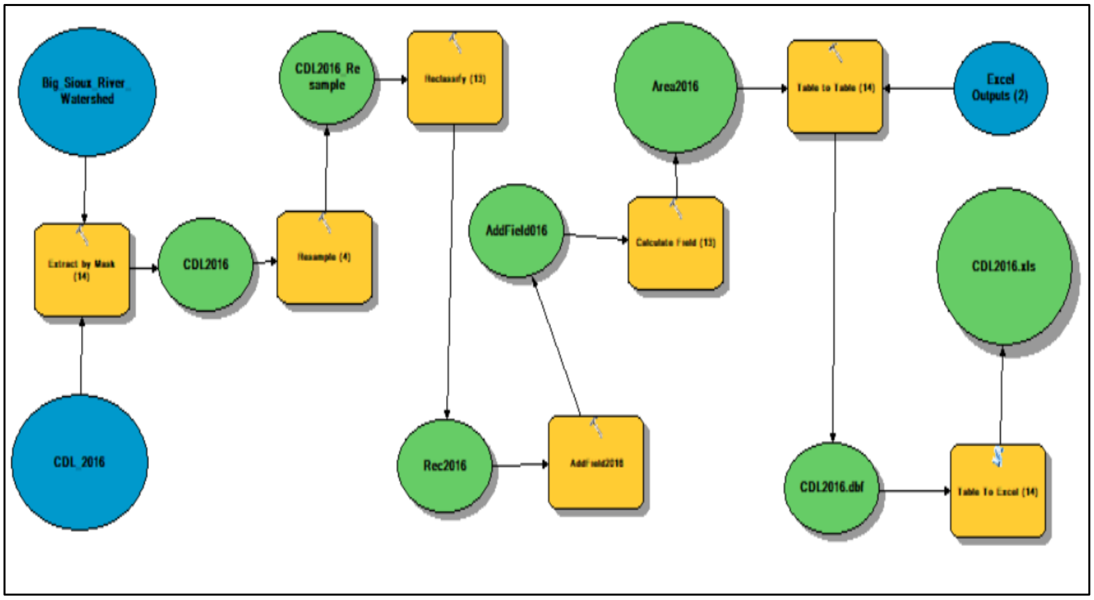


Figure 6: ArcGIS Model Builder Area Coverage Calculation Method.

3.4 Nitrate Trends

The analysis of nitrate trends in the BSR watershed involved the following steps (Figure 7):

- Collect the available nitrate data from all gauging stations within the watershed region.
- Filter the raw data to just the gauging stations supplying nitrate data for multiple years.
- Perform the Mann-Kendall test and generate Sen's slope estimates to identify potential nitrate trends.

Steps 1 and 2 are considered in greater detail in this section. Step 3 is discussed later in this chapter.

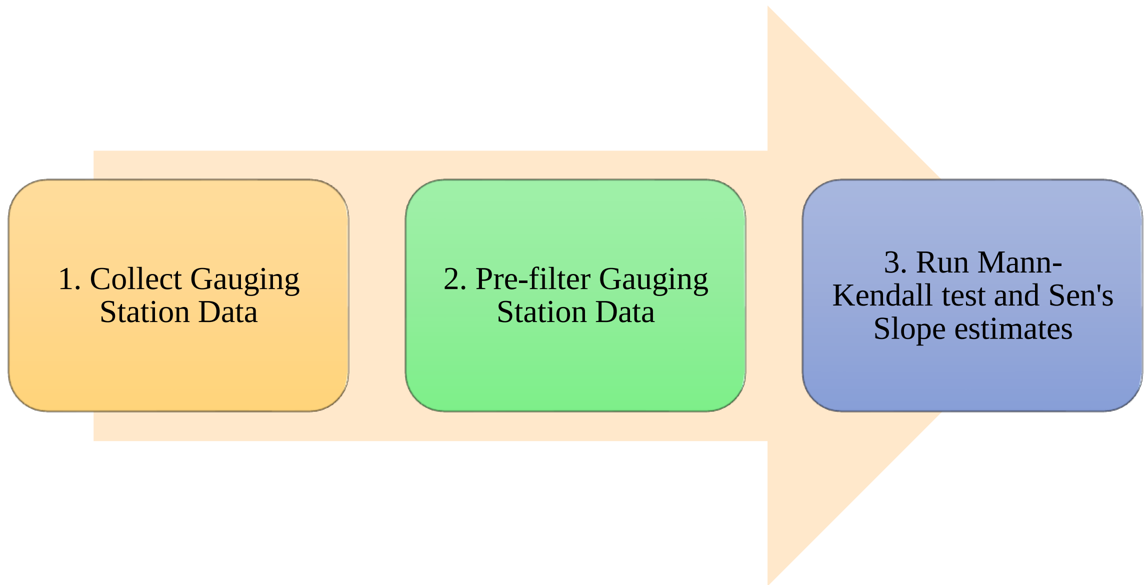


Figure 7: Nitrate Trend Analysis Flowchart

3.4.1 Collect Available Nitrate Data

Most of the available nitrate data were obtained through the Eastern Dakota Water Development District (EDWDD) headquartered in Brookings. Additional nitrate data were obtained through websites maintained by the South Dakota DENR, the USGS, the Minnesota Pollution Control Agency, the Iowa Department of Natural Resources, and the Flandreau Santee Sioux Tribe. These data were initially collected at 48 gauging stations located throughout the watershed region, and ultimately compiled into Microsoft Excel spreadsheets by the various agencies.

3.4.2 Filter Gauging Station Data

From the initial set of 48 gauging stations, only 15 supplied nitrate data. Table 2 presents these 15 stations. Again, out of 15 stations, only 11 stations supplied data over 4 years and were labelled as “Candidate Stations” (CS) and are represented by red point symbol in Map 4. These 11 stations are SD Grant SA1, SD Codington K06, SD Hamlin

S08, SD Moody BSA, MN Pipestone 094, MN Pipestone 099, MN Rock 528, MN rock 811, R13 EDWDD, IA Lyon 001, and Iowa Hawarden. These stations are labelled as CS because these stations are eligible for a Mann-Kendall test. Remaining 4 stations supplied data for 2 years and were labelled as "Non-Candidate Stations" (NCS) and represented with green point symbols in Map 4. These NCS stations do not have enough data points for Mann-Kendall test. There will be further discussion about these stations labelled in section 5.2.

Out of 11 stations, only one station had monthly data. All others had the annual data. Some stations had missing annual data as well. These missing data were left as they were and labeled as NA. The station WQM32 EDWDD, located near Richland, SD also served as a pour point during watershed delineation (Map 4).

Table 2: BSR Watershed Gauging Stations Supplying Nitrate Data Over Multiple Years

S.No	Station Name	Organization Name	State	County	Remark
1	MN Pipestone 099	MPCA - Ambient Surface Water	Minnesota	Pipestone	CS
2	MN Pipestone 094	MPCA - Ambient Surface Water	Minnesota	Pipestone	CS
3	MN Rock 528	MPCA - Ambient Surface Water	Minnesota	Rock	CS
4	MN Rock 811	MPCA - Ambient Surface Water	Minnesota	Rock	CS
5	Iowa Hawarden	Iowa Dept. of Natural Resources	Iowa	Sioux	CS
6	IA Lyon 001	Iowa Dept. of Natural Resources	Iowa	Lyon	CS
7	SD Moody BS-A	Flandreau Santee Sioux Tribe (SD)	South Dakota	Moody	CS

8	SD Hamlin S08	SDDENR	South Dakota	Hamlin	CS
9	SD Grant SA1	SDDENR	South Dakota	Grant	CS
10	SD Codington K06	SDDENR	South Dakota	Codington	CS
11	R13 EDWDD	EDWDD	South Dakota	Ritchie	CS
12	WQM65	EDWDD	South Dakota	Lincoln	NCS
13	WQM66	EDWDD	South Dakota	Lincoln	NCS
14	WQM67	EDWDD	South Dakota	Union	NCS
15	WQM32 EDWDD	EDWDD	South Dakota	Plymouth	NCS

Map 4: Geographic Location of Gauging Stations in the BSR Watershed

3.5 Trend Analysis

To identify and characterize potential trends in the land cover and nitrate concentration data, non-parametric statistical analysis based on the Mann-Kendall test and Sen's slope estimator was used. These analytical tools are considered in greater detail in the following sections.

3.5.1 Mann - Kendall Test

The Mann-Kendall test has been widely used to identify trends in environmental data. Chang (2008) used a seasonal version of the test to determine the significance of nitrate trends between 1993 and 2002 in the Han River basin of South Korea. Koh et al. (2017) used the test to determine the impacts of land use change and groundwater management on long-term nitrate/free nitrogen and chloride trends in groundwater on the South Korean island of Jeju. Similarly, Eregno et al. (2014) used the test to identify trends in the concentration of fecal indicator organisms in an unprocessed water source at the Nedre Romerike Vannverk drinking water treatment plant in Norway.

As originally conceived, the test assumes that the dataset possesses the following characteristics: i) the data are not acquired seasonally; ii) the data are not affected by covariate factors other than those under consideration; and iii) there is only one data point in each sampled time period (Kendall 1948). For seasonally acquired data; a modified Mann-Kendall test accounting for seasonal effects can be run (Mann and Whitney 1947). If multiple samples of data are collected in any time period, the median of the data points can be used.

The test hypotheses are stated as follows (Mann and Whitney 1947; Kendall 1948):

- The null hypothesis, H_0, is that the data come from a population with independent observations that are identically distributed. In other words, the data do not follow a monotonic trend
- The alternative hypothesis, H_A, is that the data follow a monotonic trend

The Mann-Kendall test statistic, S, is generated as follows. First, compute the Kendall statistic τ:

$$\tau = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k) \tag{1a}$$

where n is the total number of data points in the dataset. $sign(x_j - x_k)$ is the "rank" of the sign difference between two distinct data points (x_j, x_k, $j \neq k$). The total number of distinct data point pairs needing to be considered is given by n(n-1) / 2.

$$sign\left(x_{j} - x_{k}\right) = \begin{Bmatrix} +1, if\ x_{j} - x_{k} > 0 \\ 0, if\ x_{j} - x_{k} = 0 \\ -1, if\ x_{j} - x_{k} < 0 \end{Bmatrix} \tag{1b}$$

Finally, normalize τ by the total number of distinct data point pairs:

$$S = \frac{\tau}{n(n-1)/2} \tag{2}$$

The Mann-Kendall test was applied to the BSR watershed land cover and nitrate concentration data between 2007 and 2016, at a 0.05 significance level. For the land cover, the test was applied to all classes. Nitrate data that showed a statistically significant increasing or decreasing trend were then flagged for application of Sen's slope estimator to determine the magnitude of the trend.

3.5.2 Sen's-Slope

The Sen's Slope estimator is commonly used after the Mann-Kendall test identifies a linear trend, to determine the true slopes (change per unit time) (Sen 1968). Like Mann-Kendall tests, the Sen's Slope estimators are widely used to identify trends in environmental data. Chang (2008), Koh et al. (2017), and Eregno et al. (2014) used Sen's Slopes to identify the magnitude of the linear trend determined by the Mann-Kendall test in their research.

Sen's Slopes estimators are only used if the Mann – Kendall test determines a linear trend in the data. The Sen's Slope estimate computes the median slope of each point-pair slope in the dataset. The linear model f(t) for Sen's Slope is described as:

$$f(t) = Qt + B \tag{3}$$

where Q is the slope and B is a constant.

Then, the slopes of all data pairs are calculated to estimate of the slope Q. For *n* values of xi in the time series we get as many as *N= n(n-1)/2* slope estimates Q.

$$Q = \frac{x_j - x_k}{t_j - t_k}\ , j = 1, 2, 3, \ldots\ldots N,\ j > k \tag{4}$$

In this research, for all the gauging stations showing significant increasing and decreasing trends in nitrate concentrations in the Mann–Kendall test, the magnitude of trends was computed by using the Sen's slope estimator which is a median value (Q') among slopes of trends (Q) in the n data records (Sen 1968; Eregno et al. 2014; Koh et al. 2017).

$$N' = \frac{n(n-1)}{2}, Q' = \left\{ Q_{\frac{N'+2}{2}}\ ,\ \ if\ N'\ is\ odd \right\} \tag{5a}$$

$$N' = \frac{n(n-1)}{2}, Q' = \{\frac{1}{2}\ \ [\frac{Q_{N'}}{2} + \frac{Q_{N'+2}}{2}, if\ N' is\ even\} \tag{5b}$$

To obtain an estimate of B in equation (3) the *n* values of differences $x_i - Qt_i$ are calculated. The median of these values gives an estimate of B (Sirois 1998). The estimates for the constant B of lines of the 99 % and 95 % confidence intervals are calculated by a similar procedure. For this study, data were processed using an Excel macro named MAKESENS created by Salmi et al. (2002). The MAKESENS Excel template which was developed by the Finnish Meteorological Institute (FMI) to detect and estimate trends in the time series of annual values of atmospheric and precipitation concentrations (Salmi et al. 2002). The MAKESENS template and its working principle are further discussed in Appendix H.

The Mann-Kendall test and Sen's Slope estimates were applied employed to the entire BSR to determine the LLC trends in the watershed, and to all the gauging stations within BSR to determine the nitrate trends in each station. With a drainage area of approximately 9,000 square miles and connections to several smaller tributaries, it would be difficult to reliably estimate actual changes occurring within the area near any BSR gauging station. Therefore, estimates for the HUC12 catchments were done. Tomer et al. (2013) suggested the use of the HUC12 catchment for a more detailed analysis at a localized level because these catchments also account for tributaries. Moreover, Tobler's first law of Geography suggests that "Everything is related to everything else. But near things are more related than distant things" (Tobler 1969).

3.6 Linear Regression

Linear regression is the most popular parametric statistical method to identify a monotonic trend in a time series dataset, especially with a small sample number (Meals et al. 2011). For a simple linear regression of Y_i in time, all these assumptions:Y_i is linearly related to t_i, residuals are normally distributed, residuals are independent, and variance of residuals is constant, should be satisfied. Let Y_i denote the response variable observed at time, t_i. A conventional linear regression model for trend analysis is given by:

$$Y_i = b_0 + b_1 t_i + e_i \tag{5}$$

The parameter b_1 in a linear regression model expresses the rate of change of y_i in time. For this research, the Sen's slope of Nitrates will be treated as independent variables, y_i and the Sen's Slopes of percentage of each class types will be considered as dependent variables (b_0, b_1, and so on).

The slope coefficient (b_1) is statistically tested under the null hypothesis that it is equal to zero. The null hypothesis for a simple linear regression is that the slope coefficient b_1 = 0. The t-statistic on b_1 is tested to decide if it is significantly different from 0. If the slope is non-zero (upward or downward slope), the null hypothesis of zero slopes over time is rejected and one can conclude that there exists a linear trend in y over time. Besides providing a measure of significance based on the hypothesis test on the slope, it also gives the magnitude of the rate of change (Petreson and Brakebill 1999; Abaurrea et al. 2011). Missing values are allowed in the linear regression.

In some cases, it might have been necessary to log-transform the data. We can do this by log-transforming the original data. To make the trend easier to interpret, the linear trend can be expressed in percent per year. If b_1 is the estimated slope of the linear trend in $\log_{10}$ units, then the percentage change over any given year is $(10^{b1} – 1) *$ 100. When there is no trend, the slope is zero and the equation results in a zero percent change (i.e., b_1 = 0).

For a series of observations over time, such as nitrate levels in a given body of water, we are concerned about whether the values are going up, down, or staying the same. In this case, trend analysis is applicable to all the water quality variables. Trends occur in two ways: a gradual change over time that is consistent in the direction (monotonic) or an abrupt shift at a specific point in time (step trend) (Meals et al. 2011). In this study, trends are consistent over the time, therefore, a simple trend analysis may be the best approach (Meals et al. 2011; Abaurrea et al. 2011). For data from a short-term, Mann-Kendall and Sen's Slope estimate are appropriate to determine monotonic (upward and downward) trends (Koh et al. 2017; Eregno et al. 2014; Mann and Whitney 1947; Kendall 1948).

After the upward and downward trends of land cover and nitrates were determined, a linear regression of the Sen's slopes of percentage area of all class types versus the Sen's slopes of nitrates was done. This linear regression is expected to show how strongly the slopes of percentage area of the class types were associated with the slopes of nitrates.

CHAPTER 4: RESULTS

This chapter explains the results that were identified in the Mann-Kendall test and Sen's Slope estimates. Additionally, this chapter presents detailed results at the HUC12 catchment level. Furthermore, a linear regression model for the Sen's slopes of the percentage of land-cover classes versus Sen's slopes of nitrates in the BSR watershed will be discussed.

4.1 Land Cover Trend

Table 2 gives the resulting annual coverage estimates (x 100,000 acres) for each reduced class. Table 3 represents the resulting coverage estimates for each reduced class for each year in percentage area. Figure 9 shows a graphical representation of the change in the annual percentage of coverage of each class.

It is clearly seen from Table 3 that the percentage of corn and soybean acreage increased from 56% (2,900,000 acres) in 2007 to 63% (3,300,000 acres) in 2016, whereas the percentage of grassland acreage decreased from 27% (1,400,000 acres) in 2007 to 19% (987,000 acres) in 2016. During this period, the absolute amount of water-related and human-developed acreage varied somewhat; however, the percentage of acreage in these cover classes remained constant. The apparent absolute decreases in developed acreage in (years) are more likely explained by the reduced accuracy in the CDL classification of classes other than corn, soybeans, and grassland (Noe 2015), rather than human activities directly converting the land back to a more natural state (which does not appear to have been reported); this issue will be considered later in Section 5.4.1. The remaining reduced classes did not show any significant changes.

Table 3: Coverage estimates (x 100,000 acres) for each reduced class for each year.

Class Type/Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Corn and Soybeans	29.23	30.04	29.89	32.18	31.93	33.08	32.97	33.30	33.17	33.41
Grassland	14.20	13.65	13.59	11.25	10.67	9.94	10.60	9.34	9.82	9.87
Other Crops	2.40	2.50	2.62	3.81	3.99	3.78	3.31	4.18	3.49	3.33
Water	2.95	2.94	3.10	2.87	3.44	3.25	3.15	3.16	3.52	3.39
Developed	3.07	3.07	3.08	3.08	3.20	3.20	3.21	3.25	3.24	3.23
Total	52.93	53.26	53.26	53.19	53.24	53.24	53.24	53.23	53.24	53.24

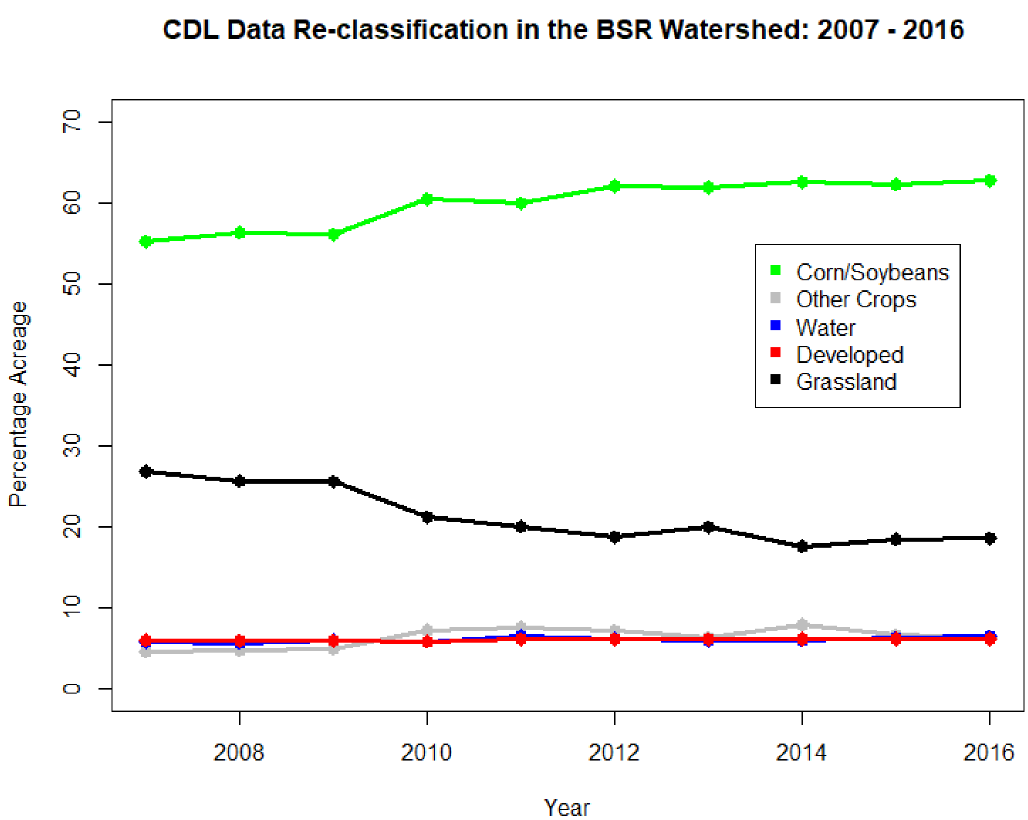


Figure 8: Graphical representation of change in percentage coverage of each class in each year (from 2007 through 2016).

Table 4: Area (in percentage) covered by each class type from 2007 through 2016.

Classes / Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Corn and Soybeans	56	58	57	60	60	62	62	63	63	63
Grassland	27	26	26	21	20	19	20	18	19	19
Other Crops	5	5	5	7	7	7	6	8	7	6
Water	6	6	6	6	6	6	6	6	6	6
Developed	6	6	6	6	6	6	6	6	6	6
Total	100	100	100	100	100	100	100	100	100	100

Table 4 represents the change in acreage estimates for each class type from the years 2007 to 2016. This estimate is represented by the pixels in each class in the 2007 CDL converting to a different class, without changing spatial locations between the 2007 and 2016 CDLs. For example, a conversion from corn and soybeans to grassland means that the pixels that were corn and soybeans in 2007 were converted to grassland in 2016. The additional corn and soybean acreage were mainly gained from converted grassland and other crops (Appendix G). Nonetheless, some corn and soybean acreage were converted to grassland and/or other crops as well. Similar behavior was observed with other crop and grassland classes.

A summary of the aggregated land cover trends is presented in Table 5 as a contingency table, with the 2007 CDL class types in the first two columns and the corresponding 2016 CDL class types in the remaining columns. The contingency table indicates a net increase of 11% in conversion from grassland and other crop acreage to corn and soybean acreage between 2007 and 2016. The table also shows that 2% of developed acreage was converted to corn and soybean acreage during this same period.

As no evidence of human conversion of developed land to farmland has been reported, this estimate should be considered suspect given the limitations in current CDL data.

Table 5: Contingency table for percent land use/land cover change from 2007 to 2016.

		2016	**2016**	**2016**	**2016**	**2016**	
		Corn and Soybeans	Other Crops	Water	Developed	Grassland	Total
2007	Corn and Soybeans	50.97	2.81	0.40	0.86	1.30	56.33
2007	Grassland	7.44	2.02	1.54	0.84	15.53	27.37
2007	Other Crops	3.23	1.01	0.06	0.07	0.25	4.63
2007	Water	0.52	0.33	4.25	0.07	0.52	5.70
2007	Developed	2.04	0.01	0.01	3.90	0.01	5.98
	Total	64.20	6.18	6.27	5.73	17.62	100.00

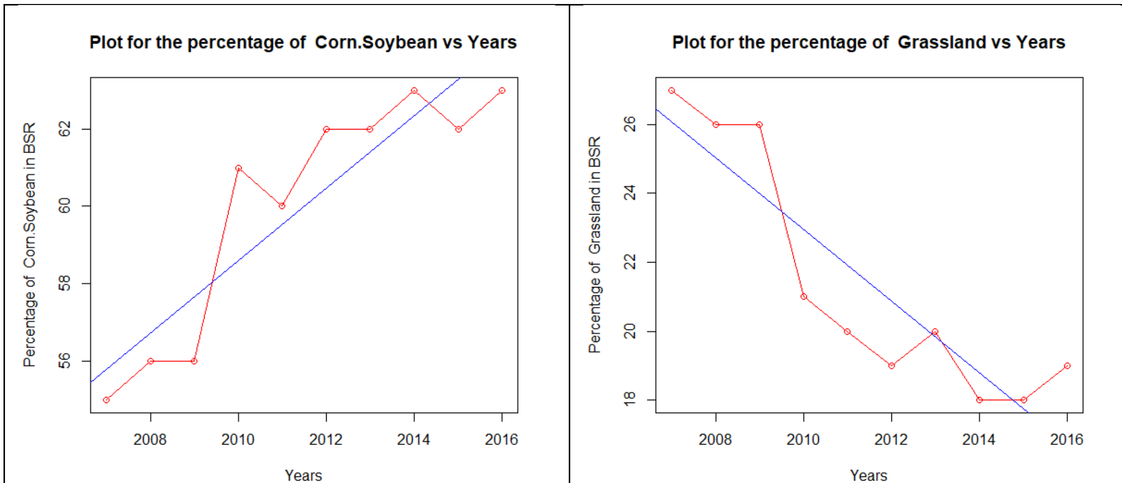
4.1.1 Land Cover Trend – Mann-Kendall Test

For the entire BSR region, the tau value from the Mann-Kendall test for the percentage of corn and soybean acreage was 0.85, with a statistically significant p-value of 0.001. The positive tau value suggests an increasing trend in the percentage of corn and soybean acreage. The tau value from the Mann-Kendall test for percentage grassland, however, was -0.815, with a statistically significant p-value of 0.002. The negative tau value suggests a decreasing trend in the percentage of grassland acreage (Figure 9 and Table 6).

The tau values for the percentage of other crop, water-related, and developed acreage were, respectively, 0.428, 0.325, and 0.683, with the p-values of 0.13, 0.300, and 0.023 respectively (Table 6). With respect to the other crop and water body acreage, there was insufficient evidence to conclude their percentages had changed, the developed land acreage had a statistically significant p-value of 0.023; given the low percentage of this acreage, however, any change in percentage would be small. Additional information on these other classes can be found in Appendix B.

Table 6: Summary of the output from Mann-Kendall Test and Sen's Slope Estimate for Reclassified CDL Classes for entire BSR Watershed

CDL Classes	Mann-Kendall Test			Sen's Slope Estimate		
	Tau	p-value	Trend	Z Score	Slope (Q)	Const (B)
Corn and Soybeans	0.85	0.001	Increasing	3.22	0.86	56.1
Grassland	-0.815	0.002	Decreasing	-3.22	1.03	26.4
Other Crops	0.428	0.13	No Trend	1.43	0.195	50.1
Water	0.325	0.3	No Trend	1.97	0.009	55.3
Developed	0.683	0.23	No Trend	-0.89	0.11	69



tau = 0.849, 2-sided, p-value =0.001

tau = -0.815, 2-sided, p-value =0.002

Figure 9: Scatterplot and Mann-Kendall test results of percentage corn and soybeans and grassland for entire BSR.

4.4.2 Land Cover Trend – Sen's Slope

For those classes where the Mann-Kendall test identified a statistically significant slope (represented by p-values < 0.05), Sen's method was used to estimate the magnitude of the slope. Using the MAKESENS Excel template, the confidence intervals for the estimated slope, Q, and intercept, B, were computed for $\alpha = 0.01$ and $\alpha = 0.05$.

Figure 10 shows the results obtained from Sen's method with respect to percentages of corn and soybean acreage. From Table 5, the corn and soybeans class had a Z score test of 3.22, indicating the percentage of corn and soybean acreage was monotonically increasing at the $\alpha = 0.01$ significance level, with Q = 0.86 and B = 56.1.

The grassland class (Figure 11) had Test Z score of -3.22, indicating the percentage of grassland acreage was monotonically decreasing at the 0.01 significance level, with Q = -1.03 and constant B = 26.4. This provides additional support for the Mann-Kendall results.

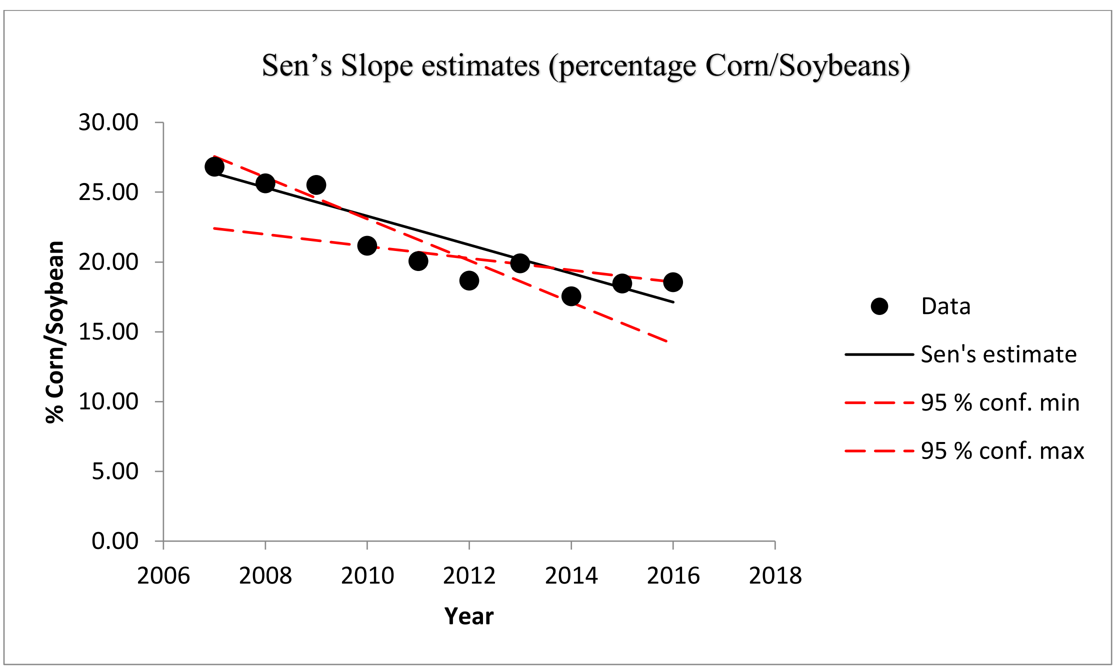


Figure 10: Percentage of Corn/Soybean Acreage Trend in BSR Basin, 2007-2016

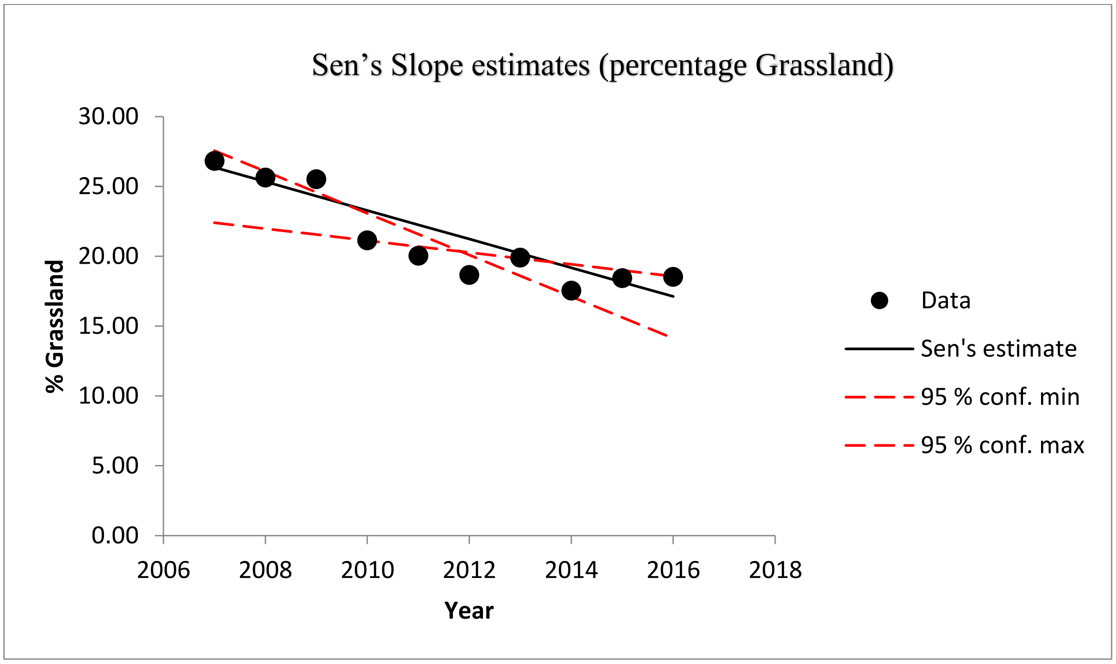


Figure 11: Percentage of Grassland Acreage Trend in BSR Basin, 2007-2016

4.2 Nitrate Trend

The selected gauging stations with multiple years of nitrate data were also run through the Mann-Kendall test and Sen's Slope estimator. The results from these tests are discussed below.

4.2.1 Nitrate Trend – Mann-Kendall Test and Sen's Method

Mann-Kendall tests for nitrate were run in R, and Sen's Slopes were determined using the MAKESENS excel template. The confidence interval at confidence level α = 0.05, Sen's slope estimate (Q), and the constant (B) were determined using the template.

Table 7 summarizes the outputs from Man-Kendall tests and Sen's slopes. Out of 11 stations, 2 showed increasing trend, 1 station showed a downward trend, and remaining stations did not show any trend (Table 7 and Map 5). The stations that showed increasing trend were MN Pipestone 099 and MN Pipestone 094. SD Codington K06 showed a decreasing trend. The other gauging stations including SD Grant SA1, SD Hamlin S08, SD Moody BAS, MN Rock 528, MN Rock 811, R13 EDWDD, Iowa Hawarden, and IA Lyon 001 were "Neutral".

Table 7: Summary of the output from Mann-Kendall Test and Sen's Slope Estimate for Nitrate Gauging Stations

Gauging Stations	Mann-Kendall Test			Sen's Slope Estimate	
	Tau	p-value	Trend	Slope (Q)	Const (B)
SD Grant SA1	0.422	0.107	No Trend	0.7	1
SD Codington K06	- 0.742	0.008	**Decreasing**	-0.233	2.4
SD Hamlin S08	- 0.067	0.858	No Trend	-0.013	1.84
SD Moody BSA	0.4	0.462	No Trend	0.194	0.22
MN Pipestone 094	0.524	0.033	**Increasing**	0.487	8.90
MN Pipestone 099	0.571	0.004	**Increasing**	0.722	2.49
MN Rock 528	0.167	0.602	No Trend	0.123	3.53
MN Rock 811	0.449	0.088	No Trend	0.242	4.99
R13 EDWDD	0.6	0.133	No Trend	0.158	2.79
IA Lyon 001	- 0.067	0.858	No Trend	-0.058	1.50
Iowa Hawarden	0.047	1	No Trend	-0.058	1.50

Map 5: BSR Nitrate Level Trends, 2007-2016.

4.3 Land Cover Trends and Nitrate Trends at Hydrological Unit Code (HUC12) Catchments

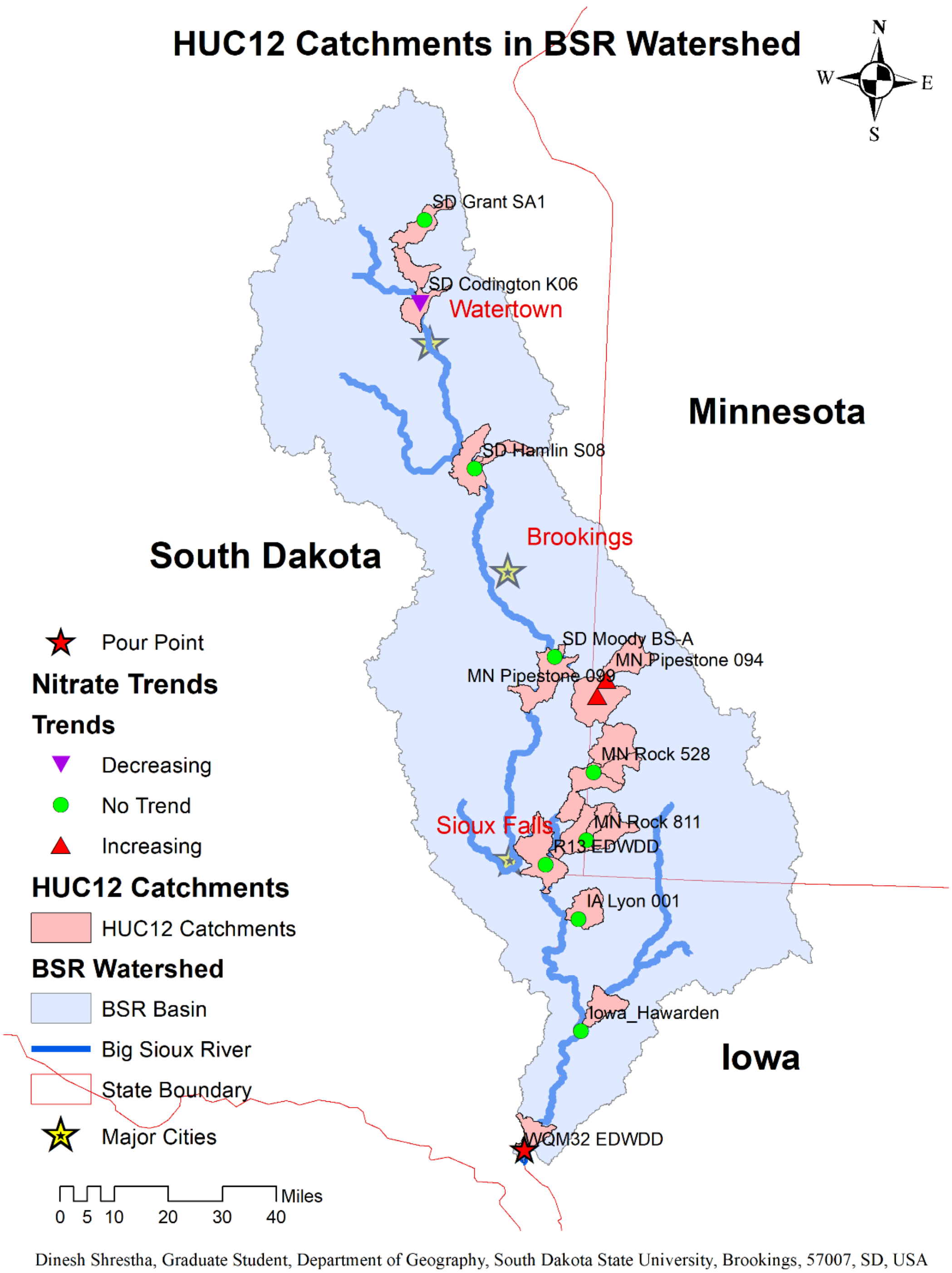
As shown in the previous section, the Mann-Kendall test and Sen's Slope estimates for the percentage of corn/soybean and grassland acreage for the entire BSR show significant upward and downward trends, respectively, while for other land acreage classes, no significant trends were identified. This section identifies the LCC and nitrate trends at more local watershed level, that is, HUC12 catchments (Map 6).

