South Dakota Water Research Institute
Annual Technical Report
FY 2009

Introduction

South Dakota's Water Resources Research Institutes program is administered through the College of Agricultural and Biological Sciences at South Dakota State University (SDSU). Dr. Van Kelley has been the Director since August 1, 2000. Dr. Kelley is also the head of the Agricultural and Biological Engineering Department. The annual base grant from the United States Geological Survey (USGS) and a legislative appropriation of $85,106 form the core of the SDWRRI budget. The core budget is supplemented by research grants from a variety of funding agencies as well as private organizations interested in specific water issues.

The mission of the South Dakota Water Resources Institute is to address the current and future water needs of people, agriculture, and industry through research, education, and service. To accomplish this mission, SDWRI provides leadership in coordinating the research and training at South Dakota State University and other affiliated educational institutions and agencies across the state in the broad area of water resources. Graduate research training, technology transfer, and information transfer are services which are provided through the Institute. This report is a summary of activities conducted during Fiscal Year 2009 to accomplish this important mission.

Research Program Introduction

Water is one of the most important resources in South Dakota. Together with the state's largest industry, agriculture, it will play an important role in the economic future of the state. Enhancement of the agricultural industry and allied industries, the industrial base and, therefore, the economy of South Dakota all depend on compatible development of our water resources.

During 2009, the South Dakota Water Resources Institute (SD WRI) used its 104B Grant Program funds to conduct research of local, state, regional, and national importance addressing a variety of water problems in the state. These included year 2 studies on winter manure management, management of shallow alluvial aquifers, and modeling of watersheds converted from CRP to crop production. A fourth project studied the concept of encapsulating limestone filter media in concrete to immobilize arsenic. Progress reports for each project are included in this report.

During October 2009 the Advisory Committee reviewed 8 grant applications and recommended 5 projects for funding that addressed research priorities that had a good chance of success, and would increase our scientific knowledge. Emphasis was placed on use of cover crops to reduce runoff of nutrients, effectiveness of vegetative treatment areas to reduce nutrients and bacteria in feedlot runoff, arsenic removal from drinking water, study of pharmaceuticals in surface water and uranium detoxification in ground water using bacteria. These projects were scheduled to begin March 1 2010.

As the livestock industry grows and develops in South Dakota, manure management and its impact on water quality will continue to be a priority for research. Animal feeding operations are a major industry in South Dakota and across the Midwest. The practice of applying manure to frozen or snow covered ground varies from state to state in the Midwest because of variation in state regulations and interpretation of the risk of this practice by producers receiving conservation funding from the USDA-NRCS. Substantial data and research is needed in evaluating the potential water quality impacts (relative to standard practices) and assessing the risk of occurrence of weather conditions that can lead to increased risk from applying manure on frozen or snow covered ground. This project seeks to evaluate this practice by assessing the frequency (risk) of climatic conditions expected to lead to excessive runoff from winter conditions and the laboratory comparison of winter applications to typical spring/summer/fall applications.

Some areas of South Dakota have elevated levels of arsenic, cadmium, and lead in drinking water supplies. Removal of these metals especially by small rural water system operators is a challenge. A research project to improve the efficiency of limestone-based materials for metal removal from drinking water was supported in FY2009. This is part of the effort to develop low-cost remediation technology that can be used to help small or rural water supply systems meet regulations.

Nutrient and sediment loads from animal feeding operations (AFOs) can negatively impact the quality of surface waters and groundwaters. A research project to evaluate the technical and financial feasibility of vegetated treatment areas (VTAs) as a non-basin alternative for reducing nutrient and sediment loads from AFOs having less than 1,000 animal units was supported. Five AFOs in different areas of South Dakota were established.

A South Dakota survey conducted in May 2007 indicated that approximately 50% of the CRP acres due to renewal in the next four years will not be renewed. Conversion of these areas from CRP back to row crop production without regard to environmental quality could have huge impacts on water quality in the state. Watershed modeling was conducted and data analysis is nearing completion. A modest set of runoff and sediment loss data were used to validate WEPP. The validated WEPP is being used to estimate the soil loss from lands that may be removed from the CRP program.

The use of groundwater as a public water supply had increased from 26 percent in 1950 to 40 percent for 1985. The water use percentage of groundwater has remained at 40 percent through 2000. Starting in 2000, various regions across the United States, especially in the Western United States, saw a decrease in precipitation causing drought conditions. As these conditions have persisted, concerns have been raised regarding public and private water supplies. Many cities across the Western United States are developing plans for sustainable water supply alternatives to address concerns about climate changes and economic factors. An existing GIS based rainfall-runoff model was used to develop a robust data set for shallow alluvial aquifer recharge in stream beds as a function of time and storm event size.

Microbial Indices of Soils and Water Associated with Vegetated Treatment Areas (VTAs) from Five Animal Feeding Operations (AFOs) in South Dakota

Basic Information

Title:	Microbial Indices of Soils and Water Associated with Vegetated Treatment Areas (VTAs) from Five Animal Feeding Operations (AFOs) in South Dakota
Project Number:	2006SD74B
Start Date:	3/1/2006
End Date:	6/30/2009
Funding Source:	104B
Congressional District:	First
Research Category:	Water Quality
Focus Category:	Water Quality, Surface Water, Acid Deposition
Descriptors:	
Principal Investigators:	Bruce Bleakley, Todd P. Trooien

Publications

There are no publications.

Microbial indices of soils and water associated with vegetated treatment areas (VTAs) from five animal feeding operations (AFOs) in South Dakota

Basic Information

Title: Microbial indices of soils and water associated with vegetated treatment areas (VTAs) from five animal feeding operations (AFOs) in South Dakota
Project Number:
Start Date: 3/1/2007
End Date: 2/28/2009; (with extension for an additional year to 6/30/2009)
Funding Source: 104B
Congressional District: First
Research Category: Water Quality
Focus Category: Water Quality; surface water; wastewater.
Descriptors: None
Principal Investigators: Bruce Bleakley; Todd Trooien

Introduction: *Write a brief overall introduction to your progress/completion report.*

Nutrient and sediment loads from animal feeding operations (AFOs) can reduce the quality of surface waters and groundwaters. Basin technologies can help alleviate some of these problems, but they can be costly, and cause odor problems. The potential for development and implementation of alternative non-basin technologies interests a variety of stakeholder groups. An EPA funded grant, "Evaluating the Performance of Vegetated Treatment Areas," (Dr. Todd Trooien, P.I.), seeks to evaluate the technical and financial feasibility of vegetated treatment areas (VTAs) as a non-basin alternative for reducing nutrient and sediment loads from AFOs having less than 1,000 animal units. For this EPA grant, each of five AFOs in different areas of South Dakota have had or will have VTAs established. Performance of each VTA is being measured by sampling inflows and outflows from vegetated areas. The samples are being analyzed for nutrients (N and P), salts, sediment, and numbers of fecal coliform bacteria. Data from these measurements will allow calculation of water and salt balances, loss or gain of nutrients, removal of sediment, and fecal coliform numbers. Data will be entered in a basin model to simulate basin performance, that will be compared to measured VTA performance. Samples have been obtained from 2005 to 2009, with the Howard, SD site receiving the most attention since it has been operational the longest; some of the other sites (like the one near Claire City in Roberts County, and the one in Minnehaha County) are only becoming operational in 2009. For the EPA project, only numbers of fecal coliform bacteria are being measured. Other aspects of the microbiology of the inflow and outflow areas associated with the VTAs are not addressed, and are the focus of this 104b proposal.

Information Transfer Program: Some of the information presented here was also presented at a Stakeholders Meeting on the SDSU campus in Spring of 2010.

Data from this project will continue to be presented at such stakeholder meetings; and at field days at one or more of the VTA sites of the study.

Problem:

Nutrient and sediment loads from animal feeding operations (AFOs) can negatively impact the quality of surface waters and groundwaters. One accepted way to reduce nutrient and sediment loads from AFOs is by use of basin technologies, which are effective but can be costly, and lead to air quality problems due to unpleasant odors. The potential for development and implementation of alternative non-basin technologies interests a variety of groups, including the South Dakota Cattlemen's Association, South Dakota Farm Bureau, South Dakota Association of Conservation Districts, South Dakota State University, South Dakota Department of Agriculture, Natural Resources Conservation Service, South Dakota DENR, and cattle producers. The Iowa Cattlemen's Association (ICA) is also interested.

An EPA funded grant, "Evaluating the Performance of Vegetated Treatment Areas," (Dr. Todd Trooien, P.I.), has been underway since 2005 to the present. Its goal is evaluation of the technical and financial feasibility of vegetated treatment areas (VTAs) as a non-basin alternative for reducing nutrient and sediment loads from AFOs having less than 1,000 animal units. Each of five AFOs in different areas of South Dakota have had or will have VTAs established. Performance of each VTA will be measured by sampling inflows and outflows from vegetated areas. The samples are being analyzed for nutrients (N and P), salts, sediment, and numbers of fecal coliform bacteria. Data from these measurements will allow calculation of water and salt balances, loss or gain of nutrients, removal of sediment, and fecal coliform numbers. Data will be entered in a basin model to simulate basin performance, that will be compared to measured VTA performance.

For the EPA project, counts of *E. coli* before and after each VTA are the only measure being taken of bacterial effects on water quality in pre- and post-VTA areas. Other microbial measures affecting water quality would also be valuable, such as detecting presence or absence of toxigenic *E. coli*, such as *E. coli* O157:H7; and numbers of non-toxigenic *E. coli* in pre- and post-VTA areas at each site, to better assess whether water quality in post VTA areas is better (has lower numbers of these bacteria) than in pre-VTA areas. Also, since microbial activity can influence physical and chemical parameters of soil and water, such as whether aerobic or anaerobic processes are occurring, other measures of microbial activity would be valuable for both pre-VTA and post-VTA areas at each site, to further assess water quality in these areas. The 104b project described here is providing a more detailed and broader understanding of some microbiological issues relating to this waste management system.

Research Objectives:

For the EPA project described above, counts of *E. coli* before and after each VTA are the only measure being taken of bacterial effects on water quality in pre- and post-VTA areas. Other microbial measures affecting water quality would also be valuable, such as detecting presence or absence of toxigenic *E. coli*, such as *E. coli* O157:H7; and total *E. coli* other than *E. coli* O157:H7 in pre- and post-VTA areas at each site, to better assess whether water quality in post VTA areas is better (has lower numbers of these bacteria) than in pre-VTA areas; or if the presence of *E. coli* diminishes across the landscape as one moves further away from the feedlot across the VTA. Also, since microbial activity can influence physical and chemical parameters of soil and water, such as whether aerobic or anaerobic processes are occurring, other measures of microbial activity would be valuable for both pre-VTA and post-VTA areas at each site, to further assess water quality in these areas.

Differences in the microbiology of soils in the inflow and outflow areas associated with VTAs is being assayed by measuring the following microbial indices: (a) Soil respiration; (b) oxidation/reduction potential; (c) heterotrophic microbial activity; (d) soil bacterial diversity; (e) numbers of total culturable *E. coli* in water ; and (f) presence or absence of culturable pathogenic *E. coli* O157:H7. Data for these microbial indices will be added to the data sets from the EPA project, to get a better idea of the number and activity of microbes in soils associated with inflow and outflow areas.

Methodology:

Soil respiration was initially measured in the field with a portable soil respirometer. The assay is now being done on samples in the lab. Both plant root respiration and microbial respiration can contribute to the values obtained in the field (Alef, 1995a; Beck, 1996). Oxidation/reduction potential of wet soils are being assayed with a portable meter fitted with an oxidation/reduction electrode (Zausig, 1995). Heterotrophic microbial activity is being evaluated by assaying ability of soil samples to hydrolyze fluorescein diacetate (Alef, 1995b). Soil bacterial diversity is being assayed in two ways: (1) by use of Biolog EcoPlates that assay the ability of a soil microbial community to utilize different carbon sources (Insam and Goberna, 2004) ; and (2) by molecular methods, using polymerase chain reaction (PCR) and denaturing gradient gel electrophoresis (DGGE) (Hastings, 1999; Baker and Harayama, 2004). We are evaluating the numbers of *E. coli* of humans and animals in both inflow and outflow water. Water samples have been analyzed by counting coliforms on mFc agar, then picking these colonies over onto Chromagar plates that are more specific in identifying colonies of *E. coli*. A serologic test is being used to determine if water samples contain *E. coli* O157:H7.

Principal Findings

i) Assessing the redox state of the soil and/or water in inflow versus outflow areas: Because of dry conditions throughout the state for most of 2006 including at the Howard site, redox potential was not measured at Howard or elsewhere for that year. At the end of 2007, initial readings were taken at Howard in the fall when standing water was present at several of the sampling areas for this site. Using a portable redox electrode, redox values were found to be negative at most of the water saturated sites, with negative values ranging from -120 millivolts to -250 millivolts. These negative readings indicate that the sample sites were largely or entirely anaerobic, so that processes such as fermentation, sulfate reduction, and denitrification were likely occurring. In June of 2008, soon after major rainfall events, redox electrode readings were again taken in Howard when the soil was moist but not water saturated. Readings at all sample sites were positive, ranging from 124 to 280 millivolts, indicating that the soils were largely aerobic and conducive to aerobic microbial processes and plant root metabolism. Engineering changes occurred in the layout of the drainage pipes at the Howard site between 2007 and 2008 to further spread flow of water from the feedlot over the landscape, and may be promoting more positive redox values/aerobic conditions over the entire landscape, even during wet periods.

Some problems in taking the redox measurements in situ have included breakage of the delicate and expensive redox electrodes in heavy clay soils/clay pans that are often hard to detect in the field. Also, it has been more difficult to access and take measurements during wet periods in the field (the only times when redox measurements are meaningful in the field) than we initially expected. We are now making redox measurements on soil samples brought back to the lab, where measurements can be made more easily.

The hypothesis being tested is that redox values will be more negative in areas having largest amounts of organic load from the AFOs; where microbial respiration will have depleted oxygen gas concentration and led to anaerobiosis. By relying more heavily on redox measurements made in the lab, we will be able to generate more data on more soil samples from the field sites, and better evaluate this hypothesis. About half the soil samples so far obtained have had redox measured in the lab; the remaining samples will be completed in 2010.

ii) Assessing the activity of microorganisms in soil and/or water in inflow versus outflow areas by use of a portable soil respiration monitor (for drier soils only): Carbon dioxide measurements were made at the Howard site in pre VTA and post VTA areas from late summer to fall of 2006. Preliminary analysis of respiration data (not yet statistically analyzed) suggests that there were not significant differences in CO_2 production between pre VTA and post VTA areas on the dates sampled, possibly because the respiration of grass roots was so dominant and equivalent in both areas. It is clear from data obtained to date that soil temperature is a major determinant of soil respiration, more so than moisture. Soil temperatures around 21^o C gave respiration values (g CO_2/m^2/hour) ranging from 2 to 6; while soil temperatures around 8^o C gave values that were three to eight times lower.

During 2007 and 2008, soil respiration readings at Howard were taken in summer and fall, (after the soil had dried enough to be assayed). Values were no higher than 2006, especially in the summer. How soil respiration values correlate to FDA hydrolysis measures, and to soil temperature and moisture, needs to be examined.

We have established a standard assay for soil respiration of samples brought back to the lab (where the contribution of living plant roots can be eliminated; so that measured respiration will be only microbial).

We are testing the hypothesis that respiration will be higher in inflow areas compared to outflow areas, due to greater organic matter load stimulating microbial respiration in the inflow areas than in the outflow areas. Data obtained to date from the Howard site do not clearly support this, but work over the next year including data from Howard and the other VTA study sites will help decide whether the hypothesis is supported.

