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Managing Water Quantity and Quality with Subsurface Drainage in Eastern South Dakota

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MANAGING WATER QUANTITY AND QUALITY WITH SUBSURFACE DRAINAGE IN EASTERN SOUTH DAKOTA

BY

MORGHAN HURST

A thesis submitted in partial fulfillment of the requirements for the

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2022

THESIS ACCEPTANCE PAGE

Morghan Hurst

This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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This thesis is dedicated to my family and friends. Thank you for encouraging me through all the demanding requirements of life.

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CONTENTS

ABBREVIATIONS

SSD	subsurface tile drainage
FD	free subsurface tile drainage
CD	controlled tile drainage
DP	drainage-pump controlled station
$NO_3^- - N$	nitrate-nitrogen
EPA	United States Environmental Protection Agency
USDA	Unites States Department of Agriculture
NASS	National Agricultural Statistics Service
RMA	Risk Management Agency
MPCI	Multiple Peril Crop Insurance
ET	evapotranspiration
WTD	water table depth
DDR	drainage design rate
DI	drainage intensity

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ABSTRACT

MANAGING WATER QUANITY AND QUALITY WITH SUBSURFACE DRAINAGE IN EASTERN SOUTH DAKOTA

MORGHAN HURST

2022

Moisture extremes (excess and deficit) impact crop loss and water quality. Due to excessively wet springs and dry summers, crop damage can occur within the same county or field within the same year. To determine the magnitude of this problem in eastern South Dakota, indemnified crop insurance data for drought and excessive moisture claims were assessed for the years 1991-2020 for the occurrence of both excess moisture and drought in four counties in eastern South Dakota. Results show that there is greater than a 70% chance of the moisture extremes happening in the same year, making subsurface drainage, controlled drainage, and irrigation viable options for mitigating the damages. To determine the number of times controlled drainage could have had an impact on soil moisture, a DRAINMOD simulation was analyzed for the years 1950-2012. The results showed on dry and average years, when controlled drainage has potential for the greatest impact on soil moisture, 20 of 47 years had potential to retain soil moisture in the soil profile. In addition to challenges related to water quantity, water quality can be impacted by tile drainage systems. To assess the amount of nitrate-nitrogen entering surface water, 23 tile outlets were monitored weekly for nitrate concentration and flow depth in the tile outlet pipe. The results showed of 352 samples taken (mean 12.4 mg L^{-1} nitrate-N), 195 samples were above and 157 were below the drinking water standard of 10 mg L^{-1}, with the majority of samples taken at a depth less than 0.15 of the tile diameter, indicating a low flow year.

1. GENERAL INTRODUCTION

1.1. Background

Eastern South Dakota has over 14.6 million acres used for row crop farming of corn, soybean, and wheat (USDA NASS, 2017). To deal with excess moisture, especially during the spring, subsurface drainage (SSD) is installed to lower the water table allowing for aerated soil and sufficient root growth. By lowering the water table, conventional SSD allows for better planting and harvest conditions as well as improved root development. While there are average values available in various parts of the Midwest, no comprehensive water quality data exists for eastern South Dakota, which has different climate, soil, and growing conditions than other parts of the Midwest.

Controlled drainage (CD) uses a control structure to hold water in the field when drainage is not needed. CD improves downstream water quality by reducing tile outflow and downstream nutrient loading (Helmers et al., 2022). CD is usually activated prior to planting/harvesting to dry the soil enough for improved trafficability and optimal growing conditions for seedlings (Almen, 2020).

1.2. Objectives

The overall goal of this study is to determine the impact that subsurface drainage has on water quality and opportunities for controlled drainage to improve crop resilience. The specific objectives of this study are:

1. Use historic crop insurance indemnity data to identify impacts of deficit and excess moisture conditions to crop loss in Brookings, Clay, Codington, and Minnehaha counties in Eastern South Dakota,

2. Determine opportunities for CD at the field scale using outputs from a DRAINMOD (Drainage Model) simulation, and

3. Establish a baseline of nitrate-nitrogen concentration in tile drainage outflow in eastern South Dakota and determine the impact of various agricultural management variables.

1.3. Organization

Chapter one is an introduction to subsurface tile drainage (SSD). Chapter two is a review of literature showing previous research that is available. Chapter three is an interpretation of crop insurance data to expose deficit and excess moisture conditions in the field. Chapter four determines the efficiency of installing controlled drainage (CD) in agricultural fields using a DRAINMOD simulation with parameters set for Beresford in eastern South Dakota. Chapter five is looking at nitrate-nitrogen ($NO_3^- - N$) water analysis data from twenty-three different SSD outlets sites with different farming practices across eastern South Dakota. Chapter six explains the conclusion from the thesis.

2. LITERATURE REVIEW

2.1. Eastern South Dakota

Eastern South Dakota is a gently rolling landscape with a semi-humid climate that receives around 64 cm (25 inches) of precipitation annually (Karki, 2017). It consists of lakes and fertile soils created from periods of glaciation with silty textures, high base saturation, and mollisols. Farmers use these fertile soils to cultivate row crops such as corn (*Zea mays*), soybeans (*Glycine max*), and wheat (*Triticum aestivum*). As well as being fertile, these soils contain elevated levels of clay generally have a high-water table causing soil moisture conditions to exceed field capacity and depend on surface storage or surface runoff. With these cash crops being planted, management decisions, such as subsurface drainage to control excess moisture, have been implemented to increase the yield of these row crops.

2.2. Subsurface Drainage

Subsurface tile drainage (SSD) was first introduced to the United States in the 1830’s to Seneca County, New York by John Johnston, “the father of tile drainage in America” to help remove excess water and raise a high crop yield of wheat (Hayes, 2021). Since this time, SSD has evolved from hand digging clay tile into the lowest part of the field to mechanically trenching plastic perforated pipe at a designed size, space, and depth while following the landscape of the field to allow gravity to force excess water to flow to a specified outlet, usually at the lowest part of the field. The design of installed pipe allows factors such as the amount, timing, and location of the water to be known before installation begins.

Researchers have studied SSD to figure out the effects it has on the overall water balance of an agricultural field. With water being one of the greatest components of agricultural systems, being able to control it allows farmers to operate with less hazard through planting, harvesting and field maintenance work and reduces the risk of overall impaired yield. SSD systems allow for earlier planting, increased soil aeration, and improved field conditions for greater crop yields by allowing the corn belt region of the United States to drain highly productive cropland (Schilling and Helmers, 2008). An increase of planted acres is another result of SSD. With less over saturated soil, farmers are able to get closer to wetlands and plant shallow potholes in the middle of fields. Often, these soils are nutrient rich from an excess of topsoil erosion being deposited over them, allowing excellent conditions for crops to achieve high yields.

Research has also been completed on the surrounding effects on topography, wildlife, and human residents downstream. Tile drains reduce surface runoff by increasing rainfall infiltration, depending on soil type, storm characteristic, and topography, which can increase or decrease peak flow (Schilling and Helmers, 2008). Increasing the infiltration of water is going to allow water to enter the soil profile and not cause erosion by surface runoff during storms. But this also allows for more water to run through the tile drainage pipe and bypass filtration through the natural riparian zone, or the zone where biological processing often reduces transport of contaminants such as nitrate-nitrogen ($NO_3^- - N$) (Schilling and Helmers, 2008). By being able to pass the riparian zone, $NO_3^- - N$ is allowed to pollute natural water ways and fresh drinking water sources. This is starting to raise concern with researchers around the world as to whether edge of field practices such as controlled drainage, buffer strips, or bioreactors should be implemented with SSD to keep the levels of $NO_3^- - N$ below 10 mg L^{-1} (the drinking water standard for humans).

The economics of SSD has also been the focus of researchers. The cost of trenching in perforated pipe across a field has different expenses associated with it. Even though the input costs can be high, the advantages gained are often greater. An increase of acres planted, an increase in yield or tonnage, and fewer claims to insurance companies increasing the actual production history (APH) for future claims. The value of the land with the installed tile is also worth more when the farmer is ready to sell the land. All these benefits make SSD a potentially economically beneficial practice for farmers to install in their fields.

2.3. DRAINMOD Hydrological Modeling

Hydrologic models are used to simulate many different hydrologic scenarios in a short period of time. They help to understand water on a field scale basis with fixed parameters chosen for the simulation. DRAINMOD is a field-scale, process-based, distributed simulation model originally developed to provide a means of quantifying, on a continuous basis, the performance of multi-component drainage and related water management systems (Skaggs et al, 2012).

DRAINMOD is a widely used field scale hydrological model for simulating hydrology in poorly drained soils (Karki, 2017). Parameters of the soil and weather patterns are used as inputs for the simulation. Results of DRAINMOD are primarily dictated by soil hydraulic properties and evapotranspiration (ET) (Karki, 2017). The soil hydraulic properties used in the model are saturated hydraulic conductivity, soil water characteristics curve, drainable porosity, upward flux, and Green-Ampt parameters (Skaggs et al., 2012).

DRAINMOD calculates surface and subsurface water balances for a thin column of soil that has a unit surface area which extends from the ground surface to the subsurface impermeable layer and is located midway between two subsurface drains (Karki, 2017). The simulation is able to give results of rainfall, infiltration, ET, drainage, total runoff, water table depth (WTD), dry zone, surface storage, and soil drainage. Upon knowing these results, trafficability, relative yield, and wetland hydrology are able to be better understood.

2.4. Crop Insurance

Crop insurance allows farmers to navigate part of the risk of planting certain row crops. There are two different types of crop insurance that the American farmer can buy, Crop-Hail insurance and Federal crop insurance. Crop-Hail insurance is only offered through private insurers and must be bought at least 24 (some insurers have different time intervals) hours before the damage occurs. It will cover any damage that is done by hail and wind from a storm. “In 2000, Congress passed the Agricultural Risk Protection Act, which provided further subsidies to encourage federal crop insurance purchases” (Glauber, 2004). Federal crop insurance coverage, or Multiple Peril Crop Insurance (MPCI), must be purchased prior to planting. It covers loss of crop yields due to natural causes such as drought, excessive moisture, freezing, and disease (NCIS, 2021). The crop insurance program boasts an “80% participation rate with over 215 million acres enrolled and a total liability estimated in excess of $46 billion for 2004” (Glauber, 2004).

After purchasing crop insurance, certain rules must be followed to be able to claim any damage. First, the farmer must report the crop, number of acres planted, type of crop, all acres not able to be planted, and date of planting. There are also dates that must be followed. These dates will change by crop and area being planted/harvested. An example of such dates is the planting date. A crop needs to be planted before a certain date, they change per region and crop, for the insurance to be valid for the acres that are planted. If there is a complete loss of acres, meaning that no acres were able to be planted, the farmer will be able to apply for prevented planting payment (PP). This payout will cover the cost of the acres with the current market rate for whatever crop was planned for those acres.

When there is crop damage that is reported to the insurer, the damage is verified by a crop insurance adjustor. This individual will go out to the site of the damage and record the amount of acres, as well as the cause of the damage. They will report this damage to the federal government. In 2020, there were 16.4 million acres (about the area of South Carolina) that were covered in South Dakota alone, with many of these acres planted to corn, soybeans, and wheat. Crop insurers paid $498.4 million to cover crop losses, and farmers paid $175.1 million in premiums (NCIS, 2021).

3. QUANTIFYING CROP DAMAGE FROM DROUGHT AND EXCESS MOISTURE IN EASTERN SOUTH DAKOTA

3.1. Abstract

Moisture extremes, too much or too little, cause significant crop loss throughout the US. In 2020, farmers spent just over $1 billion on Crop-Hail insurance to protect $36 billion worth of crops, and 1.1 million polices were sold protecting more than 130 different crops covering almost 480 million acres, with an insured value of $114 billion (NCIS, 2021). This study examined how frequently both moisture extremes, excess and drought, occurred in the same year in the same county. Excess moisture can be addressed through tile drainage and improved soil health while moisture deficit can be addressed through irrigation, controlled drainage, or improved water holding capacity. Twenty-nine years of crop insurance indemnity data were analyzed for four eastern South Dakota counties to determine the magnitude of impact of moisture extremes compared to total planted acres. The results of this study show that in a majority of years, either excess or limited moisture accounts for substantial crop loss. For corn and soybeans, out of 120 county-years, only 31 county-years and 20 county-years respectively, did not have crop loss from either excess moisture or drought. For corn and soybeans, out of 120 county-years, 89 county-years and 100 county-years respectively, recorded crop loss due to both extremes within the same county and year. Moisture extremes caused damage to row crops demonstrating the need for structural practices such as subsurface drainage, controlled drainage, and irrigation, to mitigate crop loss.

