Kansas Water Resources Research Institute
Annual Technical Report
FY 2005

Introduction

The Kansas Water Resources Institute is part of a national network of water resource institutes in every state and territory of the U.S. established by law in the Water Resources Research Act of 1964. The network is funded by a combination of federal funds through the U.S. Department of the Interior/Geological Survey (USGS) and non-federal funds from state and other sources. KWRI is administered by the Kansas Center for Agricutlural Resources and the Environment (KCARE) at Kansas State University. An Administrative Council composed of representatives from participating higher education or research institutions, state agencies, and federal agencies assists in policy making. The Mission of KWRI is to: - Develop and support research on high priority water resource problems and objectives, as identified through the state water planning process; - Facilitate effective communications among water resrouce professionals; - Foster the dissemination and application of research results. We work towards this mission by: - Providing and facilitating a communications network among professionals working on water resources research and education, through electronic means, newsletters, and conferences; - Supporting research and dissemination of results on high priority topics, as identified by the Kansas State Water Plan, through a competitive grants program.

Research Program

Our mission is partially accomplished through our competitive research program. We encourage the following through the research that we support: interdisciplinary approaches; interagency collaboration; scinetific innovation; support of students and new young scientists; cost-effectiveness; relevance to present and future water resource issues/problems as identified in the State Water Plan; dissemination and interpretation of results to appropriate audiences. In implementing our research program, KWRI desires to: - Be proactive rather than reactive in addressing water resource problems of the state; - Involve the many water resources stakeholders in identifying research needs and utilize their input to priortize the water resources research needs of the state; - Foster collaboration among state agencies, federal agencies, and institutions of higher education in the state on water resource issues; - Leverage additional financial support from state, private, and other federal sources; - Be recognized in Kansas as a major institution to go to for water resources research.

Reduced Irrigation Allocations in Kansas from Grain Yield -- ET Relationships and Decision Support Model

Basic Information

Title:	Reduced Irrigation Allocations in Kansas from Grain Yield -- ET Relationships and Decision Support Model
Project Number:	2003KS31B
Start Date:	3/1/2003
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	2nd District
Research Category:	Not Applicable
Focus Category:	Irrigation, Water Use, None
Descriptors:	None
Principal Investigators:	Norman Klocke, Gary Clark, Troy Dumler, Loyd Stone

Publication

1. Klocke, N.L., C. Hunter, Jr., M. Alam, 2003. Application of a linear move sprinkler system for limited irrigation research. 2003. ASAE Paper No. 032012. July, 2003, Las Vegas, NV, 13 pp.
2. Klocke, N. L., Schneekloth, J. P., Melvin, S. R., Clark, R. T., and Payero, J. O. 2004. Field scale comparison of limited irrigation strategies. American Society of Agricultural Engineers Paper No. 042280. Aug. 2004.13 pp.
3. Melvin, S. R., Payero, J. O., Klocke, N. L. ,and Schneekloth, J. P., 2004. Irrigation management strategies for corn to conserve water. In: Proceedings Central Plains Irrigation Short Course & Exposition Proceedings. Feb. 17-18, 2004. Kearney, NE. pp 37-44.
4. Klocke, N.L., G. A. Clark, S. Briggeman, L.R. Stone, and T.J. Dumler. 2004. Crop water allocator for limited irrigation. In Proc. High Plains Groundwater Conference. Lubbock, TX. Dec. 7-9, 2004. 196-206.
5. Klocke, N.L., G.A. Clark, S. Briggeman, T.J. Dumler, and L.R. Stone. 2004. Crop water allocation program. Abstracts of: 21st Annual Water and the Future of Kansas Conference. March 11, 2004. Lawrence, KS. p.19.
6. Klocke, N.L., L.R. Stone, G.A. Clark, T.J. Dumler, S. Briggeman. 2005. Crop water allocator for limited ground water. ASAE Paper No. 052187. July 17-20, 2005. Tampa, FL. 11 pp.
7. Klocke, N.L., L.R. Stone, G.A. Clark, T.J. Dumler, S. Briggeman. 2005. Optimizing water

allocations and crop selections for limited irrigation. 26th Annual Irrigation Association Tech. Conf. Nov. 6-8, 2005. Phoenix, AZ. 4 pp.

8. Klocke, N.L., G.A. Clark, L.R. Stone, T.J. Dumler, and S. Briggeman. 2005. Water allocation among crops for limited irrigation decisions. In Report of Progress 945. Kansas State University, AES and CES, Aug. 25, 2005, Garden City, KS.
9. Klocke, N.L., R.S. Currie, and M. Brouk. 2005 Cropping systems for limited irrigation management. In Report of Progress 945. Kansas State University, AES and CES, Aug. 25, 2005, Garden City, KS.
10. Klocke, N.L., L.R. Stone, G.A. Clark, T.J. Dumler, S. Briggeman. 2005. Optimizing water allocations and crop selections for limited irrigation. 26th Annual Irrigation Association Tech. Conf. Nov. 6-8, 2005. Phoenix, AZ. 4 pp.
11. Klocke, N.L., L. R. Stone, G. A. Clark, T. J. Dumler, S. Briggeman. 2006. Water allocation model for limited irrigation. J. of App. Eng. In Agric.22:3:381-389.
12. Stone, L.R., A.J. Schlegel, A.H. Khan, N.L. Klocke, R.M. Aiken. 2006. Crop Yields Associated with Water Supply in the Central High Plains. In Press.
13. Klocke, N.L., L.R. Stone, T.J. Dumler. 2006. Optimizing water use for irrigation under limited supplies. Abstracts of: 23rd Annual Water and the Future of Kansas Conference. March 16, 2006. Topeka, KS.

"Reduced Irrigation Allocations in Kansas from Grain Yield--ET Relationships and Decision Support Model"

Final Report

Start Date: March 1, 2003
End Date: February 28, 2006

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Key Words:
Limited irrigation; Deficit Irrigation; Decision support; cropping system; Evapotranspiration; Irrigation allocation

Problem and Research Objectives

Many irrigators in Kansas are facing immediate challenges with declining water yields from their wells. Estimates show that as many as 50% of irrigation wells in western Kansas are pumping below original capacity. Irrigators in Kansas also face the possibility of shrinking water allocations with changes in water policy or simply enforcement of current water policy. Any of these scenarios will mean more limited irrigation than has been used in the past.

