Iowa Water Center
Annual Technical Report
FY 2007

Introduction

The Iowa Water Center is a multi−campus and multi−organizational center focusing on research, teaching and outreach activities. The Center's goal is to encourage and promote interdisciplinary, inter−institutional water research that can improve Iowa's water quality and provide adequate water supplies to meet both current and future needs of the state. The Iowa Water Center continues to build statewide linkages between universities and public and private sectors and to promote education, research, and information transfer on water resources and water quality issues in Iowa. The Center also plays a vital role in identifying critical water research needs and providing the funding or impetus needed to initiate research that cannot or is not being conducted through other means.

Research Program Introduction

Water quality remains a critical concern in Iowa. While our understanding of nutrient and sediment movement processes and how these materials affect Iowa's surface and ground water is improving, we do not fully understand a variety of issues linking land management and water quality at multiple scales. This is particularly important because Iowa is repeatedly identified as a major contributor of nutrients and sediment to the Gulf of Mexico where hypoxia research continues. There are numerous research questions that are critical to understanding Iowa's water quality issues and the state's contributions to regional problems. The Iowa Water Center plays a role in addressing these questions through administering the 104B program and garnering additional funds for other research projects. The Iowa Water Center focused on two critical areas: 1) impact of changing land use and anticipated future land use changes on water quality, and 2) health of Iowa streams and rivers and this impact on quality of water leaving Iowa. There were three projects funded through the 104B program and one project supported with 104G funding during this funding period. In addition to addressing critical water resource research needs in Iowa, these projects support graduate and undergraduate students participating in the research.

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Impact of Swine Manure Application on Phosphorus, NO3−N, Bacteria, and Antibiotics Concentrations in Surface Runoff and Subsurface Drainage Water

Basic Information

Title:	Impact of Swine Manure Application on Phosphorus, NO3−N, Bacteria, and Antibiotics Concentrations in Surface Runoff and Subsurface Drainage Water
Project Number:	2006IA94B
Start Date:	3/1/2006
End Date:	2/29/2008
Funding Source:	104B
Congressional District:	Iowa 3rd
Research Category:	Water Quality
Focus Category:	Nitrate Contamination, Nutrients, Water Quality
Descriptors:	
Principal Investigators:	Ramesh Kanwar, Allah Bakhsh, Matthew J. Helmers, Antonio P. P. Mallarino, John E. Sawyer

Publication

1. Bakhsh, A., R.S Kanwar, C. Pederson, T.B. Bailey. 2007. N−Source effect on temporal distribution of NO3−N leaching losses to subsurface drainage water. Water, Air &Soil pollution. 181:35−50.
2. Ma, L., R.W. Malone, P. Heilman, L.R. Ahuja, T. Meade, S.A. Saseendran, J.C. Ascough II, R.S. Kanwar, 2007. Sensitivity of tile drainage flow and crop yield on measured and calibrated soil hydraulic properties. Geoderma 140: 284−296.
3. Ma, L., R.W. Malone, P. Heilman, D.B. Jaynes, L.R. Ahuja, S.A. Saseendran, R.S. Kanwar, J.C. Ascough II., 2007. RZWQM simulated effects of crop rotation, tillage, and controlled drainage on crop yield and nitrate−N loss in drain flow. Geodema 140: 260−271.
4. Ma, L., R.W. Malone, P. Heilman, D.L. Karlen, R.S. Kanwar, C.A. Cambardella, S.A. Saseendran, L.R. Ahuja, 2007. RZWQM simulation of long−term, crop production, water and nitrogen balances in Northeast Iowa. Geoderma 140: 247−259.

IMPACT OF SWINE MANURE APPLICATION ON WATER QUALITY

Problem and Research Objectives:

Swine manure application in agricultural fields has been recognized as a source of nutrients for crops as well as could potentially increase nitrate-nitrogen (NO_3-N) leaching to subsurface ground water, which can have serious impacts on the quality of water. Recognizing this issues, several states in the US are in the process of creating laws and/or regulations to reduce nitrogen (N) and phosphorus (P) loading from manure to soil and water resources. This study was conducted for seven years (2001-2007) with grant funds from several funding sources including Iowa Water Center, Leopold Center for Sustainable Agriculture, and National Pork Board with an overall objective of evaluating the effect of six different nutrient management practices on subsurface water quality. The specific objectives of this project are:

1. To determine the impacts of recommended swine manure application rates based on (N) and (P) needs of crops, on subsurface drain water quality.
2. To study the long-term effects of over-application of swine manure on nitrogen (N) and phosphorus (P) losses with subsurface drainage water.
3. To study the long-term effects of spring and fall injection of swine manure on crop yields, nitrogen, phosphorus and bacteria concentrations in subsurface drain water.
4. To develop and recommend appropriate manure and nutrient management practices to reduce the water contamination potential from manure and fertilizer N (UAN) applications and enhance the use of swine manure as an alternative to the use of inorganic fertilizers for Iowa's sustainable agriculture.

Methodology:

The experimental site for this study was located at Iowa State University's Northeast Research Center, Nashua, Iowa. The study site has 40, one-acre experimental plots with fully documented tillage and cropping records for the past twenty seven years. Figure 1 show 36 of the 40 one-acre plots which were used for experimental treatments 1 through 6 in this study (Table 1). The subsurface drainage system has been in place at this site for more than 29 years. Tile drainage was installed in 1979 into all of the 40, one-acre blocks (190 ft x 220 ft). The tile lines were installed about four feet deep at 95 ft spacing. Each one acre plot has one tile line passing through the middle of the plot and another tile line at each of the two borders. The tile lines at the borders help in minimizing the effect of cross contamination between plots. A total of ten one-acre plots in a row and plot rows are separated by an uncultivated area of 30 ft. width. The tile line installed in the middle of the plot drains about half an acre area. The middle tile lines of all the plots were intercepted and connected to individual sumps in December 1988 for measuring subsurface drain flows (tile flows) and collecting water samples for chemical analyses. To monitor tile flow on a continuous basis, each tile sump was provided with a 110 volt effluent pump, water flow meter, and an orifice tube to collect water samples for water quality analysis. Data loggers, connected to water flow meters, record tile flow data continuously as a function of time.

For analyzing NO_3-N and PO_4-P concentrations, an orifice tube was designed to deliver about 0.2% of the tile water into a sampling bottle each time effluent is pumped from the sump. This procedure allows not missing any subsurface drainage water from sampling and results in an accurate count on the loss of chemicals with subsurface drainage water. Starting from late March to the beginning of December during the each year in study period, cumulative subsurface drain flows were monitored and sampling bottles were removed three times per week.

Principal findings and Significance (for years 2001-2007):

Effect of nutrient management treatments on NO_3-N loss and leaching: Tables 1 and 2 summarize experimental results of the monthly and yearly average of NO_3-N losses and concentrations respectively, for years 2001 through 2006. Water samples from 2007 are

Table 1. Nitrate-nitrogen losses for 2001-2006 as a function of farming systems

		Nitrate-Nitrogen loss, kg/ha												
Month '01-'06	**Rain (cm)**	**Point Inject 150 # N**		**Fall Manure 150 # N**		**Fall Manure P Based**		**Fall Manure Excessive P**		**LCD 150 # N**		**Spring Manure 150 # N**		
Corn Rotation		**System 1**		**System 2**		**System 3**		**System 4**		**System 5**		**System 6**		**LSD**
March	4.2	0.0	a	0.0	a	0.0	a	0.0	a	0.0	a	0.0	a	0.0
April	8.2	1.3	a	2.9	a	1.6	a	3.6	a	1.9	a	2.4	a	2.6
May	12.5	4.5	b	8.9	ab	5.2	b	11.2	a	4.5	b	6.1	b	5.1
June	11.4	4.5	b	8.4	ab	5.2	b	10.3	a	5.3	b	6.8	ab	4.0
July	10.6	1.2	a	1.9	a	1.1	a	2.5	a	0.9	a	1.6	a	1.8
August	8.9	0.1	b	0.5	ab	0.0	b	0.4	ab	0.3	ab	0.6	a	0.5
September	10.0	0.2	a	0.1	a	0.4	a	0.8	a	0.5	a	0.6	a	0.9
October	3.4	0.2	a	0.3	a	0.4	a	0.8	a	0.5	a	0.6	a	0.8
November	3.6	0.0		0.0		0.0		0.0		0.0		0.0		0.0
Total	72.8	11.1	c	21.4	ab	13.0	bc	27.3	a	12.7	c	17.3	bc	8.7
Soybean Rotation								**Fall Manure Excessive P**						**LSD**
March	4.2	0.0	a	0.0	a	0.0	a	0.0	a	0.0	a	0.0	a	0.0
April	8.2	1.5	a	3.4	a	1.9	a	4.8	a	3.0	a	3.7	a	3.3
May	12.5	4.7	b	6.7	b	4.5	b	15.4	a	6.4	b	6.1	b	5.5
June	11.4	3.5	b	5.1	b	4.1	b	10.6	a	4.3	b	5.7	b	3.0
July	10.6	0.9	b	1.2	ab	1.2	ab	2.3	a	1.0	ab	1.8	ab	1.4
August	8.9	0.1	a	0.2	a	0.1	a	0.2	a	0.2	a	0.4	a	0.3
September	10.0	0.2	a	0.9	a	0.2	a	0.9	a	0.3	a	0.4	a	0.9
October	3.4	0.2	a	0.6	a	0.3	a	0.9	a	0.3	a	0.3	a	0.8
November	3.6	0.0	a	0.0	a	0.0	a	0.0	a	0.0	a	0.1	a	0.1
Total	72.8	10.3	b	16.6	b	11.5	b	32.1	a	14.3	b	17.3	b	8.3

currently being analyzed and results of these samples will be reported in the next annual report. Six year (2001-2006) average NO_3-N concentrations in tile water from plots under corn-soybean rotation and receiving swine manure (system/treatment # 4) were highest and almost twofold higher than that of other systems/treatments. Statistically, the NO_3-N concentrations in tile water for systems 1, 5 and 6 had no significant difference under the corn crop, while plots under fall manure application for systems #2, #3, and # 4 showed much higher NO_3-N concentrations in comparison to other systems indicating that swine manure applications in larger rates could result in larger NO_3-N losses with tile water.