The land cover trends and nitrates trends at HUC12 catchment levels for stations with statistically significant trends are explained below. The resulting Sen's slope Q and B estimates for these stations are given in Table 8.

Table 8: Results from Mann-Kendall Test and Sen's Slope estimates at HUC12 catchments

Gauging Stations / HUCs	Nitrates / LCC Trends	**Mann-Kendall Test**			**Sen's Slope Estimate**	
		Tau	***p-value***	***Trend***	***Slope (Q)***	***Const (B)***
SD Codington K06	Nitrate	-0.743	0.008	Decreasing	-0.23	2.40
	Corn and Soybeans	0.689	0.007	Increasing	1.65	35.68
	Grassland	-0.644	0.012	Decreasing	-1.29	39.75
MN Pipestone 094	Nitrate	0.524	0.033	Increasing	0.49	8.90
	Corn and Soybeans	0.067	0.858	***No Trend***	0.07	76.33
	Grassland	-0.733	0.004	Decreasing	0.46	17.63
MN Pipestone 099	Nitrate	0.571	0.034	Increasing	0.72	2.49
	Corn and Soybeans	0.733	0.004	Increasing	0.34	76.19
	Grassland	-0.511	0.049	Decreasing	-0.46	16.16

Between 2007 and 2016, the percentage of corn and soybean acreage increased in all of the HUC12 catchments at the expense of grassland acreage. The most conversion occurred near or along the banks of the BSR itself.



Map 6: HUC12 Catchments in BSR Watershed

The SD Codington K06 is the only gauging station with a statistically significant decreasing nitrate trend (p-value of 0.008). It is located north of Watertown. The corresponding HUC12 catchment showed a statistically significant increasing trend for corn and soybean acreage and a decreasing trend for grassland with the p-values of 0.007 and 0.012, respectively. Within this catchment, corn and soybeans increased from 35% (11,900 acres) in 2007 to 49% (17,200 acres) in 2016 (Figure 12). The corn and soybean acreages were obtained from converted grassland along the edge of the BSR and northwest side of the watershed (Map 7). There was a significant increase in corn and soybean acreage between 2011 and 2012 and it increased until 2016. Grassland and other crops appeared to be consistently decreasing (from 40% and 16% in 2007 to 29% and 12% in 2016, respectively).

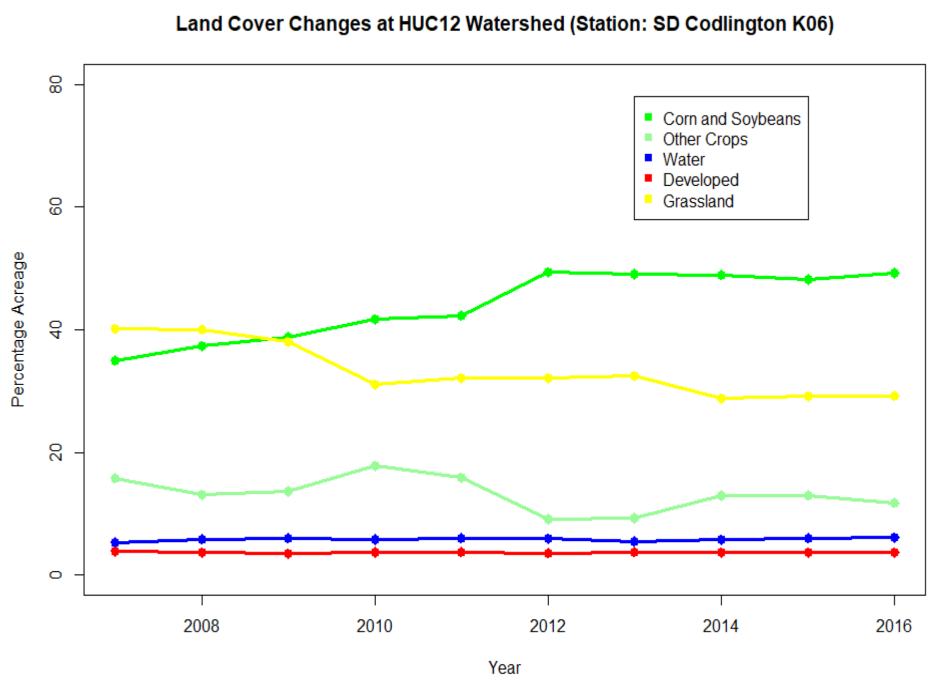


Figure 12: Plot of Land Cover Trends at HUC12 Catchment (SD Codington K06, HUC12 = 101702010604).

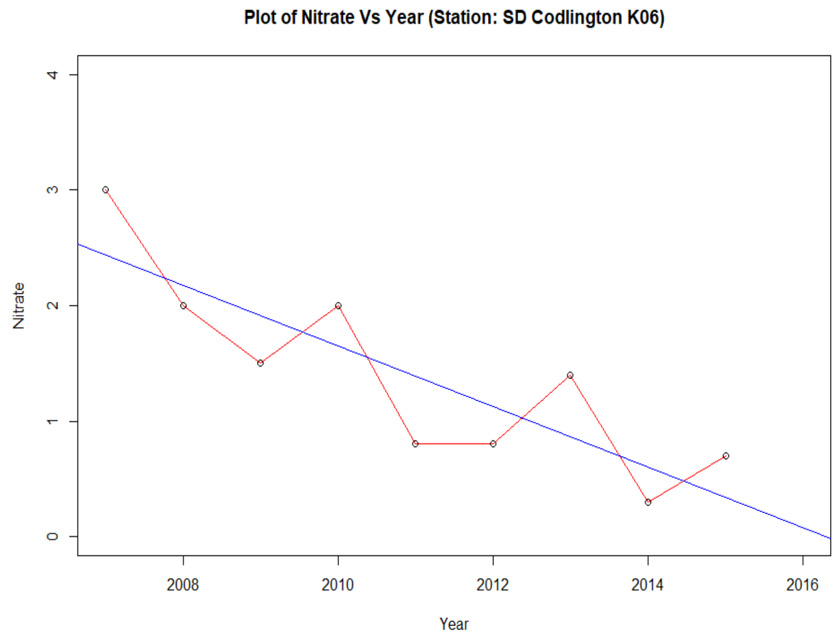
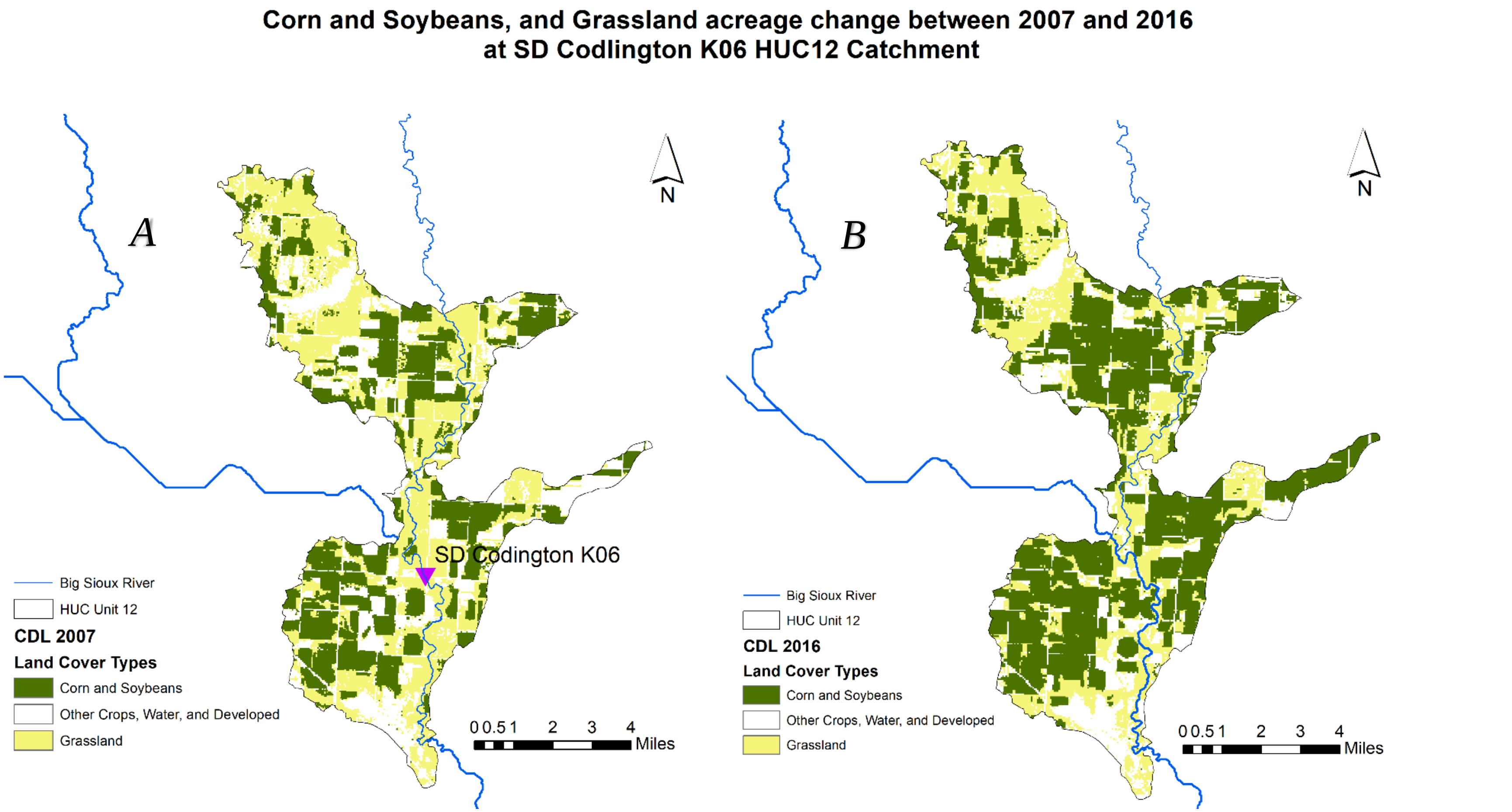


Figure 13: Plot of Nitrate Trends at HUC12 Catchment (SD Codington K06, HUC12 = 101702010604).



Map 7: Land Cover (A) in 2007 and (B) in 2016 at HUC12 Watershed (SD Codington K06, HUC12 = 101702010604)

The MN Pipestone 099 station that is located in Pipestone County in Minnesota showed a statistically significant increasing nitrate trend with a p-value of 0.034. The nitrate level at this station increased from 1.8 mg/L in 2007 to 11.23 mg/L in 2016 (Figure 15) The corresponding HUC12 catchment showed a statistically significant increasing trend for corn and soybean acreage and a decreasing trend for grassland with p-values of 0.004 and 0.049, respectively. Within this sub-watershed, corn and soybean acreage increased from 75% (29,600 acres) in 2007 to 79% (31,700 acres) in 2016 (Figure 14). The corn and soybean acreages were obtained from converted grassland along the edge of the BSR (Map 8). Grassland acreage appeared to be consistently decreasing (from 16% in 2007 to 12% in 2016). Other crops seem to be increasing gradually (from 1% in 2007 to 3% in 2016).

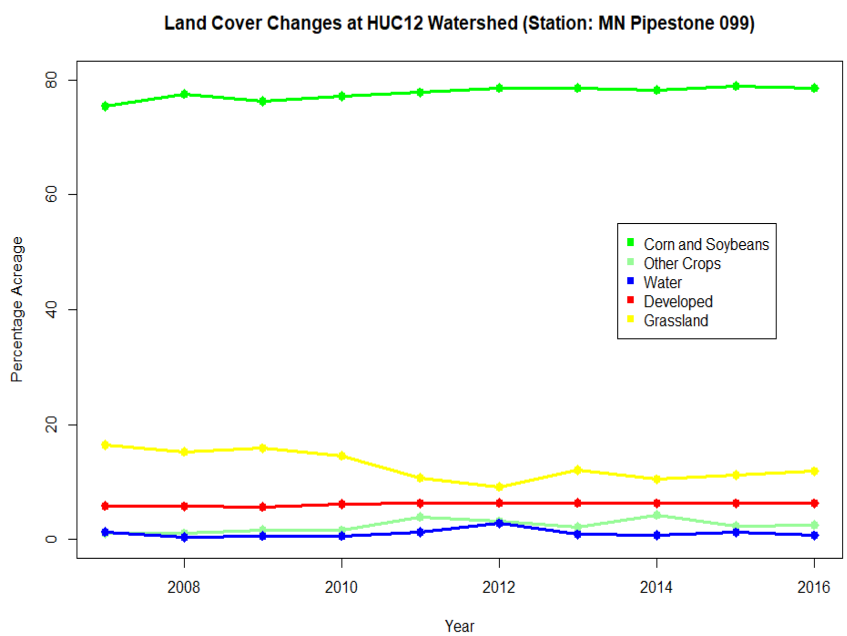


Figure 14: Plot of Land Cover Trends at HUC12 Catchment (MN Pipestone 099, HUC12 = 101702031304).

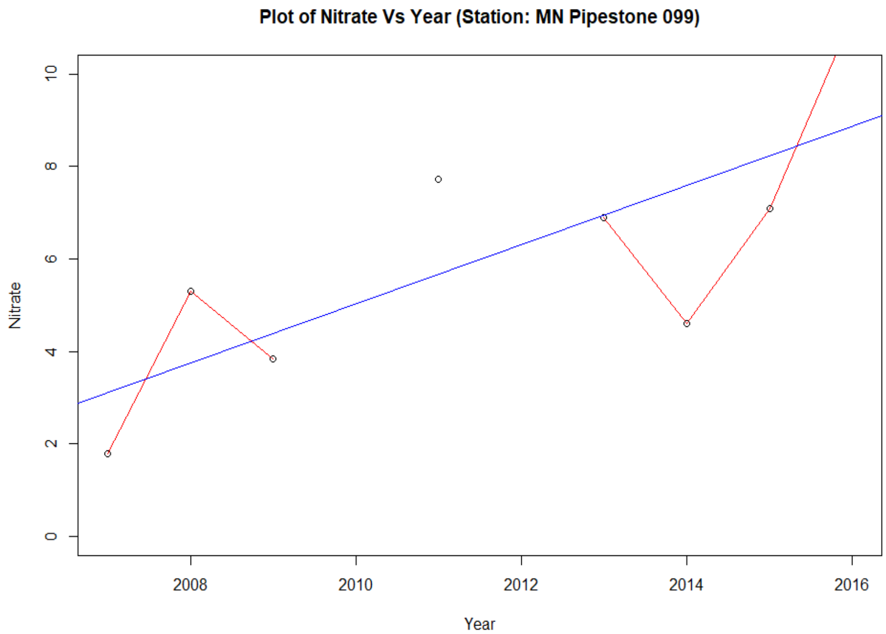
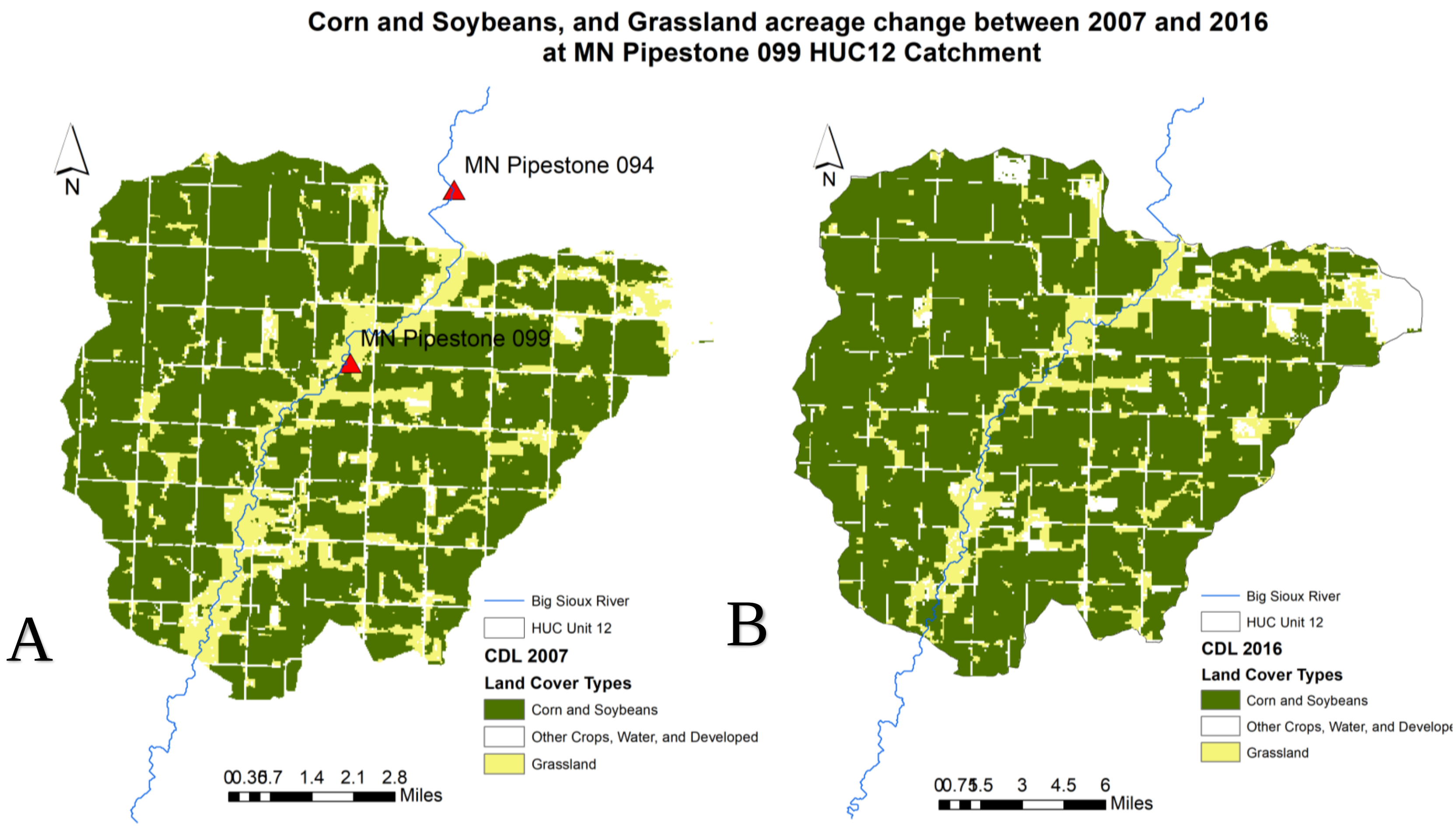


Figure 15: Plot of Nitrate Trends at HUC12 Catchment (MN Pipestone 099, HUC12 = 101702031304).

The MN Pipestone 094 station that is located in Pipestone County, Minnesota, and just above the MN Pipestone 099 gauging station showed a statistically significant increasing nitrate trend with p-values of 0.033. The nitrate level at this station increased from 6.85 mg/L in 2007 to 12.00 mg/L in 2012 (Appendix G). However, for the corresponding HUC12 catchment, a linear trend for corn and soybeans acreage was statistically insignificant with p-value of 0.858, therefore, the measurement for this station was considered “No Trend”. Within the catchment, corn and soybean acreage increased from 74% (19,400 acres) in 2007 to 76% (20,600 acres) in 2016 (Appendix G) and grassland consistently decreased from 20% in 2007 to 14% in 2016.



Map 8: Land Cover (A) in 2007 and (B) in 2016 at HUC12 Catchment (MN Pipestone 099, HUC12 = 101702031304)

Besides these stations, other stations including SD Grant SA1, MN Rock 528, MN Rock 811, SD Moody BSA, R13 EDWDD, SD Hamlin S08, IA Lyon 001, Iowa Hawarden, and WQM32 EDWDD did not show any trend. Even though the tau values from the Mann-Kendall test show that the linear trends were either "Increasing" or "Decreasing", they were statistically insignificant at $\alpha = 0.05$, therefore, these stations were considered as "No Trend".

4.4 Linear Regression

Finally, a linear regression model for the Sen's slopes of the percentage of land-cover classes versus Sen's slopes of nitrates in the BSR watershed was built. The Sen's slopes of nitrates were considered as the independent variables, y_i and the Sen's Slopes of percentage of each class types were considered as dependent variables (b_0, b_1, and so on). The purpose of linear regression was to determine how strongly the slopes of percentage area of the class types and the slopes of nitrates were associated. The lower R^2 values and insignificant p-values were not significant and suggest that slopes of percentage land cover classes were not strongly associated with slopes of nitrates (Table 9).

Table 9: Linear model of the Sen's slopes of nitrates versus the Sen's slopes percentage of land cover types

Nitrates Slope Vs	**R^2**	**P-values**
Percentage Corn/Soybeans Slope	0.059	0.447
Percentage Other Crops Slope	0.015	0.706
Percentage Water Slope	0.228	0.116
Percentage Developed Slope	0.003	0.876
Percentage Grassland Slope	0.0009	0.925
Overall	0.369	0.641

CHAPTER 5: DISCUSSION

Earlier research into grassland-to-cropland conversion found a positive correlation with adverse effects on regional water quality. From 2006 to 2012, grassland-to-cropland conversion in eastern South Dakota significantly increased (Reitsma et. al, 2014). During this same period, the BSR was identified as one of the most polluted river systems in the US. These issues have led to additional local research into possible connections between land use/land cover trends and BSR water quality trends.

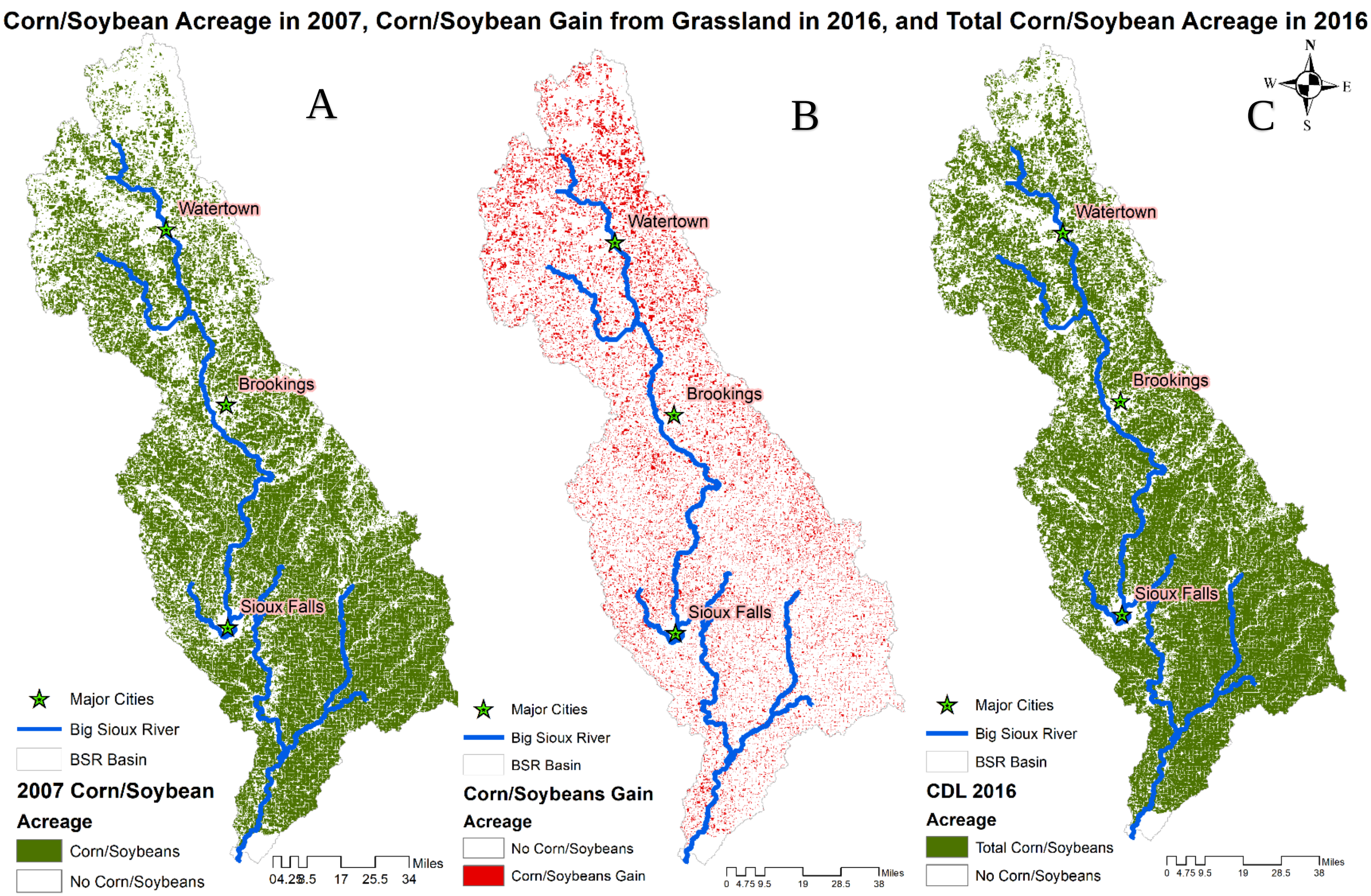
The research described in this thesis has attempted to quantify the spatial and temporal changes of corn/soybean and grassland acreages within the BSR watershed, and to establish a correlation between these changes and BSR nitrate levels. Several questions have been addressed in this research, including identifying and characterizing LCC trend(s) in the BSR watershed; identifying and characterizing the temporal and spatial trends of BSR nitrate levels; and determining whether a causal relationship can be established between LCC and changes in BSR nitrate levels.

5.1 Land Cover Change

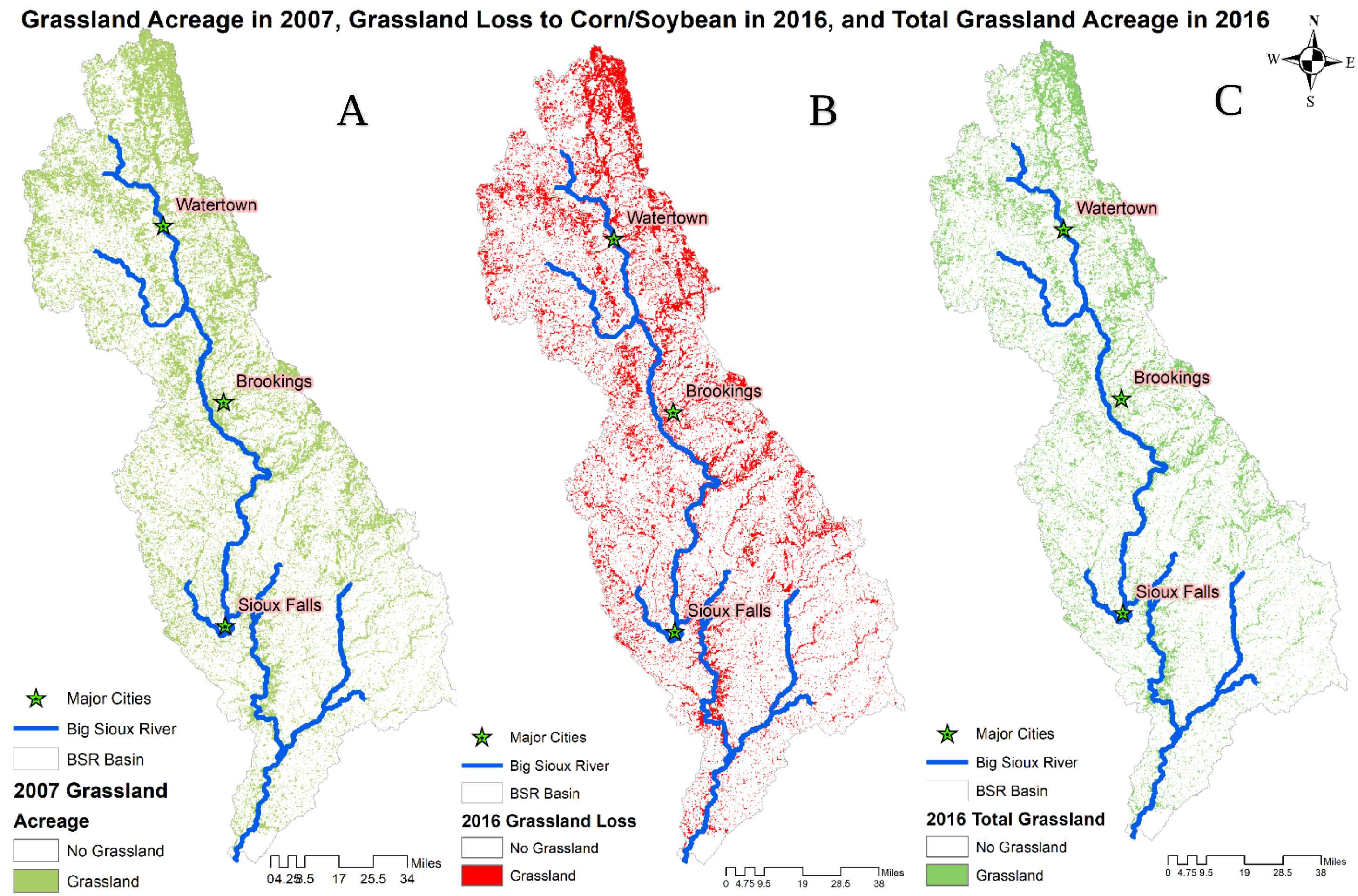
Within the BSR watershed, corn and soybean land cover increased by 418,000 acres, from 2,923,000 acres in 2007 to 3,341,000 acres in 2016. During the same time period, grassland cover decreased by 9% (433,000 acres), from 1,420,000 acres to 987,000 acres. Most of the new corn/soybean acreage came from of the existing grassland acreage which declined by 7%. Additionally, approximately 3% of other crop acreage was converted to corn/soybean acreage and approximately 3% of the corn/soybean acreage was converted to other crops, while approximately 1% of the corn/soybean acreage was converted to grassland acreage.

Most of the grassland conversion to corn/soybean acreage occurred in the northeast and far northwest portions of the watershed region (Map 9 and Map 10). A new ethanol manufacturing plant was constructed in Watertown, which stimulated greater demand for corn and led to higher corn prices (Koplow and Earth Track Inc. 2006; Gruchow 2007; Westcott 2007; Napton and Graesser 2011, 8; Clay et al. 2014; Reitsma et al. 2015). This plant typically requires approximately 4 to 5 million bushels of corn annually to maintain peak ethanol production (McNew and Griffith 2005).

The land use / land cover change trends identified in this thesis research are consistent with the trends identified by Reitsma et al (2014), who documented a grassland-to-cropland conversion of approximately 485,000 acres throughout eastern South Dakota between 2006 and 2012. Differences in these estimated trends most likely result from i) differences in the size of the researched study areas (the trend estimates from this research included portions of western Minnesota and Iowa, while Reitsma's trend estimates were limited to eastern South Dakota); ii) differences in the techniques used to conduct each analysis; and iii) differences in the time periods analyzed.



Map 9: Corn/Soybean Acreage Gain between 2007 and 2016. A) The total Corn/Soybeans acreage in 2007, B) Corn/Soybean acreage gained from grassland between 2007 and 2016, and C) The total Corn/Soybeans acreage in 2016.



Map 10: Grassland acreage Lost between 2007 and 2016. A) The total Grassland acreage in 2007, B) Grassland acreage lost to cropland between 2007 and 2016, and C) The total Grassland acreage in 2016.

5.2 Nitrate Trends

Previous research of other river watersheds in the US has identified a positive correlation between increased corn acreage and increased nitrate levels. This thesis research into the BSR watershed, however, could not consistently identify any such correlation applicable for the entire region. Even though net corn and soybean acreage within the region increased, the overall nitrate levels in the river did not significantly increase; indeed, some stations observed decreased nitrate levels between 2007 and 2016. In the case of the SD Codington K06 station, the upstream SD Grant SA1 station measured slightly higher nitrate levels (0.98 mg/L in 2007 vs 1.02 mg/L in 2016); vegetative cover along the river banks near SD Codington K06 could have prevented downstream nitrate concentration. This could account for the drop in measured in nitrate levels from approximately 3 mg/L in 2007 to 0.7 mg/L in 2016. Unfortunately, there is no data for other stations below and above this station to show the relation between nitrate levels at different stations.

In the case of the Iowa Lyon 001 station, the upstream R13 EDWDD station also measured higher nitrate levels (2.98 mg/L in 2007 vs 4.26 mg/L in 2016). As would be expected, higher nitrate levels were measured between 2007 and 2011 (1.74 mg/L in 2007 vs 3.05 mg/L in 2008 vs 4.18 mg/L in 2011). However, the measured nitrate level had dropped to 0.8 mg/L by 2015 and then increased to 3.47 mg/L throughout 2016. Interestingly, the Mann-Kendall nitrate test results suggested a statistically insignificant decreasing trend (p-value of 0.858).

The WQM65, WQM66, and WQM67 stations which are just below Iowa Lyon 001, these stations are located on the Big Sioux River (not the tributaries), and Sioux

Falls and Sioux City. These stations have increasing nitrate levels for the year 2015 (that is 4.34, 4.5, and 6 mg/Ltr. respectively). There is a similar pattern (6.8, 7.2, and 11.01 mg/Ltr.) for 2016 as well.

The MN Pipestone 099 station had the highest nitrate levels among all the stations. The nitrate level at this station increased from 1.8 mg/L in 2007 to 11.23 mg/L in 2016. During this period, there was also an increase in corn and soybeans acreage. The Mann-Kendall test for LCC trend show an increasing trend for corn and soybeans acreage and also an increasing trend for nitrates. The third objective of this research, that is, land cover trends be associated with nitrate trends holds true at this station only. Conversely, the station SD Codington K06 showed an increasing trend for corn and soybeans and decreasing trend for nitrates.

5.3 Trend Analysis

The Mann-Kendall tests for land use/land cover change indicated significant trends only for corn/soybean acreage and grassland acreage in both the HUC catchments and the main BSR watershed (a statistically significant increasing trend for corn/soybean acreage vs a statistically significant decreasing trend for grassland acreage). With respect to nitrate levels in the BSR watershed / HUC12 catchments, the Mann-Kendall test results indicated significant trends for only two stations (a decreasing trend at SD Codington K06 vs an increasing trend at MN Pipestone 099). Based on these results, there does not appear to be sufficient evidence to indicate a positive correlation between land use/land cover change and rising nitrate levels in the BSR. The linear regression results for these two stations tend to support the lack of evidence supporting identification of any statistically significant trend. As there is insufficient evidence to establish any significant degree of correlation, it is not possible to determine whether any such relationship, if it exists, is causal in nature.

Two factors could explain the lower than expected nitrate levels measured in the BSR watershed despite increased grassland-to-cropland conversion. First, South Dakota farmers, in cooperation with the SDDA, EDWDD, and other agencies, voluntarily adopted measures intended to limit soil erosion and improve general water quality, such as strip/no-till cultivation, cover crops, riparian buffers, buffer strips, and best management practices (BMPs) (USGS 2001; Clay et al. 2014). Buffer strips and riparian buffers provide additional vegetative cover, reducing the velocity of flowing water; this can limit, or even prevent, deposition of suspended nitrate particulates (Lam, Schmalz, and Fohrer 2011). South Dakota has also enacted various water management programs that attempt to protect water quality by reducing bacteria, sediments, and nutrient loads flowing into its river systems (Priner 2016).

Second, Minnesota enacted a law in 2015 requiring its farmers to install buffer strips between 30 ft. and 50 ft. in width along rivers and streams, and 16 ft. in width along ditches. The state is currently planning to install additional buffer strips along 33,700 miles of rivers and streams (Pfankuch 2018). These buffers should help reduce the increasing nitrate trends observed in the MN Pipestone 099, MN Pipestone 094, and other stations.

5.4 Limitations of the study

As discussed in the previous section, this thesis research did not find conclusive evidence of a correlative or causal relationship between land use/land cover changes and rising nitrate levels in the BSR. This could very well be the result of limitations in the data analyzed in this research and/or the methods used to analyze the data. These limitations are considered in greater detail in the following sections.

5.4.1 Data Limitations

5.4.1.1 Incomplete Nitrate Data

Of the 48 gauging stations currently operating in the BSR watershed, only 15 stations provided any nitrate level data. Of those 15, 11 provided 4 years' nitrate level datasets covering the 2007-2016 study period. Some of the stations were able to provide monthly data; most only provided annual data, so the analysis presented here was performed assuming that basis. The stations also differed in their data collection schedules; some collected data bi-monthly, but most collected data only on a quarterly basis, primarily during the summer months, which did not allow for a more representative seasonal analysis.

Furthermore, some of these stations did not have data for all years. SD Codington K06 did not have data from 2016, SD Moody BSA did not have data from 2007 through 2011, R13 EDWDD did not have data from 2010-2013, and WQM32 EDWDD only had data from 2015 and 2016. Similarly, MN Pipestone 094 was missing data from 2014 through 2016, MN Pipestone 099 was missing data from 2010 and 2012, and MN Rock 528 was missing data from 2007. Finally, Iowa Hawarden was missing data from 2007, 2013, and 2014.

It is unfortunate that WQM32 EDWDD did not have a complete dataset. If it had, it could have been used to model the entire watershed region. Fortunately, availability of data from the other reporting stations allowed analysis of the HUC12 catchments.

5.4.1.1.1 Distribution of Gauge Stations throughout BSR Watershed Region

Along with incomplete nitrate level measurements at a minority of the operating gauging stations, the distribution of these stations within the watershed region itself is another limitation. This issue relates to the properties of nitrogen. Free nitrogen leaching into a river system is dissolved and forms nitrates. These nitrates settle on the river bed in pools where the river flow velocity is decreased. A gauging station located upstream or in a pool will likely measure more nitrates than a station located downstream from a pool.