To make reductions in water and energy use, irrigators are considering shifts in cropping patterns. Irrigators who have shrinking water supplies need to make decisions on the most profitable cropping systems. Furthermore, they need to allocate both land and water resources to multiple crops. Irrigation scheduling decisions for irrigation managers with limited water resources are not made on a daily basis as is the case for managers of fully irrigated systems. Limited capacity irrigation managers need to schedule their applications with a fixed amount of cropping season water, due to limited well capacity or water allocation, and plan a cropping system strategy. The objective was to develop and implement an irrigation decision model that will allow irrigators to optimize water and land resources for the best mix of crops and associated water allocations.

Past irrigation management research has demonstrated that annual grain crops respond best to water applications during flowering and seed fill growth periods. No-till management systems, which leave crop residues on the surface, have been beneficial in increasing off-season capture and retention of precipitation, reducing soil water evaporation, and reducing runoff in sprinkler irrigation. This project is designed to combine the best irrigation and crop residue management techniques into one management system. The products of this project are grain yield-water use and grain yield-irrigation relationships.

The answers to these questions are not straightforward and have many economic and policy-based implications. In order to help agricultural irrigators with these questions and to improve on their beneficial use of limited water resources, the objectives are:

1. Develop a computerized tool for irrigators to assist in their decisions regarding the best use of limited water supplies or reduced water allocations.
2. Measure irrigation and grain yield relationships for corn, wheat, soybean, grain sorghum, and sunflower crops using current varieties and no-till management to support the continued implementation of the decision tool.

Methodology

Objective 1:

A crop water allocator (CWA) has been developed to assist in planning cropping patterns and targeting irrigation to those crops. It is an economic model that will predict the net returns of possible cropping options. Net returns are to land, management, and irrigation equipment since only operating costs are subtracted from gross income. The model uses crop yield and irrigation relationships that were generated from the Kansas Water Budget, a water balance simulation model for western Kansas. The Kansas Water Budget used yield-evapotranspiration relationships for each crop. Through simulations with rainfall patterns across western Kansas and irrigation management assumptions, yield-irrigation irrigation relationships were formulated. Example output yield-irrigation relationships for corn are in figure 1. Each broken line represents annual rainfall for an area across the region. Diminishing-return relationships of yield with irrigation applied were typical for all crops used in CWA (corn, grain sorghum, wheat, soybean, sunflower, and alfalfa). Crop production and irrigation costs can be completely controlled by the user with inputs to CWA, or the user can rely on default values from Kansas State surveys of typical farming operations in western Kansas.

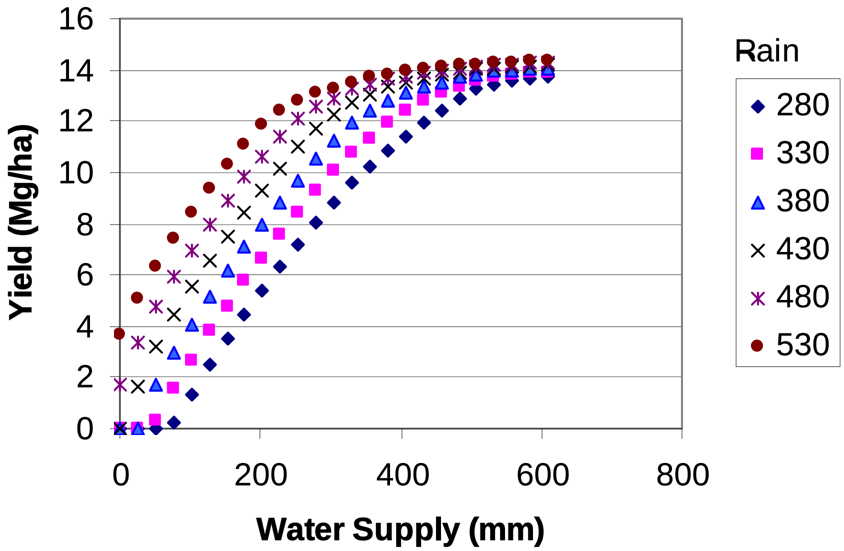

Fig.1. Corn yield in response to irrigation for annual precipitation zones in western Kansas.

The user first selects possible proportions of land considered for potential rotation of crops and/or fallow. The percentages of land splits could be: 50-50, 75-25, 33-33-33, 50-25-25, and 25-25-25-25. The user can select more crops than selected number of land splits for consideration by the program. The program will consider all possible combinations of crops and water allocations. The crop species, maximum crop yields, irrigation water costs, crop production costs, and water allocation for the season (gross irrigation) are then entered. The program then iterates, by 10% increments of the water allocation, all possible net income solutions. By changing one input value at a time, subsequent runs of the model can give the user indications of the sensitivities of net returns to commodity prices, production cost inputs, crop selections, and land allocations.

Objective 2:

The experimental field was subdivided into six (1.2 ha each) cropped strips that were irrigated by a 4-span linear move sprinkler irrigation system. The cropping sequence was corn-corn-soybean-winter wheat-grain sorghum-sunflower. The soil was a silt loam with pH 8.3 and slope of less than 1%. The six irrigation treatments, replicated four times, ranged in water application from a season total of 76 mm to full atmospheric demand. Irrigation frequency was limited to no more than 50 mm per week. If rainfall was sufficient to fill the soil profile to field capacity, irrigation was not applied. The extra irrigation allocation was rolled over to the next growth stage. If there was extra allocation at the end of the year, it was not carried over to the next year. The study area was not pre-irrigated and the same irrigation treatment followed on another from year to year. Dry plots followed dry plots and wet plots followed wet plots.

Soil water was measured once every two weeks with the neutron attenuation method in increments of 0.3 m to a depth of 2.4 m. There was one sampling site per plot. These measurements were used to calculate evapotranspiration for each two-week period from a water balance of soil water, net irrigation, and rainfall.