Table 2. Nitrate-nitrogen concentrations for 2001-2006 as a function of farming systems

		Nitrate-Nitrogen Concentrations, ppm						
Month ‘01-‘06	**Rain (cm)**	**Point Inject 150 # N**	**Fall Manure 150 # N**	**Fall Manure P Based**	**Fall Manure Excessive P**	**LCD 150 # N**	**Spring Manure 150 # N**	
Corn Rotation		**System 1**	**System 2**	**System 3**	**System 4**	**System 5**	**System 6**	**LSD**
March	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
April	8.2	12.0 bc	17.2 ab	9.5 c	23.0 a	15.3 bc	14.5 bc	7.4
May	12.5	19.7 bc	27.2 b	21.4 bc	39.4 a	16.7 c	16.1 c	8.2
June	11.4	21.9 cd	29.3 b	24.7 cb	44.5 a	17.5 d	19.1 cd	6.0
July	10.6	21.0 bc	24.9 b	24.9 b	40.2 a	17.7 c	17.9 c	6.5
August	8.9	11.6 c	19.4 b	11.9 c	35.6 a	14.2 bc	14.4 bc	7.5
September	10.0	10.2 c	12.2 bc	17.5 b	34.3 a	12.8 bc	10.8 c	5.9
October	3.4	8.9 c	14.6 bc	16.3 b	32.4 a	12.6 bc	14.6 bc	6.2
November	3.6	5.2 a	9.5 a	0.0	12.3 a	10.4 a	10.5 a	15.7
Total	72.8	18.9 c	25.5 b	20.9 bc	40.6 a	16.5 c	16.7 c	5.8
Soybean Rotation					**Fall Manure Excessive P**			
March	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
April	8.2	14.2 b	18.7 b	14.5 b	33.1 a	18.3 b	13.8 b	6.8
May	12.5	19.7 b	19.5 b	17.8 b	39.1 a	21.8 b	12.2 c	7.3
June	11.4	18.5 b	18.0 b	17.8 b	38.8 a	20.8 b	13.1 c	4.2
July	10.6	17.5 b	15.5 b	16.3 b	42.2 a	18.2 b	12.0 c	4.7
August	8.9	12.8 b	13.3 b	12.7 b	24.4 a	12.3 b	10.9 b	6.4
September	10.0	10.6 bc	13.4 b	12.9 b	34.9 a	9.9 bc	7.9 c	3.5
October	3.4	11.7 bc	13.0 b	12.9 b	35.0 a	11.4 bc	9.4 c	2.7
November	3.6	3.3 b	9.4 b	6.8 b	31.8 a	5.0 b	6.3 b	10.8
Total	72.8	17.2 b	16.9 b	16.4 b	37.4 a	19.0 b	12.5 c	3.7

Effect of nutrient management treatments on PO_4-P loss and leaching: Tables 3 and 4 give monthly and yearly average of PO_4-P losses and concentrations respectively, for years 2001 through 2006. Again, results are very similar to average NO_3-N losses and concentrations in tile water. The plots receiving swine manure under the systems # 2 and #4 resulted in highest PO_4-P concentrations and losses. Statistically, the PO_4-P concentrations in tile water had no significant difference under the corn crop, while plots under fall manure application for system # 3 resulted in highest PO_4-P concentrations in comparison to other systems. This shows results are not very conclusive in terms of PO_4-P losses to subsurface drain water.

Table 3: Orthophosphate losses for 2001-2006 as a function of farming systems

		Orthophosphate loss, g/ha						
Month (01-06)	**Rain (cm)**	**Point Inject 150 # N**	**Fall Manure 150 # N**	**Fall Manure P Based**	**Fall Manure Excessive P**	**LCD 150 # N**	**Spring Manure 150 # N**	
Corn Rotation		**System 1**	**System 2**	**System 3**	**System 4**	**System 5**	**System 6**	**LSD**
March	4.2	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0
April	8.2	0.4 b	2.9 a	0.5 a	0.3 b	0.6 b	0.8 b	2.0
May	12.5	0.5 c	3.8 a	0.8 c	1.3 bc	1.3 bc	2.5 ab	1.7
June	11.4	0.7 b	2.0 a	0.8 b	1.6 ab	1.4 ab	1.7 ab	1.0
July	10.6	0.3 a	0.6 a	0.2 a	0.3 a	0.3 a	0.4 a	0.5
August	8.9	0.1 a	0.4 a	0.4 a	0.1 a	0.2 a	0.4 a	0.4
September	10.0	0.1 a	0.3 a	0.1 a	0.2 a	0.1 a	0.2 a	0.3
October	3.4	0.1 a	0.2 a	0.1 a	0.1 a	0.1 a	0.2 a	0.2
November	3.6	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0
Total	72.8	2.0 c	9.4 a	2.7 c	3.5 bc	3.7 bc	5.6 b	2.9
Soybean Rotation					**Fall Manure Excessive P**			**LSD**
March	4.2	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0
April	8.2	0.2 b	0.6 ab	0.4 ab	0.3 ab	0.3 ab	0.8 a	0.5
May	12.5	1.3 b	2.3 b	0.8 b	12.4 a	2.2 b	3.6 b	14.8
June	11.4	0.7 b	1.4 b	1.1 b	1.1 b	1.0 b	3.0 a	1.4
July	10.6	0.2 b	0.5 ab	0.3 ab	0.2 b	0.3 ab	0.7 a	0.4
August	8.9	0.1 ab	0.2 ab	0.1 b	0.1 b	0.1 ab	0.3 a	0.2
September	10.0	0.1 a	0.3 a	0.1 a	0.1 a	0.1 a	0.6 a	0.5
October	3.4	0.1 a	0.2 a	0.1 a	0.1 a	0.1 a	0.2 a	0.3
November	3.6	0.0 b	0.1 ab	0.0 b	0.0 b	0.0 b	0.4 a	0.0
Total	72.8	2.5 b	5.0 ab	2.7 b	12.2 a	3.7 b	8.3 ab	8.3

Effect of swine manure applications on bacteria leaching: Tables 5a and 5b give limited data on fecal coliform bacteria leaching to tile water from manure plots. Both tables show that for the months of May and June, fecal coliform detects were found in tile water in small quantities but some plots resulted a bacteria count of 87/100ml. These results clearly indicate that fecal coliform has the potential to leach the shallow groundwater and contaminate groundwater under corn-soybean rotation, especially under highly intense storms occurring immediately after manure applications in months of May and June.

Effect of swine manure applications on corn and soybean yields: Figure 2 gives the average yearly corn and soybean yields from seven years (2001-2007). The system #4 resulted in an average yield of 195 bushels/ac which was the highest in comparison to other systems. The data on crop yields indicate that swine manure application has resulted in better yields in comparison UAN applications.

Table 4: Orthophosphate Concentrations for 2001-2006 as a function of farming systems

Month (01-06)	**Rain (cm)**	**Orthophosphate Concentrations, ppb**						
		Point Inject 150 # N	**Fall Manure 150 # N**	**Fall Manure P Based**	**Fall Manure Excessive P**	**LCD 150 # N**	**Spring Manure 150 # N**	
Corn Rotation		**System 1**	**System 2**	**System 3**	**System 4**	**System 5**	**System 6**	**LSD**
March	4.2	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0
April	8.2	2.9 a	11.0 a	9.1 a	4.6 a	17.4 a	17.9 a	15.5
May	12.5	4.8 a	25.5 a	10.8 b	8.4 b	7.5 b	7.4 b	14.3
June	11.4	6.7 a	10.2 a	7.1 a	7.2 a	6.2 a	6.1 a	4.5
July	10.6	14.2 a	15.3 a	17.4 a	11.2 a	6.1 a	6.9 a	13.4
August	8.9	56.7 ab	29.6 ab	82.3 a	13.4 b	11.3 b	12.6 b	65.2
September	10.0	32.9 ab	73.8 a	31.6 ab	9.0 b	3.1 b	20.9 ab	61.6
October	3.4	3.6 a	4.9 a	2.3 a	3.2 a	3.8 a	2.2 a	4.8
November	3.6	2.2 a	6.6 a	0.0 a	10.7 a	2.8 a	6.2 a	3.5
Total	72.8	15.6 a	13.1 a	23.0 a	6.3 a	6.1 a	6.6 a	23.1
Soybean Rotation					**Fall Manure Excessive P**			**LSD**
March	4.2	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0
April	8.2	14.7 ab	24.7 a	12.7 ab	5.2 b	7.1 ab	6.6 ab	19.1
May	12.5	5.0 b	6.5 b	4.2 b	26.3 a	6.2 b	7.0 b	16.8
June	11.4	5.0 a	6.7 a	7.2 a	5.3 a	6.3 a	7.3 a	3.8
July	10.6	8.1 ab	18.4 a	9.9 ab	3.6 b	9.9 ab	7.6 ab	14.3
August	8.9	92.2 a	34.6 a	14.1 a	45.7 a	12.5 a	11.0 a	92.8
September	10.0	64.0 a	5.0 a	5.0 a	2.6 a	17.4 a	43.6 a	75.7
October	3.4	2.5 a	2.6 a	2.3 a	2.2 a	2.3 a	3.8 a	3.5
November	3.6	0.6 a	2.7 a	1.5 a	3.2 a	29.1 a	5.6 a	50.5
Total	72.8	5.2 b	7.1 ab	4.9 b	13.7 a	5.7 b	6.2 ab	7.8

Table 5a: Fecal Coliform bacteria detected in the tile water at the Nashua site subsurface drained research plots for years 2000 to 2002.

