CLEAN WATER ACT SECTION 319

NONPOINT SOURCE POLLUTION CONTROL PROGRAM

FINAL REPORT

DEVELOPING BMP's TO MINIMIZE THE WATER QUALITY IMPACTS OF WINTER MANURE SPREADING

SPONSOR:

South Dakota State University

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Agricultural and Biosystems Engineering

28 February 2017

This project was conducted in cooperation with the State of South Dakota and the United States Environmental Protection Agency, Region 8.

Grant # C9-99818506, Grant # C9-99818507, Grant # C9-99818509, Grant # C9-99818512
Grant # C9-99818513

EXECUTIVE SUMMARY

PROJECT TITLE: DEVELOPING BMP'S TO MINIMIZE THE WATER QUALITY IMPACTS OF WINTER MANURE SPREADING

PROJECT START DATE: 1 AUGUST 2010 PROJECT COMPLETION DATE: 31 JULY 2016

FUNDING:	TOTAL BUDGET	$188,359
	TOTAL EPA GRANT	$120,000
	TOTAL EXPENDITURES OF EPA FUNDS	$120,000
	TOTAL SECTION 319 MATCH ACCRUED	$68,359
	BUDGET REVISIONS	0
	TOTAL EXPENDITURES	$188,359

SUMMARY OF ACCOMPLISHMENTS

This project was established to test potential best management practices (BMP's) for spreading manure during the winter. A database of potential BMP's and water quality impacts was compiled. A paired watershed study was established to compare the impacts of applying manure to the upper ½ of a watershed compared to applying manure to the bottom ½ of the watershed. A third watershed in the study received no manure and served as the control watershed. Results showed no statistical differences due to manure placement when measured in terms of nutrient loads (kg/ha) in the runoff leaving the watershed. Runoff and soil erosion simulations were performed with Water Erosion Prediction Project (WEPP) and Revised Universal Soil Loss Equation 2 (RUSLE2). WEPP simulations showed that runoff amount and resulting soil erosion (sediment loss) were much more sensitive to soil texture than they were to change of slope steepness.

RUSLE 2 simulations showed that the north downslope watershed (which received manure) was the sub-watershed most susceptible to soil erosion in our study and the south upslope (which also received manure) was the least susceptible sub-watershed to soil erosion. Snow depth data were used to estimate the potential for runoff from spring snow melt events. The probably of a 150-mm (6-inch) melt (with a snow water equivalent of about 25 mm, or 1 inch) is about 40% at Brookings. The probability of a 150-mm (6 inch) melt in one day was only 20% at Sioux Falls. Even a 150 mm (6 inches) melt over 2 days happened less than 55% of the time at Brookings and Sioux Falls.

The project advisory committee met annually. Research results were presented to groups such as CAFO training sessions, statewide and national producer groups, and others.

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1.0 Introduction

Row crop production and livestock production have been identified as two of the leading contributors of surface water impairment in South Dakota (SD DENR, 2012). The 2012 Integrated Report for Surface Water Quality (SD DENR, 2012) indicated that 65% of the approximately 6400 miles of streams assessed to determine the water quality status during the five-year reporting period did not support one or more of their designated uses. SD DENR (2012) further indicates that out of the 137 lakes assessed during the project period, 34% did not meet their designated uses.

Livestock production is a major component of the South Dakota economy. Because the importance of livestock production crosses watershed boundaries and affects both the rural and urban population, especially in heavily populated watersheds, the issue of manure management has been the subject of debate in recent years. At the center of this debate is the land application of manure and the possible impacts on the state's water resources because nonpoint source (NPS) discharges of pollutants can be significant if manure is not managed properly, especially where high concentrations of livestock are present.

Having the option of spreading manure on frozen ground is an important management tool for livestock producers since winter spreading of manure may be a "last resort" practice to avoid storage overflow (with potential to cause concentrated spills into surface waters), provides more flexibility for spreading on cropland, and reduces soil compaction problems. While winter spreading of manure is often limited by recommendation, Srininvasan et al. (2006) reported that limitations on the spreading of manure during winter periods were determined largely from perceptions, not scientific data.

Several studies show lower runoff volumes and sediment loss from manured areas compared to non-manured or control areas (Young, 1974; Hensler et al., 1970; Young and Mutchler, 1976; Khaleel et al, 1980; Meals, 1991) although concentrations of dissolved P in runoff are often higher.

In a recent literature review, Srinivasan et al. (2006) lists several key research and management issues that need to be addressed. They are:

1. Characterization of the changes in the physical and chemical properties of manure under winter conditions as they affect nitrogen (N) and P release rates;
2. Development of strategies and methods that relate the findings of small-scale experiments to large-scale soil, landscape, and climate patterns;
3. Collection of sufficient data to establish the linkages among watershed-scale water quality, winter manure spreading practices, and winter conditions that affect hydrology and erosion processes;
4. Development of empirical model(s) of snowmelt and nutrient transport for use in evaluating current winter spreading practices and developing BMPs; and
5. Development of alternate methods of manure application.

Additional monitoring is needed, therefore, to evaluate current winter spreading practices and develop BMPs that reduce the water quality impacts of spreading manure on frozen soil. The proposed project is designed to fill some of the knowledge gaps that have been identified relating to understanding winter manure spreading's impacts on water quality, and to sample information under conditions common to the upper Midwest. Based on the information gained, we will develop tools to assist livestock producers in making decisions about when and how to apply manure in an environmentally responsible manner.

The location of the demonstration site is in Moody County SD approximately 8 miles southeast of Colman SD.

Surface runoff from the demonstration site drains into Bachelor Creek located about a half mile south of the sites. Bachelor Creek drains into the Big Sioux River about five miles east of the sites. The BSR drains part of the Coteau des Prairies in eastern South Dakota, a plateau rising above the prairie composed of thick glacial deposits. The glacial drift overlays bedrock and ranges in thickness from a few feet to nearly 200 feet and groundwater levels are typically shallow. The average annual precipitation at the field sites is 23 inches, of which three-quarters typically falls during the growing season, April through October. The average annual snowfall is 37 inches per year (SDSU Climate Office, 2012).

There are several communities located downstream of the demonstration site including Sioux Falls, the largest city in the state with a population of nearly 155,000. The Big Sioux River provides recreational values such as boating and swimming, ecosystem services supporting a large population of fish and wildlife, and public utility services.

This project has had three different principal investigators. David German began the project in 2010 as part of his larger manure/water quality program. Although he was not a PI, Dr Ron Gelderman contributed his soils/nutrient/manure expertise and was of great benefit to the project. However, both German and Gelderman retired during the early years of this project. Dr Jeppe Kjaersgaard then assumed the role of PI. Under Dr Kjaersgaard's leadership, the project was renewed and amended in 2013. However, Dr Kjaersgaard also left SDSU and Dr Todd Trooien assumed the role of PI for the last two years of the project.

2.0 Project Goals, Objectives, and Activities

The project goal was to protect water quality by providing and testing a viable and practical BMP to livestock producers for the winter application of manure.

Specific objectives, tasks, and products were:

Objective 1: Manage the demonstration site using common agricultural practices and monitor runoff quantity and quality.

Task 1: Manage the watersheds and monitor runoff volumes and nutrient, sediment and E.coli export from the three watersheds.

Product 1: Manage the watersheds using normal agricultural practices and monitor the runoff volumes.

Activities:

A paired watershed experiment design was used in this project. The research site was a single field in Moody County, South Dakota, that contained 3 watersheds. There were two manure application treatments and one control treatment (Figure 1). The north watershed was 2.7 ha (6.7 acres) in size with an average slope of 13%. That watershed received the manure application on the lowest ½ of the watershed. The south watershed was 4.1 ha (10.2 acres) in size with an average slope of 8% and received manure applications in the upper ½ of the watershed. The east watershed was the control watershed. It was 2.75 ha (6.8 acres) in size with an average slope of 16%. It received no manure. Any location that did not receive manure was fertilized with commercial fertilizer at the same rates of nitrogen (N) and phosphorus (P) as the manured areas. The soils in the field were Egan-Ethan complex and Wentworth-Egan complex.

All field operations were performed by the owner/operator except the manure applications. All three watersheds received the same operations (tillage, planting, harvesting, pest control, etc,) except for manure and nutrient application. The field was in a corn-soybean rotation. For the years when corn was grown, nitrogen and phosphorus were applied to meet the yield goal of 180 bu/ac. For the years when soybean was grown, phosphorus was applied to meet the yield goal of 60 bu/ac. Prior to application, manure was sampled and nutrient concentrations were measured. The application rates (Table 1) were calculated using the South Dakota Fertilizer Recommendations Guide (Gerwing and Gelderman, 2005), measured nutrient content of the manure, and residual nutrient content based on soil samples. Manure loads were weighed on the scale of a local cooperator. Various local cooperators applied the manure during the early years of the project (Figure 2). These performed adequately. During the last 4 years of the project, a commercial applicator was hired to apply the manure with trucks with vertical beaters (Figure 3). Project matching funds provided by SD producer groups were used to pay for the manure application.

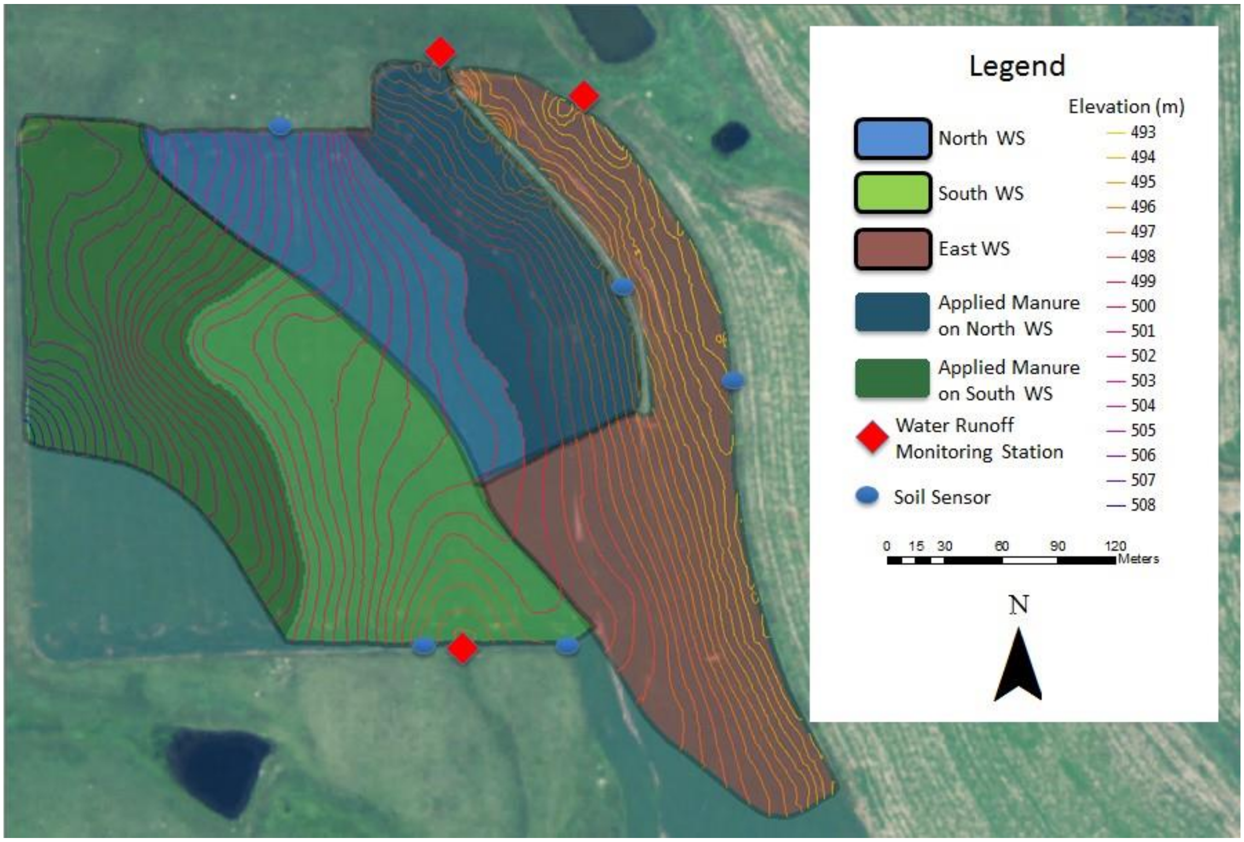

Figure 1. Location of manure application zones and monitoring stations within the three watersheds. Manure was applied to the one-half of the watershed located highest in the terrain in the south (green) watershed. On the north (blue) watershed, manure was applied to the one-half of the watershed located lowest in the terrain. No manure was applied to the east (control, shown in brown) watershed.

Figure 2. A pull-type spreader was used to apply manure in 2011.

Figure 3. Application truck with vertical beaters, 2014.

Table 1. Dates, crops, and rates of manure treatment applications.

DATE	CROP	MANURE APP RATE, TON/AC	MANURE SOURCE
6 March 2011	Soybean	6.0	Beef feedlot
16 February 2012	Corn	10.0	Beef feedlot
10 March 2013	Soybean	7.0	Beef feedlot
26 March 2014	Corn	18.0	Dairy
23 March 2015	Soybean	3.9	Dairy
22 April 2016	Corn	13.0	Beef feedlot

Product 2: Collect water samples and analyze runoff for nutrient, sediment and E. coli export from the three watersheds.

Activities:

An H-Flume had been previously installed at the outlet of each watershed to measure the flow rate of runoff (Table 2) leaving the watershed. The H-flume was designed to handle a 46 cm (18 inch) water depth and a peak flow of 0.15 m^3/s. The designed storm event for these flumes was back calculated to be 2 year, 24 hour storm event with a rainfall depth of 67 mm (2.6 inch). The depth of the water flowing through the flume was then recorded by a Stevens Type F analog stage recorder. The depth of flow was converted to flow rate using the standard calibration equation for a modified H flume. Flow rates were integrated over the runoff event duration to calculate the total runoff volume for the storm. The runoff volume was divided by the watershed area to calculate the runoff depth for the storm.

In late 2014, the instrumentation was upgraded to an automatic sampler with ultrasonic measurement of the flow depth in the flume (Figure 3). One of the autosamplers was queried from campus via cell modem when rain fell in the vicinity. If samples were collected, researchers traveled from campus that day or (in the case of overnight runoff events) the next day to collect the samples. The samples were immediately cooled and preserved as appropriate. If immediate analysis was not possible, samples were frozen for later analysis.

Objective 2: Compare in-field placement of manure during winter spreading to determine which practice that minimizes the impact on water quality and develop BMPs.

Task 2: Quantify water quality impacts from winter manure spreading.

Product 3: Quantify water quality impacts from winter manure spreading.

Activities:

A number of best management practices related to manure spreading have been suggestion in the literature. We have conducted a literature review of previous studies addressing water quality impacts of winter manure spreading (Tables 3 through 5). Many of those practices are region-specific and may therefore not be fully transferable from one region to another.

Figure 4. Automated monitoring and sampling equipment installed in late 2014. Shown are the automated sampler (yellow), battery (black box), ultrasonic depth sensor (in front of automated sampler), and data logger in the new white enclosure. A solar panel is mounted on the pole on the far side of the data logger enclosure. The white box on the right in the foreground formerly housed the Stevens stage recorder.

Table 2. Runoff events resulting from snowmelt, occurring pre-plant, or occurring during the growing season.

Year	Number of days with runoff		
	From snowmelt	Pre-planting	Growing season
2011	6	0	3
2012	0	3	0
2013	5	0	0
2014	0	0	4
2015	0	0	9
2016	1	0	1

From the literature review, manure should not be applied to melting snow or directly before a large rain event. Large runoff losses are likely to occur along with large nutrient and sediment losses. This BMP is difficult to practice because of variable climate and weather conditions. Water quality effects of the manure application treatments are best measured with loads (mass of nutrient per unit area of the watershed, or kg/ha) that leave the watershed in the runoff.