3.2. Introduction

Crop damage happens every year in South Dakota for a multitude of reasons. Two of the major causes of crop damage in eastern South Dakota are drought, too little moisture, and excess moisture. Crop insurance agencies sell insurance to help farmers with mitigating the risk of losing acres to one of these extremes. Excess moisture claims, often called preventative planting acre claims, occur in years when the spring planting season receives an excessive amount of moisture and planting is not possible. If claimed and approved, the insurer will pay the amounts specified in the protection plan that is effective for those acres. For a farmer to claim crop loss due to drought, according to Risk Management Agency (RMA) guidelines, "a producer using 'best practices' in planting, maintaining, and harvesting a crop" can claim a loss if drought conditions continue through the season (Haugen, 2021). In other words, the loss must be a result of drought and not poor management. If the insurer accepts the claim, a percentage of planting expenses would be paid back.

Due to the imbalance between precipitation and evapotranspiration timing, fields could have excess water in the spring and insufficient moisture in the summer of a given year. With excessive moisture and drought potentially happening in the same year, steps can be taken to mitigate the effects of either excessive moisture, insufficient moisture, or both. One such method is to install subsurface drainage systems (SSD). These drainage systems allow gravity to drain excess moisture from agricultural fields in times of a surplus of precipitation and snow melt. Another system that can be installed is control drainage systems (CD). These systems allow water to either be drained when saturated conditions are present or preserved in the soil profile by using a water control structure to raise the depth of the tile outlet (Chighladze et al., 2021). This allows producers to choose whether field conditions are too moist or dry during crucial times such as planting and harvesting.

To assess the frequency and magnitude of moisture extremes on crop damage this study used indemnified insurance data from the United States Department of Agriculture Risk Management Agency (RMA). Understanding this macro scale picture helps farmers and policy makers implement practices to increase resilience to extreme climate variability.

3.3. Materials and Methods

3.3.1. Data Acquisition

The United States Department of Agriculture Risk Management Agency (RMA) records crop insurance and crop loss information for every indemnified claim for every county in the US. Data for 30 variables are included in the database, of which six were used for this analysis: year, state, county, commodity, cause of loss, and number of acres per claim for the years (USDA RMA, 2022). The United States Department of Agriculture National Agriculture Statistics Service (NASS) records animals and products, crops, and economics for every county the US. Data for 12 variables are included in the database, of which the following were used for this analysis: year, state, county, commodity, and the number of acres planted per commodity (USDA NASS, 2017).

3.3.2. Data Analysis

Four eastern South Dakota counties were selected for analysis: Brookings, Clay, Codington, and Minnehaha (average annual precipitation 26, 27, 24, and 27 inches respectively) (Figure 3.1.). These counties were selected to represent a range of climate conditions within eastern South Dakota, where much of the corn and soybean production occurs within South Dakota. While several crops are included in the cause of loss database, this analysis was performed on the two major row crops, corn and soybeans. To quantify relative magnitude of loss, the total acres indemnified, or acre claims paid for drought or excessive wetness, were used as well as the total acres planted to those crops. Data cleaning, sorting, and analysis was performed in Microsoft Excel. Data were analyzed for the number of years drought occurred, number of years excess moisture occurred, number of claim acres paid, and the South Dakota County in which these occurred.

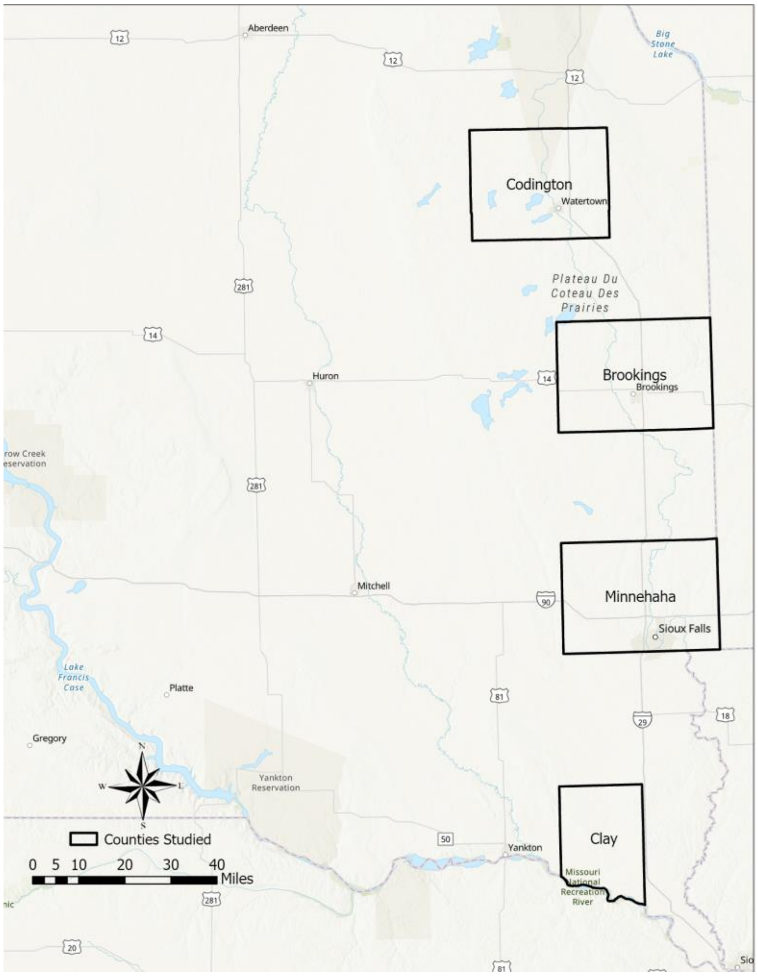


Figure 3.1. The four counties, Brookings, Clay, Codington, and Minnehaha, outlined in black.

The number of acres per county-year that were affected by both conditions was considered. The ratio of total number of indemnified drought acres to total number of indemnified wet acres was calculated.

$$\frac{Total\ amount\ of\ Indemnified\ Drought\ Acres}{Total\ amount\ of\ Indemnified\ Wet\ Acres} = Ratio \qquad (1)$$

This ratio, if close to 1.5, would tell us there are two-thirds as many dry acres as wet acres, and if close to 0.5 there are twice as many wet acres as there are dry acres. This ratio was then filtered to include years with a ratio between the interval of 0.5 and 1.5. The interval of 0.5 and 1.5 was the bounds set to include average moisture years that exclude the outliers of predominantly wet or dry years. If inside these bounds, CD would have had potential to reduce crop loss in the county since both moisture extremes occurred in the same county-year (Figure 3.2.). If the number were zero or approaching infinity, there were no indemnified drought acres or no indemnified wet acres, respectively, in the same county-year.

In addition to the number of acres per county-year that were affected by both extremes, the total amount of indemnified wet acres was compared to the total amount of planted acres per county-year as well as indemnified drought acres compared to total planted acres per county-year for each commodity. To calculate this, the total amount of indemnified drought insurance claims acres by the total number of acres planted per commodity per year by county

$$\frac{Total\ Number\ of\ Indemnified\ Drought\ Acres}{Total\ Number\ of\ Acres\ per\ Commodity\ Per\ Year} * 100 = \% \qquad (2)$$

and the total amount of indemnified excessive wetness insurance claim acres by the total number of acres planted per commodity per year by county was calculated.

$$\frac{Total\ Number\ of\ Indemnified\ Excessive\ Wetness\ Acres}{Total\ Number\ of\ Acres\ per\ Commodity\ Per\ Year} * 100 = \% \qquad (3)$$

3.4. Results and Discussion

3.4.1. Results

Historical insurance data from the RMA website was analyzed for drought and excessive wetness insurance claims for a 30-year period (1991-2020). This data was analyzed to show how often the two extreme moisture conditions occurred in the same growing year (Table 3.1). Of the 120 years examined (30 years for four counties), for the commodity corn, 89 county-years had both excessive wetness and drought indemnified insurance claims, and 31 years did not. Of these 31 years without either extreme, 3 years had no excessive moisture claims and 28 years had no drought insurance claims. All years had indemnified claims from at least one moisture extreme. For the commodity soybeans, 100 years had both excessive wetness and drought indemnified insurance claims, and 20 years did not. Of these 20 years, all 20 years had no drought insurance claims.

Table 3.1. The number of years both, no drought indemnified acres, and no excess moisture indemnified acres were recorded in the South Dakota Counties of Brookings, Clay, Codington, and Minnehaha.

Corn		**Brookings**	**Clay**	**Codington**	**Minnehaha**	**Total**
	Both	22	21	23	23	89
	No Drought	8	8	6	6	28
	No Excess Moisture	0	1	1	1	3
Soybean						
	Both	23	26	27	24	100
	No Drought	7	4	3	6	20
	No Excess Moisture	**0**	**0**	**0**	**0**	**0**

Using data from the RMA website historical indemnified insurance data was analyzed for drought and excessive wetness insurance claims for a 30-year period (1991-2020) (Table 3.2). This data was analyzed to show the magnitude of the problem across four different counties, Brookings, Clay, Codington, and Minnehaha (Figure 3.1 and Figure 3.2). Of the 120 county-years, the greatest percentage of indemnified drought acre claims paid was for the commodity soybean at 74% of the total number of acres planted in Clay County for the year 2012. Of the 120 county-years, the greatest percentage of indemnified excessive wetness acre claims paid was for the commodity corn at 62% of the total number of acres planted in Clay County for the year 1995. All counties recorded years with zero indemnified drought acre claims, but only Clay and Minnehaha counties recorded years with no indemnified excessive moisture for the commodity soybeans. On average, only one county had greater than 10% of the total acres planted turned into indemnified acres claims.

Table 3.2. The average, minimum, and maximum percentages of total indemnified acres (drought/excessive moisture) by total planted acres for a 30-year span (1991-2020).

		Average (SB)	Minimum (SB)	Maximum (SB)	Average (Corn)	Minimum (Corn)	Maximum (Corn)
Dry							
	Brookings	1.86%	0.00%	12.03%	1.76%	0.00%	14.17%
	Clay	5.68%	0.00%	74.03%	6.19%	0.00%	65.98%
	Codington	4.71%	0.00%	22.77%	4.48%	0.00%	33.24%
	Minnehaha	2.23%	0.00%	32.40%	2.90%	0.00%	54.83%
Wet							
	Brookings	3.79%	0.26%	22.94%	4.99%	0.10%	37.28%
	Clay	9.77%	0.14%	47.99%	10.82%	0.00%	62.09%
	Codington	5.48%	0.13%	26.64%	7.20%	0.22%	20.63%
	Minnehaha	3.18%	0.03%	28.26%	2.60%	0.00%	14.61%