5.4.1.1.2 “Nitrogen Legacy”

An additional limitation is a generally unknown uncertainty in the “true” nitrate level measured at a gauging station. Because of the increase in corn acreage and longer delays in rotation with soybeans, soil nitrogen levels decrease, as atmospheric nitrogen fixed to the soil during nitrification is converted into nitrates. This forces corn growers to apply nitrogen-based fertilizers to compensate for the deficit, with the potential of applying more fertilizer than is really needed. Consequently, the excess free nitrogen flows into local water systems during rain events and converts into nitrates. Currently, there is no realistic way to determine whether the nitrate level measured at a gauging station is just for this year, or due to accumulated leaching during the previous year(s). In addition, nitrates settled in pools may be washed away during major flood events. Again, there is no realistic way to determine whether the nitrate measurement is “current” or an accumulated result over multiple years.

5.4.1.2 CDL Data Issues

In general, the quality of CDL datasets has been questioned by several researchers (e.g. Wright and Wimberly 2013; Decision Innovation Solutions 2013; Clay et al. 2014; Reitsma et al. 2015). This section considers some of these issues in greater detail.

5.4.1.2.1 User / Producer Accuracies

Most research has found that the CDL estimates for the user and producer accuracies are typically high, ranging from 80% to 97%; these estimates vary both by state and the period in which the CDL dataset was generated. For example, the South Dakota 2012 CDL had estimated producer and user accuracies for the “Corn” class of 95% and 93%, respectively. However, the estimated producer and user accuracies for the “Grassland” class were significantly different, at 86% and 39%, respectively. Noe (2015) found that “Grassland” CDL producer and user accuracies were highest when grasslands were the dominant practice and “Cropland” producer and user accuracies were highest when croplands were the dominant land-use. Less concern has generally been shown towards producer and user accuracy estimates for non-crop classes, including “Water” and “Developed” (Lark et al 2017). Uncertainties in the accuracy estimates can lead to uncertainties in the resulting estimates of total acreage used by a class.

5.4.1.2.2 Resampling / Data Resolution

The CDLs released for years prior to 2009 had a spatial resolution of 56m x 56m, whereas for CDL’s released after 2009 the spatial resolution was increased to 30m x 30m. Many methods have been devised and used to resample these different resolution datasets. One of the most popular methods is the nearest neighborhood resampling method.

5.4.1.2.3 CDL Reclassification

The number of classes in the CDL dataset vary from 85 to 111. Some of the classes that are present in newer versions are missing in the earlier versions. This makes reclassification difficult. Most reclassifications are based on decisions made by the researcher which could lead to miss-classification of CDL classes and impact the ultimate study results.

CHAPTER 6: SUMMARY, CONCLUSION, CONTRIBUTION

This study presented the land cover change and nitrate trends in the BSR watershed. For the land cover trends, this study analyzed the 2007-2016 South Dakota CDL to characterize and determine rates of LCC for corn/soybean and grassland acreages, and the non-parametric Mann-Kendall test to identify increasing and decreasing trends of land-cover change within the BSR watershed. For the nitrate trends, nitrate levels measured at 11 the gauging stations established in the BSR watershed were analyzed using the Mann-Kendall test to identify decreasing and increasing nitrate trends. For land use / land cover nitrate trends identified as statistically significant, Sen's Slope estimates were employed to estimate their magnitudes. Finally, linear models of nitrate concentration versus the percentage of land cover classes were generated to identify significant relationships between land cover trends and nitrate trends.

Overall, this research demonstrated that the percentage of corn/soybean acreage exhibited an increasing trend during the 2007-2016 study period, while the percentage of grassland acreage demonstrated a decreasing trend. However, nitrate level measurements from only 2 of the 11 gauging stations operating within the BSR watershed provided sufficient evidence to identify a trend; one station in Minnesota reported an increased nitrate level well above the current EPA standard of 10 mg./L, while the other station in South Dakota reported a decreased level. This could be because farmers in South Dakota adopted various conservational approaches to limit nitrogen/nitrate flow into its waterways, while Minnesota was in the early stages of mandating and enforcing use of such approaches. Moreover, the linear models developed for these stations did not show a strong relationship between land cover trend and nitrate trends that would be applicable to the BSR watershed.

There are various factors that could have affected the results from this result. Some of these are the short temporal study period, inadequate and missing nitrate data, and CDL accuracy.

The findings of this research are likely to help water authorities make decisions to resolve water quality related issues. The findings are also important because the results of a pending court case may alter the Corn Belt Farmland management which could have an impact on EDWDD and other water districts. The findings of my research are likely to provide a better understanding of the role of LULC change to BSR water quality which can be important to water supply organizations and farmers in developing improved land management strategies.

It would be useful to incorporate the soil type, slopes, terrain, temperature, precipitation, and amount of nitrogen fertilizer applied to the crop versus nitrogen level in the river to build a regression model and see which factors strongly contribute to increases in nitrogen level in the river basin.

REFERENCES

Alexander, Richard B., Richard A. Smith, and Gregory E. Schwarz. 2000. Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico. *Nature* 758-761.

Alexander, Richard B., Richard A. Smith, Gregory E. Schwarz, Elizabeth W. Boyer, Jacqueline V. Nolan, John W. Brakebill. 2008. Differences in Phosphorus and Nitrogen Delivery to The Gulf of Mexico from the Mississippi River Basin. *Environmental Science and Technology* 42 (3): 822–830.

Alexandratos, Nikos. 1999. World food and agriculture: Outlook for the medium and longer term. *Proceedings of the National Academy of Sciences of the United States of America* (PNAS) 96 (11): 5908–5914. Accessed March 16, 2018. doi:https://doi.org/10.1073/pnas.96.11.5908.

Assimakopoulos, J. H., D.P. Kalivas, V.J. Kollias. 2003. A GIS-Based Fuzzy Classification for Mapping the Agricultural Soils for N-Fertilizers use. 2003. *The Science of the Total Environment* 19-33.

Associated Press. 2012. South Dakota's Big Sioux among dirtiest rivers in the nation. *Rapid City Journal*. May 7. Accessed April 29, 2016. http://rapidcityjournal.com/news/south-dakota-s-big-sioux-among-dirtiest-rivers-in-nation/article_26094a6e-984c-11e1-a46d-001a4bcf887a.html.

Baker, Mathhew E., Michael J. Wiley, Paul W. Seelbach. 2001. GIS-Based Hydrologic Modeling of Riparian Areas: Implications for Stream Water Quality. *JAWRA Journal of the American Water Resources Association* 37 1615–1628.

Bandaru, Varaprasad, Tristram O. West, DanielM. Ricciuto, and R. Ceasr. Izaurralde. 2013. Estimating Crop Net Primary Production using Inventory Data and MODIS-Derived Parameters. *International Society for Photogrammetry and Remote Sensing (ISPRS) Journal of Photogrammetry and Remote Sensing* 80: 61-71. doi:10.1016/j.isprsjprs.2013.03.005.

Bowman, R. A., J. D. Reeder, and R. W. Lober. 1990. Changes in Soil Properties in a Central Plains Rangeland Soil After 3, 20, and 60 Years of Cultivation. *Soil Science* 150 (6).

California Electric Transportation Coalition. 2013. *California Low Carbon Fuel Standard, Compliance Outlook for 2020.* Accessed November 29, 2017. http://www.ceres.org/resources/reports/california2019s-low-carbon-fuelfuelstandard-compliance-outlook-for-2020.

Carpenter, Stephen, Nina F. Caraco, David L. Correll, Robert W. Howarth, Andrew N. Sharpley, Val H. Smith. 1998. Nonpoint Pollution of Surface Waters with Phosphorus and Nitrogen. *Ecological Applications* 559–568.

Cassman, Kenneth G. 1999. Ecological intensification of Cereal Production Systems: Yield Potential, Soil Quality, and Precision Agriculture. *Proceedings of the National Academy of Sciences of the United States of America* (PNAS) 96 (11): 5952-5959. Accessed March 16, 2018. doi:https://doi.org/10.1073/pnas.96.11.5952.

Chang, Heejun. 2008. Spatial Analysis of Water Quality Trends in the Han River Basin, South Korea. *Water Research* 42 (12): 3285-3304. doi:https://doi.org/10.1016/j.watres.2008.04.006.

Chang, Jiyul, David E. Clay, Stephanie A. Hansen, Sharon A. Clay, and Thomas E. Schumacher. 2014. Water Stress Impacts on Transgenic Drought-Tolerant Corn in the Northern Great Plains. *Agronomy Journal* 106 (1): 125-130. doi:10.2134/agronj2013.0076.

Chang, Jiyul, Mathhew C. Hansen, Kyle Pittman, Mark L. Carroll, and C. DiMiceli. 2007. Corn and Soybean Mapping in the United States using MODIS Time-Series Data Sets. *Agronomy Journal.* 99: 1654–1664. doi:10.2134/agronj2007.0170.

Chaplin-Kramer, Rebecca, Perrine Hamel, Richard Sharp, Virgina Kowal, Stacie Wolny, Sarah Sim, and Carina Mueller. 2016. Landscape Configuration is the Primary Driver of Impacts on Water Quality associated with Agricultural Expansion. *Environmental Research Letters* 1-11.

Chin, David A. 2012. Sources of Water Pollution. In *Water-Quality Engineering in Natural Systems: Fate and Transport Processes in the Water Environment*, by David A. Chin, 1-22. John Wiley & Sons.

Claassen, Roger, Fernando Carriazo, Joseph C. Cooper, Daniel Hellerstein, and Kohei Ueda. 2011. *Grassland to Cropland Conversion in the Northern Plains: The Role of Crop Insurance, Commodity, and Disaster Programs.* Report No. EER-120, US Department of Agriculture Economic Research Service, Washington, DC: Economic Research Service. https://www.ers.usda.gov/webdocs/publications/44876/7105_err120_reportsummary.pdf?v=41056.

Clay, David E., Kurtis D. Reitsma,, and Sharon A. Clay. 2009. Best Management Practices for Corn Production in South Dakota. *SDSU Extension Circulars* 490.

Clay, David E., Sharon A. Clay, Kurtis D. Reitsma, Barry H. Dunn, Alexander J. Smart, Gregg G. Carlson, David Horvath, James J Stoned. 2014. Does the Conversion of Grasslands to Row Crop Production in Semi-Arid Areas Threaten Global Food Supplies? *Science Direct* 3 (1): 22-30. doi:https://doi.org/10.1016/j.gfs.2013.12.002.

Clay, Sharon A., and Immer Aguilar. 1997. Weed Seedbanks and Corn Growth following Continuous Corn or Alfalfa. *Agronomy Journal* 90 (6): 813-818. doi:10.2134/agronj1998.00021962009000060016x.

Corwin, Dennis L., Keith Loague, and Timothy R. Ellsworth. 1999. Introduction. In *Assessing Non-Point Source Pollution in the Vadose Zone with Advanced Information*, by Dennis L. Corwin, Keith Loague, and Timothy R. Ellsworth Corwin. American Geophysical Union.

Cully, Anne C., Jack F. Cully Jr., Ronald D. Hiebert. 2003. Invasion of Exotic Plant Species in Tallgrass Prairie Fragments. *Conservation Biology* 17 (4): 990-998. Accessed March 16, 2018. doi:https://doi.org/10.1046/j.1523-1739.2003.02107.x .

Danielson, Patrick A. 2012. A Method for Identifying Commission and Omission Errors for Cultivated Crops in the National Land Cover Dataset (NLCD) 2006. Master's Thesis. South Dakota State Univeristy.

Davidson, E. A., Mark B. David, James N. Galloway, Christine L. Goodale, Richard Haeuber, John A. Harrison, Robert W. Howarth. D.B. Jaynes, R.R. Lowrance, Nolan B. Thomas, J.L. Peel, R.W. Pinder, E. Porter, C.S. Snyder, A.R. Townsend, and M.H. Ward. 2012. Excess Nitrogen in the US Environment: Trends, Risks, and Solutions. *Ecological Society of America.*

Decision Innovation Solution. 2013. 2013 Multi-State Land Use Study: Estimated Land Use Changes 2007-2012. Urbandale, IA 50322. Accessed March 22, 2018. http://www.decision-innovation.com/webres/File/docs/130715%20Multi-State%20Land%20Use%20Report.pdf.

DeFries, R. S., C. B. Field, I. Fung, G. J. Collatz, and L. Bounoua. 1999. Combining Satellite Data and Biogeochemical Models to Estimate Global Effects of Human-Induced Land Cover Change on Carbon Emissions and Primary Productivity. *Global Biogeochemical Cycles* 13, 803-815.

Des Moines Water Works lawsuit questions. 2016. 01 11. Accessed 04 29, 2016. https://www.scribd.com/doc/295174322/D-M-Water-Works-lawsuit-questions#fullscreen.

Derpsch, Rolf, Theodor Friedrich, Amir Kassam, and Hongwen Li. 2010. Current Status of Adoption of No-Tillage Farming the World and Some of Its Main Benefits. *International Journal of Agricluture and Biological Engineering* 3 (1): 1-26. doi:10.3965/j.issn.1934-6344.2010.01.0-0.

Diebel, Matthew W., Jeffrey T. Maxted, Dale M. Robertson, Seungbong Han, and M. Jake Vander Zanden. 2009. Landscape Planning for Agricultural Nonpoint Source Pollution Reduction III: Assessing Phosphorus and Sediment Reduction Potentail. *Environmental Management* 43: 69–83. doi:DOI 10.1007/s00267-008-9139-x.

Dieterman, J. Douglas, and Charles R. Berry, Jr. 1998. Fish Community and Water Quality Chnages in the Big Sioux River. *The Prairie Naturalist* 30 (4): 199-224. Accessed March 31, 2018.

https://www.researchgate.net/publication/269393535_Fish_community_and_water_quality_changes_in_the_Big_Sioux_River_South_Dakota

Ditxler, Craig A., and Arlene J. Tugel. 2002. Soil Quality Field Tools: Experiences of USDA-NRCS Soil Quality Institute. *Agronomy Journal* (U.S Department of Agriculture) 94 (1).

Downing, John A., James L. Baker, Robert J. Diaz, Tony Prato, Nancy N. Rabalais, Roger J. Zimmerman. 1999. Gulf of Mexico Hypoxia: Land and Sea Interactions. *Task Force Report, Council for Agricultural Science and Technology*. Accessed March 07, 2018. http://www.public.iastate.edu/~downing/tier%202/jadpdfs/1999%20Gulf%20of%20Mexico.pdf.

Du, Xiaodong, and Dermot J. Hayes. 2008. The Impact of Ethanol Production on U.S. and Regional Gasoline Prices and on the Profitability of the U.S. Oil Refinery Industry. Working Paper 08-WP 467 (Center for Agriculture and Rural Development. Iowa State University). Accessed February 25, 2018. https://www.card.iastate.edu/products/publications/pdf/08wp467.pdf.

Eastdakota.org. 2016. More about the Big Sioux River. April 20. Accessed April 25, 2016. http://eastdakota.org/bsrwatershed/More%20About%20Watersheds.html.

Elliott, Joshua, Bhavna Sharma, Neil Best, Michael Glotter, Jennifer B. Dunn, Ian Foster, Fernando Miguez, Steffen Mueller, and Michael Wang. 2014. A Spatial Modeling Framework to Evaluate Domestic Biofuel Induced Potential Land-Use Changes and Emissions. *Environmental Science and Tecnology* 48: 2488–2496. doi:10.1021/es404546r.

Ellis, Erle, and Robert Pontius. 2009. Land Use and Land Cover Change and Climate Change. *Encyclopedia of Earth.* Accessed March 18, 2018. http://ecotope.org/people/ellis/papers/ellis_eoe_lulcc_2007.pdf.

Energy Independence and Security Act. 2007. *Summary of the Energy Independence and Security Act.* Summary, United States Environmental Protection Agency. https://www.gpo.gov/fdsys/pkg/BILLS-110hr6enr/pdf/BILLS-110hr6enr.pdf.

Environmental Systems Research Institute (ESRI). 2018. *Arc Gis Pro.* ESRI. Accessed 10 28, 2018. http://pro.arcgis.com/en/pro-app/tool-reference/data-management/resample.htm.

Eregno, Fasil E., Vegard Nilsen, Razak Seidu, and Arve Heistad. 2014. Evaluating the Trend and Extreme Values of Faecal Indicator Organisms in a Raw Water Source: A Potential Approach for Watershed Management and Optimizing Water Treatment Practice. *Environmental Process.* (Springer International Publishing) 1: 287–309. doi:10.1007/s40710-014-0026-6.

Evrendilek, Faith, Ismail Celik, and Seref Kilic. 2004. Changes in Soil Organic Carbon and Other Physical Soil Properties Along Adjacent Mediterranean Forest, Grassland, and Cropland Ecosystems in Turkey. *Journal of Arid Environments* 59 (4): 743-752. doi:https://doi.org/10.1016/j.jaridenv.2004.03.002.

Fargione, Joseph, Jason Hill, David Tilman, Stephen Polasky, Peter Hawthorne. 2008. Land Clearing and the Biofuel Carbon Debt. *Science* 319 (5867): 767–777. doi:10.1126/science.1152747.

Farm Service Agency. 2015. CRP Enrollment and Rental Rates by State, 1986-2014. Accessed March 18, 2018. http://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crpst

Fernandez-Cornejo, Jorge, and Margriet Caswell. 2006. The First Decade of Genetically Engineered Crops in the United States. Economic Information Bulletin Number 11, United States Department of Agriculture, Washington, DC. *Economic Research Service*. Accessed March 20, 2018. http://www.ers.usda.gov/publications/eib11/eib11.pdf.

Fowler, Richard, and Johan Rockstram. 2001. Conservation Tillage for Sustainable Agriculture: An Agrarian Revolution Gathers Momentum in Africa. *Soil and Tillage Research.* 61 : 93–108. doi:10.1016/S0167-1987(01)00181-7.

Fredrick, Ayiva. 2017. Impact of Land-Use Land-Cover Change on Stream Water Quality in the Reedy Fork-Buffalo Creek Watershed, North Carolina: A Spatiotemporal Analysis. Master’s Thesis. University of North Carolina at Greensboro. Accessed 06 06, 2018. https://search.proquest.com/docview/1927470767?pq-origsite=gscholar.

Freedman, Bill. 1995. *Environmental Ecology.* Vol. 2nd ed. San Diego: Academic Press.

Gangolli, Sharat D., Piet A. Van Den Brandt, Victor J. Feron, Christine Janzowsky, Jan H. Koeman, Gerrit JA Speijers, Berthold Spiegelhalder, Ronald Walker, and John S. Wishnok. 1994. Nitrate, nitrite and N-nitroso compounds. *European Journal of Pharmacology: Environmental Toxicology and Pharmacology* 292 (1): 1-38.

Gates, Paul W. 1976. An Overview of American Land Policy. *Agricultural History* (Agricultural History Society) 50 (1): 213-229 . doi:ttp://www.jstor.org/stable/3741919 .

Gebhart, D. L., H.B. Johnson, H.S. Mayeux, and H.W. Polley. 1994. The CRP increases soil organic carbon. *Journal of Soil and Water Conservation* 49 (5): 488–492.

Gilbert, Richard O. 1987. Statistical Methods for Environmental Pollution Monitoring. *Wiley*, New York. 204–252.

Goulart, F. F., P. Salles, C. H. Saito. 2009. Assessing the Ecological Impacts Oo Agriculture Intensification Through Qualitative Reasoning. *In 23rd Annual Workshop on Qualitative Reasoning (QR), Proceedings*, 44-48.

Grossman, Mark, and Gary C. Bryner. 2012. *U.S. Land and Natural Resource Policy*. Amenia, NY: Grey House Publishing, Inc.

Gruchow, Matthew. 2007. Ethanol Industry Basks in Big Profits. *Sioux Falls Argus Leader* 1-3.

Guo, L. B., and R. M. Gifford. 2002. Soil Carbon Stocks and Land Use Change: A Meta Analysis. *Global Change Biology* 8: 345–360.

Han, Weiguo, Zhengwei Yang, Liping Di, and Richard Mueller. 2012. CropScape: A Web Service Based Application for Exploring and Disseminating US Conterminous Geospatial Cropland Data Products for Decision Support. *Computers and Electronics in Agriculture* 84: 111-123. doi:https://doi.org/10.1016/j.compag.2012.03.005.

Helms, J. Douglas. 1985. Brief History of the USDA Soil Bank Program. *Historical Insights*, Natural Resource and Conservation Service. January. Accessed 9 12,

2018.
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1045666.pdf

Hartman, Melannie D., Emily R. Merchant, William J. Parton, Myron P. Gutmann, Susan M. Lutz, and Stephen A. Williams. 2011. Impact of Historical Land-Use Changes on Greenhouse Gas Exchange in the U.S. Great Plains, 1883–2003. *Ecological Applications* 21 (4): 1105-1119. doi:https://doi.org/10.1890/10-0036.1.

Hatfield, J. L., K. J. Boote, B. A. Kimball, L. H. Ziska, B. C. Izauralde, D. Ort, A. M. Thomson, and D. Wolfe. 2010. Climate Impacts on Agriculture: Implications for Crop Production. *Agronomy Journal* 103 (2): 351-370. doi:10.2134/agronj2010.0303.

Hellerstein, D. M. 2015. The US Conservation Reserve Program: The Evolution of an Enrollment Mechanism. *Land Use Policy* (Elsevier Ltd.) 63: 601-610. doi:https://doi.org/10.1016/j.landusepol.2015.07.017.

Herschy, R., and Rhodes F. (Eds.). 1998. *Encyclopedia of Hydrology and Water Resources.* Boston: Kluwer Academic Publishing.

Higgins, Ken F., Naugle David E., Forman Kart J. 2002. A Case Study of Changing Land Use Practices in the Northern Great Plains, U.S.A.: An Uncertain Future for Waterbird Conservation. *Waterbirds: The International Journal of Waterbird Biology* 25 (2): 42-50. http://www.jstor.org/stable/1522450

Homer, Collin, Jon Dewtiz, Limin Yang, Suming Jin, Patrick Danielson, George Xian, John W. Coulston, Nathaniel Herold, James D. Wickham, and Kevin Megown. 2015. Completion of the 2011 National Land Cover Database for the Conterminous United States – Representing a Decade of Land Cover Change

Information. *Photogrammetric Engineering and Remote Sensing.* doi:10.14358/PERS.81.5.34.

Hudson, John C. 1994. *Making the Corn Belt: A Geographical History of Middle-Western Agriculture.* Indiana University Press.

Huntington, Thomas G. 2006. Evidence for Intensification of The Global Water Cycle: Review and Synthesis. *Journal of Hydrology* 319 (1): 83-95.

Intergovernmental Panels on Climate Change. 2014. Fifth assessment report (AR5). Synthesis Report. http://www.ipcc.ch/report/ar5/syr/.

Iowa Department of Natural Resources and South Dakota Department of Environment and Natural Resources. 2007. Total Maximum Daily Loads for Pathogen Indicators: Big Sioux River, Iowa and South Dakota. 1-142.

Iowa Environmental Council. 2016. Nitrate in Drinking Water: A Public Health Concern For All Iowans. Executive Summary, Iowa. doi:11/20/2016.

Janssen, Larry, Burton Pflueger, and Bronc McMurtry. 2013. *Agriculture Land Market Trends 1991-2013.* South Dakota State University. Accessed March 02, 2018. https://igrow.org/up/resources/03-7007-2013.pdf.

Jha, Manoj K., Philip W. Gassman, and Jeffrey G. Arnold. 2007. Water Quality Modeling for the Raccoon River Watershed using SWAT. *Transactions of the American Society of Agricultural and Biological Engineers (ASABE)* 50 (2): 479-493.

Johnson, David M. 2013. A 2010 Map Estimate of Annually Tilled Cropland within the Conterminous United States. *Agricultural Systems.* 114: 95–105. doi:10.1016/j.agsy.2012.08.004.

Johnston, Carol A. 2013. Wetland Losses due to Row Crop Expansion in the Dakota Prairie Pothole Region. *Wetlands 33* 175–182.

Kalkhoff, S. J., Kimberly K. B., Kent D. B., Mark E. S., Douglas J. S., Eric M. S., Stephen D. P., Daniel J. S., and John C. 2001. Water Quality in the Eastern Iowa Basins. *Agriculture and Natural Resources* 1-6.

Kayden, Jerold S. 2000. National Land-Use Planning in America: Something Whose Time Has Never Come. *Washington University Journal of Law and Policy.* 3. Accessed March 18, 2018. http://openscholarship.wustl.edu/law_journal_law_policy/vol3/iss1/18.

Kendall, Maurice G. 1948. Rank Correlation Methods. *Charles Griffin, London.*

Knobeloch, L., Barbara S., Adam H., Jeffrey P., and Henry A. 2000. Blue Babies and Nitrate-Contaminated Well Water. *Environmental Health Perspectives.*

Koh, Eun-Hee., Seung H. L., Dugin K., Hee S. M., Eunhee L., Kang-K. L., Bong-R. K. 2017. Impacts of Land Use Change and Groundwater Management on Long-Term Nitrate-Nitrogen and Chloride Trends in Groundwater of Jeju Island, Korea. *Environmental Earth Sciences.* doi:10.1007/s12665-017-6466-3.

Koplow, Doug, and Earth Track, Inc. 2006. *BIOFUELS - AT WHAT COST ? Government support for ethanol and biodiesel in the United States.* The Global Subsidies Initiative (GSI) of the International Institute for Sustainable Development (IISD). Geneva, Switzerland. Accessed March 15, 2018. https://www.iisd.org/gsi/sites/default/files/Brochure_-_US_Report.pdf.

Kreiling, Rebecca M., and Jeffrey N. Houser. 2016. Long-Term Decreases in Phosphorus and Suspended Solids, but not Nitrogen, in Six Upper Mississippi River Tributaries, 1991–2014. *Environmental Monitoring and Assessment 188* 1-19.

Lam, Q. D., B. Schmalz, and N. Fohrer. 2011. The Impact of Agricultural Best Management Practices on Water Quality in a North German Lowland Catchment. *Environmental Monitoring and Assessment* 183 (1-5): 351-379. Accessed 10 13, 2018. doi:https://doi.org/10.1007/s10661-011-1926-9.

Lambin, E. F., and P. Meyfroidt. 2011. Global Land Use Change, Economic Globalization, and the Looming Land Scarcity. *Proceedings of the National Academy of Sciences* 108 (9): 3465-3472. Accessed March 25, 2018. doi:https://doi.org/10.1073/pnas.1100480108 .

Lark, Tyler J., Richard M. Mueller, David M. Johnson, and Holly K. Gibbs. 2017. Measuring Land-Use and Land-Cover Change Using the U.S. Department of Agriculture's Cropland Data Layer: Cautions and Recommendations. *International Journal of Applied Earth Observation and Geoinformation* 62: 224-235. doi:https://doi.org/10.1016/j.jag.2017.06.007.

Leaver, J. D. 1991. The Role of Fertilizer Nitrogen in the 1990s. Management Issues for the Grassland Farmer in the 1990's. In *Occasional symposium-British Grassland Society* 25: 140-147.

Lee, Sanghun, David E. Clay, and Sharon A. Clay. 2014. Impact of Herbicide Tolerant Crops on Soil Health and Sustainable Crop Production. In *Convergence of Food Security, Energy Security And Sustainable Agriculture*, by J.L. Hatfield, and D.T. Tomes D.D. Songstad, 211–236. Springer-Verlag, Berlin.

Li, Ruopu, Qingfeng Guan, and James Merchant. 2012. A Geospatial Modeling Framework for Assessing Biofuels-Related Land-Use and Land-Cover Change. *Agriculture, Ecosystems and Environment* 161: 17-26. doi:https://doi.org/10.1016/j.agee.2012.07.014.

Li, Siyue, Sheng Gu, Xiang Tan, and Quanfa Zhang. 2009. Water Quality in Relation to Land Use and Land Cover in the Upper Han River Basin, China. *Journal of Hazardous Materials* 165 (1-3): 317-324. doi:https://doi.org/10.1016/j.jhazmat.2008.09.123.

Lin, Brenda B., Ivette Perfecto, and John Vandermeer. 2008. Synergies Between Agricultural Intensification and Climate Change Could Create Surprising Vulnerabilities for Crops. *BioScience* 58 (9): 847–854. Accessed March 20, 2018. doi:https://doi.org/10.1641/B580911.

Liska, Adam J., Haishun Yang, Maribeth Milner, Steve Goddard, Humberto Blancoanqui, Matthew P. Pelton, Xiao X. Fang, Haitao Zhu, and Andrew E. Suyker. 2014. Biofuel From Crop Residue can Reduce Soil Carbon and Increase CO2 Emissions. *Nature Climate Change* 4: 398–401. doi:10.1038/nclimate2187.

Lowrance, Richard, Altier Lee S., J. Denis Newbold, Ronald R. Schnabel, Peter M. Groffman, Judith M. Denver, David L. Correll, J. Wendell Gilliam, James L. Robinson, Russel B. Brinsfield, Kenneth W. Staver, William Lucas, Albert H. Todd. 1997. Water Quality Functions of Riparian Forest Buffers in Chesapeake Bay Watersheds. *Environmental Management* 21(5): 687–712.

Lubowski, Ruben N., Andrew J. Plantinga, and Robert N. Stavins. 2008. What Drives Land-Use Change in the United States? A National Analysis of Landowner

Decisions. *Land Economics*, University of Wisconsin Press, 84(4): 529-550. doi:10.3368/le.84.4.529.

Maitima, Joseph M., Simon M. Mugatha, Robin S. Reid, Louis N. Gachimbi, Amos Majule, Herbert Lyaruu, Derek Pomery, Stephen Mathai, and Sam Mugisha. 2009. The Linkages Between Land Use Change, Land Degradation and Biodiversity across East Africa. *African Journal of Environmental Science and Technology* 3 (1): 310-325. http://www.wec.ufl.edu/faculty/giulianob/private/wis3401/Maitima%20landuse%20change%20and%20biodoversity.pdf.

Malcolm, Scott A., Marcel Aillery, Marca Weinberg. 2009. *Ethanol and Changing Agricultural Landscapes.* Report 86, United States Department of Agriculture, Washington, DC: Economic Research Service. Accessed March 15, 2018. https://core.ac.uk/download/pdf/6239000.pdf.

Mann, Howrd B, and Donald R. Whitney. 1947. On a test of whether one of two random variables is stochastically larger than the other. *The Annals of Mathematical Statistics.* 50-60.

Mann, Howard B. 2010. Foreign Land Purchases for Agriculture: What Impact on Sustainable Development? *Sustainable development innovation briefs* 8. Accessed March 19, 2018. https://sustainabledevelopment.un.org/content/documents/no8.pdf.

McNew, Kevin, and Duane Griffith. 2005. Measuring the Impact of Ethanol Plants on Local Grain Prices. *Applied Economic Perspectives and Policy* (Oxford

University Press) 27 (2). Accessed 9 12, 2018. doi:https://doi.org/10.1111/j.1467-9353.2005.00219.x.

Meals, Donald W., Jean Spooner, Steven A. Dressing, and Jon B. Harcum. 2011. *Statistical Analysis for Monotonic Trends.* Tech Note 6, November: 23. Accessed 09 24, 2018. https://www.epa.gov/sites/production/files/2016-05/documents/tech_notes_6_dec2013_trend.pdf.

Morgan, Dan. 2008. *Emptying the Breadbasket.* Edited by The Washington Post. Washington, DC, April 29. Accessed March 26, 2018. http://www.washingtonpost.com/wp-dyn/content/article/2008/04/28/AR2008042802509.html.

Mousel, E.M. 2010. SDSU IRM-SPA: Trend Analysis 2002 – 2008. *South Dakota Beef Report, 2010, South Dakota State University.* Accessed March 15, 2018. https://openprairie.sdstate.edu/sd_beefreport_2010/15.

Mueller, Rick, and Mark Harris. 2013. Reported uses of the CropScape and National Data Layer Program. *6th International Conference on Agricultural Statistics.* Accessed March 15, 2018. https://www.nass.usda.gov/Research_and_Science/Cropland/docs/MuellerICASVI_CDL.pdf.

Müller, Marcelo M. L., Maria F. Guimaraes, Thierry Desjardins, and Danielle Mitja. 2004. The Relationship Between Pature Degredation and Soil Properties in The Brazilian Amazon. A Case Study. *Agriculture, Ecosystems and Envrionment.* 288: 103:279. doi:10.1016/j.agee.2003.12.003.

Napton, Darrell and Jordan Graesser. 2011. Agricultural Land Change in the Northwestern Corn Belt, USA: 1972–2007. *Geologica Carpathica.* 11, no 11 65-81.

National Agricultural Statistics Service. 2014. *Commodity Costs and Returns.* Accessed March 01, 2018. https://www.ers.usda.gov/data-products/commodity-costs-and-returns/commodity-costs-and-returns/#Recent Costs and Returns: Corn.

National Water Quality Monitoring Council, NWQMC. 2007. Glossary of water-quality monitoring terms: Advisory Committee on Water Information. Accessed April 3, 2016.

Nickerson, C., M. Morehart, T. Kuethe, J. Beckman, J. Ifft, and R. Williams. 2012. *Trends in U.S. Farmland Values and Ownership.* Washington, DC.: USDA Economic Research Service, Februry. http://www.ers.usda.gov/media/377487/eib92_2_.pdf.

Noe, Ryan R. 2015. Uncertainty in Cropland Data Layer Derived Land-Use Change Estimates: Putting Corn and Soy Expansion Estimates in Context. *Thesis. University of Minnesota.*

Nolon, John R. 2006. Historical Overview of the American Land Use System: a Diagnostic Approach to Evaluating Governmental Land Use Control. *Pace Environmental Law Review* 26 (3): 821-853. Accessed March 22, 2018. http://digitalcommons.pace.edu/pelr/vol23/iss3/8.

Olimb, S. 2013. Land conversion risk assessment: cropland/grassland conversion 2008-2012. *World Wildlife Fund.*

Omernik, James M. 1987. Ecoregions of the Conterminous United States. *Annals of the Association of American* 77 (1): 118-125. doi:https://doi.org/10.1111/j.1467-8306.1987.tb00149.x.

Omernik, James M. 1995. Ecoregions: A Spatial Framework for Environmental Management. *In: Wayne S. Davis and Thomas P. Simon, eds. Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making.* (Lewis Publishers) 49-62.

Perry, Charles A., F. Victor Robbins, and Philip L. Barnes. 1988. Factors Affecting Leaching in Agricultural Areas and an Assessment of Agricultural Chemicals in the Ground Water of Kansas. *Water-Resources Investigations Report* 88-4104, Lawrence, Kansas: U.S. GEOLOGICAL SURVEY.

Petreson, Stephen D., and J. W. Brakebill. 1999. *Application of Spatially Referenced Regression Modelling for the Evaluation of Total Nitrogen Loading in the Chesapeake Bay Watershed.* USGS Water-Resources Investigations Report, 1-12.

Pfankuch, Bart. 2018. Should South Dakota farmers be forced to improve pollution control methods? *South Dakota News Watch*. September 11. Accessed October 13, 2018. https://www.sdnewswatch.org/stories/should-farmers-be-forced-to-improve-pollution-control-methods

Pohlert, Thorsten. 2017. Non-parametric trend tests and change-point detection. *CC BY-ND 4.* Accessed Jan 02, 2018. http://cran.stat.upd.edu.ph/web/packages/trend/vignettes/trend.pdf.

Postel, Sandra L., Gretchen C. Daily, and Paul R. Ehrlich. 1996. Human appropriation of renewable fresh water. *Science* 271: 785-788.

Priner, Steven M. 2016. The 2016 South Dakota Integrated Report for Surface Water Quality Assessment. *South Dakota Department of Environment and Natural Resources.*

Qi, Sabine, and Grunwald, Chen. 2006. GIS-Based Water Quality Modeling in the Sandusky Watershed, Ohio, USA. *Journal of the American Water Resources Association (JAWRA.)* 957-973. doi:10.1111/j.1752-1688.2006.tb04507.x.

Rabalais, Nancy N., R. Eugene Turner, and Donald Scavia. 2002. Beyond Science into Policy: Gulf of Mexico Hypoxia and the Mississippi River Nutrient policy development for the Mississippi River watershed reflects the accumulated scientific evidence that the increase in nitrogen loading is the primary factor in the worsening of hypoxia in the northern Gulf of Mexico. *BioScience* 52 (2): 129-142.

Rashford B.S., Johann A. Walker, Christopher T. Bastian. 2011. Economics of Grassland Conversion to Cropland in the Prairie Pothole Region. *Conservation Biology* 25 (3): 276-284. doi:https://doi.org/10.1111/j.1523-1739.2010.01618.x.

Raun, William R., G. V. Johnson, and R. L. Westerman. 1999. Fertilizer Nitrogen Recovery in Long-Term Continuous Winter Wheat. *Soil Science Society of America Journal.* 63 (3): 645-650.

Reimer, Adam, Julie E. Doll, Bruno Basso, Sandra T. Marquart-Pyatt, G. Philip Robertson, Diana Stuart, and Jinhua Zhao. 2017. Moving toward Sustainable Farming Systems: Insights From Private and Public Sector Dialogues on Nitrogen Management. *Journal of Soil and Water Conservation* 72 (1): 5A- 9A.

Reitsma, Kurtis D., Barry. H. Dunn, Umakant Mishra, Sharon A. Clay, T. DeSutter, and David E. Clay. 2015. Land-Use Change Impact on Soil Sustainability in a Climate and Vegetation Transition Zone. *Agronomy Journal* 107 (6): 2263-2372.

Reitsma, Kurtis D., R. Gelderman, P. Skiles, K. Alverson, J. Hemenway, Haward J. Woodard, Thomas E. Schumacher, Douglas Malo, and David E. Clay. 2008. Nitrogen Best Management Practices for Corn in South Dakota.

Ritchie, Jerry C., Paul V. Zimba, and James H. Everitt. 2003. Remote Sensing Techniques to Assess Water Quality. *Photogrammetric Engineering and Remote Sensing* 69 (6): 695-704.