About half the soil samples so far obtained have had soil respiration measured in the lab; the remaining samples will be completed in 2010.

iii) Assessing the heterotrophic activity of microorganisms in soil and/or water in inflow versus outflow areas by use of a spectrophotometric assay of fluorescein diacetate (FDA) hydrolysis in inflow vs. outflow soil and/or water: Soil samples from pre VTA and post VTA areas of the Howard site collected from 2006, 2007, 2008, and 2009 have been analyzed for FDA activity, (with some samples yet to be processed); but data have not yet been statistically analyzed. It is clear that different sites at Howard have different FDA hydrolysis values over time, and there are differences between sites. How these values correlate to values of soil respiration, temperature, and soil moisture needs to be examined.

We hypothesize that FDA hydrolysis will be greater in inflow areas than outflow areas, since higher amounts of organic matter in inflow areas should stimulate more microbial activity than in outflow areas. Data obtained to date do not clearly support this, but data analysis completed in 2010 will help decide whether this hypothesis is supported.

iv) Assessing soil bacterial diversity in inflow versus outflow soil and water by means of denaturing gradient gel electrophoresis (DGGE) to compare number of gel bands obtained from samples from inflow versus outflow soil and water, employing 16S ribosomal DNA primers and polymerase chain reaction (PCR) methodology: This is a molecular method that will be able to assess both the culturable and non-culturable bacteria in soil samples. Soil samples from pre VTA and post VTA areas of the VTA sites will be analyzed using DGGE.

An initial DGGE gel running samples from the Sturgis, SD site was shown in last year's progress report. Work on samples from the Brandon, SD and Howard, SD sites has since been completed, and is shown in Fig. 1 and Fig 2.

At the Brandon, SD site, samples from different parts of the VTA landscape were labeled by their orientation to pipes (P2, P2, and P3) emerging from the large earthen berm separating the VTA from the feedlot, and by the smaller berms (B1, B2, B3, and B4) in the VTA that water flows across after emerging from the pipes. As can be seen in Fig.1, there are some differences in presence or absence of bands, and in band intensity, between samples from different sites. Similarly, for the Howard site (Fig. 2), differences in presence or absence of bands and in band intensity are evident in samples from the sme site in different years, and between sites in the same year. Each band likely represents one specific DNA sequence of a numerically dominant prokaryote in the soil (including both culturable and non-culturable prokaryotic groups). Detailed analysis of this and other DGGE gels from these sites will be completed in 2010.

We hypothesize that bacterial diversity will be greater in inflow versus outflow areas, due to greater amounts and types of organic matter available in the inflow areas; and to more likely frequent periodic aerobic/anaerobic transitions in the inflow areas, versus the outflow areas.

v) Assessing soil bacterial diversity in inflow versus outflow soil and water by means of carbon source utilization profiles of soil microbial communities in the inflow and outflow areas using Biolog EcoPlates: Soil samples from pre VTA and post VTA areas of the Howard and Sturgis sites have been/are being analyzed using Biolog plates, but have not yet been statistically analyzed. We will contact Dr. Mike Lehman of the USDA NCAUR lab in Brookings for aid in the statistical analysis, since he has had extensive background and experience in analyzing Biolog results for environmental samples.

We hypothesize that bacterial diversity will be greater in inflow versus outflow areas, due to greater amounts and types of organic matter available in the inflow areas; and to more likely frequent periodic aerobic/anaerobic transitions in the inflow areas, versus the outflow areas.

vi) Evaluating the numbers of specific fecal coliforms and/or potential pathogens of humans and animals in both inflow and outflow soil and water by use of several agar media that are selective and differential for specific bacterial types: Water samples from the Howard site have been analyzed by counting coliforms on Mfc agar, with numbers ranging from 10^4 to 10^5 CFU coliforms/ml in the pre-VTA and post-VTA samples. Picking these colonies over onto Chromagar plates has shown for 2006, 2007, and 2008 samples that most (in excess of 50%) but not all of the initial isolated colonies were *E. coli* in the pre-VTA and post-VTA areas. In 2006 water samples from the river in the area behind the post-VTA area, fecal coliforms were found in lower numbers (10^2 CFU coliforms/ml) than in pre and post VTA areas, with from 20% to 70% of those in the river verified as *E. coli*. For 2006 samples we detected presence of *E. coli* O157:H7 in pre-VTA and post-VTA water samples, but not in river samples situated after the post-VTA area. This indicates that the VTA is effectively removing *E. coli* strains of the greatest health concern before they reach the river.

For Howard in 2007, with water samples from the river in the area behind the post-VTA area, fecal coliforms were found in lower numbers than in pre-VTA and post VTA areas, but for some sampling dates the numbers in the river were only one log less than in the post VTA area. For 2007 samples we detected presence of *E. coli* O157:H7 in pre-VTA and post-VTA water samples, but not in river samples situated after the post-VTA area, again indicating that the VTA is effectively removing *E. coli* strains of the greatest health concern before they reach the river. However, there were times where cattle were grazing beside the river, so that numbers of E. coli in the river cannot be totally tied to the VTA but may instead originate from these grazing cattle near the river bank.

Results of samples for 2008 from the Howard and Sturgis sites are shown in Table 1. The fecal coliform numbers at the Howard site were similar to counts from previous years in the VTA areas preceding the river. Counts from the river were very low or zero, indicating that the VTA is succeeding in helping to reduce the fecal coliform load entering the river.

In 2009, we concentrated on sampling from the creek that is close to the Howard VTA site, for fecal coliform counts. Based on previous years of data, we knew that surface flow of water carrying sediment in the VTA would likely have high fecal coliform counts. We wanted to see if fecal coliform counts in the nearby creek were similar or lower than in the VTA. The data (Table 1) strongly suggest that the creek is wel protected from elevated fecal numbers. Most of the fecal coliform counts of the creek water column (taken under the bridge that runs beside a gravel road) were at or near zero. The water column was almost always clear, with little or no suspended solids visible to the unaided eye. When the bottom sediment was sampled, fecal coliform counts were higher than for the water column, but still not extremely high (Table 1).

Significance

Management issues that could be impacted by results of the study include management of undesirable odors affiliated with the AFOs; extent of anaerobic versus aerobic microbial processes in inflow versus outflow areas; ability of the VTAs to filter out specific pathogenic bacteria such as *Escherichia coli* O157:H7 ; amount of CO_2 gas produced from soil in pre-VTA versus post-VTA areas; and overall heterotrophic microbial activity and microbial community diversity in soil and water in pre-VTA versus post-VTA areas as a measure of the ability of the VTA in removing organic compounds from the AFO inflow. Results could influence future management decisions for AFOs making use of VTAs; and afford information to better understand how to manage microbial populations in the soils affiliated with the VTAs to achieve desirable air and water quality in these areas.

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Zausig, J. 1995. Redox potential measurement, pp. 274-276. *In* K. Alef and P. Nannipieri (eds.), Methods in applied soil microbiology and biochemistry. Academic Press, Inc., San Diego, CA.

Publication Citations
Bleakley, B.H. 2007. Microbial indices of soil and water. South Dakota Water Resources Institute Water News. January 2007, volume 3, number 1.

Student Support:
Number of students supported with section 104b: 2006-2010
One Ph.D. graduate student (summer 2006 and 2007 support)
Five undergraduate students (2007 to present)

Student Information Table

	Total	Major
Undergrad.	5	(2) Microbiology; (1) Biology; (2) Pre-pharmacy
Masters	0	
PhD.	1	Plant Science
Post-Doc.	0	
Total	6	

Notable Awards and Achievements:

Table 1: Fecal coliform counts: 2009

I) Howard, SD:

Date: 6/27/09: Location: Creek under bridge by road
Count: 0.0 CFU/ml

Date: 07/05/09: Location: Creek under bridge by road
Count: 0.0 CFU/ml

Date: 10/07/09: Location: Creek under bridge by road
Count: 0.0 CFU/ml

Date: 10/08/09: Location: Creek under bridge by road
Count: 0.0 CFU/ml

Date: 10/15/09: Location: Creek under bridge by road
Count: 2.6 CFU/ml

Date: 10/22/09: Location: Creek under bridge by road
Count: 0.0 CFU/ml (water only; no sediment)
1.04×10^3 CFU/ml (water with bottom sediment); with 80% of isolates verified *E. coli* on Chromagar

Date: 10/29/09: Location: ¾ toward creek; near trees
Count: 1.106×10^4 CFU/ml; with 100% of isolates verified as *E. coli*

Location: Creek under bridge by road:
8.0×10^1 CFU/ml; with 25% of isolates verified *E. coli* on Chromagar

II) Sturgis, SD:

Date: 6/28/09
Count: 0.0 CFU/ml in each chevron

Fig. 1: Brandon Gel (All samples collected 5-19-09)

Lane	Site
1	B1 P1
2	B1 P2
3	B1 P3
4	B2 P1
5	B2 P2
6	B2 P3
7	B3 P1
8	B3 P2
9	B3 P3
10	B4 P1
11	B4 P2
12	B4 P3

This gel was run with a 40% to 75% gradient at 70 V for 18 hours at 60 °C

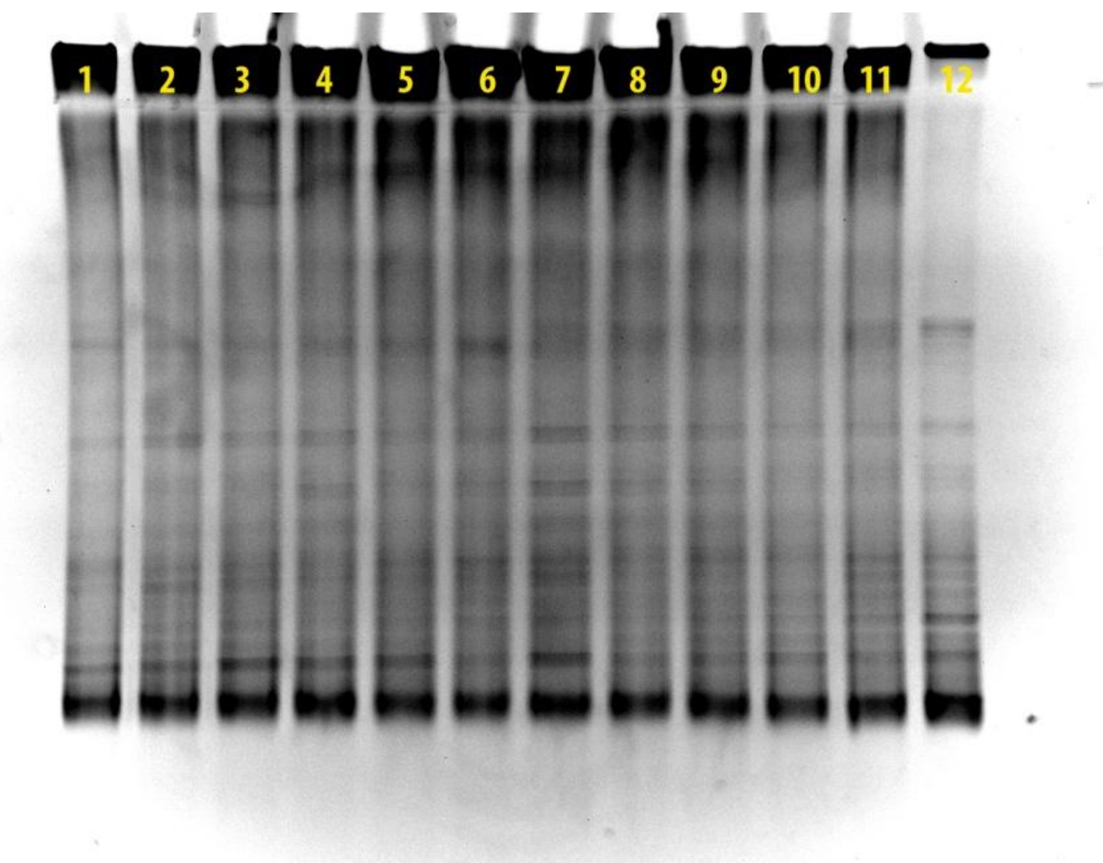
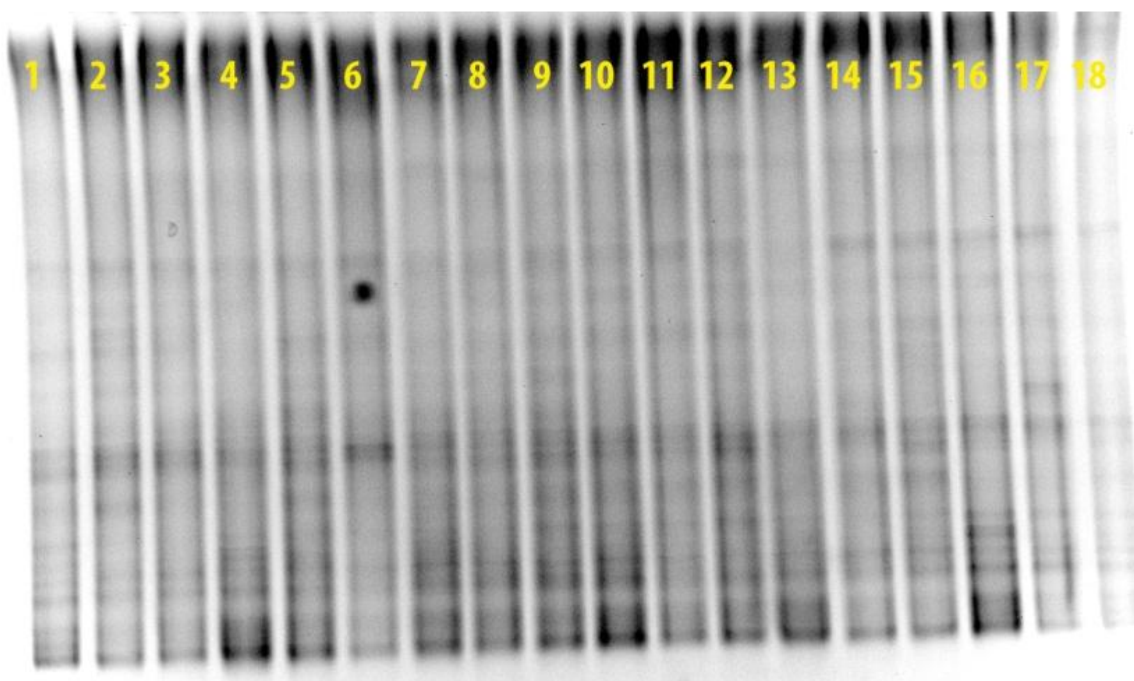


Fig. 2: Howard Gel (All samples collected during August of different years)

Lane	Site	Year Collected
1	1	2006
2	1	2007
3	1	2008
4	4	2006
5	4	2007
6	4	2008
7	7	2006
8	7	2007
9	7	2008
10	11	2006
11	11	2007
12	11	2008
13	12	2006
14	12	2007
15	12	2008
16	14	2006
17	14	2007
18	14	2008

This gel was run with a 40% to 75% gradient at 70 V for 18 hours at 60 °C



Alternative Irrigation Water Management Strategies to Conserve Water

Basic Information

Title:	Alternative Irrigation Water Management Strategies to Conserve Water
Project Number:	2007SD105B
Start Date:	3/1/2007
End Date:	6/30/2009
Funding Source:	104B
Congressional District:	First
Research Category:	Engineering
Focus Category:	Irrigation, Water Use, Models
Descriptors:	
Principal Investigators:	Hal D. Werner, Todd P. Trooien

Publications

1. Heeren, Derek M., Hal D. Werner, and Todd P. Trooien. 2007. Evaluation of Deficit Irrigation Strategies for Corn. ASABE Regional Meeting. Fargo, ND.
2. Heeren, Derek M. 2008. Evaluation of Deficit Irrigation Strategies for Corn. MS Thesis. South Dakota State University. Brookings, SD.
3. A paper based on this research has been accepted for the IA International Conference in Anaheim, CA. Additional manuscripts are also being prepared.
4. Heeren, DM, HD Werner, and TP Trooien. 2008. Evaluation of deficit irrigation strategies for corn. In Proceedings of the Irrigation Association Technical Conference. Irrigation Association, Falls Church, VA.
5. Heeren, DM, HD Werner, TP Trooien, and N Klocke. In review. Evaluation Of Deficit Irrigation Strategies For Corn. Submitted to Irrigation Science.