System	Application Timing and Source of N	Tillage	2000			2001			2002			
		Date	6/13	6/20	6/27	5/1	5/21	6/5	5/6	5/13	6/14	8/6
			Membrane Fecal Coliform Plots Positive/Plots Sampled									
1 Corn	Spring UAN Incorporated	CP	1/3	1/3	0/3	0/3	0/3	0/3	0/0	0/0	0/1	2/3
2 Corn	Fall Manure Inject	CP	0/3	0/3	0/3	0/3	0/3	0/3	0/2	0/2	1/3	0/3
3 Corn	Fall Manure Inject	CP	2/2	0/3	0/3	1/3	0/3	0/3	0/0	0/0	1/1	2/3
4 Corn	Fall Manure Inject	CP	0/3	0/3	0/3	0/3	0/3	0/3	0/2	0/3	0/3	1/3
4 Soybeans	Fall Manure Inject	CP	0/3	0/3	0/3	0/3	0/3	0/3	0/2	0/2	0/1	2/2
5 Corn	Fall UAN Localized Compaction	CP	Not Tested			Not Tested			Not Tested			
6 Corn	Spring Manure Inject	NT	1/3	1/3	0/3	3/3*	0/3	0/3	0/3	0/3	0/3	1/3

* Average of 87 CFU/100 ml

Table 5b: Fecal Coliform bacteria detected in the tile water at the Nashua site subsurface drained research plots for years 2000 to 2002

System	Application Timing and Source of N		2003					2004						
		Date	5/1	5/13	5/27	6/3	7/1	5/12	5/19	5/26	6/2	6/9	6/16	6/23
			Membrane Fecal Coliform Plots Positive/Plots Sampled											
1 Corn	Spring UAN Incorporated	CP	0/3	0/3	0/3	0/3	0/3	Not Tested						
2 Corn	Fall Manure Inject	CP	0/3	1/3	0/3	0/3	0/3	0/2	0/3	0/3	0/3	0/3	0/2	0/2
3 Corn	Fall Manure Inject	CP	0/3	0/3	0/3	0/3	0/3	-	-	0/3	0/3	0/3	0/3	0/3
4 Corn	Fall Manure Inject	CP	0/3	1/3	0/3	0/3	0/3	0/1	0/1	0/3	0/3	0/3	0/3	0/3
4 Soybeans	Fall Manure Inject	CP	0/3	0/3	0/3	0/3	0/3	-	0/1	1/3	0/3	0/3	0/3	0/3
5 Corn	Fall UAN Localized Compaction	CP	Not Tested					Not Tested						
6 Corn	Spring Manure Inject	NT	0/3	0/3	0/3	0/3	0/3	0/2	0/3	0/3	0/3	0/3	0/3	0/3

Figure 1: Plot layout at the Nashua Water Quality Research site (2001-2006)

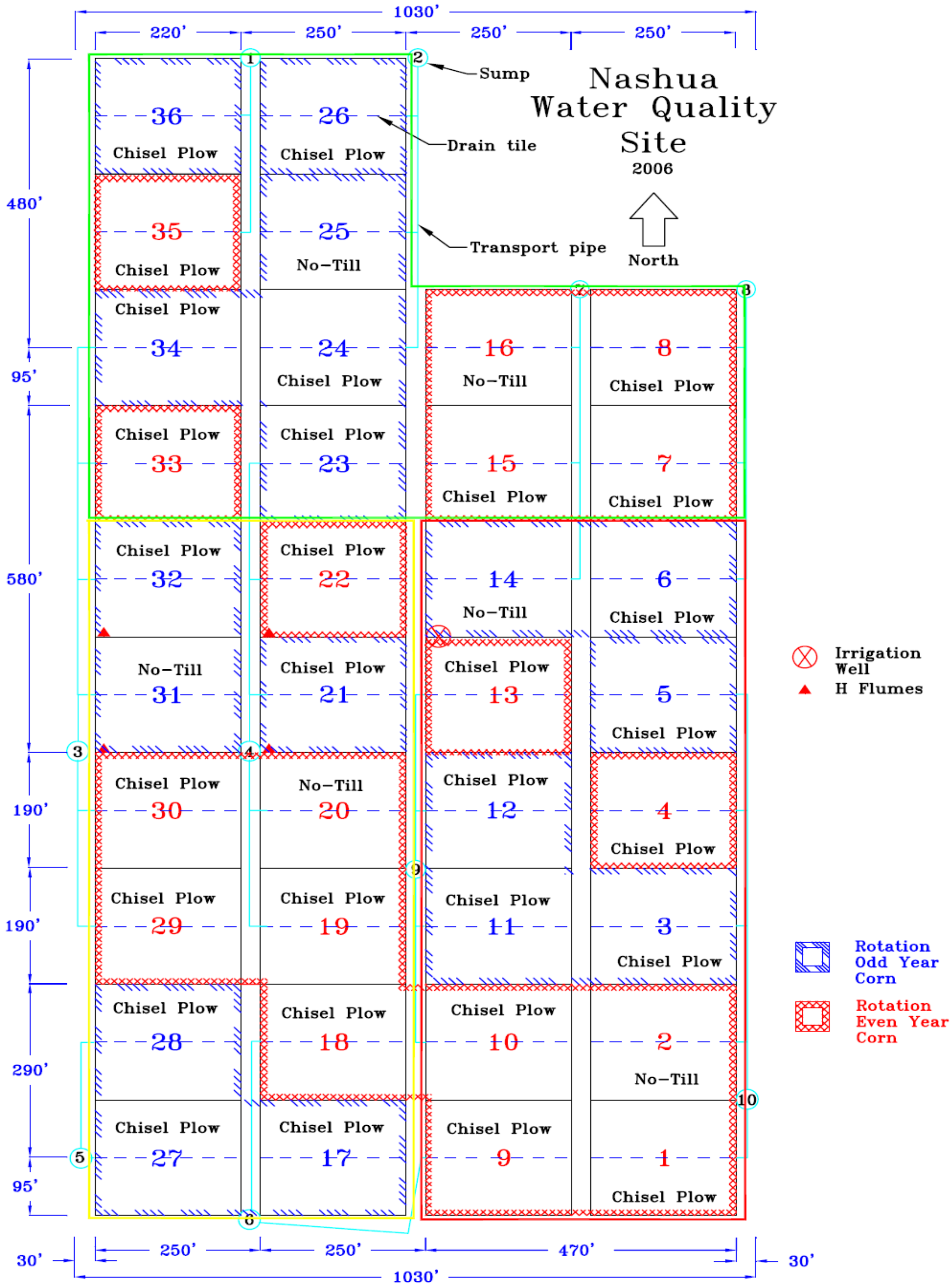
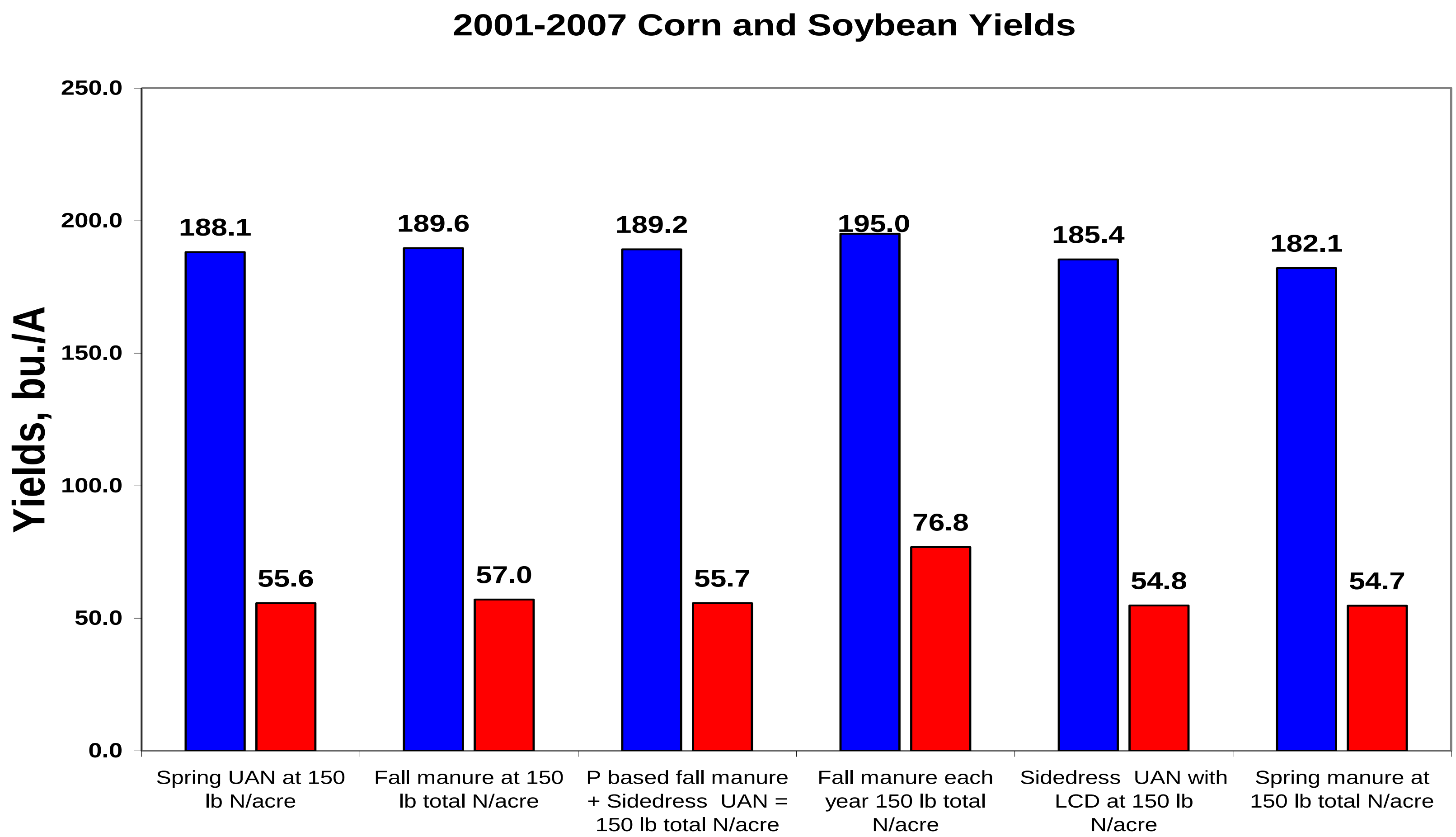


