NEW APPLICATIONS OF STEPL WATERSHED MODELING OF CAFO FEEDLOT RUNOFF AND IMPLICATIONS OF SURFACE WATER IMPACTS

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By
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NEW APPLICATIONS OF STEPL WATERSHED MODELING OF CAFO FEEDLOT RUNOFF AND IMPLICATIONS OF SURFACE WATER IMPACTS

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ABSTRACT

Concentrated Animal Feeding Operation (CAFO) cattle feedlot runoff is hydrologically modeled using the Spreadsheet Tool for Estimating Pollutants Load (STEPL). STEPL estimates the annual nutrient load of nitrogen and phosphorus, among other pollutants, by land use for a watershed. The Dry Creek Watershed Basin of Sioux County, Iowa, is delineated to capture runoff from large CAFO cattle feedlots. Feedlots are classified by digitizing land use data in ArcGIS, in order to estimate pollutant loads from each sub-watershed and determine the nutrient contributions from direct discharges from CAFO feedlots. Five CAFO feedlots are modeled within the Dry Creek watershed. The number of cattle confined at each CAFO ranges from 3,000 to 7,588 per sub-watershed. Cropland area comprises more than 80% of the total land use in all sub-watersheds, with the exception of one. STEPL assumes that cropland has added animal waste from land application of manure. STEPL also assumes feedlots are managed by routine scraping and removal to reduce some of the waste within the feedlots. Despite these assumptions, this modeling shows that CAFO feedlots discharge an estimated 67% to 98% of the nitrogen from the sub-watersheds compared to other land uses. Environmental impacts including dead zones, hypoxia, toxic algal blooms and other harmful aquatic impacts are attributed to excess nutrients. Many hydrological and water quality modeling studies seek to determine the source, transport and fate of nutrients in watersheds to address these environmental concerns. However, national land use data,

specifically National Land Cover Dataset (NLCD) data created and managed by U.S Geological Survey does not have feedlots as a land use class (Homer *et al*., 2014). It would be difficult to determine nutrient loads directly from runoff without adequate land use data to represent feedlot land area. This study estimated the nutrient loads in runoff using CAFO feedlots at a small watershed scale. This method can be further applied to a larger scale to estimate the magnitude of the contribution CAFOs have on watershed contamination.

APPROVAL PAGE

The faculty listed below, appointed by the Dean of the College of Arts and Sciences, have examined a thesis titled "New applications of STEPL watershed modeling of CAFO feedlot runoff and implications of surface water impacts." presented by Angela DeAngelo Acord, candidate for the Master of Science degree, and certify that in their opinion it is worthy of acceptance.

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CHAPTER 1

INTRODUCTION

Overview

This research examines the impact of industrial-sized concentrated animal feeding operations (CAFO) on streams, using the Spreadsheet Tool for Estimating Pollutant Loads (STEPL, 2011). Current hydrological watershed models assess environmental impacts and nutrient transport on large geographical scales, with limited land use classifications, which does not capture the significant impact of concentrated animal feeding operations on feedlot runoff (Howarth *et al*., 1996; Carpenter *et al*., 1998; Alexander *et al*., 2008; Greene *et al*., 2009). The innovation of this research is the application of STEPL, a best practices tool, to estimate annual pollutant loads from cattle feedlots by focusing on the sub-watershed scale. The sub-watersheds in this study range from approximately twenty-five acres to 953 acres, within the Dry Creek watershed of Sioux County, Iowa. The Dry Creek watershed encompasses approximately 32,133 acres, within the Mississippi River basin, which empties to the Gulf of Mexico.

Runoff from feedlots during precipitation events can carry manure and pollutants to streams and other surface waters. In this study STEPL specifically estimates the pollutant loads for nitrogen and phosphorus from each sub-watershed. STEPL uses a combination of inputs including; land use data, feedlot area, precipitation, soil conditions, runoff factors, and pollutant concentrations from animal waste. Fine resolution watershed modeling based on local data is imperative for evaluating feedlot runoff impacts, rather than models which estimate impacts by averaging data over large areas.

Agencies such as the U.S Department of Agriculture (USDA), the Natural Resources Conservation Service (NRCS), the Agriculture Research Service (ARS), and others use a combination of studies, monitoring, sampling, and modeling in order to assess water quality throughout the United States. Stakeholders such as local, state, and government agencies use these assessments to make policy and regulatory decisions in the most informed manner. Watershed models use a combination of data to establish links between water constituent sources, track constituent routes of transport, and help predict the effectiveness of management practices to watersheds. This fine resolution assessment has the potential to capture significant impacts missed in larger scale studies. This assessment can be used in consort with valuable larger scale assessments to elevate watershed impacts, and help to better protect water quality.

CAFO feedlot impacts are difficult to capture in a large scale watershed study. To estimate pollutant loads watershed models use soil data, precipitation data, and land use data. To estimate pollutant loads from feedlot runoff requires additional data including animal head count and feedlot land use area. Typically, feedlot area is not classified as a land use category, and therefore estimates do not capture their potentially significant impacts. For this reason, nutrient loads from feedlot runoff can be greatly underestimated. This study applies a different method of data gathering. Rather than using the national land use data which does not have feedlots classified, in this study, the land use data was digitized by hand using ArcGIS software in order to delineate accurate area of feedlots.

CAFO Defined

The Producers' Compliance Guide for CAFOs defines an animal feeding operation (AFO) as any animal feeding facility that meets two conditions; 1) animals are confined for at least forty- five days within any twelve month period, 2) and crops or other vegetation are not sustained in animal enclosures (EPA, 2003). As CAFO is a subset of an AFO, it must first meet the definition of an AFO. Animal weight and waste amount per animal defines the size thresholds for each animal sector. The EPA provides the size thresholds for each animal sector to determine CAFO size; as a large, medium, or small facility (Table 1).

Table 1. EPA animal sector table showing size thresholds for different animal types (EPA, 2014).

Animal Sector	Size Thresholds (number of animals)		
	Large CAFOs	Medium CAFOs[1]	Small CAFOs[2]
cattle or cow/calf pairs	1,000 or more	300 - 999	less than 300
mature dairy cattle	700 or more	200 - 699	less than 200
veal calves	1,000 or more	300 - 999	less than 300
swine (weighing over 55 pounds)	2,500 or more	750 - 2,499	less than 750
swine (weighing less than 55 pounds)	10,000 or more	3,000 - 9,999	less than 3,000
horses	500 or more	150 - 499	less than 150
sheep or lambs	10,000 or more	3,000 - 9,999	less than 3,000
turkeys	55,000 or more	16,500 - 54,999	less than 16,500
laying hens or broilers (liquid manure handling systems)	30,000 or more	9,000 - 29,999	less than 9,000
chickens other than laying hens (other than a liquid manure handling systems)	125,000 or more	37,500 - 124,999	less than 37,500
laying hens (other than a liquid manure handling systems)	82,000 or more	25,000 - 81,999	less than 25,000
ducks (other than a liquid manure handling systems)	30,000 or more	10,000 - 29,999	less than 10,000
ducks (liquid manure handling systems)	5,000 or more	1,500 - 4,999	less than 1,500

[1]Must also meet one of two "method of discharge" criteria to be defined as a CAFO or may be designated.
[2] Never a CAFO by regulatory definition, but may be designated as a CAFO on a case-by-case basis.

This study evaluates large cattle CAFO's, which are concentrated animal feeding operations that feed 1,000 or more head of cattle. Agricultural terminology commonly uses "CAFO" and "AFO" interchangeably. "CAFO" is routinely used as an acronym to describe a large CAFO, and an "AFO" is an acronym commonly used to describe any size animal feeding operation. Figures 1 and 2 are images of CAFO feedlots and CAFO confinements, respectively.

Figure 1. (Left) Image from High Country News, 2011 depicts a large cattle CAFO. Figure 2. (Right) Image from the Producers Compliance Guide for CAFOs, 2003 depicts runoff from a cattle confinement.

A CAFO can confine or hold and feed cattle in outdoor feedlots or pens as depicted in Figure 1. Cattle can alternatively be held in partial or total confinement barns. There are two types of confinement barns which provide cattle shelter. A total confinement barn confines cattle entirely under roof. A partial confinement barn allows animals' outdoor access yet provides some shelter, as depicted in Figure 2. In this study, feedlots are the subject of interest to determine the amount of pollutants they contribute in runoff.

CAFO's confine and feed a large number of cattle within a small area, which concentrates the amount of manure and pollutants to a localized area. The numbers of animals CAFOs confine at one facility ranges from hundreds to hundreds of thousands. This can lead to a high volume of waste generated at a facility. "Feedlots with less than 1,000 head of capacity compose the vast majority of U.S. feedlots, but market a relatively small share of fed cattle. In contrast, lots [feedlots] with 1,000 head or more of capacity compose less than 5 percent of total feedlots, but market 80- to 90-percent of fed cattle. Feedlots with 32,000 head or more of capacity market around 40-percent of fed cattle" (USDA, 2012). These statistics speak to the immense number of cattle that are confined in U.S. feedlots. The United States has the largest cattle industry in the world, and is the largest producer of domestic and exported beef (USDA, 2012). "As the structure of animal agriculture has shifted toward fewer, but larger operations and as the percentage of animals in confinement has increased, utilization and disposal of animal waste has become an issue of environmental concern" (Kellogg, 2000).

Cattle and other livestock have been raised for human consumption in the U.S. for centuries. However, the difference between older farms, ranches and pastures versus today's CAFOs is the magnitude of animals confined in a small area. Feedlots are not intended to sustain cattle by grazing, but rather to confine cattle and feed them in place. Restricting movement allows them to gain weight faster. Today CAFOs produce most cattle and other livestock raised for human consumption (Burkholder*et al*., 2007). Thus, by concentrating the number of animals in a small area, the amount of manure and pollutants are also concentrated. "The U.S. Department of Agriculture estimates that operations which confine livestock and poultry animals generate about 500 million tons of manure annually- three times EPA's estimate of 150 million tons of human sanitary waste produced annually in the U.S." (EPA, 2012). Food animals produce nearly 5 times the waste produced by humans. There is concern as CAFOs continue to grow and become more spatially concentrated, that they will produce more manure than can be assimilated into cropland through land application (Copeland, 2010). For example, if a CAFO produces 6,000 tons of manure annually, they must have adequate land area to properly dispose of manure. If the facility plans to land apply 12 tons of manure per acre they must have at least 500 acres of land available. The USDA asserts their concerns that as the manure nutrients exceed the assimilative capacity of a region, this increases the likelihood that nutrients will runoff and become a water quality issue. (Copeland, 2010).

Environmental Impacts

CAFOs that are illegally discharging manure and other animal related waste to water are a serious threat to human health and water quality. The magnitude of this concern has lead CAFOs to be one of the EPA's National Enforcement Initiatives, which focuses on identifying violations and enforcing compliance with the Clean Water Act (EPA, 2014). CAFOs contribute pollutants to streams, rivers, lakes and other water bodies. Manure solids and animal production related process wastewater contains; nitrogen and phosphorus, organic matter, solids, pathogens and bacteria, and odorous/volatile compounds, salts, trace elements and metals, antibiotics, pesticides and hormones (Burkholder *et al*., 2007; Thorne, 2007; Copeland, 2010; EPA, 2012). Production related process wastewater is any water that comes into contact with the production of the animals which includes; raw materials, products, or by-products including manure, litter and feed (EPA, 2003). The EPA's 2000 National Water Quality Inventory reports that agriculture is the leading contributor to stream pollution (Copeland, 2010).

Dramatic observable ecological impacts from CAFO contamination include massive fish kills caused by low dissolved oxygen (Copeland, 2010; EPA, 2012). Impacts from CAFO runoff to streams have been documented as far as 30 km (18.64 miles) downstream from the discharge point. Downstream impacts include anoxic conditions, extremely high concentrations of ammonium, total phosphorus, suspended solids, and fecal coliform bacteria

(Burkholder *et al.* 1997; Mallin *et al*., 2000; Burkholder *et al*., 2007). Toxic algal blooms are also a negative impact due to decomposing organic matter from CAFO process wastewater discharges (EPA, 2012). Chapter 2 discusses CAFO environmental impact in greater detail.

Transport of stream contamination by manure and process wastewater can occur through different routes. Contaminants can enter a stream by animals with direct access to a stream, such as stream flow through the animal production area. Manure is managed by CAFO operators through feedlot and pen scrapping or the collection methods. Manure collected is stockpiled or otherwise stored awaiting land application. This manure management practice done routinely can reduce the amount of manure concentrated within the pens. However, this management practice does not ensure pollutants will not reach nearby streams. Further, stockpiled manure creates another source for pollutant runoff when these stockpiles are not managed properly.

Land application of manure is another environmental concern. Application of manure solids to cropland should be done at agronomic rates, or rates nutrients can be sufficiently taken up by crops. However, if manure and other animal related process wastewater are over applied, at rates that nutrients cannot be taken up by crops, these added nutrients will runoff or discharge into nearby surface water. Even when applied at agronomic rates, land applied manure can runoff and contaminate streams (Burkholder *et al*., 2007). This study evaluates pollutant transport from direct runoff from cattle feedlots or pens, facilitated by precipitation. During a precipitation event in which runoff would occur, manure solids and other process wastewater will discharge from feedlots and flow to the nearest stream.

“There is substantial documentation of major, ongoing impacts on aquatic resources from CAFOs, but many gaps in understanding remain” (Burkholder *et al*., 2007). Many national studies are conducted to determine sources of nutrients so emphasis can be placed on those sources in order to help reduce surface water impact (Howarth *et al*., 1996; Carpenter *et al*., 1998; Alexander *et al*., 2008; Greene *et al*., 2009).

The USDA's study using Spatially Referenced Regression on Watershed attributes (SPARROW) modeling determined that corn and soybean cultivation is the largest contributor of nitrogen to the Gulf of Mexico. The USDA study also showed that animal manure on pasture, rangelands and croplands is the largest contributor of phosphorus to the Gulf (Alexander *et al*., 2008). As discussed by Richard Alexander, U.S. Geological Services (USGS) scientist and lead investigator, the SPARROW study reveals new details regarding sources of phosphorus, including insight to the thirty-seven percent (37%) of phosphorus from animal manure on pasture and rangeland, which is nearly as much as that from cropland at forty-three percent (43%). This suggests that wastes from unconfined animals contribute more phosphorus to the Mississippi River basin than what was previously thought (Alexander *et al*., 2008). This information from the USDAs study provides insight into the need to consider more robust manure management of unconfined animals, it does not address direct runoff from AFO and CAFO feedlots.

Preston *et al*. (2011), assesses SPARROW results and reveal spatial variability in the sources that control water quality, specifically effects involving regional differences, such as those from cropland and animal wastes. While cultivated croplands and rangelands are large land use contributors of nitrogen and phosphorus to the Gulf, there is a specific need to study the nutrient contribution from CAFO feedlots to watersheds. In the study, *Differences in Phosphorus and Nitrogen Delivery to the Gulf of Mexico from the Mississippi River Basin,* some manure runoff is accounted for from land application to cropland or rangeland. However, it does not consider direct discharges from AFO nor CAFO feedlots.

The National Land Cover Database (NLCD) is land use/land cover dataset created by the United States Geological Survey (USGS) from definitive Landsat-based 30 meter resolution land cover data. “NLCD supports a wide variety of Federal, State, local, and nongovernmental applications that seek to assess ecosystem status and health, understand the spatial patterns of biodiversity, predict effects of climate change, and develop land management policy” (Homer *et al*., 2012). However, the feedlots are not classified as a land use in NLCD dataset rasters. The 30 meter resolution spatial imagery cannot accurately capture the feedlots, therefore they are missing in the classification process. It is important to model CAFO feedlots at a sub-watershed level, in order to understand the nutrient load that is contributed by them. The results of this fine resolution study can be applied to a larger scale study to more accurately determine CAFO feedlot impact to watersheds. This scale of analysis better estimates CAFO feedlot impact, because it addresses runoff from feedlot land cover.

Hydrological modeling and simulation are the most commonly used forms of watershed analysis, and are “essential for evaluating the natural processes that lead to waterbody impairments” (Nejadhashemi, 2007). Hydrological models use a combination of environmental data and algorithms in order to scientifically or empirically estimate pollutant transport in the water cycle. Hydrological models range from simple to complex. Simple models include L-THIA, PLOAD, and STEPL among others (Nejadhashemi, 2007). More complex models include GWLF, AnnAGNPS, SWAT, and HSPF (Evans and Corrandini, 2014; USDA, 2014; EPA, 2015). Watershed models are discussed in further detail in Chapter 2.