USGS 104b Annual Report

Title: Alternative Irrigation Water Management Strategies to Conserve Water

Investigators: Dr. Hal Werner and Dr. Todd Trooien

Project reporting period: March 1, 2009 to February 28, 2010

Introduction:
This project is a continuation project begun in 2006 with the goal of outlining the management and information required to develop an automated irrigation management system for center pivot irrigation that will perform scientific irrigation scheduling. The expected outcome is that farmers will save water and energy, improve production and protect the environment. This specific research described the model to be used within the scheduling program to evaluate strategies then optimize the scheduling of the irrigation water.

Project Information:

SDSU Management Software, developed by Oswald (2006) and modified by Heeren (2008), was used to simulate center pivot irrigation and corn yield. Simulations were performed on seven locations across the Great Plains, for 16 to 24 years of historical weather data for each location, 30 irrigation strategies, three soil types, and three pumping rates. A total of 40,000 simulations were performed. Output files included data for ET, soil water levels, irrigation amounts, and yield.

The SDSU Management Software was set up to simulate a center pivot irrigator with an effective length of 418 meters (1370 feet) , covering 55 hectares (135 acres). The maximum speed was set to one full revolution in 12 hours. Irrigation application efficiency was assumed to be 90%. Evapotranspiration was calculated with the tall reference Penman-Monteith equation (Allen et al., 2005) and dual crop coefficients for corn (Allen et al., 2007). The yield ratio was calculated with a normalized transpiration ratio (Steduto et al., 2006).

The locations and their associated planting dates for corn are shown in Table 1. All simulations ended on September 30th. Years of available weather data (downloaded from the High Plains Regional Climate Center, 2007) are also shown.

Table 1. Locations where simulations were performed.

Location	Planting Date	Season Length (days)	Years
Akron, CO	April 1st	180	1983 – 2006
Brookings, SD	April 15th	165	1983 – 2006
Nisland, SD	April 15th	165	1988 – 2006
Oakes, ND	May 1st	150	1990 – 2006
Ord, NE	April 1st	180	1983 – 2006
Rock Port, MO	April 1st	180	1991 – 2006
St. John*, KS	April 1st	180	1985 - 2006

*weather station at the Sandyland field station.

Pumping rates included 37.9, 50.5 and 63.1 L/s (600, 800, and 1000 GPM). Three soil types were selected to represent a range of soils. Soil types included available water holding capacity (WHC) values of 37.9, 50.5, and 63.1 mm/m (1, 1.5, and 2 in/ft), as defined in Equation 1.

$$WHC = (\theta_{FC} - \theta_{WP}) * 1000 \qquad (1)$$

Here, WHC is in mm/m, θ_{WP} is the volumetric water content at the wilting point, and θ_{FC} is the volumetric water content at field capacity. For irrigation scheduling purposes, it is helpful to define soil water content as a percentage, with zero being the soil moisture at the wilting point and 100% being the soil moisture at field capacity. This plant available water (AW) is the amount of water available to the crop and is calculated by Equation 2.

$$AW = (\theta - \theta_{WP}) / (\theta_{FC} - \theta_{WP}) * 100 \qquad (2)$$

Here, AW is the available water (%), and θ is the actual volumetric water content. An irrigation strategy offers a guideline for making irrigation decisions. A method was needed to numerically describe an irrigation strategy so that strategies could be changed and tested easily. An irrigation strategy was defined by the minimum available water (MAW) as it varies throughout the season. This concept is similar to the maximum allowable depletion (MAD), with MAW = 100 – MAD. Irrigation events were triggered when the soil directly in front of the pivot dried to the MAW.

Thirty strategies were defined for the simulations. These were inputs for the SDSU Management Software, which ran center pivot simulations for each strategy. The general shape of most of the strategies required higher AW levels mid-season and lower AW levels early and late-season. This is based on the observed effects of stress timing, showing that corn is more sensitive to water stress during flowering than the vegetative and yield formation phases of development (Doorenbos and Kassam, 1979).

Each strategy was defined by timing parameters (defining the early and middle stages of the season) and correlating MAW parameters. A strategy can be conveniently labeled by the MAW values for early, middle, and late season. Many strategies have similar timing parameters, although “30-60-30 extended” has a longer peak than normal. Based on the parameters, the MAW for any point in the season can be determined, as illustrated in Figure 1.

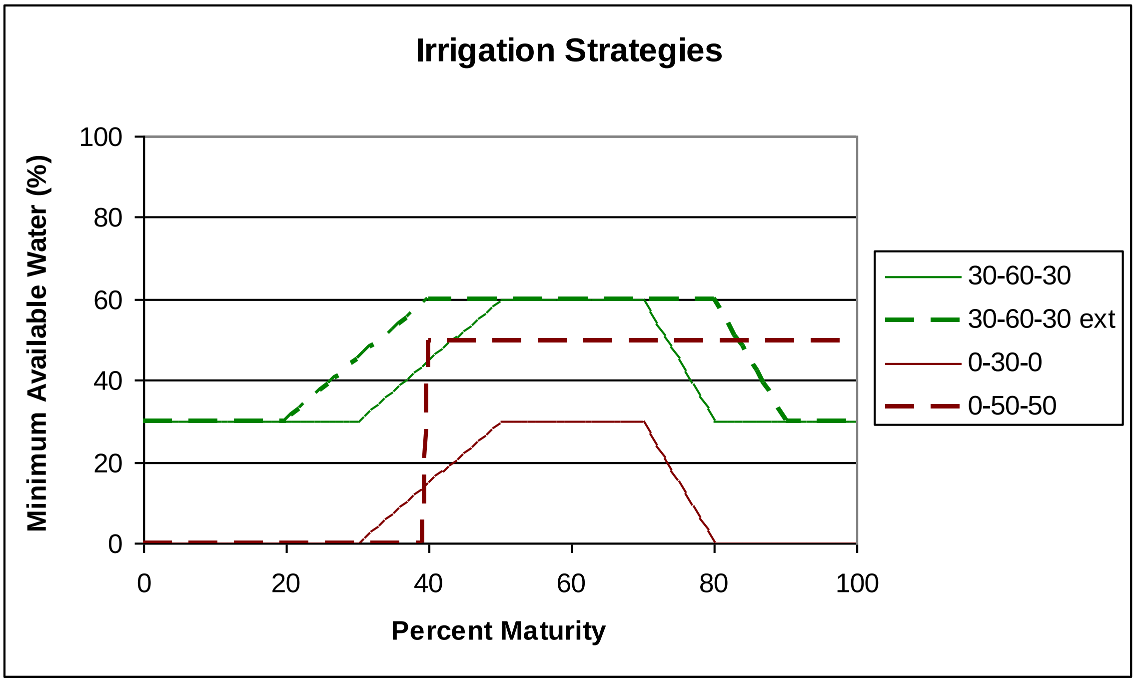


Figure 1. Selected irrigation strategies. Percent maturity expresses the ratio of days after planting to total days in the growing season.

The center pivot SDSU Management Software divides a circular field into 60 sections, each a 6˚ pie shape with its own water balance. Initial AW was set to 80% at the beginning of each season for each location. (This assumption was tested against a 20% initial AW at a dry site. While seasonal irrigation changed slightly, the shape of the yield-irrigation graph remained the same.)

The SDSU Management Software was modified to graph the mean, mean +/- one standard deviation, and the maximum/minimum AW for the 60 soil water balances. Figure 2 illustrates the variability in AW throughout a corn field for a particular season at Rock Port, MO. To account for this spatially variability, yield was calculated for three equidistant locations within the field and the results were averaged for each simulation.

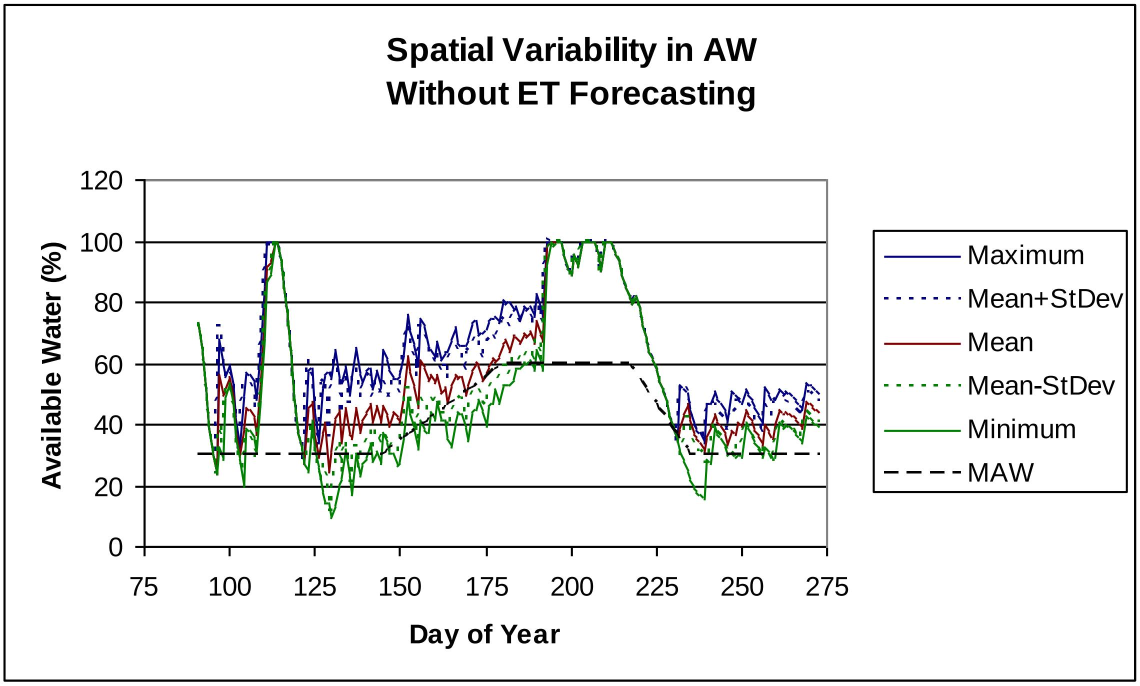


Figure 2. Example of spatial variability in AW without ET forecasting. Rock Port, MO, 1992 (driest year in dataset: 370 mm seasonal precipitation), 125 mm/m WHC, 63.1 L/s pumping rate, 30-60-30 irrigation strategy.

It was noted that ET forecasting, originally included in the SDSU Management Software, was not necessary for good irrigation management. While the drier portions of the field are often below the MAW line, high enough MAW values can be selected to achieve a desired result. The mean AW is maintained above the MAW line, if the system is able to keep up with ET demand.

Results

Water Relationships

For each site, the yield ratio is generally proportional to transpiration (Figure 3). Crops at sites with greater evaporative demand have a smaller increase in yield for each unit increase in transpiration.

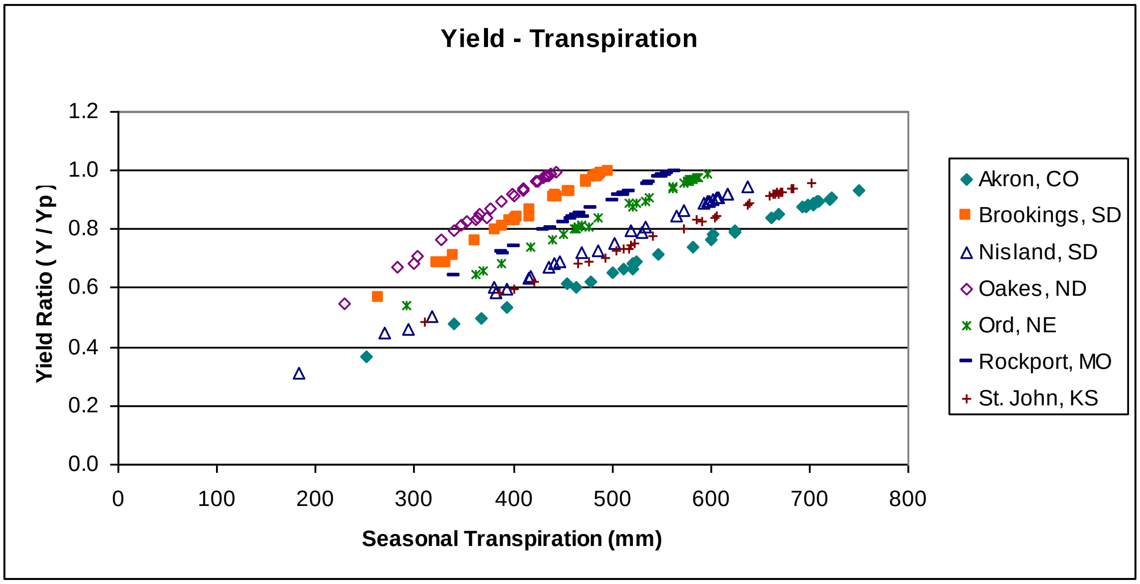


Figure 3. Yield-transpiration relationship for each site. Each point represents an irrigation strategy. Data is averaged across all WHCs, pumping rates, and years.

Yield ratio was also plotted against seasonal irrigation values in order to evaluate irrigation strategies. Figure 4 shows the summary of the results, with all 30 strategies represented for each location.

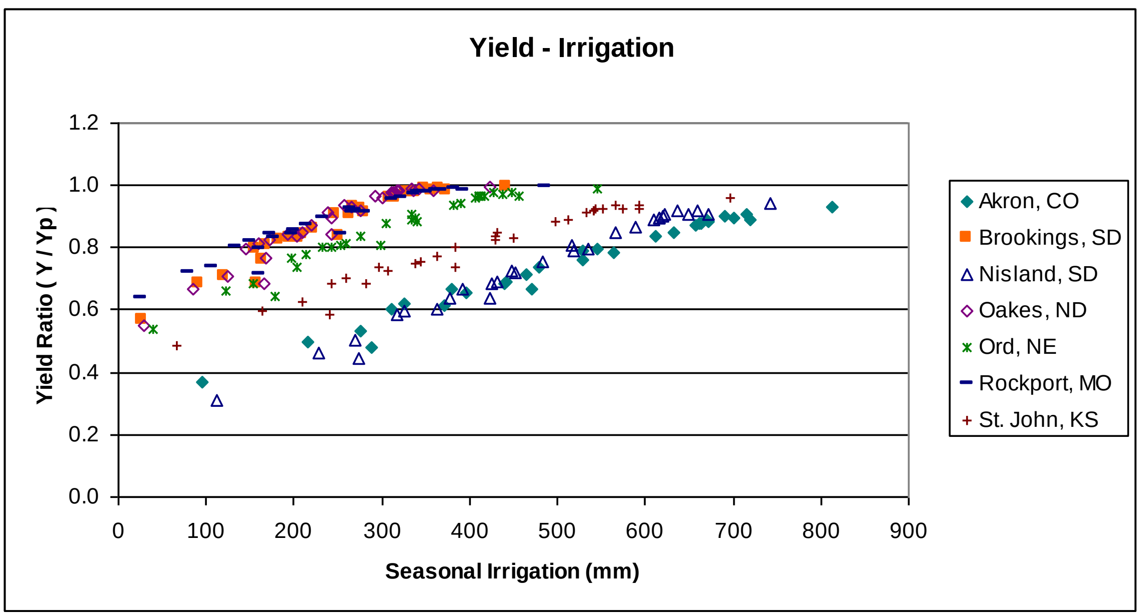


Figure 4. Yield-irrigation relationship for each site. All WHCs, pumping rates, and years. Net seasonal irrigation is used, based on a 90% application efficiency.

