Grass-fed beef in Southeast Minnesota: Evaluating potential water quality improvements with increased grass-fed beef production

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Abstract

Cropping systems that incorporate perennial vegetation have been shown to improve water quality compared to annual cropping systems. The goal of this study was to evaluate the effect of perennial forage-based cattle production systems on land-use and water quality in Southeastern Minnesota. A scenario was developed where a fraction of the land area currently used for corn and soybean production was changed into use for pasture and hay. The area of land needed for pasture and hay production was assumed to equal that needed to feed the number of cattle necessary to provide for current consumer demand for beef in Southeast Minnesota. The soil and water assessment tool (SWAT) was used to evaluate the effects of this alternative, increased grazing scenario on water quality in a representative watershed within Southeast Minnesota, the South Branch of the Root River. Three different approaches were used for determining the location of the grazing lands within the watershed: targeting areas of high slope, targeting areas of low crop productivity values, and randomly distributed. The results of the study show that to provide enough beef to meet demand for Southeast Minnesota, a minimal change in land-use is needed; only 2.6% of the total land area of the region would be needed for use perennial forage and pasture. When placed on annual cropland areas with high slope, this 2.6% change in land area into perennial forage showed reductions in sediment and phosphorus field losses up to 13% and 10%, respectively. These results indicate that when strategically placed, altering land-use from annual cropping systems to perennial forage systems could result in notable improvements in water quality.

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Introduction

At the early part of the twentieth century, agricultural production in the US occurred on relatively diverse farms where crop and livestock production were integrated. By the end of the century, innovations such as chemical fertilizers, improved crop cultivars and increased mechanization led to specialized production where farms and farming regions focus on either crop or animal production (Russelle et al., 2007); (Dimitri et al., 2005). In the Upper Midwest region, this has translated into increased acreage in simplified, short-term annual crop rotations. Adoption of current practices has resulted in significantly increased crop yields and farm productivity, but has also been identified as the cause of several environmental concerns, including the degradation of both fresh and marine water systems (Sulc and Tracy, 2007).

Coastal marine water systems downstream of the agricultural Upper Midwest have been greatly impacted by current cropping practices. Nutrient export from highly cropped agricultural areas into coastal marine systems has resulted in oxygen deprived, or hypoxic, environments (Committee on Environment and Natural Resources, 2010). Hypoxic waters are commonly referred to as “dead zones” because oxygen levels are too low to support any life, except microbes. The second largest hypoxic zone in the world is located in the Gulf of Mexico, where nutrient export, mainly from agricultural activity in the Upper Mississippi River basin, has created a dead zone extending across the Louisiana continental shelf and onto the Texas Coast (Rabalais et al., 2001). Nutrient and sediments originating from agricultural fields have also had negative effects on fresh-water systems, causing eutrophication of lakes, and contaminating drinking water sources (Schulte et al., 2006; Sharpley et al., 2001). According to a 2004 EPA report, non-point source pollution from agricultural activity is responsible for 40% of impaired river and streams (US EPA Office of Water, 2009).

Agricultural management practices that incorporate perennial crops – perennial vegetation grown for use as feed or fuel -- have been shown to reduce the losses of water pollutants such as nitrate N, total phosphorus, and soil erosion resulting from agricultural cropland (Randall et al., 1997; Russelle et al., 2007). However, finding a market for perennial crops and providing economic incentive for farmers to grow them has limited their adoption onto the landscape (Randall and Mulla, 2001).

For the states in the Upper Mississippi River Basin, cattle production systems that use perennial forages as the primary component of the diet could be a viable way to add economic value to perennial agricultural systems. Cattle production systems typically use a grain-based diet to finish the animals and prepare them for slaughter. The corn grain based diet has become favored for a number of reasons, including gains in animal production efficiency (improves cattle gain efficiency) and land-use efficiency (less acres of land needed to produce their food). Agricultural acreages in the Upper Midwest region are valued for their ability to produce grain and other plant food crops, and a livestock production system that required significant land resources would not be widely adopted. However, an increase in agricultural acreage used for grazing or hay purposes would increase the amount of perennial vegetation and could result in improved water quality (Burkart et al., 2005; Chaplot et al., 2004).

For this project, the effect of perennial forage-based cattle production systems on land-use and water quality was studied. The first part of this research was to develop a spreadsheet-based model to investigate how much land would be needed to produce cattle feed in the Upper Midwest sufficient to meet current consumer demand for beef. Acreage needs were developed for two cattle production systems: a perennial forage-based system in which the cattle obtained their entire caloric intake from perennial grasses or legume; and a conventional system typical of current US beef production, in which finishing cattle obtain most of their caloric needs from grains. The land area required for the conventional cattle production system was developed to be used for comparison against the perennial-forage based system. Regional demand for beef in Southeast Minnesota was used to determine the number of cattle to be fed.

We determined the influence on water quality from a perennial planted land area that could also support beef production in the Upper Midwest. To study the effects from an increase in grazing and hay land on the water quality in the region we constructed a watershed modeling program. The model compared current land-use conditions to three alternative land-use scenarios. Each of the three land-use scenarios incorporated different watershed locations for grazing practices and hay production and they all increased pasture and hay production at the expense of corn and soybean acreage. The current analysis presents an agricultural watershed located in Southeastern Minnesota, within the unglaciated, Driftless area. The goal of this research was to evaluate the impacts on water quality from increased grazing and decreased corn and soybean production associated with a perennial forage-based cattle production system.

Chapter 1: Calculating Beef Cattle Feed Requirements

Overview

Increasing the amount of perennial vegetation on agricultural lands in the US Upper Midwest has been shown to improve water quality compared to intensive annual cropping systems. Perennial forage production would be particularly well suited to replace marginal corn and soybean cropland areas, such as in the driftless region of Upper Midwest. The goal of this research was to determine the area of land needed to produce enough forage-fed beef to satiate the local demand of Southeast Minnesota (located within the driftless region). The land area needed to meet local beef demand was also calculated for a conventional beef production system (which utilized corn grain in the cattle's' diet), and the land-use efficiency of the two systems was compared. Cattle feed needs were calculated using a net energy approach. The results of the research show that the conventional beef production system required 29% less land area than the forage-based system. Under the conventional system, 1.8% of the total land area of Southeast Minnesota would be needed to fulfill local beef demand. The forage-based, or grass-based, production system would require 2.6% of the total land area. The results of this study indicate that despite requiring 29% more land area, the grass-based production system has a minimal impact on land-usage.

Introduction

Simple annual cropping rotations involving corn and soybean currently dominate the agricultural landscape in the US Midwest. Yields of these crops have increased immensely, but specialization in a few crops has also had negative effects on the nation's water resources. Nutrient runoff from fertilizer is considered to be responsible for creating a hypoxic zone in the Gulf of Mexico (Committee on Environment and Natural Resources, 2010), while fields left bare for most of the year have seen high rates of erosion and sediment export which has reduced soil fertility and filled in lakes (Sulc and Tracy, 2007). Incorporating perennial crop species into annual cropping systems has been shown to reduce nutrient and sediment export from agricultural lands into the water supply (Randall et al., 1997; Randall and Mulla, 2001). However, finding a market for perennial crops and providing economic incentive for farmers to grow them has limited their adoption onto the landscape (Randall and Mulla, 2001).

For states in the Upper Midwest, cattle production systems that employ forages as the primary constituent in the animals' diet could be an economically viable way to increase the amount of perennial land cover. Cattle production systems typically use a grain-based diet to finish the animals and prepare them for slaughter. The corn grain based diet has become favored for a number of reasons, including gains in animal production efficiency (improves cattle gain efficiency) and land-use efficiency (less land area needed to produce cattle feed). Agricultural acreages in the Upper Midwest region are valued for their ability to produce grain and other plant food crops, and a livestock production system that required significant land resources would probably not be widely adopted.

We developed a model to investigate how much land would be needed to produce cattle feed in Southeast Minnesota sufficient to meet current consumer demand for beef in that region. Southeast Minnesota is defined by the following 11 counties: Dodge, Fillmore, Freeborn, Goodhue, Houston, Mower, Olmsted, Rice, Steele, Wabasha and Winona (Figure 1). Acreage needs were developed for two cattle production systems: a grass or forage-based system in which the cattle obtained their entire caloric intake from perennial grasses or legume; and a conventional system typical of current US beef production, in which finishing cattle obtain most of their caloric needs from grains. Regional demand for beef in Southeast Minnesota was used to determine the number of cattle to be fed, and plant growth and yields were specific for this region. The goals of this research were to 1) develop a model to determine acreage needs given two cattle production systems, 2) calculate those acreage needs specific to SE MN for both systems, and 3) evaluate the model's performance and resulting land use changes.

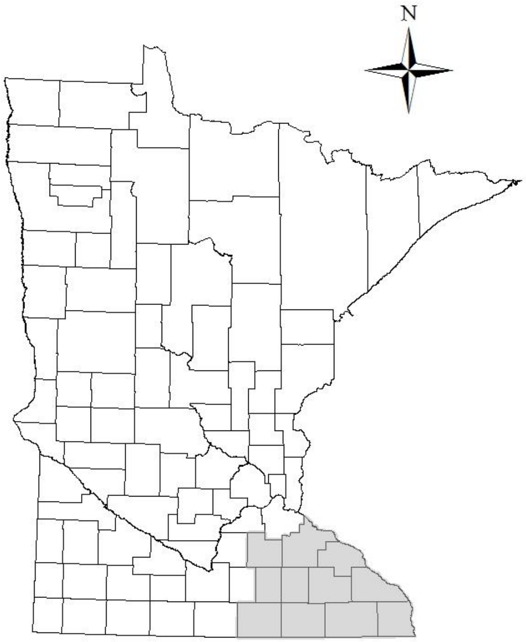

Figure 1: The eleven county Southeast Minnesota region used in this study is highlighted in the shaded area.

Methods

Model Development and Assumptions

Two cattle production systems were developed and modeled: a conventional system and a grass-based system. For the grass system, feed needs were satisfied by a diet derived from one crop: a clover-grass mix. This species mix was chosen because it is appropriate for both pasture and hay production. For the conventional system, feed needs were satisfied by diets derived from two crops: the clover-grass mix and corn. The amount of food required in either production system scenario was determined by calculating the amount of energy needed by the animals for physiological functions (NE^r), and the energy available in their feed (NE^a). Assumptions on cattle and crop production were developed in order to calculate NE^r and NE^a. Dividing the total feed requirement by assumed crop yields gave the total acreage needed for that crop. Assumptions on crop production were also used to estimate crop yields. Cattle and crop production assumptions are detailed in Section 1. Section 2 explains how those variables were used to calculate the energy required by the cattle and the energy available in their feed. Section 3 uses the results of the energy calculations to determine the total amount of feed necessary and, in conjunction with assumptions on crop productivity outlined in Section 1, the total acreage needed to produce this amount of food. An outline of the model development and flow is shown in Figure 2.

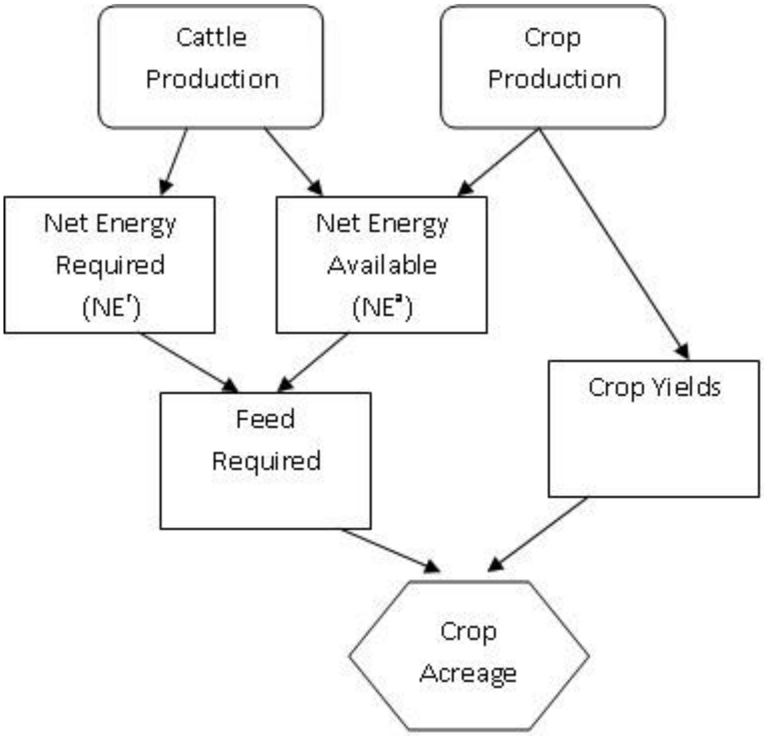

Figure 2: Model development flow chart. Model development begins with production assumptions (rounded boxes) which are used in a series of computations (rectangles) in order to determine the final outcome, the acreage required to feed the cattle (hexagon).

Cattle production in the model was considered to be a “closed-system” meaning that all aspects of cattle production were assumed to occur in Southeast Minnesota. Since cattle did not move in or out of the region, the total population of cattle that was needed to meet region beef demand had to include the population of cattle to be slaughtered in a year, as well as a supporting population of breeding and growing animals needed to sustain the finishing numbers. All population groups taken together were considered to make up the total herd. The population groups used in this model are defined in Table 1.

Table 1: Definitions of the different cattle populations that make up the entire herd.

Population	Abbrev.	Definition
Cows	--	Breeding parent, mother
Bulls	--	Breeding parent, father
Calves (steer and heifer)	--	Newly born calves feeding primarily on their mother’s milk; calf birth through weaning
Replacement Heifers	R. Heifer	Replace female breeding stock. A fraction of heifer calves will go into the replacement stock
Finishers (steer and heifer)	G. or C. Finisher	Cattle destined for slaughter. Once steer calves wean, they become finisher cattle. A fraction of weaned heifer calves also become finishers. G and C finisher refer to grass-finished and conventionally finished.

Cattle production in the US is described in terms of different production segments, where each segment specializes in one part of the production system (such as breeding cattle and raising young calves, or focusing on increasing the weight of cattle for slaughter). To match real-world production practices, production segments were defined for both the conventional and grass systems. In this model, production segments are a way of grouping populations of cattle by similar production practices and diets. For the conventional system, the assumptions made for each production segments were based on typical practices in Minnesota. The populations and diets that characterize each segment are outlined in Figure 3.

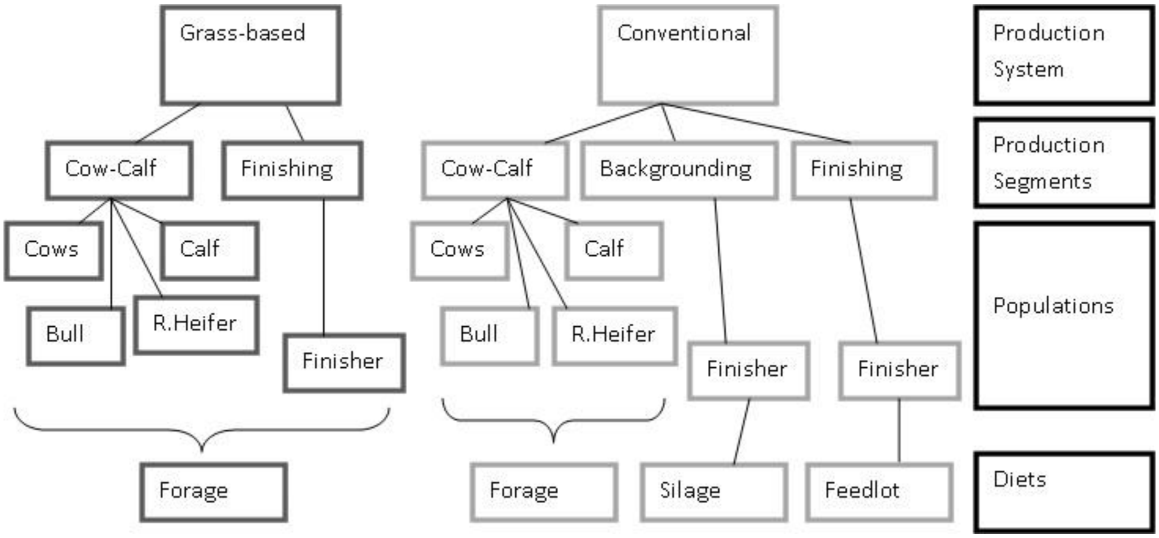

Figure 3: Outline of cattle production systems.

1. Cattle and Crop Production Assumptions

Detailed assumptions on cattle and crop production were developed in order to calculate the energy required by the herd and the energy available in their feed. The energy required by the cattle fluctuates with time, depending on cattle growth or pregnancy status. Additionally, available energy (NE^a) changes throughout the year depending on plant growth. To account for the correlation between time and energy, 1) cattle production variables (growth, weight and pregnancy), 2) cattle numbers, and 3) crop production variables (diet composition and available crop yields) were stated on a monthly basis for a one year period. One year was defined as beginning in January and ending in December.

1.1. Cattle Growth and Production

The energy required (NE^r) by a population of cattle is dependent on several cattle production variables, including: the animal's weight, rate of growth, and/or stage of pregnancy (in the case of breeding cows). Important dates and growth information for each population are described in the following sections, and growth rates are summarized in Table A1. Assumptions on cattle growth were developed based primarily on literature values for British-breed cattle.

Cow-Calf Segment: Conventional and Grass-based Systems

Cows: All cows were assumed to have a constant mass of 567 kg (1,250lbs). Calving was timed so that lactation, the time of greatest energy expense for the cow (Marston, 2005), occurred during the grazing period when the energy content of the feed was highest (Section 1.3). Lactation began when the calf was born and continued until weaning, approx 200 days after birth. To allow cows access to fresh forage material during the 6 months of lactation, the calves were assumed to be born on April 15. The gestation period for Angus and other British breeds of cattle is approximately 283 days (Andersen and Plum, 1965; Cundiff et al., 1998) so pregnancy was assumed to begin on July 6. Cows were in the first trimester of their pregnancy from July through September, the second trimester from October through December, and the third trimester from January through March. Lactation began in April, with the onset of calving, and continued through October.

Calves: Not all calves that were born survived through weaning, resulting in two calf population numbers: an initial number of calves born, and the number that survived to weaning (Table 2). The decrease in calf population between the number born and the number weaned was arbitrarily accounted for in July; the calf population for April through June equaled the number of calves born, and in July the population was decreased to reflect the weaning losses, and is equal to the number of calves weaned. Steer calves weighed 43.5kg (98lbs) at birth and heifers weighed 40.2 kg (89lbs) (Casas et al., 2011). It was assumed that the rate of gain for steer calves was 1.0 kg day^{-1} (2.205 lbs day^{-1}) and 0.93 kg day^{-1} (2.05 lbs day^{-1}) for heifer calves (Casas et al., 2011). Calves weaned after 200 days, resulting in weaning weights of 243.5kg (537lbs) for the steers and 225kg (496lbs) for the heifers. Average monthly calf masses are shown in Table A1.

Replacement Heifers: In a typical cow-calf operation, a percent of cows are culled each year for reasons such as fertility problems or old age (Chenoweth, 2005). These culled cows are replaced by a population of replacement heifers. In this model, after weaning, a fraction of heifer calves joined the replacement heifer population instead of the finishing population. Replacement heifers had the same rate of weight gain as the finisher heifers in the forage finishing production system (Table A1). Once replacement heifers reached maturity, they join the cow population, and are no longer separately categorized. British breed cattle are expected to reach puberty when they are about 60% of their mature weight (Larson, 2005). In this model, it was assumed that the average weight of the mature cow was 567kg (1,250lbs), so replacement heifers reached puberty at 340kg (750lbs). Replacement heifers reach this weight at the end of July of their second year, 472 days after birth (Table 2).

Table 2: Important dates in the cow-calf production segment.

Month	**Date**	**Event**
April	15	Calves born, lactation begins
July	1	Calf death loss taken into account
	6	Pregnancy begins
	31	R. Heifers reach maturity
October	31	Calves weaned

Backgrounding and Finishing Segments: Conventional System

***Finishers (Conventional*):** Following weaning in the conventional system, finishers were fed a corn-silage diet (Section 1.3) for three months, beginning November 1 each year and ending three months later on January 31 (Table A1). While on this diet, finishers were part of the backgrounding segment of cattle production. Backgrounding is done in conventional cattle production systems in order to allow for more gains before entering the feedlot. Gains on corn silage were assumed to be 1.1 kg day^{-1} (2.4lbs day^{-1}) for steers and 0.88kg day^{-1} (1.9lbs day $^{-1}$) for heifers (Chamberlain et al., 1971; Folmer et al., 2002; Keith et al., 1981; Tjardes et al., 2002). At the end of the three months, steers weighed 344 kg (758lbs) while heifers weighed 305 kg (672lbs). The average monthly weights of finisher cattle in the backgrounding segment are shown in Table A1.

Following their time on the corn-silage diet, finishing cattle in the conventional system changed to a feedlot diet (Table 3). Average daily gains for the feedlot finishing cattle were based on industry averages in the state of Minnesota, and were assumed to be 1.5kg day^{-1} (3.3 lbs day^{-1}) for steers and 1.35kg day^{-1} (2.97lbs day^{-1}) for heifers (Land O'Lakes Beef Feeds, 2010). Cattle in the conventional system reached their slaughter weight on July 31, when steers weighed 614 kg (1354 lbs) and heifers weighed 548 kg (1208 lbs). (These finishing weights are slightly less than those reported in as industry averages in Minnesota, but were chosen so that cattle production ended at the end of the month.) Including the 199 days (6 ½ months) the calf spends with its mother pre-weaning, it took a total of 471 days (15 ½ months) to finish one animal.

In a twelve month period, January through December, there were two groups of finishing cattle in the conventional system. The youngest group (C. Finisher 1, or C. Steer 1 and C. Heifer 1 when referring to a particular gender) was born in April of the "current" year. A second group of finishing cattle (C. Finisher 2, or C. Steer 2 and C. Heifer2) was born the year previous (Figure 3). The corresponding weights for each of these populations are shown in Table A1.