In the study, STEPL, a simple watershed model, was used to estimate nutrient concentration in runoff from CAFO feedlots. Land covers including feedlots were delineated by digitizing them with ArcGIS software. This land use data aids in accurately quantifying the nutrients from CAFO feedlots at a sub-watershed level within the Dry Creek watershed, Iowa. The literature review and the initial data gathering phase of this study suggests feedlot runoff is underestimated in many watershed modeling assessments.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

CAFO History

The cattle industry has grown significantly over the past several centuries from family farms to the present agricultural business. Contrary to popular belief, domesticated cattle are not native to the American continent. The Spanish introduced domesticated cattle to the new world in 1540 (Piatti-Farnell, 2013). In 1952, the average American consumed 62 pounds of beef per year. During the Cold War beef became a powerful symbol of propaganda of American superiority through a 1960s promotional movie called *Beef Rings the Bell*. This movie was a propaganda tool to encourage Americans to consume more beef to support the American cattle industry (Piatti-Farnell, 2013). This encouragement appears to have had a strong effect on the cattle industry which continued to boom. In the 1960s, the modern large-scale U.S. cattle feeding industry had begun to appear in the Great Plains region (Kahn *et al*., 2014). By "1970, the average American consumed 110 pounds of beef per year"(Piatti-Farnell, 2013).

Today, large CAFOs are a small fraction (5%) of the 1.2 million farms with livestock and poultry, however, they account for more than 40% of the livestock raised in the U.S. (Copeland, 2010). Figure 4 shows the USDA beef cattle inventory for each state in 2012.

Figure 3. USDA beef cow inventory for each state in 2012. The total U.S. beef cow inventory in 2013 was estimated to be 29.883 million. Image provided by Kahn, 2014.

Exponential growth in the CAFO industry is clear in a USDA study indicating the number of animals raised at large feedlots increased by 88%, and the number of large feedlots/CAFOs increased by more than 50% from 1982 to 1997. The total number of livestock operations fell by 24%, during this same time period, which shows the total number of farms in the U.S. are declining and moving toward fewer but larger farms (USDA, 2000). Figure 4 illustrates the counties in the United States which have increased the number of animal units over time from 1982 to 1997 (USDA, 2012).

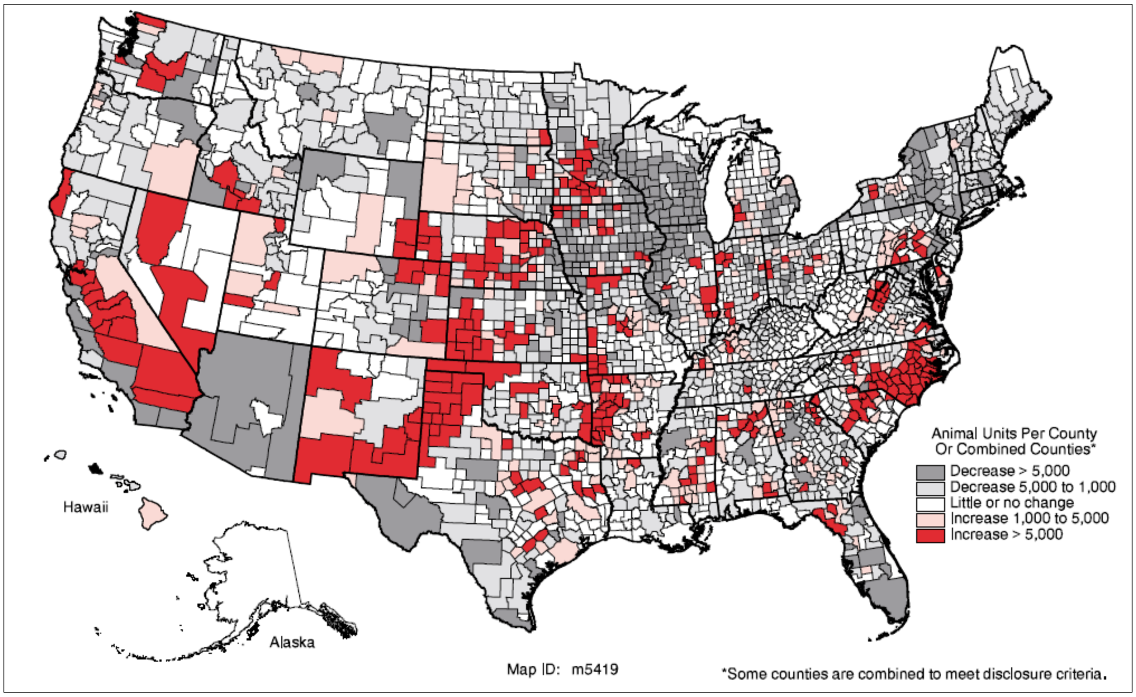


Figure 4. Change in animal units for confined livestock from 1982 to 1997 provided by USDA, 2012.

Further, a 2008 U.S. Government Accountability Office (GAO) study estimates that the number of large CAFOs has increased by approximately 230% from about 3,600 in 1982, to approximately 12,000 in 2002 (GAO, 2008). The Food and Agriculture Organization of the United Nations states, “expanding population and incomes worldwide, along with changing food preferences, are stimulating a rapid increase in demand for meat, milk and eggs...” (FAO, 2006).

The USDA’s Economic Research Service estimates that in 2010, the U.S. beef industry retail value equivalent was $74 billion. They estimate that Americans consumed 26.4 billion pounds of beef in 2010, and 34.2 million head of beef were slaughtered commercially including steers, heifers, and dairy cows (USDA, 2014). The EPA’s Region 7 states [Iowa, Kansas, Nebraska and Missouri] “rank among the highest in the nation with regard to livestock inventory numbers and market value of agricultural products produced" (EPA, 2014). In 2013, the EPA estimated there are approximately 4,917 CAFOs in Region 7, up from the estimated 3,469 CAFOs in 2010 (EPA, 2014).

Over the past two decades livestock production dramatically shifted. This trend towards fewer farms, yet larger industrial CAFOs, has a significant impact on environmental health. Traditional farms, ranches, and pasture operations balanced the number of animals at their facility with the amount of cropland needed; raising only the amount of animals their cropland could support (Thorne, 2007). At today's CAFOs, livestock are raised in large quantities in a small area of land without necessary concomitant increase in cropland, concentrating the amount of manure produced. If animal waste is not properly managed it can be flushed across agricultural land to nearby surface waters (Copeland, 2010).

CAFO Environmental Impacts

"Nutrients are essential for plant and animal life, but in high concentrations they can act as contaminants in water" (Sprague *et al*., 2003). According to the EPA, animal related wastes from feedlots in surface waters can have a wide range of human health and ecological impacts (EPA, 2002). The contaminants present in manure and other AFO process wastewater are nitrogen, phosphorus, organic matter, solids, pathogens, pesticides, antibiotics, hormones, salts, and various trace elements including metals (EPA, 2002). CAFO runoff and its associated nutrient pollution to surface water, continues to be an environmental concern (Burkholder *et al*., 2007). Nitrogen and phosphorus, which are found in feedlot runoff, are known to be one of the largest pollutant sources to surface water (Sprague *et al*., 2009). Nutrient pollution associated with AFO runoff can cause harmful and noxious algal blooms, hypoxic or anoxic conditions, fish kills, and overall have major negative impacts to aquatic habitat (Carpenter *et al.* 1998).

Runoff from CAFO feedlots contain extremely high amounts of nutrients. Excessive nutrient loads are well established as the primary cause of eutrophication of coastal estuaries as well as streams and lakes (NRC, 2000; Sprague, 2009; EPA, 2009; Copeland, 2010). For example, AFOs in the North Carolina Coastal Plain produce 124,000 metric tons on nitrogen and an estimated 29,000 metric tons of phosphorus annually (Mallin *et al*., 2003). Increased nutrients in the water column allow increased growth of algae and aquatic weeds which interfere with aquatic habitat, and impact aquatic biodiversity. Algal blooms, also called red or brown tides in marine ecosystems, can cause problems by releasings toxins into the water (Carpenter *et al*., 1998). These toxins can have severe impacts on aquaculture and shellfisheries. Toxic shellfish can cause poisoning in humans and other mammals (Shumway, 1990; Anderson, 1994; Carpenter *et al*., 1998). Eutrophic conditions cause freshwater algal blooms of cyanobacteria, which can cause fish kills, noxious odors, foul drinking water, and if ingested by livestock can be deadly (Lawton and Codd, 1991; Kotak *et al*., 1993; Carpenter *et al*., 1998).

In 1999, a major governmental study conducted by the National Science and Technology Council Committee of Environmental and Nature Resources (CENR) determined nitrogen pollution “is intrinsically linked” to the Gulf of Mexico hypoxia (Alexander *et al*., 2008). Hypoxia is a condition of reduced dissolved oxygen in the water, which can be caused by excessive amounts of nitrogen and phosphorus in surface water (EPA, 2014). When sufficient dissolved oxygen is unavailable in the water it suffocates the fish (Mallin, 2000). Hypoxia is a growing concern in the United States, and is well documented in the Gulf of Mexico and Chesapeake Bay (Mallin, 2006). Major fish kills associated with anoxic conditions and high ammonia have killed a variety of freshwater fish species including; minnows, gar, largemouth bass, striped bass and flounder (Burkholder *et al*., 2007).

The most visible impact to water by CAFO related waste is mass fish kills. A journal article by Dr. Michael Mallin associate professor with the Center for Marine Science Research at the University of North Carolina, documents the harm associated with an effluent spill from a swine CAFO. This spill demonstrates the magnitude of the damage associated with concentrated manure discharge to surface waters. In 1995, a swine lagoon discharged 25 million gallons of concentrated animal waste into the New River of North Carolina. Impact was documented as far as 22 miles downstream of the spill. The N.C. water quality standard for a healthy river is 5.0 mg/L of dissolved oxygen, and levels recorded downstream of the spill were less than 1.0 mg/L. The fish kill extended more than 20 miles. Typical river ammonium range from 0.01 to 0.30 mg/L, nitrate 0.05 to 1.0 mg/L, and phosphate 0.005 to 0.150 mg/L. Ammonium levels of 40mg/L are capable of causing death in fish, due to toxicity, and were sampled to be 46.21 mg/L downstream. Multiple harmful algal blooms resulted from this spill and killed an estimated 10,000 Atlantic menhaden in one estuary. (Mallin, 2000).

Highly publicized fish kill incidents have occurred in nearly every state nationally (Copeland, 2010).

Animal Waste Management

CAFO waste can be managed in appropriate ways in order to reduce its impact to streams. The design of CAFO feedlot enclosures has gentle slopes which guide water and waste away from the animals, to protect the health of the animals. Structures can be installed at AFOs to capture this waste. Solids settling basins are a waste management structure in which animal waste flows in and manure solids settle out. Effluent from the settling basins are gravity fed or pumped into holding structures such as; holding ponds, storage structures, lagoons and other wastewater catchments. Process wastewater is also stored in these holding ponds until weather conditions are suitable for land application. Manure solids may be scraped from feedlots and pens using mechanical equipment, to reduce the amount of manure solids in animal production areas. The manure is stockpiled, or otherwise stored until weather conditions are suitable to land apply manure on cropland.

Manure is a fertilizer nourishing soils to aid in crop growth. If manure is applied appropriately crops absorb the available nutrients, mainly nitrogen and phosphorus. Manure applied to soil's aerobic environment can convert manure nitrogen to nitrate which is highly soluble in water. When soils become too saturated and nitrate residues become too high, they will runoff, and can contaminate surface and ground water (Reynolds *et al.,* 2001). However, many factors influence successful manure application to soil. Tracking applications involves determining the amount of available nitrogen and phosphorus contained in the manure by manure sampling. Further, soil samples from each field must be taken to determine nutrient needs. Careful tracking and monitoring of soil nutrients at land application sites will ensure overapplication is not occurring (Reynolds *et al*., 2001). Land application of manure should only occur during suitable weather conditions. Manure should be land applied during dry weather conditions, to reduce nutrient transport. Manure application to saturated soils will reduce the amount of nutrients that can be absorbed. Furthermore, if precipitation events occur immediately following land application, nutrients will wash away, and enter nearby streams.

CAFO Pollutant Transport

Management practices if followed appropriately, can effectively reduce the amount of CAFO process wastewater and manure related pollutants entering streams. When CAFO management practices are not used, or manure management structures are not installed or operated as designed, they can cause devastating environment impacts (Mallin, 2000). Crop management, soil conditions, nutrient properties, and application rates affect the transport of manure contaminants (Burkholder *et al*., 2007). CAFO process wastewater and manure can enter streams through a variety of routes. Routine clean-out of solids settling basins is necessary for them to work effectively. If solids accumulate and fill the available capacity within the basin it will no longer settle out manure solids, which are then subject to transport. CAFO effluent lagoons must also be managed appropriately. Proper design of lagoons will ensure that they have adequate storage capacity to hold the amount of effluent produced by the number of animals confined. For adequate holding capacity, lagoons should be pumped in preparation for future precipitation when weather and soil conditions permit. Lagoons not managed appropriately become full and overtop during rainfall, discharging hundreds to millions of gallons of raw waste to streams. Manure applied to cropland at agronomic rates, allows soils to adsorb nutrients which can be taken up by crops. Phosphorus stored in soils is primarily fixed to soil minerals and other organic matter, thus most phosphorus in runoff is due to sediment transport (Reynolds *et al.,* 2001).

Rainfall events contribute significantly to water contamination. During a rainfall event, water will comingle with manure and process wastewater from a CAFO, and flow to nearby surface water. "Annual nutrient concentrations in U.S. streams draining predominately agricultural watersheds were found to be about nine times higher than those in streams draining predominantly forested watersheds and about four times higher than those in streams draining predominantly rangeland watersheds" (Omernik, 1977). During precipitation events feedlots without properly designed manure management structures will discharge animal wastes to surface water. Over time as continued precipitation events occur, erosional pathways begin to form within the soil, facilitating the transport of process wastewater and manure to streams.

CAFO Regulation

The U.S. Environmental Protection Agency has the authority through the Clean Water Act (CWA) to regulate discharges associated with CAFO sources. CAFOs are defined by the CWA as a pollution point source, and are subject to National Pollutant Discharge Elimination System (NPDES) permitting, if discharges reach a water of the U.S. (EPA, 2012). In the late 1990s, the EPA began reviewing the CWA rules which had not been revised since the 1970s. Final rules to include CAFOs as a point source became effective in February of 2002 (Copeland, 2010). Initial CAFO rules proposed were more stringent; however, they were scaled back in favor of agricultural groups. The more stringent rules would subject thousands more CAFOs to regulation (Copeland, 2010).

In subsequent years, multiple parties have challenged CAFO rules, and federal courts continue to adjust rulings generally in favor of CAFOs. This further limits the authority of the EPA to regulate these facilities. An animal feeding operation must meet the definition of a CAFO in order to be defined as a point source and subject to enforcement under EPA authority. NPDES permits have detailed requirements that must be following by CAFO operators. If NPDES permits are violated CAFOs are subject to enforcement actions, which may include penalties. Currently the EPA has authority to regulate large CAFOs, limited authority to regulate medium sized CAFO, and little to no authority to regulate medium AFOs and small AFOs. Further, EPA has the burden of proving a CAFO discharges to a water of the U.S., which can be a difficult task due to the many transport factors. As reported by the USDA, there are 1.2 million farms with livestock and poultry in the U.S., and small AFOs account for an estimated 95% of those operations (Copeland, 2010). Although large CAFOs account for the majority of the animals confined in the U.S., it is important to consider the combined pollutant discharges capable of entering streams from medium and small AFOs, which are outside of the EPA authority to regulate. Further, as courts continue to limit EPA authority it becomes more difficult to regulate the larger facilities. Careful consideration and re-evaluation of CAFO rules is in order to address the magnitude of the environment impact caused by all animal feeding operations. This study seeks to model large CAFO cattle feedlot runoff at a fine resolution, which can then be applied on a large scale to identify the magnitude of the problem.

Hydrological Modeling

Nutrient sources and transport within a watershed are difficult to measure due to the many variables that affect transport, and the wide area of land involved (Carpenter *et al*., 1998). To determine nutrient loads within a watershed, it is important to select the most applicable hydrological watershed model for a specific research question. A study comparing four water quality models: STEPL, PLOAD, L-THIA, and AVSWAT-X, identifies the STEPL model as useful in assessing the effects of land use changes on pollutant loads, and provides rapid initial assessment of water quality conditions (Nejadhashemi *et al*., 2007).

Hydrological watershed models are similar in nature in that they require data inputs such as rainfall, soil properties, and land use/land cover in order to estimate transport of constituents to a watershed. Models are developed using extensive research and common scientific practice, and algorithms to estimate transport of constituents from land sources within a watershed. Loads or concentrations of pollutants for different parameters such as nitrogen, phosphorus, organic carbon, sediments, BOD, and fecal coliform, are embedded in the models. SCS Curve Number (CN) method is routinely used to estimate runoff coefficients for different land uses. Models vary in how they calculate estimates by time series, such as single event models, long term models and annual estimates. The following watershed models were reviewed in order to determine which watershed model best fit the purposes of this study.

Minnesota Feedlot Annualized Runoff Model (MinnFARM), is a hydrological model developed to estimate annual pollutant loading of feedlot runoff for Minnesota (Schmidt and Wilson, 2008). This model uses similar algorithms and equations as STEPL to determine runoff, however information for rainfall and other inputs are for the state of Minnesota, only. This model estimates COD, phosphorus, nitrogen, BOD, and fecal coliform from a number of inputs including, animal head count, land use area, soil conditions, rainfall, and pollutant buffers to stream. The MinnFARM has the capability to be further developed for use at a national level, to allow the user to estimate pollutant loads from feedlot runoff from land sources other than Minnesota. The MinnFARM is used to help the Minnesota Pollution Agency determine if water quality standards are being met by feedlots (Schmidt and Wilson, 2008).