Sites with lower rainfall and higher ET demand showed greater yield loss for deficit irrigation strategies and required more water for high yields. The yield-irrigation relationship is relatively linear for each location until maximum yield is approached.

Figure 5 illustrates the differences among three yield-water relationships. The yield-transpiration line was nearly linear. Evaporation introduced more variability, which was shown in the yield-ET relationship. The precipitation plus irrigation was substantially different from ET. This difference was likely due to runoff and deep percolation losses. The amount of water loss generally increased with the amount of irrigation applied, and some strategies had more loss than other strategies with similar yields.

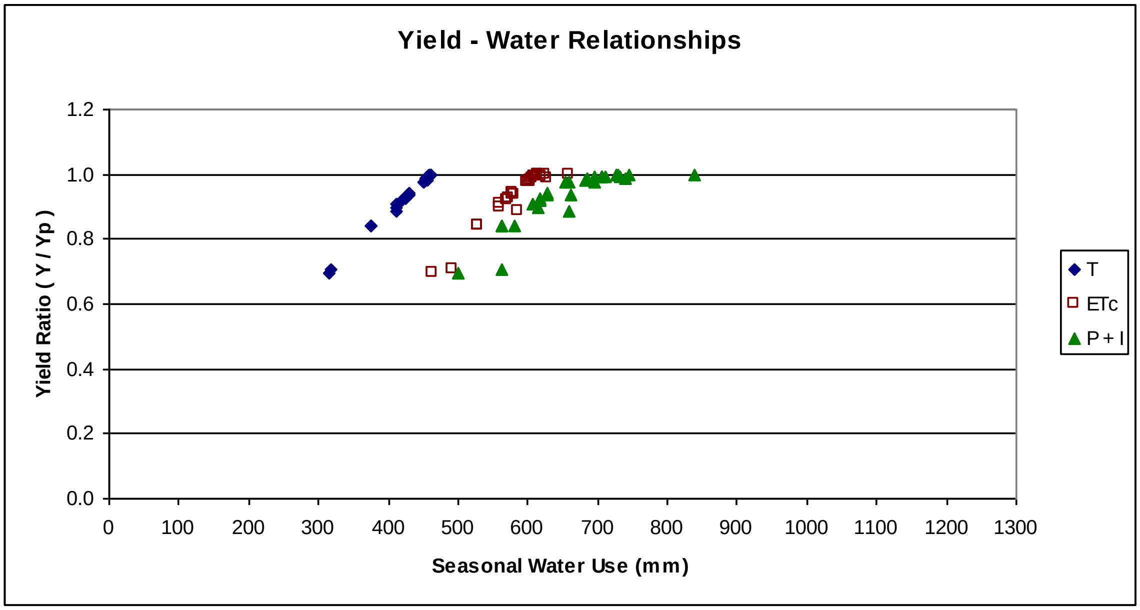


Figure 5. Yield-transpiration, yield-actual crop evapotranspiration, and yield-precipitation/irrigation relationships. Oakes, ND, 2005, 83 mm/m WHC, 63.1 L/s pumping rate.

Besides total seasonal precipitation, the timing of the precipitation is also important when considering crop water stress. Figure 6 shows climagraphs comparing average monthly reference ET to rainfall during the growing season for each location (based on weather data used for this project). While the curve for precipitation follows the ET curve for Rock Port, MO; Nisland, SD, and Akron, CO, reach peak rainfall two months before peak monthly ET. Climate trends can indicate the potential for mid to late-season water stress for a given location.

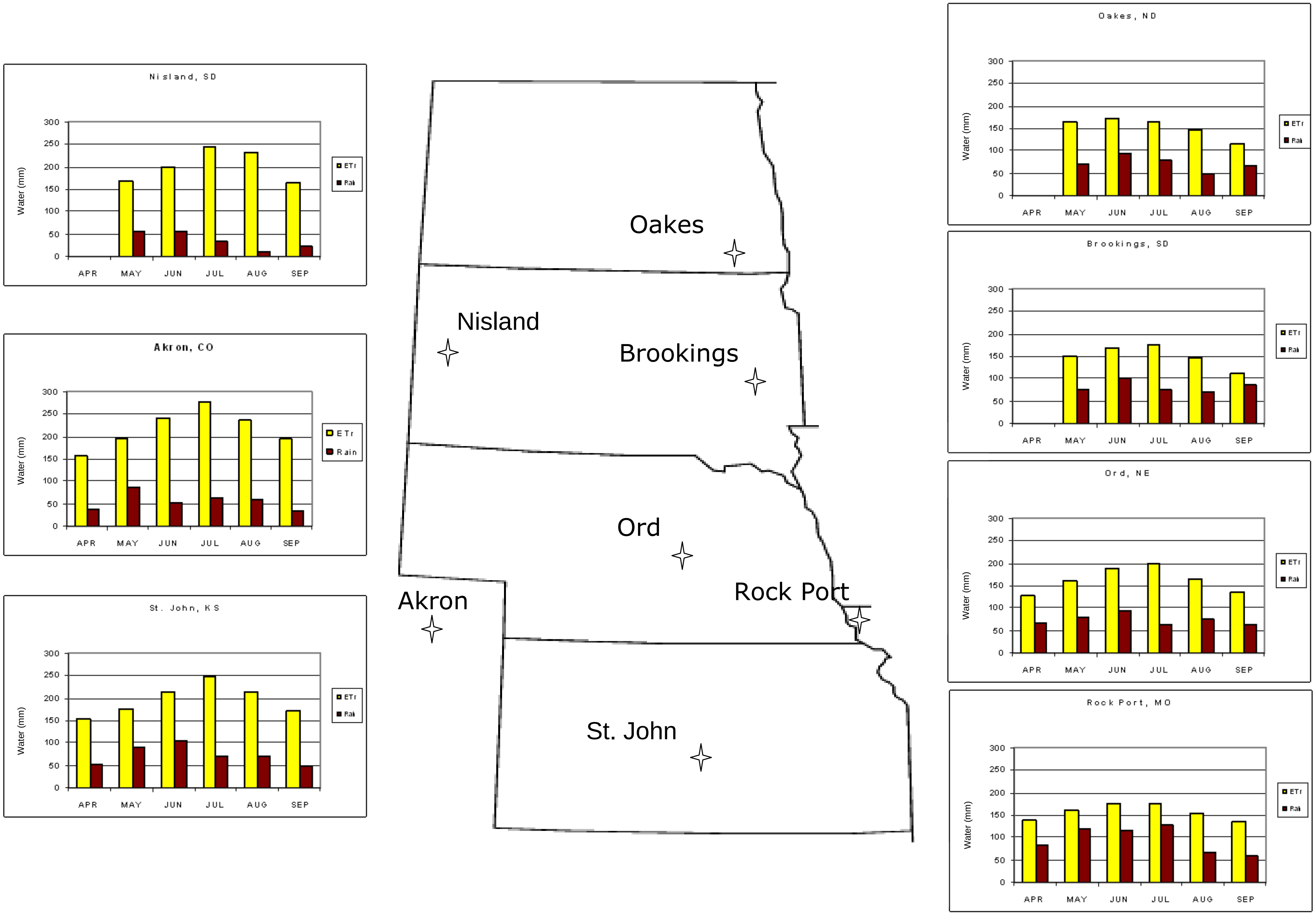


Figure 6. Climagraphs showing average monthly reference ET and rainfall (mm) for each location.

Recommended Strategies

The yield-irrigation relationship is the most relevant of the yield-water relationships for evaluating irrigation strategies. An example yield-irrigation graph is show in Figure 7, with strategies of interest labeled.

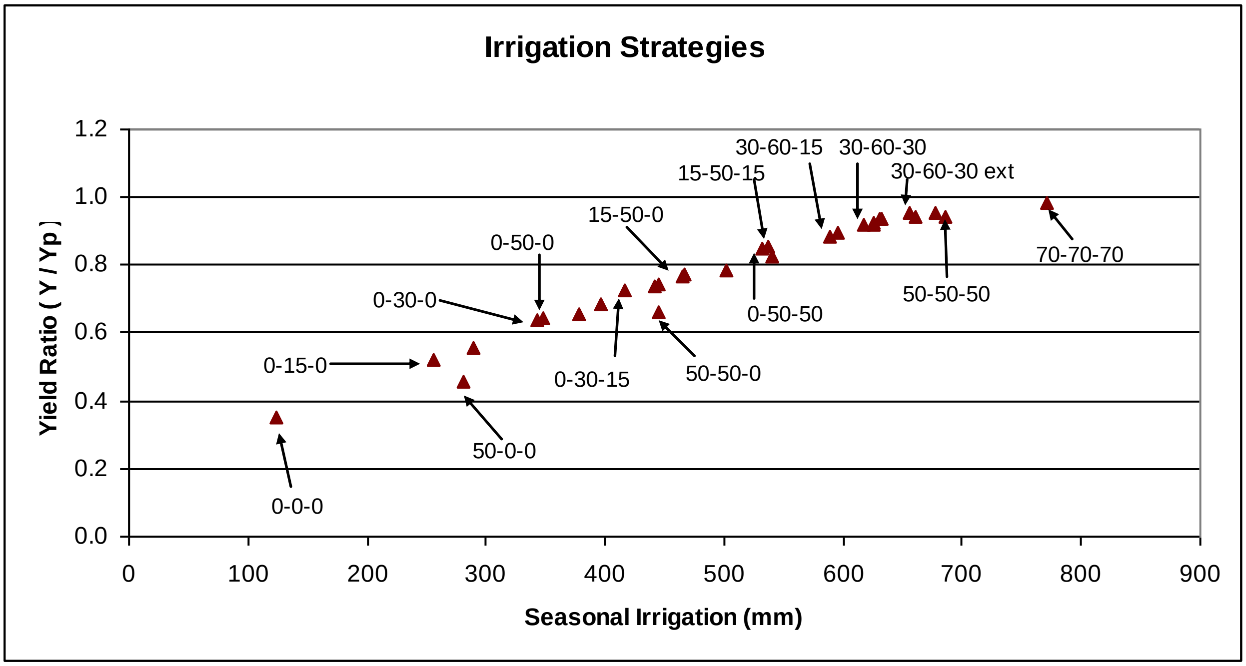


Figure 7. Example of yield-irrigation relationship with selected strategies labeled. Nisland, SD, all years, 83 mm/m WHC, 63.1 L/s pumping rate.

The basic shape and distribution of points (in relation to each other) in Figure 7 is representative of plots for all simulations. The 0-0-0 strategy, which irrigated only when the wilting point was reached, provided a lower bound on the data set. The 70-70-70 strategy, providing an upper limit on the data set, produced a minimal increase in yield (compared to similar strategies) for the large amount of applied water it required. The 30-60-30 strategy was the original strategy in the SDSU Management Software.

The historical strategy of 50-50-50 resulted in high yields, but it also consistently used more water than other strategies with similar yields. The 50-0-0 and 50-50-0 strategies, representing situations where available irrigation water was used up before the end of the season, consistently performed poorly. This indicates the benefit of good irrigation management, resulting in higher yields for a given supply of water.

Water use efficiency (WUE) is a concept that compares crop production to water used, and has been defined in numerous ways. For pragmatic reasons, WUE here will be considered relative grain yield per unit of irrigation. The best irrigation strategies result in high WUE; that is, they result in a large yield for a given amount of irrigation. On a yield-irrigation graph, “High WUE” strategies are the points above and left of the trend. The High WUE strategies in figure 12 performed well across locations, soil types and pumping rates.

The 0-50-50 and 0-30-15 strategies resulted in High WUE. This indicates that delaying irrigation early in the season (unless wilting point is reached), a deficit strategy that is relatively easy to implement, results in good water use efficiency. Yield and irrigation data for these and other strategies are shown in Table 2.

Table 2. Yield ratio and seasonal irrigation (mm) for High WUE strategies. Data is averaged over all soil types, pumping rates, and years.

Strategy	Akron, CO	Brookings, SD	Nisland, SD	Oakes, ND	Ord, NE	Rock Port, MO	St. John, KS
30-60-30 ext	0.903	0.987	0.920	0.988	0.976	0.986	0.937
	691	348	637	333	428	362	567
30-60-30	0.875	0.976	0.891	0.977	0.960	0.974	0.913
	656	328	610	311	406	336	533
30-60-15	0.838	0.959	0.848	0.963	0.939	0.953	0.886
	611	308	567	293	381	312	497
15-50-15	0.797	0.929	0.806	0.936	0.908	0.927	0.847
	544	268	516	257	335	264	432
0-50-50	0.791	0.906	0.793	0.897	0.888	0.920	0.839
	530	264	519	243	334	269	429
15-50-0	0.740	0.906	0.728	0.914	0.878	0.897	0.805
	480	246	447	238	305	231	383
0-30-15	0.668	0.827	0.668	0.826	0.801	0.841	0.736
	380	183	392	172	232	172	297
0-50-0	0.622	0.810	0.594	0.812	0.781	0.820	0.705
	326	167	325	159	213	149	260
0-30-0	0.605	0.794	0.584	0.794	0.764	0.801	0.687
	312	156	318	146	197	134	244
0-15-0	0.498	0.682	0.463	0.670	0.659	0.720	0.596
	215	91	228	86	123	79	163

Data from Table 2 (or yield-irrigation graphs) can be used for long term planning. As a simple example, consider a corn producer in Nisland, SD, with enough irrigation water to apply 320 mm (13 in) of irrigation water on 55 hectares (135 acres) with his center pivot irrigator. Would it be beneficial for him to apply 640 mm on half of his field, and leave the other half fallow? According to the table, yield ratios of 0.92 and 0.58 could be expected on average. Since 0.58 * Y_p * 55 hectares is greater than 0.92 * Y_p * 27.5 hectares, deficit irrigation is preferred to full irrigation in this case. In fact, similar results to this question would be found for all locations in this study, where average seasonal precipitation exceeds the amount of water typically lost to evaporation (when planting more acres, the benefit from rainfall outweighs the increased evaporative losses). Planting one half the field to a dryland crop (instead of fallow), however, could change the results.

For practical management purposes, the many strategies in Table 6 are not necessary. Of the High WUE strategies, four were selected that resulted in good spacing and covered a range of deficit and full irrigation conditions. Recommended deficit irrigation strategies are 15-50-0, 0-30-0, and 0-15-0 for minimal, moderate, and severe water restrictions. The recommended maximum yield strategy is 30-60-30 extended for Akron, CO, Nisland, SD, Ord, NE, and St. John, KS. For Brookings, SD, Oakes, ND, and Rock Port, MO, where the 30-60-30 extended provided little yield benefit for the extra water required, the recommended maximum yield strategy is 30-60-30. These strategies will be incorporated into the SDSU Management Software. Producers can select the best strategy based on the amount of water available to them, and have the option of changing strategies mid-season due to atypical rainfall or other factors.

Simulation data from the recommended maximum yield strategies were compared to results from a traditional strategy (50-50-50). Water savings and changes in relative yield are reported in Table 3.

Table 3. Benefit of recommended maximum yield strategies. All WHCs, pumping rates, and years.