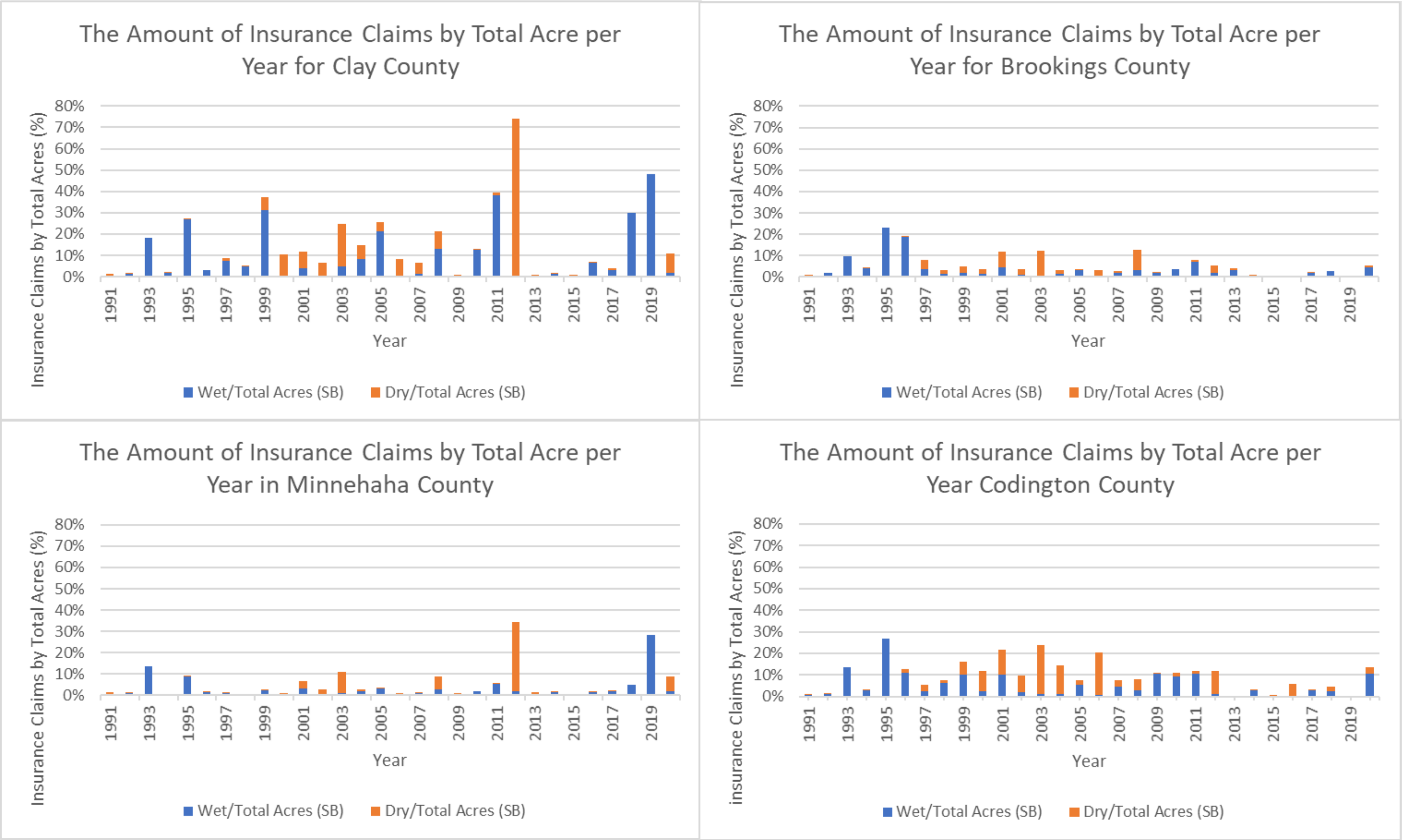
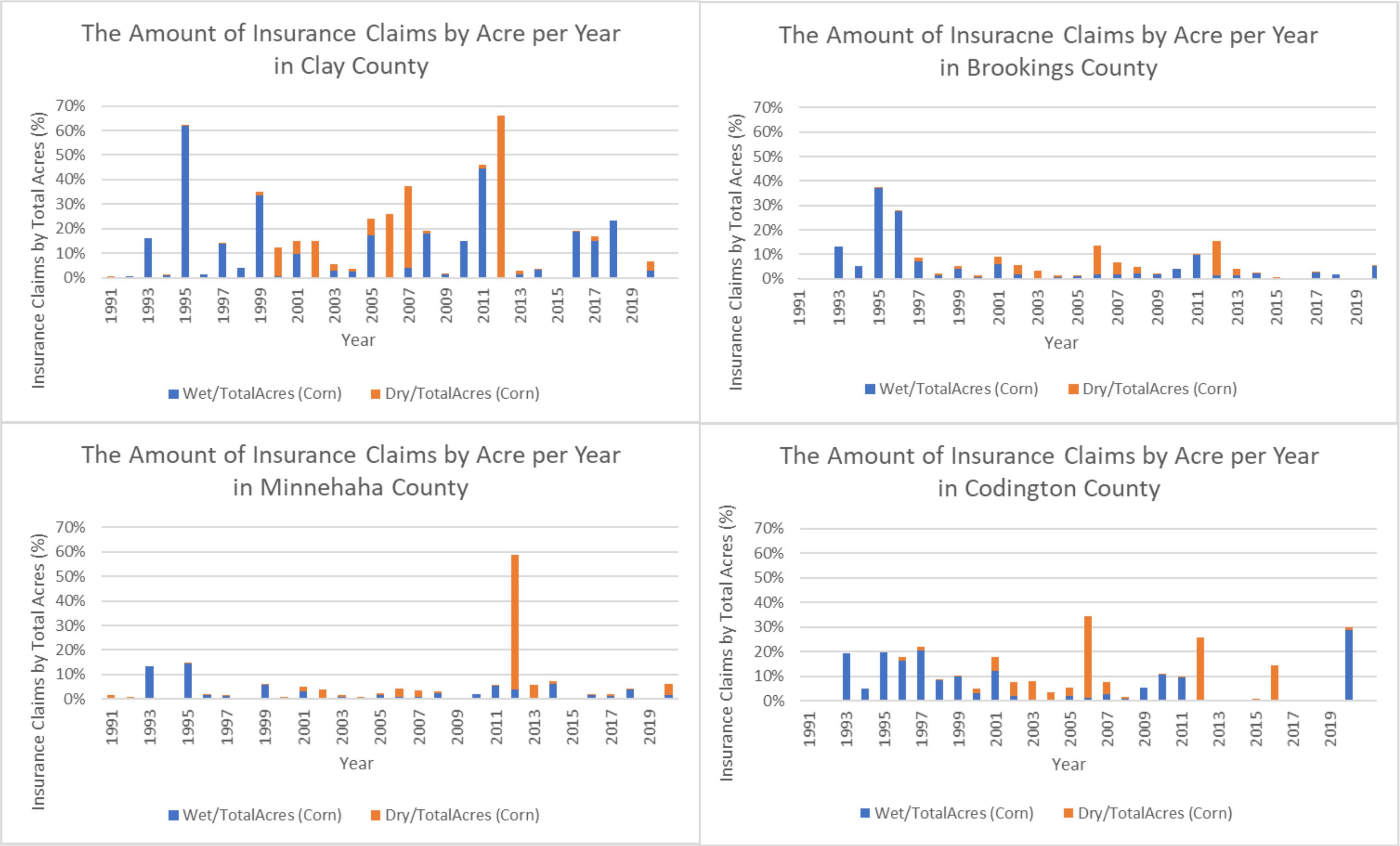


Figure 3.2. The amount of indemnified drought/excessive moisture insurance acre claims divided by the total amount of acres planted in the county per year from 1991-2020 for soybeans.


The Amount of Insurance Claims by Acre per Year in Clay County

The Amount of Insuracne Claims by Acre per Year in Brookings County

The Amount of Insurance Claims by Acre per Year in Minnehaha County

The Amount of Insurance Claims by Acre per Year in Codington County

Figure 3.3. The amount of indemnified drought/excessive moisture insurance acre claims divided by the total amount of acres planted in the county per year from 1991-2020 for corn.

When the ratio of indemnified drought acres to indemnified excess moisture acres was between 0.5 and 1.5, a similar amount of both moisture extremes occurred in that county-year. While SSD can address excess moisture, it cannot address drought. County-years in which both moisture extremes coexist may be good candidates for CD. For corn, 17 of 120 years (14%) had an excess moisture to drought ratio between 0.5 and 1.5 and for soybeans, 15 county-years (12.5%) had ratio between 0.5 and 1.5.

3.4.2. Discussion

Crop insurance information indicates that moisture is a significant driver of crop loss. Across four eastern South Dakota counties with a range of average annual precipitations, crop loss from one or the other extreme accounted for an average total acres loss of 6.8%, 17%, 11.7%, and 5.5% for corn and 5.7%, 15.5%, 10.2%, and 5.4% for soybeans in Brookings, Clay, Codington, and Minnehaha counties, respectively. With the climate variability increasing and increasing disparity between precipitation and evapotranspiration timing, eastern South Dakota will continue to experience large intervals of drought and excess moisture. Engineering solutions, such as SSD or CD systems could be considered for installation in agricultural fields. With the addition of a SSD system, subsurface water is drained more quickly from production fields and the water table drained to a manageable level for the crops. Another addition could be CD, which would allow the soil profile to be drained of saturated moisture conditions to a preferred water table level. This may help the soil profile maintain moisture for crop use later in the growing season.

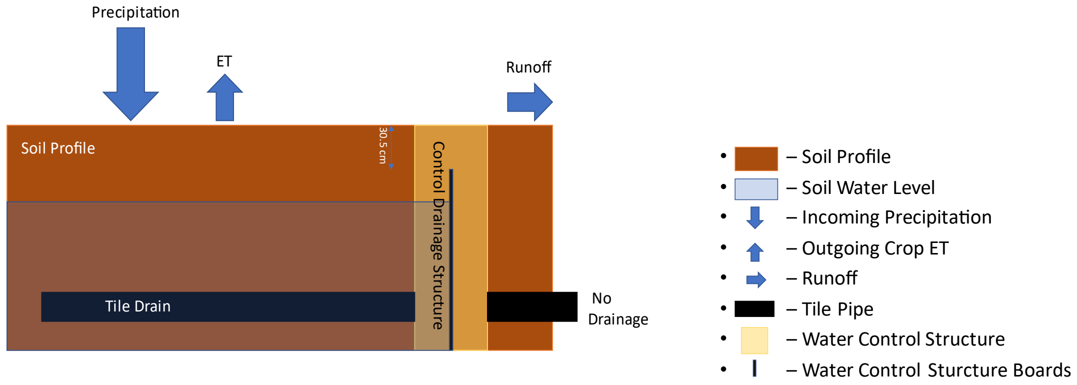


Figure 3.4. The soil profile when there is an opportunity, with a precipitation event, to conserve soil moisture in the soil profile. The control drainage structure has the tile outlet depth set at 30.5 cm (12 in) below the soil surface.

While CD and SSD are viable tools, they require significant investment. Landscape practices, such as no-till, cover crops, and perennial crops may improve water cycling and resilience to weather extremes. One management practice that has demonstrated improved available water capacity, water stable aggregation, and water infiltration rate is long-term no-till. Long-term no-till fields showed an increase in organic matter and infiltration rates (Nunes et al., 2018). If long term no-till increases the amount of organic matter, this improved soil structure can result in increased infiltration as well as enhanced water holding capacity. High organic matter and large soil aggregates are able to hold water from precipitation events leading to an increase in water availability for dry periods (Bhadha et al., 2017). With these added benefits of water infiltration and water holding capacity, soil health could also be looked at to help mitigate extreme moisture conditions.

Conditions that were conducive to CD (ratio of excess moisture to drought between 0.5 and 1.5) were present in 14% of county-years and 12.5% of county-years for soybeans. While this is a relatively low number of site-years, CD is never installed by itself and always installed as part of a SSD system. Contractor estimates for adding CD to SSD systems is an increased cost of 7% (S. Hansen, personal communication, 2021). It is difficult to estimate the difference in yield and profitability in these county-years if CD could be used to mitigate extreme moisture conditions. However, because CD would be viable in a significant number of years compared to the marginal increase of cost of CD to SSD systems, this analysis demonstrates that CD could potentially reduce risk of crop loss enough to justify the additional cost. In addition to potential increased resilience to extreme moisture conditions, there are water quality benefits to controlled drainage. CD has been demonstrated to reduce overall downstream nitrate loading by 36 percent (Helmers et al., 2012). With these added benefits, CD has been shown to be beneficial to agricultural fields with the greatest benefit in flat fields.

3.5. Conclusion

Four eastern South Dakota counties were analyzed, Brookings, Clay, Codington, and Minnehaha using indemnified insurance data for drought and excessive wetness acre claims from the USDA RMA. When looking at the impact CD could have had on soil moisture, within the boundaries of 0.5 and 1.5 from equation one, it was found that with the corn commodity a total of 17 years (14% of the total years) and a total of 15 years (12.5% of the total years) in the soybean commodity. Without the boundaries of equation one set, the data was analyzed to examine how often the two extreme moisture patterns happen in the same year. It was found that of the 120 county-years, for the commodity corn, 76.6%, and 97.5% of the years for drought and excessive wetness, respectively, damages were paid to the producer. For the commodity soybeans, 83.3%, and 100% of the years for drought and excessive wetness, respectively, damages were paid to the producer.

Results showed that there is a 14% prospect of CD retaining moisture in average years of precipitation, but with a marginal investment of 7% added to the original SSD installation, it makes it a viable resource to conserve soil moisture. Along with preservation of soil moisture, studies show that the amount of $\mathrm{NO_3^-} - \mathrm{N}$ is reduced, and the direct amount of drainage is decreased. With greater than a 70% chance of drought and excessive moisture conditions happening in the same year, SSD with CD is an option to help mitigate both extreme moisture conditions.

4. QUANTIFYING OPPORTUNITIES FOR CONTROLLED DRAINAGE USING A DRAINMOD SIMULATION OF A SITE IN EASTERN SOUTH DAKOTA

4.1. Abstract

Soil moisture is a significant variable that determines the productivity of agricultural crops. Too much soil moisture can result in insufficient aeration for root development and growth, and not enough soil moisture can result in reduced plant vigor and reduced yield. This study examined how often conditions were present that controlled drainage (CD) could have been used to reduce tile drain outflow and store water in the soil profile. Using outputs from a previously run DRAINMOD simulation, daily rainfall, evapotranspiration (ET), and runoff from 63 years (1950-2012) were evaluated to determine how often CD preserved soil moisture. Results showed of the 63 years, 36 had potential for CD. In those 36 years, CD had the potential to preserve soil moisture 100% of the time in wet years (top 25% annual precipitation), 58% of the time in average precipitation years (middle 50% annual precipitation), and only12.5% in dry years (bottom 25% annual precipitation). Soil moisture levels are a concern for millions of people around the world, making structural installations, such as CD, a viable option to be considered for soil moisture retention.