PLOAD is a model used by states to help them develop numeric water quality standards (EPA, 2001). PLOAD is a simple watershed model which estimates long-term annual pollutant load, using a GIS interface. Two methods are applied in the tool; 1) export coefficient, and 2) event mean concentration. The export coefficient estimates pollutant load by land use type, and event mean concentration estimates pollutant load by a runoff coefficient. The results of this simple model identify total load per watershed, but does not itemize land use differences (EPA, 2001). PLOAD uses NLCD for land cover information which does not include feedlots as a landuse classification, and does not incorporate animal inputs to study runoff from feedlots.

AnnAGNPS is the Annualized Agricultural Non-Point Source Pollution hydrological model, part of a system of models within AGNPS (USDA, 2014). AGNPS is a system of complex models considered a continuous simulation surface runoff model which estimates nitrogen, phosphorus, organic carbon and pesticides within an agricultural watershed. This is a complex model with heavy data inputs which considers hydrological processes related to precipitation, irrigation, surface runoff, sediment erosion nutrients, land use, and has recently incorporated feedlots. Feedlots are not incorporated in the land use data, but are addressed with an add-on from an animal waste characteristics database. However, no further information could be found regarding how this database accounts for animal waste characteristics. AnnAGNPS is a very technical model and involves thorough understanding of all processes to conduct a relevant analysis.

MapShed is a newer model developed in 2011, which is a non-commercial watershed model, developed from the AVGWLF model (Evans and Corradini, 2014). AVGWLF (ArcView Generalized watershed Loading Functions) was developed for use in ArcGIS, from its original version GWLF. Mapshed assesses non-point source nutrient loads from urban and rural watersheds. Mapshed has been continually updated to incorporate new routines to better address nutrient drivers. Routines have been added to address farm animals which allow the user to input animal counts, grazing or confined, among other inputs to estimate manure nutrient loads. Mapshed, however does not spatially distribute source area, but rather combines all nutrient sources, for a watershed total load. This model developed at Pennsylvania State University, uses data from Pennsylvania. However, other versions have been developed to allow use in other regions such as New England and New York. This model has been used for federally-mandated total maximum daily load (TMDL) studies in Pennsylvania (Evans and Corradini, 2014).

The SPARROW (Spatially referenced regression on watershed attributes) surface water quality model, relates stream water quality monitoring with spatially referenced characteristics of a watershed, to show spatial patterns in monitored streams (Preston *et al*., 2009). SPARROW modeling is currently being applied at a national scale to assess nutrient conditions for six regions of the nation, as shown in Figure 5 below.

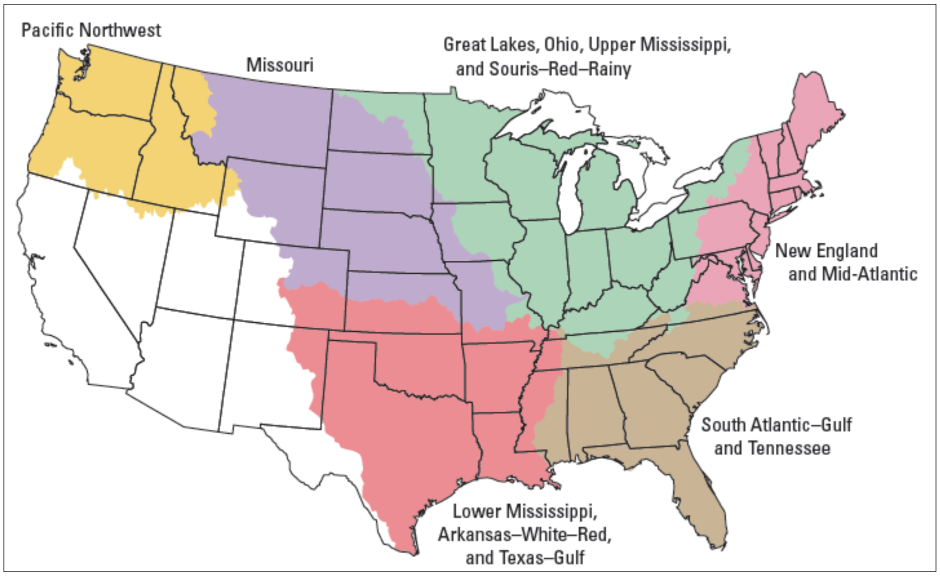


Figure 5. Regions being assessed by SPARROW modeling provided by Preston *et al.*, 2009.

SPARROW modeling has been adopted by the U.S. National Water Quality Assessment Program to assess nutrient conditions for the base year 2002. The NAWQA program assesses the conditions of water quality, through water quality monitoring, study, and modeling to help stakeholders make informed decisions regarding our Nation's water.

Although many models produce quality results, they can require large amounts of data and calibration, and can easily exceed many project budgets. Further, there has been recognition of the value provided by simple models to assess load based estimations for watersheds (Schwartz, 2006). Simple models such as STEPL, L-THIA, and PLOAD can be used to estimate pollutant loads from different land uses (Nejadhashemi, 2007).

CHAPTER 3

STUDY AREA

Thirty-one states contribute to the Mississippi River Basins, however, nine of those states, including Iowa, contribute the majority of the nutrients to the Gulf of Mexico (Alexander *et al.,* 2008). Figure 6 below illustrates the Mississippi River Basin drainage area, which empties to the Gulf of Mexico.

Figure 6. Mississippi River drainage basin illustrates the area of the United States encompassing the basin to the Gulf of Mexico. It includes the hypoxic zone in the Gulf of Mexico. Image provided by Progress Illinois, 2012.

The EPA's Region 7 states include Kansas, Iowa, Nebraska, and Missouri, which are ranked "among the highest in the nation with regard to livestock inventory numbers and market value of agricultural products produced" (EPA, 2013). Of the states in this region Iowa has the largest number of CAFOs, estimated at 3,055 facilities (EPA, 2013). A study conducted by Alexander *et al.* (2007) shows that of the 24 states within the Mississippi and Atchafalaya River Basins contributing nitrogen to the Gulf of Mexico, Iowa is the second highest. Figure 7 below illustrates the spatial distribution of AFOs and CAFOs within the state of Iowa, based on data from the Iowa Department of Nature Resources AFO database (IDNR, 2014).

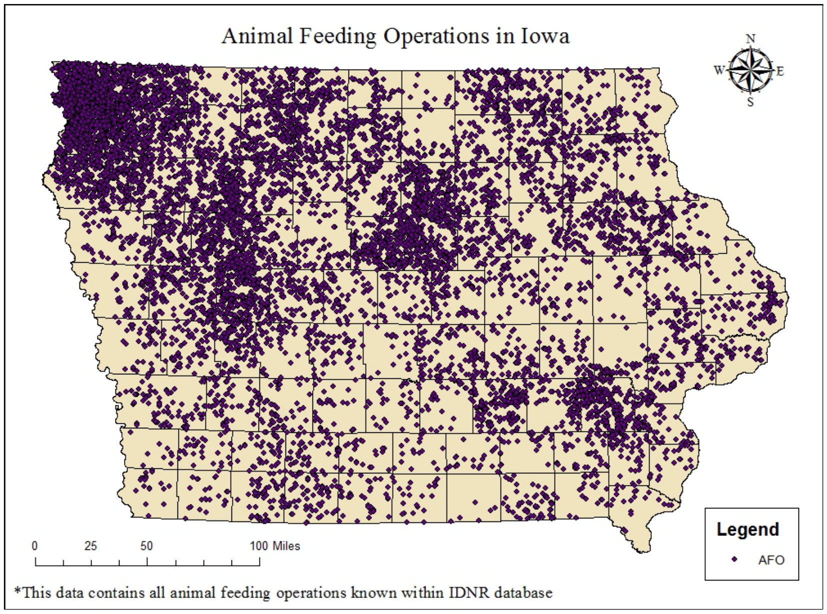


Figure 7. Spatial representation of the AFO population in Iowa (IDNR, 2014).

Figure 7 illustrates that there is an extremely dense population of AFOs and CAFOs in the northwestern corner of Iowa, within Sioux County. This further narrows the scope of interest to a study area in the northwest corner of Iowa.

Figure 8 is a GIS map that shows impaired streams in Sioux County Iowa. This map, with the CAFO population layer, identified many areas of interest.

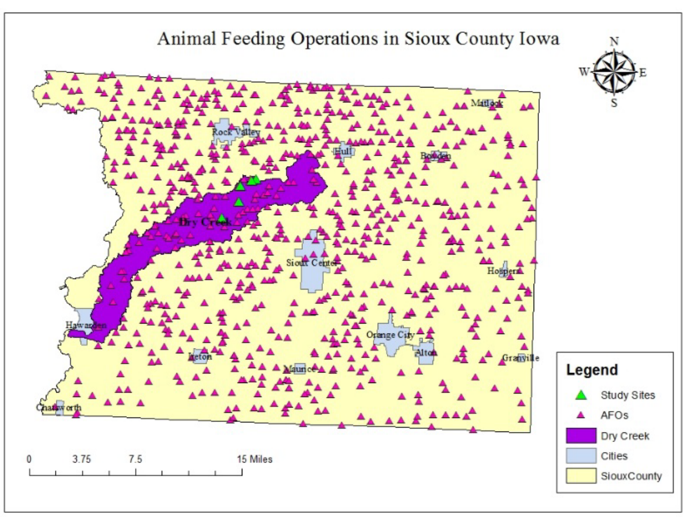


Figure 8. A GIS map illustrating AFOs in Sioux County, Iowa, and the Dry Creek watershed.

The scope is further narrowed by an evaluation of the impairments to the stream. The Dry Creek watershed is the area of interest, because the stream impairments identified can be caused by CAFO runoff.

The Dry Creek watershed of Sioux County sits within northwestern Iowa. Dry Creek flows approximately 32.4 miles into the Big Sioux River. The Mississippi River Basin is a large drainage basin that captures flow from many watersheds including the Dry Creek watershed. The EPA 303(d) list identifies the Dry Creek stream for impairments including low dissolved oxygen and organic enrichment. A 2003 fish kill in Dry Creek had an estimated 1,501 fish killed. The cause of the fish kill is unknown; however, low dissolved oxygen was a contributing factor. Further, the Iowa Department of Natural Resources biological assessments in 2004 and 2005 could not identify any fish in the stream (IDNR, 2006).

Iowa has seasonal weather, with cold winters averaging around 14 degrees Fahrenheit, and warm humid summers typically around the mid-80s. Average annual precipitation in northwestern Iowa is around 26 inches (Iowa, 2014). Northwestern Iowa's dendritic topography can be summarized as a gently rolling relief, with gradual hills from a network of streams which span most of the land area. The southeastern portion of the state has the lowest elevation at 480 feet and gradually increases to the north and west of the state reaching a maximum elevation of 1,670 feet (Prior, 1991).

Five CAFOs selected for the modeling study within the Dry Creek watershed are in close proximity to a stream and large numbers of cattle being confined. The focus of this study is to model runoff from large CAFOs, so each study site selected has at least 1,000 head of cattle. Figure 9 shows the Dry Creek watershed and the five CAFO sites used in this study.

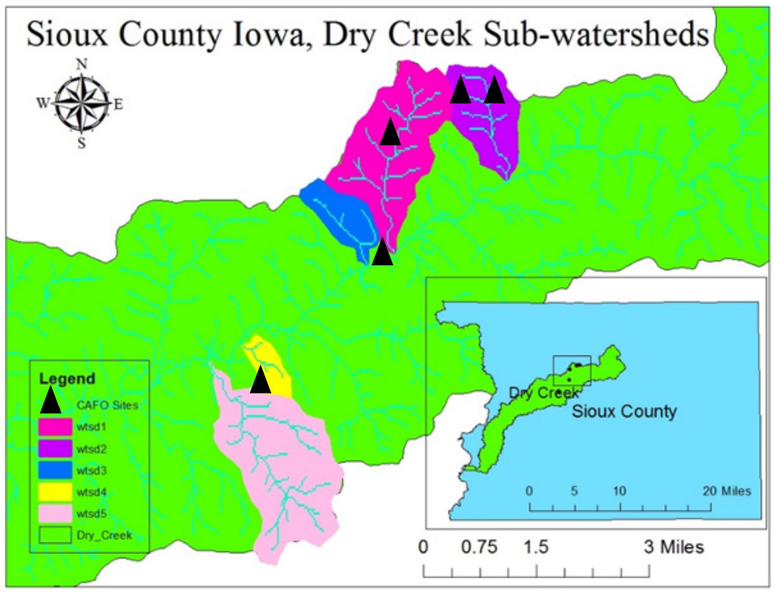


Figure 9: Dry Creek Watershed and five CAFO study sites.

CHAPTER 4

METHODOLOGY

STEPL Background and Usage

STEPL was developed for use by the United States Environmental Protection Agency by Tetra Tech, Inc. (STEPL, 2011). The Spreadsheet Tool for Estimating Pollutant Load (STEPL), Version 4.1, estimates total annual pollutant load for each sub-watershed in this study. STEPL was originally developed to assist state non-point source project managers report load reductions to EPA. It is also used by state agencies to measure performance of nitrogen, phosphorus and sediment reductions, and derives data to enter into grant reporting and tracking systems (STEPL, 2011). There are a variety of hydrologic modeling tools that estimate pollutants loads for watersheds, at a large and small scale. Many models such as SWAT (Soil Water Assessment Tool, 1990) and HSPF (Hydrologic Simulation Program-Fortran, *et al*., 2001) require large amounts of data, calibration, and can easily exceed project budgets. Simple models such as STEPL, L-THIA, and PLOAD can be used to estimate pollutant loads from different land uses (Nejadhashemi, 2007). STEPL is a watershed model with empirical equations which do not typically need calibration, and is widely used for 319 rule and for estimating TMDLs (total maximum daily load) for water quality standards at federal and state agencies (Wang, 2014, personal communication). STEPL is a simple watershed tool with a visual basic interface, and allows the user to create a spreadsheet based model in Microsoft Excel. Algorithms in this tool calculate pollutant loads from each land use (STEPL, 2011).

A detailed review of STEPL identified how the model runs and calculates pollutants loads. The model estimates total annual load in surface runoff for nitrogen, phosphorus, 5-day biological oxygen demand (BOD) and sediments. STEPL is a great tool for estimating agricultural based runoff because it allows the user to input land use data in acres which includes cropland, pastureland, forest, urban and feedlots. It also allows the user to input animal count information and the number of months manure is land applied, to estimate the pollutant load generated by a specified animal sector. Worksheets in the model use various algorithms to generate runoff estimations. Average annual runoff is calculated based on precipitation, soil hydrologic group and soil curve number data. The model will calculate surface runoff in inches and runoff volume in acre-feet for each land use in a watershed using the Soil Conservation Service (SCS or NRCS) curve number method (NRCS, 2004).

The two main tabs or worksheets to note for the purposes of this study are the animals input worksheet and the feedlots land use worksheet. The animal input, uses nutrient contributions from animals to derive load estimates for all land uses except urban. The model assumes manure is collected and applied to cropland. For the purpose of this study cattle are the only animal sector evaluated, no additional animal sectors were looked at. Animal numbers are converted to animal equivalent weight unit (AEU). 1 AEU is equal to 1,000 pounds per acre (lb/ac) used with months of land application in conjunction with runoff nutrients in milligrams per liter (mg/l) for each AEU.

The feedlot worksheet accounts for runoff from the feedlots by calculating loads based on contributing area in acres, percent paved, average event rainfall in inches and animal design weights in pounds. Animal nutrient ratios estimate nutrients produced by the animals relative to 1000 pounds of beef steer, which is a general term for an animal equivalent of one. STEPL accounts for nutrient runoff from a feedlot and land application of manure. The curve number used for feedlots is ninety-one (91), which indicates very little infiltration, and high runoff factor. SCS curve number methodology is used to determine runoff in inches from the feedlots. SCS CN methodology equation from the National Resource Conservation Services, National Engineering Handbook (NRCS, 2004) determines runoff in inches:

$$Q = (P\text{-}Ia)^2 / [(P + Ia) + S],\ Ia = \lambda S.$$

This equation is defined as:

Q= Runoff in inches,

P = Rainfall in inches,

Ia = Initial Abstraction in inches,

S = Potential maximum retention in inches, and

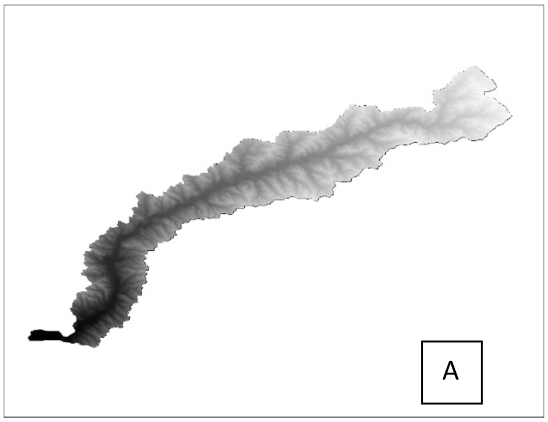
$\lambda = 0.2$.