		Akron, CO	Brookings, SD	Nisland, SD	Oakes, ND	Ord, NE	Rock Port, MO	St. John, KS
I (mm)	Traditional	720	372	671	359	456	392	593
	Recommended	691	328	637	311	428	336	567
	Change	-29	-44	-34	-47	-27	-56	-26
Y / Y_p	Traditional	0.892	0.983	0.910	0.984	0.968	0.981	0.924
	Recommended	0.903	0.976	0.920	0.977	0.976	0.974	0.937
	Change	0.011	-0.007	0.011	-0.007	0.008	-0.007	0.013

Annual Variation

Each irrigation strategy resulted in a different yield ratio and irrigation use for each year. Figure 8 shows error bars (standard deviation) on a yield-irrigation plot for both an arid and a sub-humid climate. There was more annual variation in irrigation use for strategies with higher water use. There was more annual variation in yield for strategies with lower water use. This information is valuable for risk management. For example, a deficit irrigation strategy may be economically beneficial on average, but the producer would have to be willing to accept greater variability in yield from year to year.

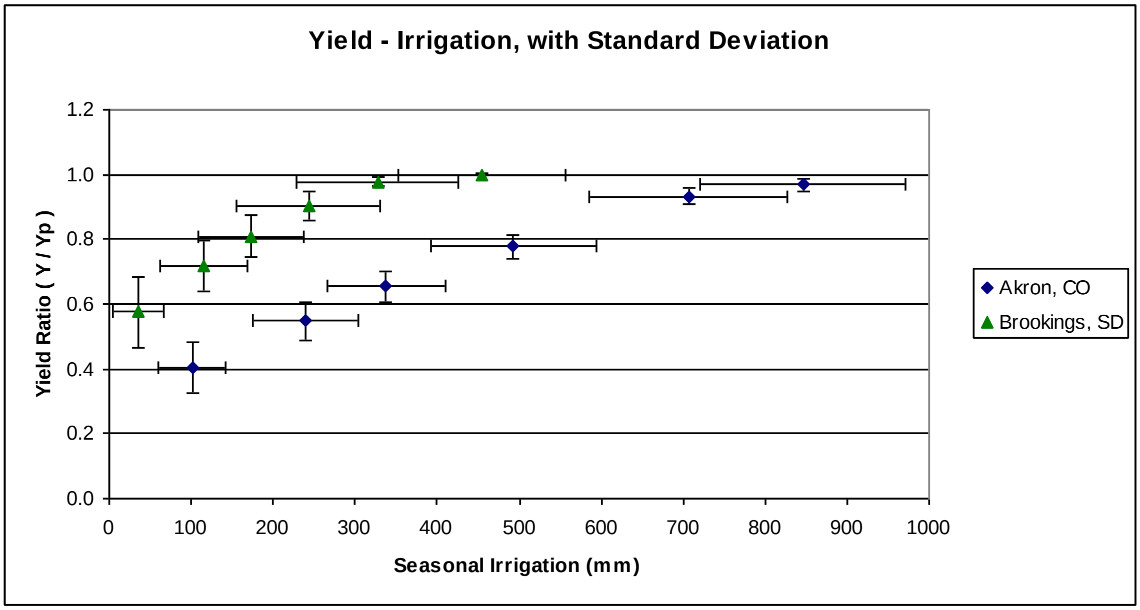


Figure 8. Example of standard deviation (for annual variation) shown on a yield-irrigation plot. 83 mm/m WHC, 63.1 L/s pumping rate, all years, 0-0-0, 70-70-70, and recommended strategies.

Soil Type and Pumping Rate

The effect of soil type was also evaluated. Soils with a high WHC had less water loss (i.e. runoff and deep percolation) since they were able to store more of the rain from large rain events. However, Rock Port, MO, was the only site to have increased water use efficiency for heavier soils. Rock Port had the highest mean annual precipitation (573 mm), and, perhaps more importantly, it had the most large rain events (greater than 25 mm) per season (Table 4).

Table 4. Large rain events and their impact on benefits of high WHC.

Location	Large rain events per season	WHC with best WUE
Akron, CO	2.1	83 mm/m
Brookings, SD	3.8	minimal difference
Nisland, SD	0.8	83 mm/m
Oakes, ND	2.7	83 mm/m
Ord, NE	4.2	minimal difference
Rock Port, MO	6.1	167 mm/m
St. John, KS	4.4	minimal difference

A high WHC allowed a soil to take advantage of large rain events, so it is reasonable that Rock Port, MO, would benefit the most from this. According to these simulations, Brookings, SD, Ord, NE, and St. John, KS, showed a minimal difference in WUE among WHC treatments. For Akron, CO, Nisland, SD, and Oakes, ND, however, the 83 mm/m soils performed the best, with 167 mm/m showing the smallest yield for a given irrigation amount. This was due to the increased evaporation loss in heavy soils, which is illustrated in Figure 9 (evaporation loss is indicated by the horizontal space between the ET and T lines).

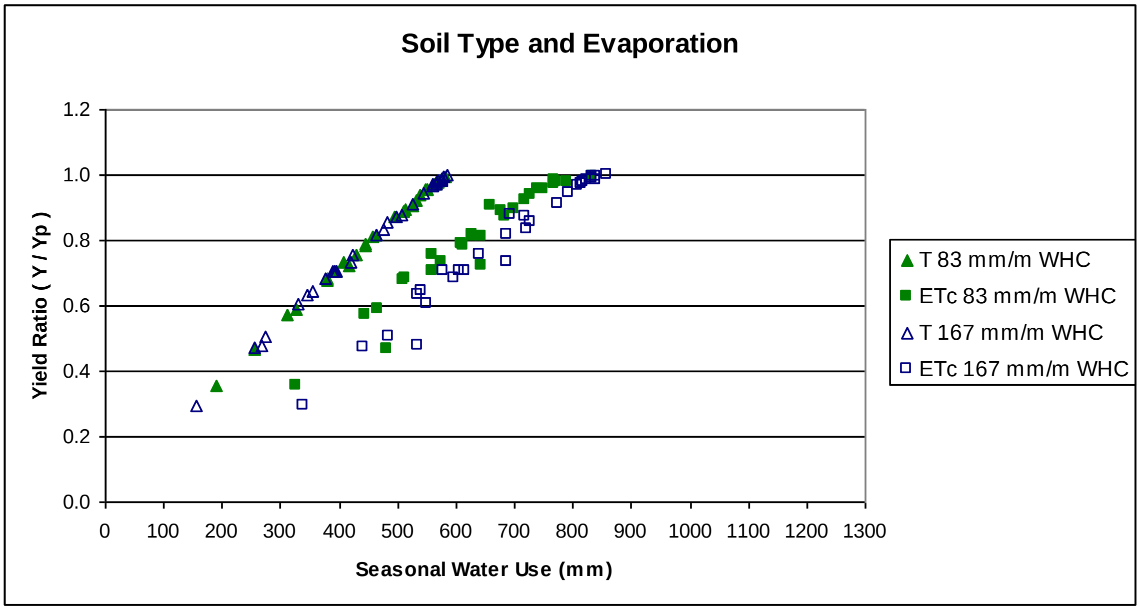


Figure 9. Example of soil type impact on yield-transpiration and yield-actual crop evapotranspiration relationships. Nisland, SD, 1997 (seasonal precipitation near the mean: 210 mm, zero rain events greater than 25 mm), 63.1 L/s pumping rate.

In medium to small rain events (and irrigations), drainage and runoff were small. For a high WHC soil, more of the moisture was held in the surface layer and lost to evaporation; less of the water made it deeper into the root zone to benefit the plant. For locations with few large rainfall events, this drawback overrides the benefits of a heavy soil. Two notes of caution are in order here. Soils with very low WHC, 42 mm/m (0.5 in/ft) for example, were not simulated. It is doubtful that the trend would continue and show such a soil to be desirable. Also, these results are highly dependant on the method for calculating evaporation from the topsoil (Heeren, 2008). Soil parameters describing the amounts of water that topsoil can hold and readily evaporate should be verified with laboratory tests in order to strengthen this observation.

The above analysis regarding WHC and WUE is especially appropriate from a deficit irrigation perspective. It should be noted, however, that if water is not limiting and the maximum yield is desired, a high WHC is preferable. The highest yields from maximum irrigation strategies were consistently obtained by the 167 mm/m WHC soils.

Pumping rates had a negligible effect on which strategies performed best. The same strategies are recommended for all pumping rates. However, for a particular strategy, pumping rate did impact yield. Figure 10, showing the four recommended irrigation strategies, provides an example of the effect that pumping rate has on the yield-irrigation relationship.

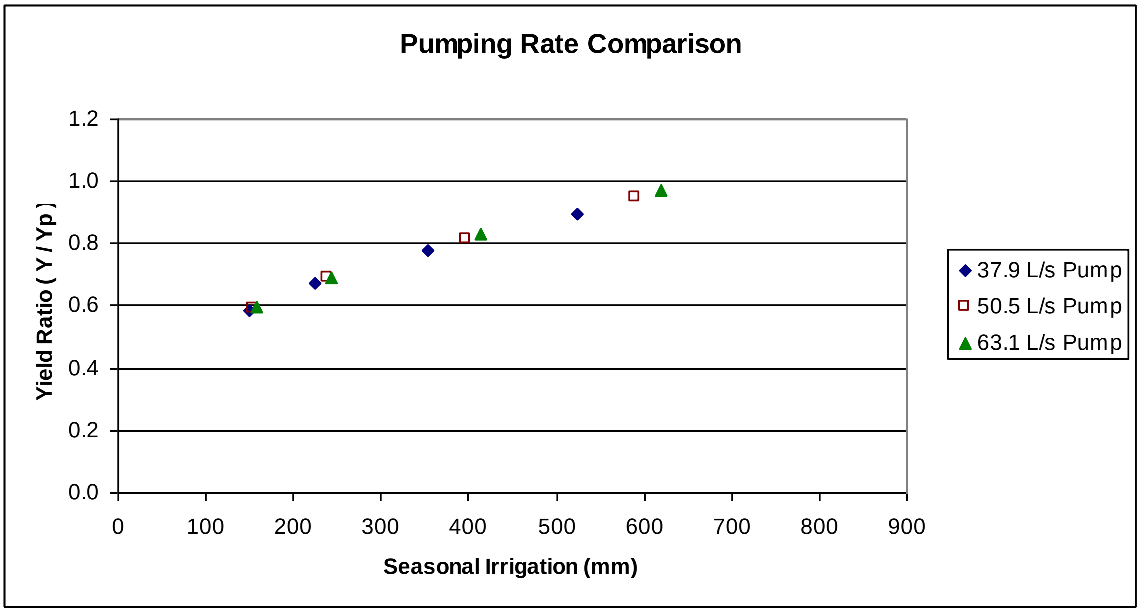


Figure 10. Example of the effects of various pumping rates. St. John, KS, 125 mm/m WHC, all years, recommended irrigation strategies.

Pumping rate appeared to have a small effect on water use efficiency; the points above form a fairly smooth irrigation-yield curve. The primary difference is where they lie on the curve. All sites showed at least a slight reduction in yield when the pumping rate was limited to 37.9 L/s. Akron, CO, Nisland, SD, and St. John, KS, showed substantial yield losses with a pumping rate of 37.9 L/s, and small losses with 50.5 L/s compared to 63.1 L/s. It is not surprising that the sites with the greatest middle and late-season difference between monthly ET and precipitation (Figure 5) showed the largest yield reductions from limited water delivery rates. From a design standpoint, a 50.5 L/s pump may be sufficient to achieve maximum yield in Brookings, SD, Oakes, ND, Ord, NE, and Rock Port, MO. Another implication involves situations where the pumping rate is being reduced due to declining aquifer levels. These data provide indications of the effects on water use and yield in those scenarios.

Conclusions

The recommended maximum yield strategy for corn is 30-60-30 for Brookings, SD, Oakes, ND, and Rock Port, MO, and 30-60-30 extended for Akron, CO, Nisland, SD, Ord, NE, and St. John, KS. Recommended deficit irrigation strategies (for all sites) are 15-50-0 for minimal water restrictions, 0-30-0 for moderate water restrictions, and 0-15-0 for severe water restrictions. Recommended irrigation strategies did not depend on soil type or pumping rate.

Variability in yield from year to year is greatest for strategies that use the least water. Pumping rate had a small effect on the general yield-irrigation relationship, but a rate of 37.9 L/s substantially limited maximum yields in Akron, CO, Nisland, SD, and St. John, KS. The benefit of soils with high WHC may be limited to locations with a high frequency of large rainfall events.

Publications and presentations:

Heeren, DM, HD Werner, TP Trooien, and N Klocke. In review. Evaluation of deficit irrigation strategies for corn. Submitted to Irrigation Science.

Student Support:

Undergraduate and graduate students were supported from this project including:

- Two undergraduate student
- One graduate student

Notable Awards and Achievements:

None during the reporting period.

Thermal Stability of Limestone Waste for Recycling after Arsenic Removal from Drinking Water

Basic Information

Title:	Thermal Stability of Limestone Waste for Recycling after Arsenic Removal from Drinking Water
Project Number:	2008SD130B
Start Date:	3/1/2008
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	SD First
Research Category:	Water Quality
Focus Category:	Toxic Substances, Treatment, Water Supply
Descriptors:	
Principal Investigators:	Arden D Davis, David J. Dixon, Marion Hansen

Publications

1. Davis, A.D., C.J. Webb, D.J. Dixon, J.L. Sorensen and S. Dawadi, 2007, Arsenic Removal From Drinking Water By Limestone-Based Material. Mining Engineering, Volume 59 (Number 2), pages 71-74.
2. Chintalapati, P.K., A.D. Davis, M.R. Hansen, J.L. Sorensen and D.J. Dixon, 2009, Encapsulation Of Limestone Waste In Concrete After Arsenic Removal From Drinking Water. Environmental Earth Sciences, Volume 59 (Number 1) pages 185-190.

Final Report

South Dakota Water Resources Institute
U.S. Geological Survey 104b Program

Thermal Stability of Limestone Waste for Recycling after Arsenic Removal from Drinking Water

Dr. Arden D. Davis
Dr. David J. Dixon
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South Dakota School of Mines and Technology
Rapid City, South Dakota 57701

Introduction

Limestone-based material has demonstrated the ability to remove arsenic and other metals from drinking water. The technology offers the potential for low-cost disposal of waste product after arsenic removal, either in an ordinary landfill or by recycling during the manufacture of cement. Research by the principal investigators has shown that the waste product from the limestone-based technology passes the Toxicity Characteristic Leaching Procedure (TCLP) test. Disposal of arsenic-enriched waste is critical for commercial viability of removal technologies. Low-cost disposal of waste in an ordinary landfill gives the method an advantage that could help communities meet the new maximum contaminant level for arsenic. The ability to reuse or recycle the waste material in the manufacturing of cement would add a significant economic benefit, further reducing overall costs. Other methods of arsenic removal, such as iron-based material, suffer from the disadvantage of higher disposal costs because of the potential for leaching of arsenic from the waste product.

Project Information

This project investigated recycling of waste product during the manufacturing of cement, and focused on thermal stability tests. The tests will help demonstrate the potential for recycling of the waste material, thereby decreasing overall costs of limestone-based technology. In laboratory tests with limestone-based material, arsenic-contaminated water was combined with the material in batch tests. The adsorbed mass of arsenic was determined. The limestone waste material then was removed for thermal stability testing and leaching potential. The proposed work could give limestone-based technology a distinct advantage for use in small rural water systems.

Objectives

The objectives of this work are to:

1) Determine arsenic adsorption in batch tests using limestone-based material as the treatment media.
2) Remove the waste material and conduct analysis for thermal stability.
3) Analyze thermal stability test results, and determine the suitable for reuse or recycling of the waste material during the manufacturing of cement.