Finishing Stage: Grass-based system

Finishers (Grass): Forage finished cattle had two rates of gain, one for each of the two feeding seasons in this model (Section 1.3). Steer gains were based on averages from published grazing or hay feeding studies. Such values could not be found for heifers, therefore it was conservatively assumed that heifers rate of gain was 85% that of steers (which is less than the 88% determined by (Steen et al., 2003). For the grazing period, the rate of gain per day for steers was assumed to be 0.70 kg day^{-1} (1.54lbs) (Allen et al., 1996; Clanton, 1977; Greenquist et al., 2009; Martz et al., 1999; Neel et al., 2007; Sainz and Vernazza Paganini, 2004) and for heifers was assumed to be 0.6kg day^{-1} (1.4lbs). During the dry-lot season (Section 1.3), the rate of gain decreased in correlation to a decrease in forage quality, to 0.47kg day^{-1} (1.0 lbs day^{-1}) for steers (Allen et al., 1992; Petit and Flipot, 1992), and 0.4kg day^{-1} (0.88lbs day^{-1}) for heifers. Cattle in the grass-based system reach their finishing weight on May 31, when steers weigh 564 kg (1244lbs) and heifers weigh 499kg (1101lbs) (Table 3). Including the 199 days (6 ½ months) the calf spends with its mother pre-weaning, it took a total of 775 days (25 ½ months) to finish one animal. Since it takes more than a year to finish, the feeding period for grass finishers was further subdivided into dry-lot 1, grazing 1, dry-lot 2 and grazing 2 (Table A1).

In the grass-based system, given the assumptions on cattle growth, there were three groups of finishing cattle in a year period. The youngest group, (G. Finisher 1, or G Steer 1 and G. Heifer 1 when referring to a particular gender) had just weaned in the "current" year. A second group of finishing cattle (G. Finisher 2) was one year older than the first, while the third group of cattle (G. Finisher 3) was born two years previous to the first group (Figure 4). The corresponding weights for each of these populations are shown in Table A1.

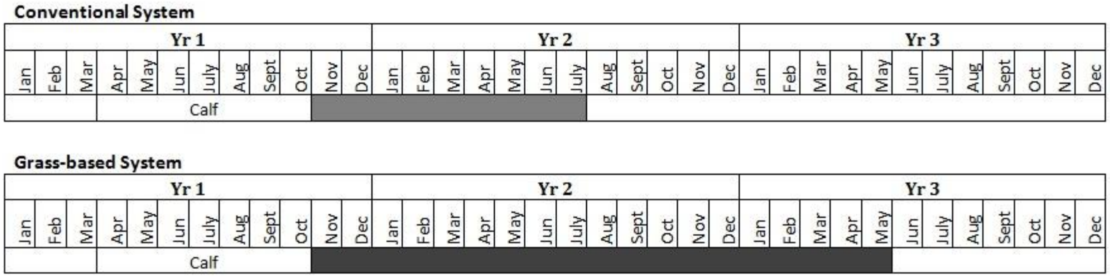

Figure 4: Conventional and grass-based finishing groups in a year period. Each line shows the lifespan for a group of cattle from the time they were born (calves, shaded in light) through finishing (finishing population shaded dark).

1.2. Characterizing Cattle Population Sizes

In order to calculate the total energy required by the entire herd of cattle, the number of cattle in the herd needed to be determined. The number of cattle slaughtered in a year, as well as the supporting herd size required to produce that number, were determined via a set of relational equations. The equations used to calculate the herd size are the same for both the conventional and grass based systems, but the actual herd numbers of each differ however because the finishing weights of cattle in the two systems differs. Population sizes for each month are shown in Table A2.

Finishing Cattle Numbers

The number of live cattle that needed to be finished each year to produce the amount of beef consumed in SE MN was determined by first using the amount of money spent on beef in SE MN to calculate the pounds of beef meat sold. Next, the cattle live-weight needed to provide that much meat was calculated by converting the pounds of meat sold, first from salable meat into a carcass weight, and then from the carcass weight into a live-weight.

Pounds Meat Sold*:* The amount of beef consumed in Southeast Minnesota was estimated from the amount of money spent by consumers for all beef products purchased in a supermarket in the eleven-county region of southeast Minnesota during 2008 and was estimated to be equal to $46,265,222 (Wang, 2011).This total dollar amount was divided by the average price per pound for all beef for the United States in 2008 to obtain the amount (in pounds), of beef sold. In 2008, the average price per pound for all cuts of retail beef in the United States was $3.97 (USDA ERS, 2011).

Carcass Weight: The pounds of retail beef sold, or salable meat, is a fraction of the live animals' weight. The weight of the animal after removal of the head, hide and internal organs is called the carcass weight. The carcass weight was determined by dividing the total pounds of meat sold by the fraction of salable retail cuts obtained from a carcass, known as the carcass yield percentage (Table 3) (Aberle et al., 2001). Carcass yield percentage can be affected by the finishing system used (Neel et al., 2007), but to simplify calculations it was assumed that finishers from both the grass system and conventional system had the same carcass percentage. The carcass yield percentage used was 52.3 percent, corresponding to beef yield grade 2 (Aberle et al., 2001). (Yield grade is standardized measure that estimates the amount of boneless retail cuts provided by a carcass based on the total area of the ribeye muscle and amount of fat on the carcass).

Live-weight: To determine the cattle live-weight from the carcass weight, the carcass weight was divided by the dressing percentage (Table 3). The dressing percentage is the ratio of the cattle's carcass weight to its live-weight and takes into account intestinal tract size, muscle bone ratio and carcass fatness (Aberle et al., 2001). Dressing percentages are correlated with the beef quality grade, which is a standardized measure of the palatability, or eating quality, of beef. Carcass grades can differ among finishing systems (Neel et al., 2007), but for this project it was assumed that finishers from both the conventional and grass systems have the same carcass grade, which was chosen to be Select grade beef. The dressing percentage that corresponds with Select grade beef is 59 percent (Aberle et al., 2001).

Number of Finishing Cattle: The live-weight was then divided by the average finishing weight of cattle in both the conventional and grass-based systems to determine the number of cattle needing to finish each year to fulfill regional demand. The average finishing weight of cattle was a weighted average of the finishing weights of steers and heifers (Table A1) based on the relative proportion of the finishing population that was each gender.

Table 3: Relational equations used to calculate the number of finishing cattle needed to satiate beef demand in Southeastern Minnesota.

Definition	Computational Formula
Pounds salable (retail meat sold)	$\frac{\text{Amount spent on beef}}{\text{Price per lb}}$
Pounds carcass weight	$\frac{\text{lbs salable beef}}{\text{Carcass yield \%}}$
Total cattle live-weight	$\frac{\text{Carcass weight}}{\text{Dressing \%}}$
Number of finished cattle	$\frac{\text{Total live-weight}}{\text{Finishing weight}}$

Herd Numbers

The only population value that could be calculated from the consumer expenditure data was the number of cattle that finish, so to determine the size of the rest of the populations, a series of relationships and assumptions were defined between the finishing population and the rest of the population. Cows and the number of finishing cattle were directly related, while the rest of the populations were related via the number of cows. The results of the population size calculations shown below are in Table A2 for both conventional and grass systems.

Cows: The number of cows is related to the total number of finishing cattle (n_{tf}) by:

$$C = \frac{n_{tf}}{0.72032} \tag{1.1}$$

Full details on how the relationships between the number of cows and finishers were created are defined in Appendix B.

Bulls: To determine the number of breeding bulls (B) to support this population, it was assumed that one bull was required to impregnate 30 cows:

$$B = \frac{C}{30} \tag{1.2}$$

Steer and heifer calves born**:** All cows were assumed to be exposed to, or mated with, a bull. However, not all pregnancies result in calf birth, and the calving percentage (defined in Table 4) takes this into account (Sanderson, 2005). The calving percentage (F_C) was estimated to be 95% (Brudelie and Deters, 2009). It was assumed that half of the calves born were male, and half female, resulting in the number of steer calves (n_{bc}) and heifer calves (n_{gc}) born equal to:

$$n_{bc} = n_{gc} = \frac{F_C C}{2} \tag{1.3}$$

Steer and heifer calves weaned: Of the calves born, not all survive to weaning. The percentage of calves that survive to weaning is called the weaning percentage (defined in Table 5) (Sanderson, 2005). The weaning percentage (F_w) for this study was assumed to be 88% (Brudelie and Deters, 2009). Since half of the calves born are steers and the other half are heifers, the number of steers weaned (n_{bw}) and number of heifers weaned (n_{gw}) equals the total number weaned divided by 2:

$$n_{bw} = n_{gw} = \frac{F_W C}{2} \tag{1.4}$$

Replacement heifers: The average replacement rate (F_R) used in this model was 15%, based on data from North Dakota (North Dakota State University, Dickson Research Extension Center, 2011). The number of heifer replacements (n_{gr}) equaled the fraction replaced (F_R), multiplied by the number of cows (C):

$$n_{gr} = F_R C \tag{1.5}$$

Steers finishing: The number of steers that finish (n_{bf}) is equal to the number of steers that are weaned minus the losses that occurred post-weaning – in addition to pre-weaning losses to the calf population numbers, some animals will also die post-weaning. Mortality rates for finisher cattle in a feedlot program normally range between 0 and 15%, with a 1 to 5% loss being the most common (Roeber et al., 2001). A study of the mortality of breeding heifers in Western Canadian beef herds showed an incidence of mortality of 1.1% (Waldner et al., 2009). While neither of these values are from the same system modeled here, they were used as an approximation of death losses of finisher cattle, and a death loss of 1.1% after weaning was used for both the conventional and grass-based systems. To calculate the number of cattle that die post-weaning, the number of cattle that survive up to weaning is multiplied by the 0.011, the fraction dead (F_D):

$$n_{bf} = (1 - F_D)\frac{F_W C}{2} \tag{1.6}$$

Heifers finishing: The number of heifers that finish equaled the number of heifer calves weaned minus the losses occurring post-weaning (as for the steers that finish), but also includes an additional loss from the replacement heifers:

$$n_{gf} = (1 - F_D)\frac{F_W C}{2} - F_R C \tag{1.7}$$

Table 4: Relational equations used in determining the population numbers of the supporting herd.

Definition	Computational Formula
Calving percentage	$\frac{Number\ of\ calves\ born}{Number\ of\ females\ exposed}$
Weaning percentage	$\frac{Number\ of\ calves\ weaned}{Number\ of\ cows\ exposed}$

1.3. Crop Production and Diets

The energy available (NE^a) to the cattle is dependent on the type of food, or diet, they are given. In the conventional cattle production system, different diets are given to cattle as they reach certain weight thresholds and different populations of cattle receive different diets (Figure 2). The assumed crop management practices also impact the energy available in the feed. Assumptions on diet composition, crop management practices and expected yields are outlined in this section.

Forage Diet

Diet Composition: Finishers in the grass-based system, as well as cows, bulls, replacement heifers, and calves in both the conventional and grass-based systems, were given the forage diet (Figure 2). The forage diet was made up of two feeding periods: dry-lot and grazing. The climate of Southeast Minnesota was assumed to support the growth of perennial grass and legume plants for six months out of the year. Fresh plant material from pasture was used as feed in the forage diet during this grazing period. For the other six months out of the year (the dry-lot period), the feed needs of cattle given the forage diet were met by conserved, dried forage material (hay). The grazing period occurred between May 1 and October 31 (184 days), and the dry-lot period occurred from November 1 through April 31 (181 days).

Both hay and pasture were composed of the same plant species: a red clover-orchardgrass mix. Orchardgrass made up two-thirds of the total dry matter yield, while red clover made up one-third. A legume- grass mixture was chosen because they have shown improved yield, quality and seasonal distribution compared to monocultures of grass or legume (Sleugh et al., 2000). Both species were chosen because they provide high quality feed both in the pasture for grazing, and harvest and dried as hay. Additionally, orchardgrass was chosen because it recovers quickly from grazing or harvesting events (Ehlke and Vellekson, 2011).

Forage Yield: It was assumed that grazing and harvesting practices were done to maximize both the quality and yield of the plants. Hay was harvested three times per year -- on June 1, July 1 and September 1 -- when the plants were in an early bloom stage (harvests occurred on the 1st of the month for ease of calculations). We incorporated a Management Intensive Rotational Grazing (MIRG) into the model. This allowed grazing to be timed to the growth stage of the forage and provided cattle access to pastures of early vegetative growth and high quality (Undersander et al., 2002).

The yearly total yield of the red clover-orchardgrass mix was assumed to be 7,839 kg dry matter (DM) ha^{-1} (3.5 ton DM acre^{-1}), which is the area weighted average yield predicted on common soil types in Southeast Minnesota (MN NRCS, 2001). Regional averages for non-alfalfa hay is less than the yield assumed here – in 2008-2009, it was reported to be between 4,480 to 5,600 kg ha^{-1} (2 to 2.5 tons acre^{-1}) (Minnesota NASS, 2010). However, three cut monocultures of red clover or orchardgrass have been shown to yield 8,736 kg ha^{-1} (3.9 tons acre $^{-1}$) (Sheaffer et al., 2003) and 7,392 kg ha^{-1} (3.3 tons acre^{-1}) (Ehlke and Vellekson, 2011)respectively. Therefore an expected average yearly yield of 7,839 kg DM ha^{-1} (3.5 tons acre^{-1}) was assumed to be reasonable.

Of the yearly total yield, only a fraction was available for harvest each month of the growing season. The percent of new biomass growth and yield (on a dry-weight basis) available per month is shown in Table 5 (MN NRCS, 2001). Of the harvested yield, not all available will be grazed by cattle. We assumed that cattle will consume 80% of the total yearly forage yield (Gerrish, 2002). Multiplying the yield of new biomass each month by a seasonal pasture utilization percentage (80%) gave the amount of forage available to the herd for grazing during each month in the grazing season (Table 5).

Table 5: Forage specie's monthly growth and yields. The harvested yield is based on yield assumptions for red-clover/orchardgrass mix. The grazing yield gives the plant yield available for grazing, and is 80% of the harvested yield.

		May	June	July	Aug	Sept	Oct	Yearly
Plant growth	*%*	23	32	17	10	13	5	100
Harvested Yield	*t acre*$^{-1}$	0.81	1.12	0.60	0.35	0.46	0.18	3.5
	kg ha^{-1}	1,802	2,509	1,333	785	1020	393	7,839
Grazing yield	*t acre*$^{-1}$	0.64	0.90	0.47	0.28	0.36	0.14	
	kg ha^{-1}	1,442	2,007	1,067	627	815	314	

Silage Diet

Diet Composition: Finisher cattle in the backgrounding segment of the conventional system were fed the silage diet. The silage diet was assumed to be composed of 90% well-eared corn silage and 10% supplement, on a dry matter basis. The exact composition of the protein supplement was not defined since it was only kept as a "placeholder" component of the diet – it was never used in calculations of amount of feed needed. Corn silage used in this diet was assumed to be grown for the explicit purpose of use as silage for cattle feed.

Silage Yield: The estimated in-field yield for corn silage was taken from farm data in 2008 to be 53,679 kg ha^{-1} (24 tons acre^{-1}) (Brudelie and Deters, 2009). Given assumed water content of 66% for in-field corn silage, the dry matter yield was 18,367 kg ha^{-1} (8.2 tons acre^{-1}) (Sheaffer and Swanson, 2010).

Feedlot Diet

***Diet Composition*:** Finisher cattle in the feedlot stage of the conventional system were fed the feedlot diet. The feedlot diet was formulated to contain corn grain, corn distillers grain (a by-product of corn ethanol production), hay and a supplement. As with the silage diet, the supplement was only used as a placeholder component of the diet, and the exact composition never defined. Feedlot diets in the cattle industry are varied. The diet given to cattle in this model was created to contain a concentration of distillers grains commonly found in Minnesota feedlot rations, and was set to be 25% of the total dry matter in the feed. The proportionate amounts of the other components of the diet were allowed to fluctuate so that the total net energy in the diet available for growth (NE_g, discussed further in Section 2), would equal that given by Minnesota industry averages. A ration formulation program was used to find the concentration of the other diet components so that the total NE_g in the diet equaled 60.4 Mcal NE_g per 100lb dry matter (Land O'Lakes Beef Feeds, 2010). The resulting proportions of the diet were: 55% corn grain, 25% distillers grains, 18% hay and 2% supplement, by dry matter weight.

Feedlot Yields: Hay in this diet was assumed to be the same red clover-orchardgrass mix used in the forage diet, with the same management practices and therefore the same expected yield. The in-field yield of corn grain was assumed to be 11,917 kg ha^{-1} (190 bu $acre^{-1}$) (Brudelie and Deters, 2009; Hoverstad et al., 2011). Assuming a field moisture percentage of 15.5% (Hoverstad et al., 2011), the resulting yield of corn grain on a dry matter basis was determined to be 10,098 kg ha^{-1} (161 bu $acre^{-1}$).

Distillers grains are a by-product of corn ethanol production. One tone (1,000 kg) of corn grain used for ethanol production yields 309kg of dried distillers grains (distillers grains with 10% moisture content) (Renewable fuels association, 2011). The yield of distillers grains was determined to be equal to the dry matter yield of corn grain for Southeastern Minnesota, 10,098 kg ha^{-1}, multiplied by 31%, to give a yield available for distillers grains equal to 3,132 kg ha^{-1} (50 bu $acre^{-1}$).

Table 6: Assumed yields for corn-based diet components.

Diet Component	DM Yield	
	Metric	English
Corn Silage	18,367 kg ha^{-1}	8.2 t $acre^{-1}$
Corn Grain	10,098 kg ha^{-1}	161 bu $acre^{-1}$
Corn Distillers Grain	3,132 kg ha^{-11}	50 bu $acre^{-1}$

2. Energy Demands and Energy Available

2.1. Net Energy

The total energy available in a particular feed is the amount of energy released by burning it under controlled conditions (Agnew and Yan, 2005; Blair, 2011). Cattle (and all animals) require energy input in the form of digested feed to support vital physiological processes (maintenance) and to accumulate new body tissue (production). Of the total energy available in the cattle's foodstuff, only a portion of it will be available to do work for the cow. During digestion, some of the potential energy available in the feed will not be fully digested and absorbed, while other energy will be lost in the form of heat.

Undigested material will be passed from the animal in the feces and urine, resulting in a loss of the total energy available. The formation of methane during digestion by microbes in the cow's rumen also results in a loss of energy. Additional energy is lost as heat during digestion, metabolism of nutrients and waste excretion (Blair, 2011). The net energy available in a foodstuff describes the energy available to cattle after taking into account energy lost from these sources – undigested material, methane gas by-product production and heat. Cattle energy demands can be described by the NE from feed required to fulfill different physiological functions; net energy describes the energy used by the ruminant animal for maintenance and for production (growth, lactation, and pregnancy) (Blair, 2011). Net energy is measured in units of megacalories (Mcal).

The net energy available (NE^a) or required (NE^r) is partitioned into uses for maintenance and for production. Energy for maintenance is used with a different physiologic efficiency than that used for production. The physiologic efficiency of energy used for maintenance, pregnancy and lactation are all similar enough that they are considered to be equal (National Research Council (US). Subcommittee on Beef Cattle Nutrition, 2000). Since the efficiencies of maintenance and growth differ, despite having the same units they are not directly additive terms.

2.2. Net Energy Required (NE^r)

The energy demands of cattle in both the conventional and grass systems were determined by calculating the Net Energy (NE) necessary for maintenance and growth. Net energy was calculated for both production systems on a monthly basis for each population group, based on assumed average monthly weights, milk production and days pregnant (Section 1.1).

The National Research Council (US) subcommittee on Beef Cattle Nutrition has established a set of prediction equations for estimating the energy requirements (in Mcal day^{-1}) for cattle maintenance (NE_m), growth (NE_g), pregnancy ($NE_{m,p}$) and lactation ($NE_{m,l}$). All of the cattle populations required energy for maintenance – the energy required to maintain basic bodily function. Cows had an extra energy expense during pregnancy and while lactating, and finishers, calves and replacement heifers had an extra energy need for growth.

Maintenance

The energy required for maintenance (Mcal day^{-1}) was calculated for each population using the equation (National Research Council (US). Subcommittee on Beef Cattle Nutrition, 1984):

$$NE_m = 0.077W^{0.75} \qquad (2.1)$$

This equation uses the average monthly mass of the population to determine the energy required for maintenance per day. The monthly average mass, *W*, was taken to be the animal's mass on the 15th of that month (Table A1).

***Calf NE_m*:** Calf NE_m calculations are slightly different from the rest of the population groups because they receive some of their energy from cow's milk. When calves are first born they are able to obtain all of their energy needs from milk, but as they grow, milk production concurrently declines, resulting in the calves energy needs being higher than that supplied by milk. Calves in this model were assumed to graze fresh forage to accommodate the difference in energy demanded versus that supplied in the milk. In order to determine how much forage the calf would need to eat to meet its total energy demands, its energy demand was split between that provided for by milk and that provided for by forage.

In order to simplify calculations, it was assumed that all of the energy available in milk went towards fulfilling NE_m requirements. Additionally, rather than calculating NE_m requirements on a monthly basis, an average total NE_m was calculated for the entire cow-calf period. The average NE_m was based on the average weight of the calf from birth through weaning; for steer calves this weight was equal to 137.23kg, and for heifers it was equal to 126.63kg. Applying these average weights to equation 2.1 gave the average NE_m needs for both steer and heifer calves per month for the entire cow-calf period. For steers the monthly NE_m was equal to 3.09 Mcal day^{-1}, and for heifer calves it was equal to 2.91 Mcal day^{-1}. To determine how much of the total NE_m milk fulfilled, the average milk yield for the period, 5.74kg was multiplied by the NE_m content for fresh cow milk (0.42 Mcal kg^{-1} fresh milk)(National Research Council (U.S.), 1982). The result was that milk would provide 2.41 Mcal day^{-1} of the total NE_m demand. The difference between the NE_m required by the calves and the NE_m provided by the milk was the energy for maintenance that needed to be fulfilled by forage intake. Steer calves required an additional 0.68 Mcal day^{-1} provided by forage to meet their NE_m demands, and heifers needed an additional 0.50 Mcal day^{-1}. Since the NE_m demands were averaged for the entire calf-period, the NE_m forage and NE_m milk required are the same for each month.