4.2. Introduction

Hydrologic models are used to simulate events where excess water, such as flooding, and water scarcity, such as drought, can affect environments or crop yields at the field-scale level. One example of a hydrologic model is DRAINMOD. DRAINMOD is a field-scale, process-based, distributed simulation model originally developed to provide a means of quantifying, on a continuous basis, the performance of multi-component drainage and related water management systems (Skaggs et al., 2012). With an increase in SSD in eastern South Dakota in recent years, both for increased crop yield and better environmental aspects, DRAINMOD (Version 6.1) was used to simulate the hydrologic process through soils in eastern South Dakota using the model inputs soil properties, weather, drainage systems, and crop-related parameters.

DRAINMOD is used to optimize the design of both drainage depth and spacing, or drainage design rate (DDR), with inputs of parameters, such as soil and weather conditions to create a desired drainage intensity (DI) (Karki, 2017). If tile lines are spaced too close or too deep, they have a greater drainage intensity and potential of nitrate-nitrogen ($\mathrm{NO_3^-} - \mathrm{N}$) to be elevated in the outflow of water. Conversely, if tile lines are too wide or shallow, they may not drain enough of the excess water necessary for proper field conditions. To simulate the response of water through SSD, DRAINMOD uses the water balance equation for a column of soil that has a unit surface area which extends from the ground surface to a subsurface impermeable layer and is located at the midpoint between two subsurface drains (Karki, 2017). Creating the water balance equation requires inputs from soil parameters, such as soil water characteristic curve, drainage volume, upward flux, and Green-Ampt infiltration parameters, as well as weather, design configuration, and crop parameters (Karki, 2017). The simulation is able to give results of rainfall, infiltration, ET, drainage, total runoff, water table depth (WTD), dry zone, surface storage, and soil drainage. Upon knowing these results, trafficability, relative yield, and wetland hydrology are able to be better understood. This study uses the outputs of rainfall, ET, total runoff, and WTD to determine opportunities for controlled drainage at the field scale.

4.3. Materials and Methods

4.3.1. Data Acquisition

Analysis for a tile drained site water balance was performed on data produced from Karki (2017). Karki (2017) used DRAINMOD to determine rainfall, infiltration, evapotranspiration (ET), drainage, runoff, total water loss, WTD, dry zone, and surface storage, all exported to an Excel spreadsheet, for a 63-year period for a site near Beresford, SD in Clay County. The soils in the study area were Egan-Trent silty clay loam, with the climate in the area classified as dry subhumid, with average annual (1950-2012) precipitation of 642 mm, and average annual (1950-2012) daily maximum and minimum temperatures of 14.7ºC and 1.8ºC, respectively. Long-term DRAINMOD simulations were then run based on a free drainage system (FD), tile drainage discharge flows directly into surface water without help, with continuous corn input, drainage conditions, and climatological data. Rainfall, ET, drainage, and runoff were the DRAINMOD output parameters analyzed in this paper.

4.3.2. Data Analysis

The parameters of rainfall, ET, and runoff from the DRAINMOD simulation were used to calculate the amount of water that was available to be held within the soil profile. Runoff and ET were subtracted from rainfall to give us the amount of water that would have been prevented from leaving the field due to CD.

$$CD=Rainfall-Runoff-ET \tag{4}$$

That amount (CD) was used if CD was greater than zero and WTD was greater than the defined scenario depth. Six scenarios were analyzed to assess the impact that controlled drainage would have if the control structure boards were set at varying depths below the soil surface, 30.5 (12in), 45.7 (18 in), 61.0 (24 in), 76.2 (30 in), 91.4 (36 in), and 106.7 (42 in) cm. If the DRAINMOD daily output yielded a positive drainage value, that water could have been saved. If the water table depth was less than the scenario depth, then it was necessary for water to be drained from the soil profile. CD was only considered viable in situations where there was water that could be saved but not at a water table depth that was too close to the surface. For example, at a tile drain depth of 30.5 cm, if the CD was greater than zero (drainage present) and WTD was less than 30.5 cm (less than 30.5 cm from the ground surface), then the system would drain the excess moisture because the soil profile is saturated (Figure 4.1). If CD was greater than zero (drainage present) and WTD was greater than 30.5 cm (more than 30.5 cm from the ground surface), then the amount of drainage could be controlled (Figure 4.2). If CD was less than zero, there is no drainage present (Figure 4.3).

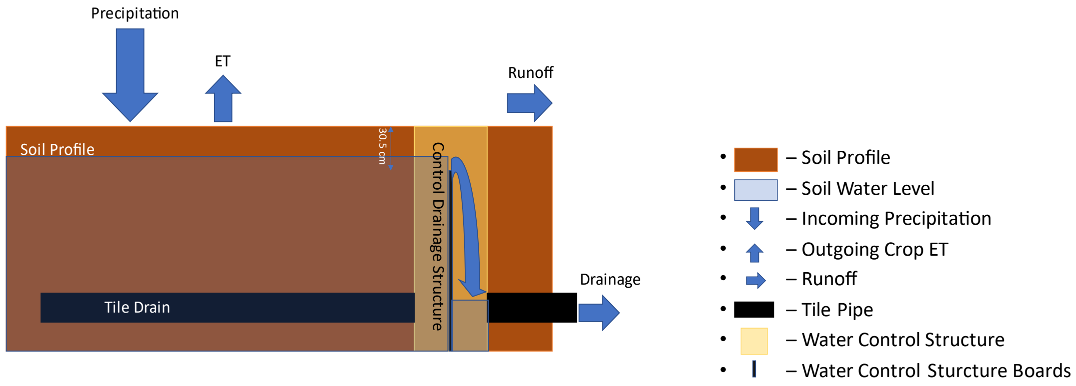


Figure 4.1. The soil profile when there is too much excess moisture for controlled drainage to preserve any moisture in the soil profile.

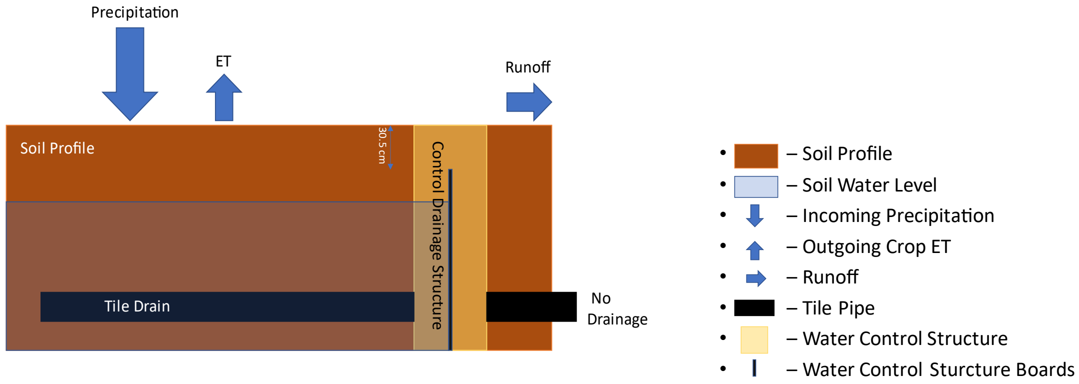


Figure 4.2. The soil profile when there is an opportunity, with a precipitation event, to conserve soil moisture in the soil profile.

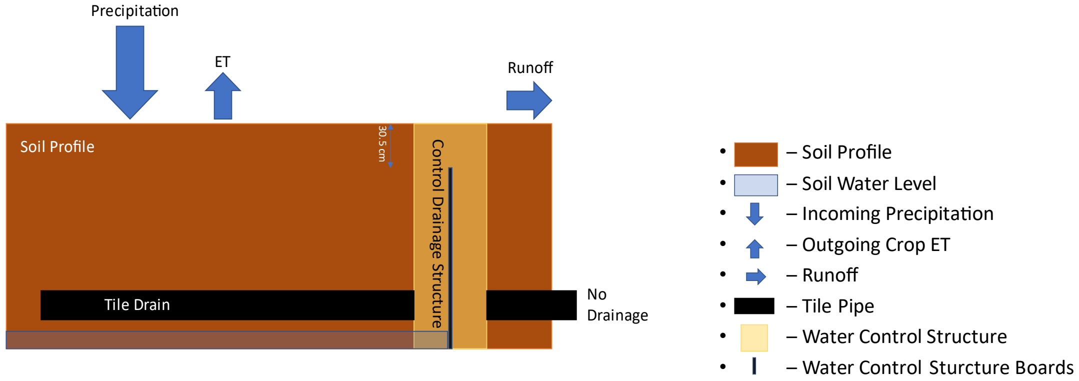


Figure 4.3. The soil profile when there is not enough moisture in the soil profile for controlled drainage to be utilized.

4.4. Results and Discussion

4.4.1. Results

Rainfall, ET, and runoff outputs from DRAINMOD from the years 1950-2012 (63 years) were evaluated to assess the number of years CD would have held water in the soil profile (Figure 4.4). There was potential for CD in 36 of 63 total years (58%). The highest annual depth of water saved, or highest annual CD potential was 12.05 cm (1993, total annual precipitation of 82.72 cm). In 27 of 63 years, there was no drainage, or rainfall never exceeded runoff and ET, so there was no potential for CD in those years.

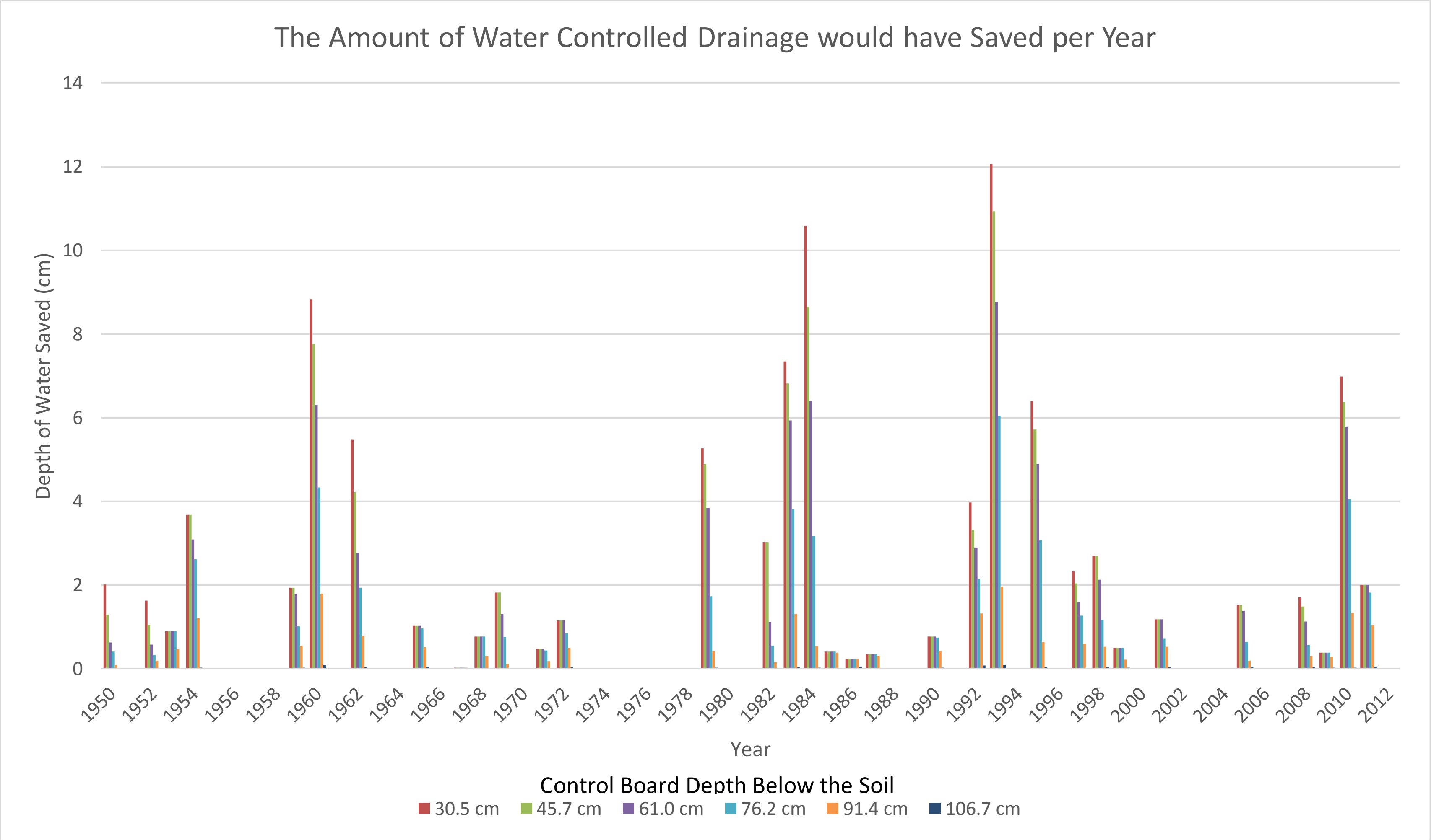


Figure 4.4. The depth of water (cm) prevented from leaving the field due to CD on a year-to-year basis from 1950-2012.