The research presented in this proposal will focus on improving the economic advantages of disposal of limestone-based material by reuse or recycling, e.g., in a kiln feed during the manufacturing of cement, which could significantly broaden potential applications of limestone-based arsenic removal methods. Overall goals include application as a pilot study at a wellhead with naturally occurring arsenic contamination, and commercial viability of the technology.

The thermal stability tests in this work are designed to determine the stability of the waste material and the potential mobility of contaminants in wastes. Infiltrating water and other liquids that come into contact with the waste can potentially leach toxins from the material. The U.S. Environmental Protection Agency's D List indicates the maximum concentration of arsenic for toxicity characteristic is five parts per million (ppm). Previous work by the researchers has shown that waste product from limestone-based material, after arsenic removal, is considered benign and suitable for disposal in a landfill. Testing is needed for thermal stability of limestone waste, however, if it is to be used in the manufacture of cement. The proposed research will help demonstrate the viability of this approach.

Methods

The research presented in this proposal will focus on improving the economic advantages of disposal of limestone-based material by reuse or recycling, e.g., in a kiln feed during the manufacturing of cement, which could significantly broaden potential applications of limestone-based arsenic removal methods. Overall goals include application as a pilot study at a wellhead with naturally occurring arsenic contamination, and commercial viability of the technology.

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In laboratory tests, arsenic-contaminated water was combined with limestone-based material in batch tests. The adsorbed mass of arsenic was determined. The waste material then was removed and tested for thermal stability to determine its potential for reuse or recycling during the manufacture of cement. The proposed work could give limestone-based technology a distinct advantage for use in small rural water systems.

Laboratory facilities at South Dakota School of Mines and Technology were used in the work.

Principal Findings and Significance

A stock As(V) solution was used to prepare influent solutions of water. Four one-liter bottles were filled with 1000 grams of 0.5 to 1 mm sized Minnekahta Limestone, and four 500-mL bottles were filled with 500 grams of 0.5 to 1 mm sized Minnekahta Limestone (Table 1). The prepared solutions were introduced into the bottles, which were shaken several times a day.

Table 1. Batch testing set-up.

Components	Bottle 1	Bottle 2	Bottle 3	Bottle 4	Bottle 5	Bottle 6	Bottle 7	Bottle 8
Amount of Limestone[gm]	1000	1000	1000	1000	500.3	500.2	500.2	500
Concentration of Solution[mg/L]	7.1	7.23	0.713	0.76	7.1	7.23	0.713	0.76
Volume of Solution[ml]	640	640	640	640	350	350	350	350
Volume of Bottle[ml]	1000	1000	1000	1000	500	500	500	500

After batch testing, the solution was drained and samples were analyzed for final arsenic concentrations. From the difference between the initial and final concentrations, the mass of arsenic adsorbed on the limestone was determined. Results are shown in Table 2. The percentage mass of arsenic removal ranged from 64% to 93%. The mass of arsenic removed, in tests under varying conditions, ranged from 0.24 mg to 3.8 mg (Table 2).

Table 2. Results of arsenic-removal tests.

	Bottle 1	Bottle 2	Bottle 3	Bottle 4	Bottle 5	Bottle 6	Bottle 7	Bottle 8
Initial arsenic concentration [mg/L]	7.100	7.230	0.713	0.760	7.100	7.230	0.713	0.760
Initial volume of the solution[L]	0.640	0.640	0.640	0.640	0.350	0.350	0.350	0.350
Initial mass of As in solution[mg]	4.544	4.627	0.456	0.486	2.485	2.531	0.250	0.266
Final arsenic concentration [ml/L]	1.890	3.640	0.038	0.038	4.040	4.380	0.078	0.047
Final volume of the solution[L]	0.375	0.445	0.425	0.420	0.202	0.210	0.180	0.215
Final mass of As in solution[mg]	0.709	1.620	0.016	0.016	0.816	0.920	0.014	0.010
% of the final to the initial concentration	26.620	50.346	5.330	5.000	56.901	60.581	10.940	6.184
Removal [%]	**73.380**	**49.654**	**94.670**	**95.000**	**43.099**	**39.419**	**89.060**	**93.816**
Mass of As removed [mg]	**3.835**	**3.007**	**0.440**	**0.470**	**1.669**	**1.611**	**0.236**	**0.256**
Percentage mass of the removed As[%]	**84.403**	**64.994**	**96.461**	**96.719**	**67.160**	**63.651**	**94.374**	**96.201**

The waste material then was removed and tested for thermal stability to determine its potential for reuse or recycling during the manufacture of cement. Heating was done in increments of 100^{o} C, up to 1000^{o} C. Results are shown in Table 3, below.

Table 3. Results of thermal stability testing.

Temperature (^{o} C)	As (ppm)
Room temp.	< 10
200^o	< 10
300^o	< 10
400^o	< 10
500^o	< 10
600^o	< 10
700^o	< 10
800^o	< 10
900^o	< 10
1000^o	< 10

As shown in Table 3, the limestone waste product with adsorbed arsenic appeared to be thermally stable during testing. The arsenic concentrations were less than 10 parts per million at all temperatures up to 1000^o C. Therefore, this testing indicates that the limestone waste shows promise for reuse or recycling during the manufacture of cement.

Information Transfer Program

Results of this research were presented at two conferences, the Eastern South Dakota Water Conference, and the Western South Dakota Hydrology Conference.

Student Support

A graduate student, Hailemelekot Betemariam, was supported by this research during spring semester, 2009, while working toward his M.S. degree in Geology and Geological Engineering at South Dakota School of Mines and Technology.

Awards and Achievements

Hailemelekot Betemariam presented the results of his work in the student speaker contest at the annual meeting of the South Dakota Association of Environmental Professionals, in March of 2010 at Pierre, South Dakota. Mr. Betemariam was awarded second place in the contest. It is expected that the results of this work will be incorporated in a Master of Science thesis or a Ph.D. dissertation.

A patent application for the limestone-based arsenic removal process has been filed (SDSM 1036037). The application number is 11/284,440. In May, 2010, South Dakota School of Mines and Technology received a Notice of Allowance from the U.S.

Patent and Trademark Office, stating that the application has been examined is allowed for issuance as a patent.

Related Publications

Davis, A.D., Webb, C.J., Dixon, D.J., Sorensen, J.L., and Dawadi, S., 2007, Arsenic removal from drinking water by limestone-based material: Mining Engineering, v. 59, no. 2, p. 71-74.

Chintalapati, P.K., Davis, A.D., Hansen, M.R., Sorensen, J.L., and Dixon, D.J., 2009, Encapsulation of limestone waste in concrete after arsenic removal from drinking water: Environmental Earth Sciences, v. 59, no. 1, p. 185-190.

Development of a Decision Support System for Water Resources Management of Shallow Glacial Alluvial Aquifers: A Laboratory Proof of Concept Study (Year 2)

Basic Information

Title:	Development of a Decision Support System for Water Resources Management of Shallow Glacial Alluvial Aquifers: A Laboratory Proof of Concept Study (Year 2)
Project Number:	2008SD131B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	SD First
Research Category:	Climate and Hydrologic Processes
Focus Category:	Water Supply, Management and Planning, Groundwater
Descriptors:	None
Principal Investigators:	Suzette R Burckhard, Patrick J. Emmons

Publications

1. Amatya, S., S.R. Burckhard, and P.J. Emmons, 2010, Development Of Climate Scenarios Using Evaporation And Precipitation Data For Brookings, South Dakota, 2010 International Student Prairie Conference on Environmental Issues, University of Manitoba, Canada, June 7-8, 2010.
2. Basnet, N., S.R. Burckhard, , and P.J. Emmons, 2010, Development Of Climate Scenarios For Precipitation For Aberdeen, South Dakota, 2010 International Student Prairie Conference on Environmental Issues, University of Manitoba, Canada, June 7-8, 2010.
3. Amatya, S., S.R. Burckhard, and P.J. Emmons, 2010, Development Of Climate Scenarios Using Pan Evaporation Data For Brookings, South Dakota, Poster presented at the 2010 Surface Water Treatment Workshop, April 27-29, 2010, Fargo, ND.
4. Basnet, N., S.R. Burckhard, and P.J. Emmons, 2010, Development Of Climate Scenarios For Precipitation For Aberdeen, South Dakota, Poster presented at the 2010 Surface Water Treatment Workshop, April 27-29, 2010, Fargo, ND.
5. Burckhard, S.R., and P.J. Emmons, 2009, Water Management Issues In These Changing Times, presented at the Eastern SD Water Conference, Nov 2-3, 2009, Brookings, SD.
6. Peschong, C., S.R. Burckhard, and P.J. Emmons, 2009, Comparison Of Climate Scenarios For Lake Levels Versus Stream Flow, Poster presented at the Eastern SD Water Conference, Brookings, SD, Nov 2-3, 2009.
7. Basnet, N, S.R. Burckhard, and P.J. Emmons, 2009, Development Of Climate Scenarios For Precipitation For Aberdeen, South Dakota, Poster presented at the Eastern SD Water Conference, Brookings, SD, Nov 2-3, 2009.

State Water Resources Institute Program (SWRIP)
March 2009 to February 2010

Project Title: Development of a Decision Support System for Water Resources Management of Shallow Glacial Alluvial Aquifers: A Laboratory Proof of Concept Study

Investigators: Primary PI: Suzette R. Burckhard
Other PIs: Patrick J. Emmons

Project narrative containing:

1. Statement of Problem
   The use of groundwater as a public water supply had increased from 26 percent in 1950 to 40 percent for 1985. The water use percentage of groundwater has remained at 40 percent through 2000. Starting in 2000, various regions across the United States, especially in the Western United States, saw a decrease in precipitation causing drought conditions. As these conditions have persisted, concerns have been raised regarding public and private water supplies. Many cities across the Western United States are developing plans for sustainable water supply alternatives to address concerns about climate changes and economic factors.

2. Research Objectives
   The objective of this project is to modify an existing GIS based rainfall-runoff model and use that model to develop a robust data set for shallow alluvial aquifer recharge in stream beds as a function of time and storm event size.

3. Methodology
   Based on the findings that the flow rate of water down, out of the stream bed, was related to the hydraulic conductivity of the stream bed material, additional data was collected to verify the relationship between cumulative stream flow and climate period. Existing stream flow data was collected from the USGS and processed to calculate the cumulative stream flow for 8 year time periods. Wet, moderately wet, average, moderately dry, and dry 8-year periods were identified by choosing the maximum, average plus standard deviation, average, average minus standard deviation, the minimum 8 year time periods. Additionally, the data for precipitation for a site within the watershed was obtained from the SD Climate Center and processed in a similar manner by calculating the cumulative precipitation for 8 year time periods. A comparison of the cumulative precipitation and stream flow was made for correlation. A comparison of the identified climate periods was made to the climate periods identified by the USGS in a previous study. Further analysis of the precipitation records was performed to identify the timing and amount of precipitation by season and number of days with precipitation.

4. Principal Findings and Significance
   The principal findings from this recent study include the following.
   - Stream flow and precipitation are well correlated in timing of major and minor flows and precipitation events. Additional study of more sites in SD is being performed to confirm this trend for a larger region and also for identification of scales of importance.

- The identified 8-year climate periods found by USGS in the Day County flooding study do not correlate to the identified 8-year climate periods found from precipitation records. The major difference in the identified climate periods is evaporation. Further study of this is being conducted at this time.
- The 8-year climate cycles identified for the Aberdeen, SD, area are as follows:

Wet	1993-2000
Moderately wet	1942-1949
Average	1977-1984
Moderately dry	1959-1966
Dry	1969-1976

- The number of days with precipitation does not vary significantly between the climate periods such that there is no clear trend that wet periods have any more days with precipitation compared to dry time periods. Additional study is being conducted on more sites in SD to confirm this trend beyond the Aberdeen, SD, region.
- The amount of precipitation during each season varies significantly between each identified 8 year climate period with wet periods having more precipitation in the summer compared to moderately wet compared to average and so on. Additional study is being conducted on more sites in SD to confirm this trend beyond the Aberdeen, SD, region.

5. Publications (8 in the last year)
   (* presenter)
   - Amatya, S*, **Burckhard, S.R**., and Emmons, P.J., 2010, Development of Climate Scenarios Using Evaporation and Precipitation Data for Brookings, South Dakota, 2010 International Student Prairie Conference on Environmental Issues, University of Manitoba, Canada, June 7-8, 2010.
   - Basnet, N*, **Burckhard, S.R**., and Emmons, P.J., 2010, Development of Climate Scenarios for Precipitation for Aberdeen, South Dakota, 2010 International Student Prairie Conference on Environmental Issues, University of Manitoba, Canada, June 7-8, 2010.
   - Amatya, S*, **Burckhard, S.R**., and Emmons, P.J., 2010, Development of Climate Scenarios Using Pan Evaporation Data for Brookings, South Dakota, Poster presented at the 2010 Surface Water Treatment Workshop, April 27-29, Fargo, ND.
   - Basnet, N*, **Burckhard, S.R**., and Emmons, P.J., 2010, Development of Climate Scenarios for Precipitation for Aberdeen, South Dakota, Poster presented at the 2010 Surface Water Treatment Workshop, April 27-29, Fargo, ND.
   - **Burckhard, S.R.*,** and Emmons, P.J., 2009, Water Management Issues in These Changing Times, presented at the Eastern SD Water Conference, Nov 2-3, Brookings, SD.
   - Peschong, C*, **Burckhard, S.R**., and Emmons, P.J., 2009, Comparison of Climate Scenarios for Lake Levels Versus Stream Flow, Poster presented at the Eastern SD Water Conference, Brookings, SD, Nov 2-3, 2009.

- Basnet, N*, **Burckhard, S.R**., and Emmons, P.J., 2009, Development of Climate Scenarios for Precipitation for Aberdeen, South Dakota, Poster presented at the Eastern SD Water Conference, Brookings, SD, Nov 2-3, 2009.
- **Burckhard, S.R**.* and Emmons, P.J., 2009, Ever Wonder How Much Stream Flow Makes it to Ground Water: Results of a Laboratory Study, 21st Annual Environ. & GW Quality Conf., Pierre, SD, 1p.

6. Student Support

Five different students have been supported directly by this project, 2 MS students and 3 undergraduate students. At this time, the three undergraduate students have graduated and one of these is staying on for an MS degree. The current two MS students plan on graduating this fall, 2010. The bulk of requested funds were used for student support. Students presented 4 posters and will be making 2 presentations in June on their research. Students have attended three different regional research meetings over the past year. Research presentations are being given by the two current MS students at a meeting in Canada in June.

At present, additional resources are being used to support students working on this project so not all the students listed have been directly supported by funds from the grant at all times.

7. Notable Achievements and Awards

The poster

- Peschong, C*, **Burckhard, S.R**., and Emmons, P.J., 2009, Comparison of Climate Scenarios for Lake Levels Versus Stream Flow, Poster presented at the Eastern SD Water Conference, Brookings, SD, Nov 2-3, 2009.

won the second place award for the student poster competition at the Eastern SD Water Conference. Additionally, Claire Peschong was elected to the Sigma Xi (Research Honor Society) for her work on this project and she also won a 2010 SDSU Woman of the Year award in part for her research work as well as other factors.

Student Information Table

	Total	Major
Undergrad.	3	Civil Engineering
Masters	2	Civil Engineering
PhD.		
Post-Doc.		
Total	5	

Simulating the Soil Erosion from Land Removed from CRP

Basic Information

Title:	Simulating the Soil Erosion from Land Removed from CRP
Project Number:	2008SD135B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	SD First
Research Category:	Water Quality
Focus Category:	Water Quality, Models, Sediments
Descriptors:	None
Principal Investigators:	Todd P. Trooien, David E. Clay, Thomas Schumacher, Dennis Todey

Publications

There are no publications.