Rothrock, Edgar P. 1943. *A Geology of South Dakota.* Vol. 1. State of South Dakota.

Rose, C. W., F. W. Chichester, and I. Phillips. 1983. Nitrogen-15-Labeled Nitrate Transport in a Soil With Fissured Shale Substratum. *Journal of Environmental Quality* 12 (2): 249-252.

Sainju, Upendra M., Andrew W. Lenssen, Thecan Caesar-TonThat, and Robert G. Evans. 2009. Dryland Crop Yields and Soil Organic Matter as Influenced by Long-Term Tillage and Cropping Sequence. *Agronomy Journal* 101 (2): 243-251. doi:doi:10.2134/agronj2008.0080x.

Sanchez, P. A. 2002. Soil Fertility and Hunger in Africa. *Science* 295: 2019–2020. Accessed March 05, 2018. doi:10.1126/science.1065256.

Scavia, Donald, and Kristina A. Donnelly. 2007. Reassessing Hypoxia Forecasts for the Gulf of Mexico. *Environmental Science & Technology*, 8111-8117. doi:DOI: 10.1021/es0714235 .

Schilling, Keith, and You-Kuan Zhang. 2004. Baseflow Contribution to Nitrate-Nitrogen Export from a Large, Agricultural Watershed, USA. *Journal of Hydrology* 295 (1): 305-316.

Schlesinger, W. H. 1997. Biogeochemistry: An Analysis of Global Change. (Academic Press) 2d ed.: 588.

Schrag, A. M. 2011. Addendum: Climate Change Impacts and Adaptation. In *Ocean of grass: A Conservation Assessment for the Northern Great Plains*, by H. Stand, W.H. Haskins, C. Freese, J. Proctor, and E. Dinerstein S.C. Forrest. Accessed March 05, 2018. https://kresge.org/sites/default/files/Uploaded%20Docs/WWF%20-%20Ocean_Grass.pdf.

Schwarzenbach, René P., Thomas Egli, Thomas B. Hofstetter, Urs Von Gunten, and Bernhard Wehrli. 2010. Global Water Pollution and Human Health. *Annual Review of Environment and Resources* (35) 109-136.

Sen, Pranab K. 1968. Estimates of the Regression Coefficient Based on Kendall's Tau. *Journal of the American Statistical Association* 63 (324): 1379-1389. doi:10.1080/01621459.1968.10480934.

Seré, Carlos, Henning Steinfeld, and Jan Groenewold. 1996. World Livestock Production Systems: Current Status, Issues And Trends. Rome: *Food and Agriculture Organization of the United Nations.* Accessed May 25, 2016. http://46.100.53.162/handle/Ebook/87278.

Sleeter, Benjamin M., Terry L. Sohlb, Thomas R. Loveland, Roger F. Auch, William Acevedo, Mark A. Drummond, Kristi L. Sayler, and Stephen V. Stehman. 2013.

Land-Cover Change in the Conterminous United States from 1973 To 2000. *Global Environmental Change* 23 (4): 733-748. doi:https://doi.org/10.1016/j.gloenvcha.2013.03.006.

Smil, Vaclav. 1999. Nitrogen in Crop Production: An account of Global Flows. 13 (2): 647–662. doi:https://doi.org/10.1029/1999GB900015 .

Smith, Val H., G. David Tilman, and Jeffery C. Nekola. 1999. Eutrophication: Impacts of Excess Nutrient Inputs on Freshwater, Marine, and Terrestrial Ecosystems. *Environmental Pollution* (Elsevier) 100 (1): 179-196. doi:https://doi.org/10.1016/S0269-7491(99)00091-3.

Spalding, Roy F., and Mary E. Exner. 1993. Occurrence of Nitrate in Groundwater—a Review. *Journal of environmental quality* 22 (3): 392-402.

Strassburg, B. B., A. E. Latawiec, L. G. Barioni, C. A. Nobre, V.P daSilva, J. F. Valentim, M. Vianna, and E. D. Assad. 2014. When Enough Should be Enough: Improving the Use of Current Agricultural Lands Could Meet the Production Demand and Spare Natural Habitat in Brazil. *Global Climate Change* 84–97.

Strauss, Josiah, Ethan L. Grossman, and Steven F. DiMarco. 2012. Stable Isotope Characterization of Hypoxia-Susceptible Waters on the Louisiana Shelf: Tracing Freshwater Discharge and Benthic Respiration. *Continental Shelf Research*, 7-15.

Stubbs, Megan. 2014. Conservation Reserve Program (CRP): Status and Issues. *Congressional Research Service Report* 42783.

Tao, Can, Chen Xiaoling, Lu Jianzhong, Philip W. Gassman. 2015. Assessing Impacts of Different Land Use Scenarios on Water Budget of Fuhe River, China Using

SWAT Model. *International Journal of Agricultural and Biological Engineering* 8 (11): 95-109. doi:http://www.ijabe.org/index.php/ijabe.

Tilman, David. 1999. Global Environmental Impacts of Agricultural Expansion: The Need for Sustainable and Efficient Practices. *Proceedings of the National Academy of Sciences of the United States of America* (PNAS) 96 (11): 5995-6000. doi:https://doi.org/10.1073/pnas.96.11.5995 .

Tobler, Waldo R. 1969. Geographical Filters and Their Inverses. *Geographical Analysis* 1 (3): 234-253.

Tomer, Mark D., Willaim G. Crumpton, Ronald L. Bingner, Jill A. Kostel, and David E. James. 2013. Estimating Nitrate Load Reductions from Placing Constructed Wetlands in a HUC-12 Watershed Using Lidar Data. *Ecological Engineering* 69-78.

Tomer, Mark D., David E. James, Isenhart T. M. 2003. Optimizing the Placement of Riparian Practices in a Watershed Using Terrain Analysis. *Journal of Soil and Water Conservation* (Iowa State University) 7. Accessed March 15, 2018. https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1179&context=nrem_pubs.

Timo, Sami, Määttä A., Pia Anttila, Tuija R. Airola, and Amnell T. 2002. Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates –the Excel template application MAKESENS. *Publications on Air Quality* No. 31, Nordic Council of Ministers, FIN-00101 Helsinki, Finland: Finnish Meteorological Institute. Accessed 01 25, 2018. en.ilmatieteenlaitos.fi/makesens.

Townsend, Alan R., Robert W. Howarth,, Fakhri A. Bazzaz, Mary S. Booth, Cory C. Cleveland, Sharon K. Collinge, Andrew P. Dobson, Paul R. Epstein, Elizabeth A. Holland, Dennis R. Keeney,Michael A. Mallin, Christine A. Rogers, Peter Wayne, and Amir H. Wolfe. 2003. Human Health Effects of a Changing Global Nitrogen Cycle. *Frontiers in Ecology and the Environment* 1 (5): 240-246. doi:10.1890/1540-9295(2003)001[0240:HHEOAC]2.0.CO;2.

Turner, B. L. I.I., Eric F. Lambin, and Anettee Reenberg. 2007. The Emergence of Land Change Science for Global Environmental Change and Sustainability. *Proceedings of the National Academy of Sciences* PNAS 104 (52). Accessed March 17, 2018. doi:https://doi.org/10.1073/pnas.0704119104 .

Unger, Paul W. 2001. Total Carbon, Aggregation, Bulk Density, and Penetration Resistance of Cropland and Nearby Grassland Soils. *Soil Science.*

United States Environmental Protection Agency. 2003. *EPA's Draft Report on the Environment 2003.* Washington, DC.: U.S. Environmental Protection Agency. http://ase.tufts.edu/gdae/es135/EPA%20Draft%20Report%20on%20the%20Environment.pdf.

United States Environmental Protection Agency. 2008. *EPA's 2008 Report on the Environment.* Washington, DC.: U.S. Environmental Protection Agency. Accessed March 05, 2018. https://cfpub.epa.gov/roe/documents/EPAROE_FINAL_2008.PDF.

Uinted States Geologcal Survey USGS. 2001. A Primer on Water Quality. *Science for a Changing World.* March. Accessed 04 03, 2016. http://pubs.water.usgs.gov/fs02701.

Utz, Ryan Michael. 2010. Interregional Differences in Stream Ecosystem Responses to Urbanization: Causes and Consequences.

Venteris, Erik R., Richard L. Skaggs, Andre M. Coleman, and Mark S. Wigmosta. 2012. An Assessment of Land Availability and Price in the Conterminous United States for Conversion to Algal Biofuel Production. *Biomass and Bioenergy* 47: 483-497. Accessed 10 6, 2018. doi:https://doi.org/10.1016/j.biombioe.2012.09.060.

Veregin, Howard. 2012. 133 Map Categories! How the US Department of Agriculture Solved a Complex Cartographic Design Problem. Wisconsin Geospatial News. https://www.sco.wisc.edu/2012/04/25/133-map-categories-how-the-us-department-of-agriculture-solved-a-complex-cartographic-design-problem/

Vitousek, P.M, R. Naylor, T. Crews, M. B. David, L. E. Drinkwater, E. Holland, P. J. Johnes, J. Katzenberger, L. A. Martinelli, P. A. Matson, G. Nziguheba, D. Ojima, C. A. Palm, G. P. Robertson, P. A. Sanchez A. R. Townsend, F.S. Zhang. 2009. Nutrient Imbalances in Agricultural Development. *Science* 324 (5934): 1519-1520. doi:10.1126/science.1170261.

Vladimir Smakhtin, Carmen Revenga and Petra Döll. 2004. *Taking into Account Environmental Water Requirements in Global-Scale Water Resources Assessments.* Comprehensive Assessment Secretariat.

Waisanen, Pamela J. 2003. Land Use and Land Cover Change in the Western Corn Belt Plains Ecoregion, 1970 to 2000. *Master's Thesis. South Dakota state University.* 1-124.

Waisanen, Pamela J., Norman B. Bliss. 2002. Changes in Population and Agricultural Land in Conterminous United States Counties, 1790 to 1997. *Global*

Biogeochemical Cycles 16 (4). https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2001GB001843.

Ward D. Andy, Trimble, Burckhard, and John G. Lyon. 2009. The Hydrologic Cycle, Water Resources, and Society. In *Environmental Hydrology*, by Trimble, Burckhard, and John G. Lyon Ward D. Andy, 1-36. CRC Press: Tylor and Francis Group.

Wenger, Seth. 1999. A Review of the Scientific Literature on Riparian Buffer Width, Extent and Vegetation. University of Georgia Institute of Ecology, Office of Public Service & Outreach. Athens, GA.

Westcott, Paul. 2007. U.S. Ethanol Expansion Driving Changes Throughout the Agricultural Sector. *Amber Waves*, September 03. Accessed March 21, 2018. https://www.ers.usda.gov/amber-waves/2007/september/us-ethanol-expansion-driving-changes-throughout-the-agricultural-sector/.

Wolfe, A. H, and Patz, J. A. 2002. Reactive Nitrogen and Human Health:Acute and Long-term Implications. *AMBIO: A Journal of the Human Environment* (Royal Swedish Academy of Sciences) 31 (2): 120-125. doi:https://doi.org/10.1579/0044-7447-31.2.120 .

World Health Organization, WHO. 2015. *Hazards in drinking-water supply and waste management.* Accessed 05 22, 2016. http://www.who.int/water_sanitation_health/hygiene/plumbing3.pdf.

Wright, Christopher K., and Michael C. Wimberly. 2013. Recent Land Use Change in the Western Corn Belt Threatens Grasslands and Wetlands. *Proceedings of the National Academy of Sciences* 110 (10): 4134-4139.

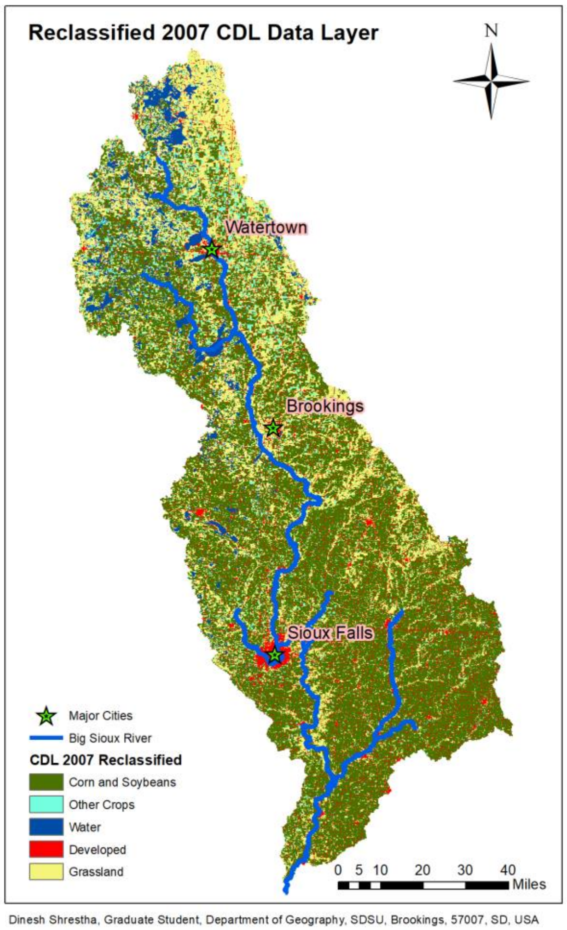
Wu, Changhua, Crescencia Maurer, Yi Wang, Shouzheng Xue, and Devra Lee Davis. 1999. Water Pollution and Human Health in China. *Environmental Health Perspectives*. 107 (4): 251-256.

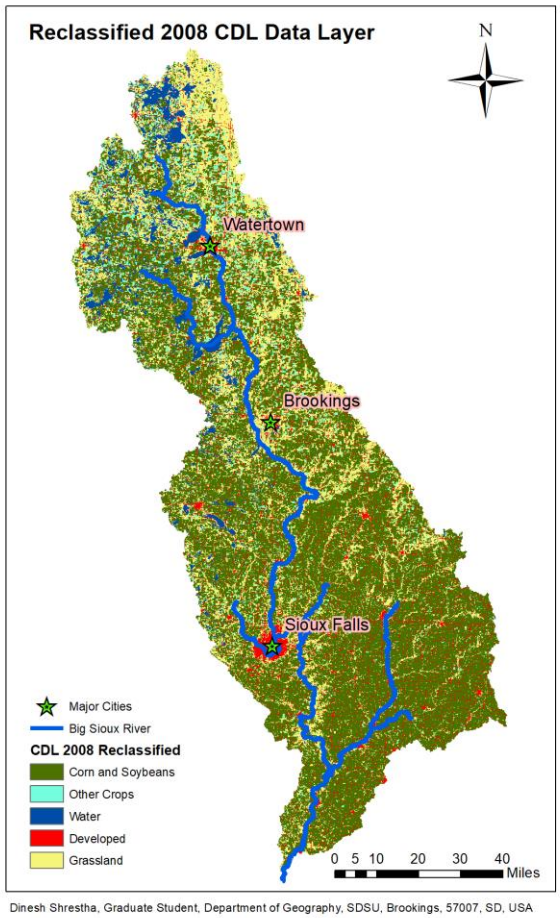
Wu, Young, Shuguang Liu, Terry L. Sohl, and Claudia J. Young. 2013. Projecting the Land Cover Change and its Environmental Impacts in the Cedar River Basin in the Midwestern United States. *Environmental Research Letters* 8 (2). http://iopscience.iop.org/article/10.1088/1748-9326/8/2/024025/pdf.

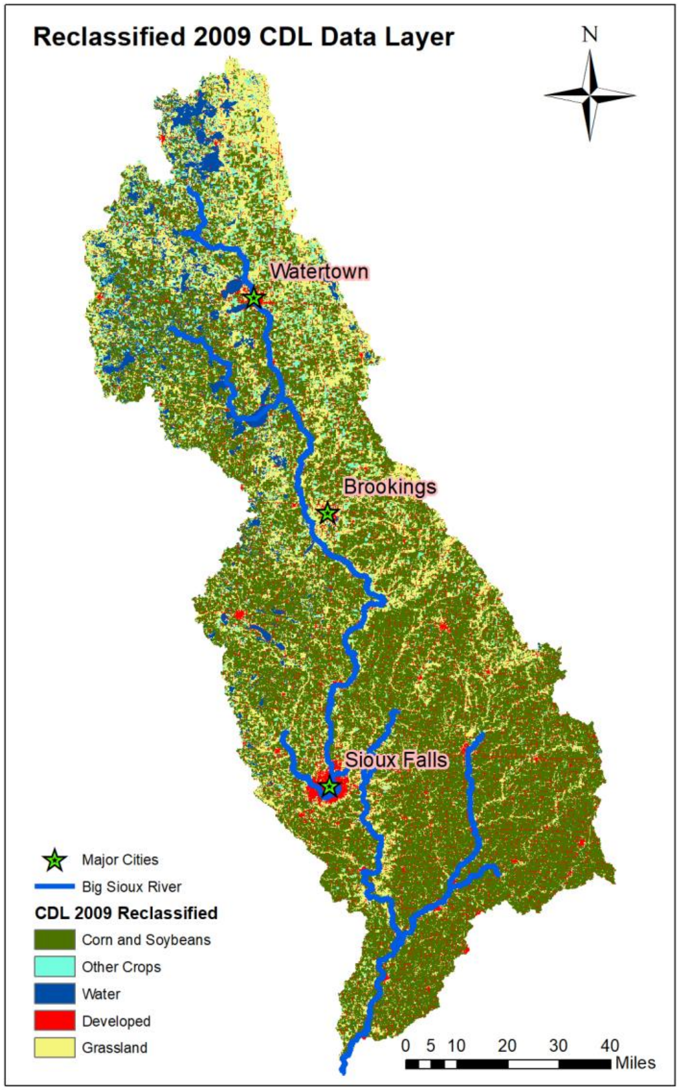
Yu SZ, and Chen G. 1996. Blue-Green Algal Toxins and Primary Liver Cancer. *Shanghai: Science and Technology* (Progress in Epidemiology) 8: 136-148.

APPENDICES

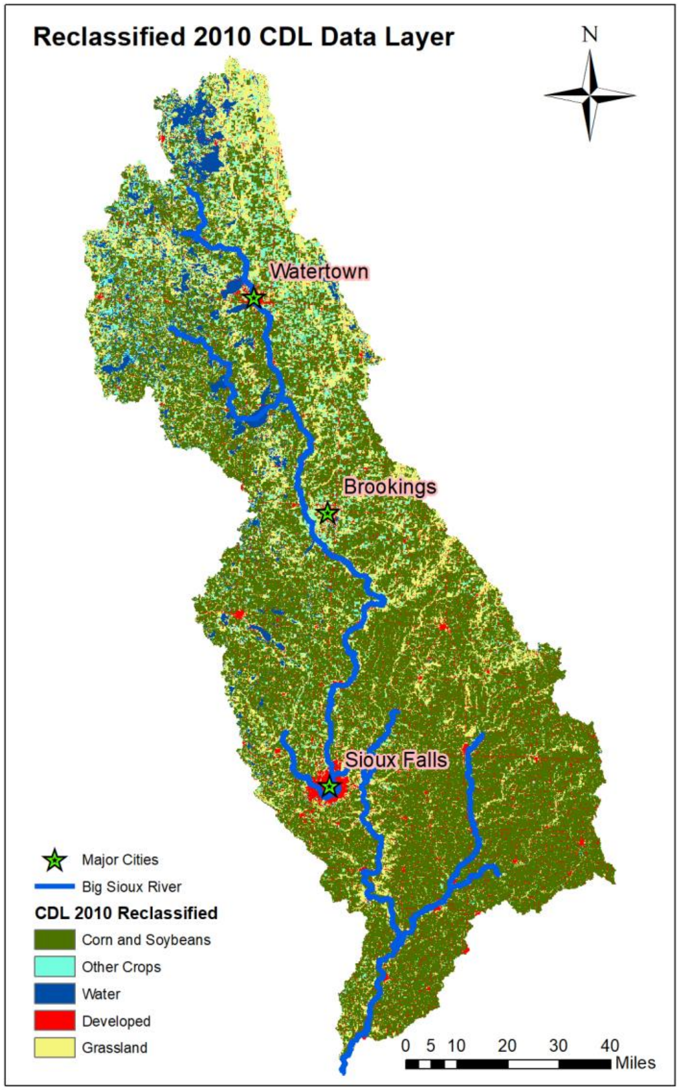
Appendix A: Reclassified CDL Data Layer Maps from 2007 – 2016



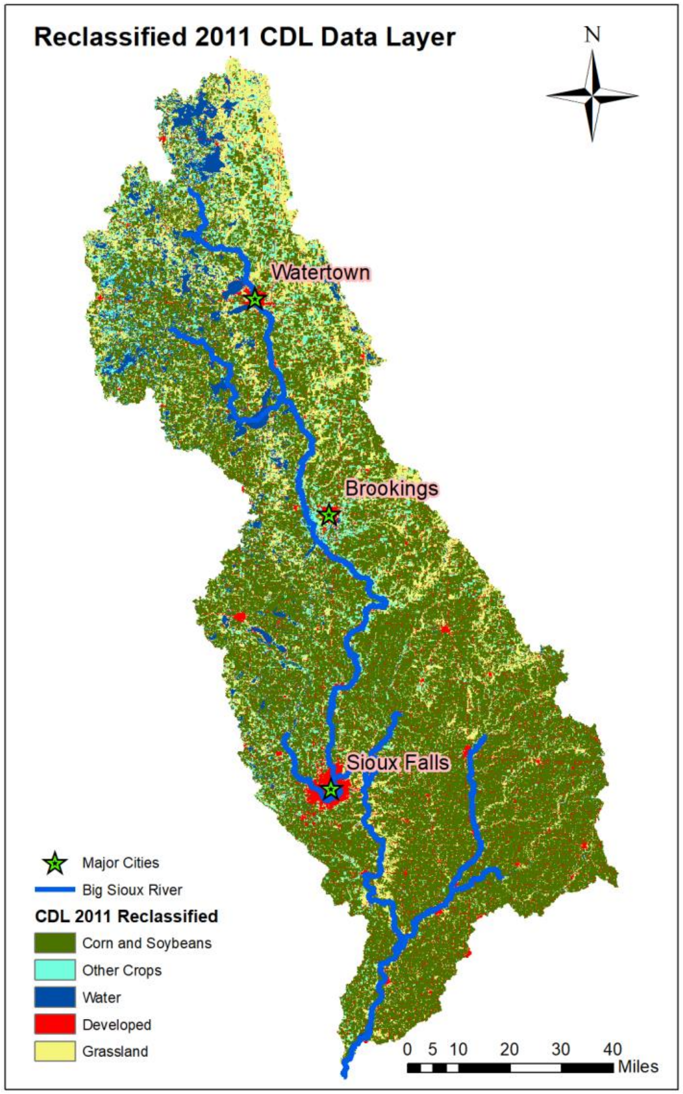




Dinesh Shrestha, Graduate Student, Department of Geography, SDSU, Brookings, 57007, SD, USA



Dinesh Shrestha, Graduate Student, Department of Geography, SDSU, Brookings, 57007, SD, USA



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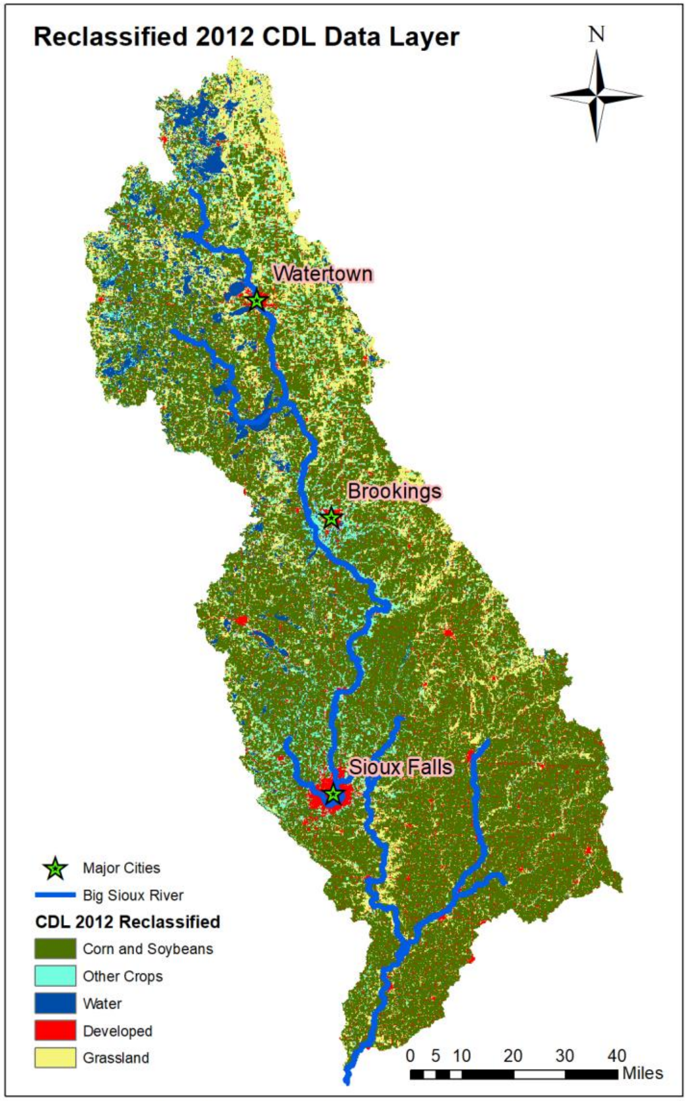
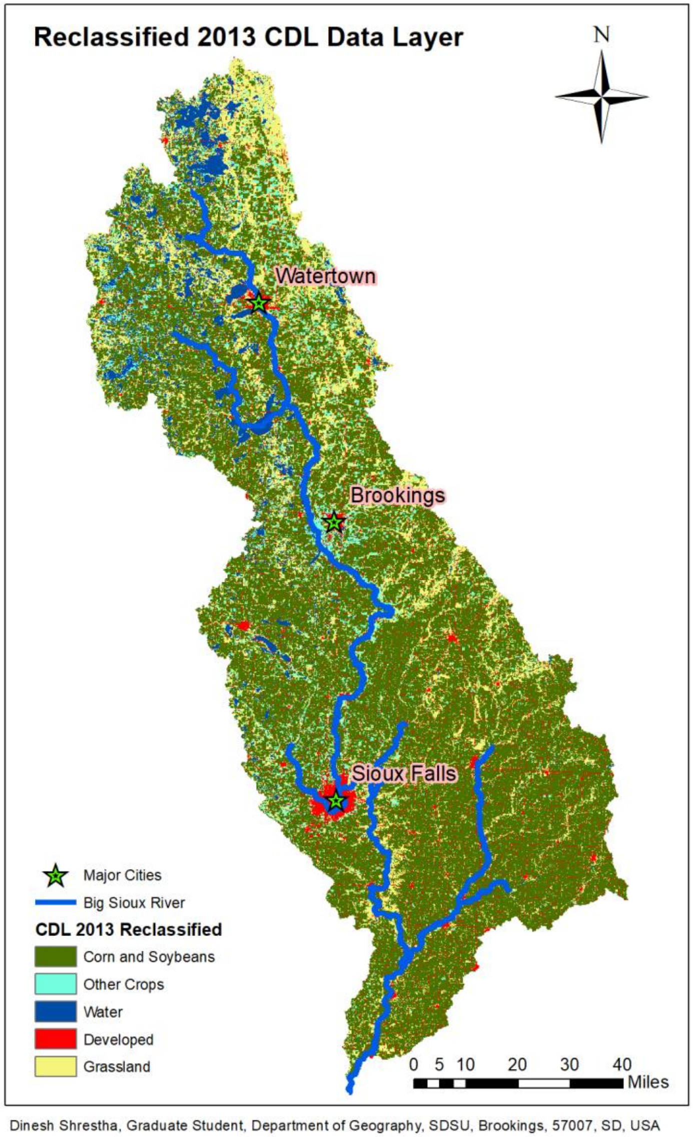
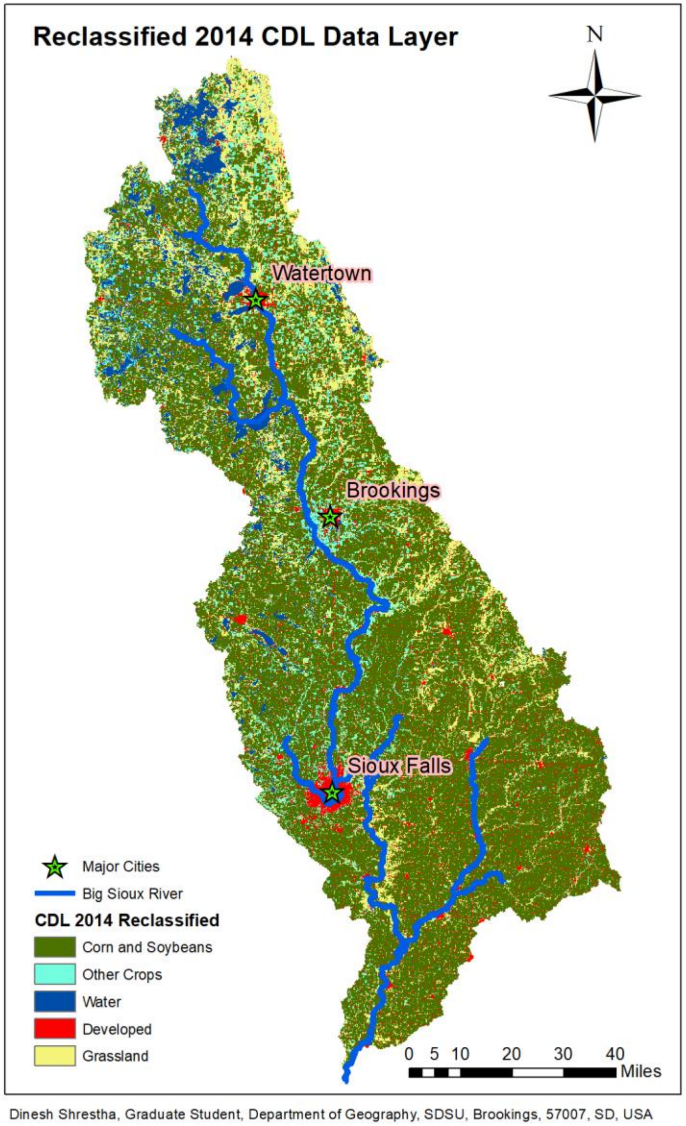
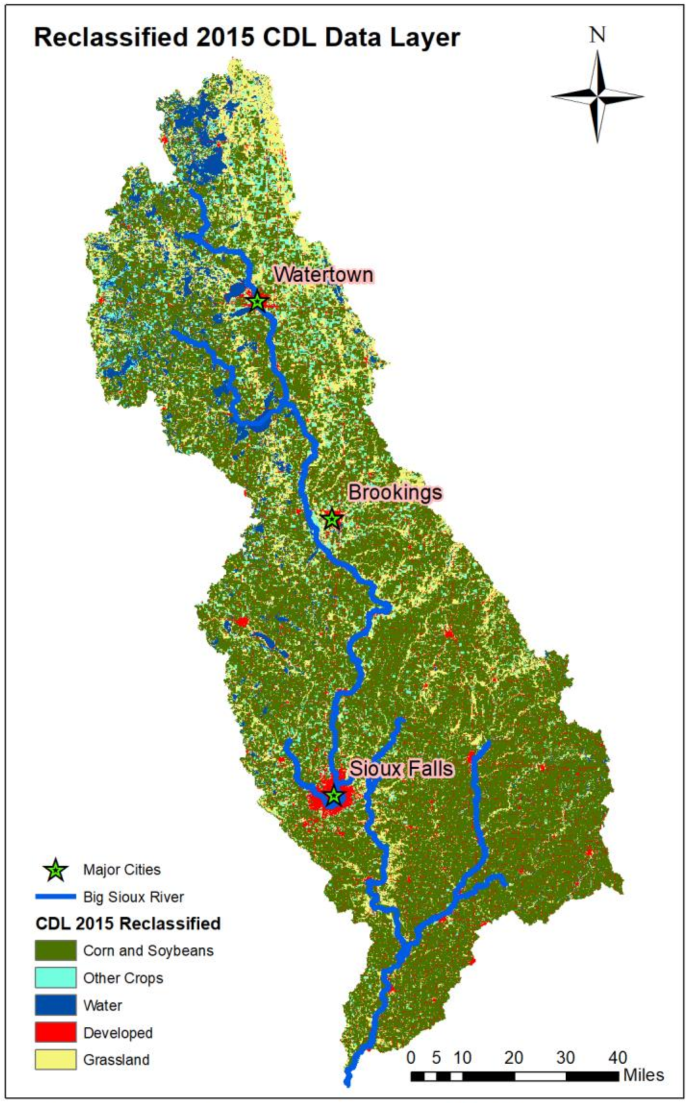


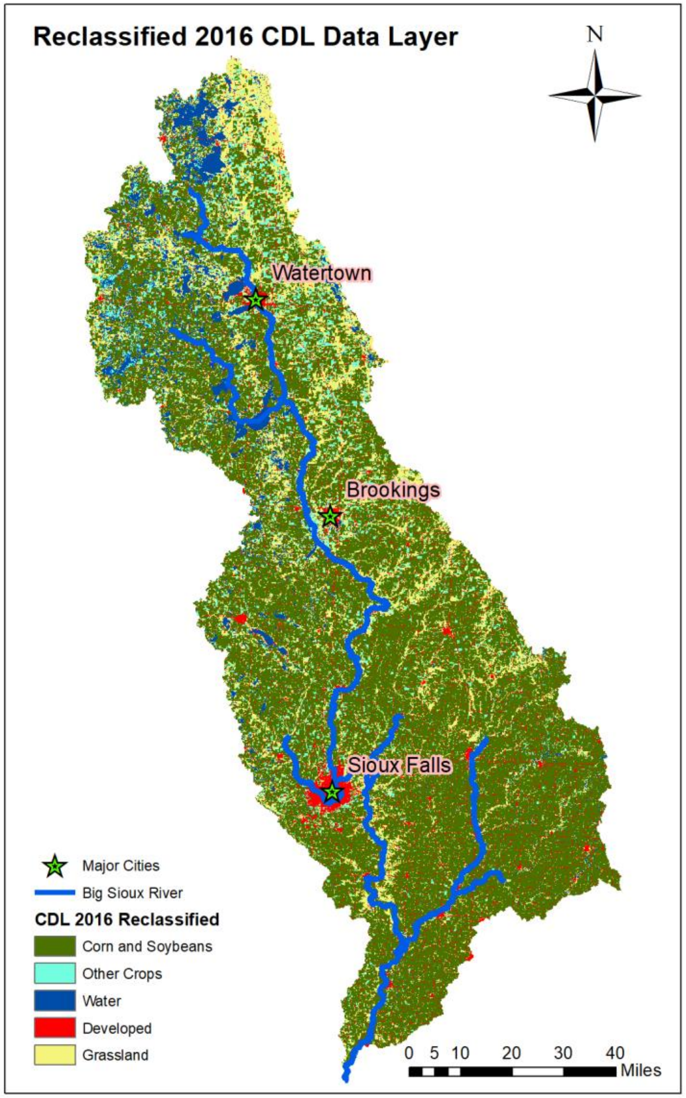
Dinesh Shrestha, Graduate Student, Department of Geography, SDSU, Brookings, 57007, SD, USA


Reclassified 2013 CDL Data Layer
N
Watertown
Brookings
Sioux Falls
Major Cities
Big Sioux River
CDL 2013 Reclassified
Corn and Soybeans
Other Crops
Water
Developed
Grassland
0 5 10 20 30 40
Miles
Dinesh Shrestha, Graduate Student, Department of Geography, SDSU, Brookings, 57007, SD, USA


Reclassified 2014 CDL Data Layer
N
Watertown
Brookings
Sioux Falls
Major Cities
Big Sioux River
CDL 2014 Reclassified
Corn and Soybeans
Other Crops
Water
Developed
Grassland
0 5 10 20 30 40
Miles
Dinesh Shrestha, Graduate Student, Department of Geography, SDSU, Brookings, 57007, SD, USA

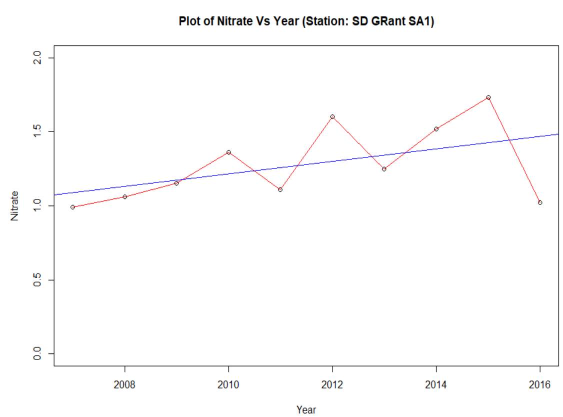


Dinesh Shrestha, Graduate Student, Department of Geography, SDSU, Brookings, 57007, SD, USA



Dinesh Shrestha, Graduate Student, Department of Geography, SDSU, Brookings, 57007, SD, USA

Appendix B: Results from the Man-Kendall test and Sen Slopes for all the Gauging stations

<table>
<tr><th colspan="3">Gauging Stations</th></tr>
<tr><th>Station Name</th><th>Scatterplot</th><th>Sen Slopes</th></tr>
<tr><td>SD Grant SA1</td><td>