Work Accomplished

Objective 1:

Crop Water Allocator (CWA) was released on the World Wide Web during December 2004 at www.oznet.ksu.edu/mil. It is available to users to download to their individual computers. Individual farmers as users of the program can guide outcomes by their own preferences and strengths. The program is sensitive to commodity prices and maximum yields which can influence results based on user inputs. Water policy agencies are reviewing CWA for application in risk management programs. The crop insurance industry is considering more options for limited irrigation cropping sequences under insured programs. Colorado is considering feasibility of rotation of fallowed water rights in cropping sequences.

Output from CWA gives irrigators who are planning strategies for their limited water, and those working in water professions the opportunity to examine trends. For example, multiple runs of the model allow the user to examine combined effects of water allocation, commodity prices, maximum yields, irrigation costs, and production costs. Figure 2 shows the results of series of CWA outputs of net returns over a range of water allocations. The first line generated for figure 2 was the “reference” scenario. The inputs for the reference scenario were typical for no-till management in western Kansas during 2006. The water costs were based on $0.70/ha-mm and the commodity prices and maximum expected crop yields with no water restrictions are in table 1. The annual rainfall was 430 mm and the land split was 33-33-33. The CWA could choose among row crops (corn, soybean, sunflower, grain sorghum, and wheat) for crop rotations. Alfalfa was excluded from consideration.

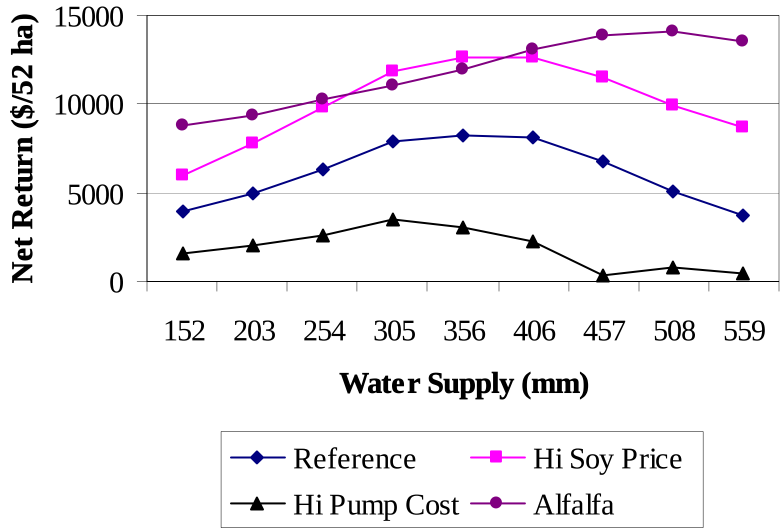

Figure 2. Trends in net return to land, management, and irrigation equipment predicted by CWA for 2006 reference (row crop) scenario, a “high” soybean price ($0.22 vs. $0.18/kg for reference) a “high” pumping cost ($0.16 vs. $0.11/ha-mm for reference), and alfalfa scenario.

Table 1. Input values for CWA reference example

Crop	Commodity Price	Maximum Yield
Corn	$0.094/kg	12.5 Mg/ha
Sorghum	$0.084/kg	7.5 Mg/ha
Soybean	$0.18/kg	4.1 Mg/ha
Wheat	$0.13/kg	4.7 Mg/ha
Sunflower	$0.24/kg	3.0 Mg/ha
Alfalfa	$0.083/kg	15.7 t/ha

First, the reference inputs were used to execute the CWA at each water supply amount to construct the points for the reference line in figure 2. When the water supply was from 300 to 500 mm, CWA selected continuous corn, but CWA selected corn-wheat rotation when the water supply was from 150 to 250 mm. Second, the soybean price was increased from $0.18 to $0.22/kg. All other reference inputs remained constant. The result was the “high” soybean line in figure 2. CWA did not select soybeans for the reference scenario, but exclusively selected soybeans for water supplies 200-560 mm. Third, the soybean price returned to $0.18/kg and the irrigation cost was increased from $0.11 to $0.16/ha-mm. This is a typical range of pumping costs reported for natural gas and diesel during 2005. CWA selected corn and wheat rotations for 150 to 250 mm water supplies, continuous corn for 300 to 400 mm, and corn-fallow rotations for 460 to 560 mm water supplies. The increased energy costs penalized high water use to the point of reducing irrigated acres. If pumping costs were to increase to $0.19/ha-mm, CWA would predict no net return from this scenario. Fourth, the pumping cost was returned to $0.70/ha-mm and alfalfa was considered for selection along with the row crops and fallow. In this selection, alfalfa was chosen exclusively over the row crops and fallow, even at the lowest water supply. When water was very limited, water was applied at full irrigation to part of the field and a nearly dryland on the rest of the field.

The CWA model allows irrigators, county agents, consultants, or water planners to evaluate combinations of land allocations, cropping systems, and water allocations for optimum economic return. The CWA model is user friendly and can be executed with a few basic inputs. However, more experienced users can modify default input and production costs to match field specific scenarios. As water resources become more limited, programs such as the CWA model can be used to help plan for future farming operations or to assess potential impacts of changes in water policy.

<u>Objective 2</u>:
Grain yield response to irrigation for 2004 and 2005 is shown in figures 3 and 4. Grain sorghum and sunflower yields were the similar for all irrigation treatments. The lowest application (76 mm) was sufficient for optimum yields both years. Grain yields were less in 2005 than 2004 because of hail damage (July 4, 2005). Wheat yields responded slightly to irrigation in 2005, but not at all in 2004. Favorable spring rain in 2004 assisted the drier wheat plots. Corn yields respond to additional irrigation both years. Favorable growing conditions and rainfall in 2004 (430 mm from May 1-September 30, 2004) produced maximum yields with 250 mm of irrigation. Again in 2005 maximum corn yields were produced with 250-280 mm of irrigation even though hail affected the crop and rainfall was less (330 mm from May 1-September 30, 2005).