Soil infiltration rate is not a water quality result of manure application but it can change in response to manure application and it has an impact on water quality. Infiltration rate controls the amount of runoff from an area, which then directly affects the water quality.

Water infiltration rate was measured for all the six landscape positions (upper and lower ½ of each of the 3 watersheds) with the double ring method (20 cm height, and 30 and 20 cm diameter for the inner and outer rings) using the ponded head method (Reynolds et al., 2002). Infiltration measurements were done in three replicates at each landscape position. Core samples were collected from 2 depths (0 to 10 cm and 10 to 20 cm) from all the landscape positions in two replicates. The cores were of 5 cm diameter and 5 cm length. The samples were sealed in plastic zip lock bags, transported to the lab and were analyzed immediately. Bulk density was analyzed using the core method (Grossman and Reinsch, 2002) for both the depths.

Concentrations of e. coli and coliforms were measured only once during this project because of lack of coordination with other researchers with analytical expertise and capability and lack of coordination among the series of project principal investigators. The samples were collected once during late February 2012. There was one runoff sample from each of the three watersheds. Each sample was analyzed for coliform bacteria concentration and e coli concentration. All three coliform bacteria concentrations were TNTC (too numerous to count), meaning coliforms were plentiful in the samples. The e coli concentration from the north watershed was TNTC. The sample from the south watershed had 461 Col/100 mL and from the east watershed, 20 Col/100 mL. All of these analyzed levels are deemed "unsafe" in terms of bacterial content. In the end, the final project principal investigator failed to review the project objectives adequately and failed to address the bacterial objective by collecting the appropriate samples. The lack of additional bacterial sampling was a failure of project management by the final investigator. A new faculty member in the ABE Department is exploring ways to undertake research at the site to assess the potential to address e. coli fate, transport, and antibacterial resistance issues.

Product 4: Set up and run an appropriate model to simulate runoff and sediment transport in the watersheds.

Activities:

The Water Erosion Prediction Project (WEPP, 2010) was used to simulate annual runoff and sediment yield dependent upon soil series and slope. WEPP sediment yield results from South Dakota were tested by Sishodia (2010). Some of the soil property and runoff data used by Sishodia (2010) were collected at our field site near Colman, SD.

To explore the utility of the model and to provide estimates of runoff and sediment transport from agricultural fields, the WEPP model was parameterized and tested using the monitored runoff data from the field site. The hill slope profile configuration of WEPP was applied in two steps: 1) model calibration and testing using information collected at the field site, and 2) extrapolating the results from our field site by estimating the runoff and sediment exports for three common South Dakota soil types across a range of slopes.

Changes were made to the default WEPP model parameters in order to correlate the model results with actual field results from 2011 and 2012. Calibration changes included actual observed soil texture, organic matter, initial saturation levels, and the hydraulic conductivity of the soil. The soil texture and hydraulic conductivity in the model were modified to match the NRCS Web Soil Survey soil textures (Web Soil Survey, 2012). The soil organic matter in the model was changed according to soil sample results collected at the field site. Soil moisture sensors were used to determine the initial saturation levels in the soil and corrected WEPP.

Table 3. TKN and TN losses per hectare and concentrations from snowmelt runoff events on plots spread with solid manure (data compiled by N. Brandenburg).

Treatment	Reference	Plot Size (ha)	Plot Slope (%)	Past Crop	TKN (kg ha^{-1})	TKN (mg L^{-1})	TN (kg ha^{-1})	TN (mg L^{-1})
Manure applied on unfrozen soil	Young and Mutchler (1976)	0.01	9	Corn	0.1-2.1	3.1-4.9	NA	NA
	Converse et al. (1976)[a]	0.004	10-12	Alfalfa	NA	NA	6.1	NA
	Komiskey et al. (2011)[b]	6.8-16	4-6	Corn/Soybean	NA	NA	0.4-3.4	3.1-11.0
Manure applied on frozen soil	Young and Mutchler (1976)	0.01	9	Corn	0.2-4.9	5.3-13.2	NA	NA
	Young and Mutchler (1976)	0.01	9	Alfalfa	15.5-37.4	23.0-33.1	NA	NA
	Converse et al. (1976)[a]	0.004	10-12	Alfalfa	NA	NA	6.6-23.1	NA
	Komiskey et al. (2011)[b]	6.8-16	4-6	Corn/Soybean	NA	NA	1.5	5.7
Manure applied on top of the snow	Young and Mutchler (1976)	0.01	9	Corn	0.7-5.3	13.2-15.5	NA	NA
	Young and Mutchler (1976)	0.01	9	Alfalfa	0.4-22.1	22.1-29.1	NA	NA
	Converse et al. (1976)[a]	0.004	10-12	Alfalfa	NA	NA	5.9-38.2	NA
	Komiskey et al. (2011)[b]	6.8-16	4-6	Corn/Soybean	NA	NA	0.3-1.3	4.0-8.0
No Manure Applied	Young and Mutchler (1976)	0.01	9	Corn	0.6-2.5	1.3-1.8	NA	NA
	Young and Mutchler (1976)	0.01	9	Alfalfa	1.6-3.7	1.8-4.0	NA	NA
	Converse et al. (1976)[a]	0.004	10-12	Alfalfa	NA	NA	5.7-14.7	NA

NA = Not available

[a]Data includes rainfall runoff events

[b]Range of mean flow-weighted concentration

Table 4. NH_4-N and NO_3 +NO_2-N losses per hectare and concentrations from snowmelt runoff events on plots spread with solid manure (data compiled by N. Brandenburg).

Treatment	Reference	Plot Size (ha)	Plot Slope (%)	Past Crop	NH_4-N (kg ha^{-1})	NH_4-N (mg L^{-1})	NO_3 +NO_2-N (kg ha^{-1})	NO_3 +NO_2-N (mg L^{-1})
Manure applied on unfrozen soil	Young and Mutchler (1976)	0.01	9	Corn	Trace-0.9	0.9-2.2	Trace-2.8	0.9-6.6
	Converse et al. (1976)[a]	0.004	10-12	Alfalfa	2.6	NA	1.2	NA
	Komiskey et al. (2011)[b]	6.8-16	4-6	Corn/Soybean	NA	0.7-0.8	NA	0.9-1.3
Manure applied on frozen soil	Young and Mutchler (1976)	0.01	9	Corn	0.1-2	1.8-5.3	Trace-0.3	0.9
	Young and Mutchler (1976)	0.01	9	Alfalfa	9.0-9.3	8.4-13.2	0.1-0.2	Trace
	Converse et al. (1976)[a]	0.004	10-12	Alfalfa	2.6-8.9	NA	0.78-1.5	NA
	Komiskey et al. (2011)[b]	6.8-16	4-6	Corn/Soybean	NA	1.9	NA	0.9
Manure applied on top of the snow	Young and Mutchler (1976)	0.01	9	Corn	0.2-1.0	3.1-4.0	0.1-0.3	0.4-7.5
	Young and Mutchler (1976)	0.01	9	Alfalfa	0.2-11.3	10.6-11.5	Trace	Trace
	Converse et al. (1976)[a]	0.004	10-12	Alfalfa	1.2-13.12	NA	0.8-1.9	NA
	Komiskey et al. (2011)[b]	6.8-16	4-6	Corn/Soybean	NA	1.0-3.2	NA	0.3-2.1
No Manure Applied	Young and Mutchler (1976)	0.01	9	Corn	0.2-1.1	0.4-0.9	3.2	2.2-8.4
	Young and Mutchler (1976)	0.01	9	Alfalfa	0.6-1.9	0.9-2.2	1.0-1.6	1.3-1.8
	Converse et al. (1976)[a]	0.004	10-12	Alfalfa	1.0-3.9	NA	1.1-2.02	NA

NA = Not available
[a] Data includes rainfall runoff events
[b] Mean flow-weighted concentration

Table 5. TP and DRP losses per hectare and concentrations from snowmelt runoff events on plots spread with solid manure (data compiled by N. Brandenburg).

Treatment	Reference	Plot Size	Plot Slope	Crop	TP		DRP	
		(ha)	(%)		(kg ha^{-1})	(mg L^{-1})	(kg ha^{-1})	(mg L^{-1})
Manure applied on unfrozen soil	Young and Mutchler (1976)	0.01	9	Corn	Trace-0.6	1.3	Trace-0.4	0.9-1.3
	Converse et al. (1976)[a]	0.004	10-12	Alfalfa	1.2	NA	NA	NA
	Komiskey et al. (2011)[b]	6.8-16	4-6	Corn/Soybean	0.2-2.0	1.8-5.6	NA	1.8-3.2
Manure applied on frozen soil	Young and Mutchler (1976)	0.01	9	Corn	Trace-1.6	0.4-4.0	Trace-1.0	0.4-2.6
	Young and Mutchler (1976)	0.01	9	Alfalfa	6.7-7.4	6.6-9.7	4.0-4.8	4.4-5.7
	Converse et al. (1976)[a]	0.004	10-12	Alfalfa	1.2-8.1	NA	NA	NA
	Komiskey et al. (2011)[b]	6.8-16	4-6	Corn/Soybean	1.0	3.6	NA	3.1
Manure applied on top of the snow	Young and Mutchler (1976)	0.01	9	Corn	0.1-0.6	1.8-2.6	0.1-0.2	0.9-1.3
	Young and Mutchler (1976)	0.01	9	Alfalfa	0.1-3.7	4.0-4.9	Trace-1.9	2.2-2.6
	Converse et al. (1976)[a]	0.004	10-12	Alfalfa	0.6-6.1	NA	NA	NA
	Komiskey et al. (2011)[b]	6.8-16	4-6	Corn/Soybean	0.2-1.1	3.1-7.7	NA	1.5-6.6
No Manure Applied	Young and Mutchler (1976)	0.01	9	Corn	0.1-0.2	Trace-0.4	0.1	Trace
	Young and Mutchler (1976)	0.01	9	Alfalfa	Trace-0.1	Trace	Trace-0.1	Trace
	Converse et al. (1976)[a]	0.004	10-12	Alfalfa	0.8-2.4	NA	NA	NA

NA = Not available
[a] Data includes rainfall runoff events
[b] Mean flow-weighted concentration

Model simulations were conducted to determine runoff and sediment loss changes in response to soil series and slope steepness. Three soil series were chosen to vary within the model: Promise, Maddock, and Houdek. The Promise soil series was a fine-textured soil with 56% clay content. The Maddock soil series was a coarse-textured soil with 86% sand content. The Houdek soil series was a medium-textured soil with 38% sand content and 25% clay content. All of the soils are found throughout South Dakota and are used for agricultural purposes. Five slopes were selected ranging from 2 to 15%. The length of each slope was 100 m and slope was constant. Climate and field management inputs were unchanged within the model. Climate data from 2003 to 2012 from Dell Rapids were obtained from the State Climate Office (climate.sdstate.edu) and used in the model. The precipitation during this ten-year range was nearly average compared to the last 40 years (Figure 5). A corn/soybean rotation with no tillage in the fall and spring disk tillage was used as the field management input. Using these inputs WEPP was used to model the average annual runoff and sediment yield

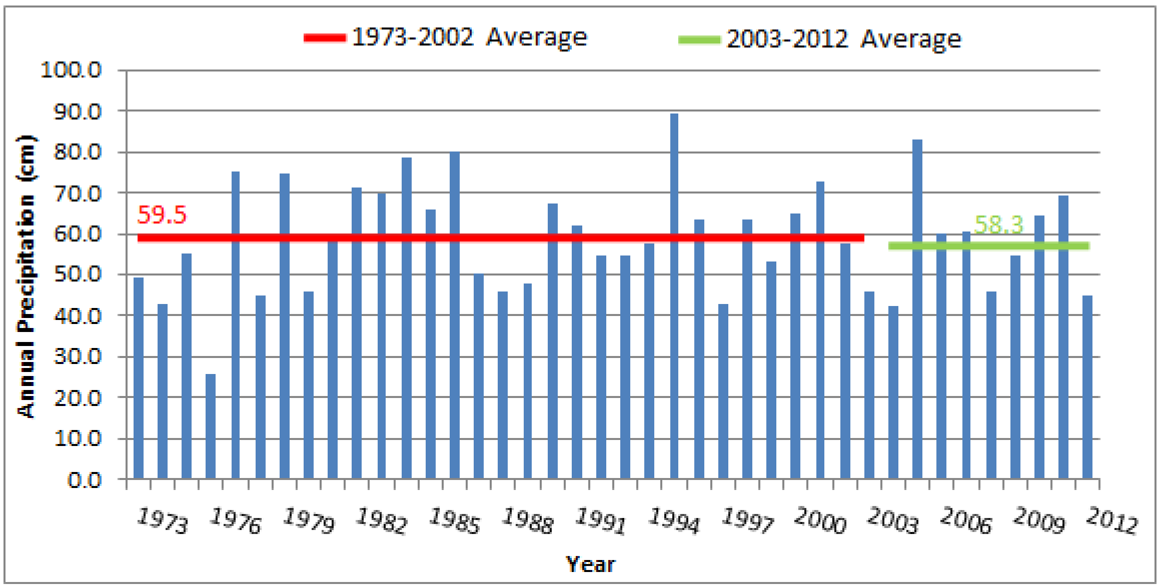

Figure 5. Climate data from 2003 to 2012 from the State Climate Office (climate.sdstate.edu) were used in the WEPP simulations. The ten-year average precipitation was nearly average, within 1.5 cm of the average for the preceding 30- year period.

For the Houdek soil series the average annual runoff event varied from 24 to 36 mm (1 to 1.5 inch, Figure 6), and the average annual sediment yield varied from 1000 to 50000 kg/ha (Figure 7). The annual runoff varied from 61 to 88 mm (2.4 to 3.5 inch) for the Promise soil series, and the annual sediment yield varied from 3700 to 132000 kg/ha. The Maddock soil series varied from 3 to 5 (0.1 to 0.2 inch) mm for the annual runoff and 0 to 40 kg/ha for the annual sediment yield.

These simulation results show that runoff and the resulting sediment loss are more dependent on soil type and texture than on slope steepness. For example, the sediment loss from the fine-textured Promise soil at 4% slopes was about the same as from the medium-textured Houdek soils at 8% slopes. And the runoff and sediment loss from the coarse-textured Maddock soil were small for all slopes examined (up to 15%).

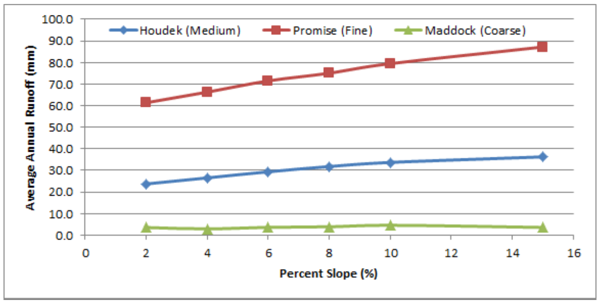

Figure 6. Average annual runoff based on WEPP simulations. (Brandenburg, 2013)

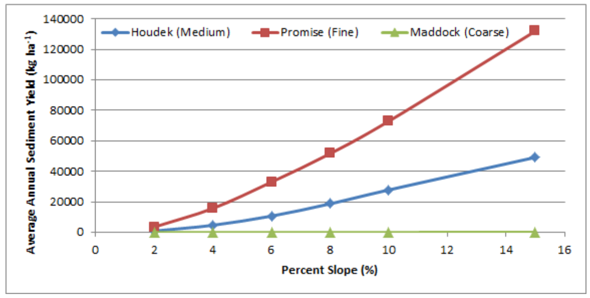

Figure 7. Average annual sediment yield based on WEPP simulations. (Brandenburg, 2013)

Singh (2016) used a complementary approach to the soil erosion simulations. Singh used RUSLE2 rather than WEPP and simulated the watersheds at the site. In fact, the RUSLE2 simulations went one step further and actually simulated the parts of the watersheds that received manure separately from the parts that did not receive manure. This resulted in six different simulated areas: the upper ("East Upslope") and lower ("East Downslope") halves of the control watershed that received no manure, the lower ½ of the north watershed ("North Downslope") that received manure, the upper ½ of the north watershed ("North Upslope") that did not receive manure, the lower ½ of the south watershed ("South Downslope") that did not receive manure, and the upper ½ of the south watershed ("South Upslope") that received manure.