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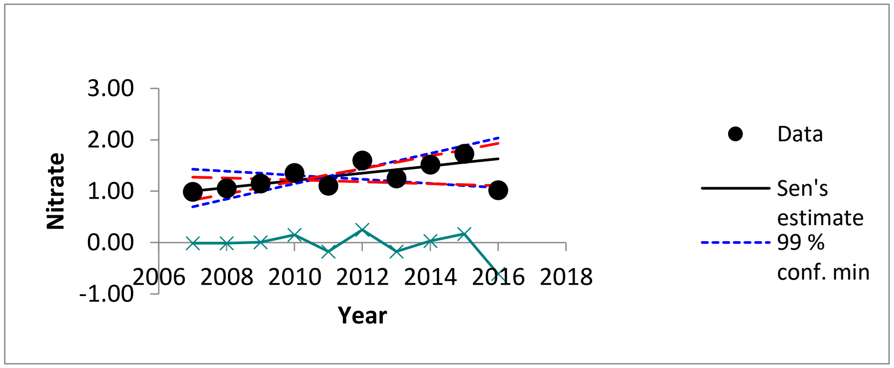
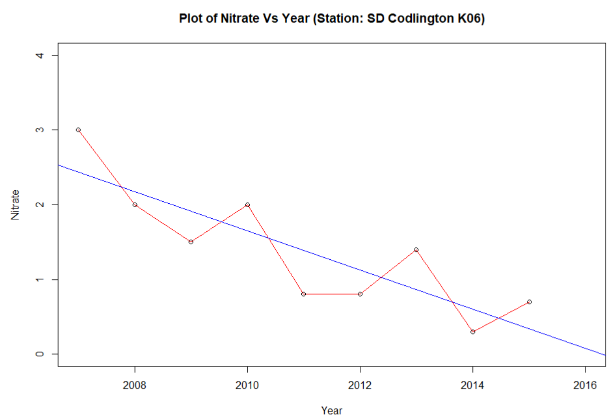
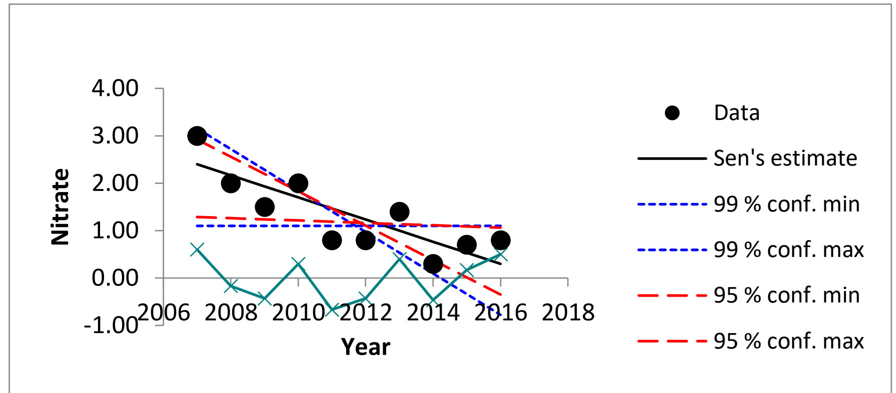


<table>
<tr><th>Test Z</th><th>Signific.</th><th>Q</th><th>B</th></tr>
<tr><td>1.61</td><td></td><td>0.070</td><td>1.00</td></tr>
</table>
</td></tr>
</table>

SD Codington K06

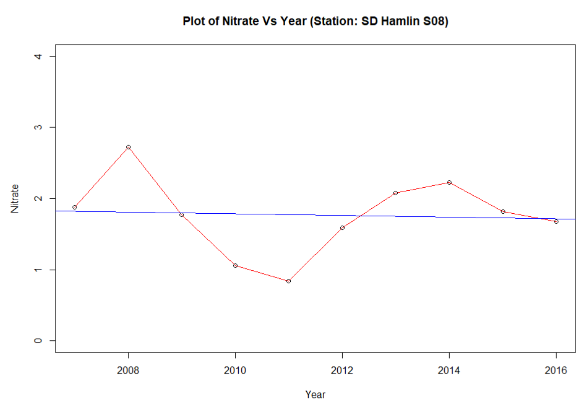


tau = -0.743, 2-sided pvalue =0.0084



Test Z	Signific.	Q	B
-2.71	**	-0.233	2.40

SD Hamlin S08



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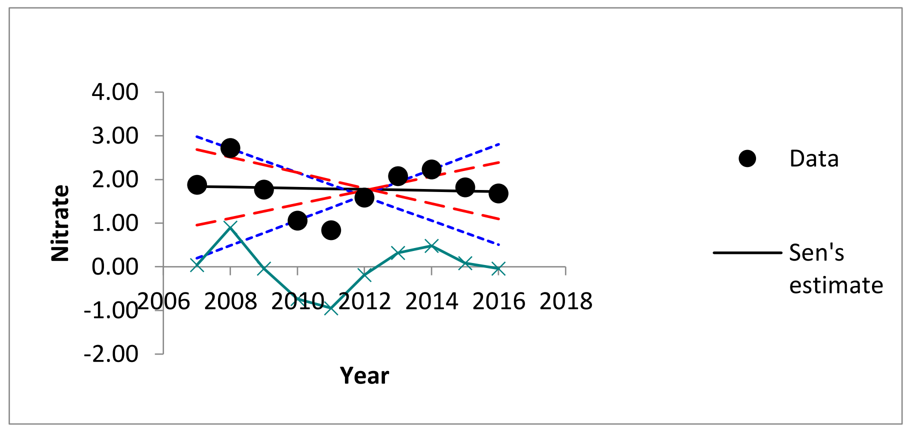
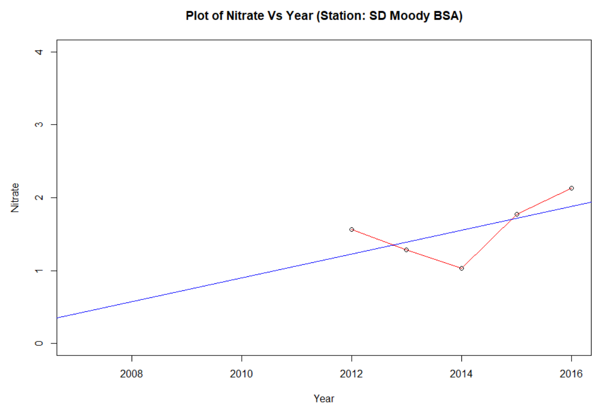


Test Z	Signific.	Q	B
-0.18		-0.013	1.84

SD Moody BSA



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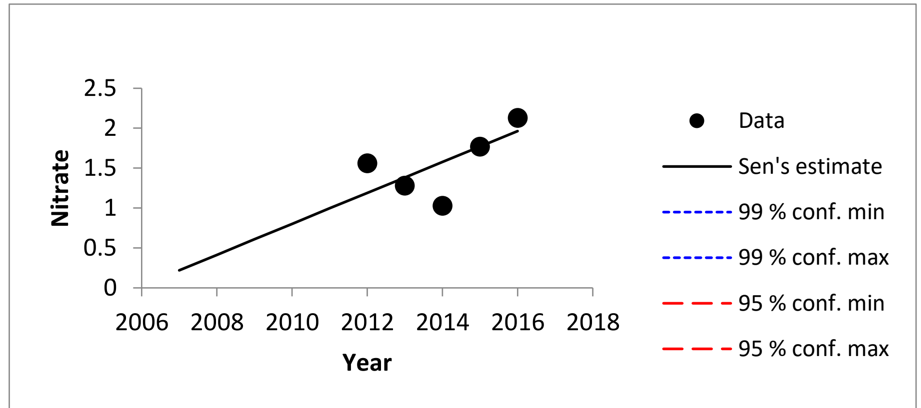
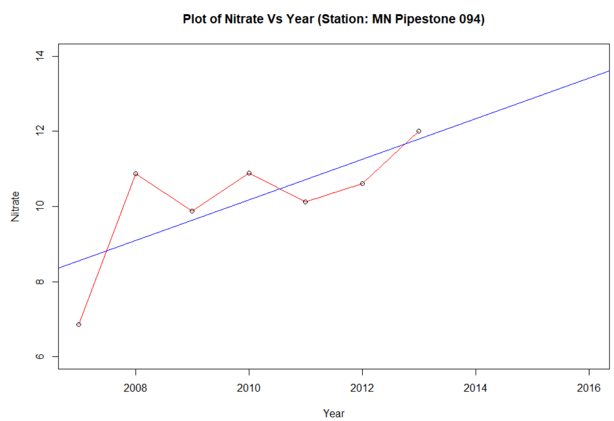


Test Z	Signific.	Q	B
		0.194	0.22

MN Pipestone 094



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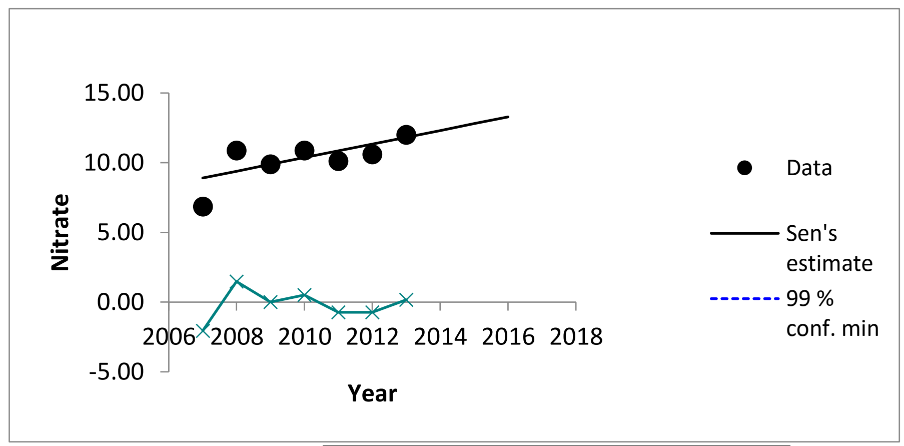
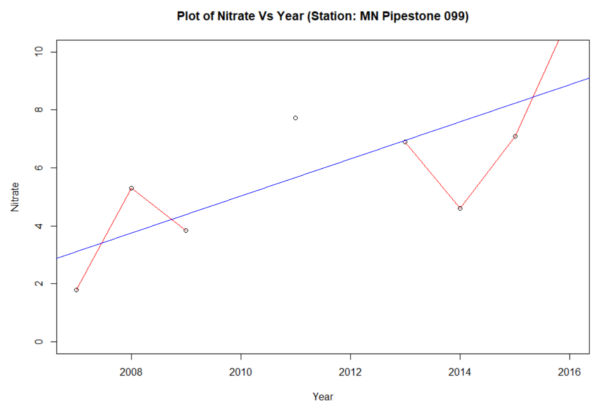


Test Z	Signific.	Q	B
		0.487	8.90

MN Pipestone 099



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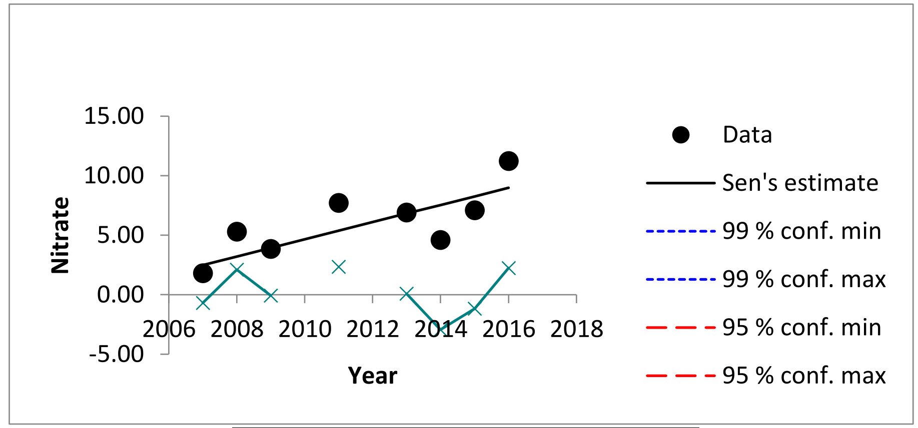
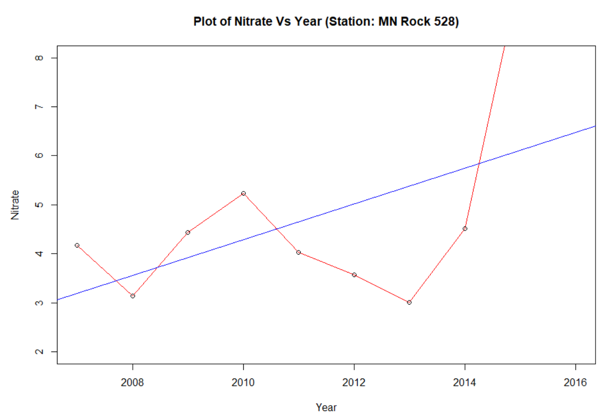


Test Z	Signific.	Q	B
	+	0.722	2.49

MN Rock 528



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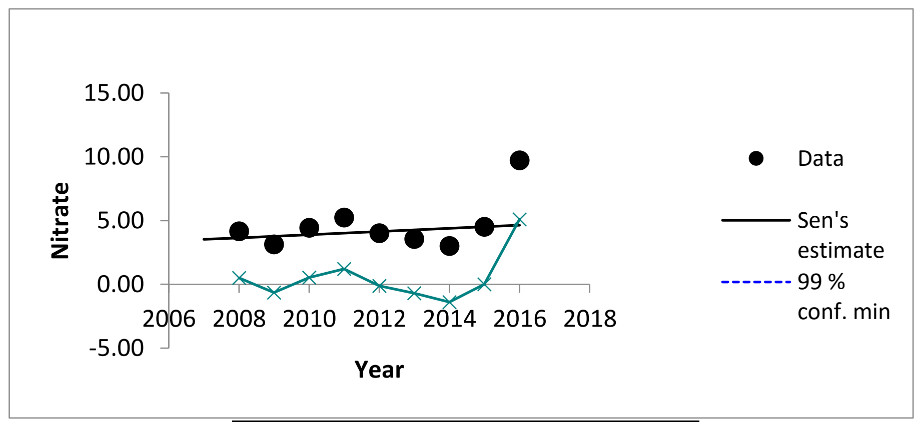
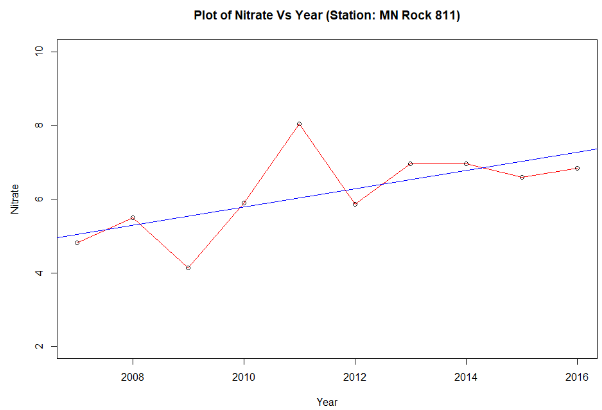
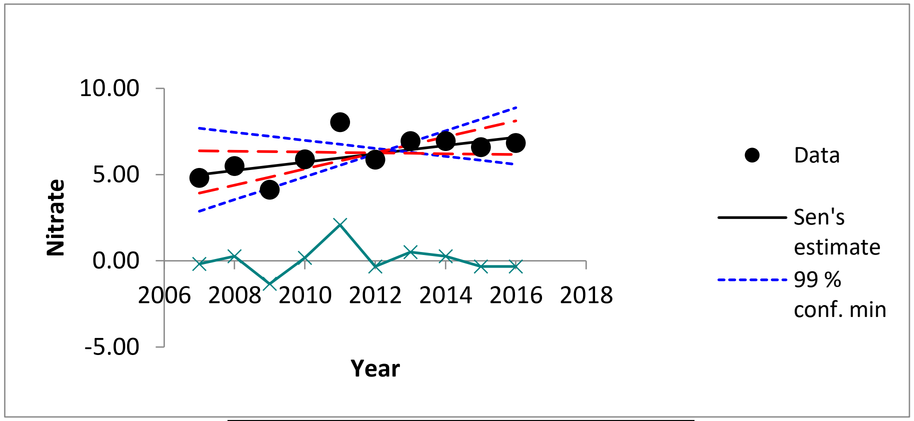


Test Z	Signific.	Q	B
		0.123	3.53

MN Rock 811

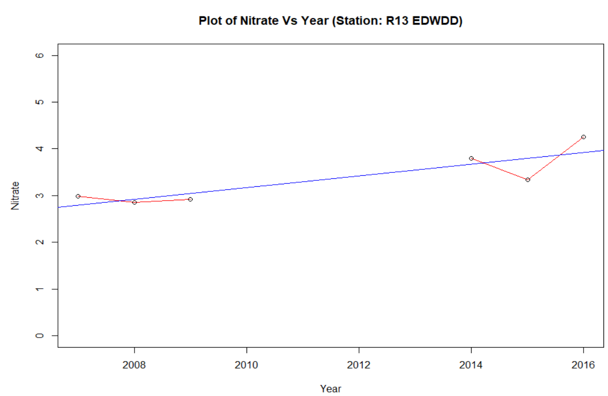


tau = 0.449, 2-sided pvalue =0.0880

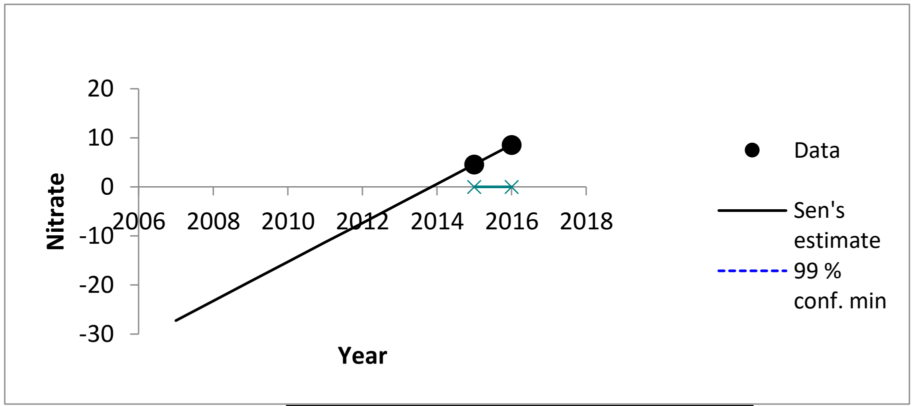


Test Z	Signific.	Q	B
1.71	+	0.242	4.99

R13 EDWDD

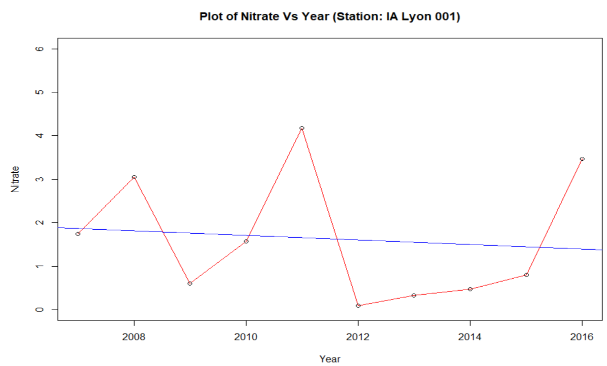


tau = 0.6, 2-sided pvalue =0.1328

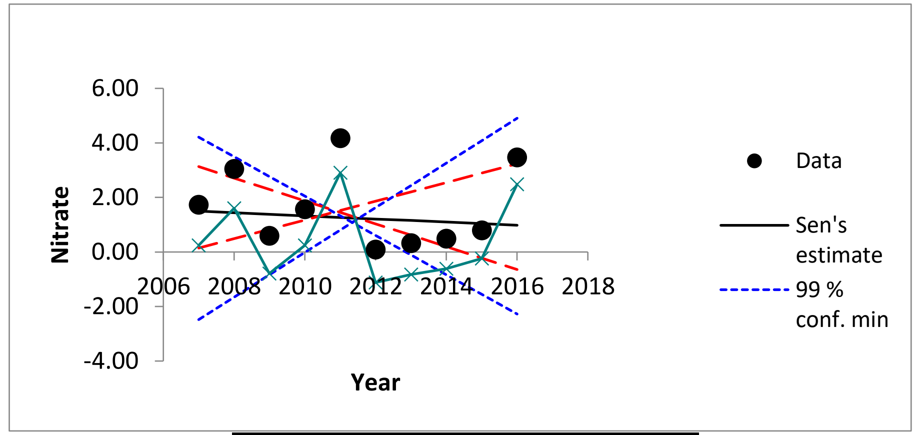


Test Z	Signific.	Q	B
		3.980	-27.25

IA Lyon 001

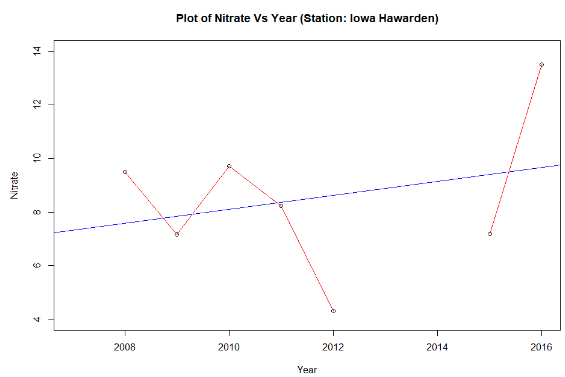


tau = -0.0667, 2-sided pvalue =0.8580

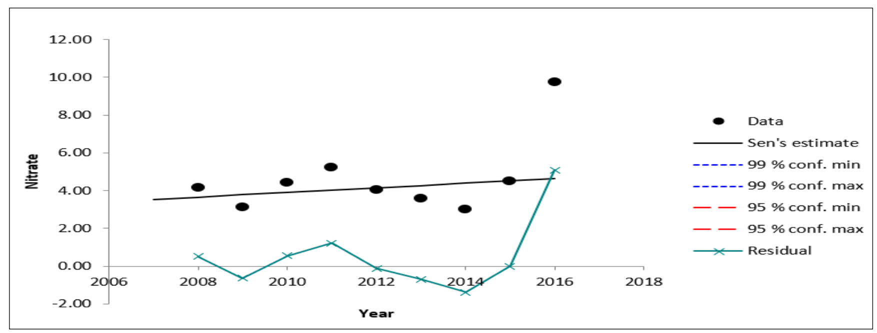


Test Z	Signific.	Q	B
-0.18		-0.058	1.50

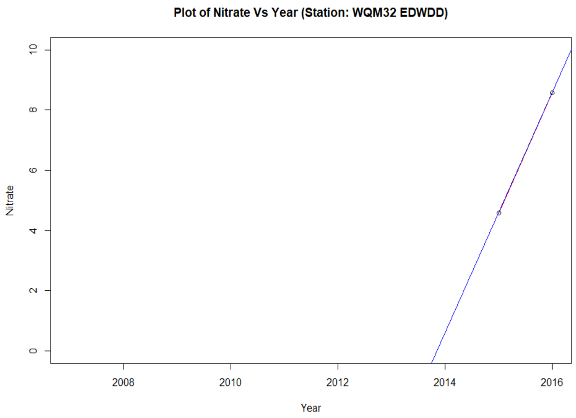
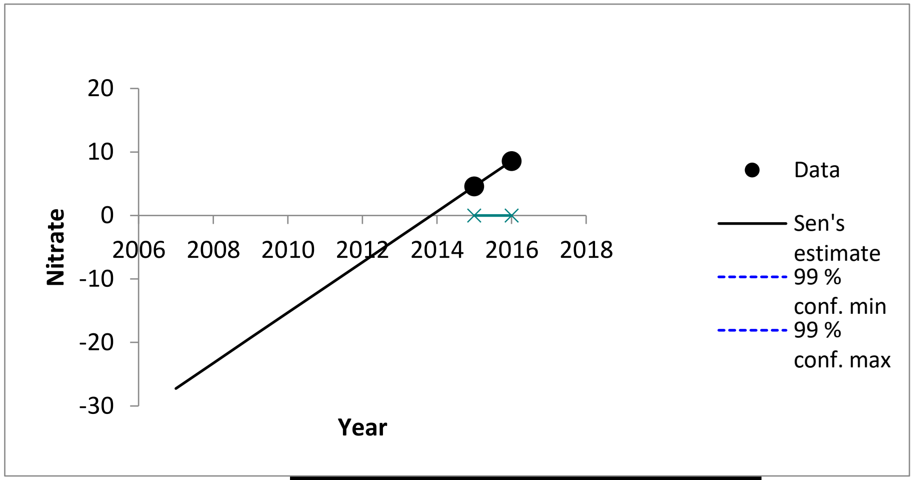
Iowa Hawarden



tau = 0.0476, 2-sided pvalue =1

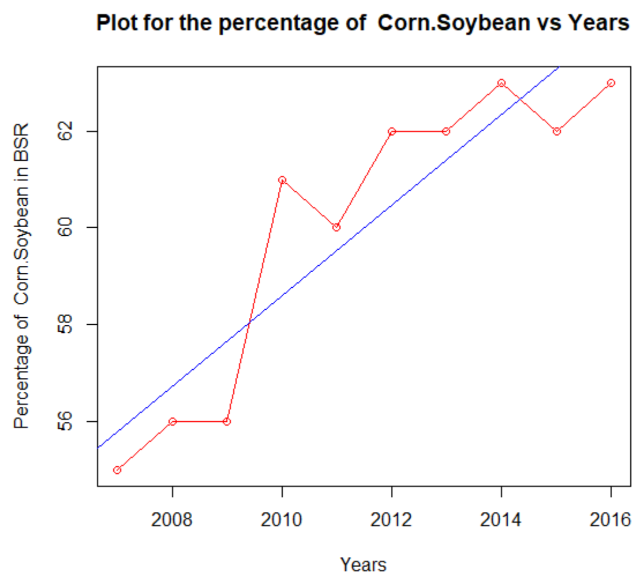
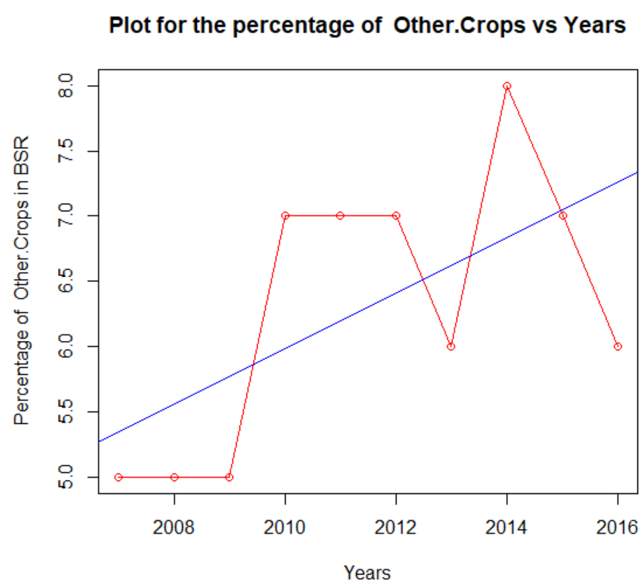


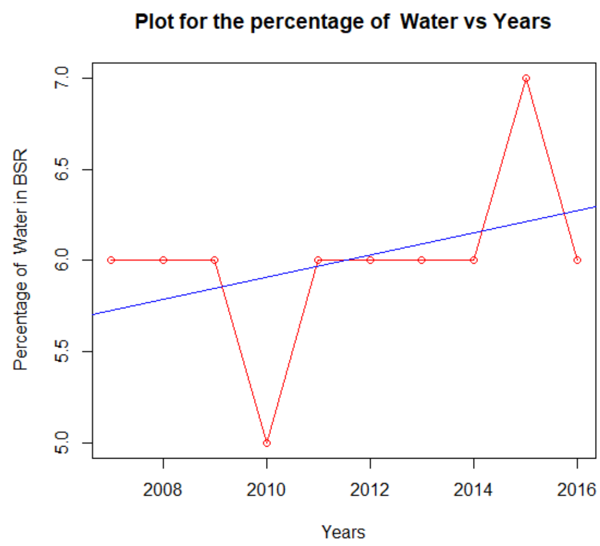
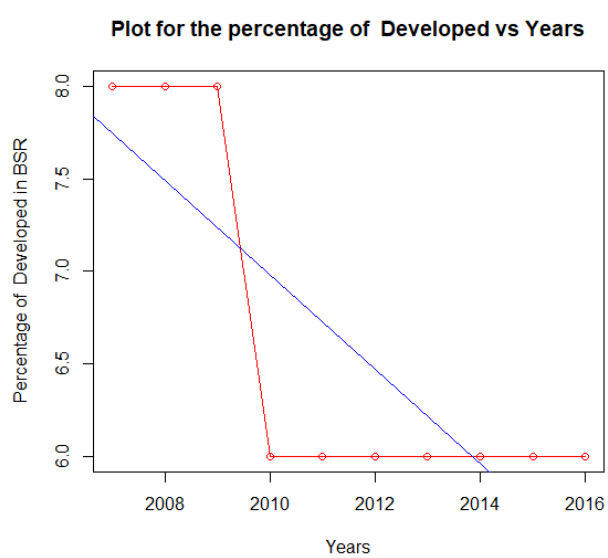
Test Z	Signific.	Q	B
-0.18		-0.058	1.50

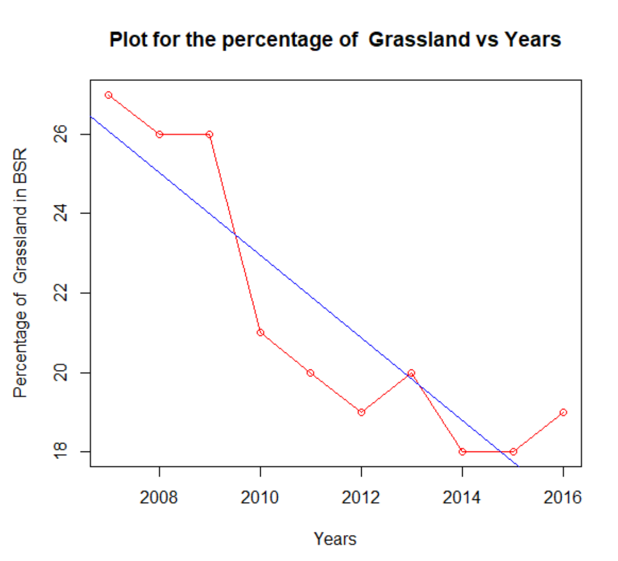
WQM32 EDWDD	 tau = 1, 2-sided pvalue =1	

Test Z	Signific.	Q	B
		3.980	-27.25

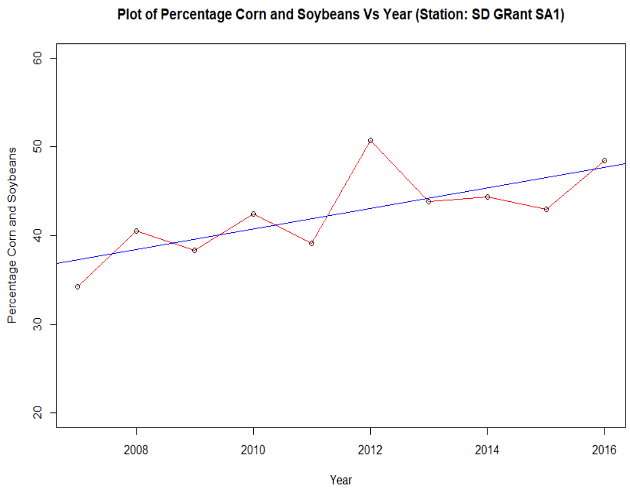
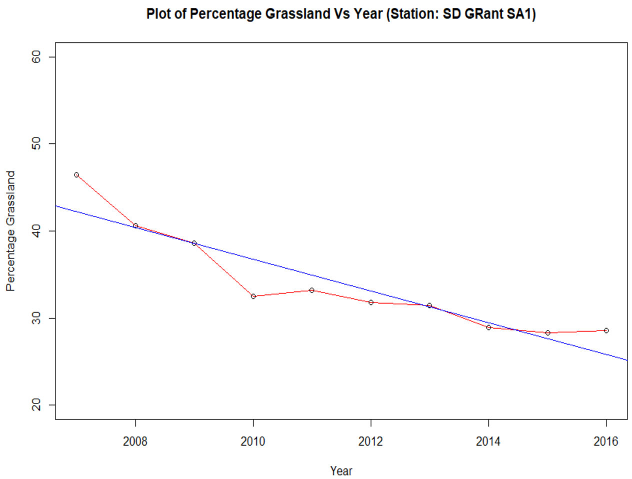
Appendix C: Results from the Man-Kendall test for the percentage of all the class types in the entire BSR watershed

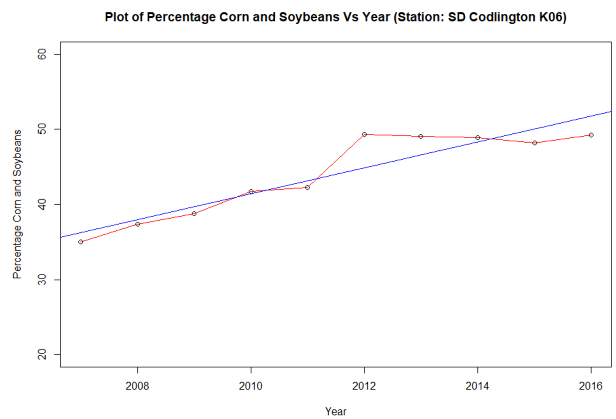
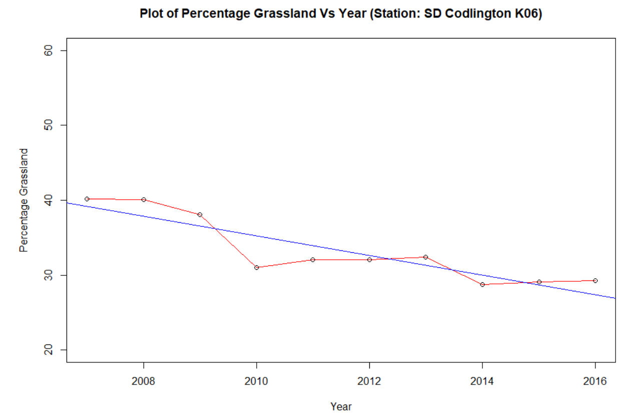
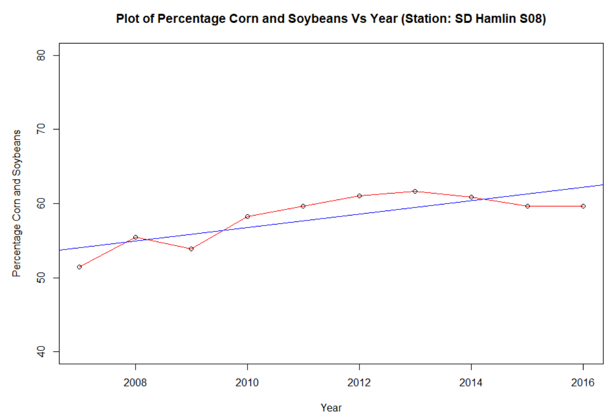
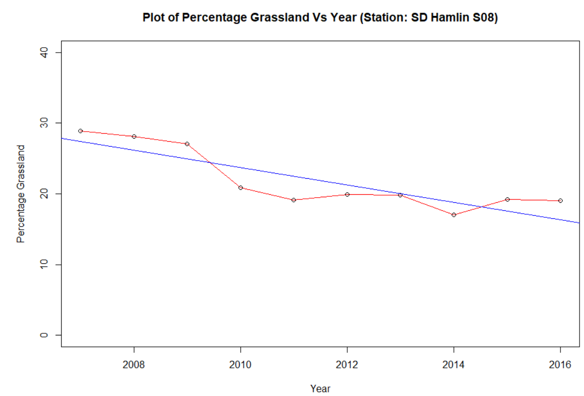
Class Types	Scatterplot	Man-Kendall
Corn/Soybean		tau = 0.849, 2-sided, p-value =0.001
Other Crops		tau = 0.428, 2-sided, p-value =0.13

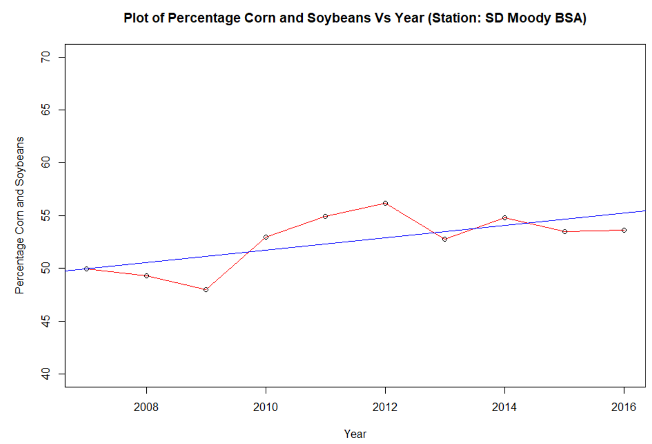
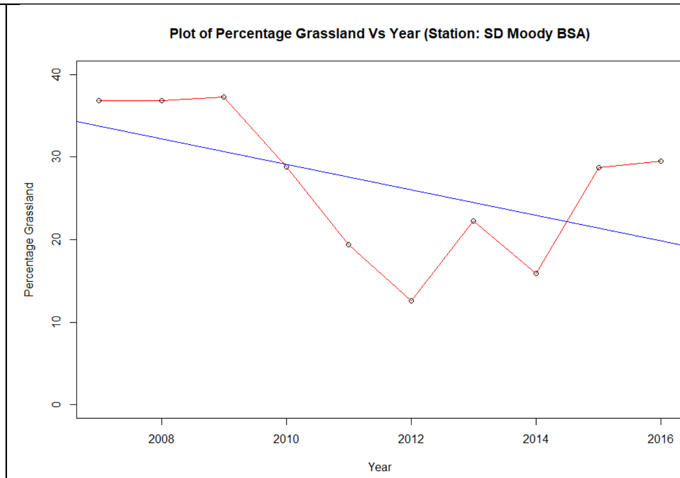
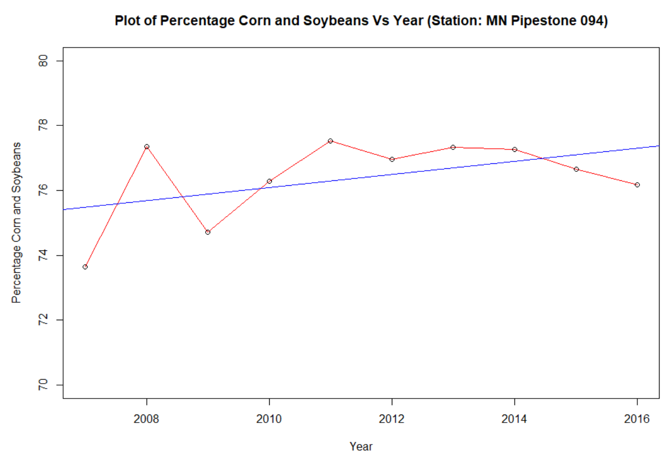
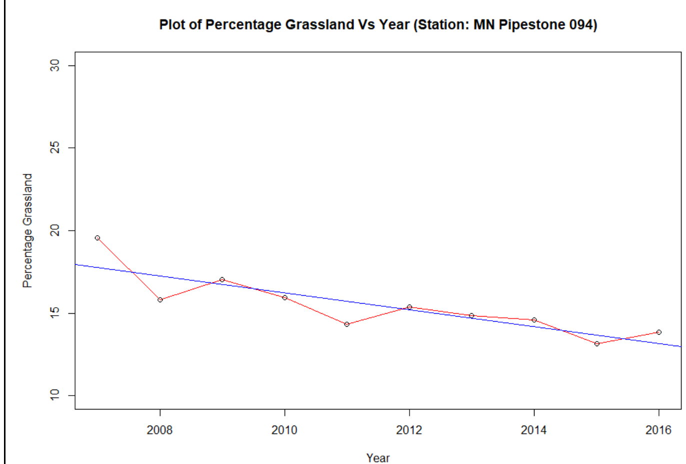
Water		tau = 0.325, 2-sided, p-value =0.300
Developed		tau = -0.68, 2-sided p-value =0.022