When timely rainfall can be held for a short dry period is when CD is most beneficial and has limited benefit during wet years although there is more moisture available to preserve. An assessment of CD potential in wet, average, and dry years yields insight into not just the frequency and amount of water that could be preserved but also the potential impact it could have, given precipitation inputs. Rainfall, ET, and runoff outputs from DRAINMOD from the years 1950-2012 (63 years) were evaluated to give us the number of years CD preserved soil moisture with the total amount of annual precipitation (Figure 4.5). All years were divided by annual precipitation into the wet years (top 25% annual precipitation), average years (middle 50% annual precipitation), and dry years (bottom 25% annual precipitation). In wet years, every year had potential to preserve water in the soil profile using controlled drainage. In 18 of 31 average years, there were opportunities to preserve soil moisture using CD. In only two of sixteen dry years, there were opportunities to preserve soil moisture using CD (1967 with 0.02 cm and 1999 with 0.50 cm). As expected, higher annual precipitation results in higher likelihood of soil moisture preservation using CD.

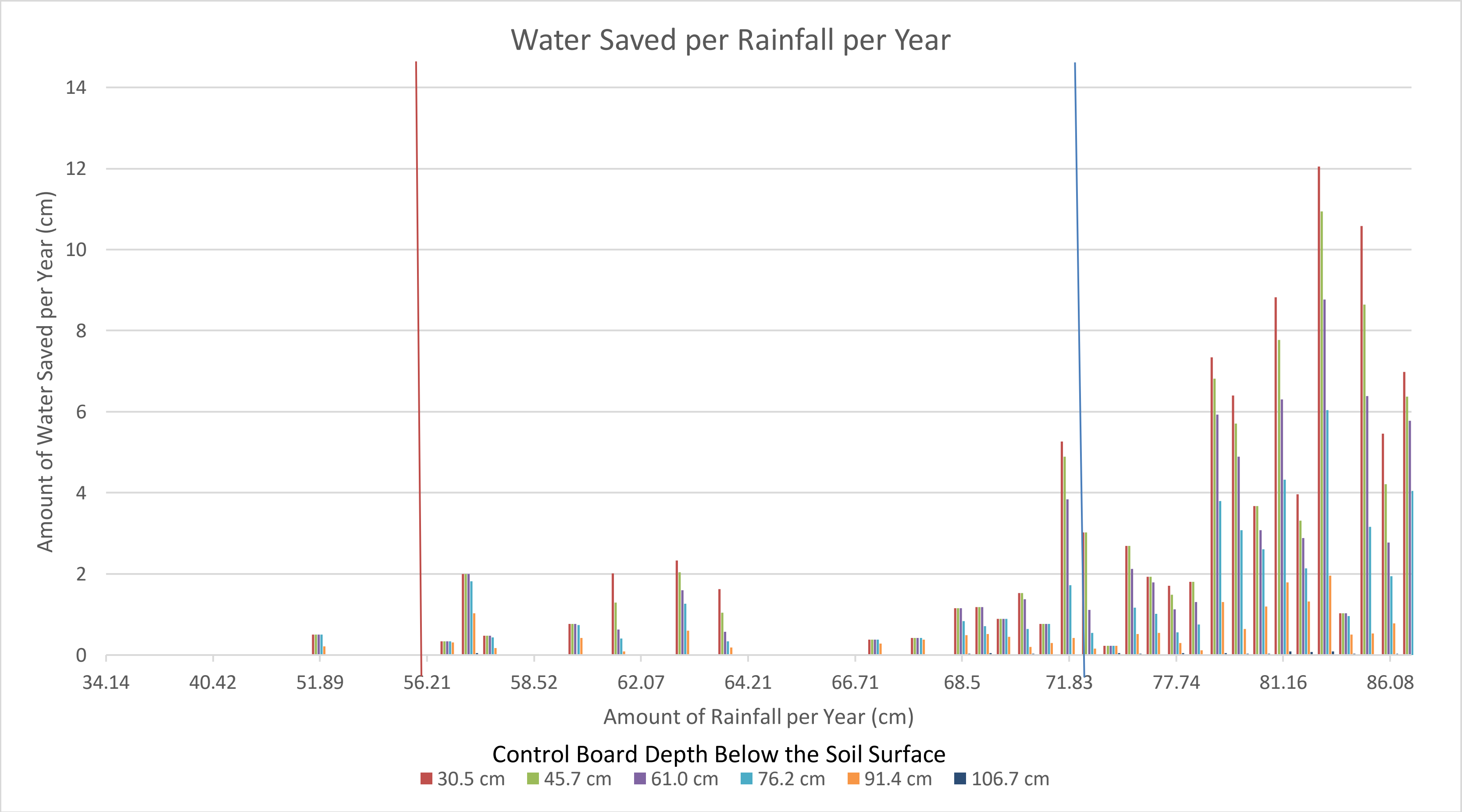


Figure 4.5. The depth of water (cm) prevented from leaving the field due to CD from the least amount of annual precipitation to the greatest amount of annual precipitation (cm) from 1950-2012.

4.4.2. Discussion

CD is most beneficial to crop growth when timely rainfall can be held in the soil profile for use during a subsequent short dry period. During wet years, although there is more moisture available to preserve, CD has limited benefit because the soil profile is saturated, and excess water is already actively draining. During dry years, CD is also of limited benefit because there is not enough moisture to raise the water table depth to allow for preservation of moisture in the soil profile.

Managing the timing and height of CD is critical to achieving the most crop benefit and reducing the risk of excess moisture. If the water table is held too close to the soil surface and roots for too long, then it is likely that the plant will be negatively impacted. If the level is maintained too far from the ground surface, then it is likely that insufficient moisture will be preserved to affect plant growth. The current industry standard approach to controlled drainage is to set the boards after planting and not adjust during the growing season. This leads to scenarios of too much or too little water being held back and can negatively affect crop growth. Previous research has demonstrated variable crop growth improvement using CD with two different studies demonstrating a yield improvement of 3.3% and 2.1% for corn and soybeans, respectively (Ghane et al., 2012) and a yield hit of 9% and 8% for corn and soybeans, respectively (Sahani, 2017). These studies were performed on manually adjusted controlled drainage where the nuance of the crop water demand and soil moisture variability throughout the season are not adjusted for which leads to an imbalance between water supply and demand.

An automated controlled drainage system that accounts for soil moisture, water table depth, crop water demand, and short-term weather forecasting would have the capability to dynamically adjust the soil moisture held in or released from the field based on the current real-time scenario. Opportunities for preserving soil moisture in average and wet years may not be able to be realized using conventional manually controlled drainage. However, because more precipitation is occurring in fall, winter, spring even in wet years, there is likely some point in the summer that ET exceeds water availability (Hay and Todey, 2011). Automated CD could release water until it is likely that the crop is entering a dry spell, and then preserve water from that point.

Regardless of yield impacts of CD, previous studies have demonstrated significant $\mathrm{NO_3^-} - \mathrm{N}$ load reduction using CD. Studies have demonstrated $\mathrm{NO_3^-} - \mathrm{N}$ reduction of 36%, 55%, 58.7% and 65.3%, 78% and 94%, and 50% (Helmers et al., 2012; Sahani, 2017; Lalonde et al., 1996; Wesström et al., 2001; Gilliam et al., 1979) in CD compared to free tile outlet drainage. These studies demonstrate CD is an effective tool to mitigate downstream $\mathrm{NO_3^-} - \mathrm{N}$ loss.

4.5. Conclusion

A total of 63 years from a DRAINMOD simulation were analyzed in eastern South Dakota. This study found that there were conditions for CD to preserve soil moisture a little over half of the time, with only 3.1% of this time being dry years and 28.6% of this time in average moisture years. As expected, there is more opportunity for CD to hold back water when there is an abundance of annual precipitation and soil moisture. When annual moisture is less than average (51.62 cm least amount of annual precipitation in this study) there are fewer instances of conditions present for CD. However, even in wet years, there may be opportunities for CD if periods of rainfall are followed by periods of drought. This study did not examine inter annual variation and potential opportunities for CD within years.

Even with the limited amount of years CD could influence soil moisture, research still needs to be done about the effect it has on crop yield and downstream $\mathrm{NO_3^-} - \mathrm{N}$ concentrations. With crop yield being so variable through different studies, more information is needed to better understand the implications that CD has on crop growth and yield. Even though CD has variable effect on crop yield, it has been shown to reduce the amount of $\mathrm{NO_3^-} - \mathrm{N}$ loss. This shows that it should be considered as a tool to decrease the downstream $\mathrm{NO_3^-} - \mathrm{N}$ loading from tile drained systems.

5. ASSESSING NITRATE CONCENTRATION AND FLOW OF TILE DRAIN DISCHARGE IN EASTERN SOUTH DAKOTA

5.1. Abstract

Nitrate-nitrogen ($NO_3^- - N$) is susceptible to being lost through subsurface drainage systems. Downstream loading creates challenges for drinking water utilities since all drinking water must be treated to achieve a $NO_3^- - N$ concentration of below 10 mg L^{-1}. In addition, excess $NO_3^- - N$ can cause eutrophication in marine systems, resulting in algal blooms and an environment with little to no dissolved oxygen.

This study monitored 23 tile outlets across three different counties in eastern South Dakota. Weekly water samples were collected and analyzed for $NO_3^- - N$ and flow depth was measured at the time of sampling. Concentration and flow depth were significantly different by site and week. While the majority of samples were below 25 mg L^{-1}, well over half (195 of 352 total samples) were above the drinking water standard of 10 mg $L^{-}1$. The study was conducted in a relatively low flow year, with normalized depth (flow depth divided by pipe diameter) less than 0.15 for the majority of samples. The first 15 weeks of the year (January 1, 2021 – April 10, 2021) and the last 28 weeks (June 13, 2021 – December 31, 2021) showed more variability in concentration than the middle weeks, likely due to a limited number of samples during those times and a high variability in flow. In the middle 9 weeks (April 11, 2021 – June 12, 2021) there was less variability in concentration, likely because of a greater number of samples and flow was higher which could have resulted in more consistent flow. While concentration varied significantly between sites, concentration was relatively consistent within each site. If

edge-of-field investment is made, baseline monitoring data should be collected to determine how to prioritize investment based on $NO_3^- - N$ and flow.

5.2. Introduction

Subsurface tile drainage (SSD) changes the water balance when installed in agricultural fields by providing excess water another route to follow through the soil profile. While SSD makes field work such as planting in the spring or harvest/tillage in the fall less of a hazard, the water also takes with it some of the nutrients, such as nitrate-nitrogen ($NO_3^- - N$), that would have been kept in the soil profile for a longer period and may have been utilized by the crop. The effects of the water taking a more direct route out of the field have been studied by many researchers and have raised some concern about the effects downstream.

After the Cuyahoga River in Cleveland, Ohio started on fire in 1969, and many times previous to this, from water pollution, the US federal government passed the Clean Water Act of 1972. This put in place pollution control measures that do not allow point sources, “any single identifiable source of pollution from which pollutants are discharged, such as a pipe, ditch, ship or factory smokestack,” (NOAA, 2020) to dump untreated water directly into a water body. Agricultural fields with SSD are not included as point sources, but as nonpoint sources. Nonpoint source pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage, or hydrologic modification (NOAA, 2020). Because SSD is a nonpoint source, water analysis of the drainage outlets is rarely examined.

One of the largest and most talked about examples of water pollution is the hypoxic zone in the Gulf of Mexico, also known as the “Dead Zone.” The hypoxic zone in the northern Gulf of Mexico is an area along the Louisiana-Texas coast, where water near the bottom of the Gulf contains less than two parts per million of dissolved oxygen, causing a condition referred to as hypoxia (US EPA, 2015). This zone is caused by nutrient rich waters coming into the ocean. These nutrients, mainly nitrogen, come from fertilization of agricultural fields, golf courses, suburban lawns, eroded soils, and discharge from sewage treatment plants (US EPA, 2015). With this area becoming increasingly larger, the media has drawn attention to the commercial fertilization of agricultural fields across the Midwest. This in turn has drawn some attention to SSD and the water discharge downstream.

In Iowa, the Des Moines Water Works filed a lawsuit claiming upstream SSD was funneling elevated levels of nitrates into Iowa residents' drinking water (Eller, 2017). The drinking water standard in the U.S. is 10 mg L^{-1} of $NO_3^- - N$ due to the negative effect it has on infants (blue-baby syndrome). The Des Moines utility sought to have the drainage districts, and indirectly farmers, regulated under the federal Clean Water Act as a "point source" of pollution, much like businesses and manufacturing plants (Eller, 2017). Water analysis and detailed record keeping could be a way to prevent another catastrophe like this from reoccurring.