The feedlot tab assumes the feedlots are scraped and manure is land applied to cropland as a best management practice, thus the total manure load is calculated between feedlots and cropland. However, different volumes based on variables specific to feedlot and cropland respectively, determines the nutrient load from each land use.

Cropland uses Animal Equivalent Unit (AEU), which is animal weight per acre of cropland. Once AEU is determined, a reference table generates pollutant loads specific to cropland runoff. However, the feedlot worksheet more specifically uses the number of animals confined on the feedlot, and not AEU. The feedlot worksheet uses a separate pollutant reference table to determine mg/l of pollutants in runoff in relation to number of animals.

Sub-watershed Delineation

Sub-watersheds within the Dry Creek watershed were delineated using ArcGIS 10.1 hydrology tools. The United States Geological Service (USGS)'s National Elevation Dataset (NED) raster for Sioux County, Iowa provided elevation data for the study area. Two NED rasters which cover the Sioux County area (grdn44w097 and grdn43w097) were mosaiced together into one continuous raster layer. To reduce processing size the Dry Creek watershed area data was clipped. The Spatial Analyst's hydrology tools were used to delineate the sub-watersheds in this study. The fill tool filled any sinks in the grid that would theoretically trap the water and not allow it to flow. The flow direction tool computed the flow direction in a given grid. The flow accumulation tool calculated the accumulated number of cells that were draining to any particular cell in the digital elevation model (DEM) using the flow direction grid (Merwade, 2012). The raster calculator created a stream network from a null statement which selects cells from the flow accumulation grid, greater than or equal to fifty, which will receive a value of one, and all other cells were set to null. Fifty was used to get the greatest segment length of stream to reach as close to the study CAFO sites as possible. At the outlets of each branch of the stream, point shapefiles were created at each CAFO study site. Each of the five study sites were delineated to get a sub-watershed for each study site. Two CAFO sites were located within the same sub-watershed, thus four point shapefiles were used to delineate each of the study sites in a sub-watershed. The watershed tool drawed the watershed boundary using the stream network created and the point locations selected for each study site. This tool creates a raster of the sub-watersheds. The raster to polygon tool converted the rasters into shapefiles. Figures 10.A through 10.E illustrate the process of delineating the sub-watersheds of Dry Creek.



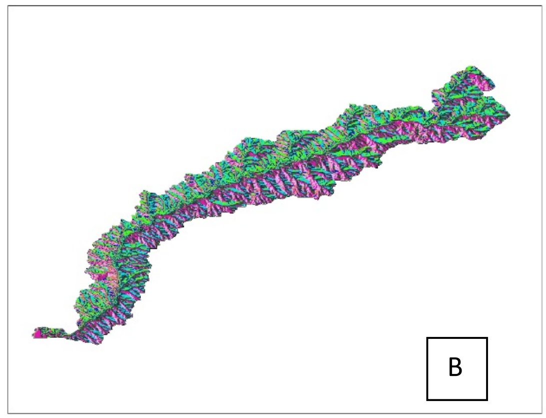
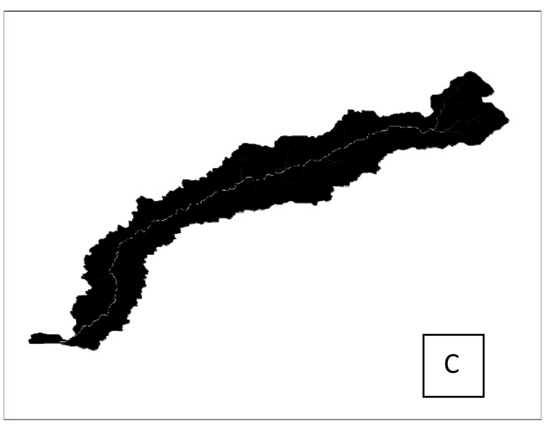


Figure 10.A. Elevation from the National Elevation Dataset of the Dry Creek watershed.

Figure 10.B. Flow Direction of the Dry Creek watershed.



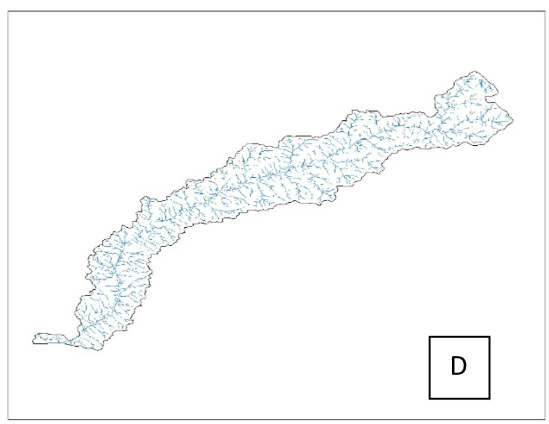


Figure 10.C.Flow Accumulation of the Dry Creek watershed.

Figure 10.D. The resulting stream network generated by the raster calculator for the Dry Creek watershed.

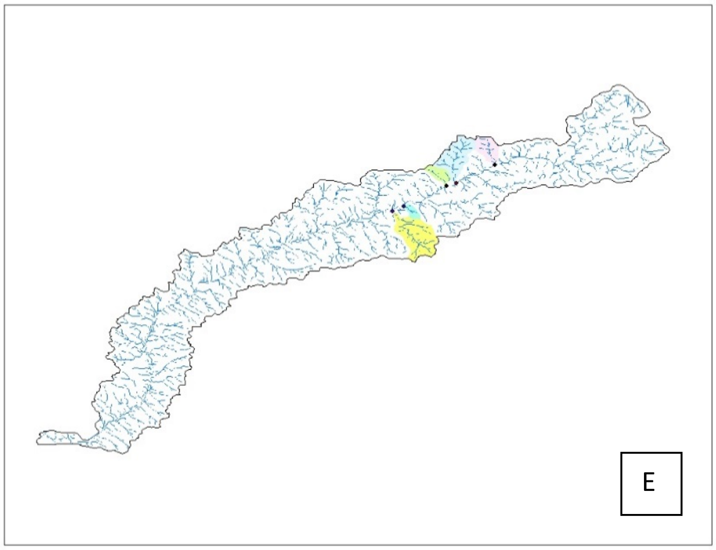
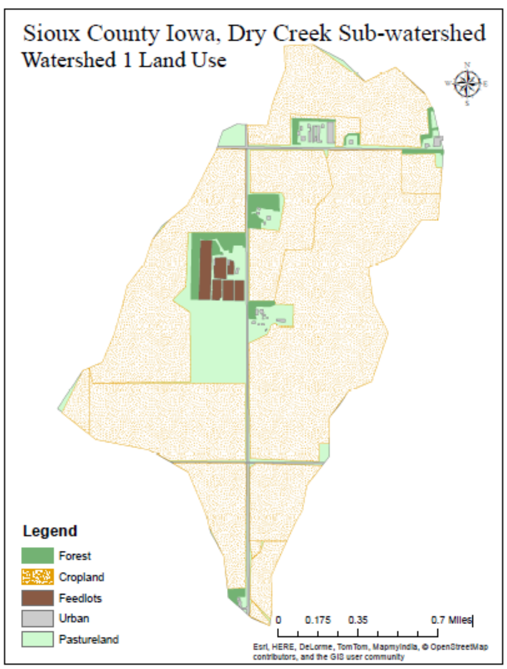


Figure 10.E. Pour Points and Watersheds from Watershed Tool

Creating Land Use Data

Land use area in acres for each sub-watershed was digitized utilizing digitizing tools in ArcGIS. Land use polygons were created for each land use including pasture, forest, urban, cropland, and feedlots. Each shapefile polygon generated from delineating the sub-watershed was made transparent so the spatial imagery below could be visualized. A world imagery basemap provided by ESRI in ArcGIS format was used to draw the land uses categories. Each map was projected with the same coordinate system, NAD_1983_UTM_Zone_15N and geographic coordinate system GCS_North_American_1983, to ensure each polygon created has been projected in the correct geographic location in relation to true geographic coordinates. Because this was a rural environment where very little contrast existed between land uses. Roofed buildings, roads, and any other impermeable surfaces were classified as urban for the purposes of this study. Feedlots were identified as areas clearly denuded of all vegetation and digitized. Any vegetated or grassed area was classified as pastureland, which excludes cropland. Cropland land use was digitized to encompass all cropped areas, which was easily identified based on patterns in planting and harvesting. Once all land uses were digitized, the attribute table was used to calculate area. A field was added in the attribute table to generate area in acres using the calculate geometry tool. All polygon areas where calculated and projected to match the data. The data table was exported to an Excel spreadsheet. The values for each land use polygon were summed together to calculate total area in acres for each land use for each sub-watershed respectively. Figures 11.A through 11.D below are the digitized land use maps for the sub-watersheds in this study.



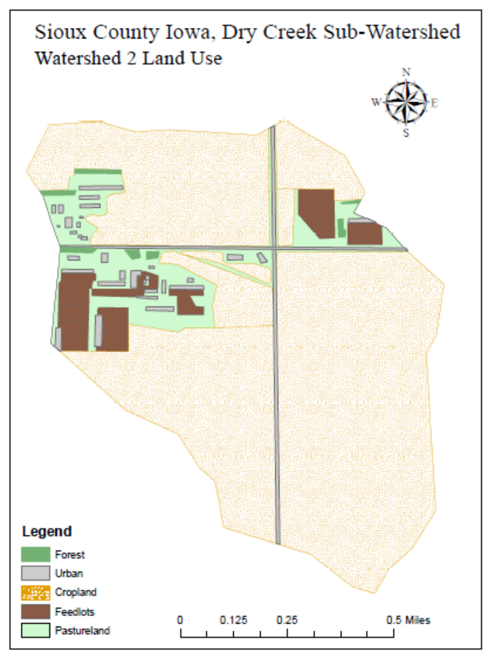
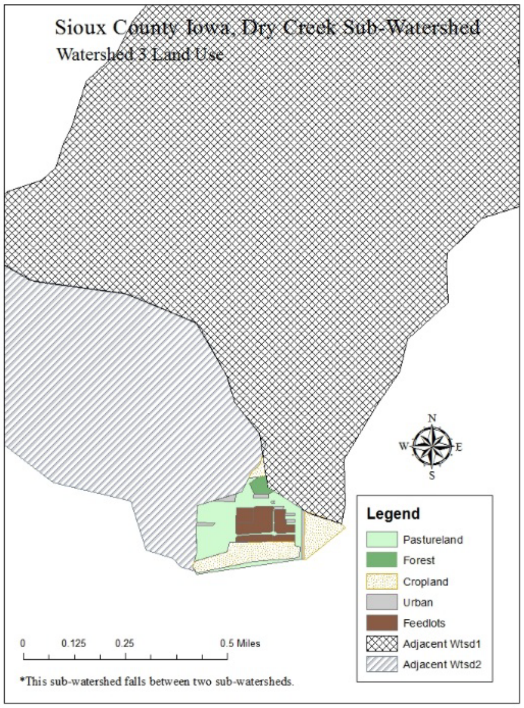


Figure 11.A. Sub-watershed 1 land use classification map digitized using GIS.
Figure 11.B. Sub-watershed 2 land use classification map digitized using GIS.



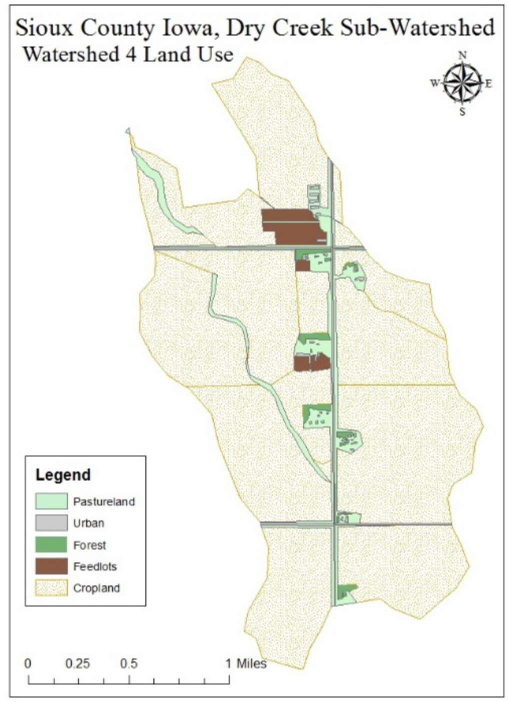


Figure 11.C. Sub-watershed 3 land use classification map digitized using GIS.
Figure 11.D. Sub-watershed 4 land use classification map digitized using GIS.

For the purpose of this study, to estimate the total pollutant load from the feedlots, an assumption was made that the feedlots did not have runoff controls, such as sedimentation basins or lagoons. If such runoff control structures existed they were not digitized, or used in the study.

STEPL Methodology

The Spreadsheet Tool for Estimating Pollutant Loads (STEPL) version 4.1 is used to estimate the total annual pollutant load in runoff from each sub-watershed. Using STEPL 4.1 allows the user to select the number of sub-watersheds in each run of the tool. In this study one watershed is used for each sub-watershed and ran individually, because the soils were slightly different for each sub-watershed. Selections are made within the tool for the state, county and weather station for the study area. This information retrieves stored data within the model for precipitation, rain correction factors, the percent of rainfall events that exceeds 5 millimeters (mm) per event for annual rainfall (average), and the percentage of rain day (events) that produce runoff. Area in acres of different land uses including; urban, cropland, pastureland, forest and feedlots are required inputs. This flow chart outlines the data gathering process to generate STEPL data inputs (Figure 12).

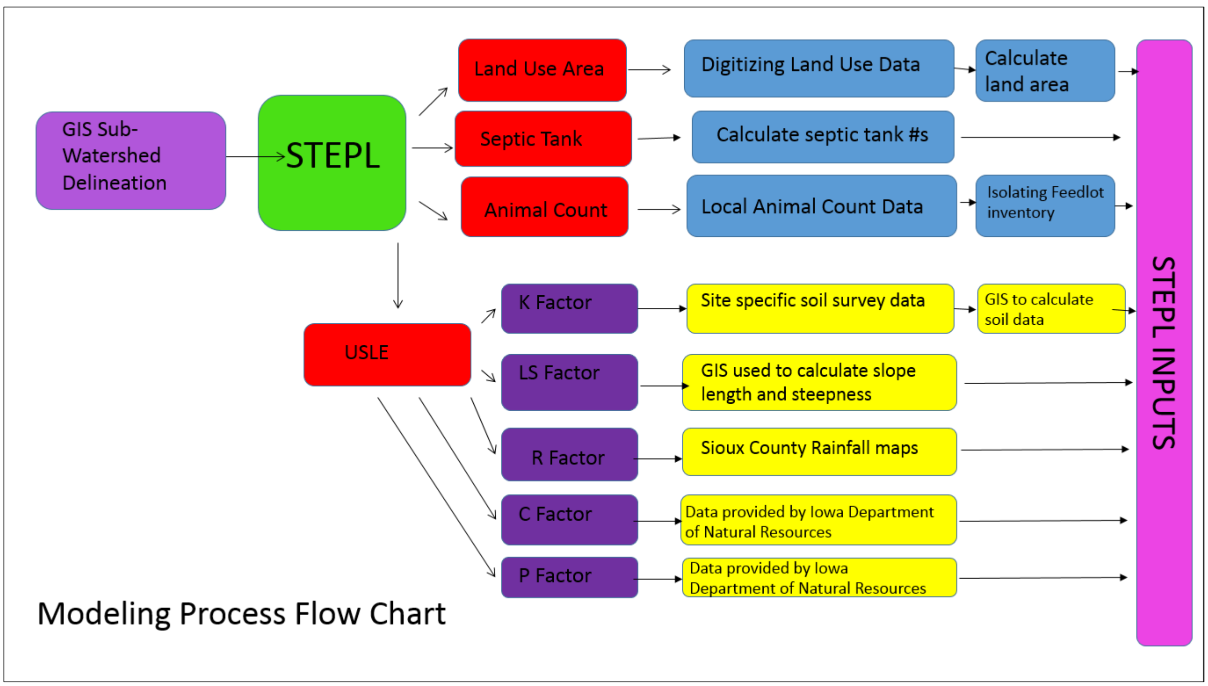


Figure 12. Hydrological modeling flow chart to outline the process used to gather and prepare data for use in STEPL.

The digitizing process in ArcMap generated land use data for the land use inputs. Each sub-watershed was delineated for each of the five CAFO sites in the study area. The Iowa Department of Natural Resources CAFO database provides local information for CAFO data layers. The 2012 AFO layer provides the data for generating the agricultural animal inputs, which was provided by IDNR Natural Resources GIS Library (NRGIS, 2012). The attribute table for this layer among other data, provides the animal count for each animal sector of a CAFO. All five CAFOs in this study are large combined operations with cattle in open feedlots. For the purpose of this study beef cattle are the only animal sector examined. The Iowa Department of Natural Resource (IDNR) provided the Nutrient Management Plans (NMP) for each of the five sites. The NMPs indicated land application was generally done from fall through spring, thus eight months of land application per year was estimated for the model.

Estimating illegal direct wastewater discharges requires information for septic systems including; the number of septic systems, human population per septic system, and septic failure percentage rate. The number of septic systems in each sub-watershed was estimated using the following equation:

(#septic systems in Sioux County) * (Watershed rural area/ County rural area).