Figure 2: **Corn and Soybean crop yields for years 2001-2007**



Assessing the Impact of Ethanol Production and Sustainability of Alluvial/Buried Valley Aquifers with Groundwater Models: A Test Case for the Ames Aquifer

Basic Information

Title:	Assessing the Impact of Ethanol Production and Sustainability of Alluvial/Buried Valley Aquifers with Groundwater Models: A Test Case for the Ames Aquifer
Project Number:	2007IA116B
Start Date:	3/1/2007
End Date:	2/28/2008
Funding Source:	104B
Congressional District:	4
Research Category:	Ground−water Flow and Transport
Focus Category:	Groundwater, Water Supply, Models
Descriptors:	None
Principal Investigators:	William Simpkins, Laurie Ann Achenbach

Publication

1. Simpkins, W.W. 2008. Impacts of Biofuel Production on a Municipal Water Supply in Ames, Iowa. Geol. Soc. Am. Absts. with Progs.
2. Simpkins, W.W., E.G. Christianson, and K.K. Tebben. 2007. Educating Citizens About the Limits of Water Supply: Hydrogeology for the Public Good in Ames, Iowa. Geol. Soc. Am. Absts. with Progs.
3. Christianson, E.G. and W.W. Simpkins. 2007. Using stable isotopes of oxygen and hydrogen to corroborate groundwater recharge/discharge relationships at Ada Hayden Lake in Ames, Iowa. North−Central, South−Central Meeting. Geol. Soc. Am. Absts. with Progs.
4. Simpkins, W.W. and E.G. Christianson. 2007. Ethanol production and aquifer sustainability in an alluvial/buried valley aquifer system in central Iowa. North−Central, South−Central Meeting. Geol. Soc. Am. Absts. with Progs.

IWC Progress Report

Assessing the Impact of Ethanol Production and Sustainability of Alluvial/Buried Valley Aquifers with Groundwater Models: A Test Case for the Ames Aquifer

PI: William W. Simpkins

June 2008 (for report period March 1, 2007 to February 29, 2008)

Problem and Research Objectives

Concern has increased about the impact of ethanol production on Iowa's water resources. Tools for assessing the larger-scale impacts of ethanol production in aquifers (including water quality and ecological impacts) and for evaluating the sustainability of aquifers in the State need to be developed in order to provide a scientific basis to strengthen administrative oversight of groundwater use. The objective of this project was to compare the ability of different types of groundwater models to assess those needs. Models were applied to a test case of the Ames aquifer, a regional, alluvial/buried valley aquifer in central Iowa that supplies water to Lincolnway Energy, Inc., a 50 MGY ethanol facility (Figure 1). The need for this work became more urgent when, in late 2007, the City of Nevada, Iowa proposed to the Iowa Department of Natural Resources (IDNR) that it be granted an increase in groundwater withdrawal from its present allocation of 325 MGY to 800 MGY. The requested increase is due primarily to the withdrawal of 329 MGY of untreated water by the ethanol plant. By using models to assess the impact of ethanol production, the results of this study provide a template to guide management and regulation of similar aquifers whose groundwater withdrawals have increased due to ethanol production.

Methodology

Results of a regional 2-D, steady-state, analytic element, groundwater/surface water model (GFLOW) and a local-scale, 3-D, steady-state, finite-difference model (MODFLOW-2000) were compared to determine which is best suited to evaluate the impacts of ethanol production at different scales. The analytic element model (GFLOW 2.1.1) was used to simulate the water table in the entire central Iowa region, set

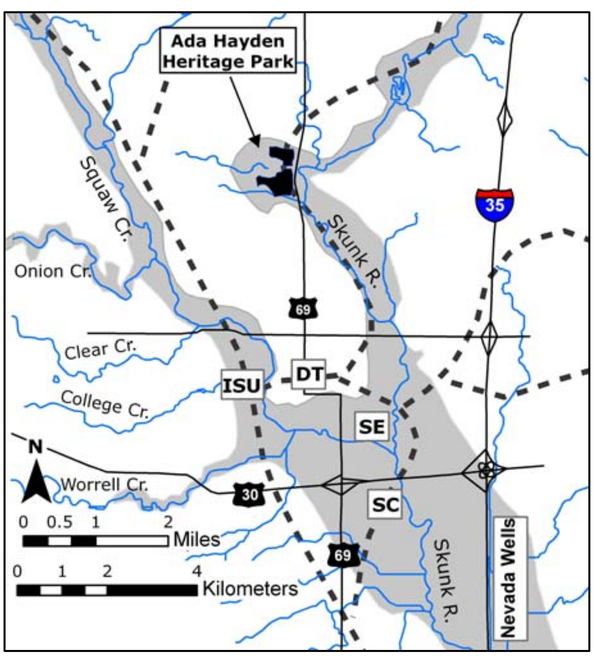


Figure 1. Map of the Ames, Iowa region showing the extent of the Ames aquifer and major streams. Extent of the alluvial aquifer is shown in gray. Trend of buried-valley aquifer shown by dashed lines. ISU, DT, SE, and SC are the Ames well fields. ISU, SE, and SC well fields take advantage of a combined alluvial buried-valley aquifer. Location of the pumping wells associated with the City of Nevada is shown in the southeastern part of the map. Lincolnway Energy is approximately 3 miles north of the Nevada well field.

Table 1. Baseflow estimates for USGS gaging stations in the model

Stream	Time Period	Baseflow Index	Baseflow (cfs)
South Skunk River N. (05470000)	1921 to 1946	0.347	30.86
Squaw Creek (05470500)	1920 to 1970	0.420	52.47
South Skunk River S. (05471000)	1953 to 1972	0.401	98.70

regional boundary conditions, and estimate aquifer parameters prior to detailed 3-D simulations. The model domain contained portions of Story and Boone Counties (Figure 2; about 815 mi^2). Calibration (history matching) was achieved using hydraulic head targets (137), streamflow data from gaging stations (3), and a specified lake stage of 896.25 ft for Ada Hayden Lake. Sources of stream discharge data included 3 USGS stream gages – the South Skunk River north of Ames (05470000), the South Skunk River south of Ames (05471000), and Squaw Creek at Lincoln Way (05470500); baseflow was estimated at each station (Table 1). The nonlinear parameter estimation program, PEST, was implemented to refine the estimation of parameters (Table 2), test their sensitivity in the model, and produce a unique fit of data and parameters. For the PEST analysis, observations of hydraulic head, streamflow, and lake stage (observation groups) were weighted for use in the objective function. The most sensitive parameters for all observations were the K of the Skunk River alluvium, the K of the entire model (Global K), and the recharge rate applied to the entire model (Global R). Confidence intervals for the remaining parameters could not be estimated (Table 2).

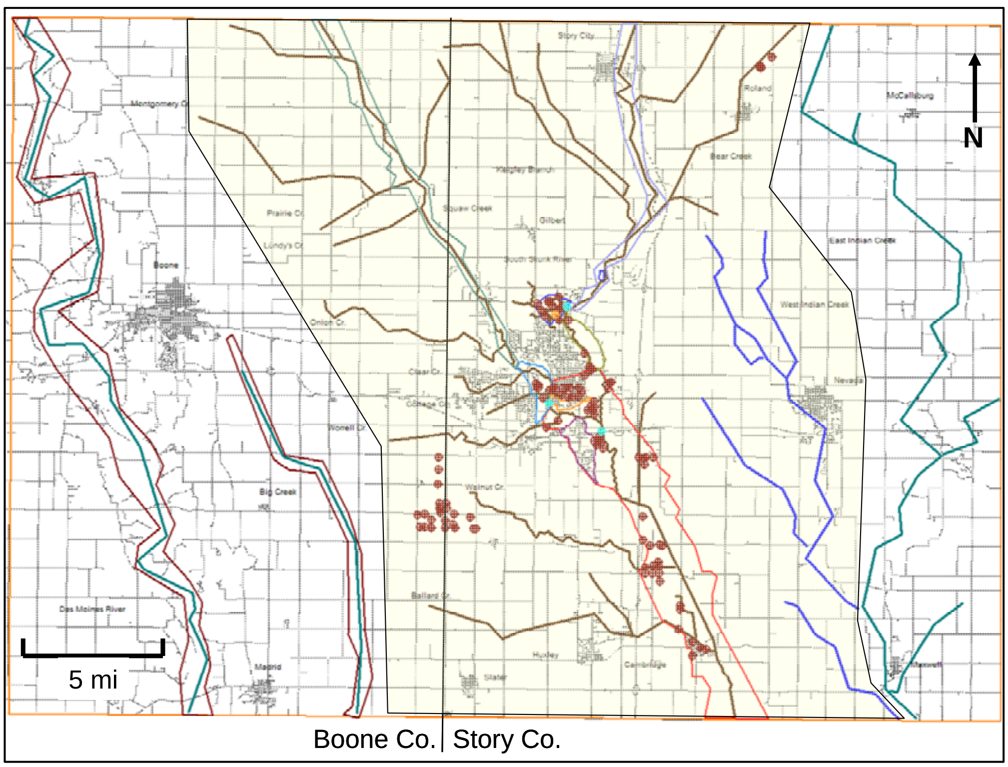


Figure 2. Domain of the 2-D GFLOW model. Area of yellow shading is the near-field area; white area is the far field. The 136 calibration targets are shown as circles with plus signs – brown for hydraulic head targets, cyan for flux targets, orange for lake stage targets. Red polygon outlines the alluvial aquifer associated with the South Skunk River.

Table 2. Parameter values used in the initial and final GFLOW model. Values with confidence intervals were most sensitive in the final solution as estimated by PEST.