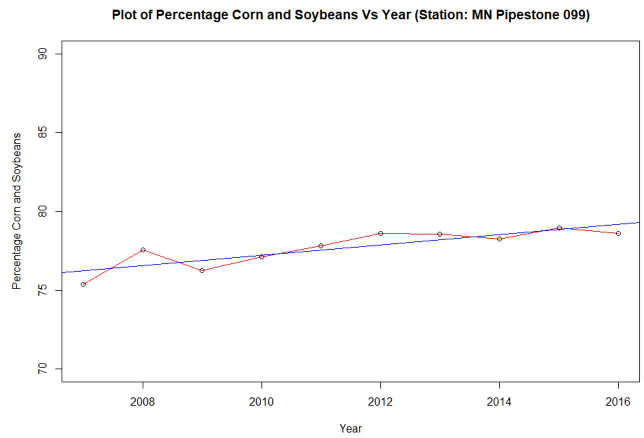
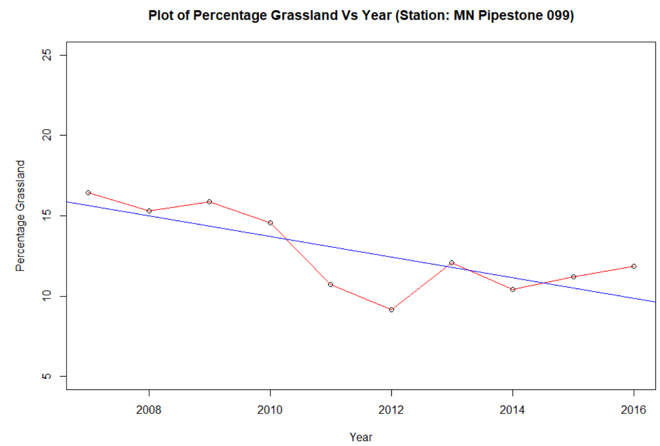
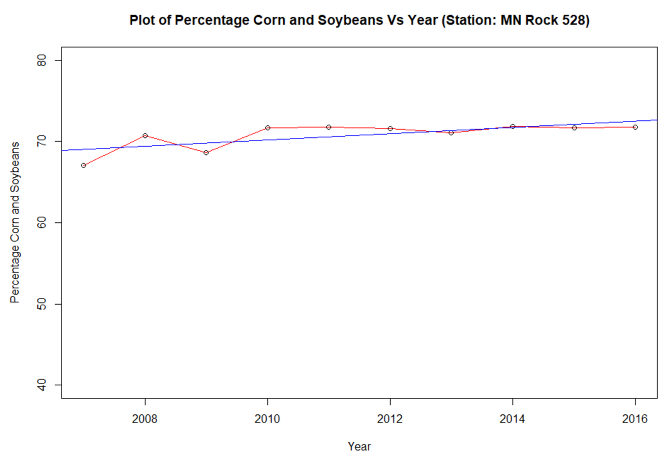
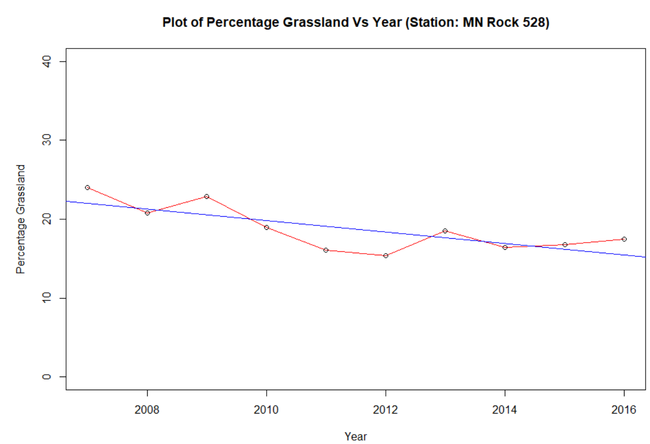
Grassland		tau = -0.81, 2-sided p-value =0.001

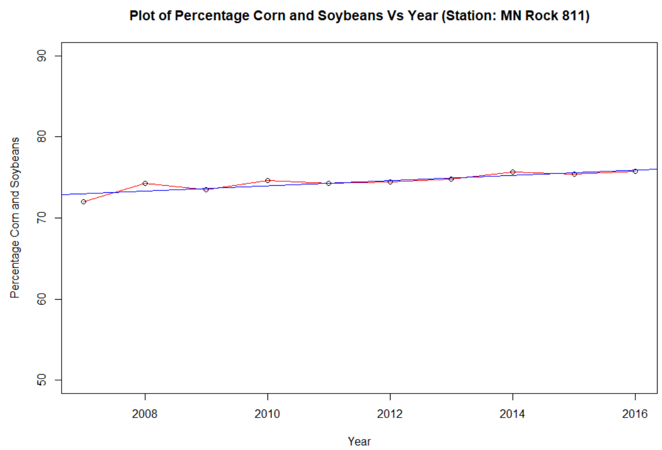
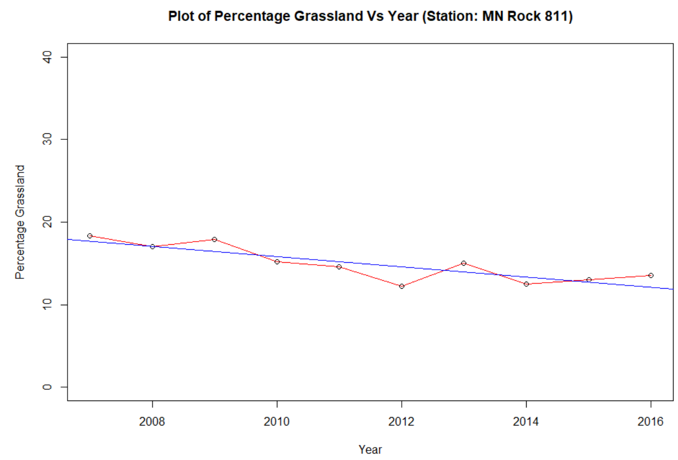
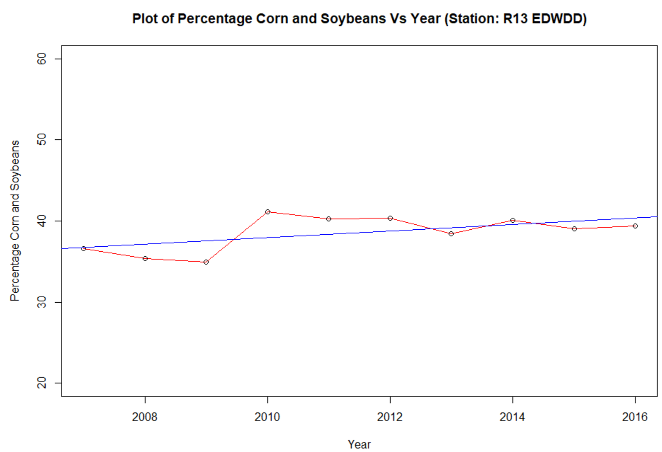
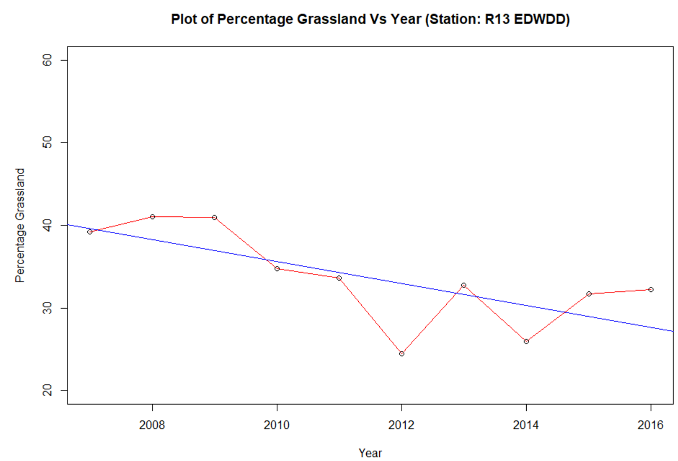
Appendix D: Results from the Man-Kendall test for the percentage of corn and soybeans, and grassland for all HUC12 Stations

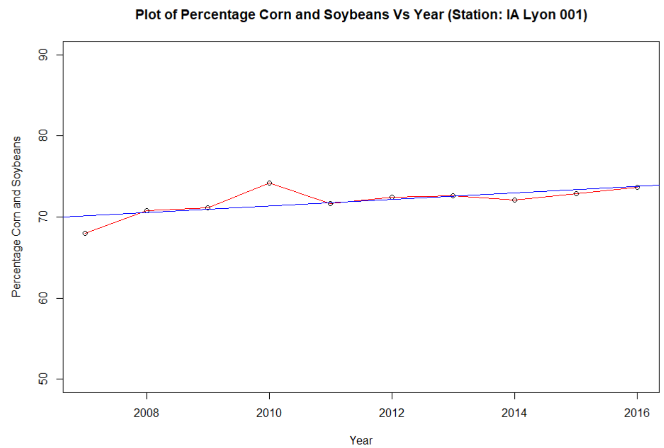
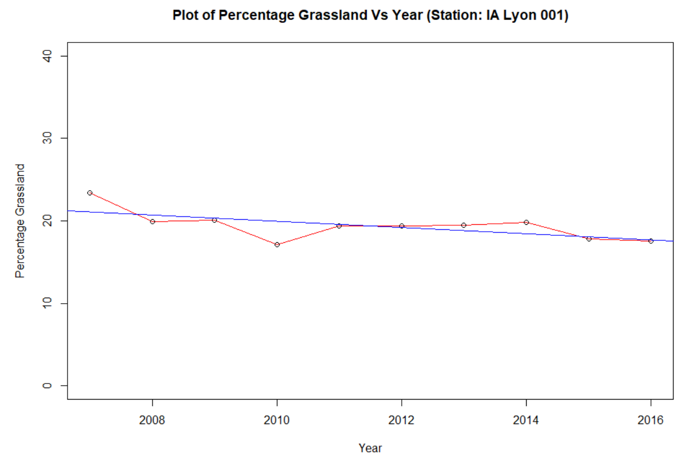
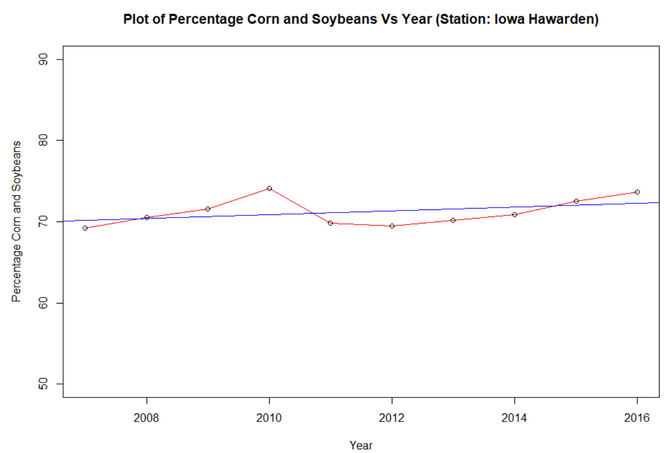
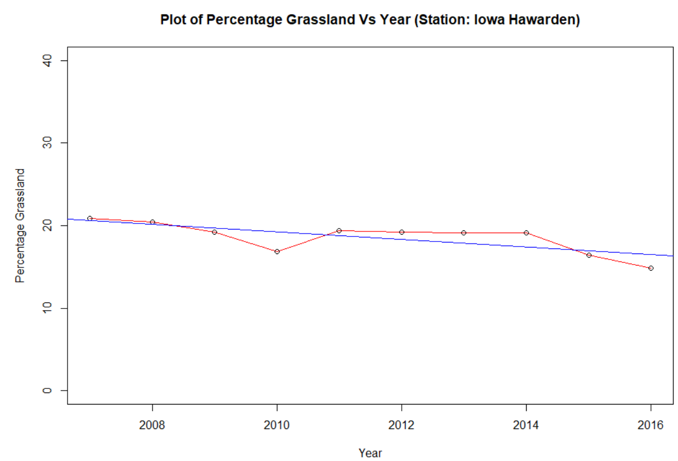
HUC12 Stations	Scatterplot/Man-Kendall test for corn/soybean	Scatterplot/Man-Kendall test for grassland
SD Grant SA1	 tau = 0.6, 2-sided pvalue =0.0200	 tau = -0.911, 2-sided pvalue =0.0003

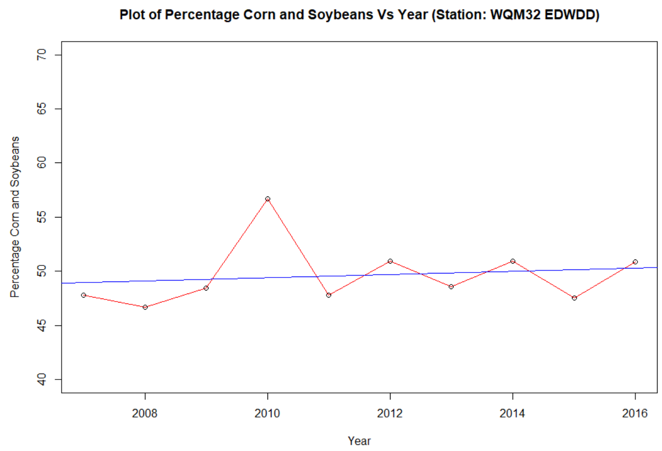
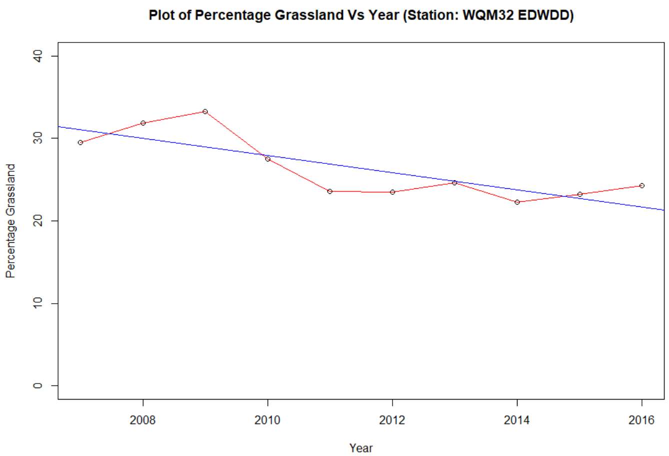
SD Codington K06	 tau = -0.743, 2-sided pvalue =0.0084	 tau = -0.644, 2-sided pvalue =0.0123
SD Hamlin S08	 tau = -0.0667, 2-sided pvalue =0.8580	 tau = -0.778, 2-sided pvalue =0.0023
SD Moody BSA		

	 tau = 0.378, 2-sided pvalue =0.1524	 tau = -0.333, 2-sided pvalue =0.2105
MN Pipestone 094	 tau = 0.0667, 2-sided pvalue =0.8580	 tau = -0.733, 2-sided pvalue =0.0042
MN Pipestone 099		

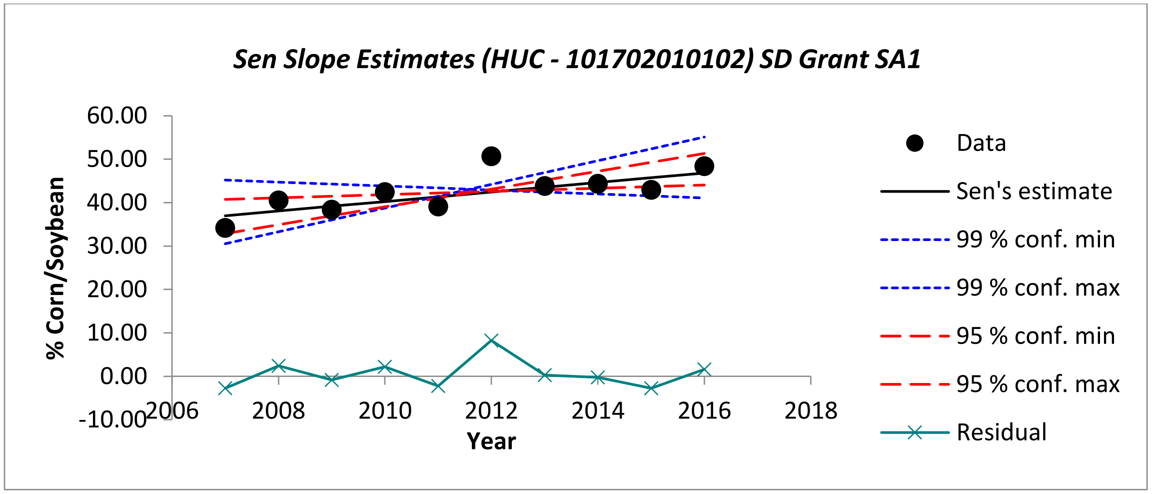
	 tau = 0.733, 2-sided pvalue =0.0042	 tau = -0.511, 2-sided pvalue =0.0491
MN Rock 528	 tau = 0.556, 2-sided pvalue =0.0318	 tau = -0.467, 2-sided pvalue =0.0736
MN Rock 811		

	 tau = 0.778, 2-sided pvalue =0.0023	 tau = -0.6, 2-sided pvalue =0.0200
R13 EDWDD	 tau = 0.156, 2-sided pvalue =0.5915	 tau = -0.6, 2-sided pvalue =0.0200

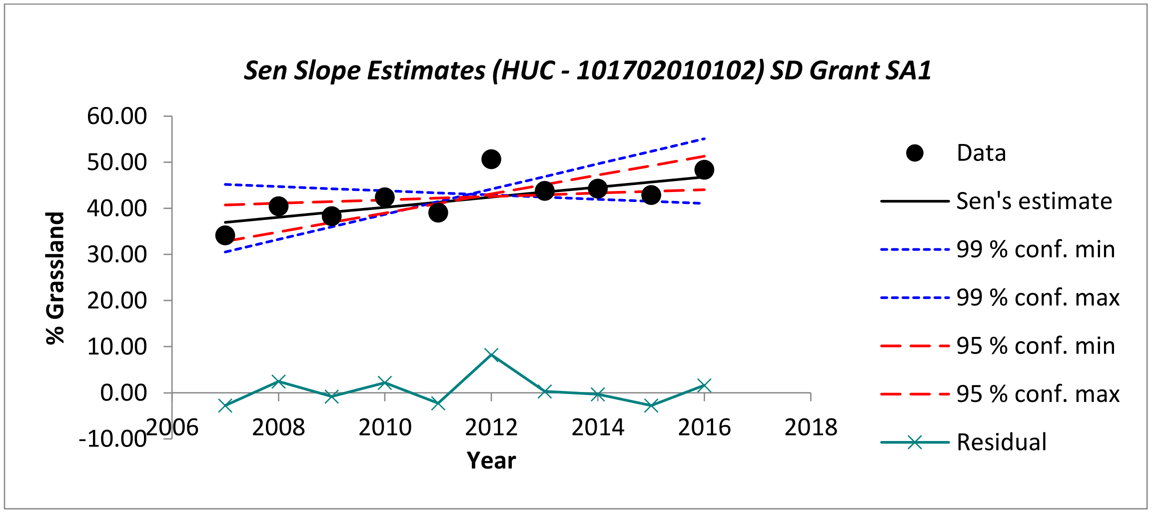
IA Lyon 001	 tau = 0.644, 2-sided pvalue =0.0123	 tau = -0.467, 2-sided pvalue =0.0736
Iowa Hawarden	 tau = 0.378, 2-sided pvalue =0.1524	 tau = -0.733, 2-sided pvalue =0.0042

WQM32 EDWDD	 tau = 0.156, 2-sided pvalue =0.5915	 tau = 0.422, 2-sided pvalue =0.1074

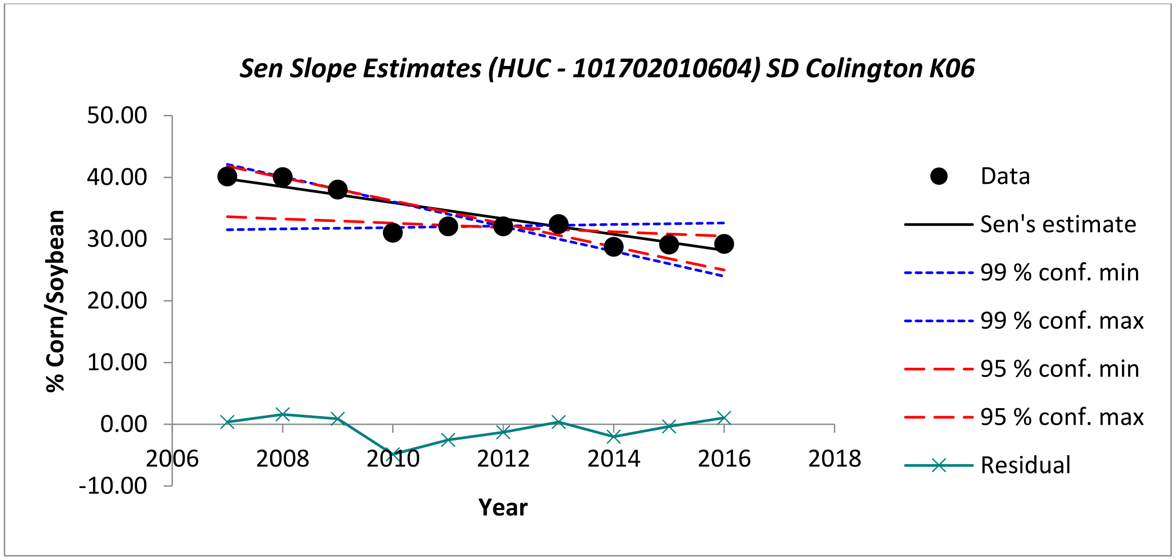
Appendix E: Sen Slopes for the percentage of corn/soybean and grassland class type for all the HUC12 catchments



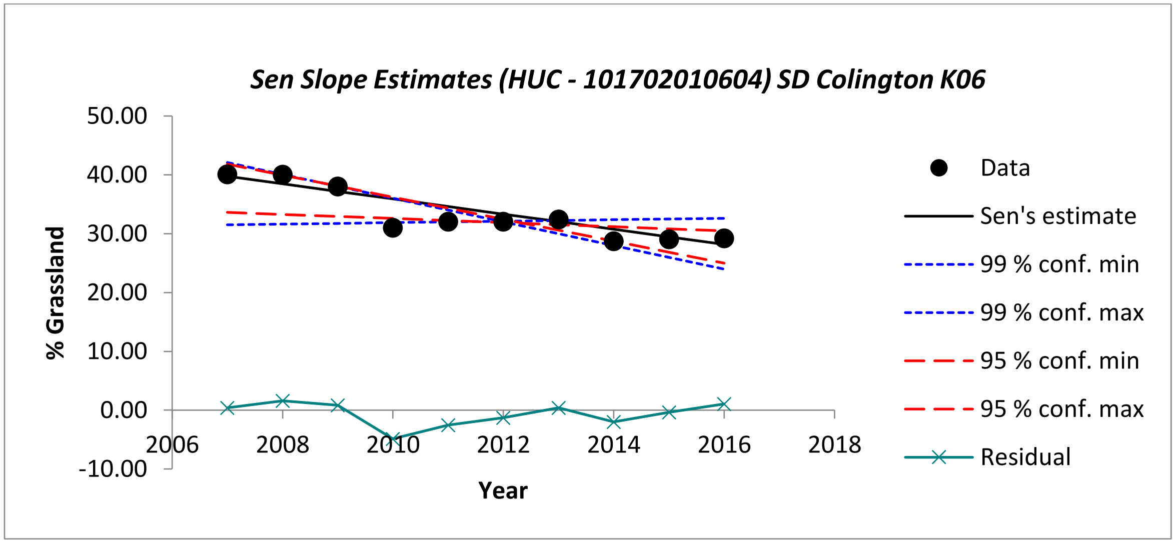
TsNumber	1
Name	% Corn/Soybean
Years	2007 - 2016
n	10
Test Z	2.33
Signific.	*



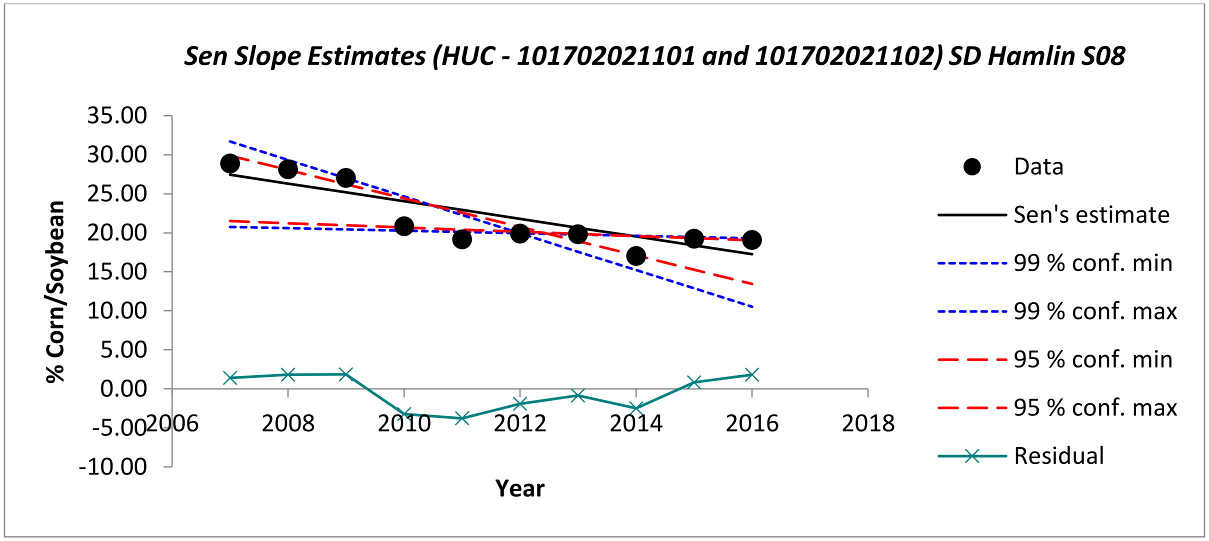
TsNumber	5
Name	% Grassland
Years	2007 - 2016
n	10
Test Z	-3.58
Signific.	***



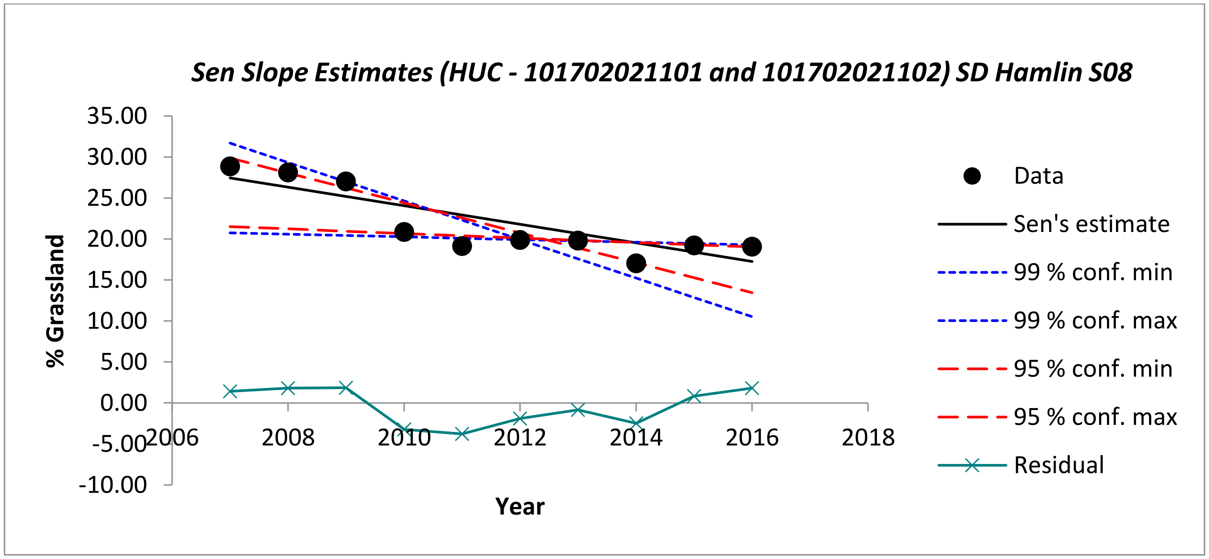
TsNumber	1
Name	% Corn/Soybean
Years	2007 - 2016
n	10
Test Z	2.68
Signific.	**



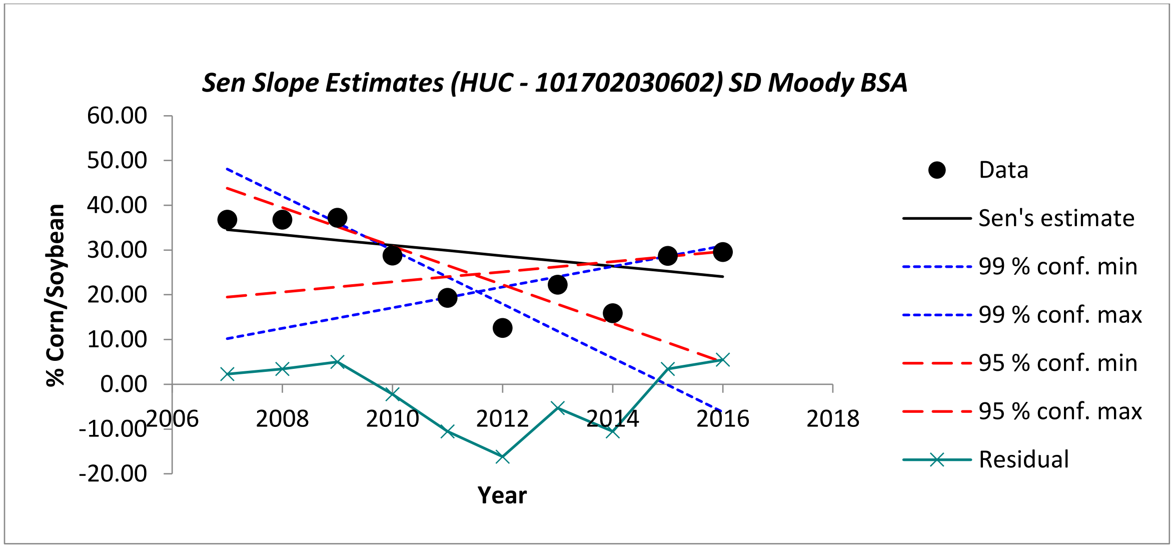
TsNumber	5
Name	% Grassland
Years	2007 - 2016
n	10
Test Z	-2.50
Signific.	*



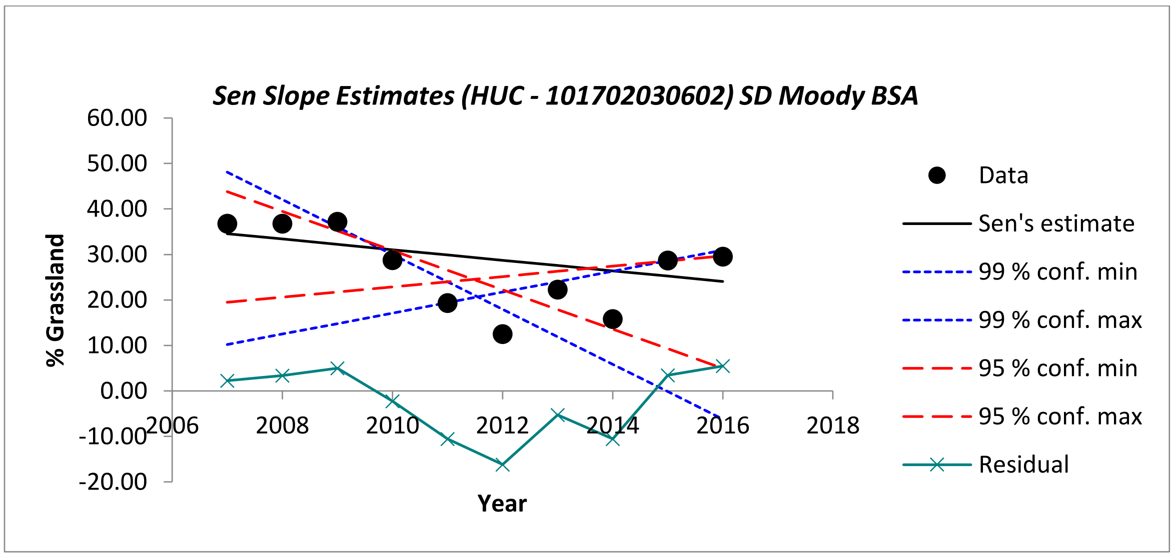
TsNumber	1
Name	% Corn/Soybean
Years	2007 - 2016
n	10
Test S	
Test Z	2.15
Signific.	*



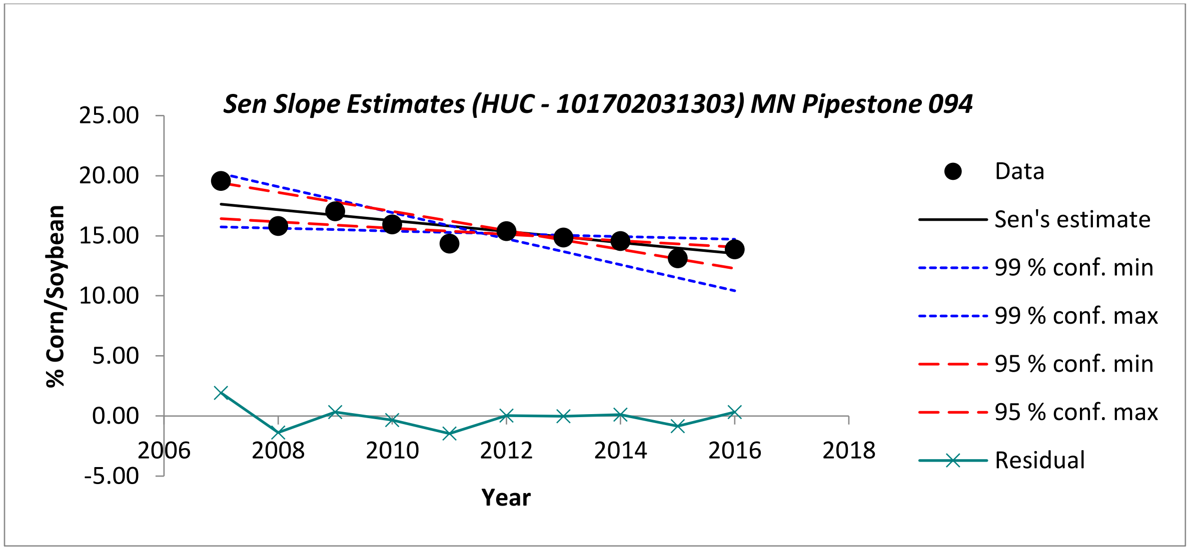
TsNumber	5
Name	% Grassland
Years	2007 - 2016
n	10
Test S	
Test Z	-3.04
Signific.	**



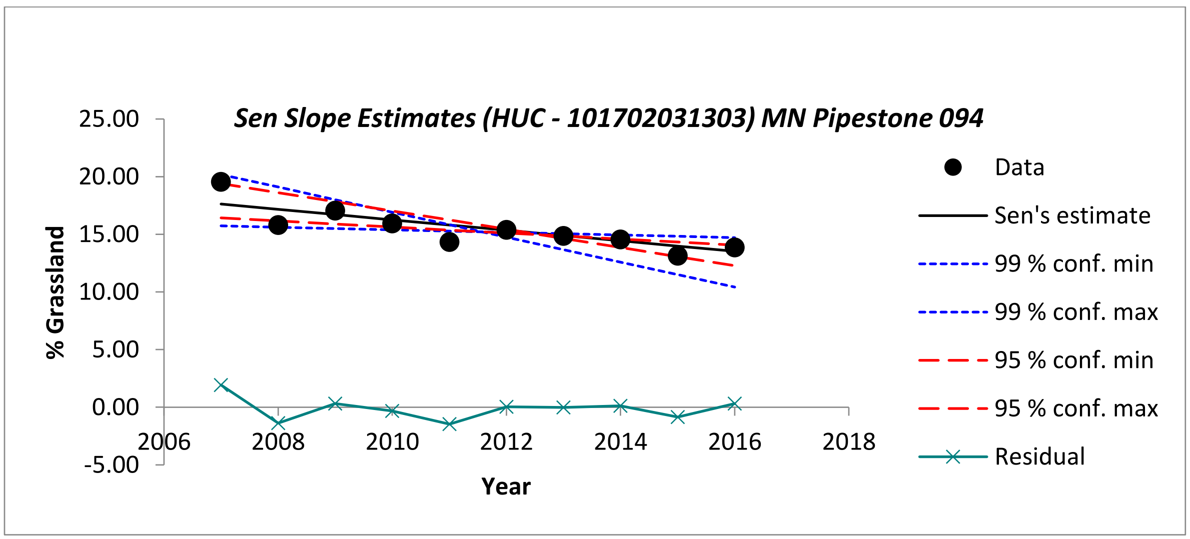
TsNumber	1
Name	% Corn/Soybean
Years	2007 - 2016
n	10
Test S	
Test Z	1.43
Signific.	