The grain yield responses to irrigation in figures 1 and 2 are based on how the water was managed on a year-around basis. Irrigation was reduced from conventional practices (normally 400-460 mm) because there was soil water available from the off-season and irrigation was managed according to atmospheric demand and soil water availability. Extra water came from snow trapped and retained by standing crop residue. Precipitation infiltrated where it fell. Soil

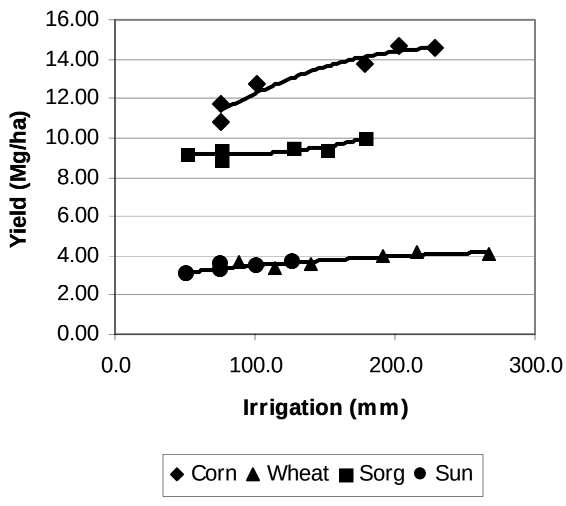

Figure 1. 2004 crop yield-irrigation relationships for crops grown at Garden City, Kansas, SWREC, Kansas State University.

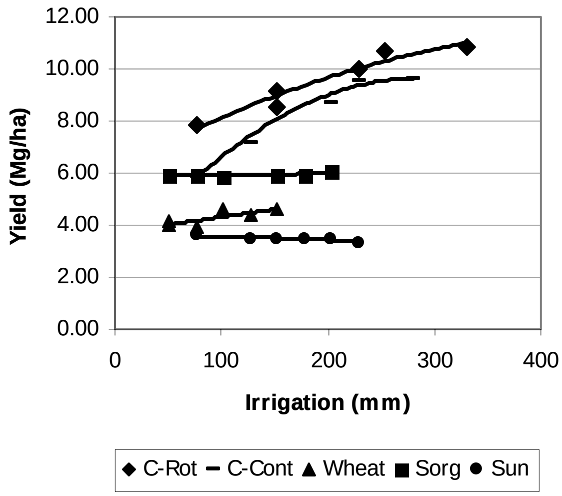

Figure 4. 2005 crop yield-irrigation relationships for crops grown at Garden City, Kansas, SWREC, Kansas State University.

water evaporation was reduced starting from harvest of the previous crop through the entire growing season by untilled crop residue. Water application on fully irrigated plots was managed to meet and not exceed atmospheric demand for water. Soil water status was measured bi-weekly and monitored for management decision. All of these factors worked together to reduce crop irrigation needs.

Table 2 has the summary data for the cropping systems research at Garden City for 2004 and 2005. The soybean crop was completely destroyed in a hail storm in early July, 2005. Corn was not in a rotation following sunflower during 2004. Irrigation treatments from 1 to 6 indicate irrigation gradations from meeting full ET demand (1) to very limited applications of 76 mm (6). The driest treatment (7) was only rainfed. Only continuous corn data are presented. Gain yields usually decreased with decreasing irrigation. This was not true for soybean in 2004, sorghum in

Table 2. Crop yield, crop evapotranspiration (ETc), water use efficiency (Y/ETc), and irrigation water use efficiency (IWUE) for crops in the cropping systems research at SWREC, Garden City, KS.

Irrigation Treatment*	Yield (kg/m^2)	ETc (mm/day)	Y/ETc (kg/m^3)	IWUE (kg/m^3)	Irrigation Treatment*	Yield (kg/m^2)	ETc Rate (mm/day)	Y/ETc (kg/m^3)	IWUE (kg/m^3)
a. Corn-2004					b. Soybean-2004				
1	1.51a	4.04a	2.75a	6.99c	1	0.31a	4.50a	0.61b	1.72c
2	1.48a	4.00a	2.68a	7.78c	2	0.28a	4.45ab	0.56b	1.82c
3	1.40ab	3.93 a	2.60ab	8.51c	3	0.31a	4.38abc	0.62b	2.39c
4	1.30bc	3.70ab	2.57ab	11.54b	4	0.27a	3.88dc	0.63b	3.60b
5	1.19c	3.54b	2.50ab	13.8a	5	0.29a	3.95bcd	0.67ab	5.76a
6	1.04d	3.46b	2.22b	13.8a	6	0.32a	3.73d	0.76a	6.19a
$LSD_{0.05}$**	0.11	0.35	0.40	1.70	$LSD_{0.05}$	0.06	0.53	0.13	0.79

Table 2. Continued.