The Soil Survey of Sioux County Iowa (USDA & SCS, 1990), estimates 490,240 acres of land in Sioux County, with approximately 468,000 acres consisting of farmland including cropland in 1985. The 1990 U.S. Census Bureau estimates 2,927 septic systems in Sioux County Iowa (USCB, 1990). (Appendix A) The number of septic systems in each sub-watershed was estimated using the census data and total area of the rural watershed, for each sub-watershed. The Dry Creek watershed of Sioux County, Iowa has an estimated 3 people per septic system, provided by the STEPL online data server cited by the National Environmental Service Center: 1992 and 1998 summary of status of onsite wastewater treatment systems. The Iowa Department of Natural Resources, which routinely use STEPL to estimate total daily maximum loads (TMDLs) for streams, use a septic system failure rate of 25%.

The Universal Soil Loss Equation (USLE) is used in STEPL to determine sediment loads, and soil erosion factors from runoff. The default values for USLE are based on county averages. For accuracy each parameter is modified by local data including; soil data, elevation data and rainfall data. The USLE equation is as follows (RUSLE, 2014):

$$E = R * K * LS * C * P$$

Where parameters are defined as:

R = Rainfall erosivity factor,

K = Soil erodibility factor,

LS = Slope length and slope steepness factor,

C = Crop management factor, and

P = Conservation practice factor.

USLE Parameter Methods

R Factor

The rainfall factor for Sioux County, Iowa is 150. This factor value is used for all sub-watersheds. This factor was identified by the technical guide section 1-C-1 January 1990 rainfall factors for Sioux County, Iowa, provided by the Nature Resources and Conservation Services (Figure 13).

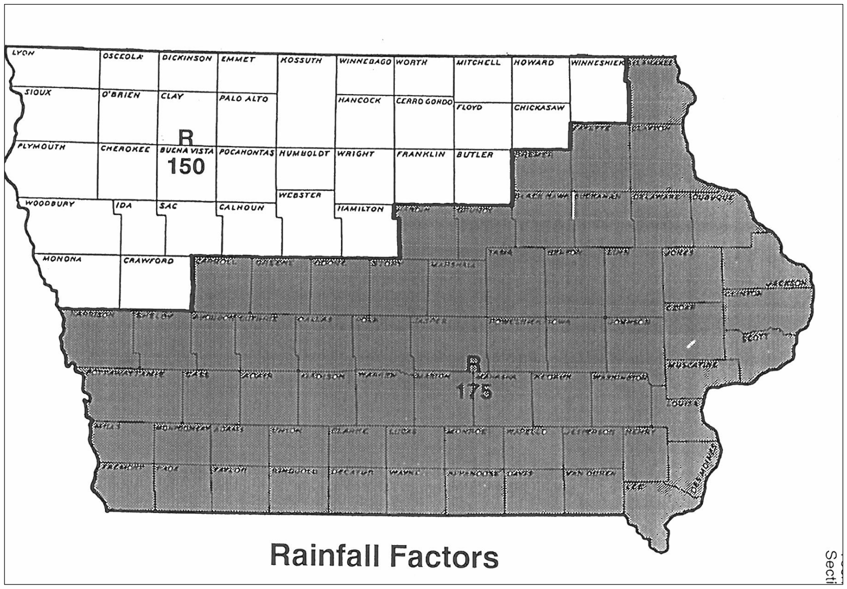


Figure 13. Rainfall factor from technical guide section 1-C-1 January 1990 rainfall factors for Sioux County Iowa, provided by the Nature Resources and Conservation Services.

K Factor

Soil layer, Soil_84 downloaded to ArcMap determines the soil erodibility factors (K). Iowa Cooperative Soil Survey and IDNR geological survey published Soil_84, a digital soil data map for Sioux County, Iowa (ICSS, 2001). The data layer is clipped by each sub-watershed. Figure 14 is an example of the clipped soil layer from soil_84 for two sub-watersheds.

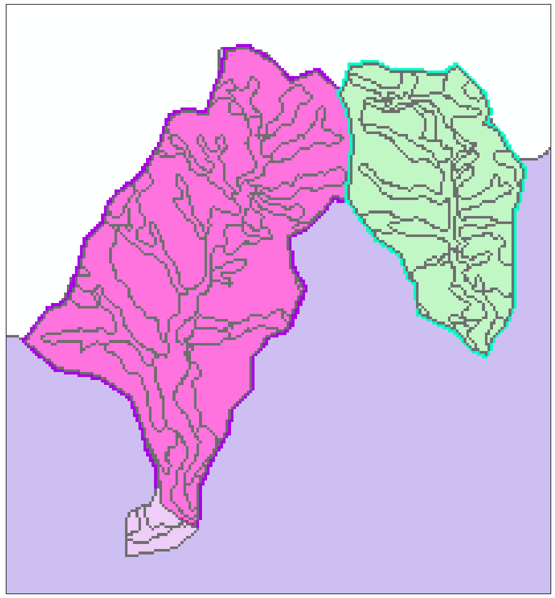


Figure 14. K factor soil data layer clipped from soil_84 for two sub-watersheds.

To generate the K factor for each land use, each soil layer was clipped by each land use, respectively. Land area is embedded in the soil_84 layer. Once the land use is clipped, the data must be refreshed so area in the attribute table reflects the spatial area in the sub-watershed. The attribute table data exported to an Excel spreadsheet by land use estimates a weighted average for each land use. The following equation finds the weighted average for the K factor for each land use in each sub-watershed:

$$(\text{K Factor}*\text{Area}) / (\text{Area}).$$

The map shows K factor soil data layers for each sub-watershed. However, actual data is embedded within the attribute table (Figure 15).

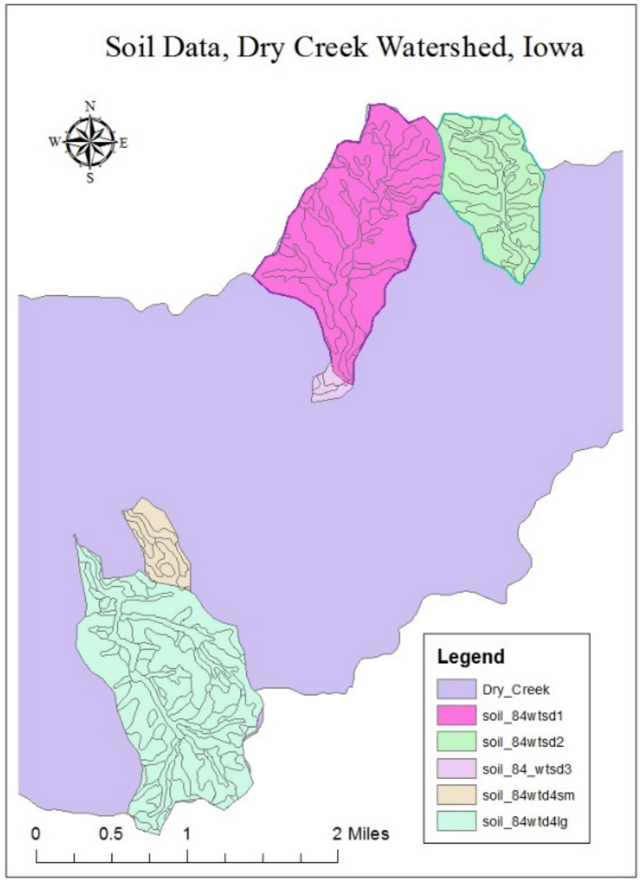


Figure 15. Soil data layers clipped by sub-watershed.

LS Factor

The slope length factor values were found using a Digital Elevation Model (DEM) in ArcGIS. Calculating Slope Length Factor (LS) in the Revised Universal Soil Loss Equation (RUSLE), (Pelton *et al*., 2014) is used to determine flow accumulation. The slope tool calculates percent slope using the clipped DEM input and the raster calculator tool calculates the LS factor using the following equation in GIS (Pelton *et al*., 2014):

LS = power (flowacc * cell resolution / 22.1, 0.4) * power(Sin(slope * 0.01745) / 0.09, 1.4) * 1.4

Defined as:

Flowacc = Flow accumulation raster,

Cell resolution = Resolution of DEM in meters, and

Slope = Slope raster in degrees.

The flow accumulation raster is input for this equation. The cell resolution of 30 is used, because the DEM is a 30-meter resolution raster. The resulting raster of LS factors for the watershed are raster files and did not have vector data. The Int tool, which converts “each cell value of a raster to an integer by truncation” (ESRI, 2013), converts the raster data to vector data. The resulting LS factor values in vector format are now present in the attribute table for the watershed. The LS factor raster is clipped by each land use; feedlots, forest, urban, pasture and cropland for each sub-watershed. Figures 16 – 21 below illustrate the process to develop the data for LS factors.

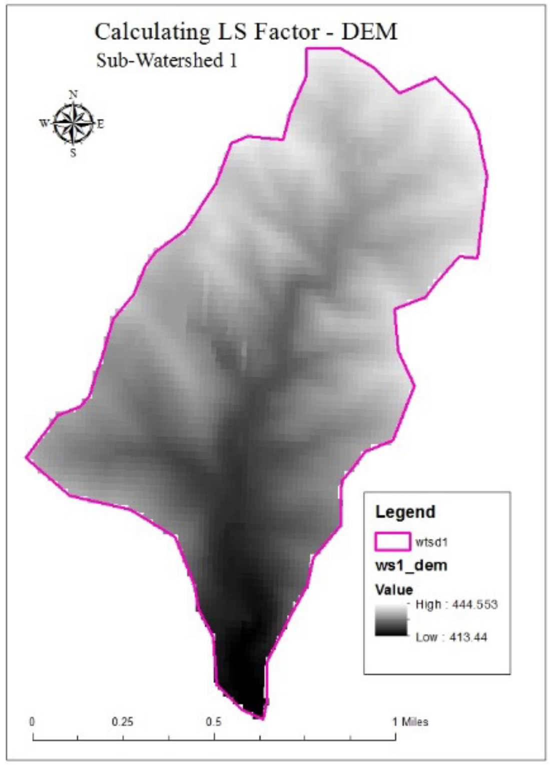


Figure 16. Elevation data clipped by sub-watershed 1.

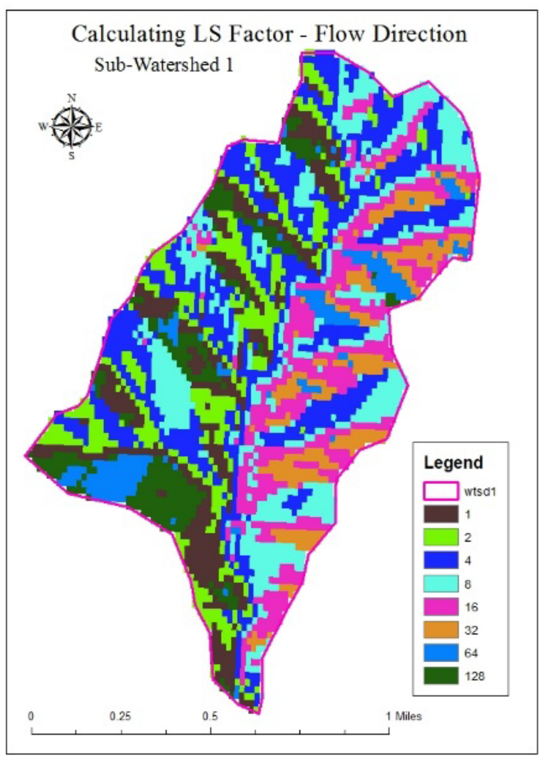


Figure 17. Flow direction data used to derive flow accumulation for sub-watershed 1.

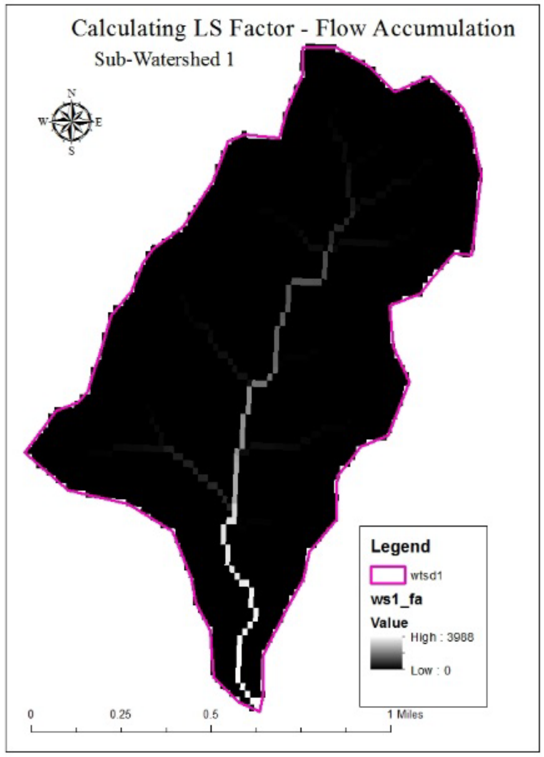


Figure 18. Flow accumulation raster data used to determine slope for sub-watershed 1.

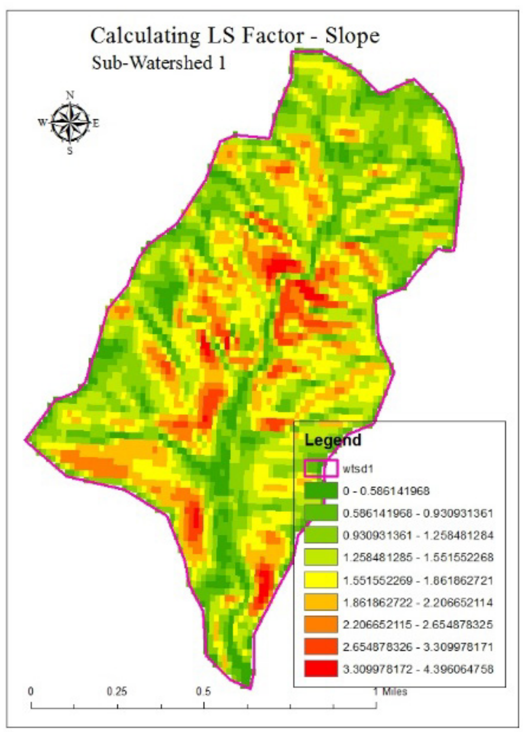


Figure 19. Slope raster used to determine LS factors for sub-watershed 1.

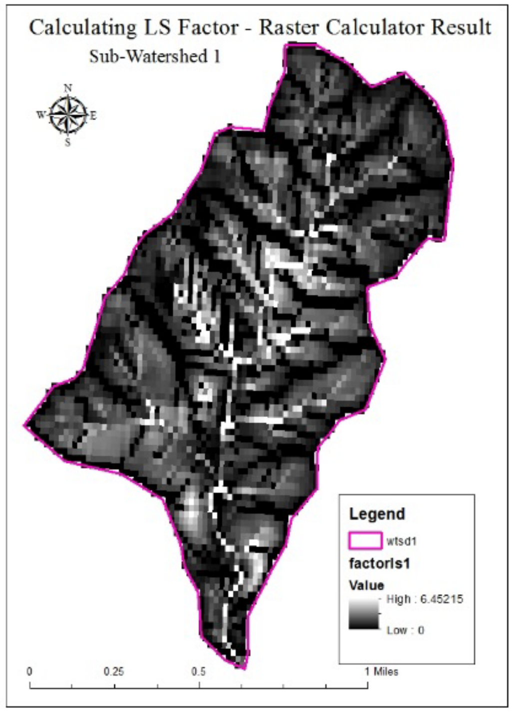


Figure 20. Raster calculator result used to derive data in LS factor.

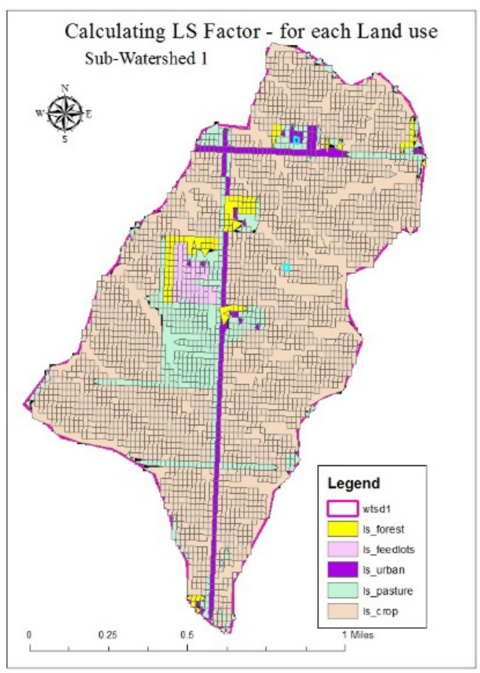


Figure 21. LS Factor map with data imbedded for Universal Soil Loss Equation (USLE).

The raster to polygon tool converts the clipped land use data to a polygon. Once the LS factor data is divided into each subsequent land use and converted to a polygon, a field is added in the attribute table to calculate area for each LS factor pixel. This data table is exported from ArcMap to an Excel spreadsheet. A column is added to divide the LS factor by one hundred. (Note, values were previously multiplied to save the decimal places.) Weighted area is calculated using the LS factors and their respective area in acres for each land use in each sub-watershed.