In the years from 2012 to 2017, due to rising crop prices, rising land prices, rising input costs, and an increase in the amount of precipitation received on an annual basis, the amount of SSD has increased by 69% in South Dakota (Zulauf and Brown, 2019). With the increase in the amount of SSD in the eastern part of the state, research is being conducted into the number of pollutants that are entering the bodies of water that flow to the Mississippi River, as well as to local drinking water and recreational water areas.

Establishing a baseline nitrate-nitrogen concentration in tile drainage discharge in eastern South Dakota and the variables that impact the concentration is the objective of this study.

5.3. Materials and Methods

5.3.1. Experimental Sites

Starting in 2020, water samples were taken from 23 different tile drainage outlet sites in Codington, Moody, and Minnehaha Counties. The 6 outlet sites in Codington County were located near the town of Hazel, SD, of the 6 outlet sites in Moody County one was located near the town of Nunda, SD and five by Ward, SD, and of the 11 outlet sites in Minnehaha County 6 were located near the town of Garretson, SD and 5 by Crooks, SD. Samples were collected weekly when the tile outlets were flowing. If they were not flowing, no sample would have been collected.

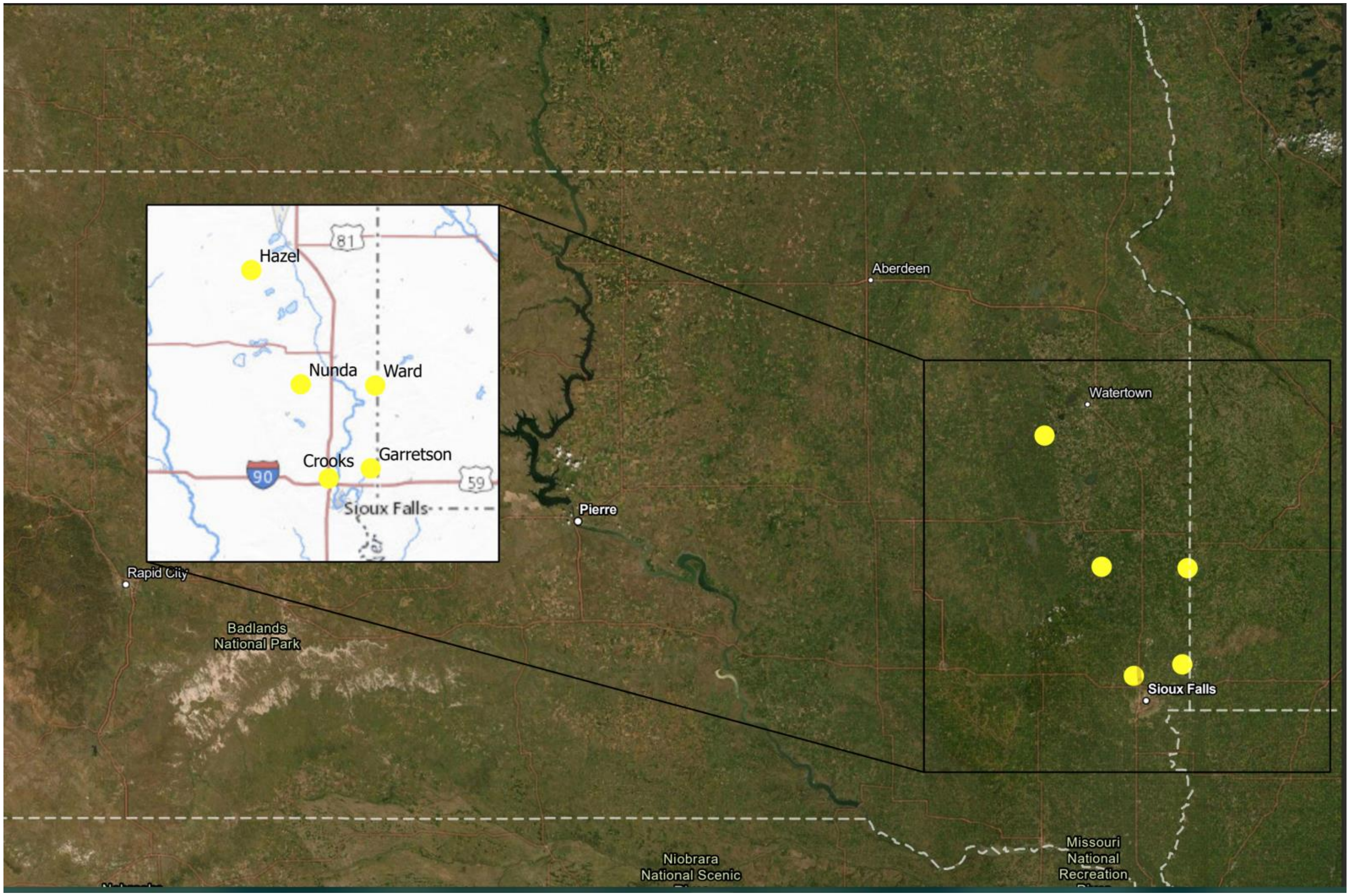


Figure 5.1. A map of the locations of SSD outlets across eastern South Dakota marked by yellow dots.

In the three different counties and twenty-three different SSD outlet locations, there were only two sites with a drainage-pump lift station (DP), with the rest being free drainage (FD). There are varied sizes and materials of SSD pipe (Table 5.1). The diameters of the SSD pipes range from 10.16 cm (4-in) to 30.48 cm (12-in) pipe. Pipe material includes smooth green plastic pipe, metal corrugated pipe, and double wall corrugated plastic pipe.

Table 5.1 Sizes, material, and number of SSD tile lines located in three different counties across eastern South Dakota.

County	Pipe Material, Type, and Configuration	Outlet Diameter (in.)	Total Number of Outlets
Codington	Smooth Plastic	6	2
	Corrugated Metal	8	1
	Double Wall Corrugated Plastic	10	1
	Smooth Plastic (Lift Station Outlet)	6	2
Minnehaha	Double Wall Corrugated Plastic	4, 8, 12	1, 1, 1
	Corrugated Metal	6	2
	Smooth Plastic	6, 8	1, 5
Moody	Double Wall Corrugated Plastic	6	1
		8	2
		10	2
		12	1
			Total = 23

5.3.2. Water Analysis

Samples were collected weekly when the outlets were flowing. The depth of flow was measured at the outlet during each visit, also. Flow depth was initially used to determine flow rate using Manning's equation (Munson et al., 2015). The bucket method was used as a method validation for one round of sampling on April 28, 2021, for 16 outlet sites. This validation analysis revealed that at low flows, flow depth and Manning's equation was not a viable method to determine flow. At low flows, measurement is inaccurate because the edge effects are a significant source of error (Akhter et al., 2021).

Since flow could not be directly calculated for many of the samples, normalized depth was used as a proxy for flow rate during the time of sampling (Equation 5.1). Normalized depth was calculated as:

$$\frac{FD}{PD} = ND \qquad (1)$$

Where FD is the flow depth in the tile pipe, PD is the tile pipe diameter, and ND is the calculated normalized depth.

The samples were collected in 50 mL acid-washed plastic bottles and kept on ice until transported to a laboratory where they were frozen. Samples were then thawed, filtered, and analyzed for $\mathrm{NO_3^-} - \mathrm{N}$ with a Seal Analytical AQ2 Discrete Analyzer. As of March 29, 2022, 352 samples were analyzed for nitrate-nitrogen concentration and used in this analysis.

5.3.3. Statistical Analysis

The Anderson-Darling test was used to determine the normality of the data. The data were determined to be non-normal, so the non-parametric Kruskal-Wallis test was used to determine if groups were significantly different ($p \leq .05$). All statistical tests were performed using Minitab 21 (Minitab LLC, State College, PA).

5.4. Results and Discussion

5.4.1. Results

5.4.1.1. Water Nutrient Concentration and Normalized Depth Per Tile Outlet

Water samples were taken at 23 different tile outlets across eastern South Dakota and analyzed for $\mathrm{NO_3^-} - \mathrm{N}$. There was limited variability within each site, with the exception of site 18 (average standard deviation of the remaining 22 sites was 2.60), but significant variability across the entire population (standard deviation with site 18 included was 7.06, standard deviation without site 18 included was 6.10) (Figures 5.2 and 5.3). In general, during the study period, flow was relatively low with no samples collected when normalized depth was greater than 0.4 and the majority collected when normalized depth was 0.16 or below (Figure 5.4). Unfortunately, this decreases the accuracy of any load calculation because standard flow equations are not reliable at this low of a normalized depth. Visually, the frequency of occurrence for concentration followed somewhat of a bimodal distribution with a significant number of samples between 8 and 10 mg L-1 and a significant number of samples between 15 and 17 mg L-1 (Figure 5.5). The majority of samples were below 25 mg L^{-1}, with 195 samples above and 157 below the drinking water standard of 10 mg L^{-1}. It should also be noted that there was no significant correlation between the nitrate-nitrogen concentration and the normalized depth of water recorded in the tile outlet.

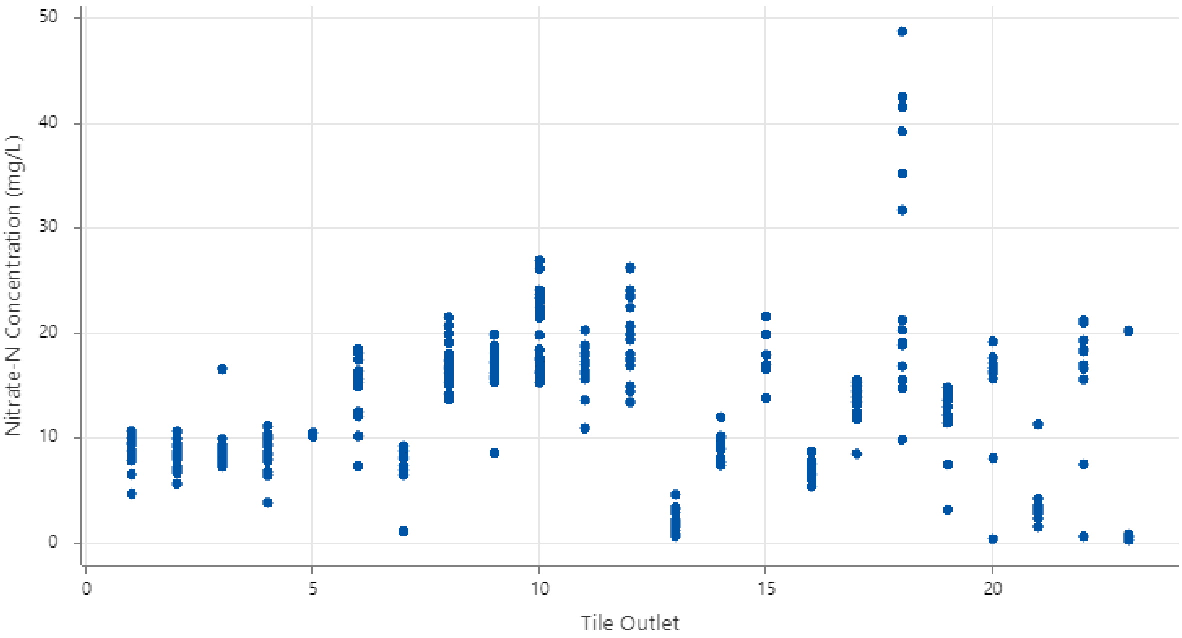


Figure 5.2. The variability and number of $NO_3^- - N$ samples at each tile outlet.