Pregnancy and Lactation

Pregnancy: Cows require extra energy during pregnancy and lactation. The energy required for pregnancy (in Mcal day^{-1}) is equal to (National Research Council (US). Subcommittee on Beef Cattle Nutrition, 1984):

$$NE_{m,p} = \frac{(CBW(0.0149 - 0.0000407t)e^{0.05883t - 0.0000804t^2})}{1000} \qquad (2.2)$$

For each month, $NE_{m,p}$ was determined by using the average number of days the cow was pregnant for that month (*t*), given the assumption that pregnancy began on July 6 each year. The birth weight (*CBW*) used was 42.35kg (93.4lbs), the average of the birth weight of steer and heifer calves (Section 1.1).

Lactation: The energy required for lactation, in Mcal kg^{-1} milk, is equal to (National Research Council (US). Subcommittee on Beef Cattle Nutrition, 1984):

$$NE_{m,l} = 0.1(M) + 0.35 \qquad (2.3)$$

The average milk fat percentage (*M*) was assumed to be 4.0% (Marston, 2005). To determine the $NE_{m,l}$ in terms of Mcal day^{-1}, rather than Mcal kg^{-1} milk as given in equation 3.3, $NE_{m,l}$ in Mcal kg^{-1} milk was multiplied by the average amount of milk produced per day for each month during the lactation period. The average amount of milk produced per week, Y(n), was a function of the weeks post-partum (n) and was determined using the equation (Jenkins and Ferrell, 1984):

$$Y(n) = \frac{n}{0.35e^{0.124n}} \qquad (2.4)$$

Given that calves were born on April 15, the average milk production used for April was for one week post-partum. For subsequent months, the average milk production was taken every 4 weeks, starting 4 weeks post partum. The kilograms of milk produced per day were multiplied by the $NE_{m,l}$ per kg of milk to give $NE_{m,l}$ in terms of Mcal per day.

$NE_{m,p}$ and $NE_{m,l}$ values per month for one cow are the same (per month for one cow) for both the grass and conventional systems. Since NE_m (maintenance), $NE_{m,p}$ (pregnancy), and $NE_{m,l}$ (lactation) are all have the same units of efficiency (maintenance), they can be added, resulting in a total NE_m demand for one cow for each month.

Growth

Animals that are growing – calves, feeders and replacement heifers – have additional energy needs to support their growth and weight gain. The net energy required for growth for steer calves and steer finishers is equal to (National Research Council (US). Subcommittee on Beef Cattle Nutrition, 1984):

$$NE_g = 0.0557W^{0.75}(LWG^{1.097}) \tag{2.5.1}$$

For heifer calves and finishers, NE_g is equal to (National Research Council (US). Subcommittee on Beef Cattle Nutrition, 1984):

$$NE_g = 0.0686W^{0.75}(LWG^{1.119}) \tag{2.5.2}$$

The mass (*W*) in equation 2.5.1 and 2.5.2 it is the average, or mid-month mass for each population for a given month. The live weight gain (*LWG*) is equal to the rate of gain for the given month (Section 1.1).

Calf NE_g: While NE_m calculations for calves are slightly different than the other populations, the NE_g calculation for calves is the same as it is for other “growing” populations. All available milk was assumed to fulfill calf NE_m requirements, so NE_g requirements must be entirely met by forage. Unlike the NE_m calculations, which were determined as an average for the entire cow-calf period, NE_g calculations are done on a monthly basis.

2.3. Net Energy Available (NE^a)

The net energy (both in terms of NE_m and NE_g) available per kg of feed (Mcal kg^{-1} feed) has been determined for most cattle feeds. By dividing the energy demands of the cattle (Mcal day^{-1}) by the relative energy amounts available per kilogram of feed in each diet (Mcal kg^{-1} feed), the mass needed for each diet to feed each animal per day (kg day^{-1}) was determined. NE^a in each diet is shown in Table 7.

Table 7: Diet composition and energy contents (NE^a).

	Diet			
	Forage		Corn Silage	Feedlot
Item	*Graze*	*Dry-lot*		
Ingredient		*%*		
Orchardgrass-red clover pasture	100	-	-	-
Orchardgrass-red clover Hay	-	100	-	20
Corn silage	-	-	90	-
Corn grain	-	-	-	50
Corn distillers grains	-	-	-	25
Supplement	-	-	10	5
Net Energy		*Mcal kg^{-1} DM*		
NEm	1.60	1.36	1.58	1.95
NEg	0.99	0.70	0.97	1.33

Forage Diet: The NE_m and NE_g available in the forage diet from pasture or hay is dependent on the plants' growth stage, with higher energy content available in the plants when they are in an early, vegetative growth stage, and lower energy content once the plants are mature and have flowered. Forage plants in this model were assumed to be of high energy content and an early growth stage (Section 1.3). NE_m and NE_g available for the forage diet are reported in Table 7. The values reported are in units of Mcal per kg dry matter, and are a weighted average of the NE_m and NE_g values reported in the US

Canadian Table of Feed Composition for orchardgrass and red clover for early vegetative growth in the grazing period, and early bloom hay for the dry-lot.

***Corn Silage Diet**:* The NE_m and NE_g available in the corn silage diet (for 100% dry matter) was determined to be equal to the NE_m and NE_g content of well earned corn silage given in the United States Canadian Tables of Feed Composition (Table 7).

Feedlot Finishing Diet: The NE_g available in the feedlot diet was set during diet formulation, and is based on industry standards for NE_g content in feedlot diets in Minnesota. NE_m was calculated from the mathematical relationship between NE_m and NE_g (National Research Council (U.S.), 1982).

3. Acreage Required

The energies available and required were used to determine the amount of feed needed to support each population. The feed amounts needed by populations given the same diet (Figure 2) were summed, to give the total amount of each diet needed to be consumed per month. Multiplying the total diet consumed by the diet composition percentages (Table 7) gave the total amount of each crop type to be consumed. The acreage needed to produce the feed in each diet was determined by dividing the crop consumed by the assumed yields for each crop (Section 1.3). The total feed requirements and acreage calculations were calculated separately for the conventional and grass-based systems.

3.1. Feed Intake

The energy intake needed by the cattle per day (as calculated in Section 2.2) was converted into a feed mass intake. Dividing the energy required by the energy available in the feed gave the mass of feed required; net energy required per day (with units of Mcal day^{-1}) divided by the energy available in the feed (units of Mcal kg^{-1}), resulted in the mass of feed needed (kg day^{-1}). Multiplying the daily feed intake by both the number of days in the month and the population size determined in Section 1.2 gave the monthly population feed intake. Populations with the same diet had their intakes summed in order to give the total feed requirement for each diet for each month. Daily intakes are shown in Table A3, and feed requirements for each population per month are shown in Table A4.

Daily Intake: The amount of feed required per day for an individual in each population was determined by dividing the daily net energy (ne_m and ne_g) requirements of the individual by the NE_m and NE_g available in their respective diets (Table 7):

$$ne_m^m = \frac{ne_m^r}{NE_m^a} \tag{3.1}$$

$$ne_g^m = \frac{ne_g^r}{NE_g^a} \tag{3.2}$$

Where lowercase "ne" denotes the net energy required per day. Because NE_m and NE_g available assume 100% dry matter for the feed, the resulting in feed mass needed to be consumed to meet the individual's energy requirements is a dry matter mass.

Net energies calculated in Section 2.2 were not additive. Once transformed into a mass of feed consumed (units of mass rather than energy) NE_m and NE_g become additive terms, the sum of which is the feed intake required (assuming 100% dry matter) to meet the total energy requirements of the individual. Dry matter intake, as the amount needed per day (kg day^{-1}) for one individual for each month in the year, is reported in Table A3.

Monthly Intake: The individual daily intakes for each month were multiplied by the number of days in that month to give the individual monthly intakes. To determine the total amount of feed required by the entire population – not just by an individual within it – the individual monthly intakes were multiplied by the corresponding population size for that month (Section 1.2). The population monthly intakes were calculated separately for the grass-based production system and the conventional system; even though *individual* intake is the same regardless of production system for some populations (i.e. cows, bulls, calves, replacement heifers), the *population* intakes differ since the population numbers differ between the two systems.

***Total Intake*:** For each production system, population monthly intakes were summed for those populations that were assumed to get the same diet (see Figure 3). The monthly intakes of each diet for the entire herd are reported as the totals in Table A4.

3.2. Crop Acreage Required

Grass-based System

In the grass-based system, all populations received the same diet: forage. As described in Section 1.2, during the growing season, that forage was fresh and grazed, and during the dry-lot season, it was hay. Hay was assumed to be harvested three times per year, on June 1, July 1 and September 1. The yearly total yield (Y_T) of the red clover-orchardgrass mix was assumed to be 7,838 kg DM ha^{-1} (3.5 tons DM acre^{-1}). The seasonal utilization of the total yearly yield that will be consumed by grazing animals (Y_G) was determined to be 80% of the total yield. The percent of the total biomass available each month during the growing season are shown in Table 5.

Grazing Acreage: The grazing acreage needed varied by month, due to the growth pattern on the forage plant species; during months of high plant productivity, less acreage was needed than during the months of lower productivity. During the grazing season, the acreage required to meet the feed demands of the herd was determined by dividing the feed demands of the herd for that month by the amount of forage available to graze that month:

$$A_G(m) = \frac{I(m)}{Y_G(m)} \tag{3.3}$$

Where $A_G(m)$ is the acreage needed for grazing for a particular month, as a function of the feed intake required for the month, $I(m)$, divided by the yield available for grazing, $Y_G(m)$. The acreage needed for grazing was calculated for the months May through October.

Equation 3.3 was modified to calculate the acreage needed for grazing in October. Since the final hay harvest occurred on September 1, areas not grazed in September but needed for grazing in October have growth available from both September and October. Thus, some areas grazed in October only have the 5% of the total grazing yield available, but other will have growth from September (13%) and October, or 18% of growth of the total grazing yield. To determine the total acreage needed for grazing in October, the amount of forage provided by the area grazed in September were subtracted from the total feed needs in October to give the amount of feed intake that needed to be met by "new" acreage (acreage greater than was utilized in September). The amount left to be fulfilled by "new" acreage was then divided by the amount of forage available in the "new" areas; October plus September re-growth, or 18% of the total grazing yield:

$$A_G(Oct) = \frac{I_G(Oct) - [Y_G(Oct) \times A_G(Sept)]}{0.18(Y_G) + A_G(Sept)} \tag{3.4}$$

Since the yield available for grazing each month assumed new growth per land area each month, the total acreage needed (A_G) to feed the herd is equal to the month with the greatest acreage required. The acreage needed in the month of October is the greatest acreage required and is therefore the total acreage needed for grazing. Acreage needed for grazing each month is shown in Table A5.

Hay Acreage: For months where a portion of the *total acreage* was grazed (May-September), the area of land not used for grazing was assumed to be harvested for hay that would be used during the dry-lot season. The total acreage needed for grazing, minus the acreage needed that month for grazing multiplied by the yield of forage available per acre, gives the amount of forage that was harvested for hay each month.

$$Y_{GH}(m) = (A_G - A_G(m)) \times Y_T(m) \tag{3.5}$$

Where $Y_{GH}(m)$ is the forage harvested for hay each month from the grazed acreage as a function of, A_G the total acreage needed for grazing, $A_G(m)$ is the acreage needed per month, and $Y_T(m)$ is the yield available each month. Since harvests were assumed to occur on the first of the month (Section 1.3), the yield of hay that is harvested is dependent on the growth, or forage available, from the month previous. The amount of hay harvested from grazing acreage each month is shown in Table A5.

Summing the total intake required during the dry-lot season (months November through April) gives the total hay requirements of the herd. The total amount of hay harvested from excess grazing lands does not equal the amount demanded by the herd during the dry-lot season, so extra acres were needed to produce exclusively hay. Any areas used solely for hay production were assumed to produce the yearly yield total every year. The difference between the hay demanded and the hay supplied from the grazing lands was equal to the amount of extra hay needed. Dividing this by the expected yield per unit area gives the additional land area required for hay production:

$$A_H = \frac{I_H - Y_{GH}}{Y_T} \tag{3.6}$$

Where A_H is the acreage needed for exclusively hay production, as a function of the total intake of hay (I_H), the mass of hay produced from grazing lands (Y_{GH}) and the seasonal yearly total yield of hay (Y_T). The sum of the total acreage needed for grazing and the extra acreage needed for hay is the total acreage needed to support the population:

$$A_T = A_G + A_H \tag{3.7}$$

Conventional System

Since the diets in the conventional system had varied components, the total intake of each diet needed to be multiplied by the percent component in order to determine how much of that component was required for intake. Then these component intakes were divided by the assumed yield (from Table 5 and 6) to give the acreage required for each component. Acreage components that were of the same crop (either corn or forage) were added together to give the total acreage for each crop.

Forage Acreage

The feed needs of the breeding population (cows, bulls, replacement heifers and calves) were all met by the forage diet. The same methods as used for the grass-based system were used to calculate the forage acreage needed to support the cow-calf populations within the conventional system. Monthly grazing acreage and hay harvested from the total grazing acreage are reported in Table A5.

Hay is also part of the feedlot finishing diet, composing 18% of the total intake of that diet. To determine the total mass of hay needed in the feedlot diet for the entire year period, the total intake of the feedlot diet was multiplied by 0.18 (Table A4, feedlot diet hay). This intake was subtracted from any excess hay produced in the cow-calf stage to give the additional area of hay needed in the feedlot diet. Dividing the remaining demand by the annual forage yield gave the land area in hay needed for the feedlot finishing stage.

Corn Acreage Requirements

Corn acreage was required to produce the corn silage component of the silage diet, and the distillers grains and rolled corn grain components of the feedlot diet. The total demand for each diet is shown in Table A4, as is the demand for component of each diet. The total acreage planted in corn required to meet herd dietary requirements was determined by summing the acreage requirements for corn silage, corn grain and distillers grains.

Silage: The corn-silage diet fed to backgrounding steer and heifer finishers was 90% corn silage and 10% supplement. The total intake of the silage diet was multiplied by 0.90 in order to determine the amount of the diet needed to be fulfilled by corn production (Table A4). The yearly total mass intake of corn silage was divided by the average yield of corn silage per area, 18,367 kg ha^{-1}, to give the land area in corn to fulfill the demands from the corn silage diet.

Rolled Grain Corn: The finishing diet fed to feeder steers and heifers is composed of 55% rolled corn grain. To determine the amount of corn grain used in the feedlot diet, the total intake of the feedlot diet was multiplied by 0.55. The yearly total intake of corn grain was divided by the average yield of corn grain per area, 10,098 kg ha $^{-1}$, to give the land area in corn required to provide the required amount of corn grain in the feedlot diet.

Distillers Grains: The finishing diet was composed of 25% distillers grains. The total intake of the feedlot diet multiplied by the 0.25 gave the amount of distillers grains to fulfill the total herd requirements. The intake of distillers grains was divided by the average yield of corn distillers grains per unit area, 3,132 kg ha^{-1}, to give the land area in corn required to provide the required amount of corn distillers grain in the feedlot diet.

Sensitivity Testing

All model input variables are listed in Table A6. Assumptions used in the finishing and backgrounding stages of the conventional system were based on well established industry standards. Many of the assumptions used for the grass-based production system – such as cattle average daily gains, forage yields, or pasture utilization percentage – are not as well established. A sensitivity analysis was conducted of selected input variables in the grass based system to get an estimate of which input variables had the greatest impact on the resulting final acreage, assuming all variables acted independently. Only the variables that were deemed particularly uncertain were changed during the sensitivity analysis; those variables that were analyzed in the sensitivity analysis are highlighted in Table A7. The average price per pound of beef was assumed to be unchangeable so that the total pounds of beef reflected demand in 2008. This sensitivity analysis measured the percent change in the final acreage calculation, given a 10% change in each input variable.

Results and Discussion

Model Evaluation

Feed Consumed: Model predicted individual daily dry matter intakes (DMI), as a percent of body weight, were compared against published values to examine the performance of the model in estimating the feed needs of the cattle on an individual basis.

Steers finished on hay are reported to require an average intake of 2.3% of their total body weight (BW), with the DMI percentage decreasing as steers' weight increased (Petit and Flipot, 1992). The model predicted an average DMI for finishing steers of 2.02%, which is slightly less, but very close to the DMI reported in the literature. Reported DMI for steers finishing on a feedlot diet is approximately 2.25% BW (Land O'Lakes Beef Feeds, 2010). For steers finishing in the conventional system, the model predicts DMI of 2.24% BW. These values are almost identical, which is to be expected given that the feedlot diet used in the model was formulated based on the same industry growth standards reported.

The daily amount of feed needed for cows is slightly lower than expected. During the 2nd trimester, expected DMI for a 567kg cow is approximately 1.7% BW, in the 3rd trimester it increases to 1.8% BW and during lactation is reported to be approximately 1.95% BW (Marston, 2005). The model predicts DMI's as percent of BW to be 1.24% for the 2nd trimester, 1.46% during the 3rd, and 1.69% during lactation. There are two apparent reasons the model could be underestimating their feed needs. First, cows should have a weight gain during pregnancy due to the growing fetus, which is not accounted for in the model, and a higher weight requires more feed intake. Secondly, it is assumed in the model that all cows are at their full size weight, even though some of them should still be growing. Replacement heifers join the cow herd at 340kg, which is well before they have reached their full grown size of 567kg. Therefore they should continue to grow once they are part of the cow population. However, the model assumes that all cows are at a static 567kg. This omission results in a slight undercount of the energy needs, and could be corrected in future work with this model. However, even though the modeled DMI for cows is slightly less than expected, it is not grossly less.

On an individual basis, the model appears to do a fair job of estimating the feed needs per day. For the finishing animals, their total feed needs will be influenced by the amount of time it takes for them to get to slaughter weight, which is a function of their gain per day. For animals finishing on a conventional diet, daily gains are well established. For animals finishing on a forage-diet, average daily gains are less well established, and the inputs used in the model had a higher level of uncertainty associated with them. Average daily gains for steers given conserved forage have been reported as low as 0.18 kg day^{-1} on hay (Allen et al., 1992) to as high as 0.88 kg day^{-1} on silage (Petit and Flipot, 1992). None of the gain studies cited in this research were conducted in the US Upper Midwest region, and it can be assumed that differences in climate and growing season could play a role in gains achieved by the animals. Additionally, there were few studies cited that included heifer gains, and so heifer gains had to estimated as some fraction less than the steers. With these uncertainties, the model may be over- or underestimating the amount of time, and therefore the amount of feed needed.

Key Input Variables**:** From the sensitivity analysis, the variables having the greatest impact on the total acreage needed in the grass-based production system were: the carcass yield percentage, the dressing percentage, the losses post weaning and the annual forage yield. A change in each of these variables of 10% resulted in the total acreage changing by the same percentage (Table A7).

The assumed carcass yield percent and dressing percent affect how many animals are needed to produce the pounds of beef. While a change in either of these two variables had approximately a 1:1 impact on the change in acreage needed (the model output), they are both numbers that have a small range of possible outcomes. For both, they would not be expected to vary more than 10% (Aberle et al., 2001), so the maximum impact they could have on the outcome would be a 10% change. The losses post weaning could vary dramatically depending on particular stresses to the herd. Assuming there was no unusual stress that could dramatically increase mortality (such as disease outbreak, severe drought, etc), it is unlikely that this variable would vary by more than 10% either.

The annual average yield of the forage also showed approximately a 1:1 response to the total acreage needed; a 10% change in the yield resulted in a 10% change in the total acreage needed. Unlike the carcass yield and dressing percentages though, the yield of forage expected does vary by more than 10%. Forage yields can vary year to year, depending on precipitation and temperatures. Yields can also vary depending on soil type and slope, which vary across the Southeast Minnesota region. The yield chosen for use here, 7,838 DM kg ha $^{-1}$ (3.5 tons DM acre^{-1}), is on the high side of possible yields; as noted in Section 1.3, varietal trial results have shown that annual average yields of 7,838 kg ha $^{-1}$ are possible, but actual yields of non-alfalfa hay in Southeast Minnesota average a lesser 4,480 to 5,600 kg DM ha $^{-1}$. A yield of 4,480 kg ha $^{-1}$ is over a 40% reduction in yield. Since yield can vary by so much, it is has the greatest impact on the acreage outcome. Having an accurate yield is very important to produce an accurate estimate of the total acreage needed.

The sensitivity analysis performed assumed that all input variables are independent to each other; a 10% decrease is one input variable only impacted the outcome, not any of the other input variables. However, many of the input variables are likely not independent of each other. Some inputs (such as forage quality and yield, or forage quality and average daily gains) are likely to be related, so that a 10% decrease in one would result in a decrease (or increase) in another. A linked change between variables (such as a concurrent decrease in both forage yield and quality) is almost certain to have a greater effect on the outcome (the total acreage needed) than a change in just one input. While there are input variables that are likely linked, there are no explicit formulas to link them, which is why they are all treated as independent in the model. The result is that changes in one variable in the model have less of an effect on the overall acreage needed than they should – decreasing yield to 4,480 kg ha $^{-1}$ does not result in even a doubling of the total acreage, which is still a very small fraction of the total acreage used for row crop production in the region currently.