The rainfall (R) and soil erodibility (K) factors were constant for all simulations, reflecting the close proximity of all sub-watersheds to each other and the relatively consistent soil types across all sub-watersheds. The soil cover factor, C, was adjusted to reflect the manure application where manure was applied. The C factor was slightly greater where manure was applied compared to an area of no manure application. Slope length and slope steepness were determined using the digital elevation model using the 10m by 10m resolution in ArcGIS. The LS factor was calculated using the method of Morgan (2006). The P factor was 1.0 for all simulations.

The RUSLE2 simulations showed that the North Downslope sub-watershed, that received manure, was the most susceptible to soil erosion (Figure 8). The South Upslope sub-watershed, the other manure treatment area in this study, was the least susceptible to soil erosion. The differences are mostly due to the differing slopes (both length and steepness) in the sub-watersheds with minor differences that can be attributed to the differences in the C factor where manure was applied. Expected soil erosion by watershed was greatest in the north watershed and least in the east (control) watershed (Figure 9).

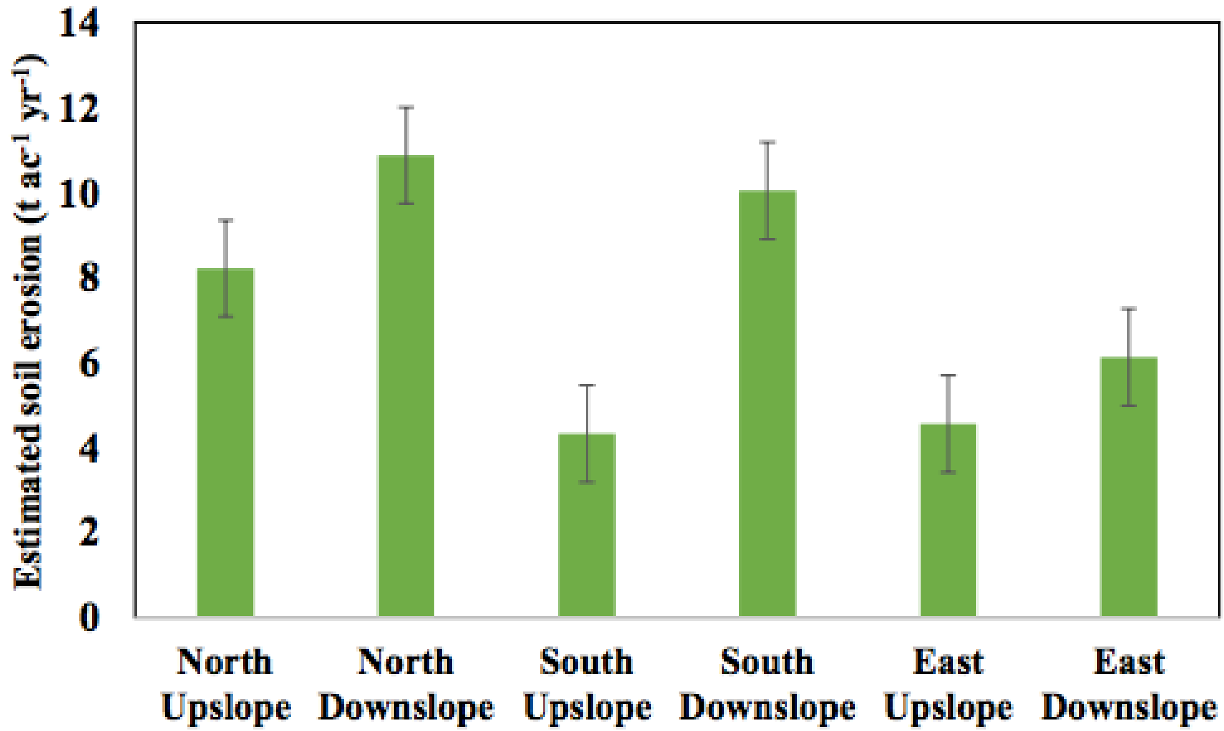

Figure 8. Sediment loss from the six sub-watersheds, based on RUSLE2 simulations. (Singh, 2016)

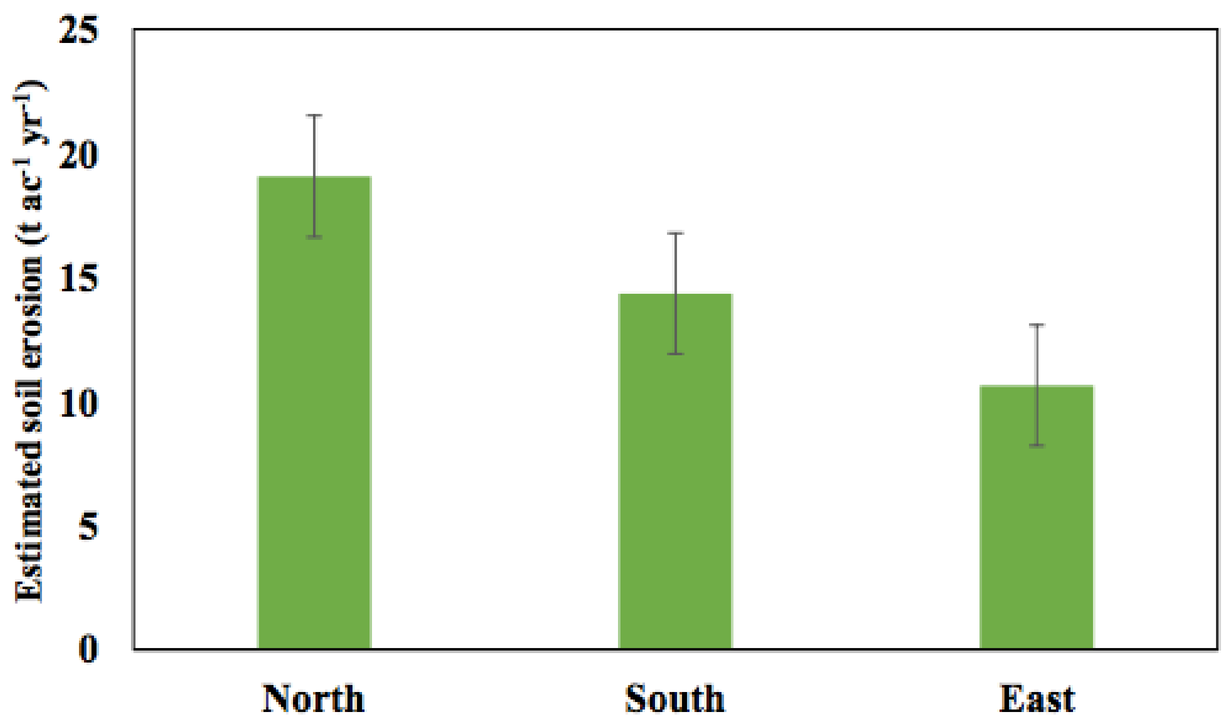

Figure 9. Simulated soil erosion by watershed, based on RUSLE2 simulations. (Singh, 2016)

Objective 3: Assess climatic risk factors using frequency of soil frost and rainfall events impacting runoff and water quality and monitor changes in soil nutrient levels.

Task 3: Mine historical meteorological information and merge it with weather information collected during the project in a database. Build database of soil nutrient levels.

Product 5: Build a database of historical meteorological information by mining historical weather data sets. Add current meteorological information, soil temperature and moisture data.

Activities:

The SDSU Office of the State Climatologist maintains the weather data base for the statewide weather station network. That network includes stations at Flandreau and Dell Rapids. Both stations provide weather data used in this project. In addition, the on-site rainfall measurements, soil temperature, and soil water content data are available from the project principal investigator.

Product 6: Collect information about soil temperature and soil moisture and collect soil samples for analysis.

Activities:

Soil moisture and soil temperature data was collected throughout the project period. New soil moisture and temperature sensors located at 6, 20 and 40 inches were installed at five different locations in the watersheds. The locations of the soil sensors are shown in Figure 1. Pictures of the sensors used for the installation are shown in Figures 10 and 11. Soil water content data from two locations during 2014 are shown in Figures 12 and 13. Note the differences of responses near dates July 20 and September 18, for example.

Figure 10. A view of the soil temperature/ water sensor.

Figure 11. Installation of soil temperature/ water sensors.

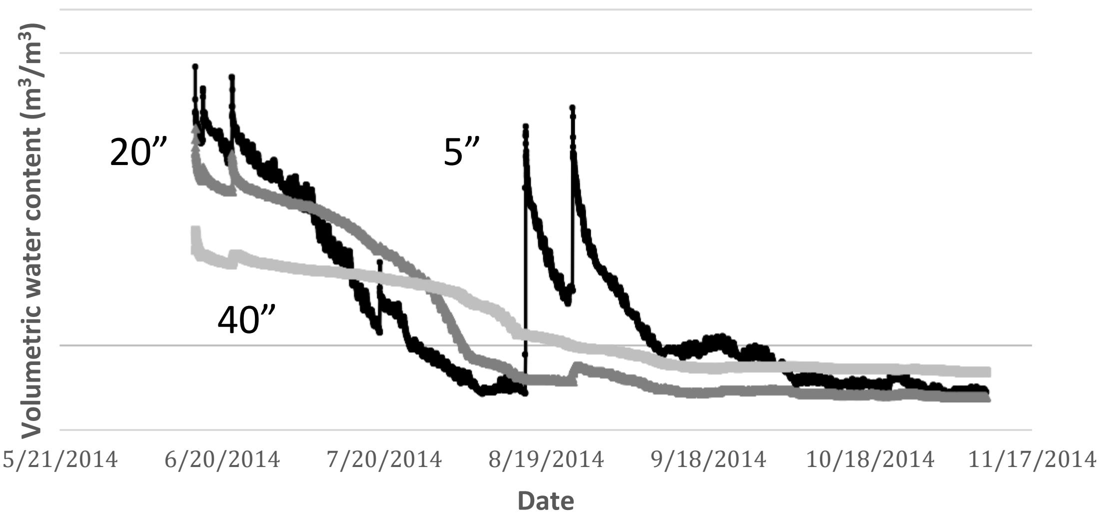

Figure 12. Soil water content at the south location during 2014.

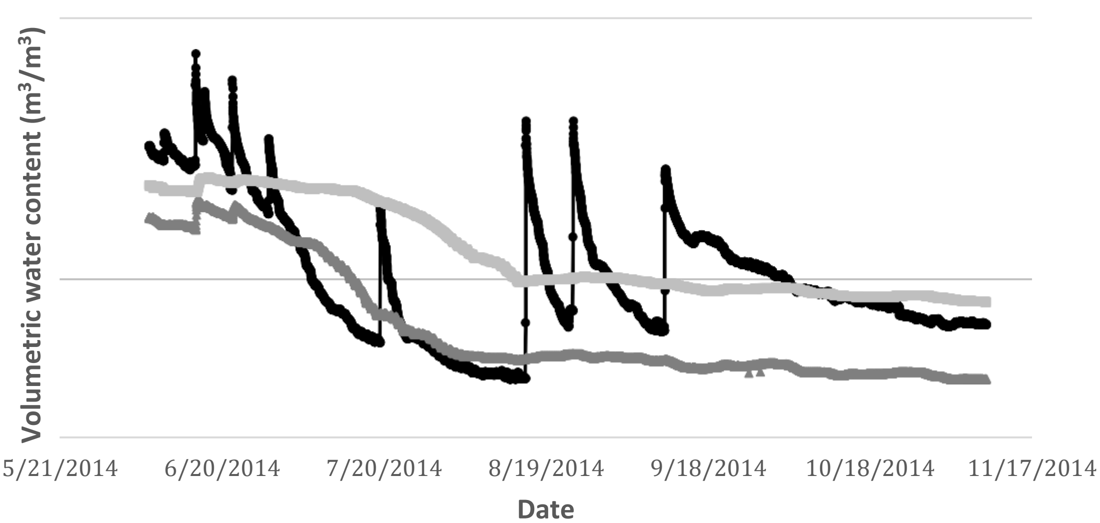

Figure 13. Soil water content at the north location during 2014.

Task 4: Meteorological data analysis.

Product 7: Complete a climate risk assessment of critical meteorological factors impacting the runoff potential of excess surface water.

Activities:

Snow depth data from 1950 through 2015 were used to calculate the probability (risk) of snowmelt and runoff at two locations: Brookings and Sioux Falls. A decrease of measured snow depth was assumed to be caused by melting. The equivalent water depth in the snowpack would be quite variable. Even so, using an average value of 4 mm (0.15 inch) of water per 25 mm (1 inch) of snow means that a 150-mm (6-inch) snow pack would contain a little more than 25 mm (1 inch) of water. If a threshold of an inch of water from melted snow per days were used as an indicator of potential runoff, the data show that 40% of the years of record had a 150-mm (6-inch) snowmelt at Brookings in one day (Figure 14). The probability of a 150 mm (6-inch) melt over 2 days is less than 55% at the Brookings location. At the Sioux Falls location, only 20% of the years had a 150-mm (6-inch) snowmelt in one day (Figure 15). The probability of a 300-mm (12-inch) melt over 2 days is less than 15% at the Brookings location and less than 10% at Sioux Falls. The probability of having 450 mm (18 inches) on the ground at any time was 12% for the Brookings location and less than 10% for the Sioux Falls location. At both locations (Brookings and Sioux Falls), every year had an event of 50 mm (2 inches) melting within 1 day (Figures 14 and 15).

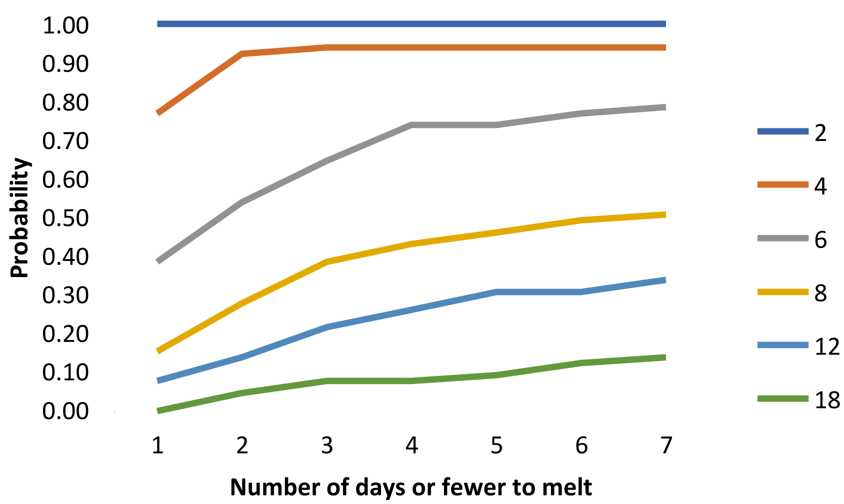

Figure 14. Probability of various depths of snow melting in xx days or fewer at the Brookings, SD location. The depth of snow melt (in inches) is shown in the legend on the right side of the figure.