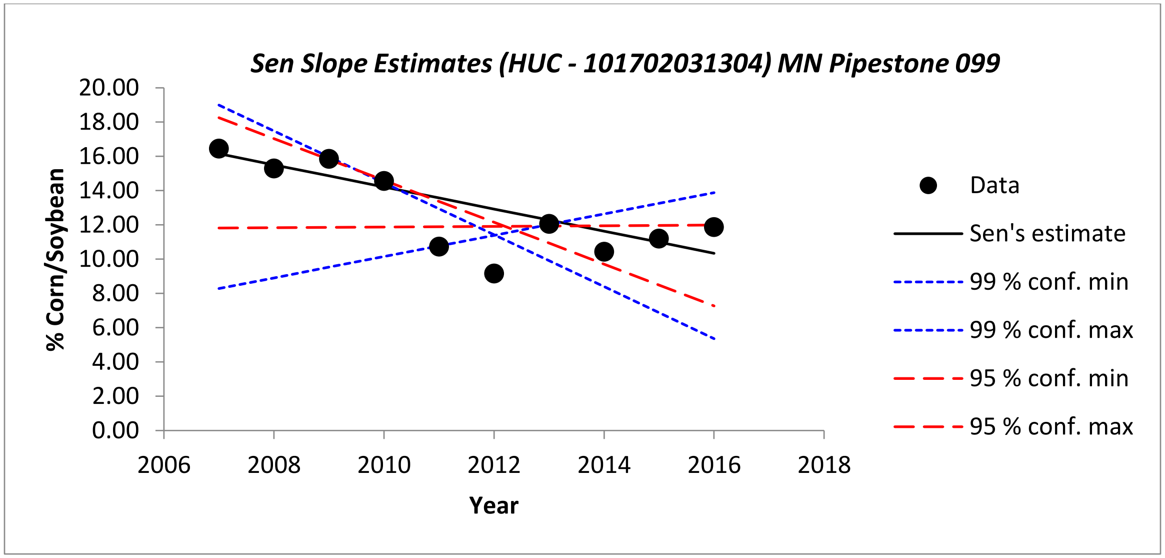
TsNumber	5
Name	% Grassland
Years	2007 - 2016
n	10
Test S	
Test Z	-1.25
Signific.	



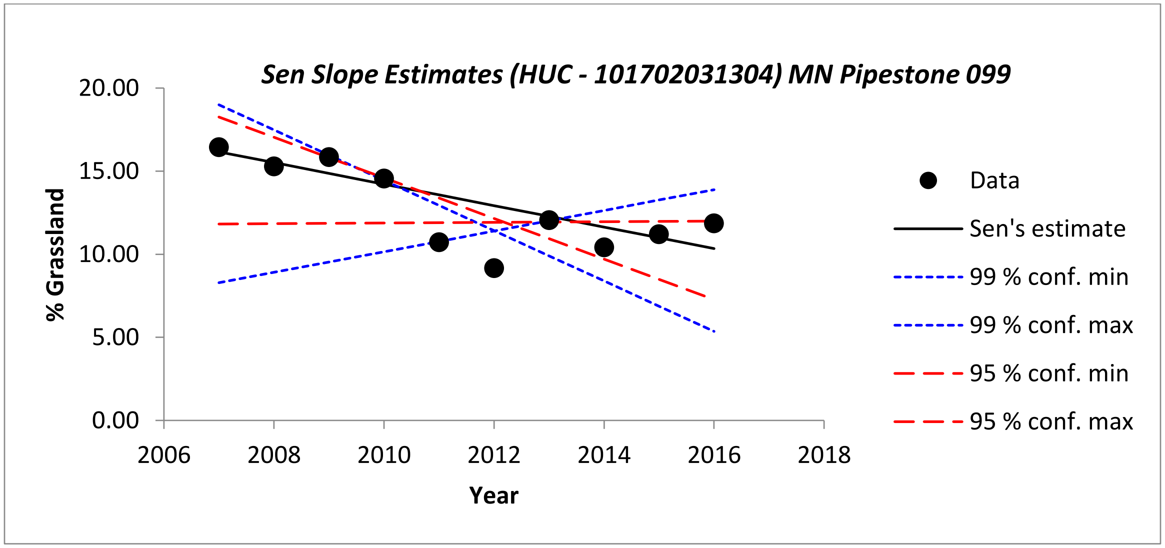
TsNumber	1
Name	% Corn/Soybean
Years	2007 - 2016
n	10
Test S	
Test Z	0.18
Signific.	



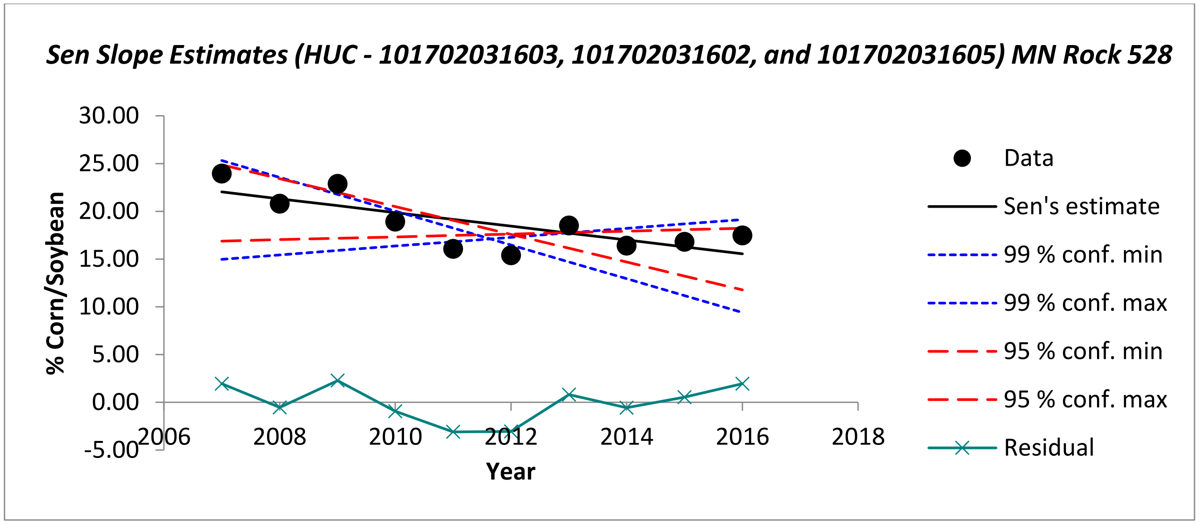
TsNumber	5
Name	% Grassland
Years	2007 - 2016
n	10
Test S	
Test Z	-2.86
Signific.	**



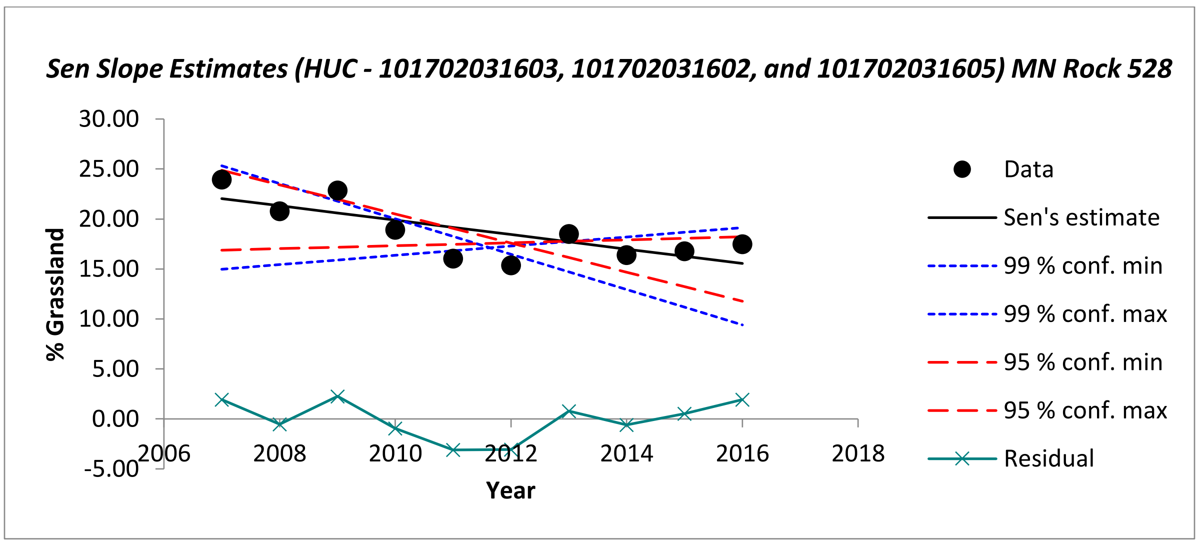
TsNumber	1
Name	% Corn/Soybean
Years	2007 - 2016
n	10
Test S	
Test Z	2.86
Signific.	**



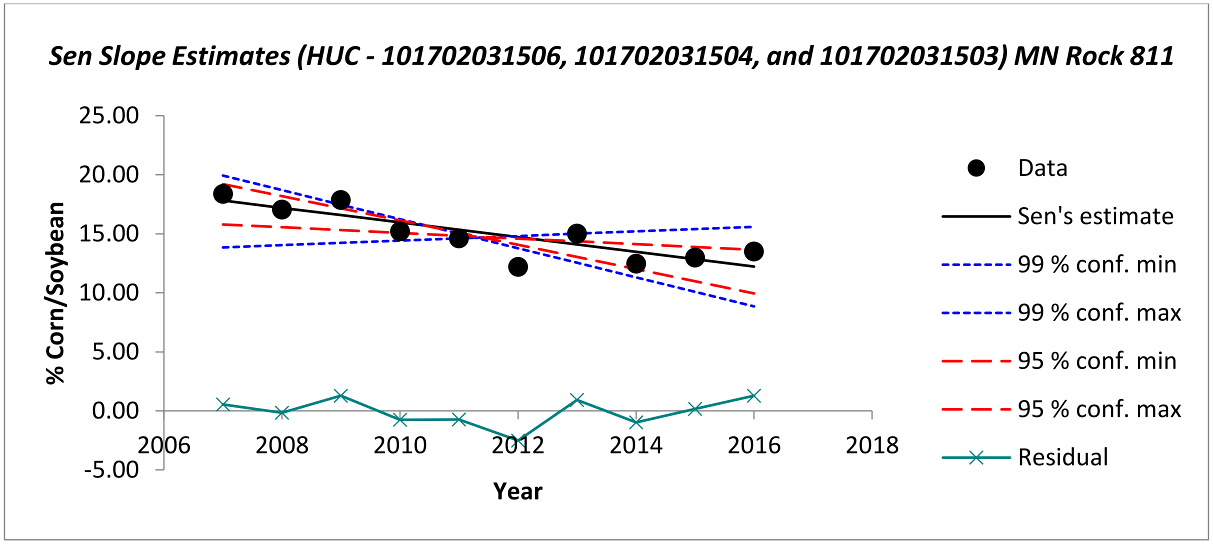
TsNumber	5
Name	% Grassland
Years	2007 - 2016
n	10
Test S	
Test Z	-1.97
Signific.	*



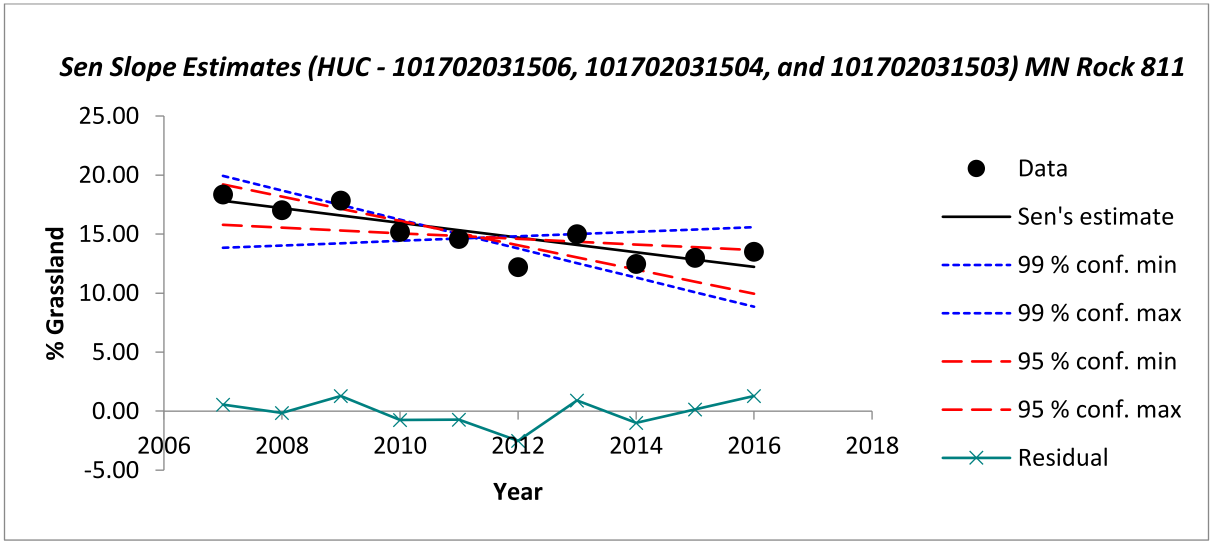
TsNumber	1
Name	% Corn/Soybean
Years	2007 - 2016
n	10
Test S	
Test Z	2.15
Signific.	*



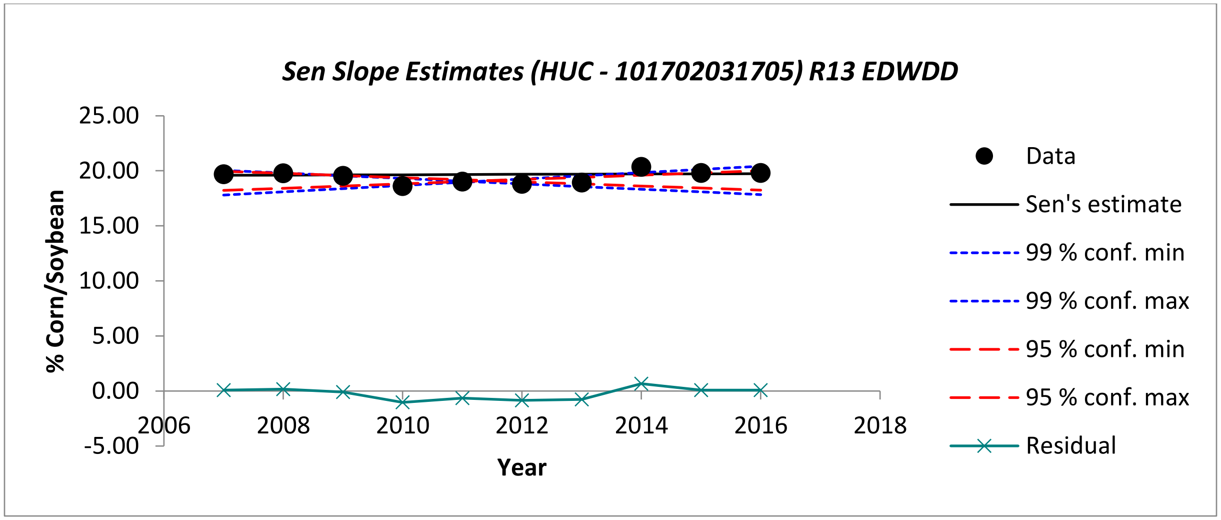
TsNumber	5
Name	% Grassland
Years	2007 - 2016
n	10
Test S	
Test Z	-1.79
Signific.	+



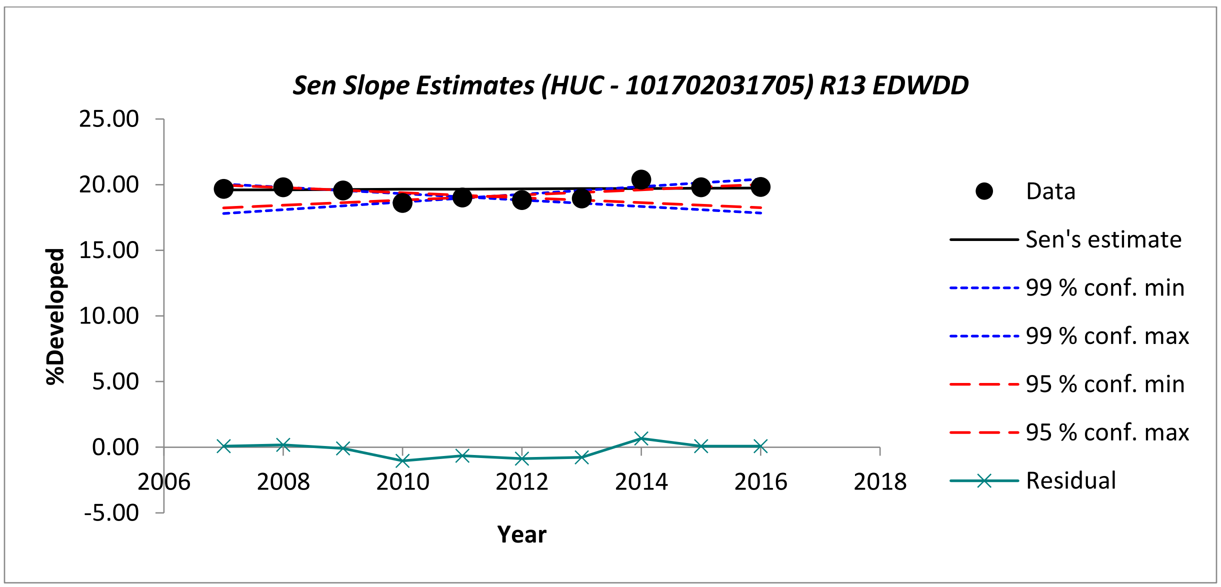
TsNumber	1
Name	% Corn/Soybean
Years	2007 - 2016
n	10
Test S	
Test Z	3.04
Signific.	**



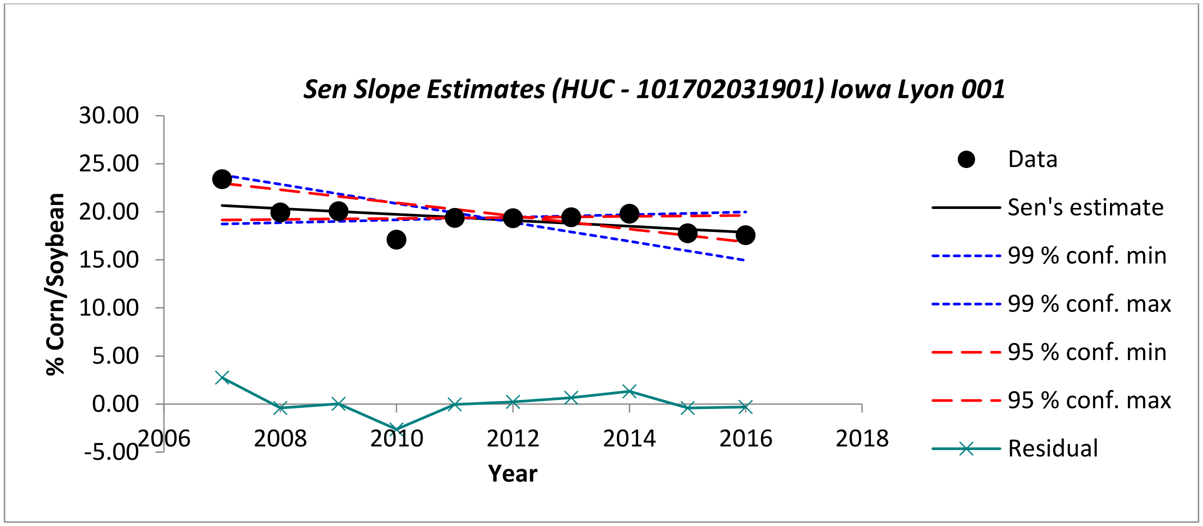
TsNumber	5
Name	% Grassland
Years	2007 - 2016
n	10
Test S	
Test Z	-2.33
Signific.	*



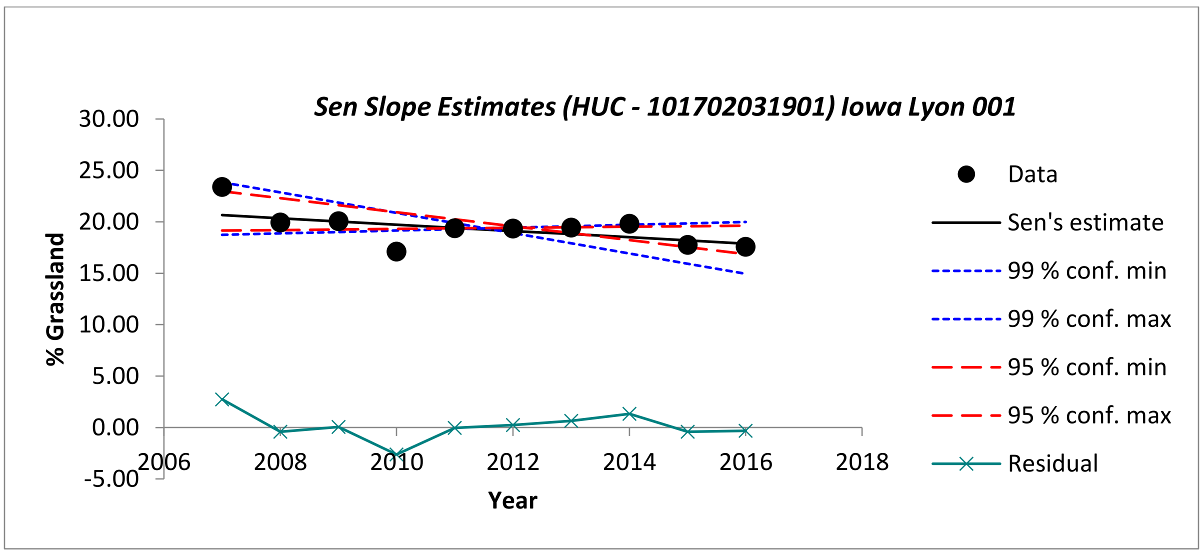
TsNumber	1
Name	% Corn/Soybean
Years	2007 - 2016
n	10
Test S	
Test Z	0.54
Signific.	



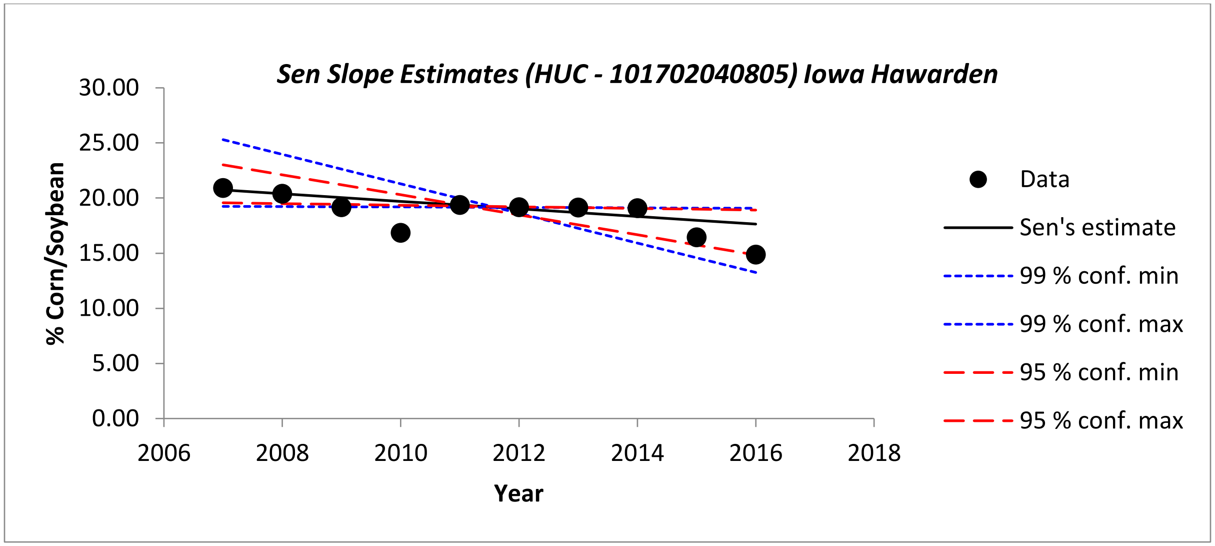
TsNumber	4
Name	%Developed
Years	2007 - 2016
n	10
Test S	
Test Z	0.72
Signific.	



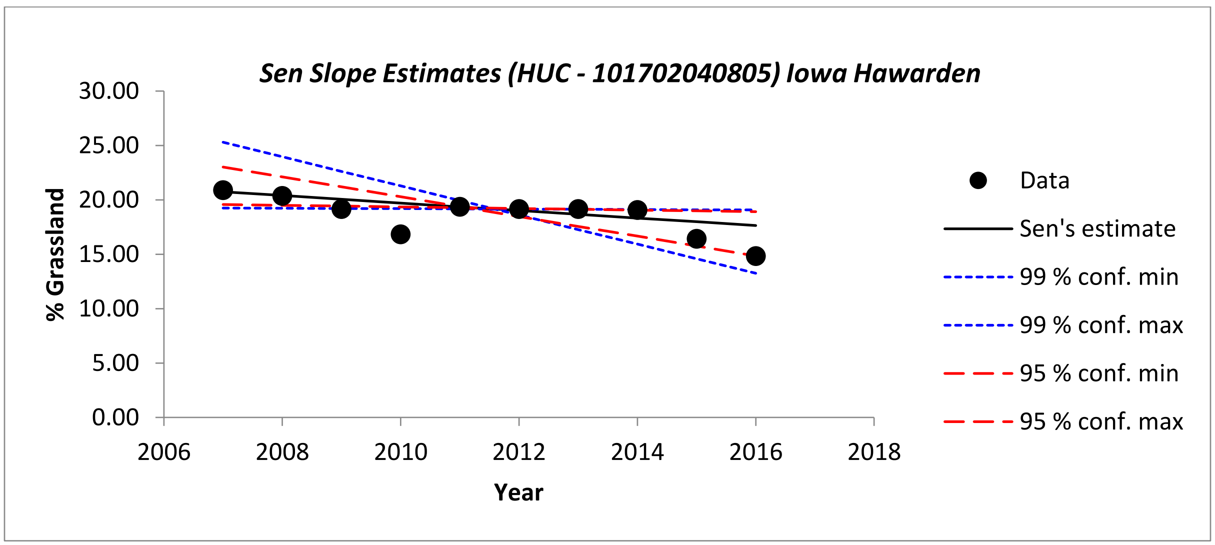
TsNumber	1
Name	% Corn/Soybean
Years	2007 - 2016
n	10
Test S	
Test Z	2.50
Signific.	*



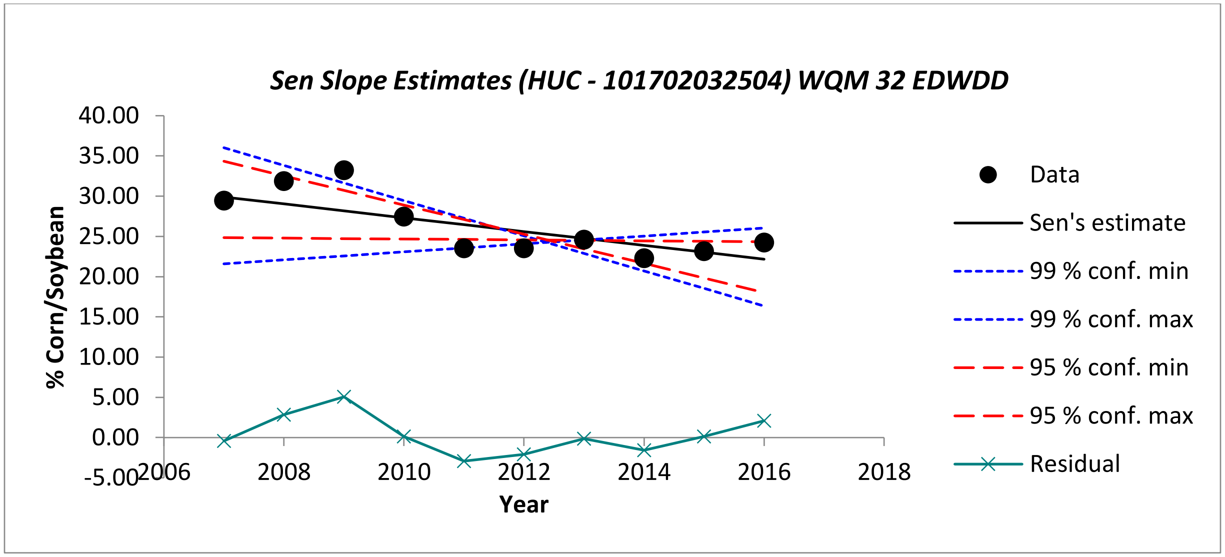
TsNumber	5
Name	% Grassland
Years	2007 - 2016
n	10
Test S	
Test Z	-1.79
Signific.	+



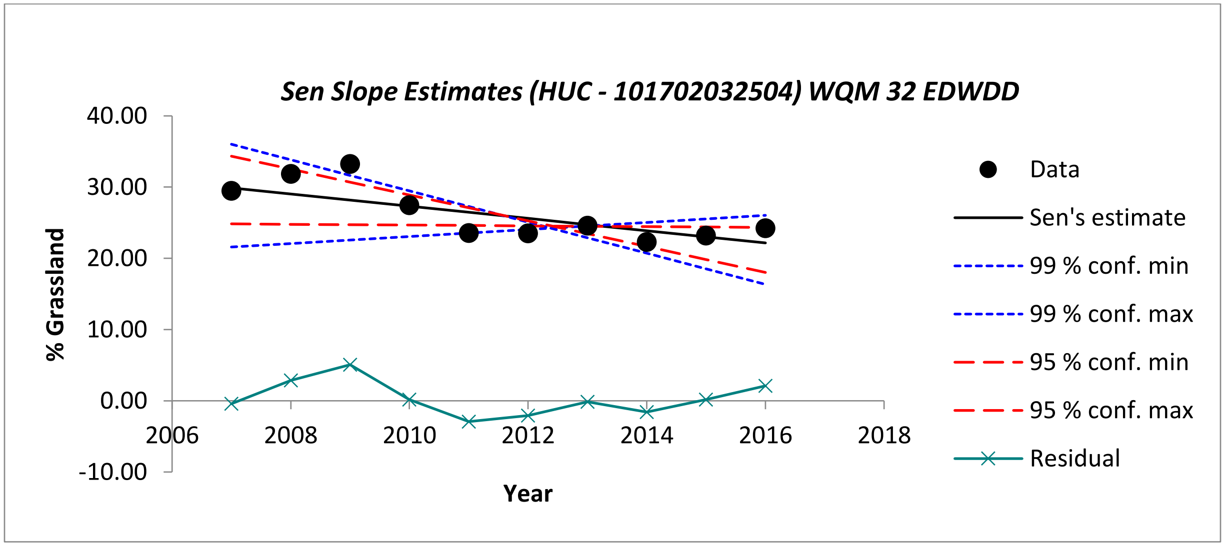
TsNumber	1
Name	% Corn/Soybean
Years	2007 - 2016
n	10
Test S	
Test Z	1.43
Signific.	



TsNumber	5
Name	% Grassland
Years	2007 - 2016
n	10
Test S	
Test Z	-2.86
Signific.	**



TsNumber	1
Name	% Corn/Soybean
Years	2007 - 2016
n	10
Test S	
Test Z	0.54
Signific.	



TsNumber	5
Name	% Grassland
Years	2007 - 2016
n	10
Test S	
Test Z	-2.15
Signific.	*

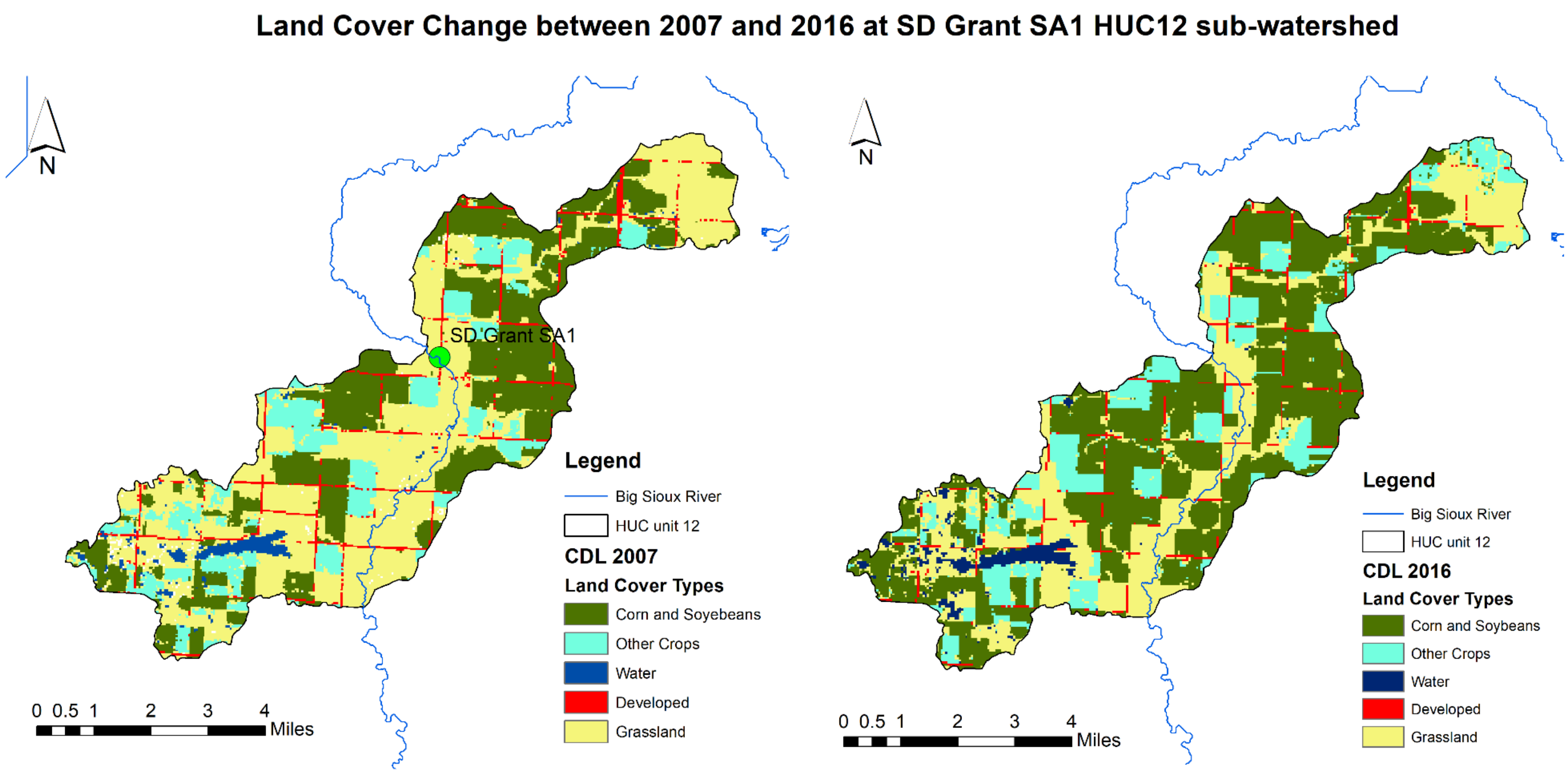
Appendix F: Summary of results from the Man-Kendall test and Sen's Slopes estimates for HUC12 Stations that didn't show a statistically significant trend

Gauging Stations / HUCs	Nitrates / Land Cover Trends	Mann-Kendall Test			Sen's Slope Estimate	
		Tau	p-value	Trend	Slope (Q)	Const (B)
MN Pipestone 094	Nitrate	0.524	0.033	Increasing	0.49	8.90
	Corn and Soybeans	0.067	0.858	No Trend	0.07	76.33
	Grassland	-0.733	0.004	Decreasing	0.46	17.63
SD Grant SA1	Nitrate	0.422	0.107	No Trend	0.70	1.00
	Corn and Soybeans	0.600	0.020	Increasing	1.09	36.97
	Grassland	-0.911	0.0003	Decreasing	-1.72	41.94
SD Hamlin S08	Nitrate	-0.067	0.858	No Trend	-0.01	1.84
	Corn and Soybeans	0.556	0.032	Increasing	0.96	54.34
	Grassland	-0.778	0.002	Decreasing	-1.13	27.44
SD Moody BSA	Nitrate	0.400	0.462	No Trend	0.19	0.22
	Corn and Soybeans	0.378	0.152	Increasing	0.47	57.33
	Grassland	-0.333	0.211	Decreasing	-1.17	34.55
MN Rock 528	Nitrate	0.167	0.602	No Trend	0.12	3.53
	Corn and Soybeans	0.556	0.032	Increasing	0.19	70.32
	Grassland	-0.467	0.074	Decreasing	-0.72	22.04
MN Rock 811	Nitrate	0.449	0.088	No Trend	0.24	4.99
	Corn and Soybeans	0.778	0.002	Increasing	0.32	72.92
	Grassland	-0.600	0.020	Decreasing	-0.62	17.82
R13 EDWDD	Nitrate	0.600	0.133	No Trend	0.16	2.79
	Corn and Soybeans	0.156	0.592	Increasing	0.30	36.62
	Grassland	-0.600	0.020	Decreasing	-1.17	39.46