After completing these detailed steps to determine LS factors for sub-watershed 1, default STEPL LS factor values, averaged for Sioux County, are compared with the calculated LS factor for each land use. There was not a significant difference between calculated values and default values for this parameter, thus STEPL default values for LS factors were applied for sub-watersheds 2, 3, and 4.

C Factor and P Factor

The C factor is the cover-management factor, used to estimate erosion rates due to the effects of cropping and management practices. The C factor encompasses plants, soil cover, soil biomass, and soil distribution activities. The average soil loss ratio, weighted according to the distribution of the rainfall factor during a given year estimates the C factor (RUSLE, 2014).The P factor is the crop support practice factor, which reflects impacts on the average annual erosion rate, due to support practices such as land contouring, strip-cropping or straight row farming, (RUSLE, 2014). The crop support factors and crop management factors used in STEPL are from data provided by the Iowa Department of Natural Resources (IDNR). The data provided by IDNR is specific to Sioux County, Iowa practices, and is used by their STEPL analysts for C and P factor inputs in STEPL. This data is included in Appendix D.

Other STEPL Inputs

STEPL provides standard values used for the runoff curve number for each land use. The default values for the curve numbers are routinely used to run STEPL by Iowa Department of Natural Resources to calculate total daily maximum loads for stream impairments, and therefore used here. Urban land use distribution was modified to reflect the rural setting. Urban land use in this study are roads and roofs, thus other urban settings (commercial, industrial, multi-family, etc.) were omitted.

CHAPTER 5

RESULTS

STEPL Model Results

STEPL estimates the total annual pollutant load in runoff in pounds per year for a watershed. The annual load estimates for each pollutant; nitrogen, phosphorus, 5-day biological oxygen demand and sediment are given for the total watershed and each land use respectively. For this study, four sub-watersheds within Dry Creek are modeled to determine nutrient loads from CAFO feedlot runoff. Sub-watershed 1 has a single feedlot operation which contributes runoff and pollutants to Dry Creek. Two feedlot facilities are within sub-watershed 2 which contribute pollutant loads to the stream. Sub-watershed 3 lies between two drainage areas, and is located directly adjacent to the stream. Sub-watershed 4 is comprised of two sub-watersheds with one feedlot operation that spans both sub-watersheds. Table 2 shows the four sub-watersheds, area in acres by land use, total area, and the number of beef cattle respectively.

Table 2. Input data for each sub-watershed

Sub-watershed Inputs							
	Land Use Area in acres (ac.)						# of Cattle per sub-wtsd
	Urban	Cropland	Pasture	Forest	Feedlots	Total Area	
Wtsd 1	13.7	568.4	75.6	19.1	10.7	687.5	3000
Wtsd 2	10.7	269.6	33.1	2.5	18.5	334.5	7588
Wtsd 3	1.1	8.6	10.2	0.8	4.8	25.5	3500
Wtsd 4	13.9	846.4	63.5	8.6	20.4	952.8	4000

Sub-watershed 2 has two CAFO feedlots within the sub-watershed for a combined number of cattle at 7,588. Sub-watershed 2 has the largest number of cattle within its watershed, compared to 3,000 head, 3,500 head, and 4,000 head of cattle at the other sub-watersheds 1, 3, and 4, respectively. The greatest total area is sub-watershed 4 at 952.8 acres, which is comprised of two watersheds with one CAFO feedlot. The feedlot within sub-watershed 4 has the greatest feedlot area of approximately twenty acres. Sub-watershed 3 has a relatively small feedlot area of approximately 5 acres with 3,500 head of cattle of cattle, which is a large steer per land area ratio. Table 3 lists the number of cattle per acre of feedlot for each sub-watershed.

Table 3: The number of cattle per acre of feedlot for each sub-watershed.

	Feedlot Area (ac.)	# of Cattle per sub-wtsd	Cattle/acre
Watershed 1	10.67	3000	281
Watershed 2	18.53	7588	409
Watershed 3	4.80	3500	727
Watershed 4	20.44	4000	195

Sub-watershed 3 has the largest number of cattle confined to a feedlot with 727 cattle per acre. Although, sub-watershed 2 has largest number of cattle confined, it only confines 409 head of cattle per acre of feedlot.

Table 4 lists the total annual pollutant load of nitrogen, phosphorus and BOD in pounds per year from the four sub-watersheds.

Table 4. Total Annual Pollutant load for nitrogen, phosphorus, and biological oxygen demand for each sub-watershed.

Pollutant Load by Sub-Watershed (lb/yr)			
	Total Load		
	Nitrogen	Phosphorus	Biological Ox Demand
Wtsd 1	28676.64	5776.59	39817.78
Wtsd 2	37992.51	7618.16	51447.67
Wtsd 3	8879.26	1772.86	11933.38
Wtsd 4	50715.61	10224.01	69574.08

The largest amount of nitrogen comes from sub-watershed 4 with 50,715 lbs/yr (Table 3). Sub-watershed 2 has the second largest quantity of nitrogen at 37,992 lbs/yr, followed by sub-watershed 1 and 3, with 28,676 lbs/yr and 8,879 lbs/yr respectively. Phosphorus follows this same trend, with sub-watershed 4 generating the greatest P load followed by sub-watersheds 2, 1 and 3 at 7,618 lbs/yr, 5,776 lbs/yr and 1,772 lbs/yr respectively. Sub-watershed 4 contributes the greatest total annual load of nitrogen (N), phosphorus (P) and Biological Oxygen Demand (BOD) at 50,715.61 lb/yr, 10,224 lb/yr and 69,574 lb/yr respectively.

Table 5 lists the annual load of nitrogen and phosphorus contributed by each land use for the four sub-watersheds in pounds per year.

Table 5. Annual load of nitrogen and phosphorus by land use from the four sub-watersheds in lb/yr.

	Pollutant Load by Sub-Watershed (lb/yr)									
	Urban		Cropland		Pastureland		Forest		Feedlots	
	N	P	N	P	N	P	N	P	N	P
Wtsd 1	93.40	15.77	8987.15	1863.19	241.62	18.12	2.48	1.21	19310.73	3862.15
Wtsd 2	73.25	12.37	4263.64	883.92	105.62	7.92	0.35	0.17	33529.60	6705.92
Wtsd 3	7.75	1.31	135.54	28.10	32.55	2.44	0.13	0.06	8701.77	1740.35
Wtsd 4	94.69	15.99	13382.97	2774.52	202.96	15.22	1.15	0.56	36976.65	7395.33

The four sub-watersheds overwhelmingly show the greatest amount of pollutants came from feedlot runoff, followed by runoff from cropland to which manure has been land applied. Urban, pastureland and forest contribute a fraction of the pollutants in the runoff compared to feedlots and cropland. Feedlots account for approximately 73% of the total nitrogen load from sub-watershed 4. Approximately 27% of nitrogen came from cropland, whereas the other land uses contribute less than one percent. This trend is consistent in all watersheds in the study, with the great majority of the pollutant load coming from the feedlot runoff, regardless of feedlot area or area of other land uses. Figures 22-25 chart the distribution of nitrogen runoff by land use from each sub-watershed.

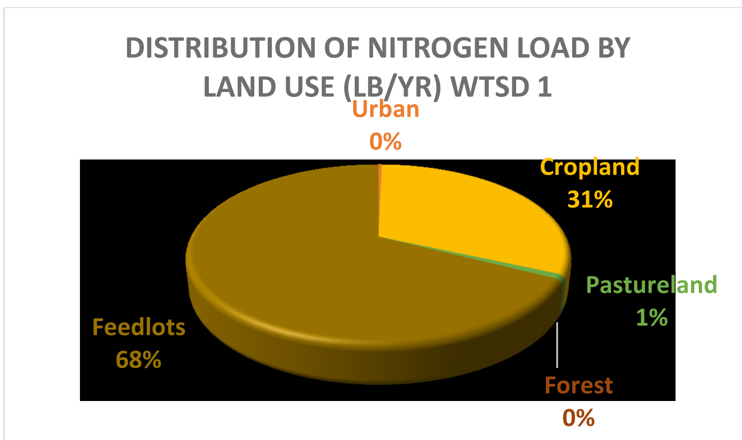


Figure 22. Pie chart of nitrogen from Sub-watershed 1

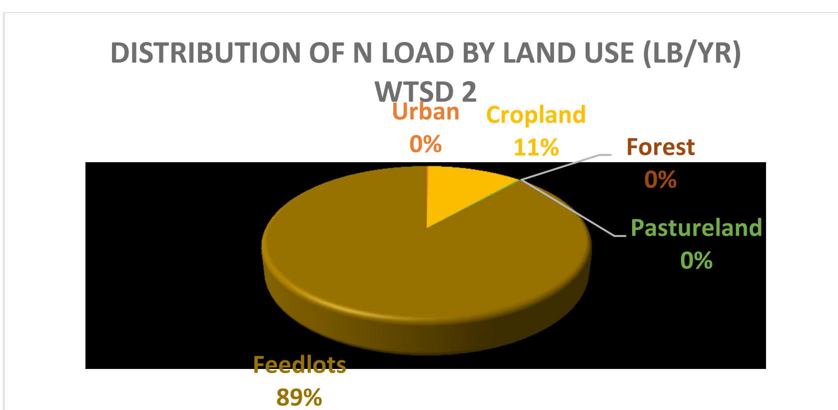


Figure 23. Pie chart of nitrogen for Sub-watershed 2 (has two feedlots).

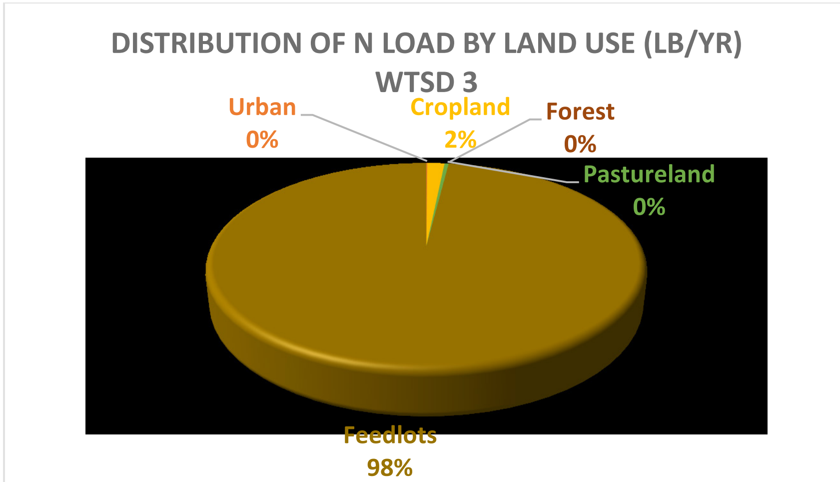


Figure 24. Pie chart of Nitrogen from Sub-watershed 3 (small feedlot area, large number of cattle).

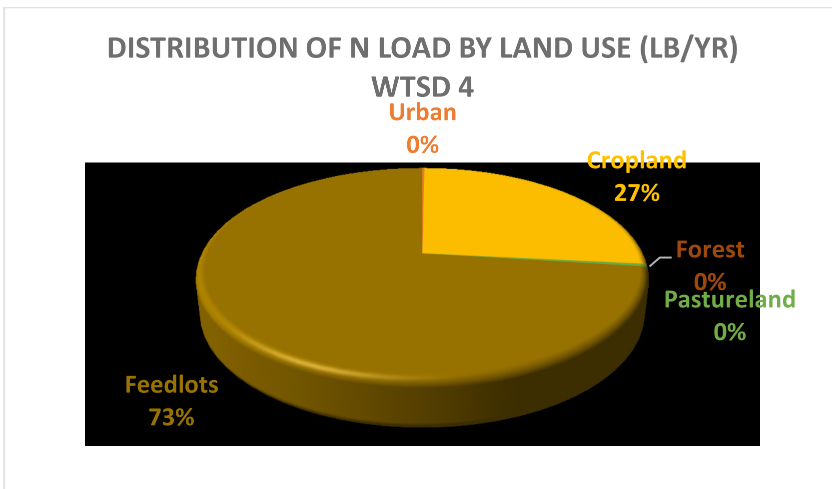


Figure 25. Pie chart of nitrogen from Sub-watershed 4 (has drainage from two sub-watersheds).

CHAPTER 6

DISCUSSION

The results of this study demonstrate the feedlot land use area is small in comparison to total area of each sub-watershed. Feedlot area only accounts for 1.5%, 5.5%, 18.8%, and 2.1% of watersheds 1, 2, 3, and 4 respectively. However, the highest N, P and BOD loads for all land uses are from the feedlot runoff. Figure 26 presents the land use distribution in acres for each sub-watershed.

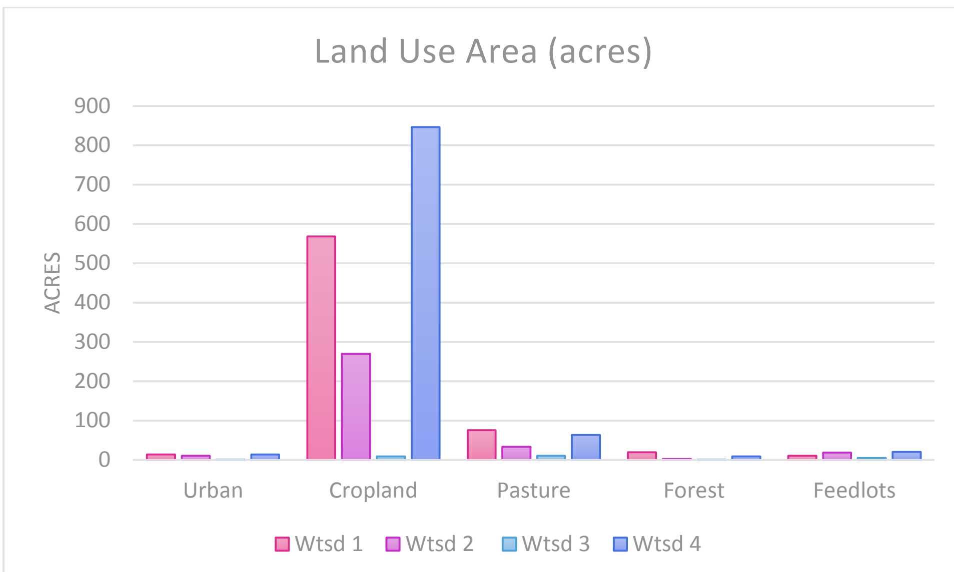


Figure 26. Bar graph of the number of acres of each land use by sub-watershed

This data shows the greatest amount of land area in the four sub-watersheds is cropland, then pasture. Forest, urban and feedlot land use categories account for a very small percent of all land use. Figure 27 presents the nitrogen load of the land use categories from each sub-watershed.

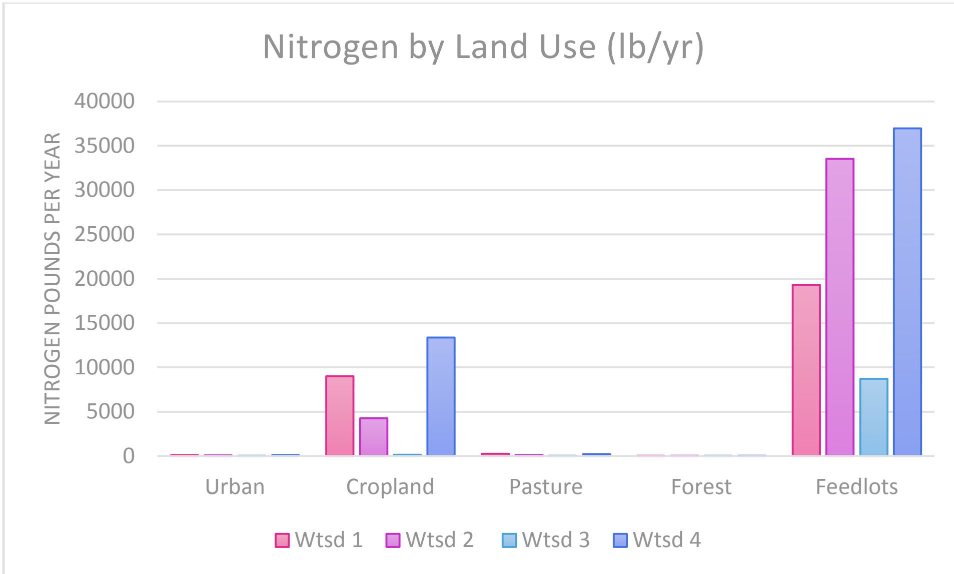


Figure 27. Bar graph of annual nitrogen load from each land use, by sub-watershed

A comparison of Figures 26 and 27 illustrate that although the greatest total land use area in sub-watersheds 1, 2, 3 and 4 is cropland and pasture, the largest nitrogen loads are from feedlot runoff in each sub-watershed. STEPL calculates for an assumed amount of manure scraped from feedlots and land applied to cropland, thus cropland also contributes high pollutant loads in runoff. STEPL uses a higher pollutant concentration to estimate runoff in relation to the number of animals per acre of land. Table 6 shows the annual nitrogen and phosphorus content in beef cattle manure, and the results of the annual load of nitrogen and phosphorus runoff from the feedlots. The estimations below are based on 0.150 kg (0.33 lb) of nitrogen, and 0.053 kg (0.12 lb) of phosphorus content in manure per beef cow per day (Ruddy, 2006).