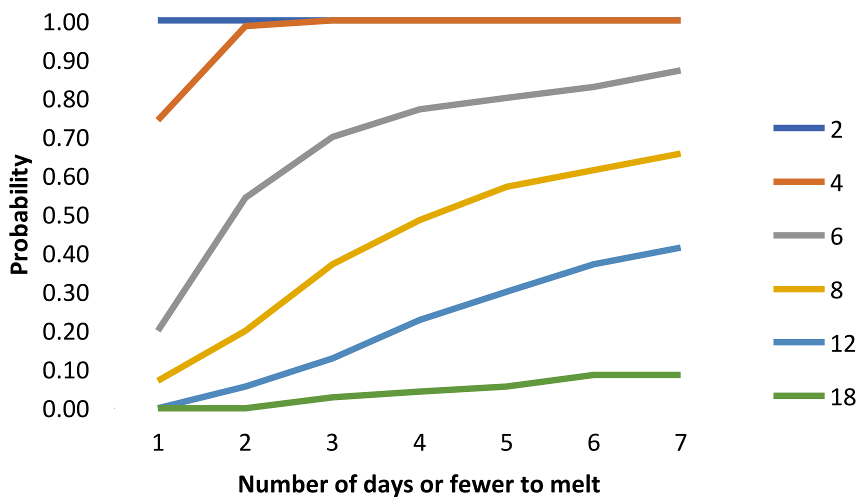

Figure 15. Probability of various depths of snow melting in xx days or fewer at the Sioux Falls, SD location. The depth of snow melt (in inches) is shown in the legend on the right side of the figure.

Objective 4: Monitor surface runoff and leaching of nitrogen to shallow groundwater from field storage of manure.

Task 5: Establish a manure pile and collect surface water and groundwater samples for nitrogen analysis.

Product 8: Monitor surface runoff and leaching of nitrogen to shallow groundwater from field storage of manure.

Activities:

During the fall of 2013, two monitoring sites were established to measure the leaching of nitrogen from manure piled at the edge of a field. One site was near Colman, SD and the other was near Hudson, SD. One up-gradient well and three down-gradient wells were established at each site. All wells were between 20 and 30 feet deep. At the time of installation, they appeared to be installed in saturated materials. Since that time the wells have been dry and no shallow groundwater data have been collected.

Objective 5: Provide education on winter manure spreading BMPs to livestock producers, extension educators, crop advisers, land managers, water quality experts, state regulators, and other stakeholders.

Task 6: Information transfer and outreach

Product 9: Maintain the project website and post results, reports, presentations and other pertinent information.

Activities:
The project website has been developed. The website address is http://www.sdstate.edu/agricultural-and-biosystems-engineering/developing-bmps-minimize-surface-water-quality-impacts.

Product 10: Develop educational brochures, fact sheets and handouts.
Activities:
A factsheet on nitrate was published in April 2012. The factsheet is available in electronic form from the Water Resources Institute website at http://www.sdstate.edu/abe/wri/water-quality/upload/NitratePublication_Kjaersgaard_Published.pdf.
A 10-page factsheet on Watershed Management was been completed in July 2012. The publication is available in electronic form through the Water Resources Institute Website and from e.g. from the South Dakota Legislative Research Council (http://legis.state.sd.us/interim/2012/documents/WTF09-25-12WatershedManagementSDSU.pdf). Printed copies are available from the offices of the Water Resources Institute and East Dakota Water Development District.

There were two MS theses that addressed various aspects of this project. They were:

Brandenburg, NA. 2013. Developing best management practices to minimize the water quality impact of winter manure spreading. MS Thesis, Agricultural and Biosystems Engineering, South Dakota State University.

Singh, Shikha. 2016. Response of soil and water quality to winter manure application from small agricultural watersheds in South Dakota. MS Thesis, Plant Science, South Dakota State University.

Product 11: Organize or contribute to nine meetings, crop clinics or CAFO training workshops to disseminate information generated during the project.
Activities:
Project results and conclusions were presented at the public hearing of the renewal of the South Dakota Livestock General Permit in September 2016. Even though the hearing was held shortly after the conclusion of this project, the event is of great enough significance and tied so closely to this project that it is listed here. The project PI testified about the results and conclusions of this project. Special emphasis was placed on the lack of statistical significance in the water quality effects (in terms of runoff nutrient loads) to the manure application treatments in the current data set. This conclusion was used to support the change of general permit rules related to the application of manure to fields during the winter, to frozen soils.

Dr Darrington presented project results to the National Cattlemen's Beef Association (NCBA) annual convention in Denver, CO on July 17, 2015. He presented the project goals and results to that national audience. Also participating in that presentation was Mike Schmidt, site owner and operator and project stakeholder.

Among various presentations given to various groups, Dr Trooien provided an update to the board of the East Dakota Water Development District on 21 July 2016.

Annual updates were provided to the SD Cattlemen's Association annual conventions each year in December. Drs Kjaersgaard, Trooien, and Darrington provided those updates at various times. For example, Dr Darrington presented to the convention in December 2015 in Aberdeen. Dr Trooien presented to the convention in December 2014, also in Aberdeen. In December 2013, Dr Kjaersgaard presented to the group.

Study results and findings were presented at two CAFO training workshops in Huron, SD during 2013. The workshops were sponsored by SDSU, SD DENR, and NRCS. Six soil and crop fertility clinics were also conducted during 2013-2014.

Study results, findings, and implications were presented to many different courses on the SDSU campus. Some of the courses were AST 463, Ag Waste Management; AST 333, Soil and Water Mechanics; and ABE 434, Natural Resources Engineering.

Annual meetings of the project advisory committee were held, usually during the winter. The three most recent meetings were held on 6 January 2016, 12 March 2015, and 10 February 2014. Stakeholder participation in these meetings was high. Participants have included representatives of these organizations and groups:

- East Dakota Water Development District
- Moody County Conservation District
- South Dakota Cattle Feeders Council of the SD Cattlemen's Association
- South Dakota Department of Environment and Natural Resources (DENR)
- South Dakota Farm Bureau
- USDA Natural Resources Conservation Service (NRCS)
- Big Sioux Community Water System

Task 7: Project reporting.

Products 12 through 14: Prepare semi-annual, annual, and final reports for the SD DENR describing project progress and results.

Activities:

The annual reports and other periodic reports were provided to DENR and this document serves as the final project report.

Milestones

This table provides information about the milestones that were planned and completed for the project titled Developing BMPs to Minimize the Water Quality Impacts of Winter Manure Spreading. The objective/task/product milestone table below (Table 6) has been reproduced from the milestone table included under section 3.3 in the project proposal.

Table 6. Milestone completion table for the project.

Task	Unit	Planned	Completed
Outcome 1: Water monitoring			
Task 1: Water sampling			
Apply manure treatments	No of watersheds	2	2
Maintain flumes at 3 watersheds	No of flumes maintained	3	3
Product 1: Runoff volume	No of runoff events	36	30
Product 2: Water quality	No of samples collected	246	164
Outcome 2: Develop BMPs			
Task 2: Compare water quality impacts			
Product 3: Quantify risk of winter spreading	No of watersheds	3	3
Product 4: Computer simulations	No of watersheds	3	6
Outcome 3: Climate risk factor			
Task 3: Databases			
Product 5: Database of meteorol. information	No of databases	1	1
Product 6: Soil data from soil sampling	No of soil samples	48	36
Install soil sensors	No of watersheds	3	3
Task 4: Meteorological data analysis			
Product 7: Climate risk assessment	No of assessments	1	1
Outcome 4: Manure storage			
Task 5: Ground water impacts			
Product 8: Ground water samples and analysis	No of samples	45	0
Objective 5: Outreach and reporting			
Task 6: Information transfer			
Product 9: maintain website	No of websites	1	1
Product 10: Handouts, factsheets, brochures	No of copies	2500	2000
Product 11: Meetings, CAFO training	No of meetings	2	8
Local steering committee	No of meetings	1	5
Crop and soil clinics	No of clinics	6	0
Task 7: Reports			
Product 12: Semi-annual reports	No of reports	3	1
Product 13: Annual Reports	No of reports	5	5
Product 14: Final Report	No of reports	1	1

3.0 Long term results in terms of behavior modification, stream/lake quality, ground water, and/or watershed protection changes

Application of manure during the winter will now be permitted under the newly-revised General Permit for CAFO's in South Dakota.

The DENR CAFO page (http://denr.sd.gov/des/fp/cafo.aspx) contains the details of the permit, including information related to the contested hearing held in September 2016.

4.0 Best management practices (BMPs) developed and/or revised (for demonstration projects)

This project was designed to test the effects of winter application of manure. The project was successful in that the state guidelines as set forth in the General Permit were revised. Because there was no significant difference found between applying manure to the upper ½ of the watershed compared to applying manure to the lower ½, producers will have greater flexibility for winter manure application and water quality will not be impaired. The results of this project showed that, in terms of nutrient loads in mass per watershed area, there was no statistically significant difference between applying manure during the winter to the upper ½ of the watershed as compared to applying to the lower ½ of the watershed.

5.0 Monitoring results for demonstration projects

Water quality effects of the manure application treatments are best measured with loads (mass of nutrient per unit area of the watershed, or kg/ha) that leave the watershed in the runoff.

Measured runoff depths by storm were variable during 2011 and 2012. They were also quite variable during 2013 and 2014 but the amounts were much less. Runoff amounts were more uniform among the three watersheds during 2015 but, again, small (Figures 16 through 20). There was only one storm with runoff recorded during 2014.

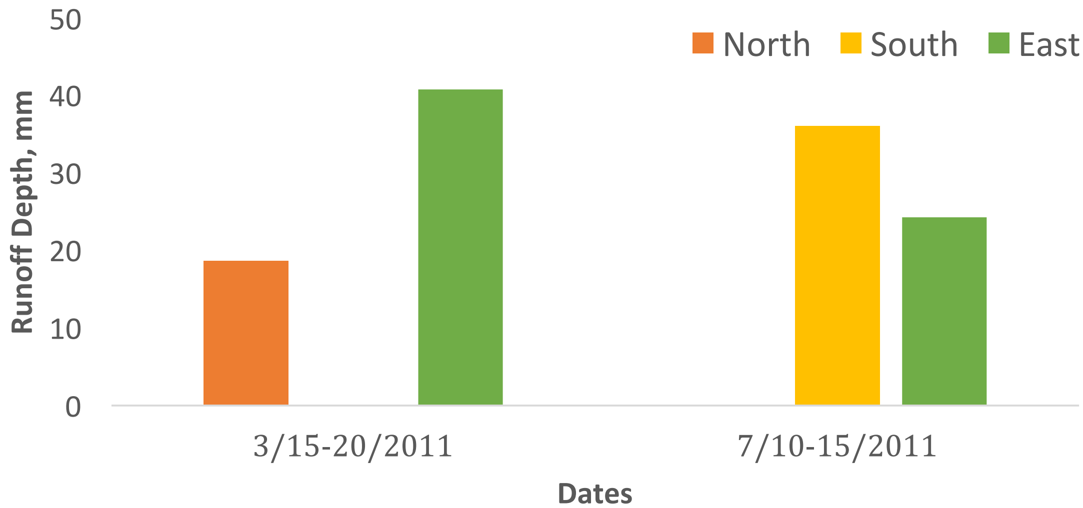

Figure 16. Runoff depths by storm during the 2011 season. The March event was due to snow melt and the July event was due to rainfall. Measurements for the south watershed were not recorded for the March event because of flume damage. (Brandenburg, 2013)

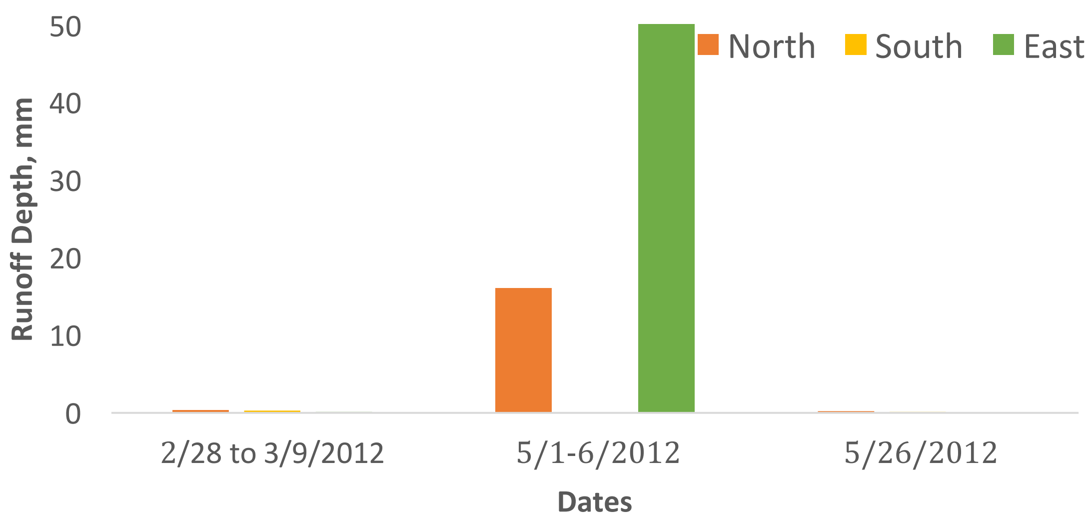

Figure 17. Runoff depths by storm during the 2012 season. The March event was due to snow melt and the others were due to rain. The early May values contain estimates because of flume sedimentation and subsequent overflow. Values for the north watershed in the early May storm were not recorded because of stage recorder malfunction. The runoff values for the late May storm were vanishingly small (less than 0.2 mm). (Brandenburg, 2016)

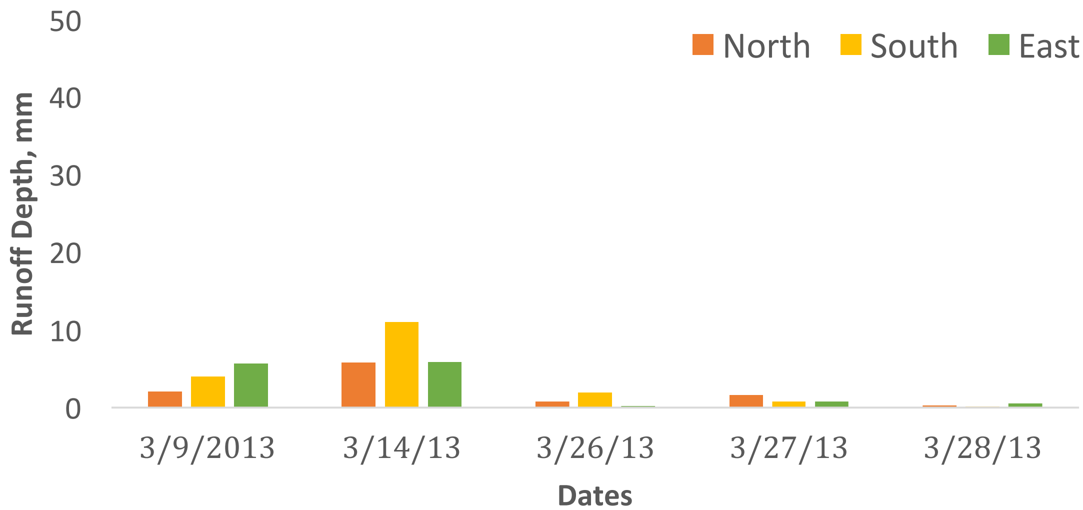

Figure 18. Runoff depths by storm during the 2013 season. (Singh, 2016)