Progress report for the project "SIMULATING THE SOIL EROSION FROM LAND REMOVED FROM CRP", (2008-09)

Introduction:

This project is in the final stages prior to completion. Final simulations are being conducted and data analysis is nearing completion. A modest set of runoff and sediment loss data were used to validate WEPP. The validated WEPP is being used to estimate the soil loss from lands that may be removed from the CRP program. The graduate student will be completing this work in the next three months and a full completion report will be available at that time.

Statement of Problem: A South Dakota survey conducted in May 2007 indicated that approximately 50% of the CRP acres due to renewal in the next four years will not be renewed. Conversion of these areas from CRP back to row crop production without regard to environmental quality could have huge impacts on water quality in the state. In this project we will calibrate an erosion model and use it to crop production under a variety of management scenarios.

The economies of grain production, especially production of row crops like corn, are much more favorable now than when the CRP contracts were established. Because of the better grain production economics, higher CRP lease rates will be required if it is desirable to keep much of the current land enrolled in CRP. Appropriate quantification of the increased erosion potential and associated water quality impairments will assist in targeting new CRP lease rates. Extensive field research to quantify soil erosion rates in South Dakota would require many years of measurements and analysis. But producers and water managers don't have the luxury of that much time because many CRP projects will be expiring during the next three years. This research proposes to use limited field research to calibrate runoff and erosion model and then use the model to estimate soil erosion to use the model to estimate soil erosion to estimate the water quality impacts of removing land from CRP and returning it to row crop (especially corn) production.

Objectives:

The objectives of this project are to characterize the runoff and transported sediment from a small watershed under continuous corn production to be used to calibrate a runoff process model, then use the model to estimate the soil loss from lands removed from CRP.

Methodology:

Field research took place at Mike Schmidt Farm in Moody County, SD. The field was corn Last year and will be soybean this year. Rainfall data will be taken by a rain gauge installed in the field. Runoff and sediment data will be taken by ISCO automatic samplers that are installed in field. Sequential time samples will be taken as soon as a runoff event occurs. Triggering of samplers will be accomplished by a variety of ways in different samplers using liquid actuator and ISCO 4230 flow meter. Runoff samples will be analyzed in SDSU Olson Biochemistry Laboratory for Total Suspended Solids (TSS). The runoff and TSS data with other required input parameters as soil type, land use, land slope and weather data will be used to calibrate WEPP and RUSLE2.

Results:

Four storms were captured at the Brookings watershed site (Tables 1 and 2). These provide a modest data set for validation of WEPP.

Table 1. Initial WEPP predicted and observed runoff at Brookings watershed**.**

Date	**Rainfall (mm)**	**WEPP Predicted runoff (m^3)**	**Observed runoff (m^3)**
6/27/2009	19	0.45	5.79
7/7/2009	18.5	33.87	116.4
7/9/2009	9.4	0	45.8
7/14/2009	10.7	0	7.98

Table 2. Initial WEPP predicted and observed sediment yield at Brookings watershed**.**

Date	**Rainfall (mm)**	**WEPP Predicted sediment yield (Kg)**	**Observed sediment yield (Kg)**
6/27/2009	19	0	0.08
7/7/2009	18.5	38.1	24.26
7/9/2009	9.4	0	2.94
7/14/2009	10.7	0	2.22

Model calibration was further performed to match observed runoff and sediment yield data with model predicted data and to obtain better model evaluation statistics as recommended by Moriasi 2007. Initial saturation level in soil files was adjusted for all four events to best simulate actual field conditions based upon the soil moisture observations taken in the field (calculation shown in Appendix). Soil parameters were adjusted from default WEPP parameters to obtain comparable results. Interrill erodibility (Ki), rill erodibility (Kr), critical shear stress (ζc) and effective hydraulic conductivity (Ke) values were adjusted to match observed and WEPP predicted results. At first effective hydraulic conductivity was decreased to obtain satisfactory runoff prediction results. While decreasing K_e, runoff prediction by WEPP increased but sediment yield also decreased as well. To better predict sediment yield and runoff as well, Interrill erodibility, rill erodibility and critical shear stress values were adjusted without changing adjusted effective hydraulic conductivity for runoff. Interrill erodibility and rill erodibility values were decreased and critical shear stress values were increased from default WEPP values to get better model evaluation statistics. While adjusting the values these were kept within the range specified in WEPP documentation (NSERL Report #10, Hillslope Profile and Watershed Model Documentation, Soil Component,1995) for crop land.

Table 3. Suggested range for baseline values of Ki, Kr and ζc for cropland (Alberts et al, 1995)

	Interrill erodibility K_i (kg-s/m^4)	Rill erodibility K_r (s/m)	Critical shear stress T_c (Pa)
Minimum	500000	0.002	0.3
Maximum	12000000	0.05	7.0

Table 4. Calibrated and default values for Ki, Kr, ζc and Ke

Soil type		Barnes-60 loam	Fordville-90 loam	McIntosh-55 silty clay loam
Interrill erodibility (kg-s/m^4)	Default WEPP value	5.052×10^6	5.014×10^6	4.537×10^6
	Calibrated value	1.006×10^6	1.0023×10^6	0.8914×10^6
Rill erodibility (s/m)	Default WEPP value	0.0056	0.0055	0.0074
	Calibrated value	0.0022	0.0021	0.0026
Critical shear stress (Pa)	Default WEPP value	3.106	3.3773	3.5
	Calibrated value	5.497	5.75	5.952
Effective hydraulic conductivity (mm/hr)	Default WEPP value	8.57	7.79	0.9822
	Calibrated value	1.937	1.822	0.3124

Texture of default soil files was also adjusted in WEPP to better represent actual soil condition. For each hillslope different parameters in soil file like percent of sand, clay, organic matter and Cation Exchange Capacity (CEC) for top layer were modified. Modified values were calculated as weighted average of different soils found in that soil map unit depending upon the composition of the soil.

Table 5. Default and modified values of different WEPP parameters for soils in Brookings watershed

Soil type		Barnes-60 loam	Fordville-90 loam	McIntosh-55 silty clay loam
Percent sand	Default WEPP value	43	41	7
	Calibrated value	41.92	40.93	10.3
Percent clay	Default WEPP value	17.5	22	28
	Calibrated value	19.38	22.07	29.26
Percent organic matter	Default WEPP value	5	5	6
	Calibrated value	4.15	4.86	6
CEC (meq/100gm)	Default WEPP value	17.5	24	28
	Calibrated value	17.46	23.93	29.25

Table 6. Calibrated WEPP predicted and observed runoff at Brookings watershed

Date	**Rainfall (mm)**	**WEPP Predicted runoff (m^3)**	**Observed runoff (m^3)**
6/27/2009	19	24.17	5.79
7/7/2009	18.5	110	116.4
7/9/2009	9.4	0	45.8
7/14/2009	10.7	7.1	7.98

Table 7. Calibrated WEPP predicted and observed sediment yield at Brookings watershed

Date	**Rainfall (mm)**	**WEPP Predicted sediment yield (Kg)**	**Observed sediment yield (Kg)**
6/27/2009	19	1.1	0.08
7/7/2009	18.5	26.4	24.26
7/9/2009	9.4	0	2.94
7/14/2009	10.7	2.3	2.22

Calibrated WEPP model performance for runoff and sediment yield was evaluated following recommendation from Moriasi (2007). NSE, RSR and PBIAS values were calculated for runoff and sediment yield prediction.

Table 8. Model evaluation statistics after calibration

	NSE	**RSR**	**PBIAS**
Runoff	0.69	0.56	19.72
Sediment Yield	0.96	0.19	-1.02

For runoff prediction NSE and RSR values indicates good model performance and for sediment yield high NSE and RSR values indicates very good model performance by WEPP (Moriasi et al 2007). Positive PBIAS for runoff indicates under prediction for runoff and negative PBIAS for sediment yield indicates over prediction for sediment yield.

Determining Soil Moisture and Temperature Condition Effects on Potential Run-Off for Cold Season Manure Application

Basic Information

Title:	Determining Soil Moisture and Temperature Condition Effects on Potential Run-Off for Cold Season Manure Application
Project Number:	2008SD136B
Start Date:	3/1/2008
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	SD First
Research Category:	Climate and Hydrologic Processes
Focus Category:	Water Quality, Agriculture, Climatological Processes
Descriptors:	
Principal Investigators:	Dennis Todey, David R. German

Publications

There are no publications.

State Water Resources Institute Program (SWRIP)
March 2009 to February 2010

Project Title: Determining soil moisture and temperature condition effects on potential run-off for cold season manure application.

Investigators: Primary PI: Dr. Dennis Todey
Other PIs: Mr. David German

Project narrative containing:

1. Statement of Problem
2.

Currently NRCS guidelines for application of manure on frozen soils are being reviewed in South Dakota. Balancing the risk of application between producer needs and protection of water quality has been a major part of the discussion. Both producers and regulators have sought scientific data to support their cause. But lacking in the discussion has been specific data related to South Dakota based on South Dakota soils and climatic conditions. This project will continue the process of evaluating those conditions and help deliver some assessment of risk of application based on soil temperature and soil moisture conditions as well as the risk of water quality impairment by run-off from frozen soils.

In addition, little work has focused on analyzing weather data to determine the risk of occurrence of conditions that are perceived as potentially detrimental to water quality from manure application on frozen ground. All economic development, whether agricultural, municipal or industrial, is carried out with the understanding of risks and implementation of policies and rules to minimize risks, especially with regard to human health and safety. There are three winter conditions that are expected to yield runoff:

1. Frozen soil and snowmelt that can not enter the soil;
2. Snowfall that insulates the soil from freezing but that is in excess to soil storage; and
3. Rainfall on snowpack or frozen soil.

3. Research Objectives
The objective of this project is to 1. Complete an assessment of the risk of spreading manure on frozen soils, compare winter manure spreading practices in relation to location, timing and placement to determine which minimize impacts to water quality to develop BMPs, and develop climatic risk factors using frequency of soil frost and rainfall events on the risk of manure application to assist livestock producers in timing manure applications during least risky time periods.

4. Methodology
The plot studies completed in 2009 evaluated several treatments of winter manure applications on 16 plots each split into two parts with the same treatment. Soil sensors were installed in each plot at the 6 inch and 20 inch depth intervals to establish temperature and soil moisture profiles before and during snowmelt runoff.
Three treatments plus a control with four repetitions on tilled and untilled soybean stubble resulted in runoff from 32 plots.

Treatments included:

1. manure applied on frozen soil in November, followed by snow,
2. manure on snow covered in January followed by more snow,
3. manure applied to snow-covered soil in March before snowmelt, and
4. the control (no manure).

Principal Findings and Significance

Natural snowmelt occurred in March 2010. Runoff was received from all 32 plots for 1 to 3 days. One Plot was compromised due to overflow of melt water from outside the plot due to an ice dam. Runoff was not collected from this plot. The graduate student is currently compiling and analyzing the data to calculate loadings of nutrients, sediment and bacteria to determine differences between treatments.

Acidic Leaching Tests to Determine Arsenic Mobility from Concrete-Encapsulated Limestone Waste

Basic Information

Title:	Acidic Leaching Tests to Determine Arsenic Mobility from Concrete-Encapsulated Limestone Waste
Project Number:	2009SD137B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	SD First
Research Category:	Water Quality
Focus Category:	Toxic Substances, Treatment, Water Supply
Descriptors:	
Principal Investigators:	Arden D Davis, David J. Dixon, Marion Hansen

Publications

1. Davis, A.D., C.J. Webb, D.J. Dixon, J.L. Sorensen, and S. Dawadi, 2007, Arsenic Removal From Drinking Water By Limestone-Based Material: Mining Engineering, Volume 59 (Number 2) pages 71-74.
2. Chintalapati, P.K., A.D. Davis, M.R. Hansen, J.L. Sorensen, and D.J. Dixon, 2009, Encapsulation Of Limestone Waste In Concrete After Arsenic Removal From Drinking Water, Environmental Earth Sciences, Volume 59, (Number 1)pages 185-190.

Progress Report

South Dakota Water Resources Institute
U.S. Geological Survey 104b Program

Acidic Leaching Tests to Determine Arsenic Mobility from Concrete-Encapsulated Limestone Waste

Dr. Arden D. Davis
Dr. David J. Dixon
Dr. M.R. Hansen
South Dakota School of Mines and Technology
Rapid City, South Dakota 57701

Introduction

Arsenic contamination of drinking water is a major problem facing many areas of the United States and the world. Limestone-based technology for arsenic removal from water is an innovative and promising method. The technology offers the potential for low-cost disposal of waste product after arsenic removal, either in an ordinary landfill or by encapsulation in concrete. There is a need for an inexpensive remediation technology for the removal of arsenic in drinking water that can be applied to small rural water systems.

Arsenic is a persistent and bioaccumulative toxin. Long-term exposure has the potential to cause heart arrhythmia, nerve damage, vascular damage, bone marrow depression, anemia, and leucopenia, as well as cancer of the lung, liver, skin, and bladder. The maximum contaminant level for arsenic, formerly 50 parts per billion (ppb), was lowered to 10 ppb in 2006 because of links to cancer. In South Dakota, it has been estimated that 15 to 20 water supply systems will not be in compliance with this mandate. Current removal technologies are expensive and their implementation will cause economic pressures for rural communities with high levels of arsenic in their drinking-water supplies.

Project Information

Limestone-based material has previously demonstrated the potential to remove arsenic and other metals from drinking water. Limestone is widely available, with suppliers in South Dakota and other states of the U.S. Earlier research by the principal investigators, using limestone particles and manufactured limestone-based granules as an adsorbent for drinking water treatment, has shown that the efficiency of the arsenic-removal process can be improved by increasing surface area while maintaining flow-through rates needed for adsorption technologies. Research by the authors also has shown that the waste product passes the Toxicity Characteristic Leaching Procedure (TCLP) test. Disposal of arsenic-enriched waste is critical for commercial viability of removal technologies. Low-cost disposal of waste in an ordinary landfill gives the method an advantage that could help communities meet the new maximum contaminant level for arsenic. The ability to recycle the waste material by encapsulation in concrete or mortar would add a significant economic benefit, reducing overall costs. Other methods of arsenic removal suffer from the disadvantage of higher waste-disposal costs because of the potential for leaching of arsenic from the waste product.

This project will investigate acidic leaching of arsenic from limestone waste after encapsulation in concrete or mortar. The work will focus on leaching with simulated rainwater and mild sulfuric acidic solutions typical of shale soils that contain minerals such as pyrite. The tests, if successful, will help demonstrate the potential for recycling of the waste material, thereby decreasing overall costs of limestone-based technology. In laboratory tests with limestone-based material, arsenic-contaminated water will be combined with limestone material. The waste material then will be removed, encapsulated in concrete or mortar, and tested for leaching potential under acidic conditions such as rainwater and weak sulfuric acid solutions.

Objectives

The objectives of this work are to:

1) Determine adsorption of arsenic by using limestone-based material as the treatment medium.
2) Remove the limestone waste material and combine the product in concrete or mortar. Prepare concrete or mortar cubes with the material.
3) Conduct leaching tests with simulated rainwater and mild sulfuric acid solutions, and analyze the leachate for arsenic concentrations.

During earlier phases of this on-going project, laboratory research has indicated that arsenic is effectively removed from water by limestone-based material, including manufactured limestone-based granules as well as material with a limestone base and an additional arsenic-removal medium. Previous work has been aimed primarily at improving the efficiency of limestone-based material in removing arsenic by increasing surface area while maintaining flow-through of the media.