Model Results

Acreage Required

Conventional System: In a year period, cattle in the conventional production system required 7.9E^{7}kg of hay, 8.6E^7 kg grazed forage, 2.0E^7 kg corn silage, 2.8E^7 kg corn grain and 1.3E^7 kg corn distillers grain. To meet this demand, a total of 31,813 ha (318 km^2 or 78,551 acres) were needed – which was a combined total of 23,938 ha (59,106 acres) pasture/hay and 7,875 ha (19,444 acres) corn. Of these totals, 23,621 ha (58,325 acres) of forage were needed to support the animals in the cow-calf stage, and 7,875 ha (19,444 acres) of corn were required for backgrounding and finishing animals (Table 8). No additional hay acres were needed for the finishers because there was excess hay production from the grazing acreage used in cow-calf production, and this amount was enough to satisfy the hay requirements in the finishing diet.

To raise one steer from birth through finishing in the conventional system required 0.95 ha (2.35 acres) of pasture/hay and corn. (This number also takes into account the feed needs of the breeding cattle.) Of this total, 0.60 ha (1.50 acres) were needed during the cow-calf stage, and 0.34 ha (0.84 acres) were needed for backgrounding/finishing (Table 8).

Grass-based System: The herd of cattle in the grass-based system required 1.7E^8 kg of hay and 1.5E^8 kg of grazed forage to meet their total feed in a year period. The total acreage needed to support this herd intake demand equaled 45,066 ha (450 km^2 or 111,275 acres) – 39,800 ha (98,271 acres) were needed for grazing/hay use, and additional 5,267ha (13,004 acres) were needed for hay production. The cow-calf stage required 26,109 ha (64,467 acres) of land and the finishing stage required an additional 18,957 ha (46,808 acres) (Table 7).

To raise one steer to finishing in the grass-based system required 1.10 ha (2.60 acres) of land in pasture/hay (including the feed demands of the animal's parents). 0.60 ha (1.50 acres) were needed during the cow-calf stage and 0.40 ha (1.10 acres) were needed for finishing (Table 8).

Table 8: Final acreage needed is shown based on the entire herd feed needs, as well as the feed needs for one steer (from birth through finishing).

Acreage	**Herd**				**1 Steer**			
	Grass		Conventional		Grass		Conventional	
	acres	*ha*	*acres*	*ha*	*acres*	*ha*	*acres*	*ha*
Total	**111,275**	**45,066**	**78,551**	**31,813**	**2.60**	**1.10**	**2.35**	**0.95**
Hay	13,004	5,267	--	--				
Graze/Hay	98,271	39,800	59,106	23,938				
Corn	--	--	19,444	7,875				
Cow-Calf	64,467	64,467	58,325	23,621	1.50	0.60	1.50	0.60
Finishing/ backgrounding	46,808	18,957	19,444	23,938	1.10	0.40	0.84	0.34

Impact on Land-use

The conventional system for raising beef required 29% less land than the grass-based system. The herd size for the conventional system was smaller than that for the grass-based system. This accounts for some of the difference in acreage needed between the conventional and grass systems when considering the total herd size – the conventional system had fewer animals to feed, and therefore required a smaller amount of food. On a per animal basis, the acreage needed to raise one steer during the cow-calf stage is the same in both the conventional and grass-based systems, since the diets are the same for cow-calf production in each stage. However, even on a per finisher basis, the acreage required during finishing is 10% less in the conventional system compared to the grass-based system. The model predicted acreage needs shown that a conventional grain-based finishing production system does increase land-use efficiency – more animals can be raised using less land.

The total land area of Southeast Minnesota is 17,527km^2 (4.3 million acres) (Minnesota NASS, 2010). Based on the results of the model detailed here, using a production system that relied entirely on forages as the energy source for cattle, it would take 2.6% of this total land to produce enough beef to feed the region's demand. If beef were produced with a conventional grain finishing system, it would require 1.8% of the land area. Currently in Southeast Minnesota, 9% of the total land is used for pasture. Assuming that none of this current pasture was used for beef production, adopting the grass-based production system described here would increase the amount of pasture land to 12%, while requiring a decrease in corn and soybean land area of 3% (Figure 5). It is likely that some fraction of the land used for pasture in Southeastern Minnesota is used for some part of the beef production system however, it was not known what amount current beef production does make up.

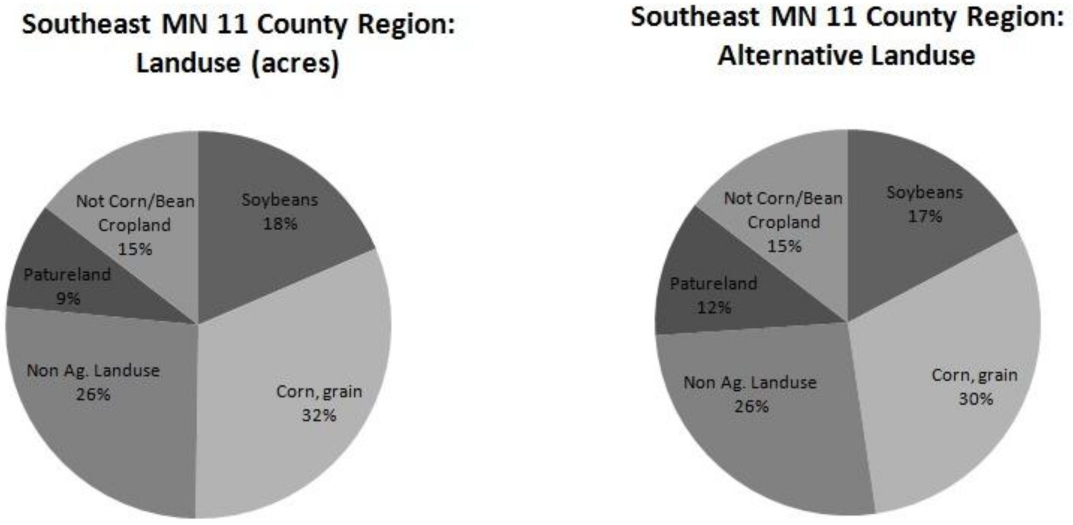

Figure5: Land area needed for grass-based production system. Chart on the left shows current land-use in Southeast Minnesota (USDA NASS, 2007). Chart on the right shows increase in grazing and hay ("pastureland") needed for a grass-based cattle production system, sufficient to meet beef demands of Southeast Minnesota.

If the model was updated to include the consumer expenditure for beef in the Twin Cities metropolitan area, the total amount spent on beef would increase from $46 million to $358 million (Wang, 2011), and the amount of beef Southeast Minnesota would need to produce would increase from 12 million pounds to 90 million pounds. With this increase in beef production, the percentage of land needed for grazing/hay would be much higher, and result in a very different agricultural system in Southeast Minnesota (Figure 5).

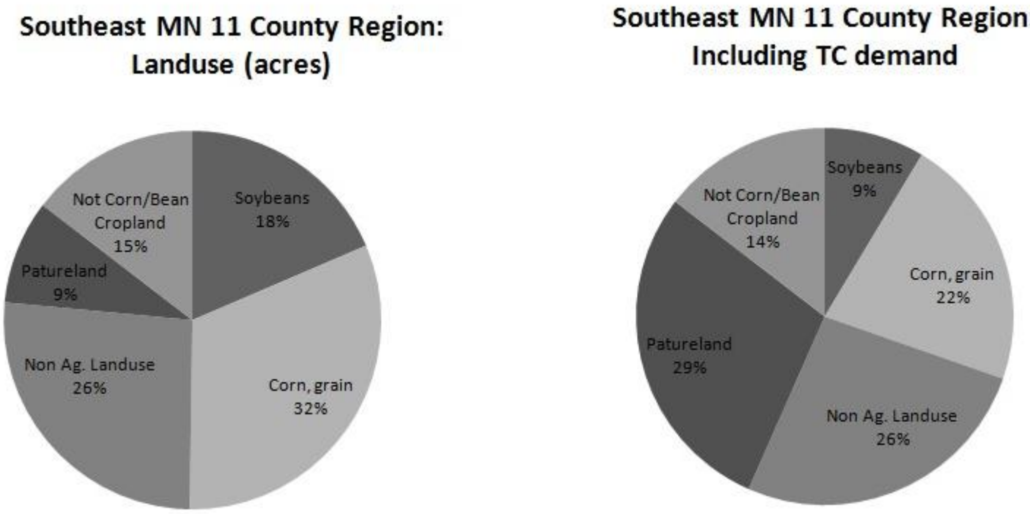

Figure 6: Land area needed for grass-based production system, including Twin Cities demand. Chart on the left shows current land-use in Southeast Minnesota (USDA NASS, 2007). Chart on the right shows increase in grazing and hay ("pastureland") needed for a grass-based cattle production system, sufficient to meet beef demands of Southeast Minnesota and the Twin Cities metropolitan area.

Summary and Conclusions

The model developed here provides and approximation of the land area needed to produce cattle for a conventional system and a grass-based system. The assumptions on both a grass-based and conventional cattle production system developed assume all animals finish at the same time, which is not a realistic approximation of cattle production systems as there is demand for beef year round. Despite there being many detailed inputs, there is a large degree of uncertainty in the results of the model for the grass-based production system, since factors such as forage yield and quality in Southeastern Minnesota are not as well established as they are for corn production. For the assumptions outlined here, overall the results of this research show that conventionally produced beef requires approximately 29% less land area for production than a grass-based system. To fulfill the beef demands of Southeastern Minnesota, 1.8% of the total land area of the region would be required for beef production under the conventional beef production system, and 2.6% would be required using a grass-based system. In this scenario, despite requiring 29% more land area, the grass-based production system has a minimal impact on land-usage. However, when the number of cattle are increased to include the beef demands of a metropolitan area (the Twin Cities metropolitan area), the amount of land needed to produce beef in the grass-based system becomes more prominent, requiring 20% of the land area, vs. 14% needed for the conventional system.

Chapter 2: Estimating water quality changes with increased grazing

Overview

The goal of this study was to evaluate the water quality effects resulting from increased land area land used for grazing and forage production in the South Branch of the Root River watershed (a karst influenced watershed located in Southeastern Minnesota) using the SWAT (Soil and Water Assessment Tool) model. Land area used for grazing/hay production was increased by 2.6% at the expense of land used for corn and soybean production. This percent increase in land-use was determined to be that necessary to provide enough forage material for cattle sufficient to meet local demand for beef. Three approaches were used to target where to locate the grazing/hay land within the watershed: using a random approach, using an approach that targeted areas of high slope, and targeting areas with low predicted corn yields. The study showed that changing land use by 2.6% could reduce both edge of field losses and stream loadings of sediment and phosphorus. The greatest reductions were seen when targeting areas of high slope, with reductions of sediment and phosphorus of 13% and 10% respectively. Little change was seen for nitrogen losses under any of the three targeting approaches. Simulation results indicate that when targeted to areas of high slope, small changes in land use from annual row crop agriculture to perennial forages could result in appreciable reductions of sediment and phosphorus.

Introduction

Nutrients and sediment originating from agricultural fields in the Upper Midwest have been attributed to the impairment of both fresh and marine water systems, contaminating drinking water sources and coastal areas (Schulte et al., 2006). Agricultural systems that incorporate perennial vegetation have been shown to reduce nutrient losses and soil erosion compared with annual cropping systems, leading to an improvement in water quality (Burkart et al., 2005; Randall et al., 1997; Russelle et al., 2007). However, lack of economic incentives and markets has limited their adoption onto the landscape (Randall and Mulla, 2001).

For the states in the Upper Midwest region, cattle production systems that use either fresh or harvested perennial forages as the primary component of the diet could be an economically viable way to add perennial species to the landscape. Overuse and continuous grazing of pasture can result in compacted soil, high rates of erosion and increased nutrient discharge; in the worst cases, the nutrient losses can be greater than seen for annual cropland (Hubbard et al., 2004). However, utilizing rotational grazing systems and not over-grazing pastures can significantly reduce the losses of pollutants. Results from a study in Iowa comparing nutrient and sediment losses from grazed pastures compared to non-grazed were inconclusive, with some years showing greater losses from the grazed areas, and other years showing greater losses from the non-grazed (Webber et al., 2010). Along stream banks in Southeast Minnesota, rotational grazing showed reduced stream turbidity compared to continuous grazing (Sovell et al., 2000). Additionally, an increase in agricultural acreage used for grazing or hay purposes would increase the amount of perennial vegetation, and could result in improved water quality through reductions in sediment and nutrient losses from agricultural fields (Burkart et al., 2005; Chaplot et al., 2004).

In this study, we examined the potential influence that changes in land use could have on water quality, based on comparisons between current land-use conditions and three alternative land-use scenarios. These three land-use scenarios increased pasture and hay production at the expense of land in corn and soybean on upland areas, but used different approaches to target the locations of grazing practices and hay production. The analysis presented here is for an agricultural watershed located in Southeastern Minnesota, within the unglaciated, Driftless area. The objectives of this work were to 1) evaluate the effect of increased grazing, and decreased corn and soybean production on water quality; and 2) to compare the effectiveness of three approaches for targeting the location of the grazing lands on water quality.

Methods

The area of land to be converted to pasture and hay was computed based on regional demand for beef in Southeast Minnesota. Consumer demand for beef in SE MN was used to determine the number of animals needed to be raised within the region to meet that demand. The land area needed to support those cattle was calculated based on their feed needs, assuming they were given a forage-only diet. These calculations and the resulting land area required to meet beef demand in SE MN are described in detail in Chapter 1.

The effect of the computed increase in pasture and hay production at the expense of corn and soybean production on water quality was modeled using the Soil and Water Assessment Tool (SWAT), a physically based watershed modeling program (Gassman et al., 2007). The SWAT model was used to simulate increased pasture/hay land-use changes for an agricultural watershed located in SE MN: the South Branch of the Root River (SBRR) (Figure 1). The SBRR was chosen as the study area for two primary reasons. First, previous SWAT work had been completed for the SBRR in the report, “Evaluation of best management practices in impaired watersheds using the SWAT model” prepared for the Minnesota Department of Agriculture (Dalzell and Mulla, 2009), so initial construction steps had already been completed. SWAT requires many detailed inputs, and model construction is a time consuming process. Having the initial model construction already completed allowed SWAT to be used for this grazing land-use study. Additionally, many of the geologic, topographic and land-use features of the entire 11 county SE MN region are found within the SBRR watershed, making it an interesting area for study.

The model was constructed for current land-use and cropping practices in the watershed. Following construction, the model was calibrated to obtain acceptable fit between the model output and measured streamflow and water quality data. Once an acceptable fit between measured and simulated data was obtained, an alternative land-use scenario was applied to the model. This alternative land use was named the grazing land use (GLU), and under this scenario, a fraction of the annual croplands were replaced by pasture and hay use. The amount of land area changed into GLU in the watershed was related to the land area required by cattle in SE MN, calculated in Chapter 1. GLU included land area needed both as pasture for cattle grazing and for hay production. Predicted field losses and stream loadings of sediment, phosphorus and nitrogen were compared between the current and three alternative land-use scenarios to ascertain the magnitude of water quality changes increased pasture and hay land-use could have in the SBRR watershed.

Study Area: South Branch of the Root River Watershed

The 301.77 km^2 South Branch of the Root River (SBRR) watershed is a tributary to the Root River, and is located in Fillmore and Mower Counties in Southeastern Minnesota (Figure 1). The western half of the watershed is mostly flat, while, in contrast, the eastern half of the watershed is located in the driftless region of Minnesota and is characterized by steeper slopes. Approximately 52% of the watershed area has less than 2% slopes, while 10% of the land is in slopes greater than 10%. The eastern portion of the watershed is also influenced by karst geology (Figure 1), which facilitates rapid communication between surface and groundwater and presents surface features such as sinkholes. The predominant land-use or land cover within the watershed is annual row-crop agriculture – of the total watershed area, 85% is cropped in a corn/soybean rotation. The western portion of the watershed is almost entirely covered with row crop agriculture in a corn/soybean rotation. The eastern portion of the watershed has more acreage in forest, pasture and range; though row crops are still the single dominate land-cover (Figure 3). Average annual precipitation in the watershed is approximately 84cm (33in) (Minnesota State Climatology Office, 2011). The average annual temperature is 6°C (43°F), with a normal average temperature during the growing season of 18°C (64°F) (normal's are 30-year mean from 1971 to 2000) (Minnesota State Climatology Office, 2011). Soils in the area are mostly well-drained, class B soil types, with a fair amount of class B/D soils, well drained soils in areas with a high water table. The outlet of the watershed is located within Forestville State Park, where stream flow is measured daily, and water quality monitoring is periodically conducted (Figure 1).

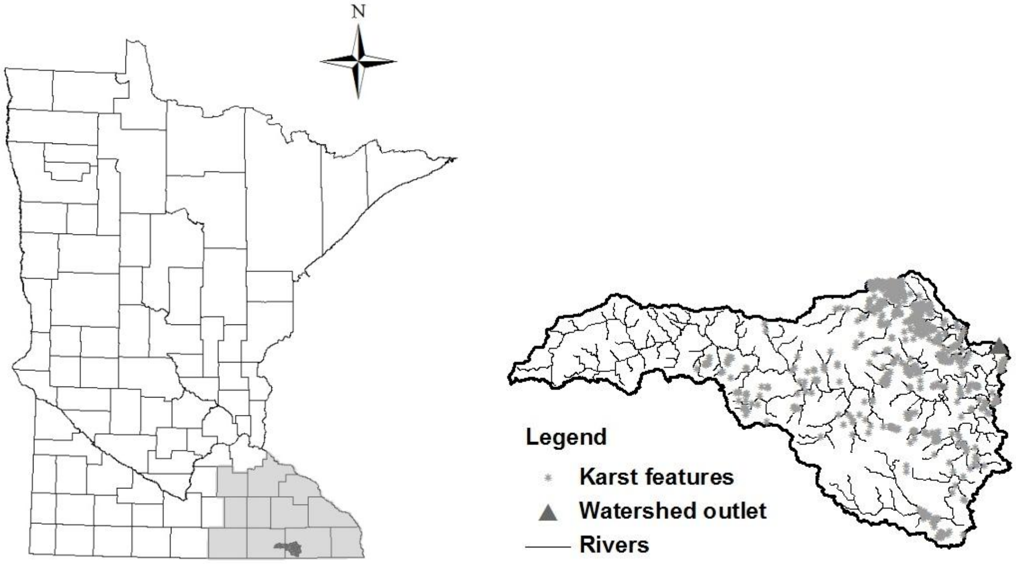

Figure 1: Location and features of the South Branch Root River watershed (image adopted from Dalzell and Mulla, 2009). SBRR watershed is filled; SE MN region is highlighted.

SWAT Model

The Soil and Water Assessment Tool (SWAT) 2005 and ArcSWAT interface were used for simulating water quality effects of the alternative land-use scenario in the SBRR watershed. SWAT is a physically based watershed modeling program developed by the Agricultural Research Service (ARS) for the US Department of Agriculture (Gassman et al., 2007). SWAT was developed to “predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time" (Neitsch et al., 2005). It uses environmental data as inputs to predict water movement, plant growth, sediment movement and nutrient cycling (Neitsch et al., 2005). Inputs required by SWAT include: climate, hydrology, topography, soils, land cover and land management data. Data input is facilitated by the ArcSWAT interface, an ArcGIS based program.

Topographic information is used by ArcSWAT to delineate multiple sub-watersheds, or subbasins, within the watershed. Each subbasin is further divided into hydrologic response units (HRUs), which are non-contiguous areas within each subbasin that share the same soil-type, land cover and slope characteristics. It should be noted when interpreting results that though the HRU concept simplifies calculation of hydrological process in the model, it also introduces a measure of unrealism because each HRU represents a spatially non-contiguous unit (Almendinger and Ulrich, 2010).

Detailed agricultural management information, such as fertilizer, tillage, and planting operations are used by SWAT to determine crop yields and plant growth. HRU level, or edge-of-field, losses of sediment and nutrients are estimated by SWAT, as are the sediment and nutrient loads reaching the watershed outlet and continuing downstream. The SWAT model is particularly useful in comparing the relative effectiveness of a baseline and alternative management or land-use scenarios – less emphasis should be placed on the exact concentrations of nutrients and sediment predicted by SWAT, and more emphasis placed on the relative differences between the results of alternative scenarios (Dalzell and Mulla, 2009).

Model Inputs/ Model Construction:

SBRR data sets

The datasets used to construct the SBRR SWAT run included topography, land cover, soils, and climate data sets, as well as stream flow and water quality data used for model calibration. Initial model construction for the SBRR watershed was done by Dalzell and Mulla (2009). Model inputs he collected and used to create the SBRR SWAT model are described in this section. Additional details on these inputs can be found in Part 2 of the report “Evaluation of best management practices in impaired watersheds using the SWAT model” prepared for the Minnesota Department of Agriculture (Dalzell and Mulla, 2009).

Climate Data: The SWAT model requires daily climate data including precipitation, temperature, relative humidity, wind speed and incoming solar radiation. Climate data were collected from weather stations in closest proximity to the watershed. Precipitation and temperature data for October 2004 through 2009 were obtained from the Spring Valley weather station, located approximately 1.6km (1 mile) from the watershed boundary. Precipitation and temperature data for periods before October 2004, or from missing data in the Spring Valley dataset, were taken from the Grand Meadow weather station, located approximately 3.2km (2 miles) from the watershed boundary. Precipitation data from these stations for the years 2004-2008 are shown in Figure C1. Wind speed and relative humidity data were obtained from stations in La Crosse, WI and Minneapolis, MN respectively. Solar radiation data were provided by the Minnesota Climatology Working Group, located in St. Paul, MN.

DEM: A digital elevation model (DEM) was used to delineate stream networks, subbasins and slopes (Figure 2). For the watershed area, a DEM with 10 m (1/2 arc second) grid size was obtained from the National Seamless Server (Dalzell and Mulla, 2009).