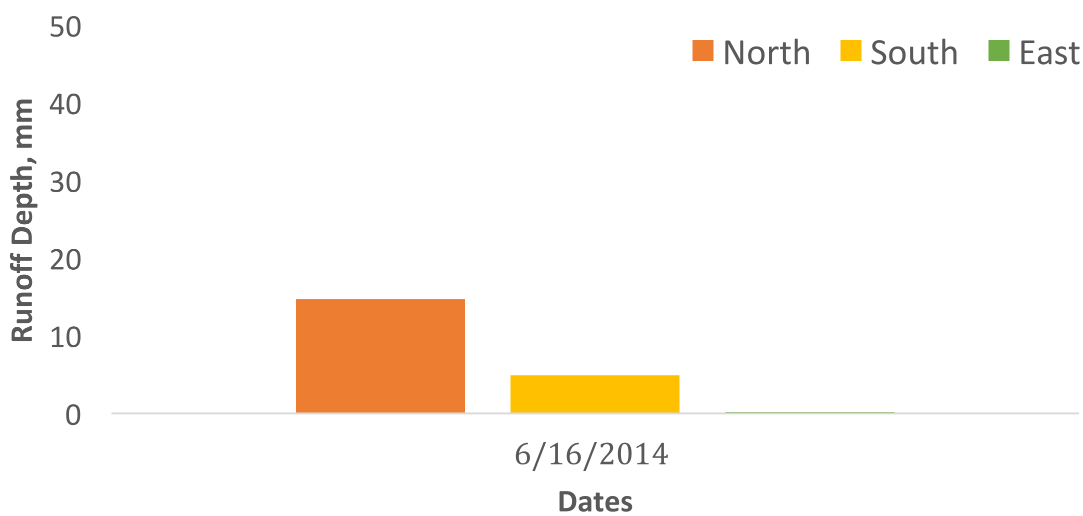

Figure 19. Runoff depths by storm during the 2014 season. (Singh, 2016)

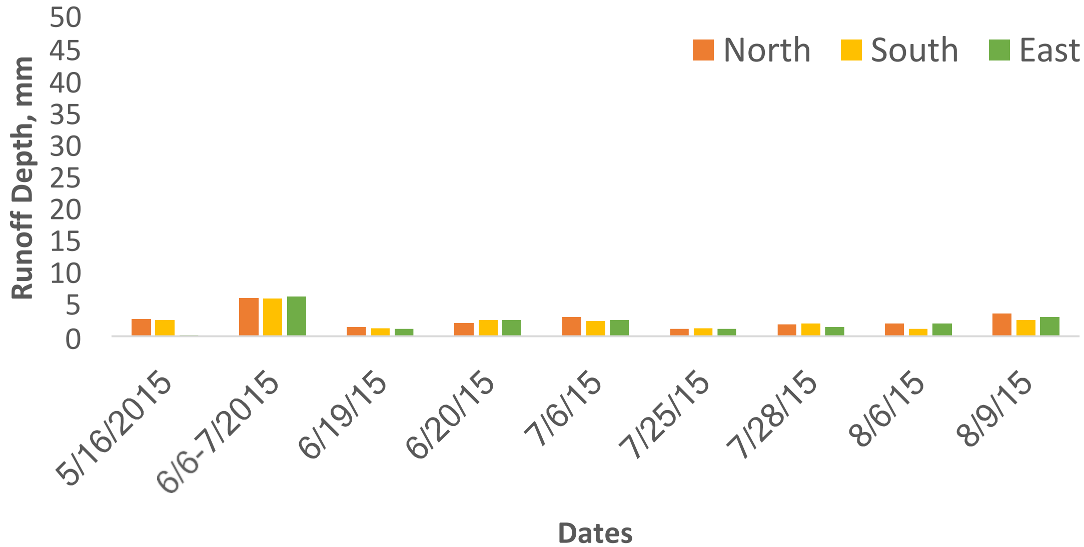

Figure 20. Runoff depths by storm during the 2015 season. (Singh, 2016)

There were no statistically significant differences among the nutrient and sediment loads (kg/ha) in the runoff from the watersheds for the time period of 2013 through 2015. There were numerical trends (Table 7) but the variability of loads was great enough to overshadow any numerical differences so the differences were not statistically significant. The statistical test was a parallel line analysis (Singh, 2016). Thus, based on these data, there is no statistically supported reason to apply manure during the winter to only the upper ½ of the watershed (Figures 21 through 26). Note the trends and variability in the data. Because of the sparsity of data, nutrient loads were not calculated for 2011 and 2012.

Table 7. Cumulative nutrient loads in runoff leaving each watershed for 2013 through 2015. All values are in kg/ha. The differences between watersheds were not statistically significant at $P<0.1$.

	North watershed	South watershed	East watershed
Nitrate-N	1.5	1.2	0.6
Ammonia-N	0.6	0.5	0.2
Total N	3.2	2.2	0.9
Total Dissolved P	0.3	0.2	0.06
Total P	1.3	0.7	0.2
Total Suspended Solids	371.1	183.2	54.3

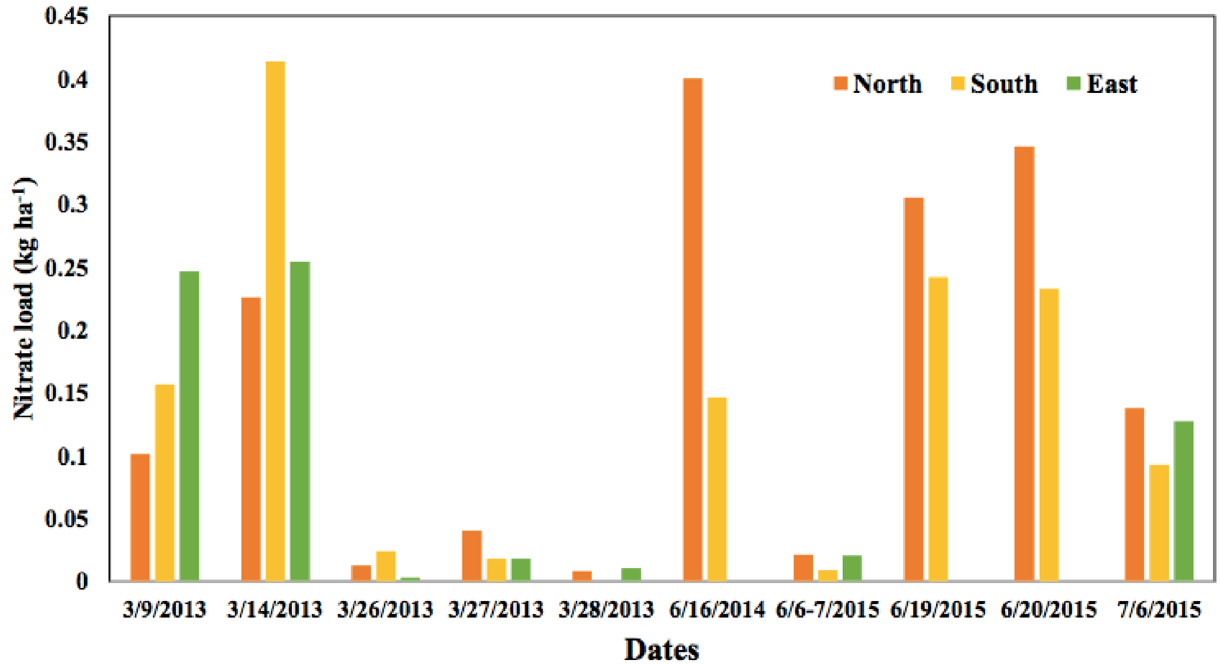

Figure 21. Nitrate-nitrogen (kg/ha) loads in runoff by storm. Differences among the loads were not statistically significant. (Signh, 2016)

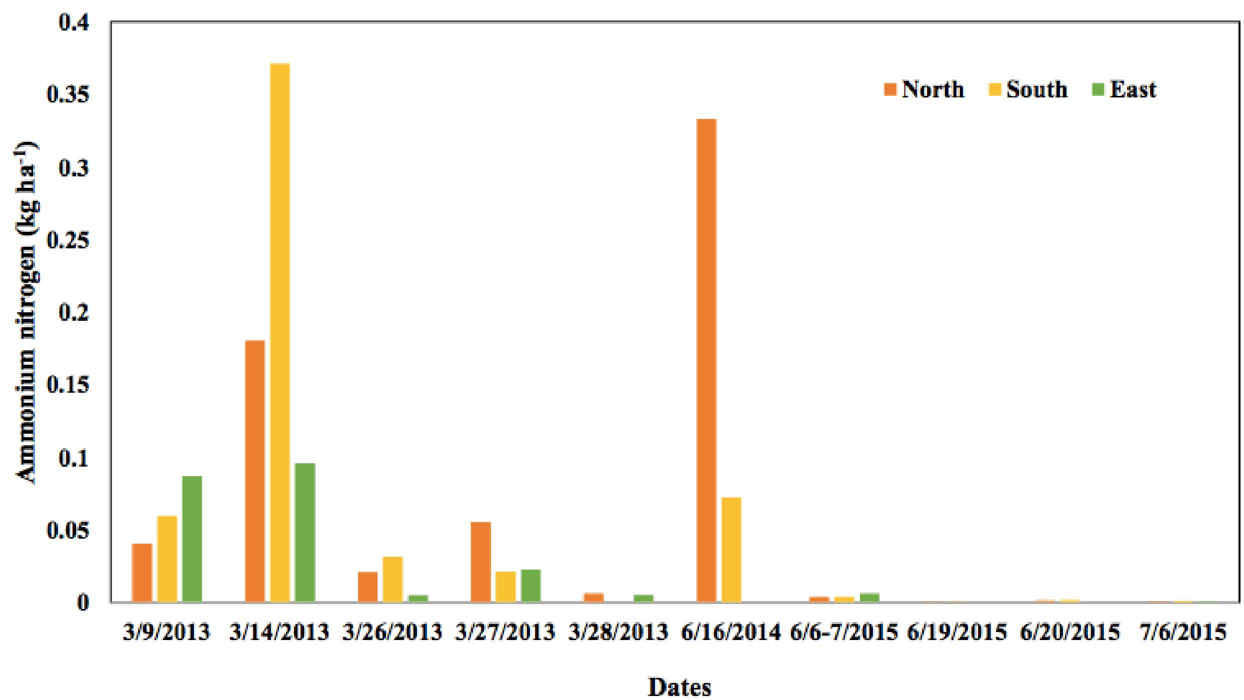

Figure 22. Ammonium-nitrogen loads (kg/ha) in runoff by storm for 2013 through 2015. Differences among the loads were not statistically significant. (Singh, 2016)

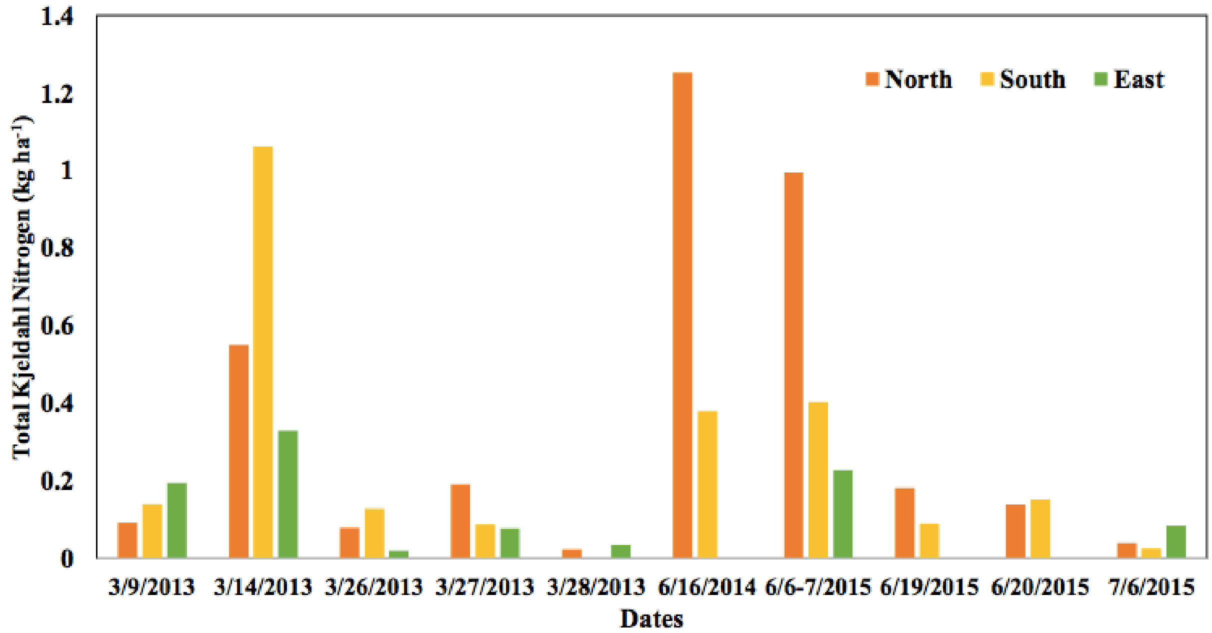

Figure 23. Total Kjeldahl nitrogen loads (kg/ha) in runoff by storm for 2013 through 2015. Differences among the loads were not statistically significant. (Singh, 2016)

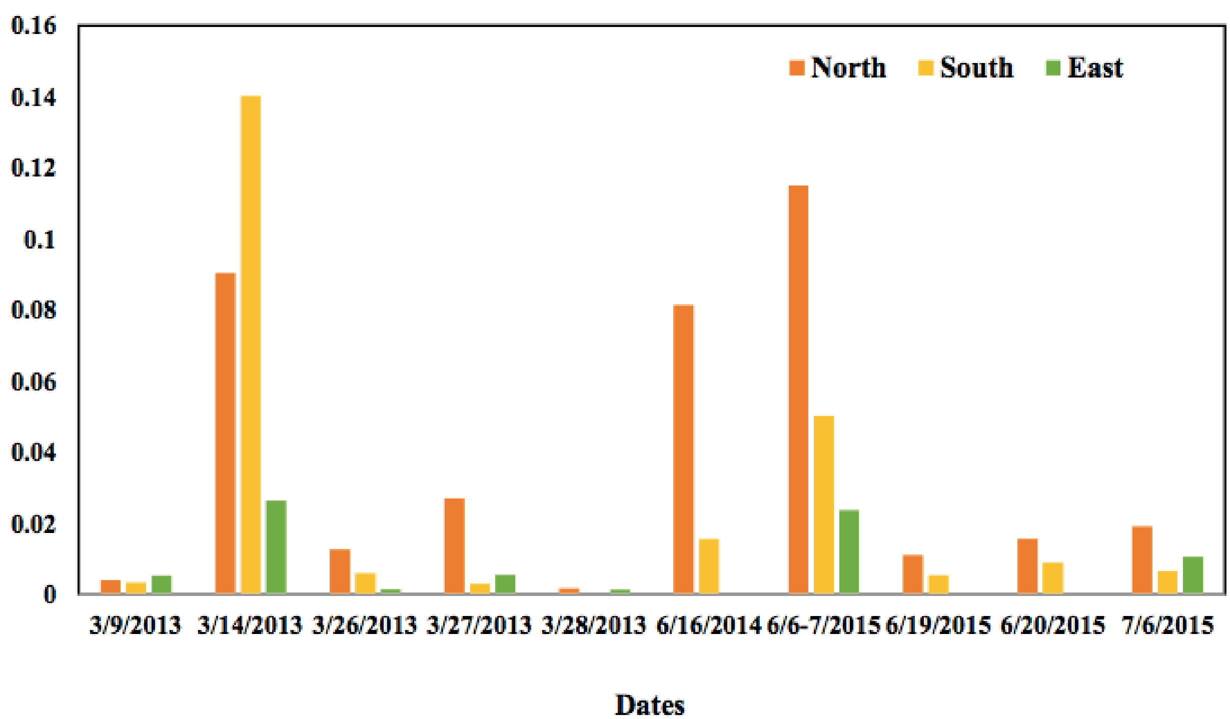

Figure 24. Total Dissolved Phosphorus (kg/ha) loads in runoff by storm. The Y axis in the original figure was mislabeled so it was excluded from this image. The label should read Total Dissolved Phosphorus, kg/ha. Differences among the loads were not statistically significant. (Singh, 2016)