Inhomogeneity	Parameter	Initial Value	Final Value	95% Confidence Int.
Global	K	5 ft/d	10.1 ft/d	9.3 to 10.9 ft/d
Global	R	3.2 in/yr	6.4 in/yr	5.9 to 6.9 in/yr
Skunk River alluvium	K	1000 ft/d	2321.2 ft/d	1593.9 to 3380.4 ft/d
Skunk River alluvium	R	N/A	0.1 in/yr	N/A
Lower Squaw	K	N/A	586.1 ft/d	N/A
Homewood alluvium	K	N/A	2000 ft/d	N/A
Ada Hayden alluvium	K	1000 ft/d	184 ft/d	N/A
Upper Skunk	K	500 ft/d	1600 ft/d	N/A
Upper Squaw	K	500 ft/d	1600 ft/d	N/A
Outwash over till	K	N/A	10.1 ft/d	N/A
Big Creek	K	500 ft/d	2000 ft/d	N/A
Des Moines River	K	1000 ft/d	2000 ft/d	N/A

Principal Findings and Significance

Results of the region GFLOW model show that groundwater flows toward the major streams and that groundwater divides to the west, north, and east of Ames provide the boundaries for Ames aquifer groundwatershed (Figure 3). Most streams that are tributary to Squaw Creek and the South Skunk River are gaining in their upper reaches; i.e., groundwater discharges into them. Many become losing streams in their lower reaches when they flow onto the alluvium. Within the South Skunk River valley, there is a considerable component of down-valley flow or underflow, as indicated by the asymmetric capture zones of each well which point entirely upstream (Figure 4).

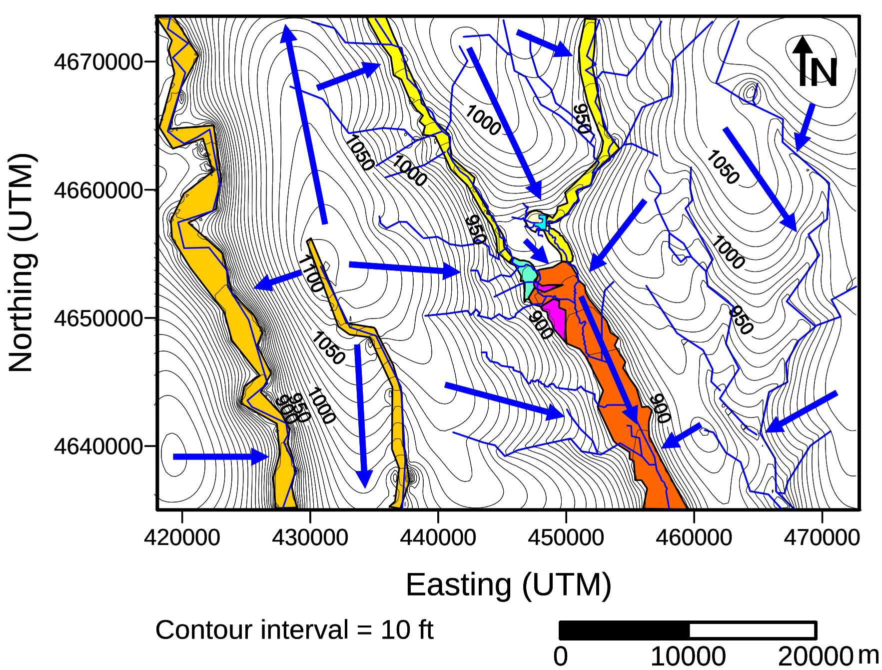


Figure 3. Water-table map generated by GFLOW for the domain shown in Figure 1. Blue arrows indicate general direction of groundwater flow at the water table. Colored areas are inhomogeneities (corresponding K values in Table 2). Orange area is the alluvial aquifer.

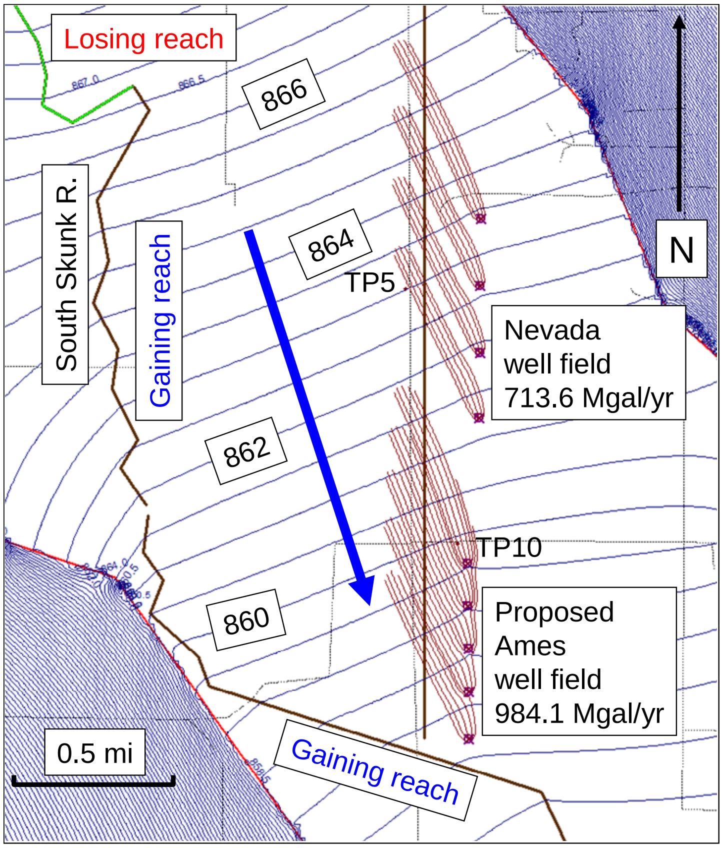


Figure 4. Water table and groundwater flow under steady-state pumping conditions in the vicinity of the Ames south and Nevada well fields. Note slight deflection of water table contours and location of capture zone upgradient from pumping wells. Pumping rates used here have been superseded by the higher rates used in the finite-difference simulation. Contour interval is 1 ft. Each capture zone equals a one year time of travel.

Given these results, a local scale, 3-D finite-difference model was extracted from the GFLOW model to determine the effect of pumping the Nevada well field at the new proposed rate of 800 MGY (2.2 MGD; 380.5 gpm at 4 wells) and a proposed Ames well field 1800 ft to the south at 2.2 BGY (6 MGD; 1042 gpm at 4 wells). The higher pumping rate accommodates the projected increase due to the ethanol plant. The model grid and boundary conditions from the extraction resulted in 64 rows, 60 columns, and 3 model layers comprising 30,000 active cells (Figure 5). The grid was imported into MODFLOW-2000. The outer boundary of the model is a specified head boundary based on the head solution in the GFLOW model and is well outside the influence of the pumping wells. The South Skunk River is a head dependent boundary (RIV package) with leakance values taken from the GFLOW model. Values of K were 696 ft/d (alluvium) and 10.1 ft/d (till); S_y was set at 0.01. Five stress periods of 30 days each were used in the transient simulations. The optimization program will be applied to the final regional 3-D finite-difference model which is under construction at this time.

The results of the steady-state MODFLOW-2000 model are similar to the GFLOW model with areas of underflow and gaining reaches of the South Skunk River (Figure 6). Similarity of hydraulic heads in the top and bottom layers suggests mostly horizontal groundwater flow down valley and not much vertical flow. Three head targets were inserted into the model (locations: R51, C46; R56, C46; R63, C46) between the two well fields to track drawdown due to pumping. The effect of the proposed Nevada pumping on the aquifer is negligible at 90 days, with a drawdown or about 2.64 ft at the south side of the well field and 0.89 ft at the northern boundary of the proposed Ames well field after 90 days (Figure 7: Table 3). Addition of the Ames well field with its higher pumping rate causes an additional drawdown of 1.82 ft for a total drawdown of 4.46 ft at the south end of the Nevada well field (Target 1; Table 3), and a total drawdown of 5.88 ft at the north end of the Ames well field (Target 3; Figure 8; Table 3). The Ames well field also induces infiltration from the South Skunk River, which becomes a source of water

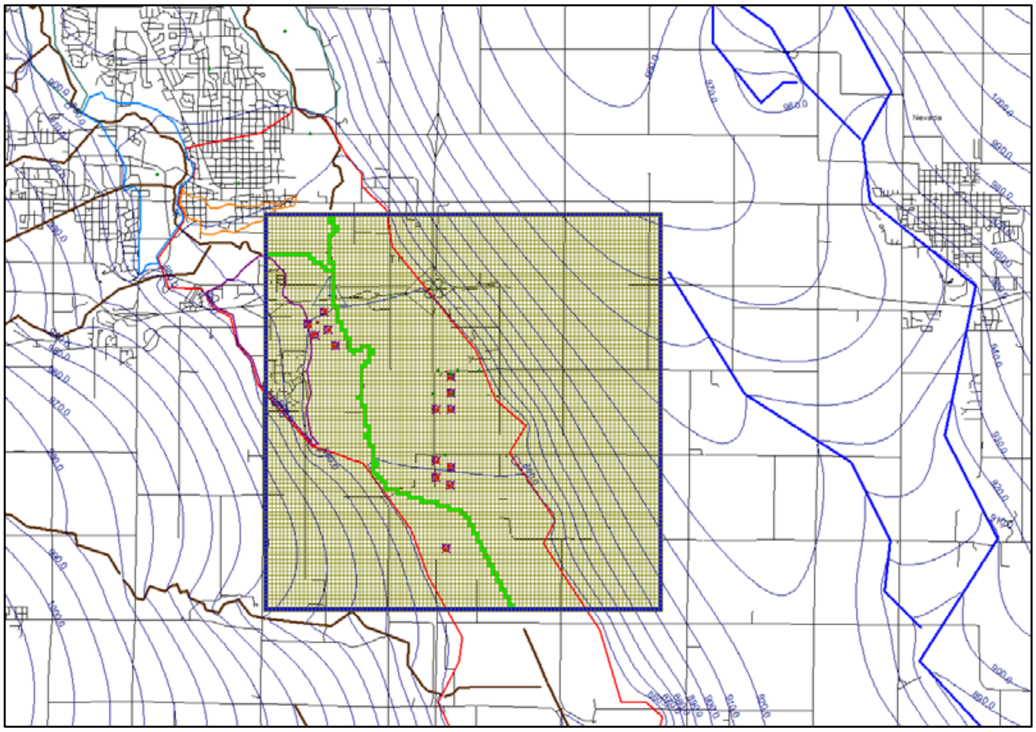


Figure 5. Area of grid extracted from GFLOW for 3-layer MODFLOW model. Boundaries of the model represent the hydraulic heads at those points in the GFLOW model, which are well outside the influence of the pumping wells under transient conditions.

for the well field. In fact, the head targets at 90 days suggest that steady-state conditions are reached very quickly (Table 3). In contrast, under drought conditions the river would be dry and likely result in increased drawdown in both well fields.