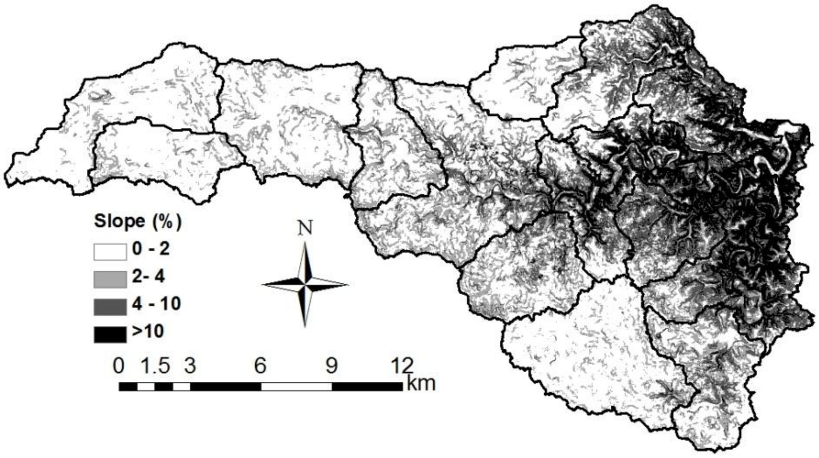

Figure 2: Slopes and subbasins delineated for the SBRR (calculated from the DEM). (Image from Dalzell and Mulla, 2009).

Soils: County level soils data were obtained from the Digital Soil Survey Geographic (SSURGO) database downloaded from the USDA NRCS Soil Data Mart (Dalzell and Mulla, 2009). User-defined soils data tables were provided by the SWAT development group at Texas A&M University. Four of the soil map units present in the SSURGO data were not available in the user defined soil data tables, and were re-named to match adjacent soils map units which had similar hydrologic groups.

Land Use/Land Cover: Land use and land cover data (with 30 m grid size) were determined from the 2001 National Land Cover Database (NLCD), downloaded from the National Map Seamless Server (Dalzell and Mulla, 2009). Some of the smallest land cover classes were aggregated to reduce the number of functional units handled by SWAT. Details on these revised classifications can be found in the report by Dalzell and Mulla (2009). Land cover information, with these aggregated changes, is shown in Figure 3.

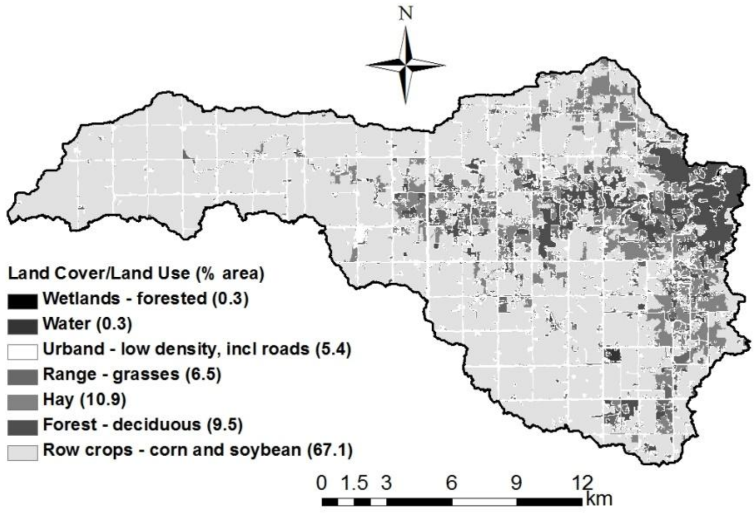

Figure 3: Land cover/land use classification for the SBRR watershed. (Image from Dalzell and Mulla, 2009).

Measured Physical Characteristics: Physical characteristics of the SBRR watershed, such as hydraulic conductivity of the channel bed material and stream channel dimensions and roughness, were measured by Dr. Toby Dogwiler of Winona State University. Measurements of stream channel dimensions and roughness (Mannings "n") where taken at 12 sites throughout the SBRR watershed, and included measurement of the channels' bankful width, depth, width to depth ratio and Manning's roughness coefficient (Table C1). Hydraulic conductivity of the channel material was measured at two sites in the watershed during varying hydrograph conditions. For subbasins considered to not be influenced by karst geology, the average hydraulic conductivity measured in Etna Creek, 37mm hr $^{-1}$, was used. For those subbasins considered to be influenced by karst geology, the average value measured at Mystery Cave, 66 mm hr $^{-1}$, was used. Subbasins were defined as being karst or non-karst based on the predominance of karst features in the area (Figure C2, from (Dalzell and Mulla, 2009).

Hydrology and water quality datasets: Measured daily stream flow to be used for model calibration and validation were available in the SBRR for a five year period (the years 2004-2008). Monthly sediment, nitrogen and phosphorus loads were estimated by coupling the daily flow values with the periodic water quality measurements. These monthly sediment and nutrient loads were estimated using FLUX, a model developed and maintained by the Army Corps of Engineers.

Management Schedules: A series of management schedules were developed by Brent Dalzell to represent typical crop and manure management practices in the SBRR. Corn and soybean planting dates were based on average weekly crop reports from 1997 to 2007 (Dalzell and Mulla, 2009). Tillage practice and timing, as well as fertilizer timing and manure application rates, were based on two FANMAP (Farm Nutrient Management Assessment Program) surveys conducted in the SBRR in 2003 and 2007 (Rasmussen, 2007). Land planted in corn and soybean was represented by a two year corn-soybean rotation (C1S1). Four management schedules were constructed for the C1S1 rotation: no manure applied, anhydrous ammonia (AA) application, swine manure application, and dairy manure application. AA was applied to corn acres during the fall for 3 subbasins in the western portion of the watershed, and included enough corn acreage to roughly account for the amount of AA reported in the 2003 and 2007 FANMAP surveys. According to the FANMAP report, the major sources of manure in SBRR were dairy, swine, and beef. Beef manure from existing operations was assumed to be mostly applied to existing grassland, and was not accounted for in the baseline management practices. Swine manure was applied in subbasins 4 and 15, while dairy manure was applied in subbasins 1 and 7. Actual manure application in the SBRR is not confined to just these few subbasins. However, though a simplification of actual practices, this approach was taken based on the general distribution of animals in SBRR and deemed acceptable for this study. Manure was applied to corn acreage only once every four years, and commercial N and P fertilizer rates were not changed in response to manure application. The details of these rotations can be found in (Dalzell and Mulla, 2009).

Model Calibration and Validation Parameters

The SWAT model was calibrated and validated for current land use, or baseline conditions, to determine the accuracy of the model in predicting stream flow, sediment and nutrient loads, as compared with measured values. Karst influenced subbasins were calibrated based on the assumption of stronger contributions from shallow groundwater and shorter delay in groundwater response time (compared wtih non-karst subbains). Calibration and validation of the SWAT model for baseline conditions was originally conducted by Dalzell and Mulla (2009).

The model was calibrated with daily and monthly stream flow data and monthly water quality data for the years 2004-2005, and validated for the period from 2005-2008. The model's performance during calibration and validation was evaluated with the Nash-Sutcliffe Efficiency metric (NSE). The NSE equation is defined as (Dalzell and Mulla, 2009):

$$NSE = 1 - \frac{\sum (Y_0 - Y_m)^2}{\sum (Y_0 - \bar{Y}_m)^2}$$

where Y_0 is the observed value for the parameter being evaluated, Y_m is the simulated value of the same parameter, and $\bar{Y}_m$ is the mean of the observed data. A value greater than 0.75 for monthly NSE can be considered very good; between 0.65 and 0.75 can be considered good model performance, while a value between 0.5 and 0.65 is considered satisfactory (Moriasi et al., 2007).

The original calibration and validation parameters determined by Dalzell and Mulla (2009) were based on use of a particular version of a SWAT executable file. The SWAT executable file used in this study was a different version, which resulted in slightly different calibration and validation results, despite use of the same model inputs. Without additional calibration for this version of the SWAT executable file, the model's performance in predicting annual average stream flow, sediment, phosphorus and nitrogen loads was generally poor (with NSE of 0.67, -0.18, 0.45, -5.66, respectively).

The original calibration work was updated to improve the hydrologic and sediment/nutrient loads for baseline land-use conditions in the SBRR, and to more closely match those obtained during the original calibration.

A comparison of the water budgets and monthly stream flows obtained with each executable file was used to identify which parameters to update. The results showed an excessive percentage of water outflow going into groundwater. To limit the amount of water going into the shallow aquifer, the deep aquifer percolation fraction (rchrg_dp) was increased, which increased the fraction of percolation from the root zone recharging the deep aquifer (Neitsch et al., 2005). To decrease monthly stream flow peaks, the baseflow alpha factor (alpha_bf) was decreased by 10% for both karst and non-karst sub basins in order to slow the groundwater flow response to changes in recharge. The calibrations parameters determined by Dalzell and Mulla (2009) are listed in Table 1, with the additional changes highlighted.

Table 1: Parameters used for calibration and validation of the SWAT model in the SBRR watershed. All parameters were initially calibrated by Dalzell and Mulla (2009), with the exception of those highlighted in gray, which were calibrated for this particular study.

Parameter	**Description**	**Default**	**Calibrated Value**
TIMP.bsn	Snow temperature lag facto	1	0
PET method.bsn	Methods for estimating potential ET	Penman Monteith	Hargreaves
ESCO.bsn	Soil evaporation compensation facto	0.95	0.60
EPCO.bsn	Plant uptake compensation factor	1	0.95
CN_FROZ.bsn	Allows application of curve number approach to frozen soils	Inactive	Active
Crack Flow.bsn	Simulates crack development in soils	Inactive	Active
SURLAG.bsn	Surface runoff lag coefficient	4	3
PRF.bsn	Peak rate adjustment factor for sediment routing	1	0.8
SPCON.bsn	Sediment entrainment factor- linear	0.0001	0.001
EPEXP.bsn	Sediment entrainment factor- exponent	1	1.5
CMN.bsn	Rate factor for humus mineralization	0.0003	0.002
CDN.bsn	Denitrifcation exponential rate coefficient	0	0.05
SDNCO.bsn	Denitrfication threshold water coefficient	0	0.95
OV_N.hru	Manning's roughness coefficient for overland flow		
	Annual crop fields	0.14	0.4
	All other land-use	0.14	0.25
DEP_IMP.hru	Depth to impervious layer in soil profile (mm)		
	A and B soils	inactive	3750
	A/D, B/D, C and D soils	Inactive	1500
CANMX.hru	Maximum canopy storage (mm)	0	4
GW_DELAY.gw	Groundwater delay time (days)	31	1*
Alpha_BF.gw	Baseflow recession constant, groundwater response to changes in recharge		
	Non-karst subbasins	0.048	0.08
	Karst subbasins	0.048	0.64
Rchrg_dp.gw		0.05	0.1
GWQMIN.gw	Threshold depth of water in shallow aquifer required for return flow to occur	0	150
FRSD.mgt	Initial age of trees	0	50
Cn2.mgt	SCS curve number	Varies	Decreased by 20%
Ch_K2.rte	Hydraulic conductivity of channel bed material		
	Non-karst subbasins	0	37
	Karst subbasins	0	66
CH_W.rte	Channel width at bankful conditions	Varies	See table
CH_D.rte	Channel depth at bankful conditions	Varies	See table
W/D.rte	Width/depth ratio	Varies	See table
CH_N2.rte	Manning's roughness coefficient for channel flow	0.014	See table

*For karst subbasins only.

Alternative Land Use Scenario

An alternative land use scenario was developed in which a small percentage of the land currently used for annual crop production was converted into use for pasture and hay production. This alternative land-use scenario was named the grazing land-use scenario (GLU). The amount of land converted from row crop agriculture to pasture/hay was equal to the acreage needed to support the number of cattle required to meet the beef demands of the region, given cattle were fed a perennial forage diet (Chapter 1). The acreage required to meet the beef demands in the 11 county Southeastern Minnesota region was calculated in Chapter 1, and determined to be 450km^2. The area in the SBRR to have GLU applied was calculated by multiplying the grazing area calculated for all of Minnesota (450km^2) by the ratio of the two regions' total areas. The total area of SBRR watershed (301.77km^2) is approximately 1.7% of the total area in Southeastern Minnesota (17,527km^2), therefore the total acreage to be changed to pasture/hay within the SBRR needed to be 1.7% of the grazing land area required in all of SE MN, or approximately 8.10km^2 (Table C2) (Minnesota NASS, 2010).

GLU Targeting Approaches: GLU practices were only applied to land used for corn and soybean production under the baseline scenario. Three approaches were used to target where GLU was applied in the watershed: 1) as a function of HRU slope and pollution loads (slope-based approach), 2) as a function of crop productivity values (CPI approach to identify marginal crop land), and 3) randomly distributed on corn and soybean areas (random approach). In the first approach, HRUs on corn and soybean land with greater than 4% slopes were targeted to have GLU applied. The pollutant losses from, and the land area of, these HRUs were aggregated by subbasins. Subbasins were ranked based on their contribution to the total losses of pollutants, calculated under the baseline scenario simulations. GLU was applied to the subbasins whose marginal HRUs showed both a high contribution of pollutants, and had a total combined area of approximately 8.10km^2. The annual cropped HRUs in subbasins 1 and 12 with greater than 4% slope met both of these criteria, and were chosen to have their land-use changed (Table C3). The total land area of these HRUs was 6.93km^2, slightly smaller than the target land area to be changed based on the relative sizes of the SBRR and SE MN.

In the second approach, locations were targeted based on the crop productivity index (CPI) -- or the expected crop yields -- of corn production in the SBRR. Areas with the lowest expected corn yield were targeted to be put into pasture. The CPI index ranges from 0 to 100, with 0 indicating very poor corn production and 100 indicating very good corn productivity (Figure C3). CPI obtained in raster format from the Minnesota Geospatial Information Office (Minnesota Geospatial Information Office, 2011) was joined to the HRU data using ESRI ArcMap to identify HRUs with the lowest CPI values. With the CPI approach, only HRUs in subbasins 1 and 12 (the same subbasins targeted in the slope-based approach) were eligible to have GLU applied. As in the marginal approach, HRUs were chosen so that the total land area of the HRUs to be changed was approximately equal to the target area, 8.10km^2. However, the amount of land changed in either subbasin 1 or 12 did not need to equal those acreages changed in the slope-based approach. CPI values for HRUs chosen to change to GLU ranged from 15 to 78.

The third approach was to locate pasture/hay randomly on annual row crop areas in subbasins 1 and 12. HRUs used for corn/soybean production under baseline conditions in these two subbasins were assigned a random number using a random number generator. Ideally, the total HRU area changed between subbasins 1 and 12 under all three approaches would be the same total. However, since land area units differed slightly between each approach, final sediment and nutrient outputs were normalized by area so all approaches could be compared.

Management Schedules: The GLU scenario was implemented in SWAT with a yearly hay and grazing rotation (G1H1), where the management of each targeted HRU rotated between grazing and hay yearly. HRUs in the G1H1 rotation were split so that half of the HRU began with grazing in year 1, while the other half began with hay, resulting in an equal land area being devoted to grazing or hay practices each year (Table C6). Winter pasture was used as the modeled vegetation-type for both grazing and hay use. All plant growth parameters were left at defaults, except the heat units to reach maturity, which were decreased to 1000 in order for the modeled plant growth to more closely match expected values.

For the G1H1 rotations, hay harvest was set to occur three times per year, on approximately May 1, June 1 and September 1. Grazing was scheduled to begin around May 1 every year and continue for 184 days, ending in approx late October. The herbage removal rate per unit area on grazing land was equal to the average of the monthly grazing intake for the SE MN herd per day, per ha, determined in Chapter 1 (Table C4). The resulting herbage removal rate was 17.96 kg ha^{-1} day^{-1}. The amount of manure produced and applied per unit area during grazing was calculated using the ASABE Standard D384.2 MAR2005, Manure Production and Characteristics (ASABE, 2005) based on cattle growth and population assumptions described in Chapter 1. The resulting manure application during grazing was applied at a rate of 6.55kg DM ha^{-1} day^{-1} (Table C5).

Grazing cattle were assumed to be housed under shelter during the winter, and the manure they produced during that time collected and applied to corn acreage the following spring. Two additional management schedules -- modifications of the C1S1 schedule constructed for baseline conditions -- were created to account for manure collected from the beef cattle during the winter season and spread on corn acreages in the spring. Manure produced during the winter was collected and applied to corn acreage the following spring, so as to achieve an application rate of 135kg nitrogen ha^{-1} (121lbs nitrogen $acre^{-1}$), the average nitrogen application rate achieved from beef manure as reported in the 2007 FANMAP survey (Rasmussen, 2007). The total nitrogen in winter manure was calculated using the ASABE Manure Standard, based on the cattle growth and population assumptions determined in Chapter 2. The total nitrogen produced was scaled to the SBRR, by multiplying 0.017 by the total nitrogen in manure calculated using the assumed population numbers in Chapter 1. According to the 2007 FANPMAP, of the total nitrogen produced in manure, 50% was available for application in the spring. For the SBRR, 56,234kg of nitrogen was produced by the grazing cattle during the winter, and 28,117kg nitrogen was available for crop application in the spring (Table C5). To achieve an application rate of 135kg nitrogen ha^{-1}, 515.87 total acres needed to have manure applied. This acreage was split between subbasins 1 and 12; manure was applied to HRUs in corn land use that were in the same sub basins as the grazing/hay land use change. The management schedule for the additional C1S1 rotations is shown in detail in Table C7 and C8.

Results and Discussion

Calibration and Validation

Observed and simulated monthly streamflow, sediment yield and phosphorus and nitrogen (discussed as the sum of both NO_3 and NO_2) stream loads during the calibration (2004-2005) and validation (2006-2008) periods are shown in Figure 4 through 7. Observed data were not available for all months, and gaps in the observed data indicate no data available. Mean monthly calibration and validation results are shown in Table 2, along with daily and monthly estimates of model performance. For predicting sediment and nutrient loads, the model performed better during the validation period than during the calibration period. During the calibration period, the year 2004 in particular showed a pronounced departure from the observed values. As noted in Dalzell and Mulla (2009), 2004 was a difficult year to model, since 2004 was an exceptionally wet year, following an exceptionally dry year. Calibration and validation values are acceptable for flow, sediment and phosphorus. However, though validation for nitrogen was acceptable, the model failed the calibration period. Results of nitrogen output should therefore be interpreted with caution, and are best used in comparison between current and alternative land-use scenarios, rather than as actual values.

Table 2: Calibration (cal) and validation (val) results for the SBRR watershed. Observed and simulated streamflow, sediment, phosphorus and nitrogen are average monthly values.

	Streamflow (m^3 sec^{-1})		**Sediment (t)**		**Phosphorus (kg)**		**Nitrogen (kg)**	
Performance Measures	**Cal**	**Val**	**Cal**	**Val**	**Cal**	**Val**	**Cal**	**Val**
Observed	3.18	3.39	998	1,477	1,820	2,544	68,957	85,712
Simulated	3.27	3.24	811	1,403	1,371	2,191	103,004	79,025
Daily NSE	0.43	0.60						
Monthly NSE	0.76	0.78	0.32	0.75	0.53	0.67	-3.87	0.60

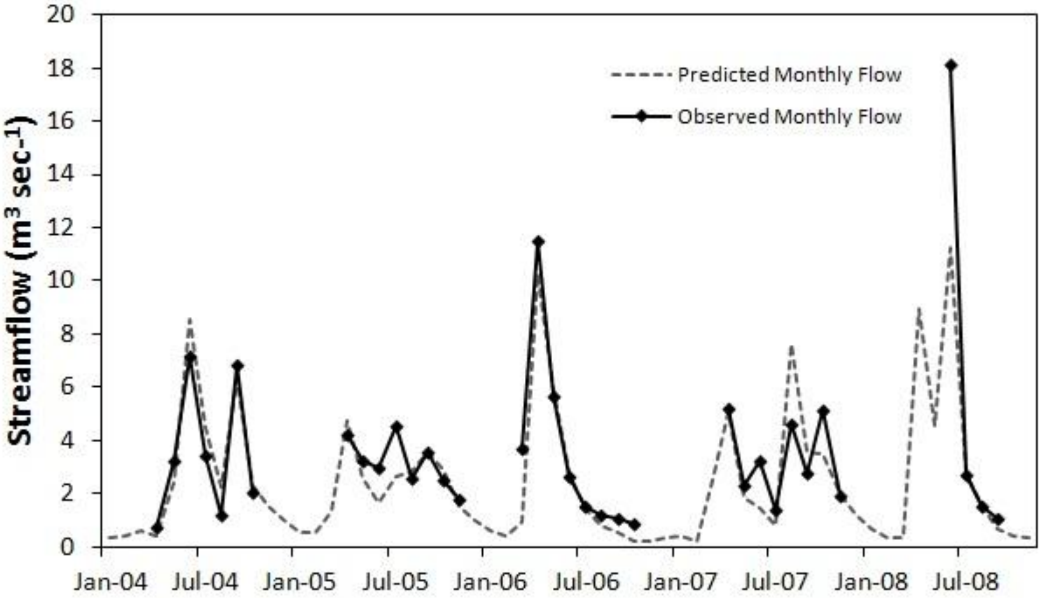

Figure 4: Observed and simulated monthly streamflow at the outlet of the SBRR watershed.

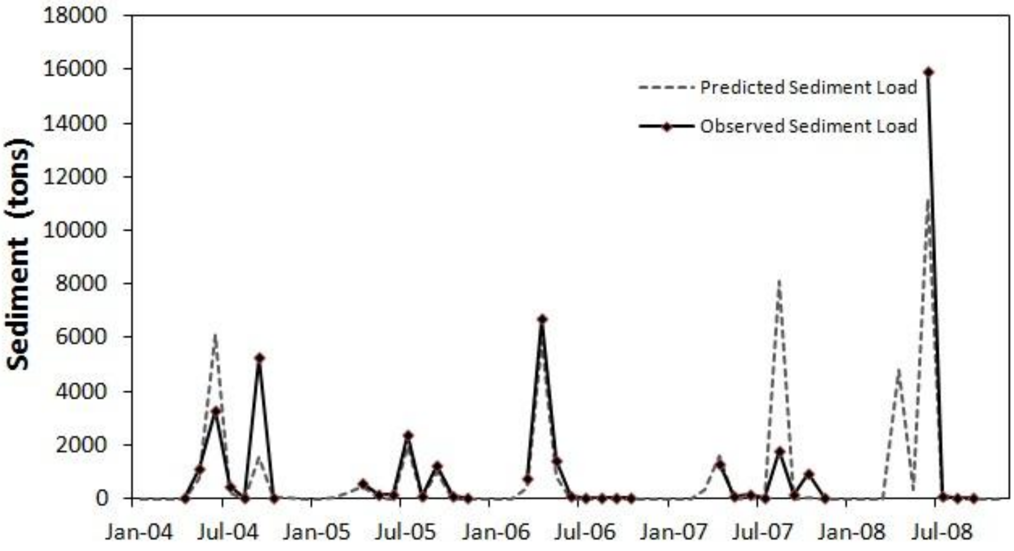

Figure 5: Observed and simulated monthly sediment at the outlet of the SBRR watershed.