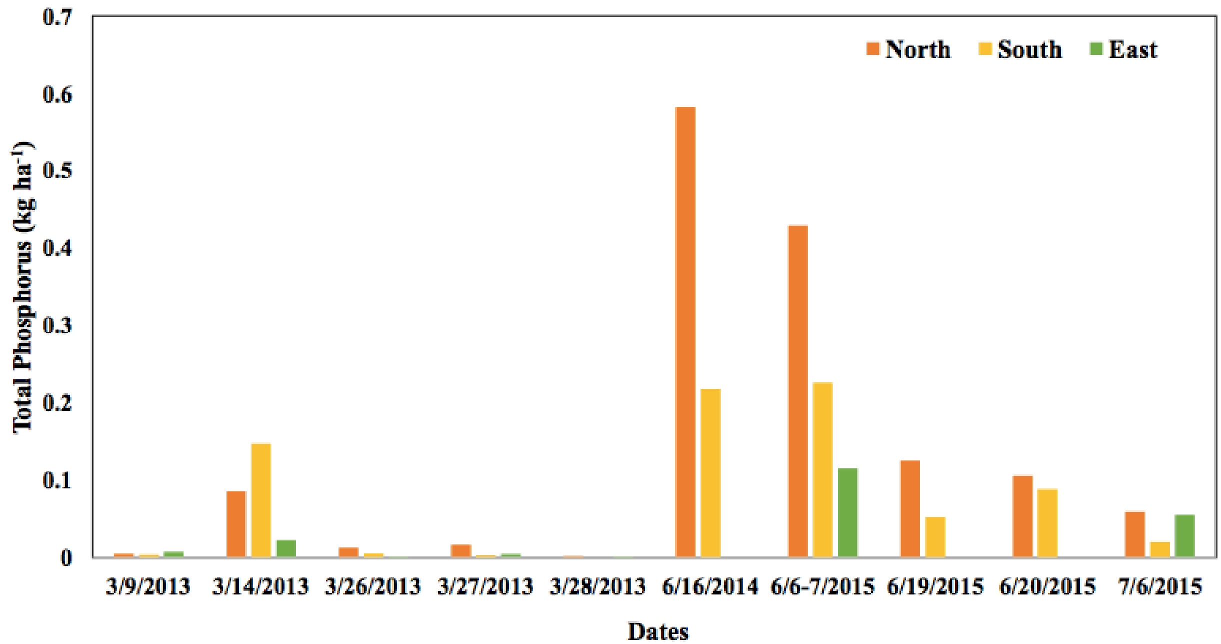

Figure 25. Total phosphorus loads (kg/ha) in runoff by storm for 2013 through 2015. Differences among the loads were not statistically significant. (Singh, 2016)

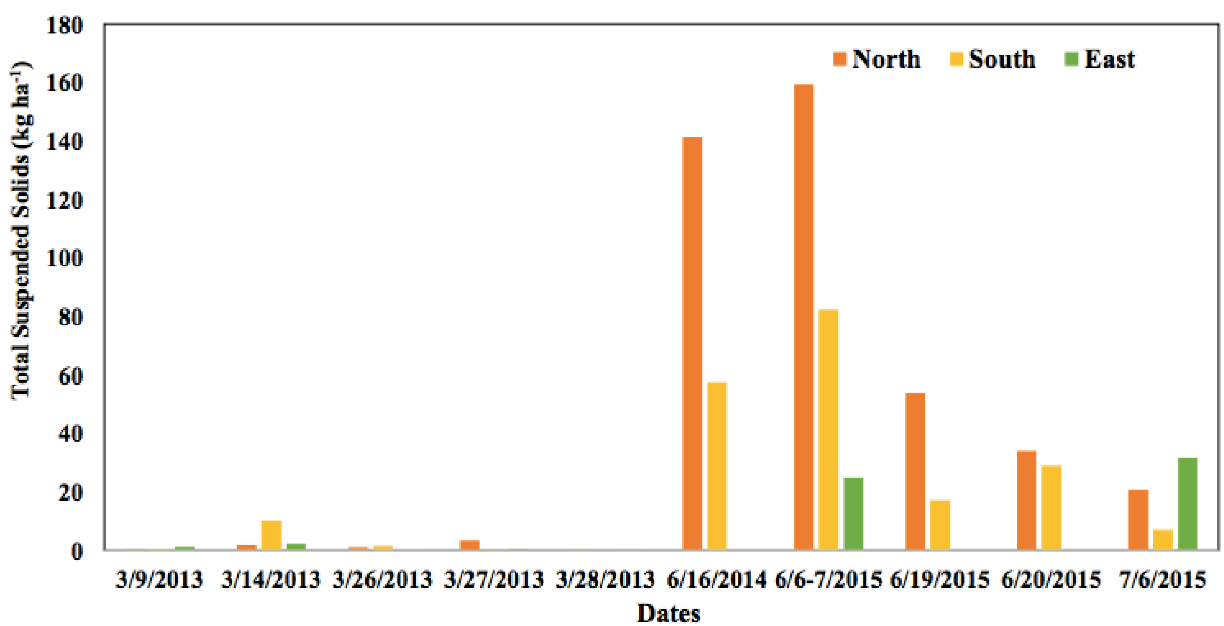

Figure 26. Total suspended solids loads (kg/ha) in runoff by storm for 2013 through 2015. Differences among the loads were not statistically significant. (Singh, 2016)

Water quality effects also can be measured in terms of concentrations (mass of nutrient per unit volume of water leaving the watershed). But concentration differences are incomplete in their description of the treatment effects because of the variation of runoff amounts from the watersheds. Nutrient concentrations in runoff showed trends and differences (Figures 27 through 44). There was only one measured storm in 2014 so the concentration data for that year are not shown. For the single storm monitored in 2014, the nutrient concentrations from the north watershed were slightly greater than the nutrient concentrations from the south watershed.

The east watershed had a very small amount of runoff (less than 1 mm) during the 2014 storm and it was not sampled.

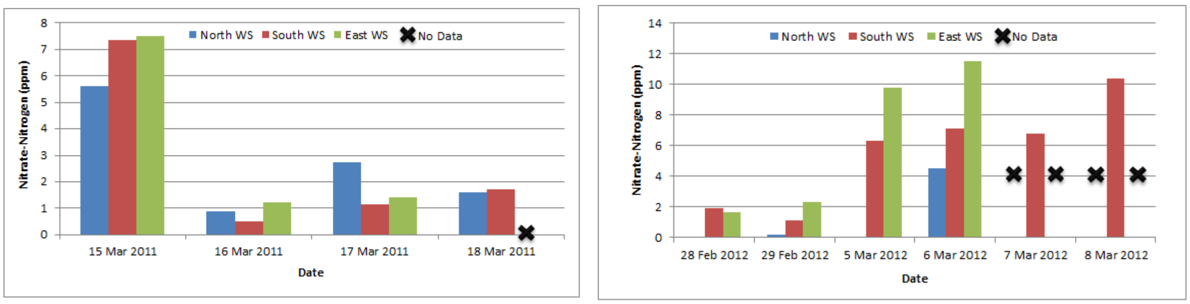

Figure 27. Nitrate-N concentrations in runoff from snow melt for 2011 and 2012. Note the different scales used for the Y axis. (Brandenburg, 2013)

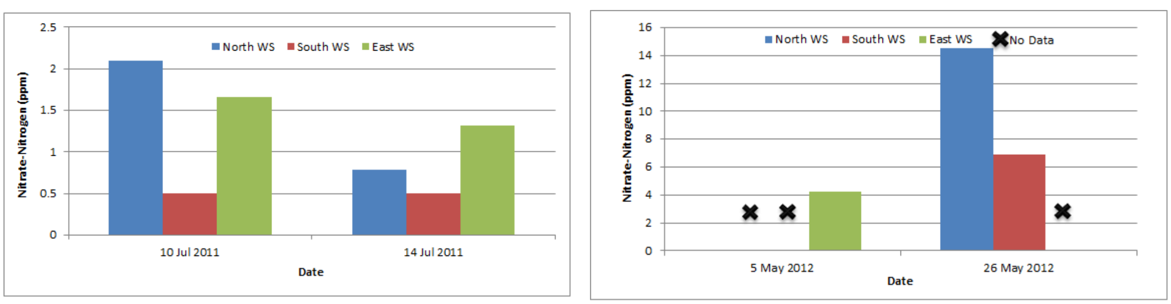

Figure 28. Nitrate-N concentrations in runoff from rainfall for 2011 and 2012. Note the different scales used for the Y axis. (Brandenburg, 2013)

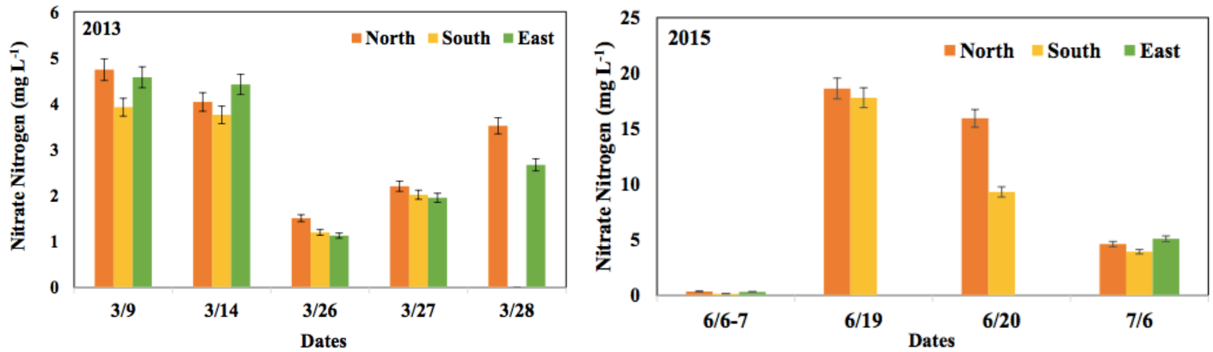

Figure 29. Nitrate-N concentrations (mg/L) in runoff by storm for all events for 2013 and 2015. Note the different scales used for the Y axis. (Singh, 2016)

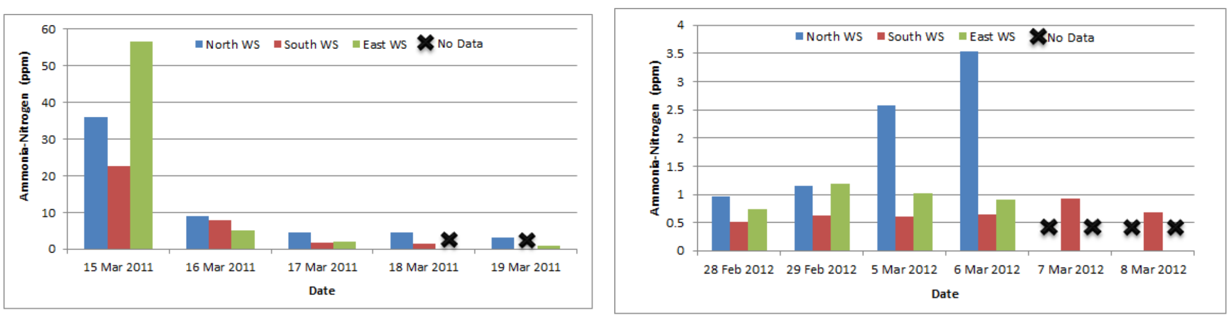

Figure 30. Ammonium-N concentrations in runoff from snow melt for 2011 and 2012. Note the different scales used for the Y axis. (Brandenburg, 2013)

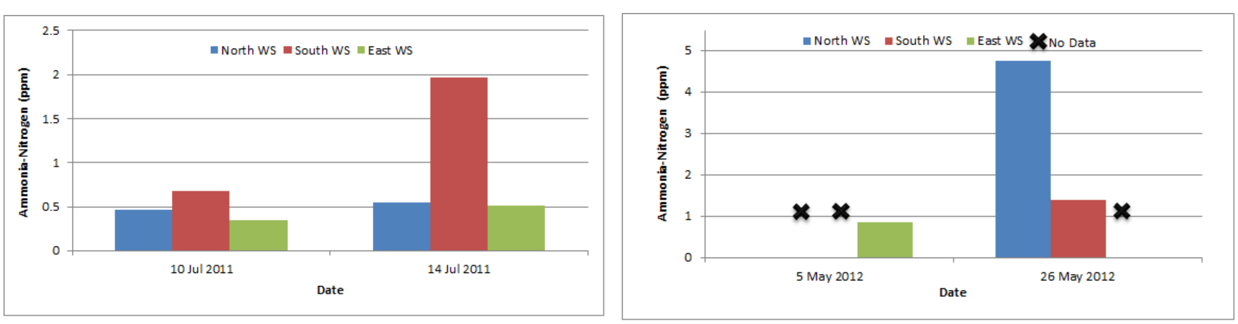

Figure 31. Ammonium-N concentrations in runoff from rainfall for 2011 and 2012. Note the different scales used for the Y axis. (Brandenburg, 2013)

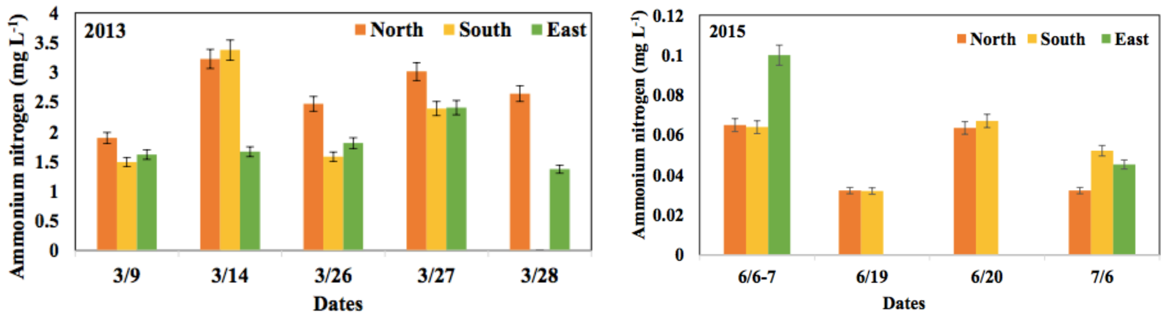

Figure 32. Ammonium-N concentrations (mg/L) in runoff by storm for all events for 2013 and 2015. Note the different scales used for the Y axis. (Singh, 2016)

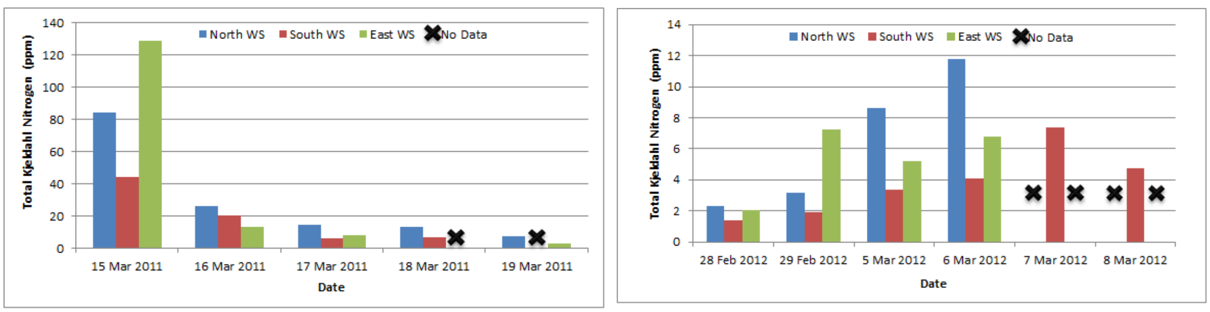

Figure 33. Total Kjeldahl N concentrations in runoff from snow melt for 2011 and 2012. Note the different scales used for the Y axis. (Brandenburg, 2013)