Irrigation Treatment*	Yield (kg/m^2)	ETc (mm/day)	Y/ETc (kg/m^3)	IWUE (kg/m^3)	Irrigation Treatment*	Yield (kg/m^2)	ETc Rate (mm/day)	Y/ETc (kg/m^3)	IWUE (kg/m^3)
c. Corn after Sunflowers-2005					d. Corn after Corn-2005				
1	1.09a	6.20a	1.69bc	3.30c	1	0.96a	6.20a	1.57ab	3.45d
2	1.07a	5.30b	1.94a	4.20b	2	0.95a	5.55b	1.73a	4.18cd
3	1.00ab	5.55b	1.73abc	4.37b	3	0.87a	5.63b	1.56ab	4.29c
4	0.92bc	4.85c	1.83ab	6.03a	4	0.85ab	5.03c	1.71ab	5.56b
5	0.85cd	5.35b	1.53c	5.58a	5	0.72bc	5.00c	1.44bc	5.65b
6	0.78cd	4.60c	1.65bc	----	6	0.58c	4.80c	1.24c	7.64a
7	0.71d	3.83d	1.75abc	----	----	----	----	----	----
LSD$_{0.05}$	0.14	0.45	0.24	0.72	LSD$_{0.05}$	0.15	0.40	0.29	0.83
e. Wheat-2004					f. Wheat-2005				
1	0.41ab	6.00a	0.87c	1.52e	1	0.46a	4.00a	1.07a	3.03c
2	0.42a	5.43ab	1.01bc	1.94de	2	0.44abc	3.73ab	1.08a	3.44c
3	0.34ab	5.20bc	0.99bc	2.09cd	3	0.46ab	3.73ab	1.14a	4.51b
4	0.35b	4.80cd	0.94bc	2.53bc	4	0.39c	3.50bc	1.03a	5.14b
5	0.35b	4.30de	1.03bc	3.02b	5	0.42abc	3.38c	1.12a	8.16a
6	0.36ab	4.13e	1.12b	4.08a	6	0.40bc	3.25c	1.12a	7.82a
7	0.38ab	3.46f	1.39a		7	0.30d	3.40c	0.78b	
LSD$_{0.05}$	0.06	0.61	0.19	0.51	LSD$_{0.05}$	0.06	0.32	0.15	0.91
g. Sorghum-2004					h. Sorghum-2005				
1	1.00a	5.85a	1.88ab	5.64d	1	0.61a	5.42a	1.11ab	2.99e
2	0.94b	5.85a	1.75b	6.13d	2	0.59a	5.38ab	1.10ab	3.34e
3	0.95ab	5.83a	1.80ab	7.44c	3	0.59a	5.20b	1.14ab	3.90d
4	0.89b	4.60b	1.86ab	11.70b	4	0.59a	4.88c	1.20ab	5.78c
5	0.92b	4.45bc	2.00a	18.02a	5	0.60a	4.85c	1.22a	7.81b
6	0.94b	4.23c	1.89ab	12.28b	6	0.59a	4.60d	1.27a	11.65a
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LSD$_{0.05}$	0.07	0.37	0.20	0.70	LSD$_{0.05}$	0.07	0.22	0.17	0.53
i. Sunflower-2004					j. Sunflower-2005				
1	0.36a	5.75a	0.72a	2.86c	1	0.34a	6.15ab	0.60ab	1.46d
2	0.34ab	5.78a	0.68a	3.39c	2	0.35a	6.58a	0.58b	1.70d
3	0.36ab	5.43ab	0.74a	4.24b	3	0.35a	5.83b	0.66ab	1.96cd
4	0.33ab	5.43ab	0.69a	4.65b	4	0.35a	5.95ab	0.65ab	2.29cb
5	0.31ab	5.03b	0.72a	6.08a	5	0.35a	5.55b	0.70ab	2.75b
6	0.31b	4.98b	0.70a	6.10a	6	0.36a	5.48b	0.73a	4.71a
LSD$_{0.05}$	0.05	0.67	0.14	0.76	LSD$_{0.05}$	0.07	0.71	0.15	0.57

* Treatment 1=full irrigation; 7=Dryland.
**LSD= least significant difference for alpha=0.05.
***data with the same letters are not significantly different within each column for each crop-year.

2005 and sunflower in 2005. In these instances, there were no significant yield differences among irrigation treatments. Crop evapotranspiration (ETc), measured with the water balance method, generally increased with added irrigation. Irrigation treatments with less water applied than treatment 1 were under a gradation of water stress at times during the growing season. The separation in ETc among treatments in terms of significant difference was not consistent. Although 2004 had less growing season rainfall than 2005 (330 vs. 530 mm), ETc differences for irrigation treatment were not consistent across the crops. Water use efficiency (Y/ETc) generally decreased with less irrigation in 2005 and increased with less water in 2004. As noted, the two years were different in terms of water available from rainfall. Irrigation water use efficiency (IWUE) increased with decreasing irrigation. This indicates less grain yield was returned from irrigation with increasing irrigation, which is a diminishing return effect (see figures 3 and 4).

Differences in grain yield among crops opens possibilities for strategies for crop selection when well capacity is limited. Corn returned more grain with added water until it became over-watered. Economic returns follow this same trend. Wheat, sunflower, and grain sorghum yielded well with small amounts of irrigation. Results are needed for dry years, but previous research at this research center indicated that these traditional dryland crops can be sustained at optimum yields with little irrigation. The two characteristics of economic response to irrigation from corn and sustainable yields with small irrigation investments can be utilized for limited capacity wells. Planting two crops, one with lower water demand than the other, the same field increases the per-acre well capacity. This option is also enhanced with crop residue management possibilities that take advantage of the stubble like wheat produces for water savings in the next crop. Systems management, including retaining crop residues and irrigation timing, for limited water resources has the potential for reducing water applications and/or increasing crop yields. .

References

Stone, L.R., O.H. Buller, A.J. Schlegel, M.C. Knapp, J.-I. Perng, A.H. Khan, H.L. Manges, and D.H. Rogers. 1995. Description and use of KS Water Budget v. T1 software. Resource Manual, Dep. of Agron., Kansas State Univ., Manhattan, KS.

Publications and presentations:

Klocke, N.L., C. Hunter, Jr., M. Alam, 2003. Application of a linear move sprinkler system for limited irrigation research. 2003. ASAE Paper No. 032012. July, 2003, Las Vegas, NV, 13 pp.

Klocke, N. L., Schneekloth, J. P., Melvin, S. R., Clark, R. T., and Payero, J. O. 2004. Field scale comparison of limited irrigation strategies. American Society of Agricultural Engineers Paper No. 042280. Aug. 2004.13 pp.

Melvin, S. R., Payero, J. O., Klocke, N. L. ,and Schneekloth, J. P., 2004. Irrigation management strategies for corn to conserve water. In: Proceedings Central Plains Irrigation Short Course & Exposition Proceedings. Feb. 17-18, 2004. Kearney, NE. pp 37-44.

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Klocke, N.L., G.A. Clark, S. Briggeman, T.J. Dumler, and L.R. Stone. 2004. Crop water

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Klocke, N.L., G.A. Clark, L.R. Stone, T.J. Dumler, and S. Briggeman. 2005. Water allocation among crops for limited irrigation decisions. In Report of Progress 945. Kansas State University, AES and CES, Aug. 25, 2005, Garden City, KS.