When arsenic is removed from water by limestone-based material, the process is believed to be either adsorption or the precipitation of hydrated calcium arsenate. Hydrated calcium arsenate has an extremely low solubility as compared to limestone. The proposed research could help answer a critical research question: when arsenic is removed from water by limestone, is the arsenic merely adsorbed on the surface of the limestone, where it could be released after dissolution of the limestone, or is it bound as a low-solubility calcium arsenate and thus unavailable for release even if the limestone base dissolved?

The research presented in this proposal will focus on improving the economic advantages of disposal of limestone-based material by recycling the waste product in concrete. Overall goals include application as a pilot study at a wellhead with naturally occurring arsenic contamination, and commercial viability of the technology. Two of the principal investigators have extensive experience with arsenic removal by limestone, and the third investigator is a recognized expert in the fields of cement and concrete.

The leaching tests in this work are designed to determine the stability of the waste material and the potential for mobility of contaminants in wastes. Infiltrating water and acidic liquids that come into contact with the waste can potentially leach toxins from the material. The U.S. Environmental Protection Agency's D List indicates the maximum concentration of arsenic for toxicity characteristic is five parts per million (ppm). Previous work by the researchers has shown that waste product from limestone-based material, after arsenic removal, is considered benign and suitable for disposal in a landfill. Results from that previous research showed final arsenic concentrations ranging from 8 to 24 parts per billion (ppb). Testing is needed for encapculated waste in concrete or mortar, however. We see the potential for recycling of the limestone waste product and its adsorbed arsenic in concrete, but testing is needed to determine long-term stability of the encapsulated waste under mildly acidic conditions typical of weathering. The proposed research will help demonstrate the viability of this approach.

Methods

This project will investigate leaching potential and stability of concrete-encapsulated limestone waste product after arsenic removal. The tests, if successful, will help demonstrate the potential for recycling of the waste material, thereby decreasing overall costs of limestone-based technology. In laboratory tests, arsenic-contaminated water will be combined with limestone-based material in batch tests. The limestone waste material then will be removed, encapsulated in concrete or mortar, and tested for leaching under acidic conditions to determine its potential for recycling in concrete. If successful, the proposed work could give limestone-based technology a distinct advantage for use in small rural water systems.

Laboratory facilities at South Dakota School of Mines and Technology will be used in the work.

Principal Findings and Significance

A stock As(V) solution was used to prepare influent solutions of water. Four one-liter bottles were filled with 1000 grams of 0.5 to 1 mm sized Minnekahta Limestone, and four 500-mL bottles were filled with 500 grams of 0.5 to 1 mm sized Minnekahta Limestone. The prepared solutions were introduced into the bottles, which were shaken several times a day.

After batch testing, the solution will be drained and samples were analyzed for final arsenic concentrations. From the difference between the initial and final concentrations, the mass of arsenic adsorbed on the limestone will be determined.

The waste material then will be removed and encapsulated in mortar cubes of 2 in x 2 in x 2 in. After curing, the mortar cubes will be broken into pieces of approximately 1 to 2 cm, and placed in acidic solutions ranging from simulated rainwater to weak sulfuric acid. The leachate then will be tested for arsenic concentrations.

The work will be completed by August 31, 2010. A final report will be submitted shortly after that date.

Information Transfer Program

Results of this research will be presented at one to two conferences, such as the Eastern South Dakota Water Conference and the Western South Dakota Hydrology Conference.

Student Support

A graduate student, Korry Burkhead, was supported by this research during spring semester, 2009, while working toward his M.S. degree in Geology and Geological Engineering at South Dakota School of Mines and Technology.

Awards and Achievements

It is expected that the results of this work will be incorporated in a Master of Science thesis or a Ph.D. dissertation.

A patent application for the limestone-based arsenic removal process has been filed (SDSM 1036037). The application number is 11/284,440. In May, 2010, South Dakota School of Mines and Technology received a Notice of Allowance from the U.S. Patent and Trademark Office, stating that the application has been examined is allowed for issuance as a patent.

Related Publications

Davis, A.D., Webb, C.J., Dixon, D.J., Sorensen, J.L., and Dawadi, S., 2007, Arsenic removal from drinking water by limestone-based material: Mining Engineering, v. 59, no. 2, p. 71-74.

Chintalapati, P.K., Davis, A.D., Hansen, M.R., Sorensen, J.L., and Dixon, D.J., 2009, Encapsulation of limestone waste in concrete after arsenic removal from drinking water: Environmental Earth Sciences, v. 59, no. 1, p. 185-190.

Information Transfer Program Introduction

Information dissemination is an important part of the South Dakota Water Resources Institute (SD WRI) program. Dissemination of research results are accomplished through journal publications, abstracts, posters, and presentations at conferences. Emphasis is placed on providing opportunities for graduate students to present and publish their findings.

Public outreach also includes a website (http://wri.sdstate.edu), SD WRI newsletters, fact sheets, and water quality interpretations. Water Resources Institute staff continues to provide interpretation of analysis and recommendations for use of water samples submitted to the Water Quality Lab. SD WRI staff also routinely responded to questions from the general public, other state agencies, livestock producers, and County Extension Educators. These inquiries include water quality and quantity, stream monitoring, surface water/ground water interactions, livestock poisoning by algae, lake protection and management, fish kills, soil-water compatibility, manure runoff, and irrigation drainage. Public outreach also included hosting water quality workshops for adults as well as water education activities for youth. These educational opportunities include hands-on participation at water festivals, field trips, presentations, workshops, and demonstrations. Institute staff participates in state, federal, and local committees and organizations. Feedback to these agencies is often given in the form of presentations at state meetings, local water development boards, conservation districts, sanitary districts, and citizen groups.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2008SD132B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	SD First
Research Category:	Not Applicable
Focus Category:	Education, None, None
Descriptors:	
Principal Investigators:	Van Kelley, David R. German

Publications

There are no publications.

FY2009 Information Transfer Program
South Dakota Water Resources Institute

PUBLIC OUTREACH

Public outreach and dissemination of research results are cornerstones of the South Dakota Water Resources Institute's Information Transfer Program. Information Transfer takes many forms. The South Dakota Water Resources Institute *Water News* newsletter is in its fifth year of publication. This is an effective format to disseminate information about activities in which the Institute participates, funds, and promotes. The newsletter is published quarterly via e-mail, as well as a link on the SD WRI homepage (http://wri.sdstate.edu) in PDF format allowing for viewing of past and present issues. Water-related research including updates on present projects, notification of requests for proposals, state-wide water conditions, conferences, as well as information on youth activities are highlights in each issue.

SD WRI's web site has been designed to allow users access to updated links which include publications intended to help diagnose and treat many water quality problems. The site allows the public to keep in touch with the activities of the Institute, gather information on specific water quality problems, learn about recent research results and links with other water resource related information available on the Web. The "Research Projects" section of the SD WRI web contains past and present research projects, highlighting the Institute's commitment to improving water quality.

Another important component of the Institute's Information Transfer Program is the Water Quality Laboratory (WQL). The lab was consolidated with the Oscar E. Olson Biochemistry Labs in 2004. The WQL provides important testing services to water users across the state. Water Resources Institute staff continues to provide interpretation of analysis and recommendations for use of water samples submitted for analysis. Assistance to individual water users in identifying and solving water quality problems is a priority of the Institute's Information Transfer Program. Interpretation of analysis and recommendations for suitability of use is produced for water samples submitted for livestock suitability, irrigation, lawn and garden, household, farmstead, heat pump, rural runoff, fish culture, and land application of waste. Printed publications addressing specific water quality problems are mailed to lab customers to facilitate public awareness and promote education.

An extensive library of information has been developed and continues to be updated on-line. Information regarding analytical services available at the Oscar E. Olson Biochemistry Labs Water Quality Laboratory and information that may be used to address drinking water problems is available on-line.

The seven year drought in western South Dakota ended in most areas in 2008 and above normal rain was received in 2009. Even with the welcome rain the inherent quality of surface waters in western South Dakota is commonly low, leading to chronic livestock production problems. Drought intensifies this problem for livestock producers in these semi-arid rangelands. During the dry period many dugouts and ponds degraded to the point of causing cases of livestock illness and, in some instances, deaths. Due to above normal rainfall in 2009 fewer cases of severe salt limitations for livestock use was observed. Lab services provided by the WQL and interpretation of results by WRI staff is important to livestock producers as they try to manage risks associated with water shortages and poor water quality.

SD WRI staff also routinely responded to water resource questions unrelated to laboratory analysis from the general public, other state agencies, livestock producers, and County Extension Agents. These inquiries include water quality and quantity, stream monitoring, surface water/ground water interactions, aquatic plant identification, livestock poisoning by algae, lake protection and management, fish kills, soil-water compatibility, and irrigation drainage. WRI continues to provide soil and water compatibility recommendations for irrigation permits to the SD Division of Water Rights.

SD WRI staff assisted in implementing the fourth annual Eastern South Dakota Water Conference held November 2-3, 2009 to provide a forum for water professionals to interact and share ideas. The theme of the 2009 conference was the year of science. Speakers highlighted to importance of the scientific method to determine the state of our water resources. The Eastern South Dakota Water Conference was started in 2006 to serve as a mechanism to educate participants on water resource issues in South Dakota.

The goal of the 2009 Eastern South Dakota Water Conference held November 2-3, 2009 in Brookings, SD was to bring together federal, state, and local governments, along with university and citizen insights. The event, in its fourth year, and included speakers and presenters from South Dakota State University (SDSU), South Dakota School of Mines and Technology, The Day Conservation District, South Dakota Department of Water and Natural Resources, and many others. In addition to the conference, a poster competition for college students was held. Eight student posters were presented. First prize of $200 went to Naga Manohar Velpuri in the SDSU GIS Center for Excellence, and a $100 second prize awarded to Claire Peschong in the SDSU Department of Civil Engineering.

Ann Bleed opened the conference with a plenary presentation on the "Role of Science in Negotiations Over the Allocation of Water Resources". Dave Greenlee from the EROS data center delivered the banquet keynote address on flooding in the Waubay Lakes Basin. Water is a crucial part of South Dakota's future, and this conference helped educate participants on the future of this resource. Information on the conference is available at this link: http://wri.sdstate.edu/esdwc.

The call for abstracts and speakers was released in July 2009. SDWRI program assistant Denise Hovland registered conference attendees through a website http://wri.sdstate.edu/esdwc) where participants could review the conference timeline and pre-register and pay for the conference.

Concurrent sessions throughout the conference offered information important to a wide array of stakeholders including engineers, industry, public officials, agricultural producers, and conservation groups. Water is an important piece of the economic future of South Dakota, and this conference served as a mechanism to educate participants on this resource. It is anticipated that this conference will be an annual event.

AGENCY INTERACTION

The SD WRI Information Transfer program includes interaction with local, state, and federal agencies/entities in the discussion of water-related problems in South Dakota and the development of the processes necessary to solve these problems. One of the most productive agency interactions is with the Non-Point Source (NPS) Task Force. The NPS Task Force coordinates, recommends, and funds research and information projects in this high priority area. Participation on the NPS Task Force allows SD WRI input on non-point source projects funded through the state and has provided support for research in several key areas such as soil phosphorus versus runoff phosphorus relationships, biomonitoring, and lake research. Many of the information transfer efforts of the Institute are cooperative efforts with the other state-wide and regional entities that serve on the Task Force.

Another example of this interaction to solve water quality problems is a program started by the Cooperative Extension Service (CES) to help livestock producers identify unsuitable water sources. The CES provides many of its Extension Educators with hand-held conductivity meters for use in the field. If samples are shown to be marginal by field testing, they are sent to the Water Quality Lab for further analysis. Often, high sulfates limit the use of waters that have elevated conductivity.

Another important interaction is with the South Dakota Department of Environmental and Natural Resources (DENR). Completion of Total Maximum Daily Load (TMDL) studies on South Dakota lakes has been a priority for DENR over the past several years. SD WRI is providing technical assistance to local sponsors working with DENR to complete the TMDL water quality assessments on several publicly owned lakes that do not have an established lakeside community.

Several other local and state agencies conduct cooperative research with SD WRI or contribute funding for research. Feedback to these agencies is often given in the form of presentations at state meetings, local boards, and public informational meetings for non-point source and research projects.

YOUTH EDUCATION

Non-point source pollution contributes to the loss of beneficial uses in many impaired water bodies in South Dakota. An important part of reducing non-point pollution is modifying the behavior of people living in watersheds through education. Programs designed to educate youth about how their activities affect water is important because attitudes regarding pollution and the human activities that cause it are formed early in life. For these reasons, Youth Education is an important component of SD WRI’s Information Transfer Program.

Water Festivals provide an opportunity for fourth grade students to learn about water. Since they began in 1992 Water Festivals have been held in seven sites including Spearfish, Rapid City, Pierre, Huron, Vermillion, Brookings and Sioux Falls. SD WRI staff members continued to support and participate in Water Festivals throughout the state in FY2009. SD WRI also supported water quality education in local schools including classroom presentations and assisting local educators with field trips.

ADULT EDUCATION

David German (SDWRI), Dennis Todey (SD State Climatologist) and Dennis Skadsen (Day Conservation District) presented a lake water quality workshop at Outlaw Ranch near Custer, SD and at Enemy Swim Lake near Waubay, SD. The workshops were made possible with funds through an EPA 319 grant. The idea behind the workshops stemmed from the fact that most water quality events like Water Festivals are usually targeted towards children.

Another reason for doing the workshops was the idea of "teaching the teachers." Helping adults learn about water quality and providing them with useful information encourages them to teach others in their home community how their behaviors affect the lake. A PowerPoint presentation and sampling equipment assembled at the workshop was available for participants to take home to help encourage them to share what they learned at the workshop. Both workshops offered participants the opportunity to earn continuing education credits and one graduate credit in the education department at SDSU.

Several hands-on activities were developed that helped workshop participants share their new-found knowledge of lakes. These activities included "The Lake Game" and demonstrations of lake stratification, photosynthesis and aquatic plants, as well as biomagnification using "mercury cookies." The group also made their own Secchi discs to monitor the transparency of the lakes they live on. This allows participants to monitor the water quality of a lake and provides an avenue for individuals to take an active part in monitoring their lake.

As part of SDWRI's outreach to the agricultural community, staff hosted a booth at DakotaFest, a three-day agricultural fair held in August each year near Mitchell, South Dakota, which draws approximately 30,000 people. A large selection of literature regarding water quality is available for distribution and SDWRI staff members field a variety of questions concerning water quality and current research from farm and ranch families. A taste of "good water" versus "bad water" (high in magnesium sulfate) was used to demonstrate that water quality cannot always be determined by visual inspection. Producers also drop off water samples to be taken back to the WQL for analysis.

PUBLICATIONS

Distribution of research findings to the public, policy makers and sponsors of non-point source pollution control projects is another important component of the SD WRI Information Transfer program. This is needed so that the lessons learned through research and implementation projects are not lost as the next generation of projects develops. SD WRI is committed to making this material readily available to persons within South Dakota as well as in other states. A library is maintained at SD WRI to make these materials readily available. Abstracts of research projects funded by the institute have been placed on the WRI web site along with photos and summaries showing progress on these projects will be published on the site as they become available.

USGS Summer Intern Program

None.

Notable Awards and Achievements

The poster Peschong, C, Burckhard, S.R., and Emmons, P.J., 2009, Comparison of Climate Scenarios for Lake Levels Versus Stream Flow, Poster presented at the Eastern SD Water Conference, Brookings, SD, Nov 2-3, 2009.

won the second place award for the student poster competition at the Eastern SD Water Conference. Additionally, Claire Peschong was elected to the Sigma Xi (Research Honor Society) for her work on this project and she also won a 2010 SDSU Woman of the Year award in part for her research work as well as other factors.