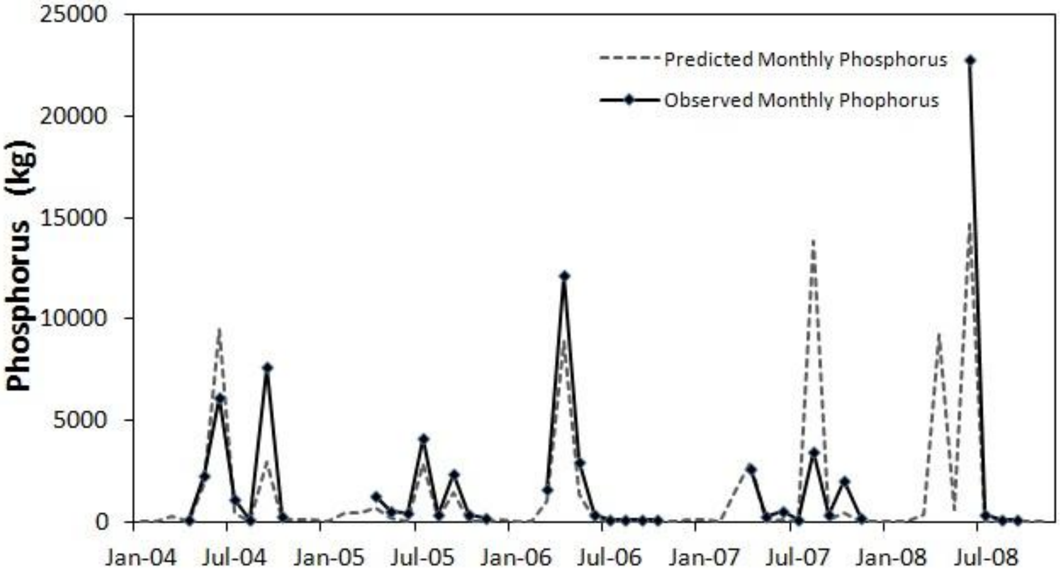

Figure 6: Observed and simulated monthly phosphorus at the outlet of the SBRR watershed

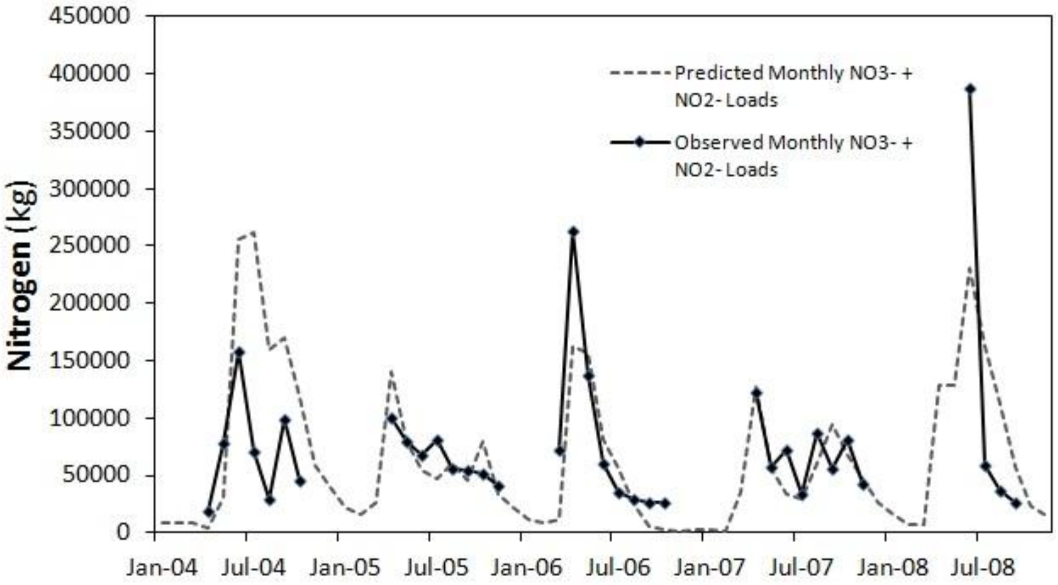

Figure 7: Observed and simulated monthly nitrogen at the outlet of the SBRR watershed.

Baseline Conditions:

Baseline Hydrology/Water budget: For the 5-year evaluation period, average annual precipitation was 1020.7mm. Under baseline conditions, evapotranspiration removed 70% of the annual precipitation from the watershed, with 25% of the average precipitation contributing to water yield at the outlet. Of the total water that reached the outlet of the watershed, the majority (59%) is from groundwater flow, 17.3% from tile flow, 14.3% from surface runoff, and 9.2% from lateral soil flow (Figure 8).

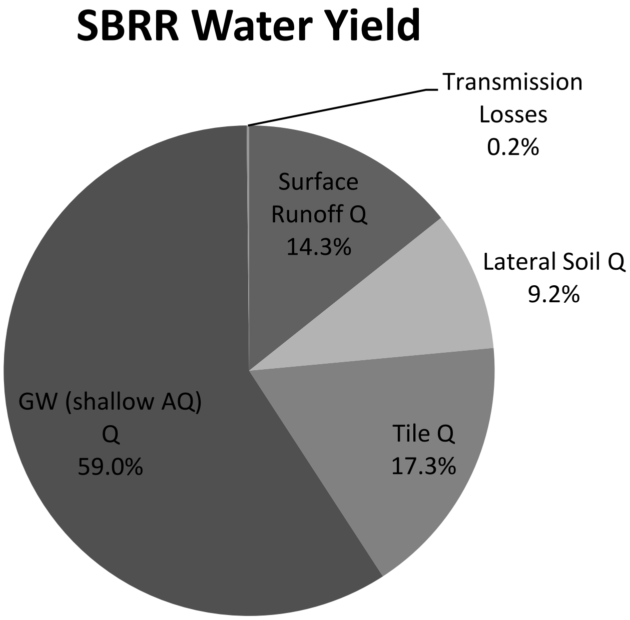

Figure 8: Average annual water yield components of the SBRR for years 2004-2008. Components are given as percentages of the total water yield.

Sediment and Nutrient Losses: Under baseline conditions, average annual edge of field losses of sediment, phosphorus and nitrogen are 0.89 tons ha^{-1}, 0.73 kg ha^{-1}, and 20.77 kg ha^{-1}, respectively. HRUs considered high slope cropland – those with annual crop use on slopes greater than four percent – contributed sediment and phosphorus amounts disproportionate to their area. HRUs cropped in annual row crops (corn or soybean) on slopes greater than 4% contributed 51% of the total sediment losses and 38% of the total phosphorus losses, even though they only accounted for 8% of the total land area. Nitrogen losses were not disproportionally found on high slopes and were fairly uniformly spread out across the watershed. It should be noted that some caution should be used when interpreting sediment losses predicted by SWAT. Factors that account for stream bank erosion were not considered for this study so the model does not take stream bank erosion into account as a sediment source. Because of this, SWAT is likely overestimating the sediment yield from fields by a factor or 20-30%.

Alternative Land-Use Results

Plant Growth: SWAT modeled ET for winter pasture was compared against recorded ET rates in grasslands in northern latitudes of the US, to ensure that modeled plant growth was similar to expected. Average ET for grassland was used from water vapor flux data from the AmeriFlux network (Ameriflux, 2012) and synthesized for sites in the Upper Midwest by Dalzell (pers. comm.; work in prep). Annual average reported ET for grassland in Illinois and South Dakota were 636 and 703 mm year^{-1}, respectively. Average modeled ET for the GLU HRUs was 687 mm year^{-1}, which is within the range of ET reported for grassland cover in the Upper Mississippi River Basin.

Sediment: Implementation of the GLU scenario using the slope and CPI approaches significantly reduced sediment losses from subbasins 1 and 12 (Figure 9a and b), and also led to an overall reduction in sediment losses from the entire watershed (Figure 9c). As mentioned previously, SWAT is likely overestimating edge of field sediment losses, which is why a comparison between the baseline and alternative scenarios is more useful than absolute losses. Sediment field losses were reduced the most under the slope-based GLU placement approach. On the watershed level, annual sediment losses were reduced by 13 percent under the slope-based approach, 9 percent with the CPI approach, and 6 percent with the random approach.

The greater reductions in sediment seen with the slope-based targeting approach are indicative of the importance of the combined effect of slope and land-cover on sediment loss in this watershed. Sediment yield is predicted in SWAT by the Modified Universal Soil Loss Equation (MUSLE) equation. MUSLE calculates expected sediment losses based on soil, slope and land-use of a particular site and has been shown through comparison with many measured data sets to predict losses with high accuracy (Williams, 1975). The MUSLE equation used by SWAT is defined as (Neitsch et al., 2005):

$$sed = 11.8(Q_{surf} \times q_{peak} \times area_{HRU})^{0.56} \times K \times LS \times CP \times CFRG$$

Where the product of Q_{surf}, q_{peak} and $area_{HRU}$ is a runoff factor (Q_{surf} is the surface runoff volume, and q_{peak} is the peak runoff rate per unit area); K is a soil erodibility factor, an intrinsic property of the soil type; LS is a factor directly related to slope length and gradient; CP is a vegetation management factor, inversely related to the amount of canopy cover and ground residue; and CFRG is the course fragment factor which takes into account percent rock in the first soil layer (Brooks et al., 2003; Neitsch et al., 2005). HRUs are constructed in SWAT based on unique combinations of soil, slope and land-use, so each HRU can express different values of these MUSLE factors; sediment yield for each HRU differs depending on the soil type (effecting the soil erodibility factor), the topography (affecting the LS factor), and the land-use and management practices (CP factor) that make up that HRU. For each of the three approaches used to locate the GLU, different HRUs, with different combinations of the MUSLE factors, were changed. The common factor changed for all HRUS was the CP factor. Since sediment was reduced under all three approaches, it is clear that the land-cover factor was important in these results. The CP factor for grass-like plants, such as well managed pasture, is lower compared to annually cropped fields which tend to have less residue and canopy cover for most of the year (Brooks et al., 2003). The greatest reductions were for the slope-based approach, when high slopes were targeted to have their land-use changed. This indicates that it was the combination of land-cover changes and slope that was the most influential in decreasing sediment losses.

Soil compaction caused by grazing animals was not accounted for in this study. Such compaction could increase sediment losses by decreasing soil infiltration, which would lead to an increase in the surface runoff volume. However, highly managed grazing, which limits cattle movement into water-saturated pastures and leaves behind adequate biomass, has been shown to have little effect on surface runoff (Hamza and Anderson, 2005). Compaction by grazing animals could be accounted for in SWAT by manually changing soil permeability, accomplished by adjusting the curve number. However, grazing in this study was assumed to be highly managed (see Chapter 1), and therefore compaction from grazing was assumed to be negligible.

Predicted field losses differ from the sediment yield at the watershed outlet because SWAT also simulates in-channel sediment deposition and re-suspension (Neitsch et al., 2005). Separate analysis was therefore done for field losses and sediment yield. However, reductions in edge of field sediment losses were very similar to those at the watershed outlet. Annual average suspended sediment loads predicted at the watershed outlet were also reduced under the GLU scenarios. Sediment yield reductions of 10% at the watershed outlet were obtained for both the slope-based and random approaches, even though they had differing field losses (Figure 10).

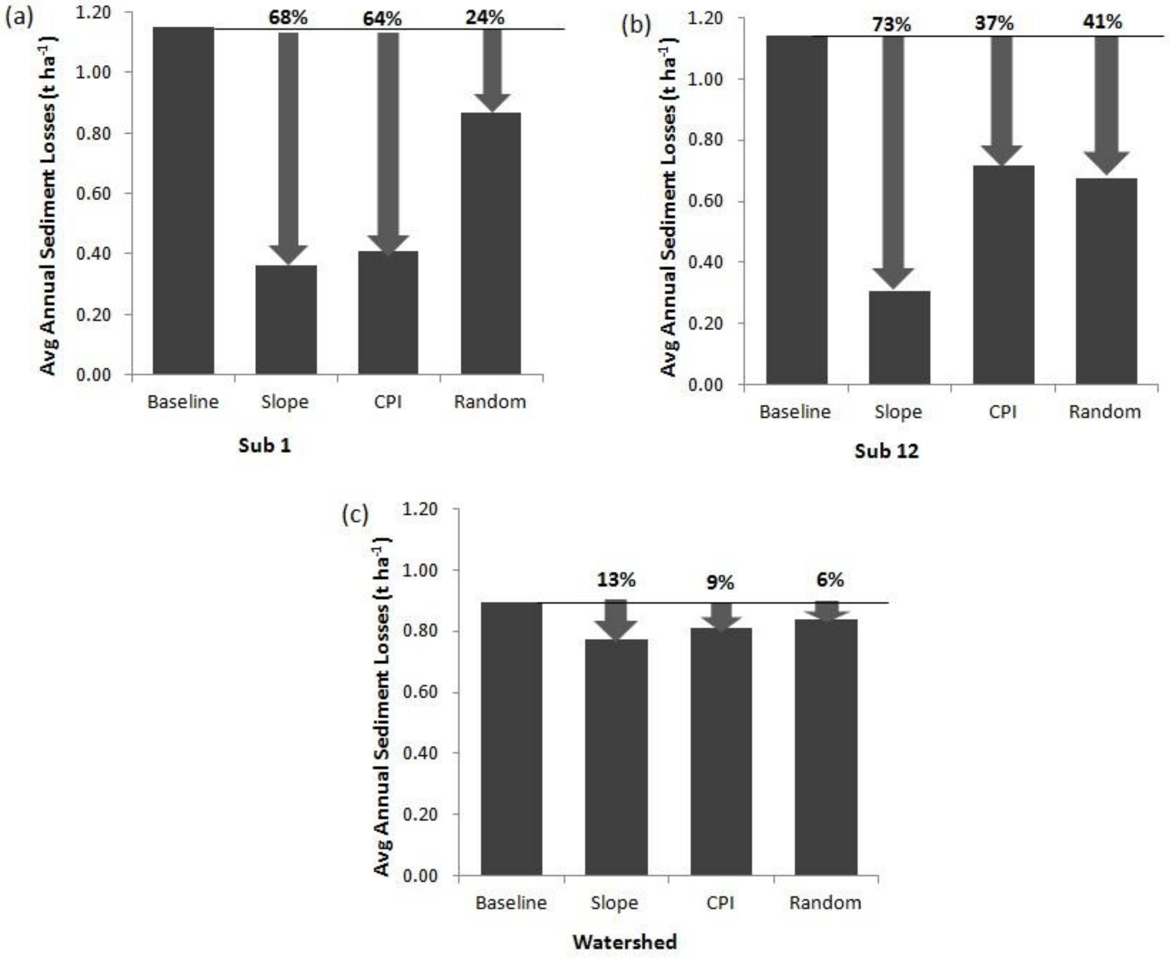

Figure 9: Sediment edge of field losses from Subbasins 1 (a) and 12 (b), and on a watershed level (c), given three approaches to locating alternative land-use practices (GLU).

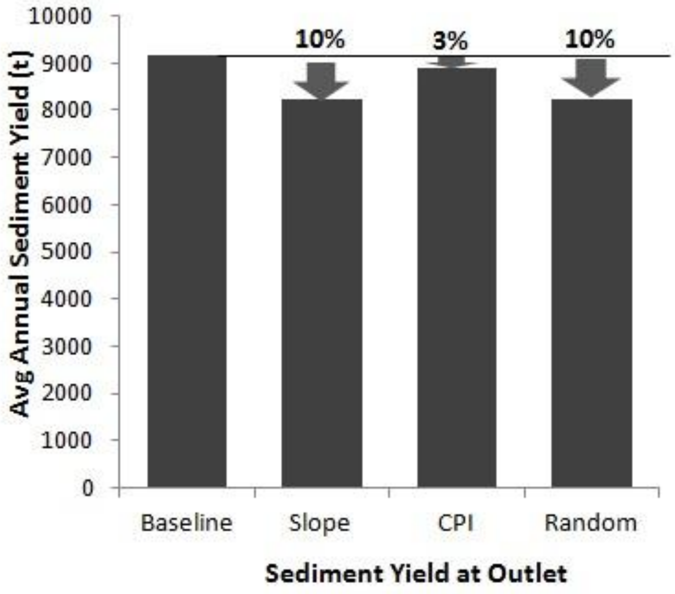

Figure 10: Sediment yield at the SBRR watershed outlet.

Phosphorus: As with sediment losses, implementation of the grazing management practices resulted in annual average edge of field reductions in phosphorus, and reductions were seen for all three approaches to locating GLU (Figure 11). Movement of phosphorus and sediments are both due to transport via surface runoff (Wilcock, 2008). It is not surprising then that the SWAT results show similar trends for phosphorus and sediment losses.

Stream loads of suspended phosphorus at the outlet of the watershed also decreased under all three GLU approaches, though not by the same degree as the edge of field losses (Figure 12). SWAT models in-stream nutrient processes such as transformations from algae growth and phosphorus cycling (Gassman et al., 2007). These in-stream processes can result in phosphorus losses differing from the loads found at the outlet.

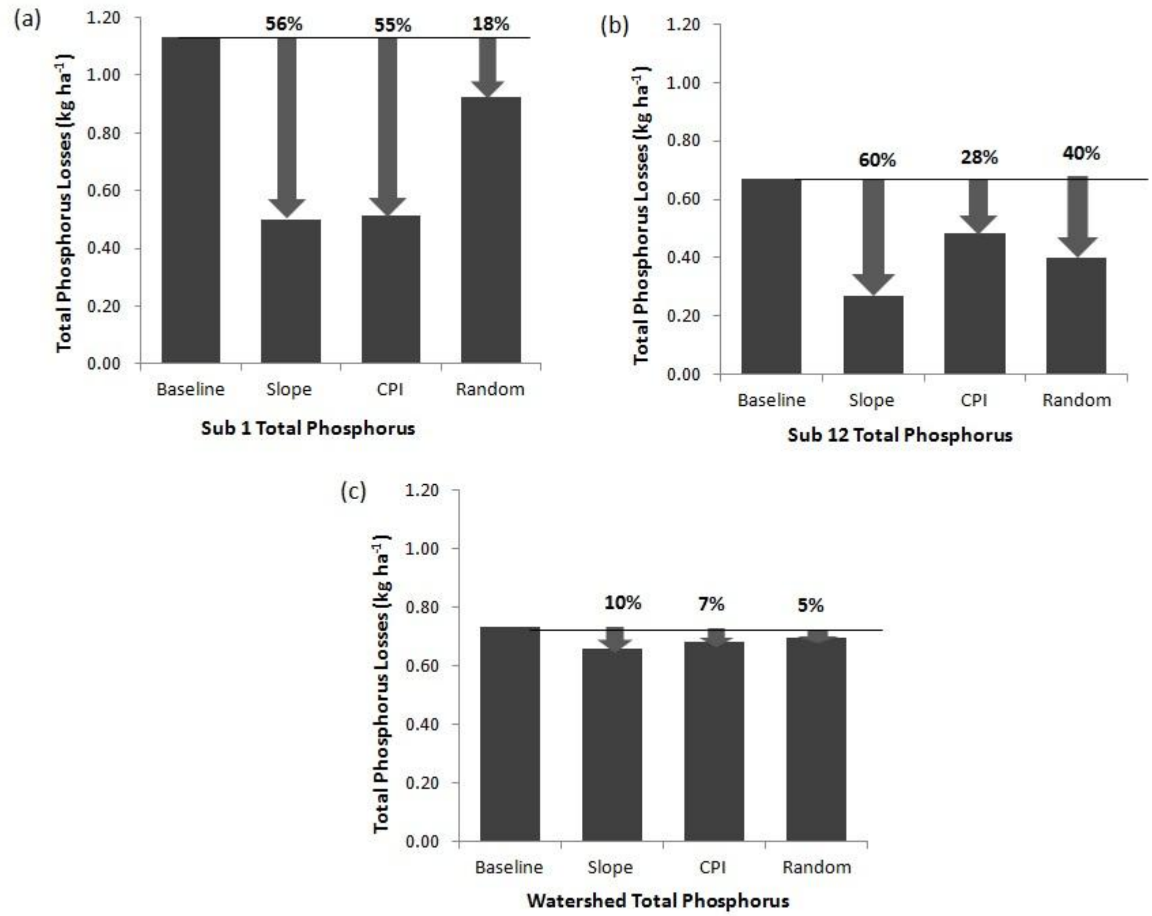

Figure 11: Phosphorus edge of field losses from Subbasins 1 (a) and 12 (b), as well as on the watershed level (c), given three approaches to locating alternative land-use practices (GLU).