Klocke, N.L., R.S. Currie, and M. Brouk. 2005 Cropping systems for limited irrigation management. In Report of Progress 945. Kansas State University, AES and CES, Aug. 25, 2005, Garden City, KS.

Klocke, N.L., L.R. Stone, G.A. Clark, T.J. Dumler, S. Briggeman. 2005. Optimizing water allocations and crop selections for limited irrigation. 26th Annual Irrigation Association Tech. Conf. Nov. 6-8, 2005. Phoenix, AZ. 4 pp.

Klocke, N.L., L. R. Stone, G. A. Clark, T. J. Dumler, S. Briggeman. 2006. Water allocation model for limited irrigation. J. of App. Eng. In Agric.22:3:381-389.

Stone, L.R., A.J. Schlegel, A.H. Khan, N.L. Klocke, R.M. Aiken. 2006. Crop Yields Associated with Water Supply in the Central High Plains. In Press.

Klocke, N.L., L.R. Stone, T.J. Dumler. 2006. Optimizing water use for irrigation under limited supplies. Abstracts of: 23rd Annual Water and the Future of Kansas Conference. March 16, 2006. Topeka, KS.

Dr. Klocke presented the CWA model in a variety of settings and gave potential users its background, philosophy, operations, and application examples. Audience members included irrigators, educators, water district board members, state and federal water agency heads, US congressmen, state legislators, water scientists. The presentations included:

Presentations by Dr. Klocke at:
ASAE International Meeting, Las Vegas, NV, 2003
Kansas State University—SWREC Research Advisory Council, 2003-2006
Kansas State University—SWREC Field Day, 2004, 2005
Central Plains Irrigation Conference, Kearney, NE, 2004
Producer meeting at Healy, Kansas, 2004
High Plains Groundwater Resources Conference, Lubbock, TX, 2004
Water and the Future of Kansas, Lawrence & Topeka, KS, 2004, 2006

Kansas Water Resources Advisory Meeting, 2004
Irrigation Technology Seminar, Dodge City, 2004, 2005
Kansas Water Authority Meeting, Ft. Scott, KS, 2004
Groundwater Management District Meeting, Garden City, KS 2005
Soil Conservation District Board Meeting, Garden City, 2005
ASABE International Meeting, Tampa Bay, FL, 2005
Irrigation Association Meeting, Phoenix, AZ, 2005
Partners in Conservation, Garden City, KS, 2005
Kansas F.A.C.T Conference, Liberal, KS, 2006

Troy Dumler presented CWA in the following extension meetings:

Ag Profitability Conferences 2005-2006
- Ulysses - Feb. 2005
- Lewis – Jan. 2006
- Goodland – Feb. 2006

Irrigated Crop Production/Energy Cost Meetings 2005-2006
- Scott City (2) - Jan. 2005, Feb. 2006
- Hugoton (2) - Dec. 2004, Jan. 2006
- Dodge City – Jan. 2006
- Garden City – Feb. 2006
- Wichita – Nov. 2005
- Ulysses – Dec. 2005
- Lakin – Feb. 2005
- Cimarron – Feb. 2005

Dr. Dan Rogers, extension irrigation engineer, conducted training sessions with the CWA. These included the following sessions:

Event	Location	Format	Date	Attendance
Irrigation Management Seminars and Field Tours				
Agent Program Planning	Great Bend	Presentation	Sept	30
Agent Program Planning	Great Bend	Presentation	Sept	30
Finny County Conservation District Crop Production	Garden City	Presentation	Jan 26	60
Grant County KanSched	Ulysses	Training	Jan 26	30
Kearny County: KanSched	Lakin	Training	Feb 14	4
Cheyenne County: KanSched	St. Francis	Training	Feb18	2
Grant County: KanSched	Ulysses	Training	Mar 1	5
South Central Ks: KanSched	Hutchinson	Training	Mar 31	10
Spring Action Conference	Salina	Presentation	April 6	40
MIL Software Seminar	Oberlin	Computer Training	April 26	8
MIL Software Seminar	Lakin	Computer Training	April 8	4
3-I Trade Show	Garden City	Booth	April 28-30	110

Information transfer

KBUF radio presentations for live interviews on five occasions

KSU news release used by High Plains Journal, Kansas Farmer

Klocke, N.L., Clark, G. A., Stone, L.R., Dumler, T.J., and Briggeman, S. 2004. Crop Water Allocator (CWA). [World Wide Web]. Version 1.5. www.oznet.ksu.edu/mil. Kansas State University, AES.

Activity for CWA on the Internet: 1,100 hits in 330 downloads during 2005.

Students Supported

Five college students and three college prep students were supported with part-time employment through this grant. They were exposed to various facets of water resources research from daily planning and coordination of research activities, execution of research protocols, to data processing and data quality control.

A Field Assessment of a Method for Estimation of Ground-Water Consumption By Phreatophytes: Methodology Refinement and Extension to Areas of Salt-Cedar Infestation

Basic Information

Title:	A Field Assessment of a Method for Estimation of Ground-Water Consumption By Phreatophytes: Methodology Refinement and Extension to Areas of Salt-Cedar Infestation
Project Number:	2003KS33B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	2nd District
Research Category:	Not Applicable
Focus Category:	Groundwater, Water Use, None
Descriptors:	
Principal Investigators:	James J. Butler, Gerard J. Kluitenberg

Publication

1. Arnold, D., and J.J. Butler, Jr., Salt-cedar control activities and water-table monitoring on the Arnold Ranch, Clark County, Kansas, an invited presentation to the CPR for Wetlands and Streams II Conference, Wichita, KS, Sept. 28, 2005.
2. Bauer, J., Evaluating the effectiveness of salt cedar control measures as a means of water conservation along the Cimarron River, Kansas, undergraduate honor's thesis, Department of Geological Sciences, University of Colorado at Boulder, October, 2005.
3. Bauer, J., Shea, J., Keller, J., Butler, J.J., Jr., Kluitenberg, G.J., and D.O. Whittemore, Diurnal water table fluctuations: An underutilized indicator of ground-water consumption by plants (abstract), Eos, v. 86, no. 52, Fall Meet. Suppl., Abstract B23A-1038, 2005.
4. Butler, J.J., Jr., Quantifying water consumption by phreatophytes in narrow riparian corridors, presentation to the University of Kansas Field Station & Ecological Reserves Seminar Series, March 11, 2005.
5. Butler, J.J., Jr., Diurnal water-table fluctuations: An underutilized indicator of groundwater consumption by plants, an invited presentation given as part of the Environmental Seminar Series at

the Desert Research Institute, Reno, NV, November 4, 2005.