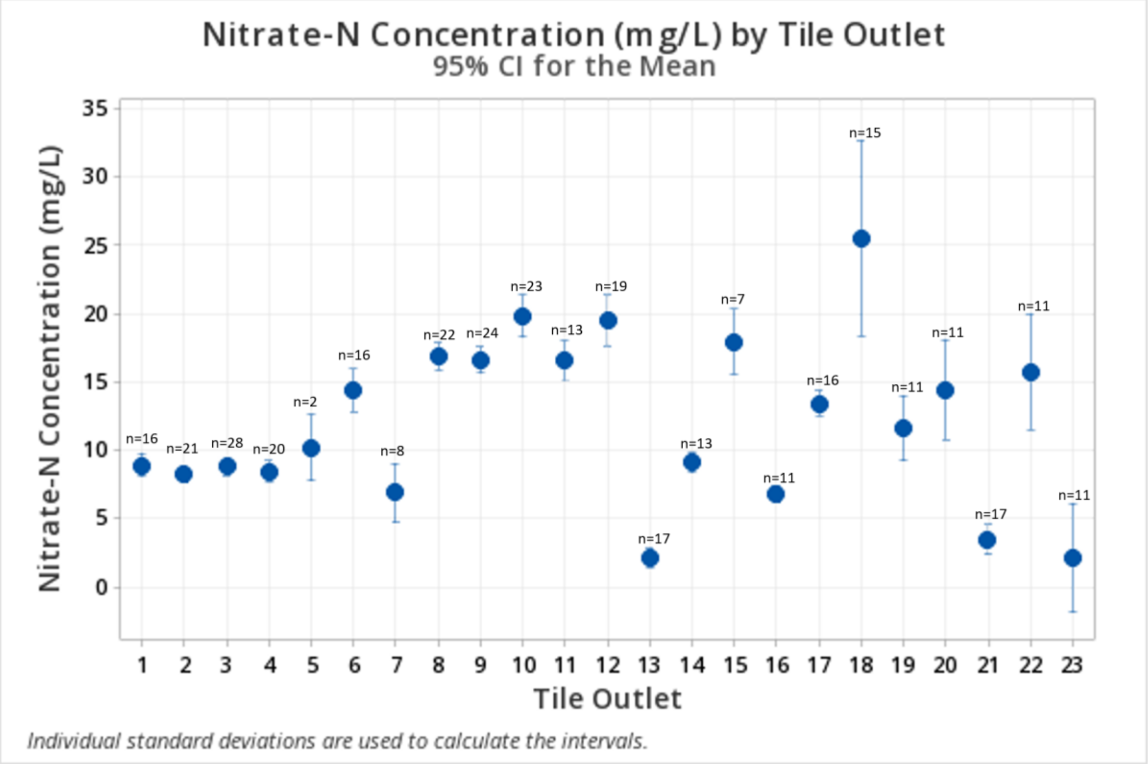
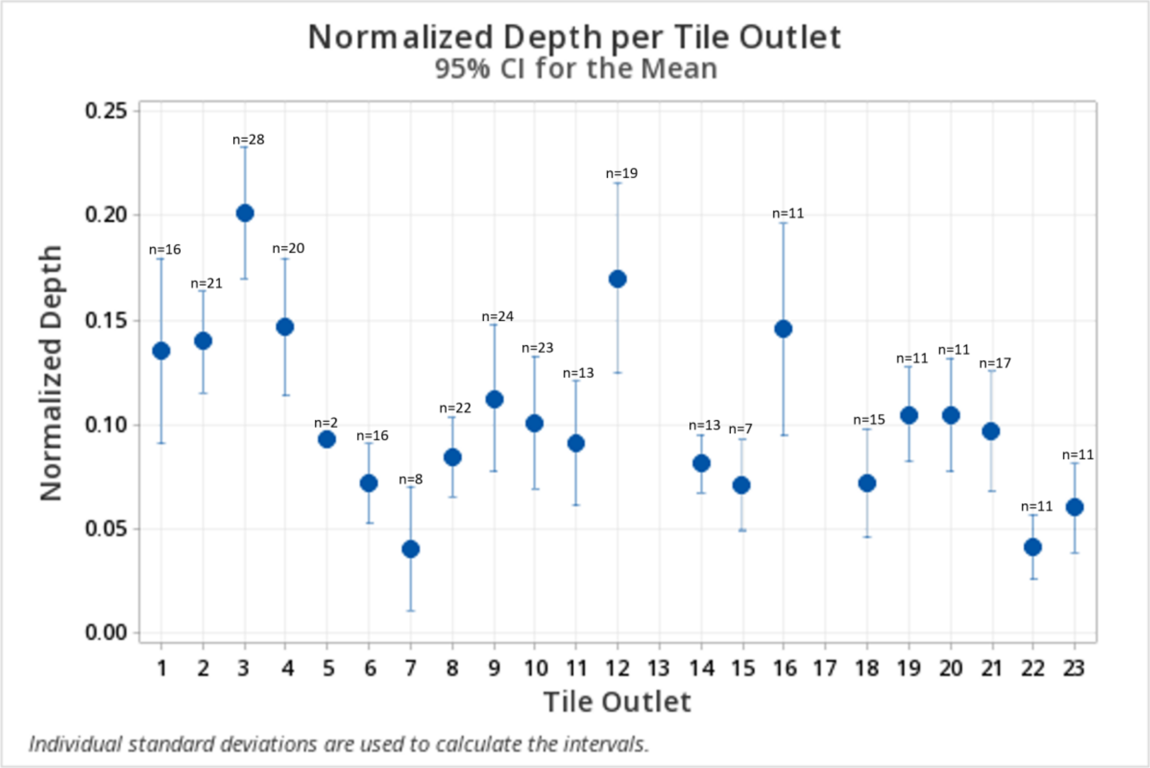


Figure 5.3. The variability of $NO_3^- - N$ samples within each tile outlet site.

Normalized depth (excluding sites 13 and 17 because they are lift stations) was variable within each outlet (average standard deviation within each outlet 0.05) as well as between outlets (overall average standard deviation 0.07) and was significantly different across outlets ($p \leq 0.001$) (Figure 5.4). Indicative of a year with low flow, most of the samples were taken at a normalized flow depth less than 0.15 (Figure 5.6).



Individual standard deviations are used to calculate the intervals.

Figure 5.4. The variability of normalized depth within each tile outlet site with the exception of tile outlet sites 13 and 17 because they are pump stations.

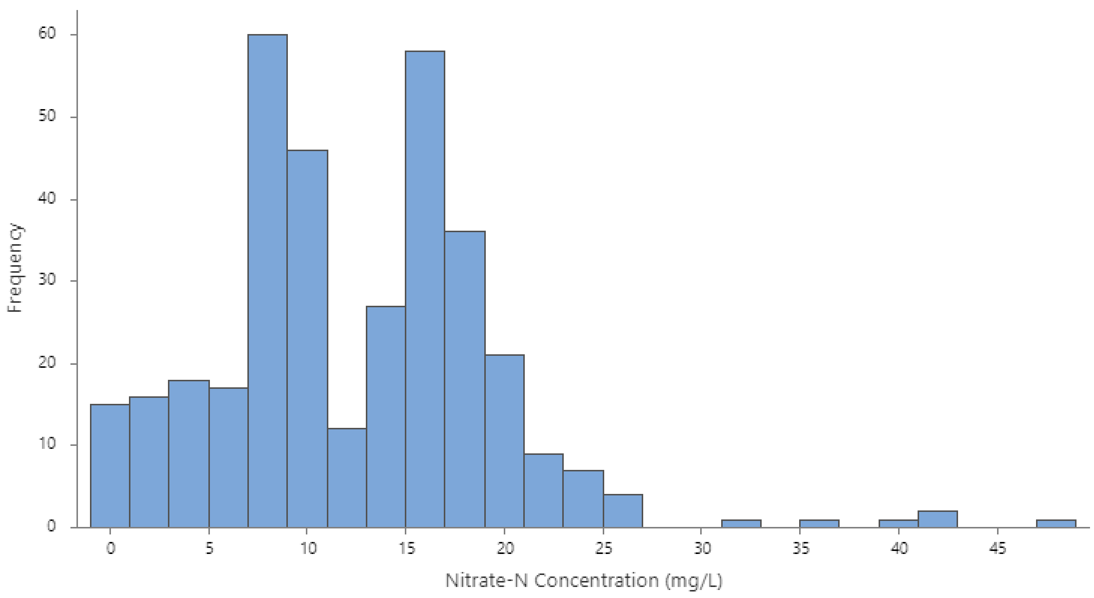


Figure 5.5. The entire population of samples looked at in a histogram for $NO_3^- - N$ concentration.

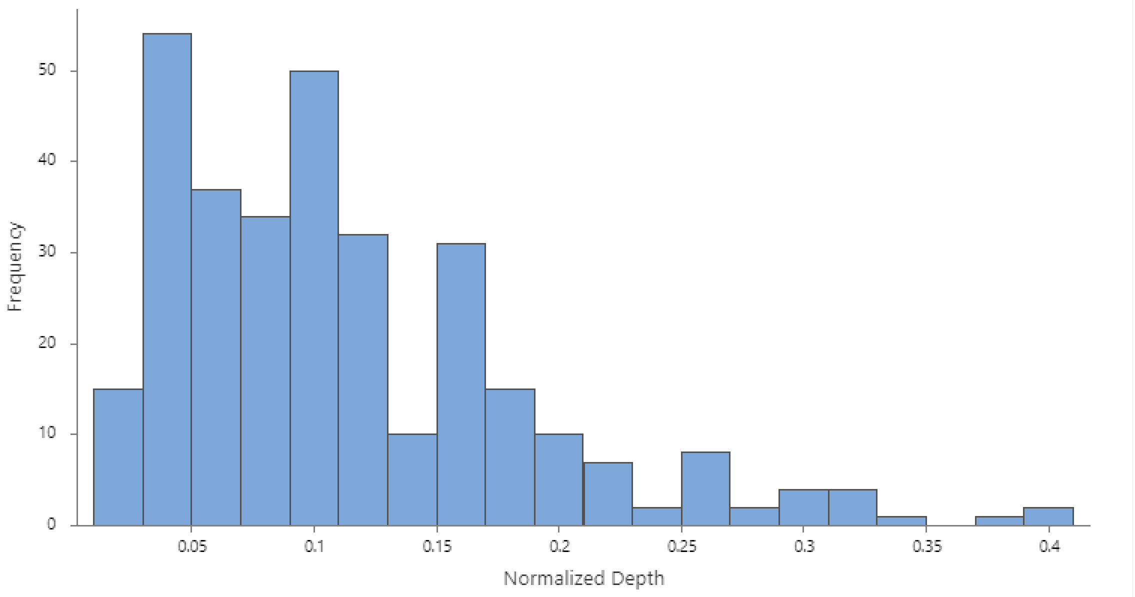


Figure 5.6. The entire population of samples looked at in a histogram for normalized depth.

5.4.1.2. Water Nutrient Concentration and Normalized Depth by Week

Water samples were taken at 23 different tile outlets across eastern South Dakota and analyzed for $NO_3^- - N$. The variability of each site depended upon what week of the year the samples were taken (Figure 5.7 and 5.8). The first 15 weeks of the year (January 1, 2021 – April 10, 2021) there was high variability in the concentration and high variability in flow depth. In the weeks 16 – 24 (April 11, 2021 – June 12, 2021) there was little variability and flows were consistently higher. Concentration was also more consistent during this period (Figure 5.9). In the latter part of the year, weeks 25 – 60 (June 13, 2021 – December 31, 2021) the variability between sites increases again, flow depth decreases, and the concentration becomes more variable. Low flow depths, significant differences between flow depths, as well as a limited number of samples per week contribute to the variability of the week-to-week sampling analysis.

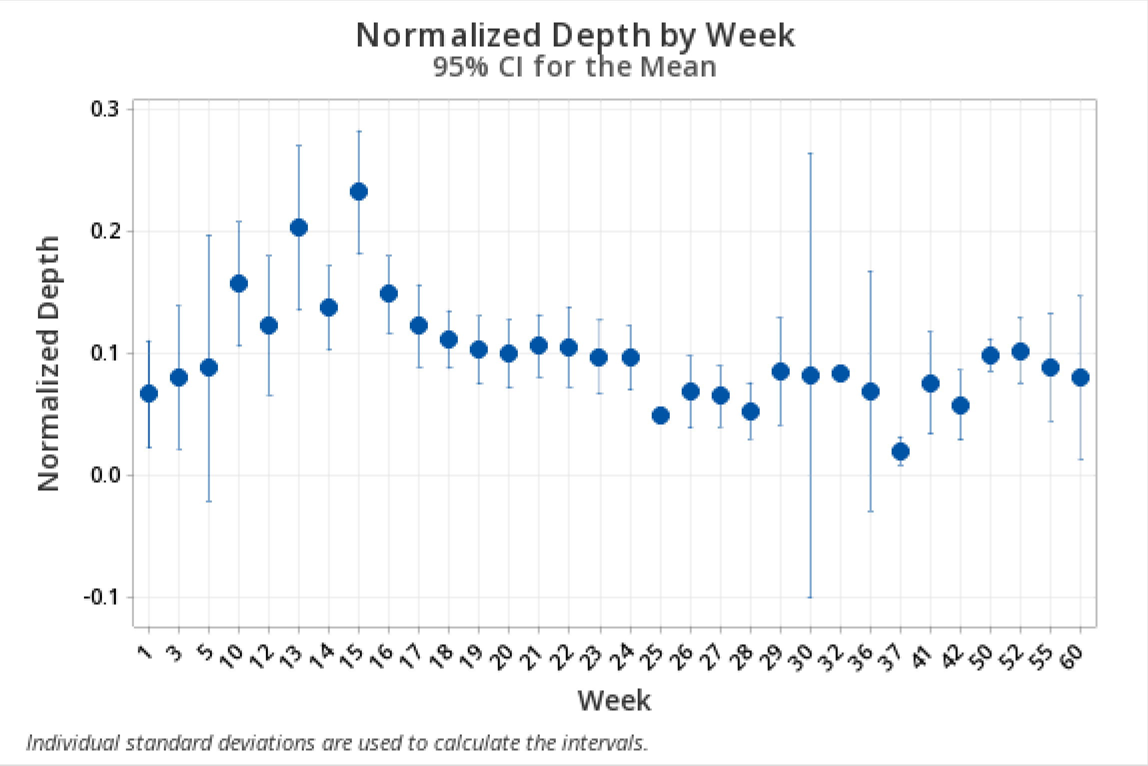


Figure 5.7. The confidence interval of 95 percent for normalized depth per week.