Based on the MODFLOW-2000 modeling, the expansion of pumping in the Nevada well field to accommodate the ethanol plant will have little effect on the proposed Ames well field 1800 ft to the south, increasing the drawdown at its northern edge by only 0.89 ft at 90 days. In contrast, pumping from the proposed Ames well field produces a cone of depression that extends north to the Nevada well field. This will increase drawdown by an additional 2 ft at the south end of the Nevada well field to a total of 4.46 ft. Hence, the Ames well field will impact the Nevada well field more because of its higher pumping rate. It is unlikely that there were be significant interference in the near term under normal climate conditions, because both well fields may pump substantially less than projected. Sustained drought conditions and drying up of the South Skunk River will alter that relationship and could increase the impact from pumping in the Ames well field. The City of Nevada was granted their new water use permit for the next 10 years, partly because of the results of this model.

Table 3. Hydraulic heads at targets in Layer 3 under steady-state and pumping conditions. Target 1 is at the south end of the Nevada well field, Target 2 is midway between the two well fields, and Target 3 is at the north end of the Ames well field (see small blue dots on Layer 3 in Figures 6 and 7).

Target	Steady state (ft)	Nevada wells only at 90 days (ft)	Nevada and Ames wells at 90 days (ft)	Nevada and Ames wells pumped to steady state (ft)
1	863.93	861.47	859.47	859.47
2	862.82	861.15	858.49	858.49
3	861.05	860.16	855.17	855.17

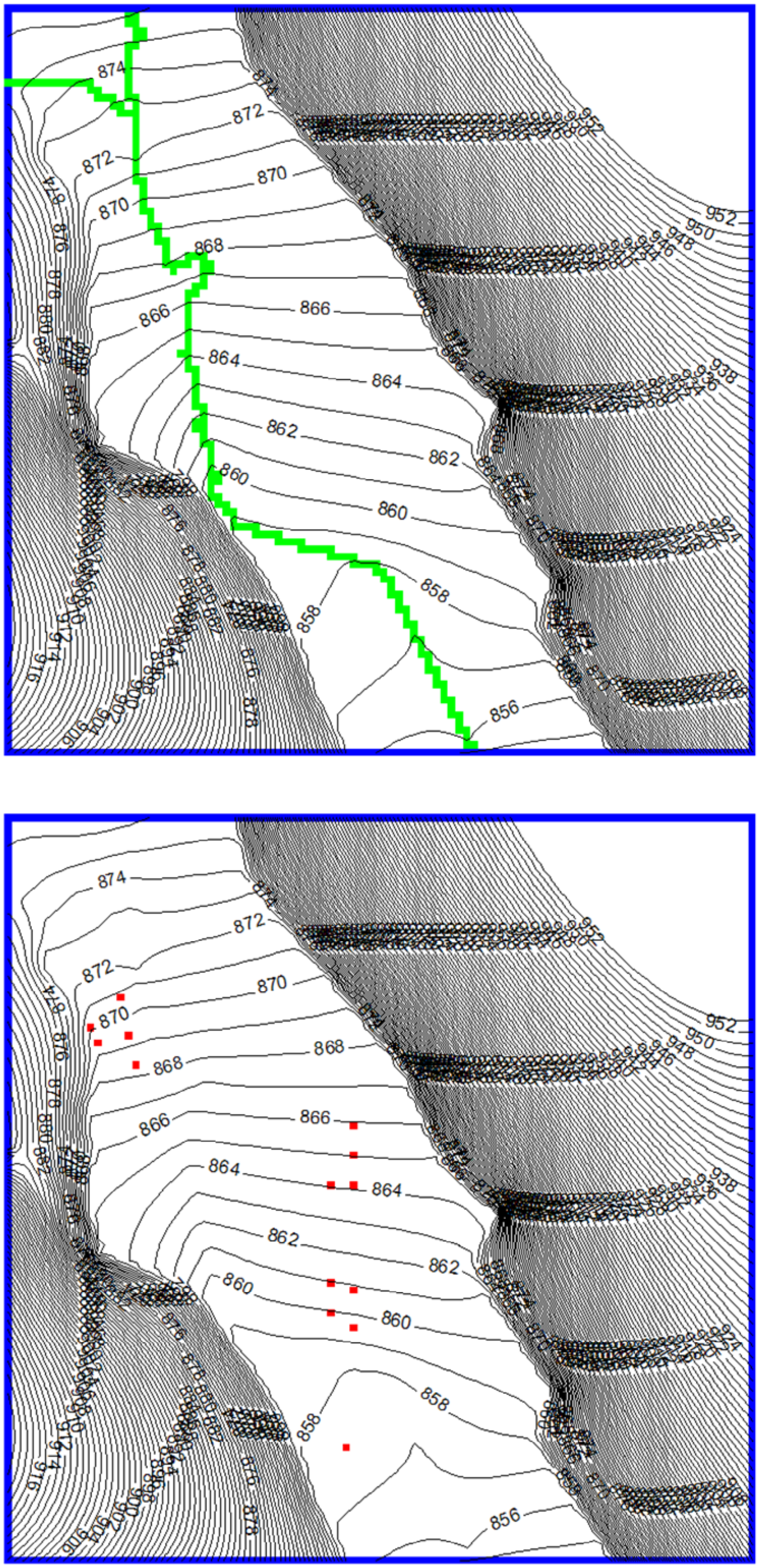


Figure 6. Steady-state model solution from MODFLOW-2000 showing the water table overlain on Layers 1 (top) and 3 (bottom) and flow in the alluvial aquifer. Underflow and gaining stream reaches are shown in this model similar to the results of the GFLOW model. White area in the upper right corner is a problem with contouring in the modeling program, not a dry cell area. Other well fields shown on the figure were not involved in this simulation. Contour interval = 1 ft.

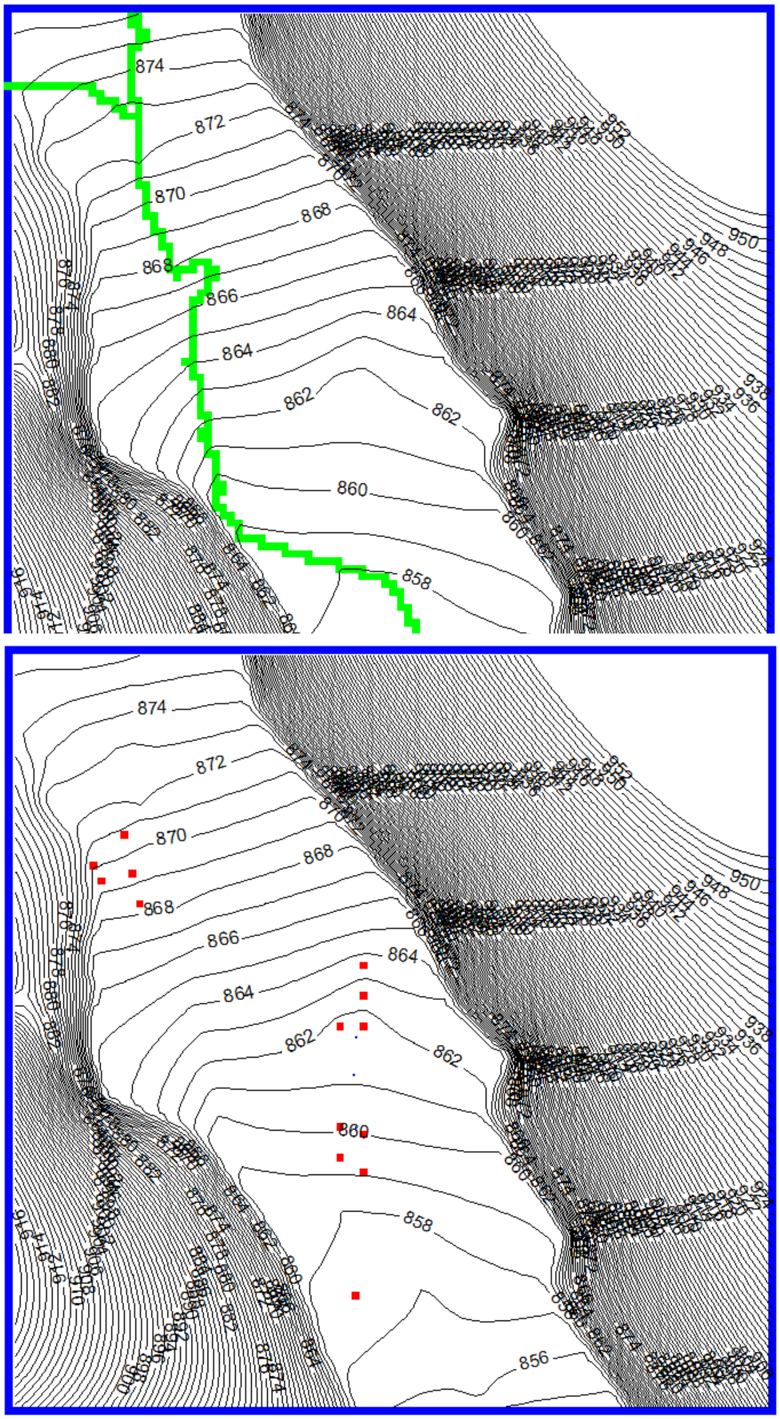


Figure 7. Transient model (MODFLOW-2000) solution in Layers 1 (top) and 3 (bottom) showing water table flow in the alluvial aquifer under pumping conditions of 800 MGY in the Nevada well field for 90 days. Some local deflection of the contours at the Nevada well field is shown by the 862 ft contour, but otherwise flow remains unchanged. Contour interval = 1 ft.