6. Butler, J.J., Jr., and D.O. Whittemore, Arkansas River phreatophytes, in Kansas Geological Survey Open-File Rept. 2005-17, pp. 4.9-4.12, 2005 (used for presentations for the 2005 Kansas Field Conference [Larned, June 9, 2005] and the Kansas Water Authority tour west of Garden City [August 10, 2005]).
7. Butler, J.J., Jr., Whittemore, D.O., and G.J. Kluitenberg, Ground water assessment in association with salt cedar control Report on year one activities, Kansas Geological Survey Open-File Rept. 2005-19, 28 pp., 2005.
8. Butler, J.J., Jr., Whittemore, D.O., and G.J. Kluitenberg, Studies of ground-water consumption by phreatophytes in river valleys of Kansas (abstract), Trans. Kansas Academy Science, v. 108, no. 3/4, pp. 165-166, 2005.
9. Butler, J.J., Jr., Whittemore, D.O., and G.J. Kluitenberg, A field investigation of ground-water consumption by phreatophytes in river valleys of Kansas (abstract), 50th Annual Midwest Ground Water Conf., Program with Abstracts, Illinois State Geol. Survey OFS 2005-13, p. 18, 2005.
10. Butler, J.J., Jr., Whittemore, D.O., and G.J. Kluitenberg, A field investigation of ground-water consumption by phreatophytes, presentation at the 14th Annual Kansas Hydrology Seminar, Topeka, November 18, 2005.
11. Butler, J.J., Jr., Kluitenberg, G.J., Whittemore, D.O., Healey, J.M., and X. Zhan, Quantifying ground-water savings achieved by salt-cedar control measures: A demonstration project (abstract), Eos, v. 86, no. 18, Jt. Assem. Suppl., Abstract H33B-06, 2005
12. Butler, J.J., Jr., Kluitenberg, G.J., Whittemore, D.O., Loheide, S.P., II, Jin, W., Billinger, M.A., and X. Zhan, A field investigation of phreatophyte-induced fluctuations in the water table, Water Resour. Res., pending revisions.
13. Keller, J., Shea, J., Bauer, J., Butler, J.J., Jr., Kluitenberg, G.J., and D.O. Whittemore, A field investigation of the influence of spatial variability in hydraulic properties on phreatophyte-induced fluctuations in the water table (abstract), 50th Annual Midwest Ground Water Conf., Program with Abstracts, Illinois State Geol. Survey OFS 2005-13, p. 19, 2005.
14. Kluitenberg, G.J., Butler, J.J., Jr., and D.O. Whittemore, A field investigation of major controls on phreatophyte-induced fluctuations in the water table (abstract), Annual Meetings Abstracts [CD-ROM], ASA, CSSA, and SSSA, Madison, WI, 2005.
15. Loheide, S.P., II, Butler, J.J., Jr., and S.M. Gorelick, Estimation of groundwater consumption by phreatophytes using diurnal water table fluctuations: A saturated-unsaturated flow assessment, Water Resour. Res., v. 41, W07030, doi:10.1029/2005WR003942, 2005.
16. Shea, J., Bauer, J., Keller, J., Butler, J.J., Jr., Kluitenberg, G.J., Whittemore, D.O., Loheide, S.P., II, and W. Jin, An assessment of the vulnerability of native phreatophytes to replacement by invasive species in a mid-continent riparian setting (abstract), Eos, v. 86, no. 52, Fall Meet. Suppl., Abstract B23A-1037, 2005.

KWRI PROGRESS REPORT – YEAR THREE

Project Title: A Field Assessment of a Method for Estimation of Ground-Water Consumption by Phreatophytes: Methodology Refinement and Extension to Areas of Salt-Cedar Infestation
Duration of Reporting Period: March 1, 2005 - February 28, 2006
Federal Funding for Reporting Period: $8,450
Investigators and Affiliations: James J. Butler, Jr., Kansas Geological Survey (PI), Gerard J. Kluitenberg, Kansas State University (Co-PI), Donald O. Whittemore, Kansas Geological Survey (Co-PI).
Research Category: Statewide Competitive Grant
Descriptors: phreatophytes, ground water, evapotranspiration, water balance

PROBLEM AND RESEARCH OBJECTIVES

Low streamflows are an increasing problem in Kansas and other areas of the U.S. As a result, smaller amounts of water are available for diversions to water supplies and wetlands, for inflows to reservoirs, for capture by wells in nearby aquifers, for sustaining aquatic wildlife, and for recreation. Stream-aquifer interactions play an important role in the generation and maintenance of low streamflows. Ground-water development in regional aquifers that discharge water to stream corridors and in alluvial aquifers immediately adjacent to streams is often a major factor responsible for low-flow periods. However, consumption of ground water by phreatophytes in riparian zones could also be an important contributor to reduction of stream flow. Recently, partly in response to concerns about water consumption, expensive measures for phreatophyte control have been advocated for stretches of rivers in western Kansas.

Present understanding of phreatophyte activity in stream-aquifer systems in Kansas is insufficient to assess the magnitude of that activity. This project is directed at refining methodologies for quantitative assessment of phreatophyte activity, and utilizing those methods to assess water savings as part of a demonstration of salt-cedar control measures along the Cimarron River. Specifically, the major objectives for the project are to 1) refine methodologies for quantifying the consumption of ground water by phreatophytes, and 2) use these methods to determine ground-water savings produced by control of invasive phreatophytes (salt cedar and Russian olive) along a portion of the Cimarron River in Kansas. An auxiliary objective of this work is to gather a detailed data set on the major fluxes in stream-aquifer systems that can serve as the basis for research proposals on the quantitative assessment of stream-aquifer interactions in settings common to the Great Plains.