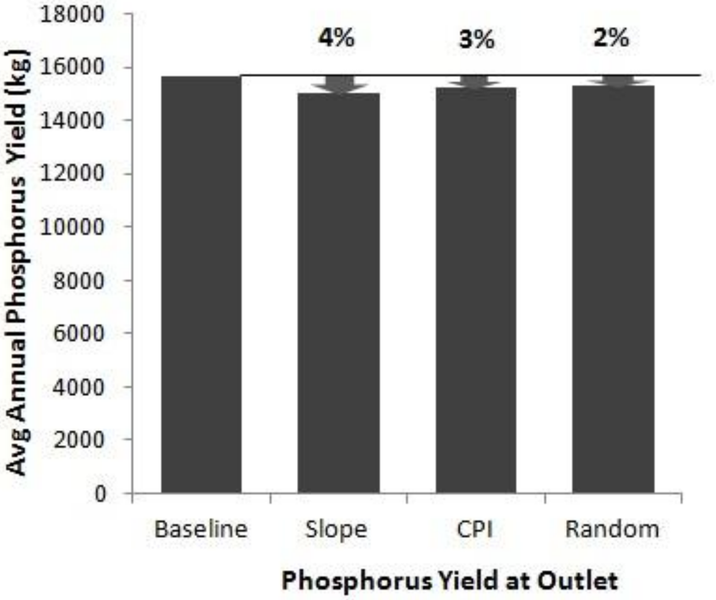

Figure 12: Phosphorus yield at SBRR watershed outlet, predicted with GLU scenario.

Nitrogen: In contrast to the effects of GLU on sediment and phosphorus losses, implementation of GLU reduced nitrogen losses in subbasin 1, but increased nitrogen losses in subbasin 12 (Figure 13). At the watershed level, GLU had no effect on nitrogen losses. Nitrogen losses likely increased in subbasin 12 because under the GLU scenario, more nitrogen was applied to the land, in the form of manure. Additional nitrogen was applied in subbasin 12 from the grazing operations and as manure applied to corn acres in the spring. In contrast, in subbasin 1, overall less nitrogen was applied in the grazing scenario than in the baseline. In subbasin 1, under baseline conditions, dairy manure was applied to annual crop acreages. In the GLU scenario, some of that dairy manure was removed; when annual cropland was converted to grazing/hay, the dairy manure that was being applied on those HRUs in the baseline scenario was not redistributed. The nitrogen added from the beef manure was less than the nitrogen applied from the dairy manure, thus resulting in a net reduction in the amount of nitrogen applied in subbasin 1. Nitrogen reductions may only be achievable through reducing nitrogen inputs.

Nitrogen losses were not affected by the different targeting approaches, with the slope-based, CPI and random approaches all showing very similar levels of nitrogen losses. Unlike sediment and phosphorus losses, which tend to occur via overland flow, nitrogen movement follows a different path, and is most commonly lost via subsurface flow (Wilcock, 2008). As shown in Figure 15, the vast majority of nitrogen losses under the baseline scenario resulted in movement of nitrates in lateral flow, or groundwater. The model results show that the rate of nitrates lost in the groundwater did decrease for land planted with winter pasture. However, the increased nitrogen applied to corn from winter beef manure caused an increase in nitrate movement from the corn land-use areas, which overall resulted in no net change in nitrogen losses.

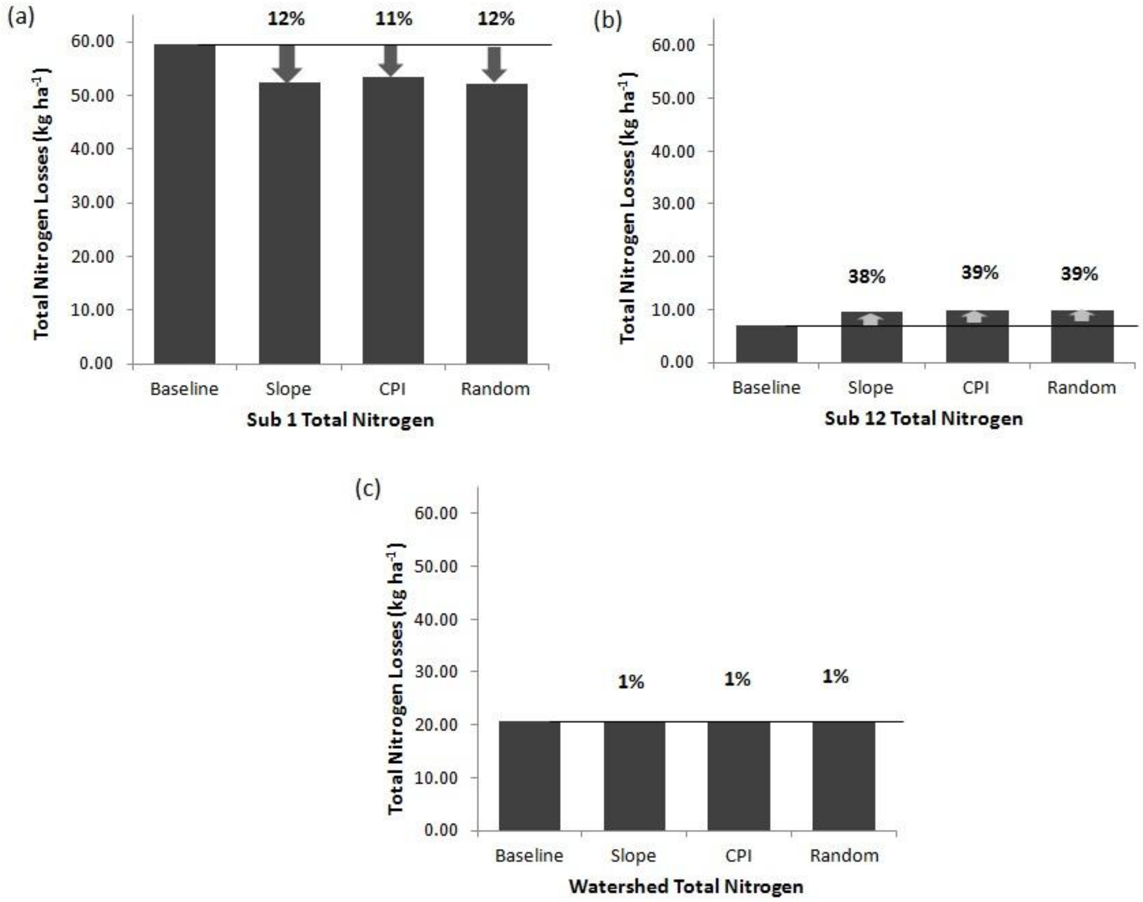

Figure 13: Nitrogen edge of field losses from Subbasins 1 (a) and 12 (b), as well as for the entire watershed (c), given three approaches to locating alternative land-use practices (GLU).

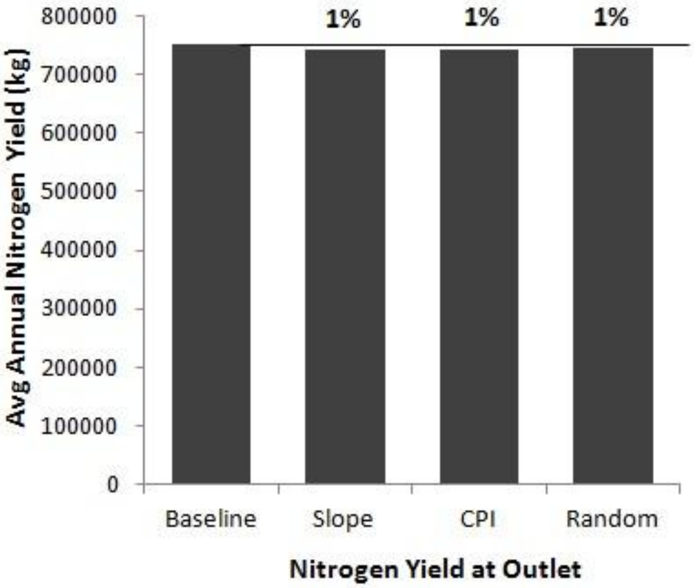

Figure 14: Nitrogen yield at SBRR watershed outlet, with GLU scenario.

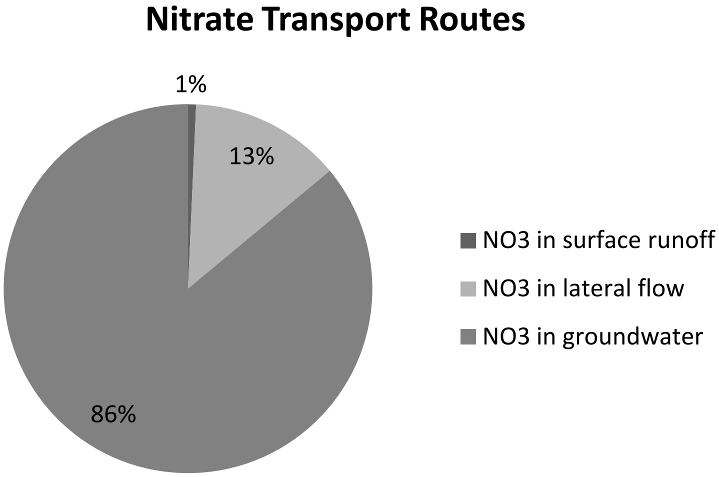

Figure 15: Routes of nitrate nitrogen transport from HRU into stream channels (from the slope-based GLU approach).

Summary and Conclusions

Simulation results of the baseline conditions indicate that annually cropped acreage on areas of high slope in the SBRR watershed may be contributing losses of sediments and nutrients disproportional to their area, with 8% of the area of the SBRR contributing 51% of total sediment losses and 38% of total phosphorus losses. The results of this study indicate that for the SBRR watershed, a small (2.6%) reduction in corn/soybean land area in favor of grazing or perennial hay production can reduce sediment and phosphorus losses (Figures 9, 11, and 13) This effect is greatest when grazing land-use is targeted to annual cropped lands planted on high slopes -- changing only 2.6% of the watershed area resulted in field losses of sediment and phosphorus of 13 and 10% in the watershed, and stream load reductions of 10 and 4%, respectively. Targeting grazing land-use to areas with a low expected crop productivity (CPI approach) showed similar reductions in edge of field losses of sediment (reduction of 9%) and phosphorus (7%). It is not surprising that reductions in edge of field losses is similar for the two targeting approaches considering 50% of the land area changed under the CPI approach was the same as those areas changed with the slope approach. The smallest reductions in edge of field losses of sediment (6%) and phosphorus (5%) were seen with the random approach. For the SBRR watershed, the random approach is the least efficient at creating changes in sediment and phosphorus losses given small changes in land use.

While decreases were seen for sediment and phosphorus losses under all three targeting approaches, nitrogen losses were unaffected by the land use change. The rate of synthetic nitrogen applied to corn acreages was not decreased despite additional nitrogen being applied as manure. This resulted in a net increase of approximately 10,000 kg of nitrogen applied in the watershed. If synthetic nitrogen fertilizer rates were decreased to take into account the nitrogen in the beef manure, nitrogen losses in the SBRR may have decreased.

The land area changed for the GLU scenario was based on calculations in Chapter 1. These calculations assumed an average annual yield of 8.64 tons ha^{-1} (3.5 tons acre^{-1}) for

Southeast Minnesota. SWAT predicted yield for winter pasture in the SBRR watershed was much lower, averaging approximately 3.0 tons ha^{-1} (1.1 tons acre^{-1}) regardless of slope or soil type. The yield of 8.64 tons ha^{-1} assumes fertilizer is applied to the land. In the SWAT run, some fertilizer was applied during grazing, but no fertilizer was applied to the hay areas, resulting in a lower overall expected yield. Additionally, winter pasture is not modeled as a legume species in SWAT, meaning that no nitrogen fixation occurred. Changing the plant species in SWAT from winter pasture to a legume could increase these yields so that they were similar to those assumed for the land area calculations in Chapter 1. If winter pasture were to remain the plant used in SWAT to model pasture and hay growth, the yield predicted by SWAT should be used in determining the total land area to be changed to GLU.

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Appendix A: Additional Tables and Figures for Chapter 1

Table A1: Finishing cattle weights in the grass-based and conventional systems, and corresponding feeding periods and generation population groups. Weights are averages for the month, except as indicated for birth and finish weights

Grass-based system

Period	Month	BW, kg		Finisher Generation
		Steer	Heifer	
Birth	April 15	44.5	40.2	
Cow-calf	April	52	48	
	May	76	69	
	June	106	98	
	July	137	126	
	Aug	168	155	
	Sept	198	183	
	Oct	229	212	
Dry-lot 1	Nov	251	232	G. Finisher 1 weights
	Dec	265	244	
	Jan	280	257	G Finisher 2 weights
	Feb	294	268	
	Mar	308	280	
	April	322	292	
Grazing 2	May	340	308	
	June	362	326	
	July	383	345	
	Aug	405	363	
	Sept	426	381	
	Oct	447	400	
Dry-lot 2	Nov	465	415	
	Dec	480	427	
	Jan	494	440	G. Finisher 3 weights
	Feb	508	452	
	Mar	522	463	
	April	536	476	
Grazing 2	May	554	491	
Finishing	May 31	564	499	

Conventional system

Period	Month	BW, kg		Finisher Generation
		Steer	Heifer	
Birth	April 15	44.5	40.2	
Cow-calf	April	52	47	
	May	76	69	
	June	106	98	
	July	137	126	
	Aug	168	155	
	Sept	198	183	
	Oct	229	212	
Back-grounding	Nov	261	239	C. Finisher 1 weights
	Dec	294	265	
	Jan	327	292	
Feedlot	Feb	365	324	C. Finisher 2 weights
	Mar	409	364	
	April	455	405	
	May	501	446	
	June	546	487	
	July	592	528	
Finishing	July 31	615	549	

Table A2: Grass-based and Conventional production system population sizes for each month.

<table>
<tr><th rowspan="2">Population</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>June</th><th>July</th><th>Aug</th><th>Sept</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><th colspan="12">Grass Production System Population Numbers</th></tr>
<tr><td>Cows</td><td colspan="12">44,042</td></tr>
<tr><td>Bulls</td><td colspan="12">1,535</td></tr>
<tr><td>Steer Calves</td><td colspan="3"></td><td colspan="3">21,879</td><td colspan="4">20,258</td><td colspan="2"></td></tr>
<tr><td>Heifer Calves</td><td colspan="3"></td><td colspan="3">21,879</td><td colspan="4">20,258</td><td colspan="2"></td></tr>
<tr><td>R. Heifer</td><td colspan="7">6,906</td><td colspan="3"></td><td colspan="2">6,906</td></tr>
<tr><td>Steer 1</td><td colspan="10"></td><td colspan="2">20,036</td></tr>
<tr><td>Heifer 1</td><td colspan="10"></td><td colspan="2">13,129</td></tr>
<tr><td>Steer 2</td><td colspan="12">20,036</td></tr>
<tr><td>Heifer 2</td><td colspan="12">13,129</td></tr>
<tr><td>Steer 3</td><td colspan="6">20,036</td><td colspan="6"></td></tr>
<tr><td>Heifer 3</td><td colspan="6">13,129</td><td colspan="6"></td></tr>
<tr><td>R. Heifer</td><td colspan="7">6,906</td><td colspan="3"></td><td colspan="2">6,906</td></tr>
<tr><td></td><th colspan="12">Conventional Production System Population Numbers</th></tr>
<tr><td>Cows</td><td colspan="12">39,956</td></tr>
<tr><td>Bulls</td><td colspan="12">1.332</td></tr>
<tr><td>Steer Calves</td><td colspan="3"></td><td colspan="3">19,012</td><td colspan="4">17,581</td><td colspan="2"></td></tr>
<tr><td>Heifer Calves</td><td colspan="3"></td><td colspan="3">19,012</td><td colspan="4">17,581</td><td colspan="2"></td></tr>
<tr><td>R. Heifer</td><td colspan="7">5,993</td><td colspan="3"></td><td colspan="2">5,993</td></tr>
<tr><td>Steer 1</td><td colspan="10"></td><td colspan="2">17,387</td></tr>
<tr><td>Heifer 1</td><td colspan="10"></td><td colspan="2">11,394</td></tr>
<tr><td>Steer 2</td><td colspan="7">17,387</td><td colspan="5"></td></tr>
<tr><td>Heifer 2</td><td colspan="7">11,394</td><td colspan="5"></td></tr>
</table>

Table A3: Dry matter intake per day per individual.

		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
		Dry Matter Intake for 1 animal (*kg day*$^{-1}$)											
Cow-Calf	Cows	7.51	8.24	9.03	10.80	8.85	9.5	9.21	8.53	7.84	7.27	6.76	7.02
	Bulls	8.67	8.67	8.67	8.67	7.35	7.35	7.35	7.35	7.35	7.35	8.67	8.67
	Steer Calf				2.03	1.86	2.28	2.67	3.03	3.38	3.72		
	Heifer Calf				1.99	1.84	2.29	2.71	3.10	3.48	3.84		
	R. Heifer	5.88	6.09	6.29	6.5	6.36	6.65	6.93				5.45	5.67
Grass Finishers	G. Steer 1											3.58	3.73
	G. Steer 2	6.25	6.49	6.73	6.96	6.82	7.14	7.45	7.76	8.06	8.36	9.15	9.36
	G. Steer 3	9.57	9.78	9.98	10.19	9.82							
	G. Heifer 1											5.45	5.67
	G. Heifer 2	5.88	6.09	6.29	6.5	6.41	6.69	6.97	7.25	7.52	7.79	8.43	8.62
	G. Heifer 3	8.8	8.98	9.16	9.34	9.09							
Conventional Finishers	C. Steer 1											7.24	7.92
	C. Steer 2	8.58	8.59	9.40	10.18	10.94	11.68	12.41					
	C. Heifer 1											4.15	5.42
	C. Heifer 2	7.65	10.24	8.46	9.17	9.87	10.55	11.21					

Table A4: Monthly Population Intake Requirements

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Yearly Total
Grass-based System	*Forage diet - Population dry matter intake (kg month^{-1})*												
Total	$2.7\ 10^{7}$	$2.8\ 10^{7}$	$3.0\ 10^{7}$	$3.5\ 10^{7}$	$3.2\ 10^{7}$	$2.4\ 10^{7}$	$2.4\ 10^{7}$	$2.3\ 10^{7}$	$2.3\ 10^{7}$	$2.2\ 10^{7}$	$2.5\ 10^{7}$	$2.5\ 10^{7}$	$3.2\ 10^{8}$
Conventional System													
	Forage diet- Population dry matter intake (kg month^{-1})												
Total	$1.1\ 10^{7}$	$1.1\ 10^{7}$	$1.2\ 10^{7}$	$1.7\ 10^{7}$	$1.4\ 10^{7}$	$1.6\ 10^{7}$	$1.6\ 10^{7}$	$1.4\ 10^{7}$	$1.4\ 10^{7}$	$1.3\ 10^{7}$	$9.5\ 10^{6}$	$9.8\ 10^{6}$	$1.6\ 10^{8}$
	Silage diet - Population dry matter intake (kg month^{-1})												
Total	$7.2\ 10^{6}$	$3.6\ 10^{6}$									$5.3\ 10^{6}$	$6.1\ 10^{6}$	$2.2\ 10^{7}$
Silage	$6.5\ 10^{6}$	$3.2\ 10^{6}$									$4.7\ 10^{6}$	$5.5\ 10^{6}$	$2.0\ 10^{7}$
	Feedlot diet - Population dry matter intake (kg month^{-1})												
Total		$4.5\ 10^{6}$	$7.9\ 10^{6}$	$8.6\ 10^{6}$	$9.2\ 10^{6}$	$9.8\ 10^{6}$	$1.0\ 10^{7}$						$5.1\ 10^{7}$
Corn		$2.5\ 10^{6}$	$4.3\ 10^{6}$	$4.7\ 10^{6}$	$5.1\ 10^{6}$	$5.4\ 10^{6}$	$5.7\ 10^{6}$						$2.8\ 10^{7}$
Hay		$8.2\ 10^{5}$	$1.4\ 10^{6}$	$1.5\ 10^{6}$	$1.7\ 10^{6}$	$1.8\ 10^{6}$	$1.9\ 10^{6}$						$9.1\ 10^{6}$
Distiller		$1.1\ 10^{6}$	$2.0\ 10^{6}$	$2.1\ 10^{6}$	$2.3\ 10^{6}$	$2.5\ 10^{6}$	$2.6\ 10^{6}$						$1.3\ 10^{7}$

Table A5: Monthly acreage requirements for grazing and the mass of hay harvested from "extra" grazing lands in both the grass-based and conventional production systems.