Table 6: Annual estimations of nitrogen and phosphorus in manure with STEPL feedlot results for nitrogen and phosphorus.

Nitrogen and Phosphorus Content in Manure				Feedlots	
	# of Cattle per sub-wtsd	Lbs. N in Manure Annually	Lbs. P in Manure Annually	N lb/yr	P lb/yr
Wtsd 1	3000	362171.25	127967.18	19310.73	3862.15
Wtsd 2	7588	916051.82	323671.64	33529.60	6705.92
Wtsd 3	3500	422533.13	149295.04	8701.77	1740.35
Wtsd 4	4000	482895.00	170622.90	36976.65	7395.33

This table displays a considerable amount of nitrogen and phosphorus produced by each sub-watershed based on animal manure output information. STEPL's estimated nitrogen and phosphorus are substantially lower than the amount of nitrogen and phosphorus contained in manure. This is reasonable, due to the amount of nitrogen and phosphorus that are taken up by crops, and other management practices assumed such as feedlot manure scraping in STEPL. Further the land within each sub-watershed would not be sufficient for land application, therefore it can be inferred that much of the manure that is produced at these facilities are land applied to cropland outside of the sub-watersheds.

Results compared with other nutrient load studies

This study estimates nitrogen loads from feedlot runoff ranging from 8701.77 – 36,976.65 lb/yr. Mean annual nutrient fluxes can have wide variability. Alexander et al. (2008) document variation in total nitrogen over 6 orders of magnitude at monitoring sites, ranging from 0.94 to 5243 kg/km²/yr (0.0084 to 46.79 lb/ac/yr). Another study for the South Fork watershed in central Iowa found total nitrogen loads ranging from 14 to 23 lb/ac/yr from 2002 to 2005 (Tomer *et al*., 2008). The total area of watershed 1 is 687.5 acres, with an estimated 28,676.6 lb/yr of nitrogen which is approximately 41.7 lb/ac/yr. This load is within the range of other nutrient studies.

Comparison with NLCD

As discussed previously in Chapter 2, National Land Cover Dataset (NLCD) does not classify feedlots as a separate land use. Therefore, watershed models using NLCD data to estimate nutrient concentrations from land use sources would not account for feedlots as a land use. Figure 28 is an aerial image outlined by sub-watershed 2.

Figure 28. Aerial map of sub-watershed 2 image provided by ESRI, 2013.

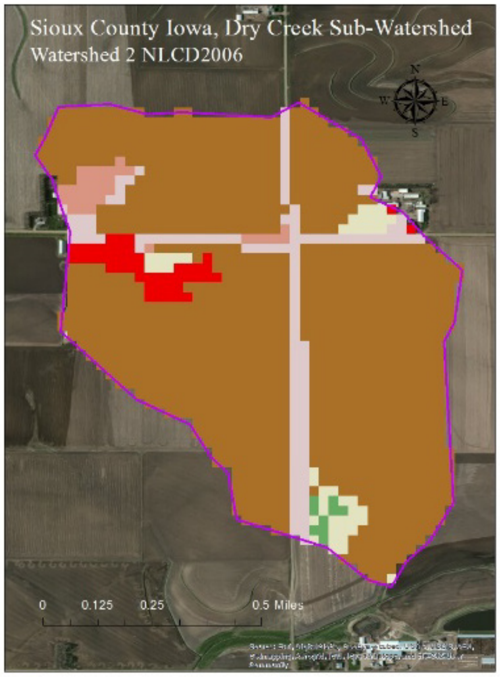


Figure 29 (Left). National Land Use Dataset (NLCD, 2006), land use raster for sub-watershed 2. Figure 30 (Right). GIS digitized land use map of sub-watershed 2.

The red pixel area of the NLCD represents high intensity developed land. The red pixel area is intended to represent urban land use such as barn roofs or other developed area. However, the feedlots in this image are not identified, and are classified as cultivated crops depicted in brown. However, the digitized land use data in Figure 37 accurately portrays the feedlots depicted in brown. A comparison of the NLCD land use data, to the land use data digitized in this study, illustrates feedlots are not characterized in large land use datasets. This further indicates the importance of modeling watersheds on a fine resolution scale to understand the impact that feedlots can contribute to the nutrient crises in the U.S. It is also important to note that sub-watershed 2 shown in figures 35-37 has a total feedlot area of 18.5 acres, one of the larger feedlot areas in this study. Since national land use data does not capture sizable feedlots such as this one, it can be reasonably inferred that other feedlots of this size and feedlots with less land area would not be characterized. This further asserts that watershed modeling estimating nutrients from feedlot runoff are being significantly underestimated. Although this comparison is compelling, further study would be necessary to determine the magnitude feedlots are not accounted.

Comparison with online data server and census of agriculture

The STEPL online data server provides data inputs to estimate pollutant load in runoff. Alternatively the user may identify and modify local data inputs. The data server provides information by Hydrologic Unit Code (HUC) 12. The HUC 12 size watersheds are searchable provides land use area, agricultural animal counts, and other required input data to run the model. It is important to note that although the online system provides land use area for feedlots, the feedlot area is not determined using land use information. Rather, it is determined based on minimal space required by each animal sector, in reflection of the agriculture animal number information also provided by the system (STEPL, 2011). The land use data in this study was digitized from aerial imagery which provides a true picture of land use area for each land use classified. Further, the animal head count data used in this study was pulled from the Iowa Department of Natural Resources database, and confirmed using documentation provide by IDNR and submitted by the facilities, confirming number of head of cattle confined at each facility.

The online data access tool allows for simple access to broad information for a rapid assessment, limiting data gathering needs. However, a comparison of animal counts from this study using local data and the data provided by the server show large variations. The online data server estimates the total area of the Dry Creek watershed as 32,129.92 acres, which is consistent with the data used in this study gathered using a measuring tool in ArcMap. The sub-watersheds delineated within Dry Creek for this research account for approximately 6%

of the total watershed area. Further, the feedlot area digitized for the 4 sub-watersheds in the study totaled to approximately 54.46 acres, which in turn only accounts for a very small percentage of the feedlots within the entire Dry Creek watershed. The online server estimate of total feedlot acres is 29.64 acres for the entire Dry Creek Watershed. It significantly underestimated the area of feedlots.

Further, the total number of cattle on feedlots within the study area total approximately 18,088 head of beef cattle (NRGIS, 2012). However, the online data server, estimates a total of 851 head of beef cattle for the all of the Dry Creek watershed. The source used to in the online data server to estimate beef cattle inventory is the USDA 2007 Census of Agriculture. This source clearly greatly underestimates the total amount of cattle confined within the Dry Creek watershed.

Furthermore, a GIS run to identify the amount of beef cattle within the Dry Creek Watershed showed an estimated 28,989 head of cattle. The methodology used in the STEPL online data server assumes 25ft^2 per beef cow, which would equate to 16.63 acres of feedlot land use for cattle. However, the server estimates 29.64 acres of feedlot area. Additional research into this disparity revealed the estimates are calculated by multiplying each animal sector including beef cow, dairy cow, swine, turkey, chicken, horse, sheep, and duck, by the minimum space required 25, 40, 15, 6, 1,45,8, and 3 ft^2 respectively, and combining the total, which is 1,291,126 ft^2, or 29.64 acres. This estimation is not representative of feedlot area in any way. Not all animals within this estimation are kept on feedlots, i.e. swine, poultry, dairy cow, and some cattle are often confined in barns as well. Totaling all the animal sectors into one is also not representative. The animal numbers estimated using USDA 2007 census of agriculture data are also incorrect. Although census data is helpful information in many ways, in the case of animal inventory it does not appear accurate by several orders of magnitude.

Local data should be used when available, for the most accurate results. The disparities in the data discussed above show the importance of local data, and indicate watershed studies may significantly underestimate nutrient loads contributed by CAFO feedlots. Future and more detailed study is necessary to determine the frequency USDA census of agriculture data is used to estimate animal inventory in other watershed models.

State and Federal Involvement

Manure and other animal related process wastewater should be managed and applied to land at rates that can be taken up by crops. However, feedlots throughout the state of Iowa may not have adequate runoff controls, or may not manage feedlots in a way to prevent all discharges of process wastewater and manure solids to streams. The Iowa Department of Natural Resources (IDNR) is the state agency which regulates AFOs and CAFOs for the state of Iowa. The IDNR requires facilities to install at minimum solids settling basins at all feedlots which hold between 300 and 999 head of cattle. However, solids settling basins will not prevent process wastewater from discharging, and when not managed appropriately solids can reach beyond the basin. The IDNR does not have the resources to inspect every AFO and CAFO regularly to ensure that they are being managed appropriately. A CAFO is subject to federal requirements, and if discharges from a CAFO enter a water of the U.S., it would be in violation of the Clean Water Act. However, medium and small AFOs are more difficult to regulate due to regulatory definitions excluding them, and may not fall within federal jurisdiction and regulation.

Although, the CAFOs modeled in this study may have some level of runoff controls, for the purpose of estimating the total load from the facilities, it is assumed that the operations do not have runoff controls. The U.S. Environmental Protection Agency recognizes runoff from a CAFO as a national priority (EPA, 2014). Despite state and federal regulations prohibiting discharges from large CAFOs, some have been found to not have controls, not have adequate controls, or not manage their operation in a way that would control all runoff from their facilities.

Nation Pollutant Discharge Elimination System (NPDES) permits issued by the state to some operations regulate the discharges from a CAFO. These permits require the CAFO to design runoff controls to capture all animal production related process wastewater and manure from the facility that would discharge in a rainfall event equivalent to a 25-year 24-hour storm. Any rainfall event greater than a 25-year storm is authorized under NPDES permitting, provided the facility was in compliance with the permit prior to the discharge. This means that if a CAFO has designed, constructed, operated and maintained runoff controls, during catastrophic rain events pollutants will discharge from these facilities. In the absence of rules and regulations to require medium and small AFOs to install runoff controls, the problems with excess nutrients in streams is not being fully addressed. As discussed previously a number of studies confirm that dead zones, hypoxia, and fish kills are attributed to excess nutrients in streams (Howarth *et al*., 1996; Carpenter *et al*., 1998; Mallin, 2006; Burkholder *et al*., 2007; Alexander *et al*., 2008; Greene *et al*., 2009). It is important for decision makers, who use the information provided by these studies to understand that runoff of nutrients from cropland is only a percentage of the problem. Direct runoff from CAFO and AFO feedlots constitute a significant source of runoff pollution.

CHAPTER 7

CONCLUSIONS

National studies continue to focus considerable efforts to determine sources of nutrient pollution within watersheds (Howarth *et al*., 1996; Carpenter *et al*., 1998; Alexander *et al*., 2008; Greene *et al*., 2009). This research evaluates feedlot impacts on a fine resolution sub-watershed scope, and demonstrates very high loads of nutrients from feedlot runoff compared to other land use/land cover sources. This indicates that CAFO feedlot runoff has been significantly underestimated as a source of nutrients within watersheds and watershed modeling.

In April of 2014, a congressional briefing by the USGS and NOAA addressed trends in nutrients and pesticides in the nation's rivers. Lori Sprague, a presenter in the briefing, states that 7,000 streams are not meeting national water quality goals. Nitrogen concentration trends in streams overall are continuing to increase. The most recent studies, modeling, and monitoring focus on the Mississippi River basin which empties into the Gulf of Mexico. The Gulf of Mexico hypoxic zone is the largest in the U.S. and in 2010 was covering 7,700 square miles, roughly the size of New Jersey (Sprague, 2014). The primary source of hypoxia to the Gulf is nutrients from the Mississippi watershed. Sprague estimates that in 2002 the largest sources of nitrogen to the Gulf were from agricultural related sources, specifically 41% farm fertilizers, 10% manure, and 9% legume crops. Data for the research in this congressional briefing includes state sources for fertilizer transport information, and USDA census of agriculture data for livestock manure and crop acreage. This congressional briefing which is presented to decision makers, is intended to give the best information possible for valuable decision making. However, if data sources which are the root of many studies are inaccurate, the results of these studies are incorrect, and further, are misleading as to the cause of watershed pollution, and main sources of the pollution.

Watershed modeling and monitoring are commonly used and credible way to study pollution sources of watershed constituents. Excess nutrients cause significant water quality impacts such as low dissolved oxygen, dead zones, fish kills, and reduced aquatic biodiversity which continue to be a hot topic of study and concern. It is important to understand the root sources of excess nutrients within a watershed, so targeted efforts can be implemented to control sources and reduce impacts. A combination of modeling, monitoring, and other data are used to estimate nutrient transport within watersheds. There are many sources of nutrient transport from a watershed such as urban environments, roads, parking lots, cropland and pasture. Emphasis in many studies as discussed throughout this paper, has been placed on cropland as the main source of nutrients, due to manure and fertilizer application. CAFO feedlot runoff is also well understood as a contributor to stream contamination. This study used new applications of the STEPL model with local data to identify the pollutant loading of nitrogen and phosphorus associated with feedlot runoff as compared to the surrounding land use/land cover.

Due to its ease of use and limited data gathering requirements STEPL is a widely used watershed model to determine nutrient transport within watersheds. In place of STEPL online data inputs, careful data gathering techniques are used to gather local information in order to get the more accurate estimation of feedlot runoff impacts. The results of this research show the high load of nutrients generated from feedlot areas and suggest feedlot nutrient transport to watersheds is underestimated by larger scale water quality models.

A number of models reviewed for this research use NLCD land cover rasters, which have national land cover information. Feedlots are not a classified land use category, thus, these studies using NLCD underestimate feedlots as a major source of stream impact. Many models account for nutrients in manure related to land application, but do not consider direct runoff from feedlots. Further, it appears studies that account for animal numbers by using USDA census of agriculture data, are greatly underestimating cattle numbers and probably other livestock as well.

Environmental impacts related to animal feeding operation wastes are well understood. Researchers continue to look for sources of nutrients within watersheds. If sources of pollution can be identified, resources and funding can be used to identify ways to help reduce or control those sources. Although runoff from cropland and other non-point sources attribute to runoff, feedlot runoff as shown in this study should also be recognized as a major contributor. Better land use data is needed, of higher resolution. Without high resolution data, such as data with less than 30 meter resolution, some land use/land cover categories cannot be clearly identified. Land uses such as feedlots, are shown here to have a large impact of nutrient loads. Although feedlots make up a small percentage of total land use, their large impact can be more clearly understood by this modeling. The majority of the land use area is cropland in the four sub-watersheds. However, feedlot runoff generates the largest nutrient contributions. This demonstrates that although CAFO feedlots make up a relatively small land area, they contribute large quantities of nutrients to the streams. This research shows the value of a fine resolution study with detailed data gathering and preparing local data inputs. Although this research identifies underestimations of CAFO feedlot runoff by other studies, and their contribution to nutrients in streams, additional research is needed.

Future Study

Watershed assessments to determine the non-point sources of excess nutrients do not fully capture the contribution from animal feeding operation cattle feedlots. This study reveals the impact of feedlots on streams from a localized and fine resolution scale, evaluating only the discharges from one watershed. Further watershed modeling of this resolution, to understand the magnitude of impacts from direct feedlot runoff to streams and estuaries is needed. This research identifies a number of subsequent studies needed, as well as the need for better data sources. To achieve a better scope of nutrient levels contributed from feedlot runoff to a HUC 12 watershed, additional CAFOs within the Dry Creek watershed should be modeled. Application of this study method to other watersheds in Iowa, and other areas of the U.S which have large livestock production and agricultural practices, would also add strength to this analysis. Small and medium size AFOs have far less regulatory requirements thus, less likely have runoff controls to reduce pollutant discharges from their facilities. This study modeled large CAFOs alone, therefore further watershed modeling to include other feedlot sizes such as small and medium facilities is needed.

Additional studies to explore the extent of underestimation of animal count between the USDA Census of Agriculture data, and local and state livestock data, is needed. The USDA Census of Agriculture data, and local state livestock data could be compiled into a national livestock inventory database to ensure that nutrient and other water quality related watershed studies have accurate livestock data to estimate pollutant loads from animal manure.

This research illustrates the large quantities of nutrients transported from feedlot runoff to streams, and how environmentally devastating CAFO pollutants are on surface waters. Best management practices at CAFOs can help prevent pollutant discharges to surface water. However, manure management practices can be costly, time consuming, or may be ignored and neglected by CAFOs operators. It is important that CAFO operators, and the public are aware of the environmental impacts caused by discharges from CAFO feedlots. As studies seek to identify causes of hypoxia, toxic algal blooms, fish kills, and massive dead zones in the Gulf of Mexico and other areas in the U.S., CAFO feedlot runoff must be considered more thoroughly as a main source of nutrient contamination.

Suggested improvements

More public exposure of CAFO environmental impacts is a driver to guide change. Government and local environmental agencies may understand the degree of environmental impacts related to wastes from CAFOs, but without public support little can be done. Public resources should be spent in the U.S. to help regulate animal feeding operation wastes, by reevaluating and re-writing CAFO federal rule. The largest animal feeding operations are subject to government regulation. However, smaller animal feeding operations are more difficult to regulate, and may not fall within government authority.