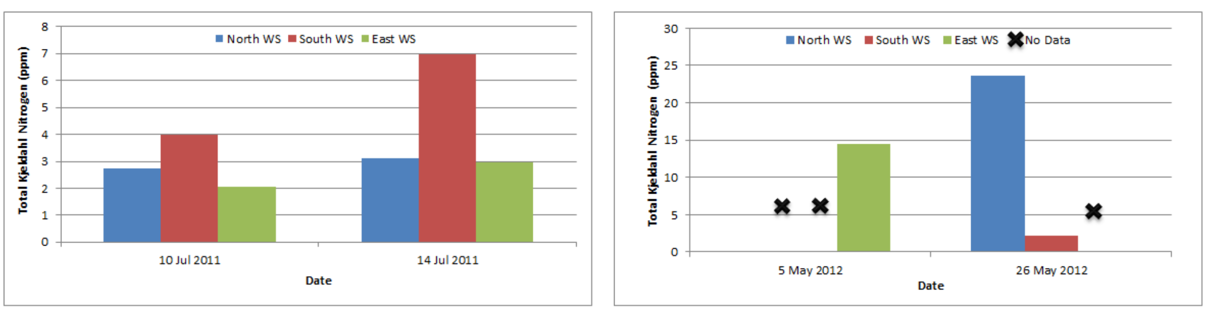

Figure 34. Total Kjeldahl N concentrations in runoff from rainfall for 2011 and 2012. Note the different scales used for the Y axis. (Brandenburg, 2013)

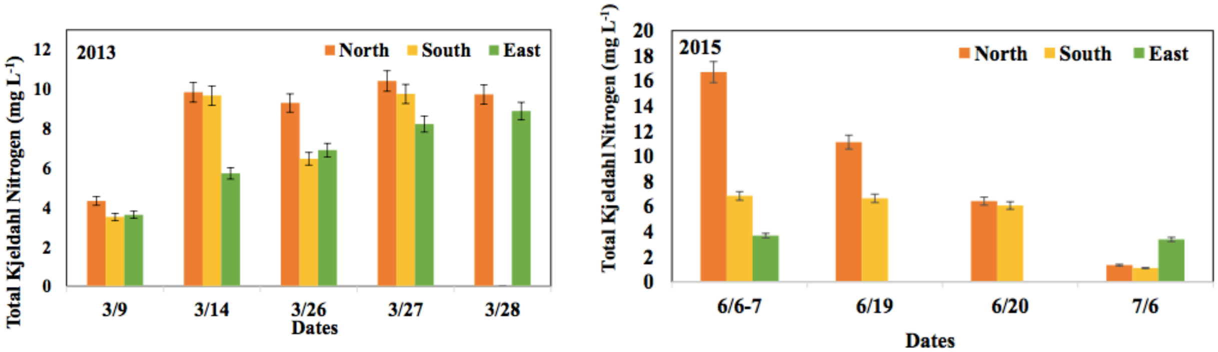

Figure 35. Total Kjeldahl N concentrations (mg/L) in runoff by storm for 2013 and 2015. Note the different scales used for the Y axis. (Singh, 2016)

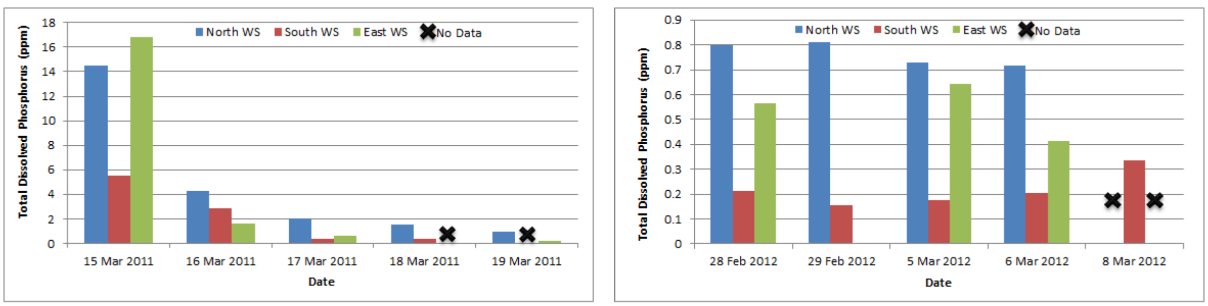

Figure 36. Total dissolved phosphorus concentrations in runoff from snow melt for 2011 and 2012. Note the different scales used for the Y axis. (Brandenburg, 2013)

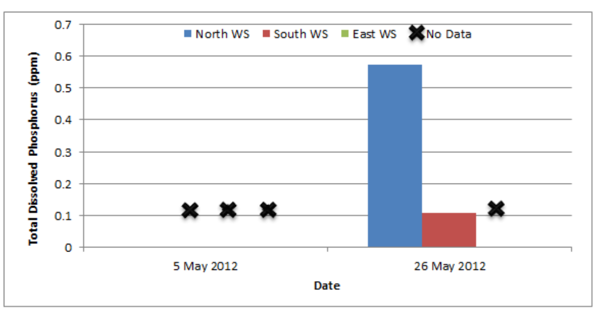

Figure 37. Total dissolved phosphorus concentrations in runoff from rainfall for 2012. There were no rainfall runoff samples analyzed for total phosphorus in 2011 because of sample bottle contamination. (Brandenburg, 2013)

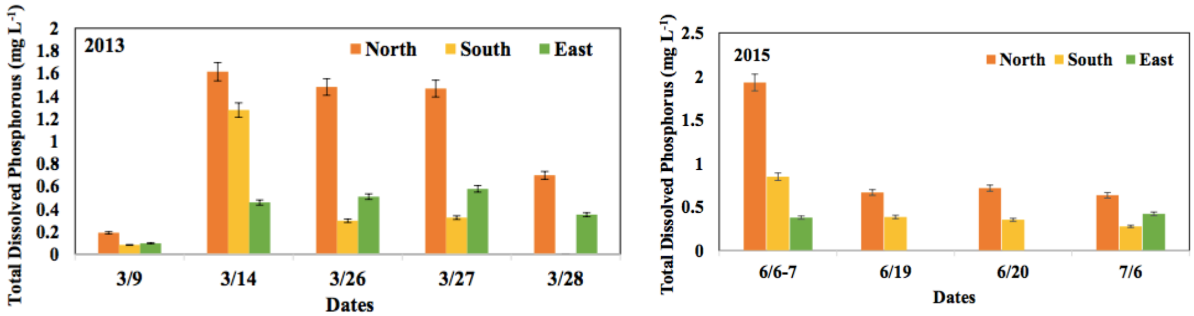

Figure 38. Total dissolved phosphorus concentrations (mg/L) in runoff by storm for 2013 and 2015. Note the different scales used for the Y axis. (Singh, 2016)

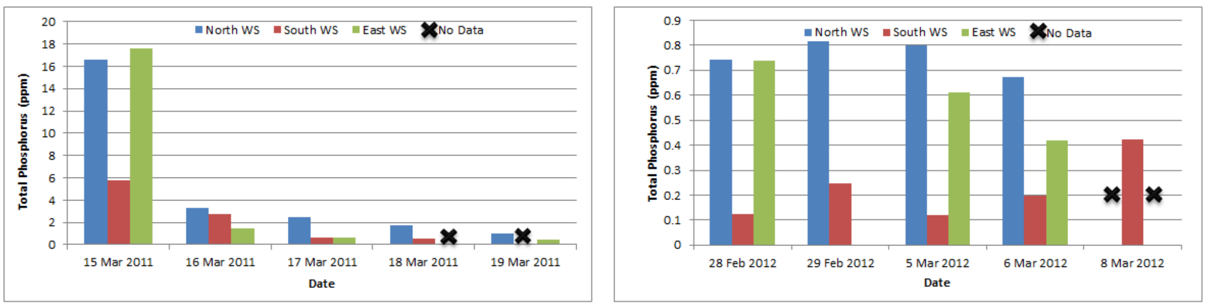

Figure 39. Total phosphorus concentrations in runoff from snow melt for 2011 and 2012. Note the different scales used for the Y axis. (Brandenburg, 2013)

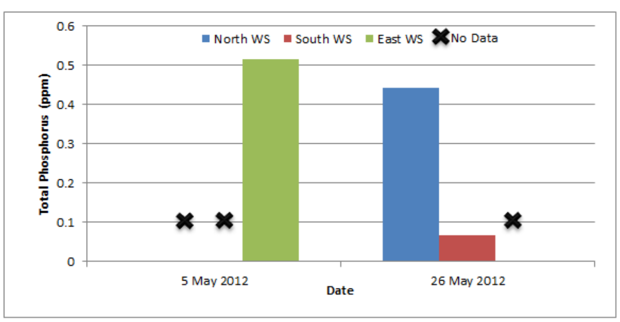

Figure 40. Total phosphorus concentrations in runoff from rainfall for 2012. There were no rainfall runoff samples analyzed for total phosphorus in 2011 because of sample bottle contamination. (Brandenburg, 2013)

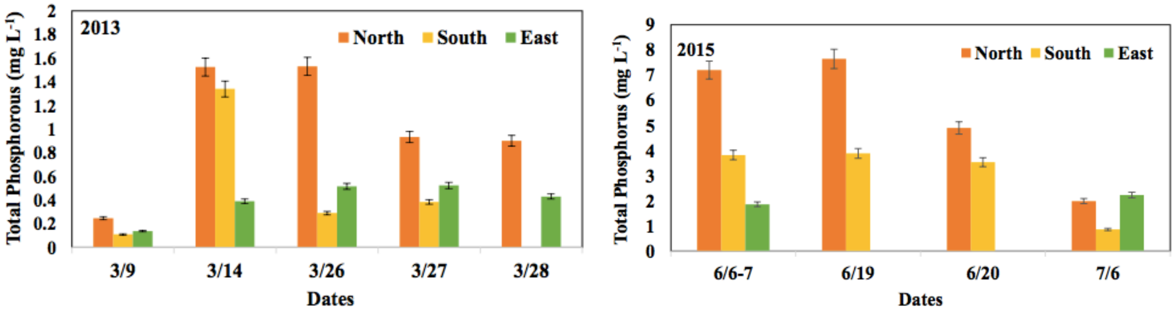

Figure 41. Total phosphorus concentrations (mg/L) in runoff by storm for 2013 and 2015. Note the different scales used for the Y axis. (Singh, 2016)

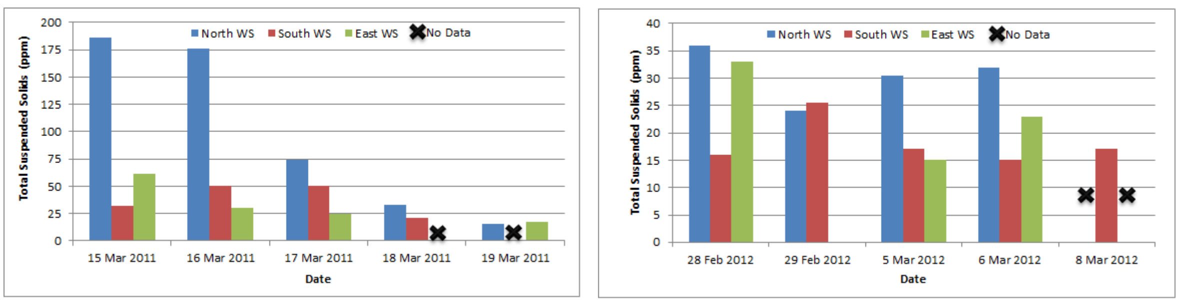

Figure 42.Total suspended solids concentrations in runoff from snow melt for 2011 and 2012. Note the different scales used for the Y axis. (Brandenburg, 2013)

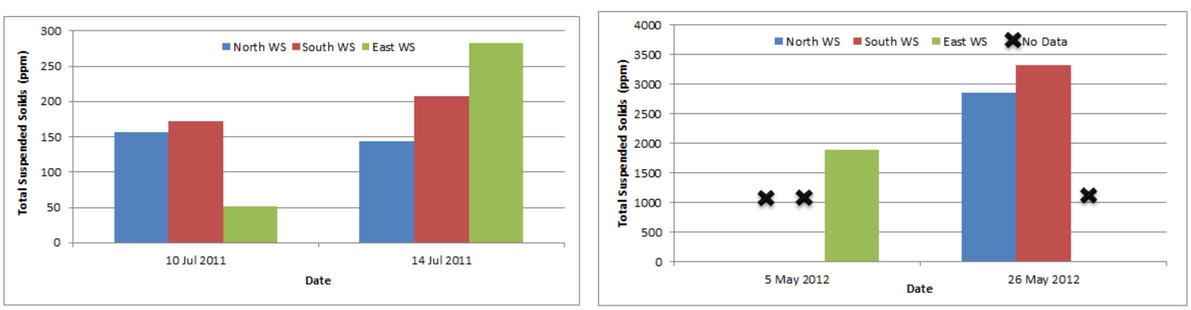

Figure 43.Total suspended solids concentrations in runoff from rainfall for 2011 and 2012. Note the different scales used for the Y axis. (Brandenburg, 2013)

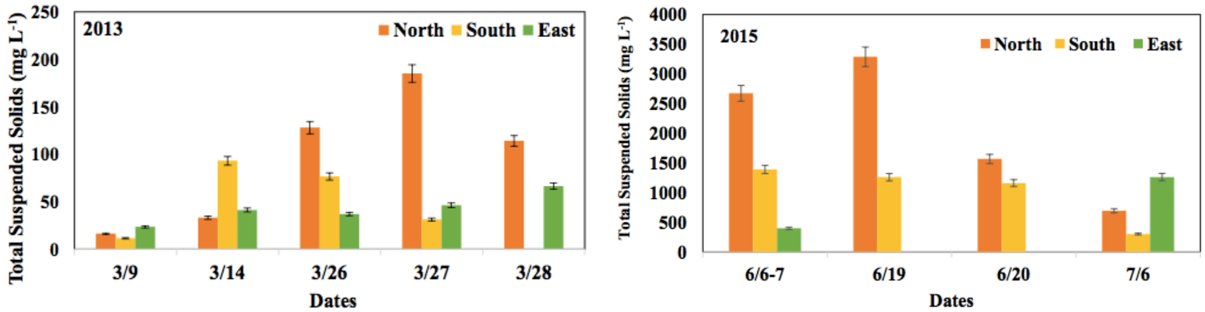

Figure 44. Total suspended solids concentrations (mg/L) in runoff by storm for 2013 and 2015. Note the different scales used for the Y axis. (Singh, 2016)

Infiltration rates:

The landscape positions treated with manure had higher infiltration rates (Table 8) compared to areas not receiving manure although the differences were not always statistically significant. The only statistically significant difference observed in the infiltration rates were in the north watershed, where north downslope (manured area) showed increased infiltration rate (14%) compared to the north upslope (non-manured) area. In the south watershed, infiltration rates in the south upslope (manured) were numerically higher but there was no statistical difference. This may be due to the manure application which helped in the improvement of infiltration rates. For the control watershed, no statistical significance was observed.

Soil phosphorus content changed little during the first two years of the study (until 2012). There is evidence of reduction of soil P in the east watershed and in the middle of the south watershed (Figures 45 and 46). Some phosphorus appears to be accumulating near the outlet of the north watershed. As of 2015, only the north watershed showed increased soil available P levels in the sub-watershed that received manure (Table 8). The east (control) watershed shows the lowest soil P levels. The upslope (manured) and downslope (non-manured) areas of the south watershed were not statistically different in their soil P levels, although the manured area (upslope) was numerically greater.

Table 8. Soil infiltration rates and soil available P levels measured at upslope and downslope landscape positions of North, South, and East (Control) Watersheds in 2015. (Singh, 2016)

Watershed	**Position**	**Infiltration rate, mm/hr**	**Available P, mg/kg**
North	Upslope (no manure)	144.4^{b}	2.5^{b}
	Downslope (manure)	165.3^{a}	3.8^{a}
South	Upslope (manure)	195.5^{a}	3.2^{a}
	Downslope (no manure)	181.1^{a}	2.3^{a}
East	Upslope (no manure)	139.6^{a}	0.5^{a}
	Downslope (no manure)	144.8^{a}	0.7^{a}

a, b: Similar letters indicate that there was no significant difference between landscape positions within the same watershed.