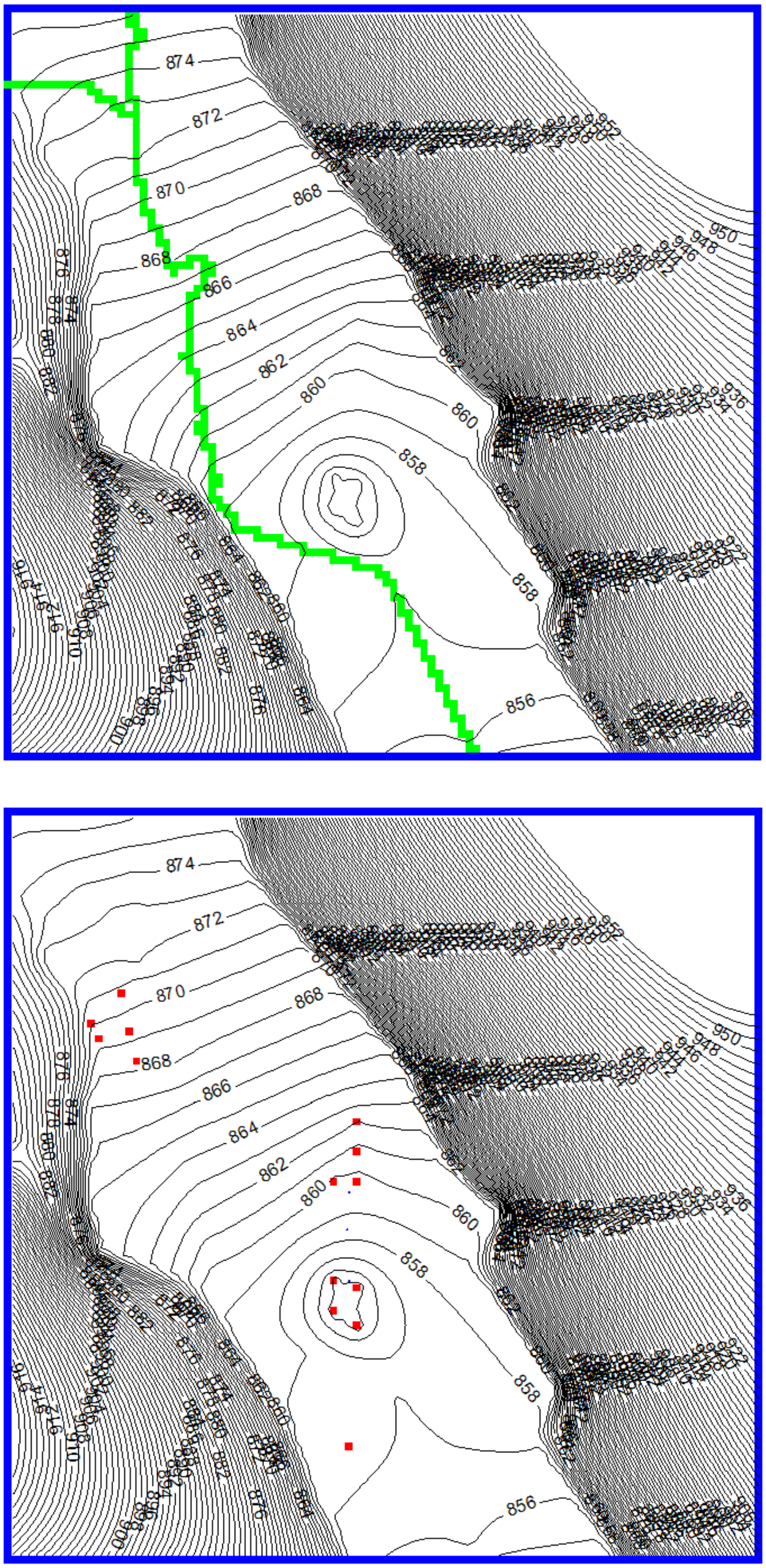


Figure 8. Transient model (MODFLOW-2000) solution in Layers 1 (top) and 3 (bottom) showing the water table and flow in the alluvial aquifer under pumping conditions of both 800 MGY in the Nevada and 2.2 BGY in the Ames well fields for 90 days. Drawdown is most noticeable in the Ames well field which also induces flow from the South Skunk River. Contour interval = 1 ft.

In summary, the 2-D and 3-D models showed the effect of pumping increases due to ethanol production. The results were similar between the two models, although the analytic element model is a 2-D model that is not able to address confined parts of the Ames aquifer (outside the influence of the ethanol plant) and is limited to steady-state pumping scenarios. The 3-D model can address confined and unconfined conditions and model transient pumping scenarios. Both models were instrumental in guiding policy decisions for the Nevada well field and the City of Ames. As mentioned previously, the Iowa Department of Natural Resources based their water permit decision on the modeling for this project.

The modeling also had some unexpected consequences. First, the City of Nevada can exercise its water rights if and when Ames puts in a new well field to the south. However, because of the predicted impact of pumping as shown by the model, Ames may need to pump less water from the well field than they had anticipated because of the potential impact to the Nevada well field. The City is now looking elsewhere in the valley for more water. Second, the simulations also suggest that there is significant induced infiltration from the Skunk River into the proposed Ames well field. Inducing flow from the river risks invoking surface water treatment rules and may be an unacceptable risk. Based on the model results shown in Figure 4, a well field location further up-valley (where the river is oriented more north to south) and further from the river would be less likely to induce infiltration. For both of these reasons, Ames is looking elsewhere in the South Skunk River valley for new municipal water supplies. We are presently enlarging the scale of the 3-D model in the region in order to incorporate the Ground Water Management optimization model for all four of the Ames well fields.

Effects of managed riparian buffers on the integrity of stream systems: a biological assessment using fish and invertebrate communities

Basic Information

Title:	Effects of managed riparian buffers on the integrity of stream systems: a biological assessment using fish and invertebrate communities
Project Number:	2007IA117B
Start Date:	3/1/2007
End Date:	5/1/2008
Funding Source:	104B
Congressional District:	4
Research Category:	Water Quality
Focus Category:	Water Quality, Agriculture, Management and Planning
Descriptors:	
Principal Investigators:	Michael Carl Quist

Publication

IWC Annual Report
PIs: Michael Quist, Timothy Stewart, and Thomas Isenhart
June 2008 (for report period March 1 2007—February 29, 2008)

Problem and Research Objectives

Large-scale changes in land use, stream channelization, and removal of riparian vegetation increase nutrient and sediment loading and solar irradiance that eliminate aquatic habitat, elevate water temperatures, and reduce dissolved oxygen concentrations. Pesticides and fertilizers may also threaten human health when they enter aquatic ecosystems (e.g., facilitation of toxic algae blooms). Despite the best efforts of government agencies and producers, significant reductions in sediment and chemical inputs are unlikely to be achieved through traditional, in-field management practices alone. Recognizing these limitations, public agencies are increasingly using conservation buffer practices such as riparian buffers, consisting of woody and nonwoody vegetation, to reduce nutrient, sediment, and pesticide inputs to streams. Nearly 2,000 km^2 of landscape buffers have been established in Iowa since the Continuous Open Enrollment of the Conservation Reserve Program was implemented in 1996, with most of these being riparian forest buffers or similar streamside buffers. In Iowa, benefits of re-establishing riparian forest buffers have been documented in recent studies by the Agroecology Issue Team at Iowa State University. Although work has documented significant reductions in nutrient and sediment loading to streams, critical knowledge gaps remain on the response of biological communities to management practices in Bear Creek. Because organisms are now acknowledged to be definitive indicators of water quality and ecosystem health, they are increasingly being used for regulatory assessments by the U.S. Environmental Protection Agency and are likewise essential tools for assessing riparian buffer effectiveness. Therefore, the objective of this project is to quantify the effects of riparian buffer systems on instream habitat and aquatic organisms. Relationships between riparian features (e.g., riparian conservation buffers), in-stream habitat characteristics (e.g., substrate composition), fish abundance, diversity, and growth, and aquatic invertebrate abundance and diversity are being used to assess effects of conservation practices on water quality and ecosystem integrity. Results of this research will be used to help guide management actions on small streams in central Iowa and will provide important insights that can be used when considering similar management practices across the Midwest.

Methodology

Fish assemblages and instream habitat features were characterized from 42 reaches (June-August 2007) in three stream systems, including Bear, Long Dick, and Kiegley Branch creeks. Bear Creek has received extensive riparian habitat enhancement. Land use in the Long Dick and Kiegley Branch creek watersheds is nearly identical to Bear Creek, but they have not yet been the focus of extensive streamside conservation practices. In addition to having similar land uses, soil types, and climate, the streams have similar connectivity to potential source populations (i.e., South Skunk River) of fishes and invertebrates. Twenty-one reaches were sampled from Bear Creek (13 buffered sites; 8 unbuffered sites), 11 reaches from Long Dick Creek (1 buffered site, 10 unbuffered sites), and 10 reaches from Kiegley Branch Creek (3 buffered sites, 7 unbufferd sites).

Fish were collected using standard sampling procedures developed by the Iowa Department of Natural Resources (IDNR) for biological assessment of wadeable streams. Specifically, fish were sampled using a backpack-mounted electrofishing unit, identified to species in the field, and measured (body length). Voucher specimens were preserved in 10% formalin. Scales and otoliths were removed from a sub-sample of central stonerollers and creek chubs for age and growth analysis. In addition to sampling fishes, aquatic invertebrates were sampled from one half of the reaches where fish were sampled. Similar to fish sampling, standard protocols developed by the IDNR for biological assessment were used for aquatic invertebrate sampling. Samples were preserved in 5% formalin and processed in the laboratory.