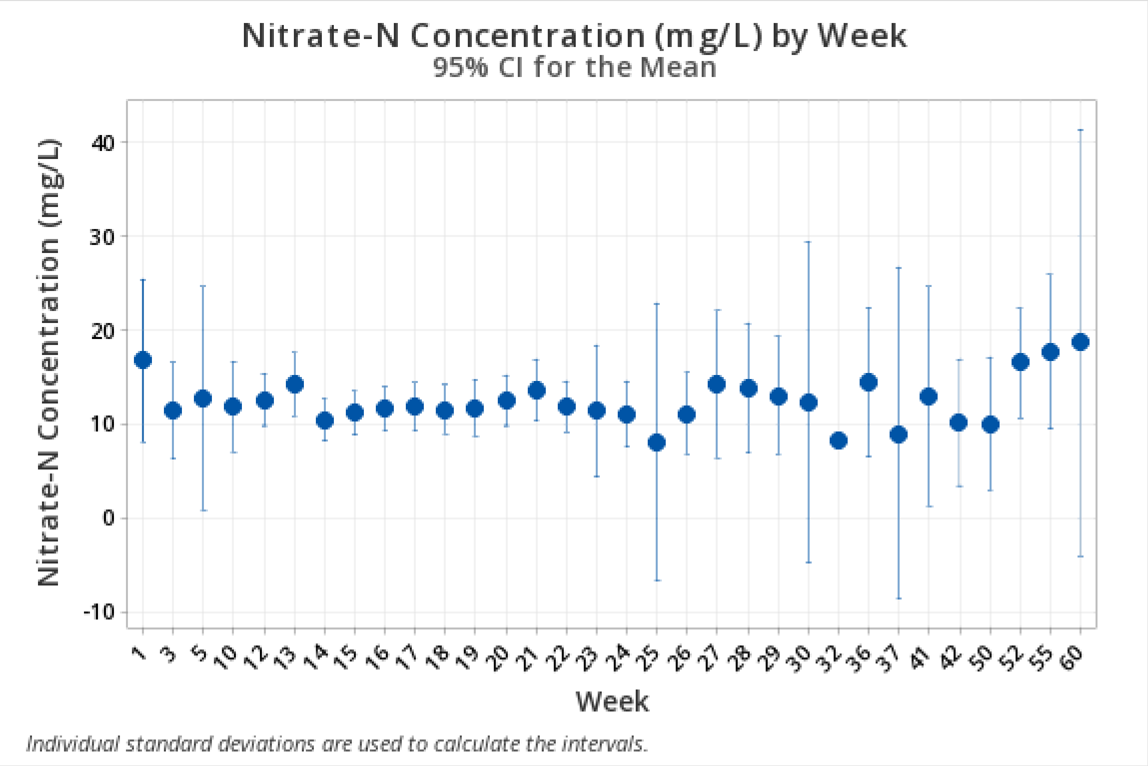


Figure 5.8. The confidence interval of 95 percent for $NO_3^- - N$ concentration per week.

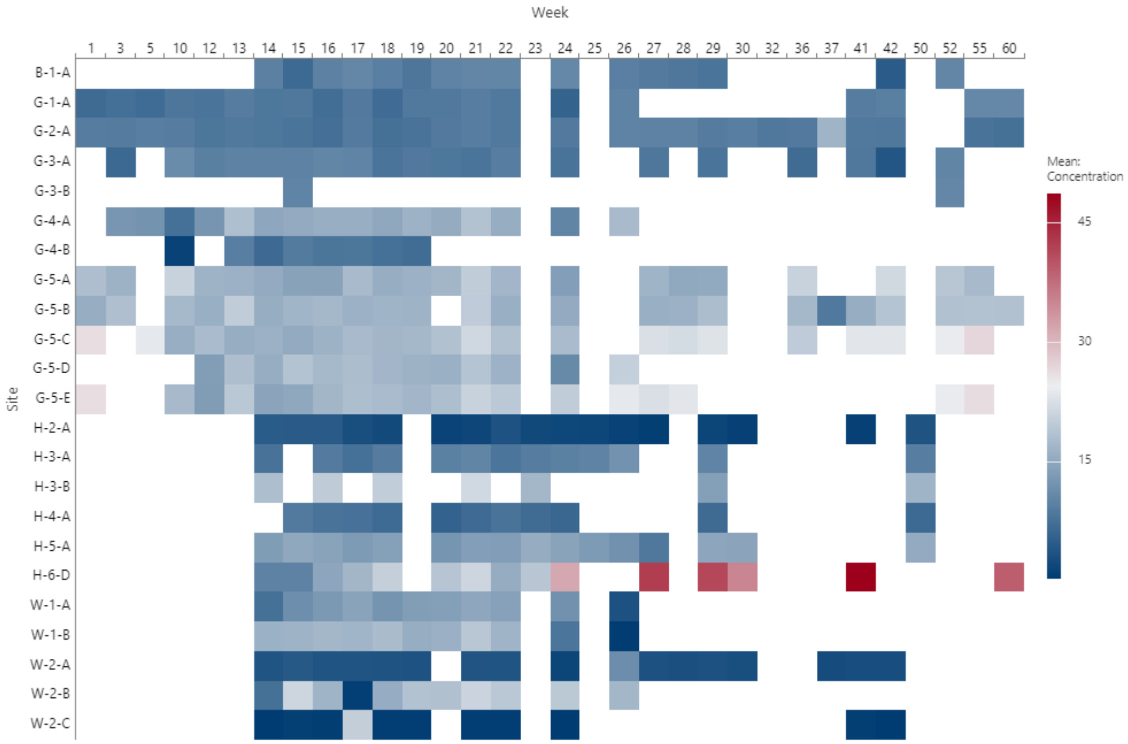


Figure 5.9. Heat graph showing mean concentration (blue lower concentration and red high concentration) by week and site.

5.4.2. Discussion

Agricultural subsurface tile discharge is put directly into surface water without knowing the amount of $NO_3^- - N$ it contains. The drinking water standard set by the U.S. Environmental Protection Agency is 10 mg L^{-1}, which makes knowing the amount of $NO_3^- - N$ in this discharge critical. This study is one of several done across the U.S. and Canada to show how much $NO_3^- - N$ is in tile drainage discharge. The results show that an average concentration of 12.4 mg L^{-1} was recorded for 23 sites in eastern South Dakota. This number is average compared to research completed in IL, MN, IA, and Ontario Canada (Table 5.2.).

Table 5.2. This table shows other research involving $NO_3^- - N$ in subsurface tile drainage across different states and Canada.

Author of Study	**Mean $NO_3^- - N$ Concentration (mg L^{-1})**	**Location**	**Additional Comments**
David, M., et al., 2016	16, 30	IL	Inflow to a bioreactor
Drury, C., et al., 2014	18, 14, 14	Ontario	1989 Conventional, Ridge, and No-till
	29, 20, 20		1990 Conventional, Ridge, and No-till
Randal, G. and Iragavarapu, W., 1995	13.4, 12.0	MN	Flow-weighted 11 yr. average for Conservational and No-till
Drury, C., et al., 1993	10.7, 7.35, 6.18 11.9, 11.4, 6.99	Ontario	Flow-weighted mean tile unrestricted, controlled, controlled w/ subirrigation
Oquist, K., et al., 2007	8.2, 17.2	MN	Flow-weighted mean alternative and conventional farming practices
Mitchell, K., et al., 2000	16.8, 10.2, 1.0	IL	Pre-plant, side-dress N application, and continuous grass
Tomer, M., 2003	9.2	IA	Flow-weighted mean from watershed catchment
Hurst, M., et al., 2022	12.4	SD	Average annual N concentration of 23 outlets

Across eastern South Dakota, samples from 23 tile outlets showed that of 352 samples, only 45% of them were below the drinking water standard. Research has shown that there are treatments that lower the amount of $NO_3^- - N$ that leaves the field or enters downstream water systems. Two studies completed 14 years apart show controlled drainage with subirrigation reduced the average annual $NO_3^- - N$ loss by 43% and 66% (Drury et al., 1996; Drury et al., 2009). Another study shows no-till management practices have a 12% higher drainage than conventional tillage, but 5% lower loss of $NO_3^- - N$ (Randall and Iragavarapu, 1995). A third study showed that winter wheat cover crop reduced the 5-year $NO_3^- - N$ loss by two percent (Drury et al., 2014). These studies show there are different ways to lower $NO_3^- - N$ from discharge of agricultural fields before it reaches our water ways.

Looking at the 23 different tile outlets in eastern South Dakota, we see that each outlet is significantly different ($p \leq .05$) from each other when comparing $NO_3^- - N$ concentrations. This study shows that 10 outlets had $NO_3^- - N$ concentrations that were consistently below the drinking water standard of 10 mg L^{-1}, 5 that ran between 10 mg L^{-1} and 15 mg L^{-1}, while the remaining eight consistently ran above15 mg L^{-1}. This information indicates there is a need to treat each outlet separately. If looked at separately, the variability in the concentration of $NO_3^- - N$ decreases throughout the year and quarterly water samples may be enough to determine the $NO_3^- - N$ levels coming out of the tile water. Also, the tile outlets with elevated $NO_3^- - N$ levels will be able to be monitored more closely to see if climate factors or management practices are the cause of the elevated numbers, making it easier to approach how to lower the $NO_3^- - N$ concentrations. So, a universal approach is not the correct way to analyze $NO_3^- - N$ concentration from tile drainage water.

5.5. Conclusion

In eastern South Dakota 23 tile outlets were monitored weekly by recording the depth of water in the tile outlet line and taking water samples. The water samples were analyzed by a Seal Analytical AQ2 Discrete Analyzer for $NO_3^- - N$. The results of this study show that normalized depth and $NO_3^- - N$ are significantly different($p \leq .05$) when compared to each tile outlet and week of year the outlet was sampled. The beginning of the year (weeks 1-15) and end of the year (weeks 25-52) had a high variability, with the middle of the year (weeks 16-24) becoming less variable. This could be due to lower sample numbers and lower normalized depth in the tile outlets at the beginning and end of the year.

When compared at each outlet most of the samples were taken at a normalized depth of less than 0.15. There was limited variability in concentration of $\mathrm{NO_3^-} - \mathrm{N}$ within each outlet with the exception of site 18, but significant variability across the entire population. This indicates that each tile outlet should be treated separately and outlets with elevated numbers should be monitored more closely than those with numbers below the drinking water standard. With close monitoring, causes of elevated $\mathrm{NO_3^-} - \mathrm{N}$ numbers, whether it be management practices or climate factors, may become clear, and a plan to reduce $\mathrm{NO_3^-} - \mathrm{N}$ can be put into effect.

6. CONCLUSION

Moisture extremes, too much or too little, cause significant crop loss throughout the US. This study showed in eastern South Dakota, there is a greater than 70% chance excessive moisture and drought conditions will exist in the same year. Excess moisture can be addressed through tile drainage and improved soil health, while moisture deficit can be addressed through irrigation, controlled drainage (CD), or improved water holding capacity. This study shows controlled drainage only preserves soil moisture a little over half of the time, but with minimal additional cost to subsurface drainage installation costs (about a 7% increase) the benefits of the reduction of the amount of $NO_3^- - N$ loss may be worth it. Without CD, tile water discharge is drained directly into surface water without knowing the amount of $NO_3^- - N$ it contains. The results of this study show that an average concentration of 12.4 mg L^{-1} of $NO_3^- - N$ was recorded for 23 sites in eastern South Dakota, which is an average amount recorded from agricultural fields.

$NO_3^- - N$ is susceptible to being lost through subsurface drainage systems, which can create challenges for drinking water utilities, since all drinking water must be treated to achieve a $NO_3^- - N$ concentration of below 10 mg L^{-1}. The results of this study show that $NO_3^- - N$ is significantly different ($p \leq .05$) from outlet to outlet, so a different mitigation approach must be used for each outlet. Determining the risk factor, either from management practices (crop type, tillage, nutrient management, etc.) or factors that cannot be changed (soil type, climate, mineralization, etc.) will allow for either a change in management practices or installation of edge-of-field practices that will give the best return on investment.

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