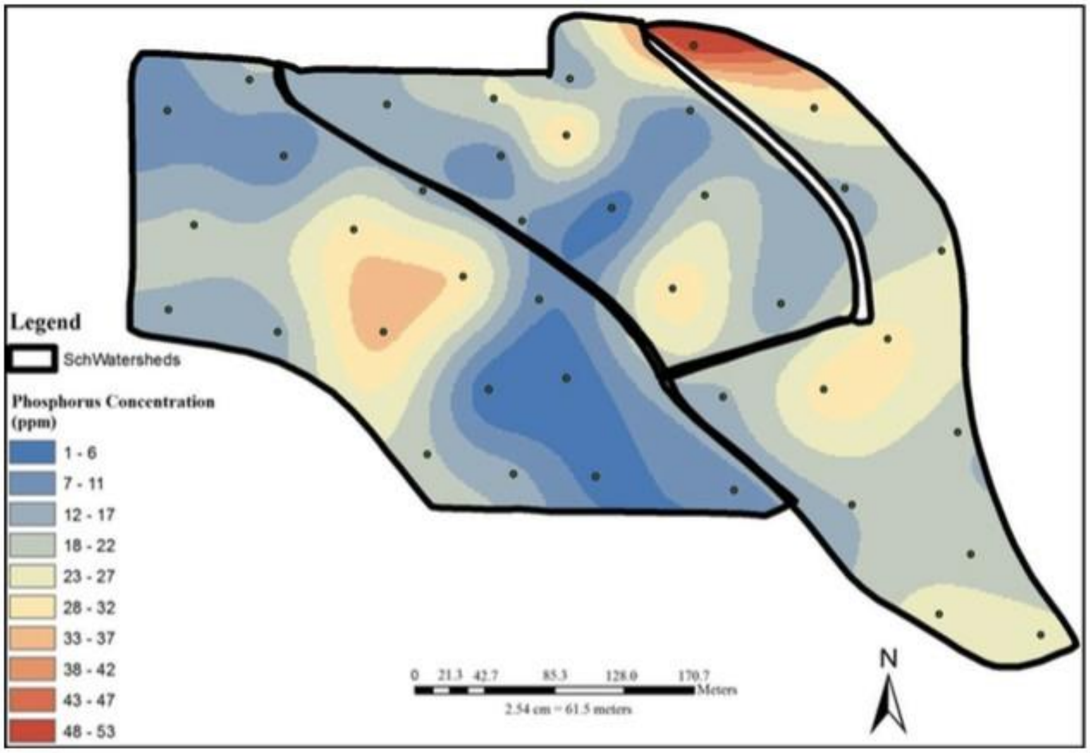

Figure 45. Distribution of soil phosphorus in 2008, prior to the imposition of treatments during this study. (Brandenburg, 2013)

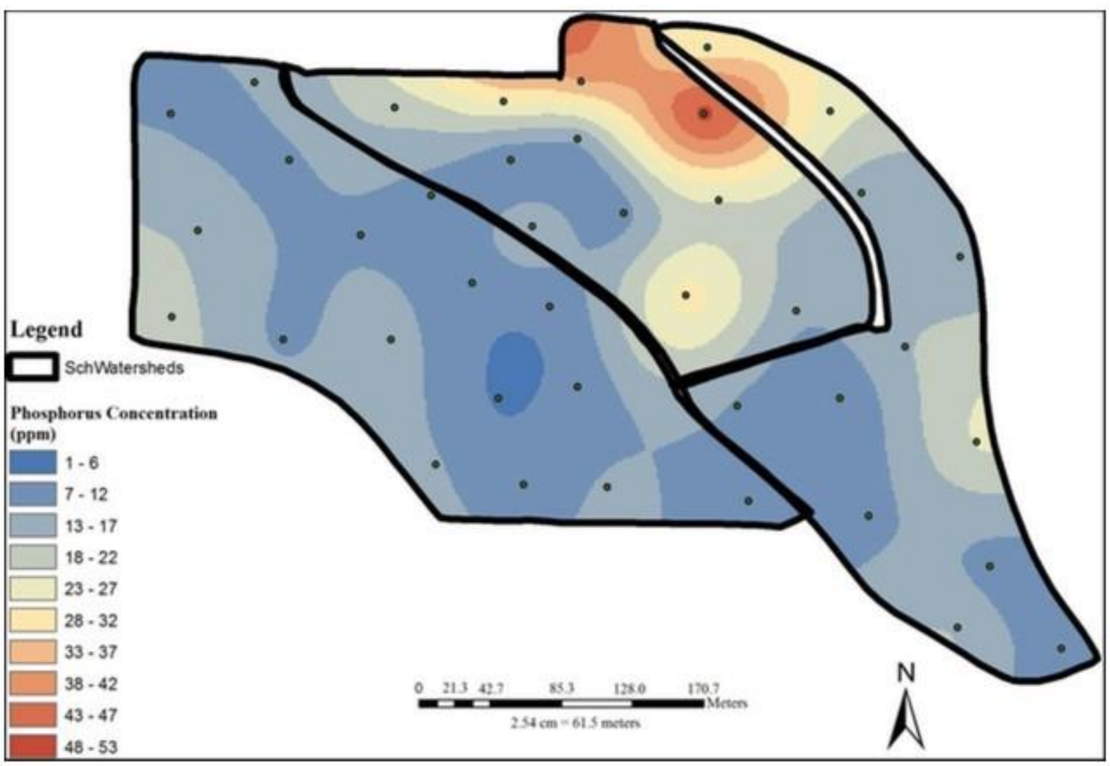

Figure 46. Distribution of soil phosphorus in 2012, after two years of treatments during this study. (Brandenburg, 2013)

Total nitrogen content in the soil was greater in areas that receive manure (Figure 47). For example, the entire east (control) watershed had lower concentrations of total N (Figure 33). Visually, both the north and south watersheds had greater concentrations in the sub-watershed that received the manure (the North Downslope and the South Upslope). These are qualitative evaluations for a single point in time (2015) and do not represent the absolute responses to the manure treatments.

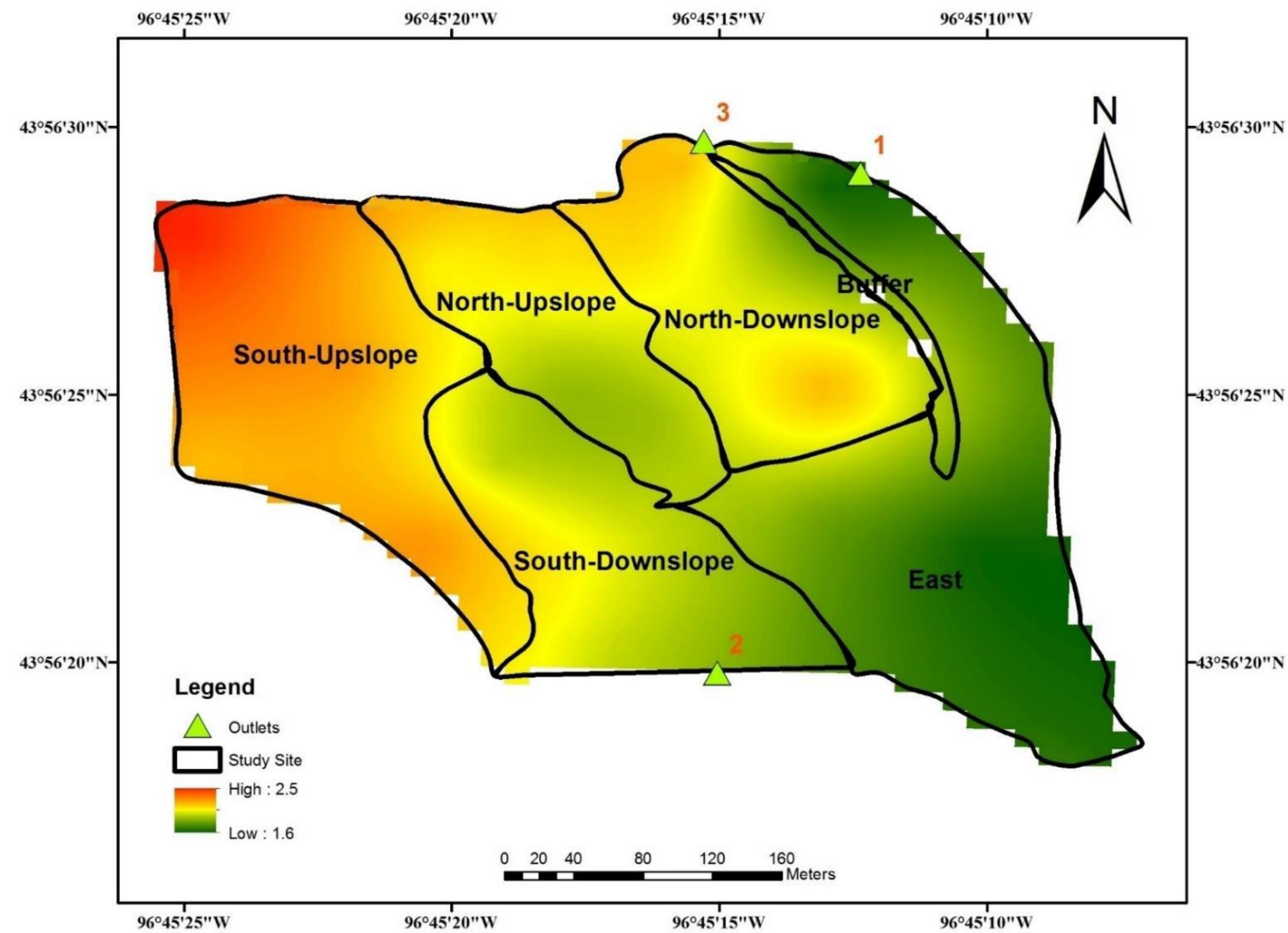

Figure 47. Spatial distribution of soil total nitrogen content (g/kg, or ppm) in 2015. (Singh, 2016)

6.0 Public involvement and coordination

The public involvement in this project was focused on annual meetings of a stakeholder committee to discuss results and receive guidance on upcoming operations. In addition, many presentations of results took place in various locations and via various media (oral presentations, poster presentation, discussion, etc.).

6.1 State agencies

The South Dakota Department of Environment and Natural Resources (DENR) has been integral to the performance of this project. Provision of the Section 319 funds have enabled this project to happen. In addition, a DENR representative has been a member of the stakeholder group.

6.2 Federal agencies

The Natural Resources Conservation Service (NRCS) was an integral part of this project. During this project, they updated their 590 (Nutrient Management) standard. The NRCS Nutrient Management standard was also used in the revision of the South Dakota General livestock permit that was completed during 2016.

6.3 Local governments, industry, environmental, and other groups, public at large

Many local, industry, and producer groups contributed to this project in many ways. The East Dakota Water Development District (EDWDD) provided cash match for the project. The EDWDD director participated in the stakeholder groups. The EDWDD board remained interested in the project and requested occasional project updates. The most recent update was provided to them 21 July 2016. The Moody County Conservation District remained interested in the project and provided guidance via the stakeholder group at the meetings. The South Dakota Farm Bureau (SDFB) provided cash match funds for project execution. Their Executive Director was actively involved during the first few years of the project. Late in the project, the Executive Director resigned but remained active in the project. The new Executive Director then became active in the stakeholder group so we had two active members from SDFB. Finally, the South Dakota Cattlemen's Association (SDCA) and the Cattle Feeders Council (CFC) have been instrumental in the performance of this project. The CFC provided cash match for project operating expenses and they provided in-kind match for many tasks, including managing the experiment field.

6.4 Other sources of funds

Matching funds in the amount of $68,358.88 were used as part of the funding for this project (Table 9).

Cash matching funds were received from three groups in South Dakota. They were the East Dakota Water Development District (EDWDD), the Cattle Feeders Council, and South Dakota Farm Bureau (SDFB). Each of these groups committed $9000. The funds were used to pay for water sample analyses, manure sample analyses, manure application, manure purchase, and other direct operating costs. Due to investigator error, the Cattle Feeders Council provided $8862 in matching funds instead of their full $9000 commitment. The EDWDD and SDFB commitments were paid in full. Thus, the total cash match paid from the three groups was $26,862.

In-kind match in the total of $10,193.83 was received from the Cattle Feeders Council. The in-kind match was in the form of producer time spent to help or manage or assist with the project and perform field operations in support of the project.

Salaries and benefits of SDSU investigators were used as matching funds for the project. Totals of $20881.80 in salaries and $4036.85 in benefits were identified for Dr Jeppe Kjaersgaard and Dr Dennis Todey. Finally, a total of $6109.85 in unrecovered indirect costs was identified by SDSU as matching funds for this project. Thus, the matching funds total from SDSU was $31,028.50.

Table 9. Matching funds spent on this project.

Source	Amount spent	Cash or In-kind	Purpose
SD Farm Bureau	$9274.55	Cash	Sample analysis, other operating costs
East Dakota Water Development District	$9000.00	Cash	Sample analysis, other operating costs
Cattle Feeders Council	$8862.00	Cash	Sample analysis, other operating costs
SDSU	$24918.65	Cash	Investigator salary and benefits
SDSU	$6109.85	Cash	Unrecovered indirect costs
Cattle Feeders Council	$10193.83	In-kind	Landowner time and management of the research site
Total	$68358.88		

7.0 Aspects of the project that did not work well

Any project that relies on runoff generated by rainfall is inherently risky because a robust data set is not guaranteed. Some years provide more runoff events than others. More storms and runoff events would have been helpful to help strengthen our data set. It is hoped that continuing this project for another year or two will result in a more robust data set.

The goal of this project was to provide and test a potential BMP for winter manure application. But monitoring water movement during times of freezing temperatures presents many unique challenges (Figures 48 and 49). Various practices were employed to monitor and sample runoff during times of freezing temperatures. Early in the project, samples were collected manually, requiring that somebody visit the site physically during runoff events. This resulted in some sample collection but many events and samples were missed. A magnetic heater was employed for one year and helped to maintain flows during times of marginally freezing temperatures. Later, automatic samplers were installed that were triggered when flow occurred. However, the samplers themselves required protection from freezing to prevent damage to the sampling pump and tubing.

Figure 48. Ice and snow present challenges to monitoring runoff.

Figure 49. The same flume with the outlet free of obstruction.

Freezing temperatures also provided challenges to applying the manure during a couple of years. When manure was piled to prepare for application to the treated watersheds, it would freeze and was difficult to load and apply. Late in the project, a local feedlot was identified with a monoslope barn. Removal of manure from the barn followed by immediate application of the manure to the treated watersheds proved to be a successful strategy. And the owner of the monoslope barn was happy to work with the project and provided assistance when sampling and provided labor and equipment (payloader) when the manure was applied to the watersheds.

Finally, the series of principal investigators and lack of coordination by the final principal investigator resulted in the lack of sample collection for bacterial analysis. The earlier investigators addressed the objective and one set of samples was collected but the objective not addressed with sampling late in the project.

8.0 Future activity recommendations

Another year or two of good runoff data probably will provide a much more robust statistical analysis of the effect of manure application to the top of a watershed compared to application to the bottom of the watershed. Although a reasonable analysis was performed with the available data, the data set was not extensive and a larger data set would inspire more confidence in the statistical results.

This project is continuing. Funding has been provided by the SD Farm Bureau and the SD Cattle Feeders Council for sample analysis and some direct operating costs such as travel and supplies. Graduate student labor costs are being borne by a companion national risk management project that will use the data from the site in the national risk analysis.

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