All AFOs and CAFOs are managing their operations in a manner that will not discharge. Depending on the amount of precipitation, inevitably outdoor confinements and feedlots will discharge. More funding, should be dedicated to cost sharing plans with CAFO operators, to install waste controls at facilities to help improve water quality. Federal loans and additional farm subsidies are also valuable options, to allow CAFO operators to install waste controls. Research of alternative cattle feeding techniques would help to find ways to raise cattle in a sustainable manner, and still be profitable for the operator.

Better land use data is a key element to understanding how each land use contributes nutrients to watersheds. If the land use data is not accurate, it does not truly or empirically represent the land uses or their runoff curve numbers in identifying impacts to streams.

Study of existing water quality models and watershed assessments to determine how, if at all, feedlots are characterized within the studies. Additional watershed modeling on a high resolution small-scale, to apply to a larger scale would aid in better understanding of nutrient pollution contributed to watersheds from CAFO feedlots.

Although it is important to determine if the level of CAFO impact is as large as estimated in this study, efforts on how to solve the issue are needed. The EPA must continue to make CAFOs one of their national priorities at the forefront of government involvement. The system of enforcement and compliance needs to be strengthened and supported by the courts and local authorities, so actions can be taken in order to move forward in addressing this issues. Public education at the local level needs to inform individuals of the magnitude of feedlot environmental impact. CAFO rules and regulations need to be re-evaluated and strengthened to capture a wider range of AFOs and CAFOs. Currently federal regulation is limited and has been further limited by bad case law and court decisions. Regulations do not help resolve the issues if the majority of the facilities are excluded from the definitions. All AFOs need to install some form of waste control facilities to ensure that no waste water or other waste materials leave their operation.

Water treatment is a necessary improvement at industrial sized feedlots. Many non-CAFO industrial facilities producing large volumes of waste have treatment facilities on site. The large cattle industries have the resources and funds to conduct treatment at their facilities. There should be no reason for wastewater to enter our natural resources from industrial production. Low cost water pollution control methods are also available. A viable low cost alternative would be installing natural berms or run-off control systems to divert flow to specific areas for storage and later treatment or land application. However, regulating authorities must monitor and enforce compliance with these mitigation methods. When berm systems fail, or manure application exceeds environmental quality limitations, these systems are no longer a solution, but contribute to the problem.

Overall this research presents an alternative approach to estimating pollutant loads from feedlot runoff. The results of this study show a surprising comparison between the amount of pollutants from feedlots, compared to other land uses despite feedlot area being relatively small. This research also identified issues with other data gathering techniques and data used for watershed modeling. Specifically, issues with the online data server for the STEPL model, and USDA Census of Agriculture, for animal count estimations. The issue incorrect animal count estimations have on watershed studies are clear. If the number of animals within a watershed are significantly underestimated, then the estimation of pollutant load from these sources will also be underestimated. Updates to local and national data for animal counts is needed to accurately depict the animal situation, and how it impacts watershed nutrient pollution. Without correct data and modeling results, emphasis is placed on the wrong point sources. In this case, current understanding is that nutrient pollution is mainly attributed from cropland sources. However, this research indicates it is more likely animal sources, such as feedlots are the main contributor of the problem. Additional study is needed not just to confirm the results of this study, but to update national animal count numbers to give more accurate implications on pollutant sources. Without these needed changes watershed quality will continue to be an environmental concern.

APPENDIX A

U.S. CENSUS BUREAU 1990, CENSUS DATA FOR SIOUX COUNTY, IOWA

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APPENDIX B

DATA FOR C AND P FACTORS FROM IDNR

LANDCOVER	C_Factor	P_Factor
, , ,		
Bin site, Not Applicable, Not Applicable, Not Applicable	na	Na
CB, Conventional Till, Not Applicable, Contour Buffers	0.215	0.86
CB, Conventional Till, Not Applicable, Contour Farming	0.215	0.73
CB, Conventional Till, Not Applicable, Contour Farming, ~~Not Applicable~~	0.215	0.73
CB, Conventional Till, Not Applicable, Not Applicable	0.215	1
CB, Conventional Till, Not Applicable, Terraces	0.215	0.6
CB, Conventional Till, Not Applicable, Terraces, Contour Farming	0.215	0.44
CB, Conventional Till, Not Applicable, Terraces, Contour Farming, ~~Not Applicable~~	0.215	0.44
CB, Mulch Till, Not Applicable, Contour Buffers	0.2	0.85
CB, Mulch Till, Not Applicable, Contour Farming	0.2	0.9
CB, Mulch Till, Not Applicable, Contour Farming, ~~Not Applicable~~	0.2	0.9
CB, Mulch Till, Not Applicable, Not Applicable	0.2	1
CB, Mulch Till, Not Applicable, Terraces, Contour Farming	0.2	0.9
CB, Mulch Till, Not Applicable, Terraces, Contour Farming, Contour Buffers	0.2	0.54
CB, Mulch Till, Not Applicable, Terraces, Contour Farming, ~~Not Applicable~~	0.2	0.95
CB, No Till, Not Applicable, Contour Farming	0.054	0.95
CB, No Till, Not Applicable, Contour Farming, ~~Not Applicable~~	0.054	0.95
CB, No Till, Not Applicable, Not Applicable	0.054	1
CB, No Till, Not Applicable, Terraces, Contour Farming	0.054	0.57
CB0MMM, Conventional Till, Not Applicable, Contour Farming	0.018	0.73
CB0MMM, Conventional Till, Not Applicable, Not Applicable	0.018	1
CB0MMM, Conventional Till, Not Applicable, Terraces	0.018	0.6
CB0MMM, Conventional Till, Not Applicable, Terraces, Contour Farming	0.018	0.44
CB0MMM, Mulch Till, Not Applicable, Contour Buffers	0.01	0.85
CB0MMM, Mulch Till, Not Applicable, Contour Farming	0.01	0.9
CB0MMM, Mulch Till, Not Applicable, Not Applicable	0.01	1
CB0MMM, Mulch Till, Not Applicable, Terraces	0.01	0.6
CB0MMM, Mulch Till, Not Applicable, Terraces, Contour Farming	0.01	0.54
CB0MMM, No Till, Not Applicable, Not Applicable	0.028	1
CB0MMM, No Till, Not Applicable, Terraces, Contour Farming	0.028	0.54
CB0MMM, *Not Applicable*, Not Applicable, Not Applicable	0.001	1
CB0MMM, *Not Applicable*, Not Applicable, Terraces, ~~Not Applicable~~	0.001	0.6
CCB, Conventional Till, Not Applicable, Contour Farming	0.144	0.73
CCB, Conventional Till, Not Applicable, Not Applicable	0.144	1
CCB, Conventional Till, Not Applicable, Terraces, Contour Farming	0.144	0.44
CCB, Mulch Till, Not Applicable, Contour Farming	0.11	0.9

CCB, Mulch Till, Not Applicable, Not Applicable	0.11	1
CCB, Mulch Till, Not Applicable, Terraces, Contour Farming	0.11	0.54
CCB, No Till, Not Applicable, Not Applicable	0.026	1
CRP, Conventional Till, Not Applicable, Not Applicable	0.001	1
CRP, **Mulch Till**, Not Applicable, Not Applicable	0.001	1
CRP, **No Till**, Not Applicable, **Field Buffers**	0.001	1
CRP, **No Till**, Not Applicable, Not Applicable	0.001	1
CRP, Not Applicable, Not Applicable, Contour Buffers	0.001	0.87
CRP, Not Applicable, Not Applicable, Contour Buffers, Field Buffers	0.001	0.87
CRP, Not Applicable, Not Applicable, Field Buffers	0.001	1
CRP, Not Applicable, Not Applicable, Not Applicable	0.001	1
CRP, Not Applicable, Not Applicable, Terraces	0.001	0.6
CRP, Not Applicable, Not Applicable, Terraces, Contour Buffers, Field Buffers	0.001	0.57
CRP, Not Applicable, Not Applicable, Terraces, ~~Contour Farming~~, Contour Buffers	0.001	0.57
Church and Cemetery, **Mulch Till**, Not Applicable, Not Applicable	na	na
Church and Cemetery, Not Applicable, Not Applicable, Not Applicable	na	na
County Sand Pile, **Mulch Till**, Not Applicable, **Contour Farming**, Not Applicable	na	na
Driveway, **Mulch Till**, Not Applicable, Not Applicable	na	na
Driveway, Not Applicable, Not Applicable, Not Applicable	na	na
Farmstead, **Conventional Till**, Not Applicable, Not Applicable	na	na
Farmstead, **Mulch Till**, Not Applicable, Not Applicable	na	na
Farmstead, **No Till**, Not Applicable, Not Applicable	na	na
Farmstead, Not Applicable, Not Applicable, Not Applicable	na	na
Field Drive, Not Applicable, Not Applicable, Not Applicable	na	na
Grassland, **Conventional Till**, Not Applicable, Not Applicable	0.001	1
Grassland, **Mulch Till**, Not Applicable, Field Buffers	0.001	1
Grassland, **Mulch Till**, Not Applicable, Not Applicable	0.001	1
Grassland, **Mulch Till**, Not Applicable, Terraces	0.001	0.6
Grassland, **Mulch Till**, Not Applicable, Terraces, **Contour Farming**	0.001	0.6
Grassland, Not Applicable, Not Applicable, Contour Buffers	0.001	0.87
Grassland, Not Applicable, Not Applicable, Field Buffers	0.001	1
Grassland, Not Applicable, Not Applicable, Field Buffers, ~~Not Applicable~~	0.001	1
Grassland, Not Applicable, Not Applicable, Not Applicable	0.001	1
Grassland, Not Applicable, Not Applicable, Terraces	0.001	0.6
Grassland, Not Applicable, Not Applicable, Terraces, ~~Contour Farming~~	0.001	0.6
Grassland, Not Applicable, Not Applicable, Terraces, ~~Contour Farming~~, Contour Buffers	0.001	0.57
Grassland, Not Applicable, Not Applicable, Terraces, Field Buffers	0.001	0.6
Grassland, Not Applicable, Not Applicable, Terraces, ~~Not Applicable~~	0.001	0.6

Gravel road, **Mulch Till**, Not Applicable, Not Applicable		na
Grazed Timber, Not Applicable, Not Applicable, Not Applicable	0.001	1
Hog Confinement, **Mulch Till**, Not Applicable, Terraces, **Contour Farming**	na	na
Hog Confinement, Not Applicable, Not Applicable, **Field Buffers**	na	na
Hog Confinement, Not Applicable, Not Applicable, Not Applicable	na	na
Hunting Preserve, Not Applicable, Not Applicable, Not Applicable	0.001	1
Pasture, **Conventional Till**, Not Applicable, Not Applicable	0.001	1
Pasture, **Mulch Till**, Not Applicable, Not Applicable	0.001	1
Pasture, Not Applicable, Not Applicable, **Contour Farming**	0.001	1
Pasture, Not Applicable, Not Applicable, **Field Buffers**	0.001	1
Pasture, Not Applicable, Not Applicable, Not Applicable	0.001	1
Pasture, Not Applicable, Not Applicable, Terraces	0.001	0.6
Pasture, Not Applicable, Not Applicable, Terraces, **Contour Farming**	0.001	0.6
Pasture, Not Applicable, Not Applicable, Terraces, ~~Not Applicable~~	0.001	0.6
Pit Silo, Not Applicable, Not Applicable, Not Applicable	0.001	1
Public Hunting Area, Not Applicable, Not Applicable, Terraces	0.001	1
Sand, Not Applicable, Not Applicable, Not Applicable	na	na
Substation, Not Applicable, Not Applicable, Not Applicable	na	na
Timber, Not Applicable, Not Applicable, Field Buffers	0.001	1
Timber, Not Applicable, Not Applicable, Not Applicable	0.001	1
Timber, Not Applicable, Not Applicable, **Terraces**	0.001	1
Urban/Residential, **Conventional Till**, Not Applicable, Not Applicable	na	na
Urban/Residential, **Mulch Till**, Not Applicable, **Terraces**, ~~Contour Farming~~	na	na
Urban/Residential, **No Till**, Not Applicable, Not Applicable	na	na
Urban/Residential, Not Applicable, Not Applicable, Not Applicable	na	na
Urban/Residential, Not Applicable, Not Applicable, **Terraces**	na	na
Water, **Mulch Till**, Not Applicable, **Contour Farming**	na	na
Water, Not Applicable, Not Applicable, **Field Buffers**	na	na
Water, Not Applicable, Not Applicable, Not Applicable	na	na
Wildlife Area, **Mulch Till**, Not Applicable, Not Applicable	0.001	1
Wildlife Area, Not Applicable, Not Applicable, Not Applicable	0.001	1
old Country School, **No Till**, Not Applicable, Not Applicable	na	na
*Everything in **BOLD** should be changed to 'Not Applicable'. Everything crossed out should be omitted.*		
Everything in red italics should be changed to 'Mulch Till'.		

APPENDIX C

NLCD LAND COVER CLASSIFICATAION LEGEND

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APPENDIX D

STEPL RESULTS FOR WATERSHED 1 THROUGH 4

WATERSHED 1

1. Total load by sub watershed				
Watershed	**N Load**	**P Load**	**BOD Load**	**Sediment Load**
	lb/year	lb/year	lb/year	t/year
Watershed 1	28676.64	5776.594	39817.78	2.39898

2. Total load by land uses				
Sources	**N Load (lb/yr)**	**P Load (lb/yr)**	**BOD Load (lb/yr)**	**Sediment Load (t/yr)**
Urban	93.40	15.77	309.13	2.30
Cropland	8987.15	1863.19	12801.20	0.00
Pastureland	241.62	18.12	785.28	0.00
Forest	2.48	1.21	6.05	0.09
Feedlots	19310.73	3862.15	25747.64	0.00
Septic	0.00	0.00	0.00	0.00
User Defined	41.26	16.16	168.47	0.00
Gully	0.00	0.00	0.00	0.00
Streambank	0.00	0.00	0.00	0.00
Groundwater	0.00	0.00	0.00	0.00
Total	28676.64	5776.59	39817.78	2.40

WATERSHED 2

1. Total load by sub watershed				
Watershed	**N Load**	**P Load**	**BOD Load**	**Sediment Load**
	lb/year	lb/year	lb/year	t/year
Watershed 2	37992.51	7618.159	51447.6662	1.82673463

2. Total load by land uses				
Sources	**N Load (lb/yr)**	**P Load (lb/yr)**	**BOD Load (lb/yr)**	**Sediment Load (t/yr)**
Urban	73.25	12.37	242.43	1.81
Cropland	4263.64	883.92	6073.08	0.00
Pastureland	105.62	7.92	343.28	0.00
Forest	0.35	0.17	0.85	0.02
Feedlots	33529.60	6705.92	44706.13	0.00
User Defined	0.00	0.00	0.00	0.00
Septic	20.05	7.85	81.89	0.00
Gully	0.00	0.00	0.00	0.00
Streambank	0.00	0.00	0.00	0.00
Groundwater	0.00	0.00	0.00	0.00
Total	37992.51	7618.16	51447.67	1.83

WATERSHED 3

1. Total load by sub watershed				
Watershed	N Load	P Load	BOD Load	Sediment Load
	lb/year	lb/year	lb/year	t/year
Watershed 3	8879.262	1772.861	11933.38	0.202739

2. Total load by land uses				
Sources	N Load (lb/yr)	P Load (lb/yr)	BOD Load (lb/yr)	Sediment Load (t/yr)
Urban	7.75	1.31	25.64	0.19
Cropland	135.54	28.10	193.07	0.00
Pastureland	32.55	2.44	105.78	0.00
Forest	0.13	0.06	0.30	0.01
Feedlots	8701.77	1740.35	11602.36	0.00
User Defined	0.00	0.00	0.00	0.00
Septic	1.53	0.60	6.23	0.00
Gully	0.00	0.00	0.00	0.00
Streambank	0.00	0.00	0.00	0.00
Groundwater	0.00	0.00	0.00	0.00
Total	8879.26	1772.86	11933.38	0.20

WATERSHED 4

1. Total load by sub watershed				
Watershed	N Load	P Load	BOD Load	Sediment Load
	lb/year	lb/year	lb/year	t/year
Watershed 4	50715.61	10224.01	69574.08	2.3903381

2. Total load by land uses				
Sources	N Load (lb/yr)	P Load (lb/yr)	BOD Load (lb/yr)	Sediment Load (t/yr)
Urban	94.69	15.99	313.41	2.34
Cropland	13382.97	2774.52	19062.58	0.00
Pastureland	202.96	15.22	659.63	0.00
Forest	1.15	0.56	2.79	0.05
Feedlots	36976.65	7395.33	49302.20	0.00
User Defined	0.00	0.00	0.00	0.00
Septic	57.18	22.39	233.47	0.00
Gully	0.00	0.00	0.00	0.00
Streambank	0.00	0.00	0.00	0.00
Groundwater	0.00	0.00	0.00	0.00
Total	50715.61	10224.01	69574.08	2.39

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