	May	**June**	**July**	**August**	**September**	**October**
Grass						
Grazing acreage month^{-1}	53,941	29,707	56,257	89,448	68,144	98,271
Hay Harvested (*kg*)	32,366,154	69,649,812	22,673,402	2,800,654		
Conventional						
Grazing acreage month^{-1}	24,632	19,457	36,340	54,900	40,859	58,325
Hay Harvested (*kg*)	24,600,476	39,483,452	11,864,391	1,087,288		

Table A6: All model inputs

Input Variable	Value		Reference(s)
	Conventional	*Grass-based*	
Energy Calculations			
Days Pregnant	283	283	(Andersen and Plum, 1965; Cundiff et al., 1998)
Birth Weight	43.5 kg (steers), 402kg (heifer)	43.5 kg (steers), 402kg (heifer	(Casas et al., 2011)
Milk Production	Varies, see equation	Varies, see equation	(Jenkins and Ferrell, 1984)
Milk Fat %	4%	4%	(Marston, 2005)
Cow Weight	567kg	567kg	
Bull Weight	816kg	816kg	
Average Daily Gain			
Steer Calf	1.9kg	1.9kg	(Casas et al., 2011)
Heifer Calf	0.93kg	0.93kg	
G. Steer -- Hay		0.47kg/day	(Allen et al., 1992; Petit and Flipot, 1992)
-- Graze		0.70kg/day	(Allen et al., 1996; Clanton, 1977; Greenquist et al., 2009; Martz et al., 1999; Neel et al., 2007; Sainz and Vernazza Paganini, 2004)
G. Heifer -- Hay		0.4kg/day	
-- Graze		0.6kg/day	
C. Steer -- Silage	1.1kg/day		(Chamberlain et al., 1971; Folmer et al., 2002; Keith et al., 1981; Tjardes et al., 2002)
- Feedlot	1.5kg/day		(Land O'Lakes Beef Feeds, 2010)
C. Heifer-- Silage	0.88kg/day		(Chamberlain et al., 1971; Folmer et al., 2002; Keith et al., 1981; Tjardes et al., 2002)
Feedlot	1.35kg/day		(Land O'Lakes Beef Feeds, 2010)
R. Heifer – Hay		0.4kg/day	
- Graze		0.6 kg/day	
Meat Produced			
Carcass Yield %	52.3	52.3	(Aberle et al., 2001)
Dressing %	59	59	(Aberle et al., 2001)
Avg Price/Lb	3.97	3.97	(USDA ERS, 2011)
Population Numbers			
Bulls per Cow	30	30	
Calving %	95	95	(Brudelie and Deters, 2009)
Weaning %	88	88	(Brudelie and Deters, 2009)

Replacement %	15	15	(North Dakota State University, Dickson Research Extension Center, 2011)
Post Weaning Loss %	1.1%	1.1%	(Waldner et al., 2009)
Crop Production			
Annual Yield, dry matter			
Forage/Pasture	7,838 kg DM ha^{-1}	7,838 kg DM ha^{-1}	(MN NRCS, 2001)
Corn Silage	18,367 kg ha^{-1}		(Sheaffer and Swanson, 2010)
Corn Grain	10,098 kg ha^{-1}		(Brudelie and Deters, 2009; Hoverstad et al., 2011)
Distillers Grain	3,132 kg ha^{-1}		
Forage % growth/month	Varies, see table 5a	Varies, see table 5a	(MN NRCS, 2001)
Seasonal utilization %	80%	80%	(Gerrish, 2002)
Energy Content			
Forage Diet	See Table 6	See Table 6	(National Research Council (U.S.), 1982)
Silage Diet	See Table 6	See Table 6	(National Research Council (U.S.), 1982)
Feedlot Diet	See Table 6	See Table 6	(National Research Council (U.S.), 1982)

Table A7: Results of sensitivity testing for grass-based production system. All variables were decreased by 10% to determine the corresponding change in percent for the y variable (the total land area required). Variables with the greatest influence on model results are highlighted.

Variable	Coefficient (% change y/% change x)
Birth weight	-0.02
Milk fat %	-0.05
Grazing ADG	0.19
Dry-lot ADG	0.12
Pasture Utilization	0.58
Yearly Yield	1.1
Hay Quality	0.90
Pasture Quality	0.94
Carcass Yield %	1.1
Dressing %	1.1
Weaning %	0.78
Losses post weaning %	-1.4

*The y variable is the total land area needed; the x variable is the input variable listed.

**Pasture and hay quality were decreased by 10% through changing the TDN by 10%, and relating this change into the corresponding NEm and NEg.

Appendix B: Population Relationship Derivations from Chapter 1

Relationships: The population numbers are all related to one another by the number of cows, which are directly related to the number of finishing animals. All of the other population numbers – bulls, feeder steers and heifers, calf steers and heifers, and replacement females – were determined once a value for cows (C) was known.

All cows are assumed to be exposed in this model, so the number of cows exposed is equal to total number of cows. The weaning percentage for this study is 88%, based on the average weaning percentage for all farms in Southern Minnesota (Brudelie and Deters, 2009). The number of steer and heifer cattle that make it through to weaning (number total weaned or n_{tw}) is equal to the number of cows (C) multiplied by the weaning percentage (fraction weaned, F_w) which is 0.88:

$$n_{tw} = F_W C \tag{A1}$$

Half of the calves that are born are assumed to be male and the other half female. Since half of the calves born are steers and the other half are heifers, the number of steers weaned (n_{bw}) and number of heifers weaned (n_{gw}) equals the total number weaned divided by 2:

$$n_{bw} = n_{gw} = \frac{F_W C}{2} \tag{A2}$$

In addition to pre-weaning losses to the calf population numbers, some animals will also die post-weaning. A death loss of 1.1% of the total population number was assumed for finishers (Roeber et al., 2001)(Waldner et al., 2009). To calculate the number of cattle that die post-weaning, the number of cattle that survive up to weaning is multiplied by the 0.011, the fraction dead (F_D), to give the number of steers dead (n_{bd}) and the number of heifers dead (n_{gd}):

$$n_{bd} = F_D n_{bw} \tag{A3}$$

$$n_{gd} = F_D n_{gw} \tag{A4}$$

Steer Finishers: The number of steers that finish (n_{bf}) is equal to the number of steers that are weaned minus the losses that occur post-weaning:

$$n_{bf} = n_{bw} - n_{bd} \tag{A5}$$

Substituting the value for n_{bd} in terms of n_{bw} (number of steers weaned) from equation A2, equation A5 is rewritten as:

$$n_{bf} = n_{bw} - F_D n_{bw} = (1 - F_D) n_{bw} \tag{A6}$$

Heifers: Unlike steers, not all heifer calves born become finishers. Replacement heifers need to be taken into account along with the finishing population.

Replacements: Based replacement rates in North Dakota, 15% of the total cow population will need to be replaced by new heifer calves each year (North Dakota State University, Dickson Research Extension Center, 2011) . The number of heifer replacements (n_{gr}) is equal to 0.15, the fraction replaced (F_R), multiplied by the number of cows (C):

$$n_{gr} = F_R C \tag{A7}$$

Finishers: The number of heifers that finish is equal to the number of heifer calves weaned minus the losses that occur post-weaning – as for the steers that finish – but also has an additional loss from the replacement heifers. The sum of the number of heifers that die (n_{gd}), heifers that are finished (n_{gf}) and heifers that go into the replacement herd (n_{gr}), equals the number of heifers that are weaned:

$$n_{gw} = n_{gd} + n_{gf} + n_{gr} \tag{A8}$$

Rearranging equation A8 gives the number of heifers finishing equal to:

$$n_{gf} = n_{gw} - n_{gd} - n_{gr} \tag{A9}$$

Substituting the value of n_{gd} in terms of n_{gw} as done above with the steers (eq A6) gives the following equation for the number of heifers that finish:

$$\begin{aligned} n_{gf} &= n_{gw} - F_D n_{gw} - n_{gr} \\ &= (1 - F_D) n_{gw} - n_{gr} \end{aligned} \tag{A10}$$

Cows: The total number of finished cattle (n_{tf}) is related to the number of finished steers (n_{bf}) and heifers (n_{gf}) through the equation:

$$n_{tf} = n_{bf} + n_{gf} \tag{A11}$$

The number of steers and heifers finished are then related to the number of cows through the number of calves weaned (eq A1) and number of replacement heifers (eq A7). Replacing n_{bf} and n_{gf} in equation A11 with their equivalents from equation A6 and A10, results in the following relationship:

$$n_{tf} = (1 - F_D)n_{bw} + (1 - F_D)n_{gw} - n_{gr} \tag{A12}$$

Since the number of steers that are weaned equals the number of heifers that are weaned ($n_{bw} = n_{gw}$,), equation A12 can be rewritten as:

$$n_{tf} = (1 - F_D)2n_{bw} - n_{gr} \tag{A13}$$

Using equation A2, which relates the number of steer calves weaned (n_{bw}) to the number of cows, equation A13 becomes:

$$\begin{aligned} n_{tf} &= (1 - F_D)\left(2\frac{F_W C}{2}\right) - n_{gr} \\ &= (1 - F_D)(F_W C) - n_{gr} \end{aligned} \tag{A14}$$

Substituting in the value for the number of replacement heifers in terms of the number of cows (n_{gr} from eq A7) gives:

$$\begin{aligned} n_{tf} &= (1 - F_D)(F_W C) - F_R C \\ &= C\left((1 - F_D)F_W - F_R\right) \end{aligned} \tag{A15}$$

Solving for the number of cows, "C", in equation A15 gives the relationship between the number of cows and total finishers:

$$C = \frac{n_{tf}}{F_W(1 - F_D) - F_R} \tag{A16}$$

By plugging in the values for F_D, F_W and F_R:

$$\begin{aligned} C &= \frac{n_{tf}}{0.88(1 - 0.011) - 0.15} \\ &= \frac{n_{tf}}{0.72032} \end{aligned} \tag{A17}$$

Appendix C: Additional Tables and Figures from Chapter 2

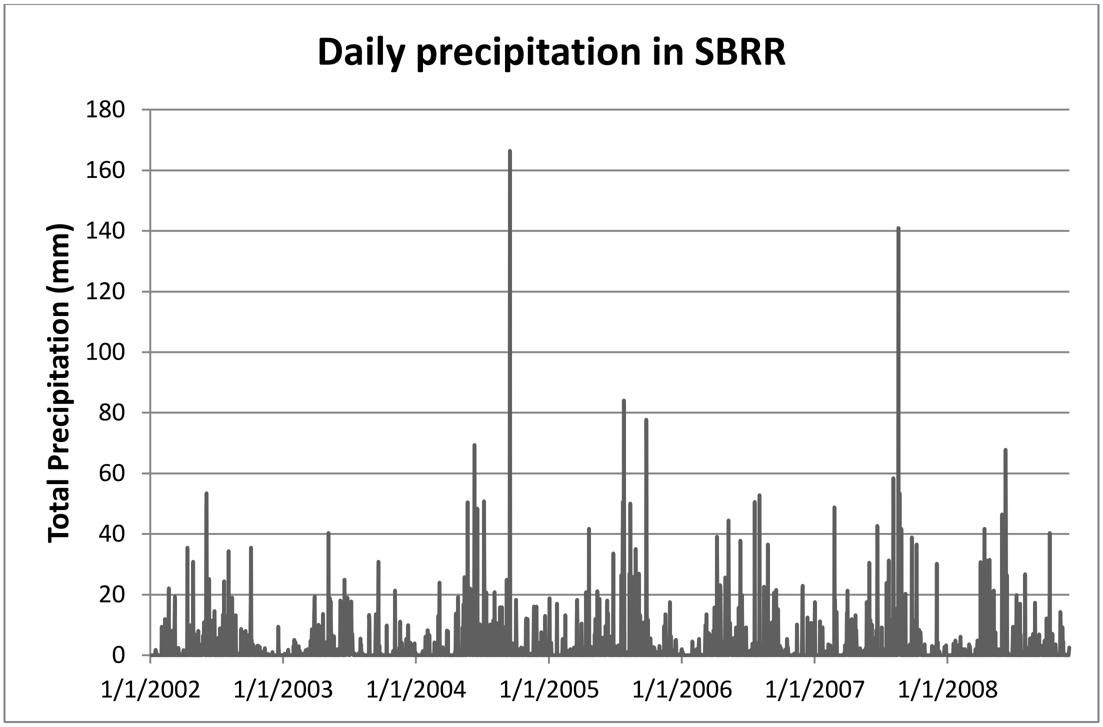

Figure C1: Precipitation data for the SBRR watershed for years simulated in SWAT model, 2004-2008.

Table C1: Physical channel dimensions and Manning's roughness values for several sites in SBRR (from Dalzell and Mulla, 2009).

Site Number*	Site Name	SWAT SubBasin	Bankfull width of main channel (m)	depth of main channel (m)	width/depth ratio	mannings roughness coefficient (n) for the main channel
1	SBRR SR2	5	12.47	2.54	4.91	0.060
2	SBRR SR3	6	12.08	1.27	9.51	0.040
3	SBRR Site 3 at Hwy 14	4	22.50	2.96	7.60	0.035
4	SBRR Trebiste Reach	8	18.50	1.22	15.16	0.025
6	SBRR 151st Ave	10	22.80	1.41	16.17	0.035
7	Etna Cr 153rd Ave	13	11.00	1.04	10.58	0.055
8	SBRR Tart Site	9	20.60	1.23	16.75	0.065
12	SBRR at confluence with Canfield Cr	3	19.30	1.01	19.11	0.030
13	Forestville Cr	7	12.00	1.45	8.28	0.040
14	Canfield Cr confluence with SBRR	12	16.10	1.18	13.64	0.024
15	Canfield Cr 201st Ave	14	11.40	1.89	6.03	0.055
17	Canfield Cr Stockdale site	15	56.20	1.49	37.72	0.065

* corresponds with site number from report by Dr. Toby Dogwiler. (does not correspont with SWAT sub basin numbers)

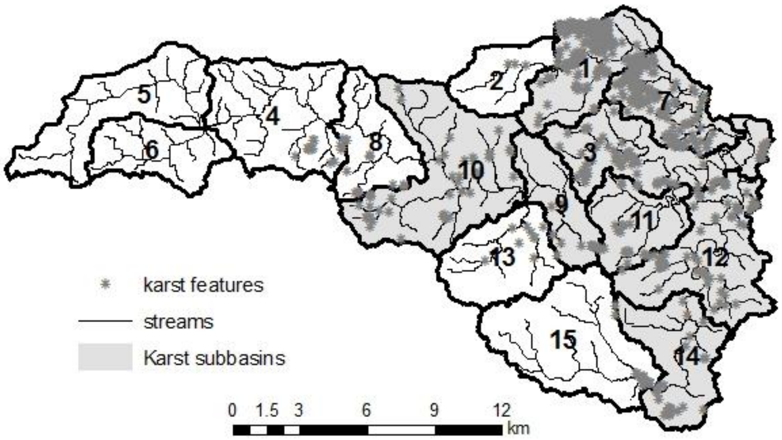

Figure C2: Karst and non-karst subbasins with the SBRR watershed. Image from Dalzell and Mulla, 2009.

Table C2: Area calculations for determine the land area needed for grazing in the SBRR, based on the land area needed for grazing in all of SE MN (calculated in Chapter 1).

Total Area	
SE MN	17,527 km2
SBRR	301.77 km2
Ratio SBRR: SE MN	0.017
Grazing Area	
SE MN	450 km2
SBRR	8.10 km2
Ratio SBRR:SE MN	0.017

Table C3: Area and percent of total pollutant losses resulting from HRUs with slopes greater than 4% on corn and soybean land.

Subbasin	**Area (ha)**	**% of total losses**		
		Sediment	**Phosphorus**	**Nitrogen**
1	278.22	6	6	4
2	14.69	0	0	0
3	157.85	3	2	0
4	27.88	0	0	0
5	4.48	0	0	0
6	3.76	0	0	0
7	283.24	5	4	5
8	68.18	1	1	0
9	175.24	4	3	1
10	272.56	8	5	1
11	439	8	4	1
12	414.68	9	6	1
13	207.06	5	4	1
14	173.16	2	2	1
15	0	0	0	0

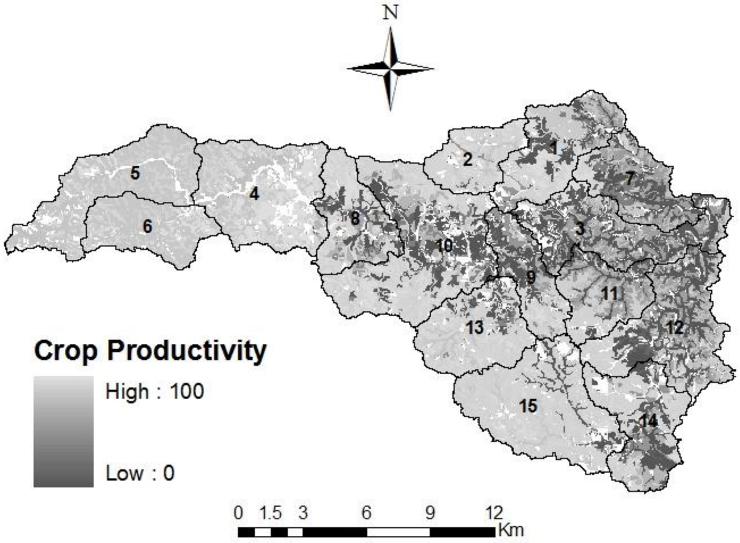

Figure C3: Crop productivity index for SBRR watershed.

Table C4: Average daily intake per unit land area for beef cattle grazing in the SBRR. Average daily intakes for the grazing period, and the total land area shown in the table are from calculations in Chapter 1.

Calculation	**Units**	**Value**
Grazing Feed Needs, seasonal Average	Kg/day	809,084
Total Grazing Area, SE MN	ha	45,051
Avg biomass eaten/day/ha	Kg/day/ha	17.96

Table C5: Manure produced and applied during grazing, and nitrogen from beef manure produced and applied on corn areas.

	SE MN	**SBRR**
Manure Produced Grazing		
Manure Produced (kg DM)	68,967,173	
Grazing Area (ha)	45,051	
Manure Applied (kg/ha/day)	6.55	
Winter Manure -- Nitrogen		
Produced (kg)	3,542,498	56,234
Applied (kg)		28,117

Table C6: GLU management schedule.

Rotation Name:		G1H1_a			
Year	**HU**	**Operation**	**Item**	**Rate Units**	**Notes**
Year 1	0.05	Plant	Winter Pasture		HU= 1000
	0.3	Graze start	Beef Manure	6.45kg/ha/ day	Bio_eaten = 17.96kg/ha/day, Bio_trmp = 3.59 kg/ha/day, length =184 days
Year 2	0.05	Plant	Winter Pasture		HU = 1000
	0.55	Harvest	Winter Pasture		
	0.65	Harvest	Winter Pasture		
	1.2	Harvest	Winter Pasture		

Notes: Two subrotations (G1H1_a and G1H1_b) were created with the initial year being either grazing or hay.

Table C7: Modifications to the C1S1 management schedule, with beef manure applied to corn in subbasin 1 (dairy manure applied).

Rotation Name:		C1S1bms1_a			
Year	**Date**	**Operation**	**Item**	**Rate Units**	**Notes**
Year 1	May 1	Fertilize	Elemental Phosphorus	41.3kg/ha	Frt_surface = 0.5
	May 1	Fertilize	Beef Fresh Manure	13,500 kg/ha	Frt_surface = 0.5
	May 1	Tillage	Field Cultivator Ge 15ft		
	May 4	Plant	Corn		HU to maturity =1700
	May 1	Fertilize	Urea	51.7kg/ha	Frt_surface = 0.5
	October 21	Harvest and Kill			
	October 28	Tillage	Disk Plow Lt23ft		
Year 2	May 12	Tillage	Field Cultivator Ge 15ft		
	May 18	Plant	Soybean		HU to maturity =

					1400
	October 7	Harvest and Kill			
	October 14	Tillage	Chisel Plow Gt 15ft		
	Nov 1	Fertilize	Elemental Phosphorus	19.41kg/ha	Frt_sruface = 0.5
Year 3	May 1	Fertilize	Elemental Phosphorus	41.3kg/ha	Frt_surface = 0.5
	May 1	Fertilize	Beef fresh manure	13,500kg/ha	Frt_surface = 0.5
	May 1	Tillage	Field Cultivator Ge 15ft		
	May 1	Fertilize	Elemental Nitrogen	91.6 kg/ha	Frt_surface = 0.5
	May 4	Fertilize	Urea	51.7 kg/ha	Frt_surface = 0.5
	May 4	Plant	Corn		HU to maturity = 1700
	October 21	Harvest and Kill			
	October 28	Tillage	Disk Plow Lt23ft		
Year 4	May 12	Tillage	Field Cultivator Ge 15ft		
	May 18	Plant	Soybean		HU to maturity = 1400
	October 7	Harvest and Kill			
	October 14	Tillage	Chisel Plow Gt 15ft		
	Nov 1	Fertilize	Minnesota Dairy Manure	31,718 kg/ha	Frt_surface = 0.5

Notes: Two subrotations (C1S1bms1_a and C1S1bms1_b) were created with the initial year being either corn or soybean. For GLU scenarios, this schedule was applied to subbasin 1, with land-use in corn or soybean, on slopes between 0-4%, and on soils Downs, Floyd and Kasson.

Table C8: Modifications to the C1S1 management schedule, with beef manure applied to corn in subbasin 12 (no dairy manure applied).

Rotation Name: C1S1bms12_a

Year	**Date**	**Operation**	**Item**	**Rate Units**	**Notes**
Year 1	May 1	Fertilize	Elemental Phosphorus	41.3kg/ha	Frt_surface = 0.5
	May 1	Fertilize	Beef Fresh Manure	13,500 kg/ha	Frt_surface = 0.5
	May 1	Fertilize	Elemental Nitrogen	91.6	Frt_surface = 0.5
	May 1	Tillage	Field Cultivator Ge 15ft		
	May 4	Plant	Corn		HU to maturity =1700
	May 1	Fertilize	Urea	51.7kg/ha	Frt_surface = 0.5
	Oct 21	Harvest and Kill			
	Oct 28	Tillage	Disk Plow Lt23ft		
Year 2	May 12	Tillage	Field Cultivator Ge 15ft		
	May 18	Plant	Soybean		HU to maturity = 1400
	Oct 7	Harvest and Kill			
	Oct 14	Tillage	Chisel Plow Gt 15ft		

	Nov 1	Fertilize	Elemental Phosphorus	19.41kg/ha	Frt_sruface = 0.5
Year 3	May 1	Fertilize	Elemental Nitrogen	91.6kg/ha	Frt_surface = 0.5
	May 1	Fertilize	Beef fresh manure	13,500kg/ha	Frt_surface = 0.5
	May 1	Tillage	Field Cultivator Ge 15ft		
	May 4	Fertilize	Urea	51.7 kg/ha	Frt_surface = 0.5
	May 1	Plant	Corn		HU to maturity = 1700
	Oct 21	Harvest and Kill			
	Oct 28	Tillage	Disk Plow Lt23ft		
Year 4	May 12	Tillage	Field Cultivator Ge 15ft		
	May 18	Plant	Soybean		HU to maturity = 1400
	Oct 7	Harvest and Kill			
	Oct 14	Tillage	Chisel Plow Gt 15ft		
	Nov 1	Fertilize	Elemental Phosphorus	19.41 kg/ha	Frt_surface = 0.5

Notes: Two subrotations (C1S1bms12_a and C1S1bms12_b) were created with the initial year being either corn or soybean. For GLU scenarios, this schedule was applied to subbasin 12, with land-use in corn or soybean, on slopes between 0-4%, and on soils Downs, Kasson, Kenyon and Racine.