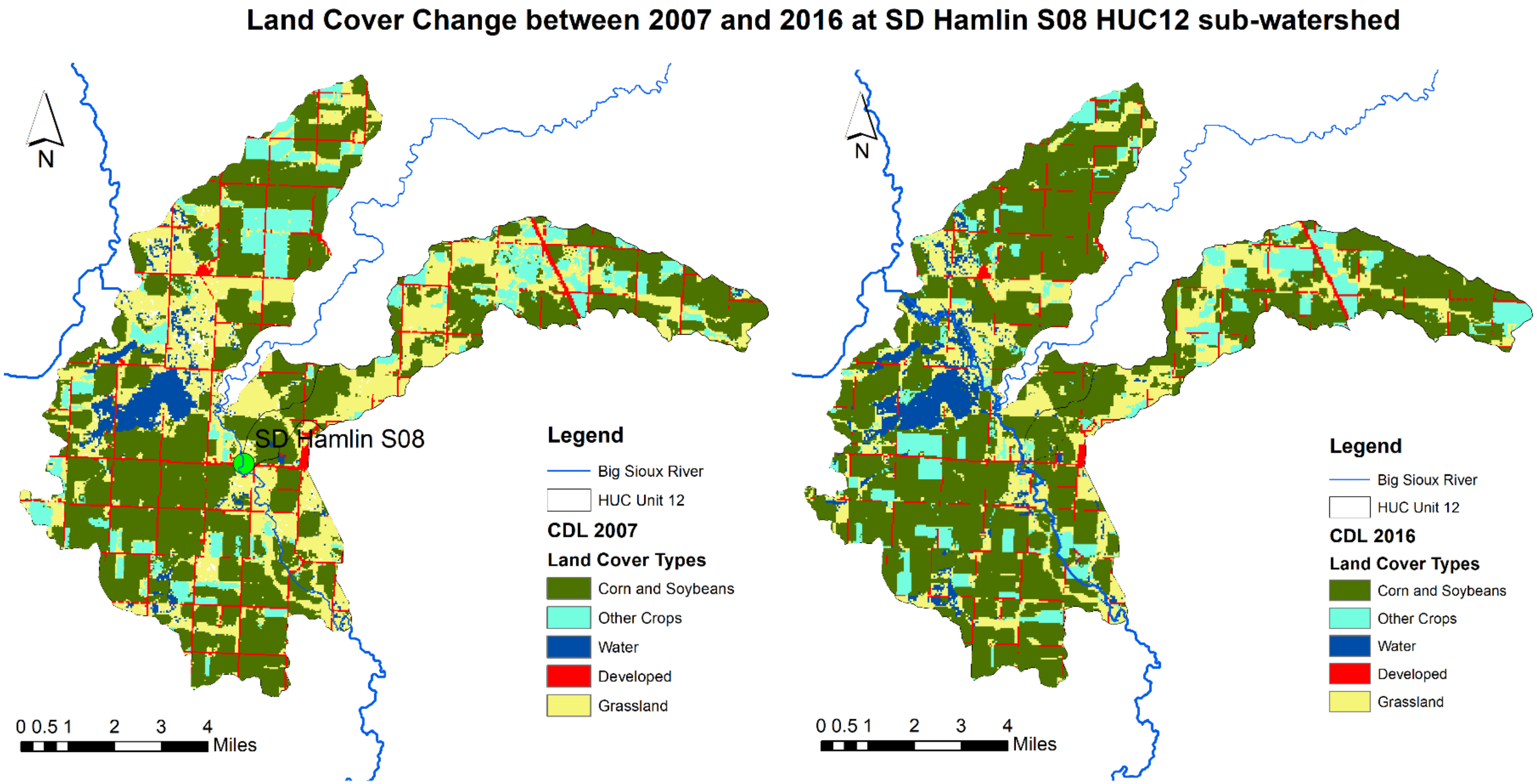
IA Lyon 001	Nitrate	-0.067	0.858	No Trend	-0.06	1.50
	Corn and Soybeans	0.644	0.012	Increasing	0.37	70.37
	Grassland	-0.467	0.074	No Trend	-1.31	20.66
Iowa Hawarden	Nitrate	0.048	1.000	No Trend	-0.06	1.50
	Corn and Soybeans	0.378	0.152	Increasing	0.30	69.69
	Grassland	-0.733	0.004	Decreasing	-0.34	20.74
WQM32 EDWDD	Nitrate	1.000	1.000	No Trend	3.98	27.25
	Corn and Soybeans	0.156	0.592	Increasing	0.31	47.81
	Grassland	-0.556	0.032	Decreasing	-0.86	28.89

Appendix G: Land Cover Changes for HUC12 Stations that didn't show a statistically significant trend

SD Grant SA1 (HUC12 = 101702010102)

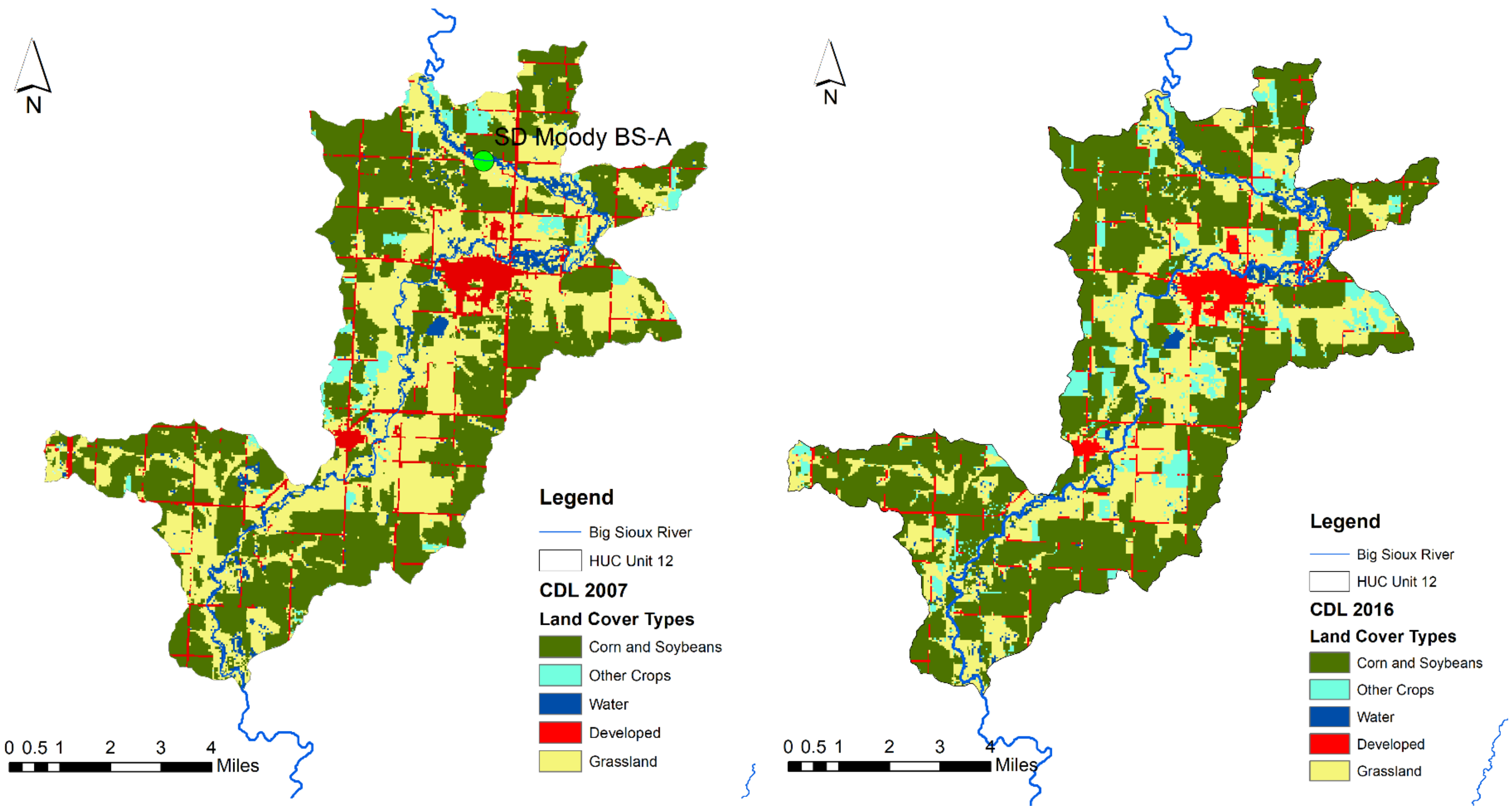


SD Hamlin S08 (HUC12 = 101702021101; 101702021102)

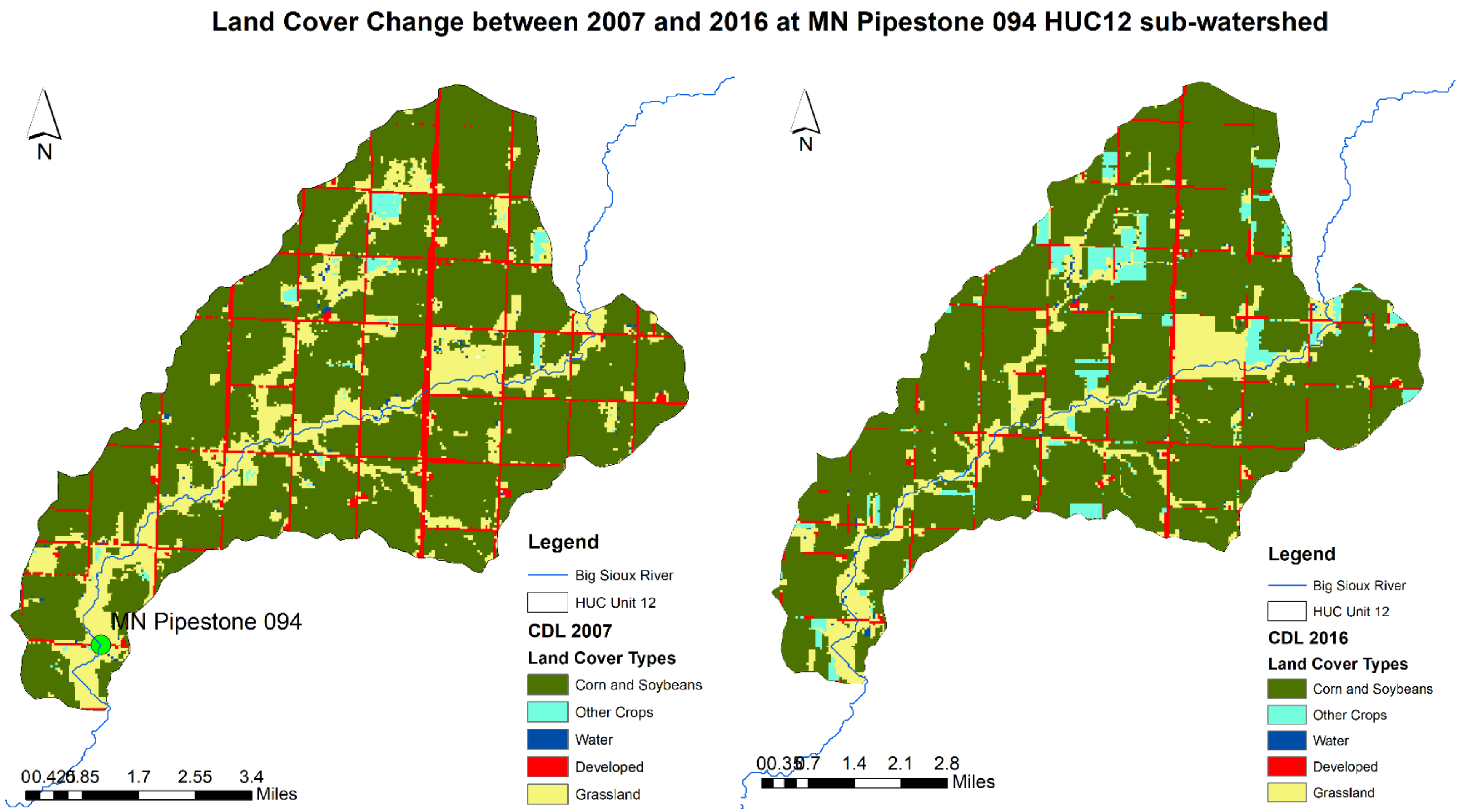


SD Moody BSA (HUC12 = 101702030602)

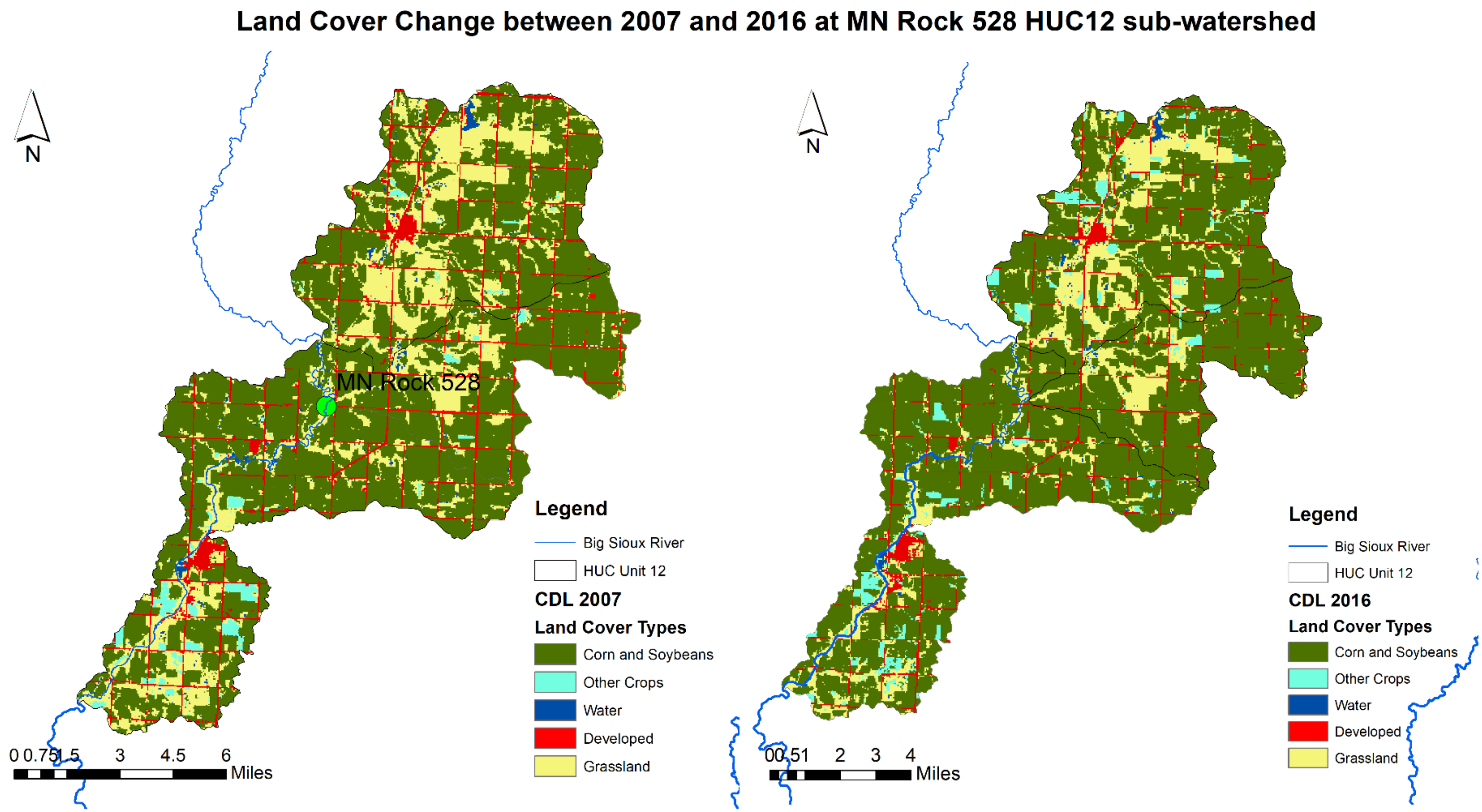
Land Cover Change between 2007 and 2016 at SD Moody BSA HUC12 sub-watershed



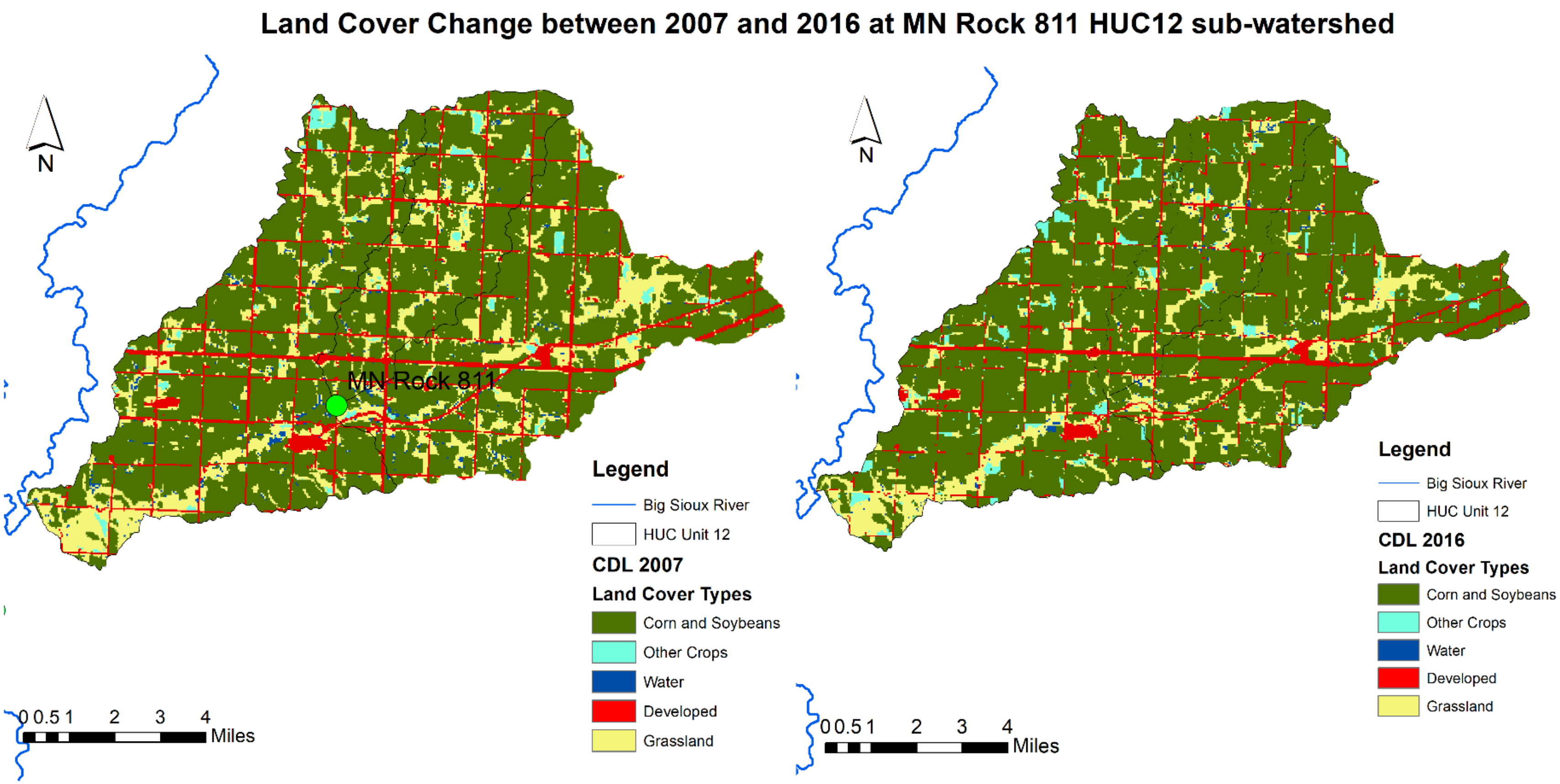
MN Pipestone 094 (HUC12 = 101702031303)



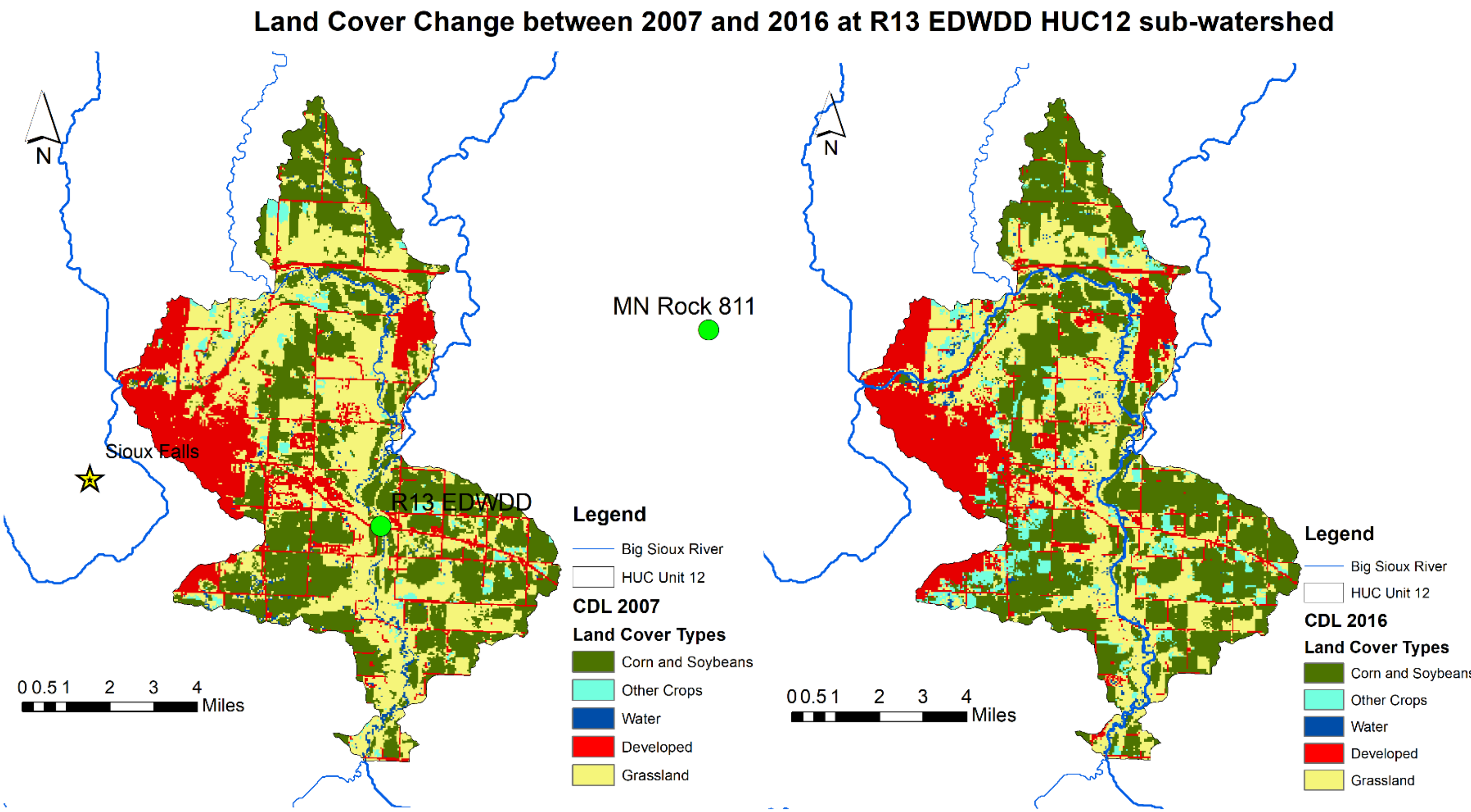
MN Rock 528 (HUC12 = 101702031603; 101702031602; 101702031605)



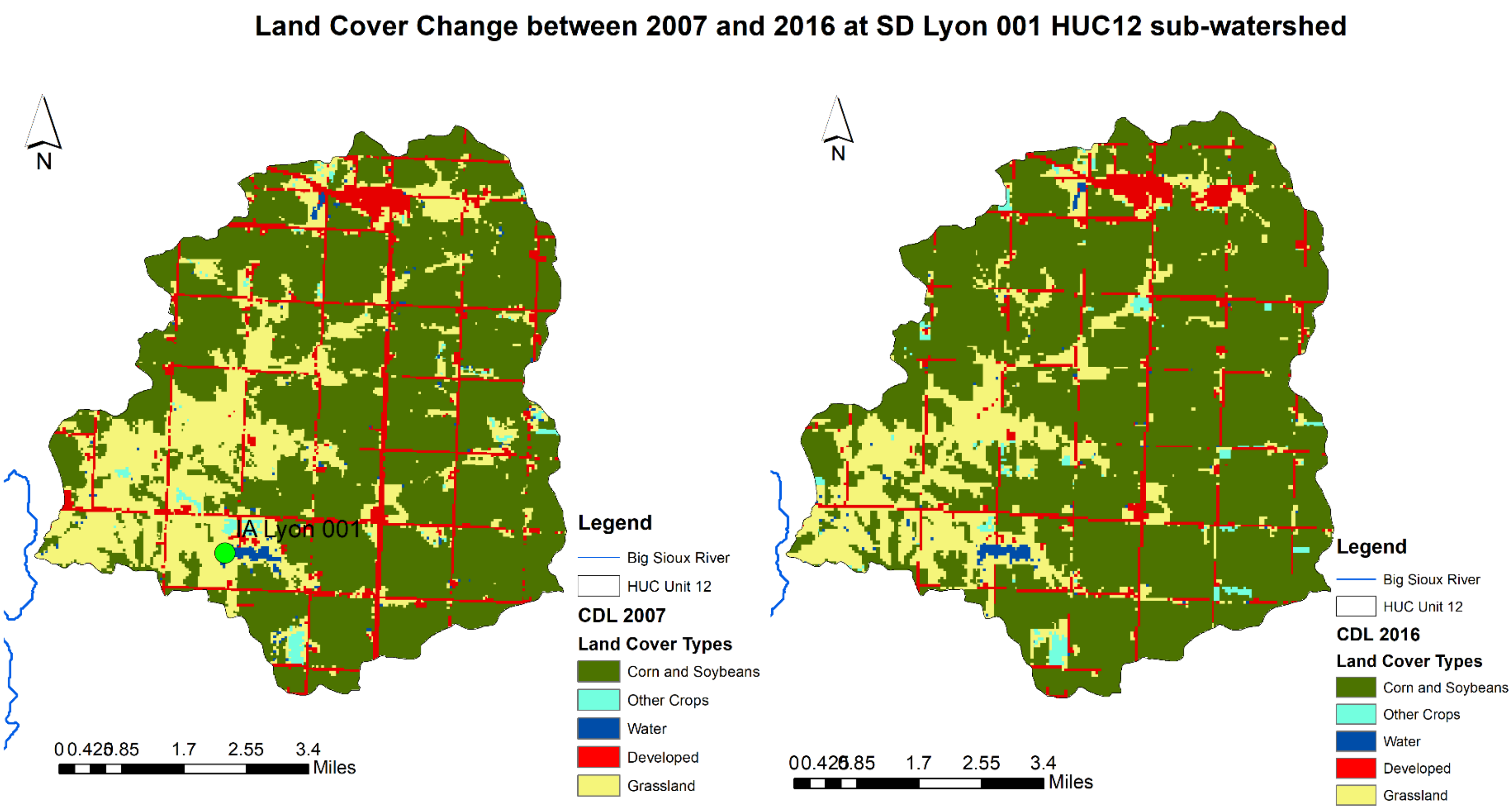
MN Rock 811 (HUC12 = 101702031506; 101702031504; 101702031503)



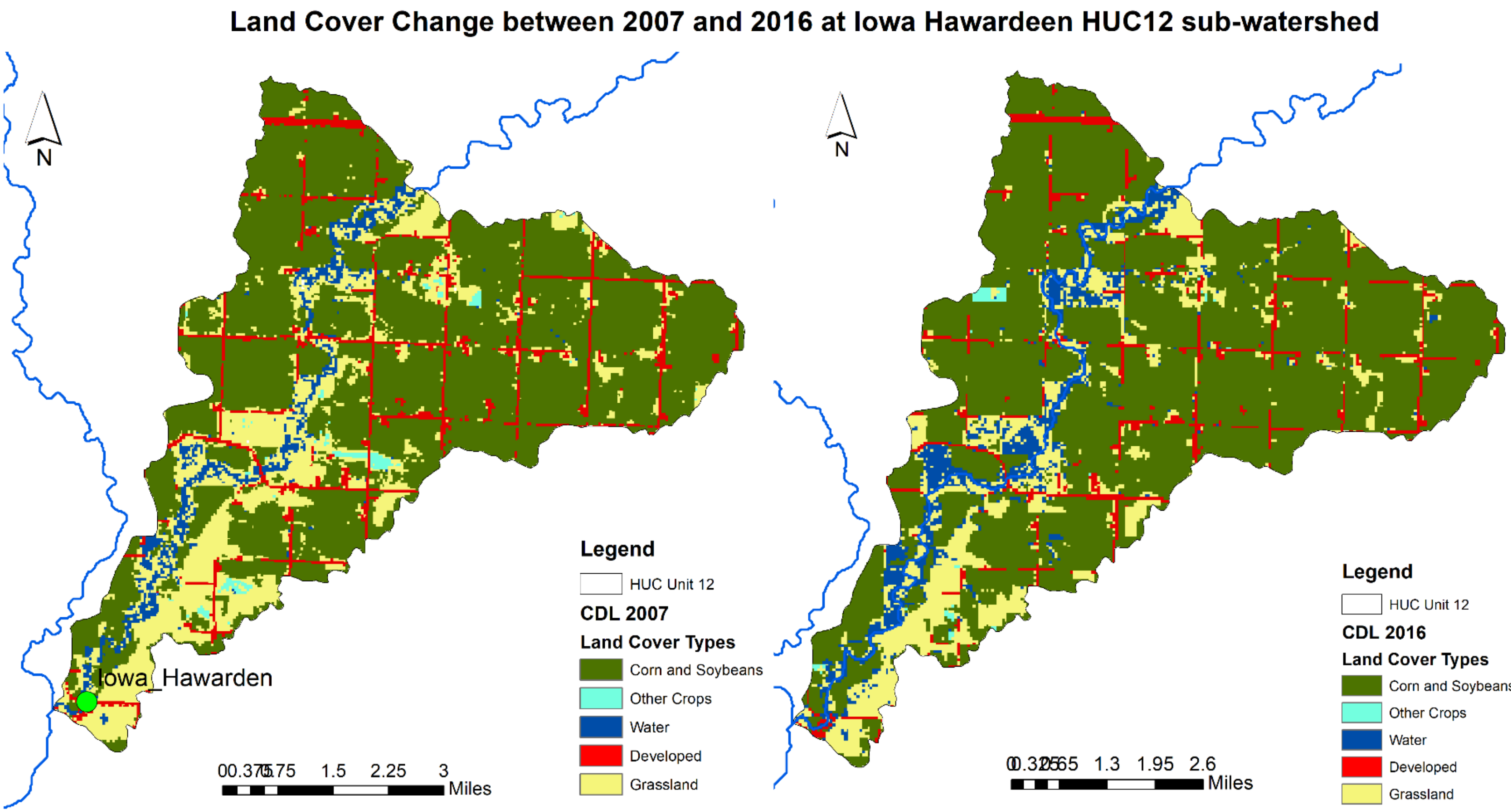
R13 EDWDD (HUC12 = 101702031705)



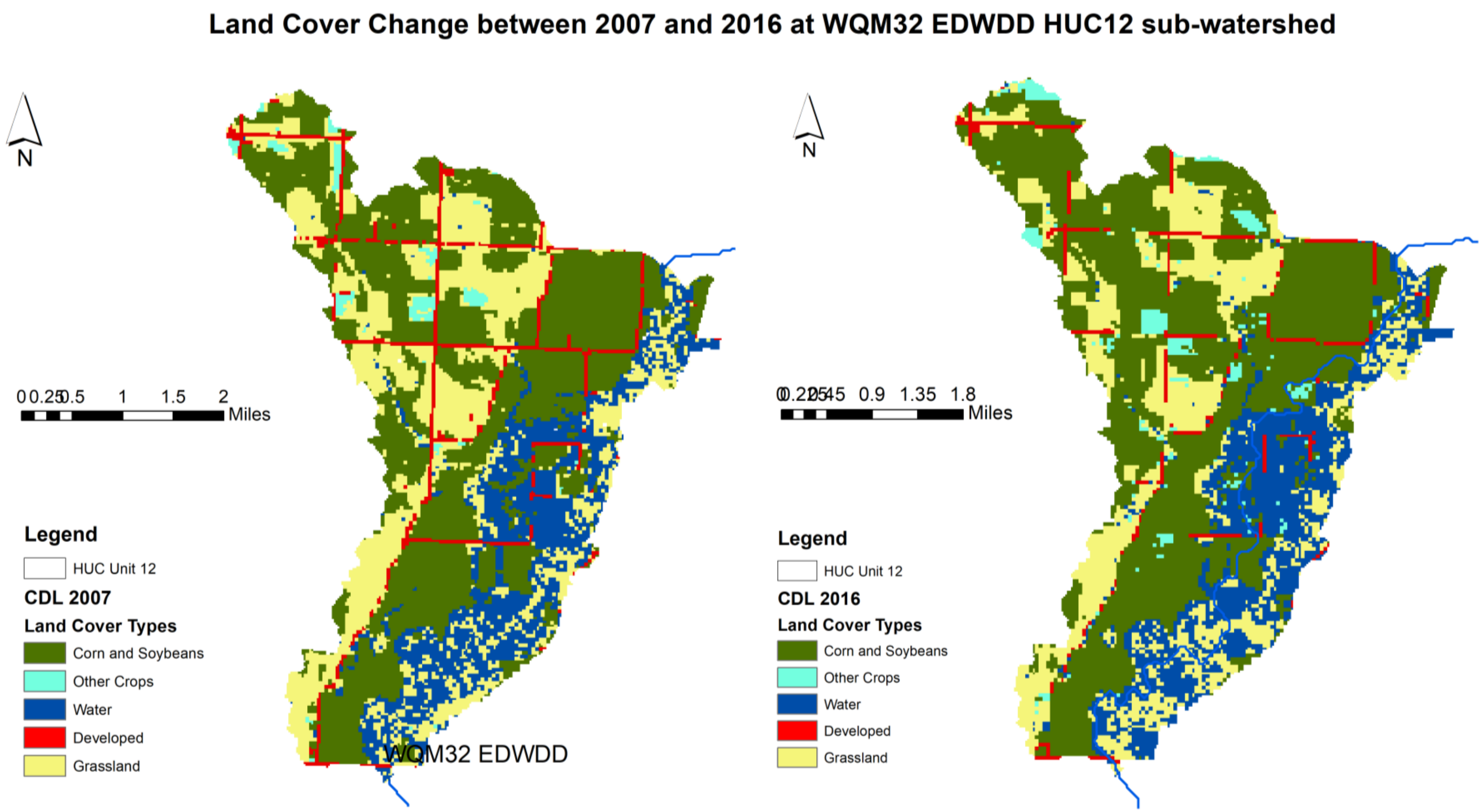
IA Lyon 001 (HUC12 = 101702031901)



Iowa Hawarden (HUC12 = 101702040805)



WQM32 EDWDD (HUC12 = 101702032504)



Appendix H: The MAKESENS template

The MAKESENS template was created using Microsoft Excel 97 and the macros were coded with Microsoft Visual Basic. The MAKESENS procedure is based on the nonparametric Mann-Kendall test for the trend and the nonparametric Sen's method for the magnitude of the trend. The FMI has developed both the MAKESENS application and the User Manual which are available in their official website http://en.ilmatieteenlaitos.fi/makesens) and are available for download.

The MAKESENS excel template is user friendly and easy to use. There are some terms that we need to understand before we use this application. The template takes the time series data, determines the first year and last year of the time series, and determines the number of annual values (n) in the calculation excluding missing values. Depending on the n values, the template does Test S or Test Z and displays in the output. For example, if n is 9 or less, the test statistic *S* is displayed. The absolute value of *S* is compared to the probabilities of the Mann-Kendall nonparametric test for trend (Gilbert 1987) to define if there is a monotonic trend or not at the level α of significance. A positive (negative) value of S indicates an upward (downward) trend. If n is larger than 9, this cell is empty. Similarly, if n is at least 10, the test statistic Z is displayed. The absolute value of Z is compared to the standard normal cumulative distribution to define if there is a trend or not at the selected level α of significance. A positive (negative) value of Z indicates an upward (downward) trend. If n is 9 or less, this cell is empty. In addition, the template displays the significance level of the data. If n is 9 or less, the test is based to the S statistic and if n is at least 10, the test is based to the Z statistic (normal approximation). The template uses four tested significance levels and the following symbols are used in the template:

*** if trend at $\alpha = 0.001$ level of significance
** if trend at $\alpha = 0.01$ level of significance
* if trend at $\alpha = 0.05$ level of significance
+ if trend at $\alpha = 0.1$ level of significance

If the cell is blank, the significance level is greater than 0.1.

Moreover, the template estimates the Sen's slope (Q) for the true slope of linear trend i.e. change per unit time period (in this case a year). The slopes are estimated four significance levels and termed as follows:

- **Qmin99**: the lower limit of the 99 % confidence interval of Q ($\alpha = 0.1$)

- **Qmax99**: the upper limit of the 99 % confidence interval of Q ($\alpha = 0.1$)

- **Qmin95:** the lower limit of the 95 % confidence interval of Q ($\alpha = 0.05$)

- **Qmax95**: the upper limit of the 95 % confidence interval of Q ($\alpha = 0.05$)

For a linear trend, the constant in the equations is termed as B, and is estimated as:

Constant **B**: f(year) = Q*(year - firstYear) + B. The constant B is estimated for four significance levels as:

- **Bmin99**: estimate of the constant Bmin99, f(year) = Qmin99 * (year - firstYear) + Bmin99 for 99% confidence level of linear trend

- **Bmax99:** estimate of the constant Bmax99, f(year) = Qmax99 * (year-firstYear) + Bmax99 for 99% confidence level of linear trend:

- **Bmin95:** estimate of the constant Bmin95, f(year) = Qmin95 * (year-firstYear) + Bmin95 for 95% confidence level of a linear trend:

- **Bmax95**: estimate of the constant Bmax95, f(year) = Qmax95 * (year-firstYear) + Bmax95 for 95% confidence level of a linear trend

When calculating the constants B in MAKESENS the time is used in the form:

t = year - firstYear, where firstYear is the first year of all data in the Annual data worksheet.

The confidence intervals are valid only if n is at least 10 and there are not many ties (equal values). If n is less than 10, the constants Q and B for the confidence intervals are not shown in MAKESENS.