Physicochemical features in individual macrohabitats (i.e., pools, riffle, runs) were measured at each sampling reach. Percent cover of the streambed by different inorganic particle-size classes (e.g., cobble, silt) and instream cover (e.g., large wood debris) were measured using standard transect-based sampling techniques. In addition, mean and maximum depth, mean wetted width, streambed topographic complexity, and canopy cover were also estimated for each macrohabitat in the reach.

Principal Findings and Significance

During the first year of the project, all field sampling was completed. Nearly all of the fish-related data have been processed and most of the aquatic invertebrate samples have been sorted. Our goal is to have all of the samples processed and the data analyzed by the end of July 2008.

Although we are still analyzing the instream habitat and macroinvertebrate data, several interesting patterns have emerged from preliminary analysis of the fishery data. For instance, run habitats typically had the highest number of fish species (mean = 8.9 species) across all stream reaches followed by pools (8.6 species) and riffles (7.3 species). Interestingly, stream reaches in Long Dick and Kiegley Branch creeks (i.e., streams with few riparian buffers) typically had more species than stream reaches in Bear Creek. Species richness was highest in Kiegley Branch (mean =13.7 species), followed by Long Dick Creek (11.9 species) and Bear Creek (9.1 species). This result is likely due to the addition of a few species highly tolerant of environmental degradation. Creek chubs (frequency of occurrence = 29%), bluntnose minnows (21%), bigmouth shiners (8%), and white suckers (7%) were the most common species sampled across sites, but their dominance differed between reaches with and without riparian buffers. Sites with riparian buffers were dominated by creek chubs (27%), bluntnose minnows (16%), white suckers (8%), and common shiners (7%); whereas, the most common species in sites without riparian buffers were creek chubs (30%), bluntnose minnows (27%), bigmouth shiners (11%), and central stoneroller (7%). Creek chubs, bluntnose minnows, and Johnny darters were the most common species in run habitats, while creek chubs, bluntnose minnows, and white suckers were the most common species in pool habitats. Riffle habitats were dominated by bluntnose minnows, creek chubs, common shiners, and bigmouth shiners. Black bullheads, black crappie, blacknosed dace, common carp, largemouth bass, and shorthead redhorse were only sampled in pools and runs. Quillback carpsucker was the only species that was sampled in riffles but not in pool or run habitats.

All of the fish species sampled during the study are common in small streams across the Midwest. Most of the species are typically considered “generalists” by aquatic ecologists, and given the relatively harsh nature of prairie streams (i.e., temperature and flow fluctuations, low substrate diversity) and the long history of ecological degradation in the region, dominance by species tolerant of poor habitat quality is not surprising, particularly in areas lacking riparian buffers. Although a few patterns have already been observed in the data, most of the data remains to be analyzed. In particular, we will be exploring relationships between fish and invertebrate communities and instream habitat using a number of univariate and multivariate statistical techniques (e.g., canonical correspondence analyses, cluster analysis). These analyses will better our understanding of the effects of riparian buffers on biotic communities and overall ecological health.

USGS Grant No. 07HQAG0163 Guidelines for Sampling and Averaging in Measurements of Discharge with Acoustic Doppler Current Profilers

Basic Information

Title:	USGS Grant No. 07HQAG0163 Guidelines for Sampling and Averaging in Measurements of Discharge with Acoustic Doppler Current Profilers
Project Number:	2007IA141S
Start Date:	9/1/2007
End Date:	12/15/2008
Funding Source:	Supplemental
Congressional District:	004
Research Category:	Engineering
Focus Category:	Surface Water, Hydrology, Methods
Descriptors:	
Principal Investigators:	Chris Robert Rehmann

Publication

<u>Iowa Water Center Preliminary Report</u>

Sampling requirements for discharge measurements with ADCPs

PI: Chris R. Rehmann

June 2008

Problem and Research Objectives

The U.S. Geological Survey (USGS) assessing water quantity in the United States by measuring river discharge at thousands of gaging stations. To verify the relations used to infer discharge from a measure of the water depth, the USGS regularly computes discharge from direct measurements of velocities at its stations. Recently the USGS has started using acoustic Doppler current profilers (ADCPs), which provide much more detail than traditional propeller meters, to measure velocity profiles across the river, and while the USGS has issued protocols for sampling with ADCPs, questions remain about the number of transects required, sampling time, the use of transects vs. profiles measured at fixed positions, etc. The objective of this project is to use synthetic velocity profiles to aid the USGS and others in determining protocols for measuring discharge with ADCPs.

Methods

Synthetic velocity profiles, for which the actual discharge is known exactly, are generated and used to test various methods of sampling. Two main types of sampling are simulated: section-by-section measurements, in which velocities are sampled at fixed points, and transects, in which velocities are measured while the instrument moves across the cross-section. In both cases, the simulated sampling follows typical USGS practice. Several effects are isolated and studied: the shape of the velocity profile, sampling at a fixed number of points, ADCP noise, and turbulence. For example, ADCP noise is specified as Gaussian noise, and turbulence is specified by imposing fluctuations that yield a given energy spectrum.

Principal Findings and Significance

Standard USGS approaches can be improved—even if the mean velocities could be measured perfectly. Replacing the mid-section method, which is used to compute discharge from velocity measurements at fixed points, with Simpson's rule increases the accuracy, though for more than 25 or 30 sections, the improvement is small. More significant is that the recommended approach of using sections with fixed discharge is less accurate (and more difficult) than using sections with fixed width: Fixed-discharge sections yield large sections near the banks, where the velocities are small, and because the velocity gradients are large near the banks, fixed-discharge sections miss the largest changes in velocity.

When ADCP noise is added, the discharge error can be predicted in terms of the characteristics of the noise, the number of profiles, and the number of sections. An analytical expression can be derived to predict the dependence of the error on the parameters, and the simulations verify the predictions. With a simple expression for the ADCP error, a sampling strategy can be designed to achieve a specified error level—for example, the “good” rating of the USGS, in which the measured discharge is within 5% of the actual value.

As this project continues, further recommendations regarding sampling strategies for velocity profiles including ADCP noise and turbulence will be generated. These recommendations will help achieve the goal of improving discharge measurements across the United States.

Information Transfer Program Introduction

While the Iowa Water Center maintains a strong research component, disseminating information to water resource professionals, policy−makers and the public is a priority. With a renewed emphasis on information−transfer and outreach, the Center is developing itself as a clearinghouse for research information.

This year the Iowa Water Center sponsored a team−building poster symposium where three different academic institutions presented 40 posters addressing water−related research in Iowa. The goal of the poster symposium was to provide opportunity for scientists to interact with each other and learn each others research interests for possible future collaborations. The symposium was well attended and participants encouraged the Center to sponsor similar events in the future.

The Center has gotten more involved with public activities, such as presenting water quality issues to K−6 students, volunteering for a high school natural resources competition and will participate in a river−cleanup canoe trip on an Iowa river. We look forward to increasing our public outreach with additional activities over the next year.

The Iowa Water Center is in the process of planning the Iowa Water Conference to be held March 2009. The focus of this year's conference will be multi−faceted and will include separate tracts to accommodate a bigger audience with more diverse interests. In addition, there are plans of holding an informational meeting for the City of Ames, where the Center and university are located, to discuss water quality research done in the watershed supplying water to the Ames community.

In addition, the Iowa Water Center webpage includes information about the Iowa Water Center as well as news about Center activities. It also serves as a link to a variety of other state and national water−related events, opportunities, and information. A “Resources” section has been added to include an Expert Directory, Fact Sheets, and a bibliography of Iowa related water research publications which the Center is in the process of developing.

Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR−USGS Internship	Supplemental Awards	Total
Undergraduate	6	0	0	0	6
Masters	2	0	0	0	2
Ph.D.	1	0	0	0	1
Post−Doc.	0	0	0	0	0
Total	9	0	0	0	9

Notable Awards and Achievements

2008, College of Liberal Arts and Sciences, Outstanding Teaching Award − Recognizes faculty members for outstanding teaching performances over an extended period of time in undergraduate education.

Podcast with Dr. Bill Simpkins, Sigma Xi Year of H2O web page http://water.sigmaxi.org/?p=81, posted June 2, 2008, discussing water use and biofuels expansion in the Midwest.

Publications from Prior Years

1. 2005IA81B ("Sensors for CyberEngineering: Monitoring and Modeling the Iowa River for Nutrients and Sediments") − Conference Proceedings − Loperfido, J.V., J.L. Schnoor, and C.L. Just, (2007). “Near Real−Time Sensing of Clear Creek Water Quality”, Proc. World Environmental &Water Resources Congress 2007, American Society of Civil Engineers, Tampa Bay, Fl. (243) 291.
2. 2004IA62B ("Identification of Relationships Between Soil Phosphorus and Phosphorus Loss Through Tile Drainage to Improve the Subsurface Drainage Component of the Iowa Phosphorus Index") − Dissertations − Assuoline, Jason, 2004. An Exploratory Study of the Formation of N−Nitrosodimethylamine (NDMA) in Chloraminated Natural Waters, MS Thesis, Dept. of Civil &Environmental Engineering, University of Iowa, Iowa City, Iowa.
3. 2004IA62B ("Identification of Relationships Between Soil Phosphorus and Phosphorus Loss Through Tile Drainage to Improve the Subsurface Drainage Component of the Iowa Phosphorus Index") − Articles in Refereed Scientific Journals − Chen, Z., and R. L. Valentine, 2006. Modeling the formation of N−nitrosodimethylamine (NDMA) from the reaction of natural organic matter (NOM) with monochloramine, Environmental Science and Technology, 40, 7290−7297.
4. 2004IA62B ("Identification of Relationships Between Soil Phosphorus and Phosphorus Loss Through Tile Drainage to Improve the Subsurface Drainage Component of the Iowa Phosphorus Index") − Articles in Refereed Scientific Journals − Chen, Z., and R. L. Valentine, 2007. Formation of N−nitrosodimethylamine (NDMA) from humic substances in natural water. Environmental Science and Technology, 41 (17), 6059−6065.