The six activities proposed for the third year of this project were as follows:

1. Monitoring of water levels and meteorologic parameters at both the Larned Research Site and the Ashland Research Site;
2. Monitoring of vadose-zone moisture during the growing season at both sites;
3. Determination of specific yield through use of moisture-content profiles and water-table changes (Skaggs et al., 1978) and other methods (Loheide et al., 2005);
4. Use water-table fluctuations to assess phreatophyte activity at both sites;

5. Characterize the initial soil-moisture and ground-water savings produced by the control activities at the Ashland Research Site;

6. Assess phreatophyte activity in the Arkansas River riparian zone from Kinsley to Great Bend.

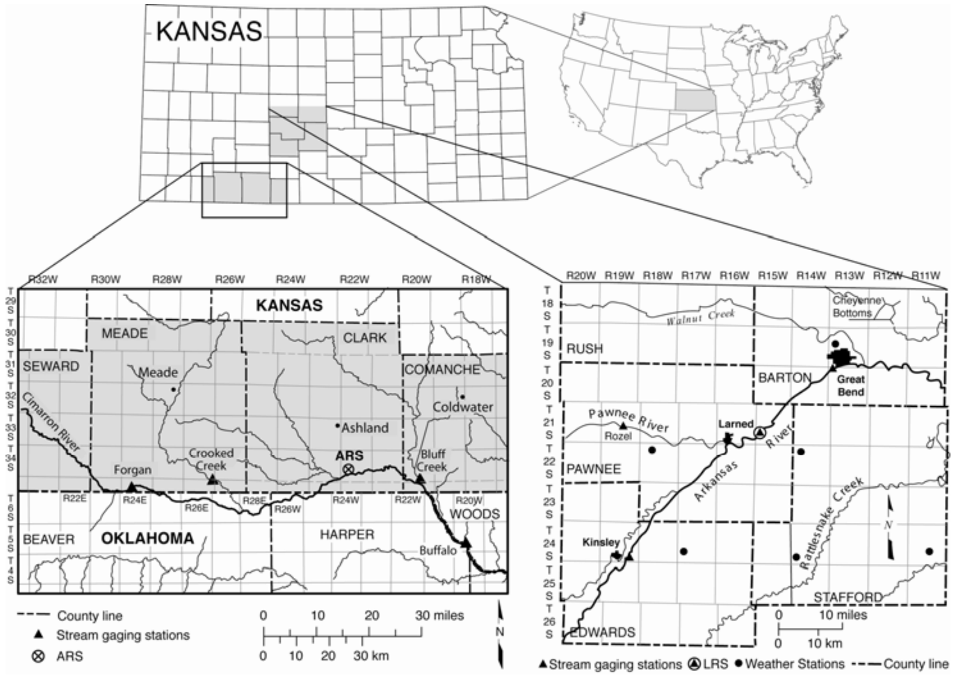


Figure 1

METHODOLOGY

The ultimate objective of this project is to develop a practical approach for quantifying phreatophyte consumption of ground water. This work is being done at two Kansas Geological Survey (KGS)/Kansas State University (KSU) research sites: the Larned Research Site (LRS) located adjacent to the United States Geological Survey stream-gaging station on the Arkansas River near Larned in central Kansas, and the Ashland Research Site (ARS) located along the Cimarron River south of Ashland in southwest Kansas (Figure 1). The KGS/KSU research team focused on the LRS in the first two years of the project and then expanded the scope of the project in year three to include the ARS. The vegetation at the LRS is dominated by phreatophytes that are native to the Arkansas River riparian zone (cottonwood, willow, and mulberry), while the ARS is dominated by invasive phreatophytes (salt cedar and Russian olive).

A series of shallow wells have been installed at the LRS and ARS to monitor the position of the water table through time. All wells are equipped with integrated pressure transducer/datalogger units (In-Situ MiniTroll) that are programmed to take pressure-head readings every 15 minutes. Since riparian-zone wells can be overtopped during periods of high stream flow, absolute pressure sensors are used at most wells (12 out of 19 wells at the LRS and all six wells at the ARS) instead of the standard gauge-pressure sensors. The absolute-pressure sensors measure the pressure exerted both by

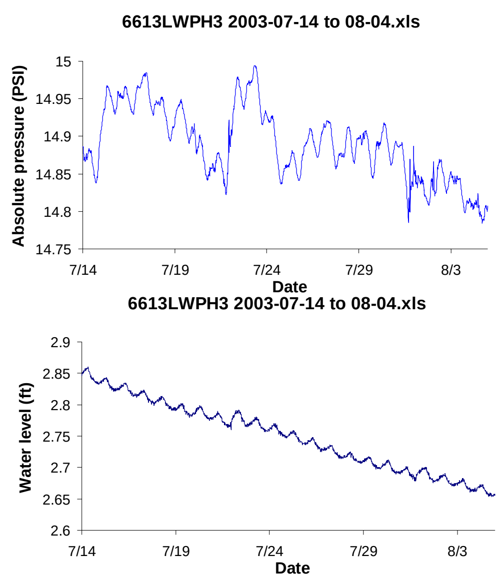


Figure 2 – Barometric pressure correction at LRS well LWPH3.

the height of the overlying column of water in the well and by the atmosphere. The atmospheric pressure component was removed using data from a barometer at the site. Figure 2 displays records from an absolute-pressure sensor in the riparian zone at the LRS prior to and after the barometric pressure correction. Manual measurements of water levels in the monitoring wells were taken biweekly during the summer and bimonthly otherwise to assess the performance of the pressure sensors and, if necessary, to adjust the calibration parameters. Three barometers were maintained at each site to ensure data collection was not impacted by failure of a barometer. Barometer performance at each site was assessed through a comparison of the three site barometers. In addition, a handheld barometer was used to assess sensor performance during site visits. Two wells were added to the LRS network in year three to assess the role of water flow through the aquitard underlying the Arkansas River alluvial aquifer in the riparian zone.

A series of neutron-probe access tubes (eight access tubes at the LRS and six at the ARS) have been installed at each site so that volumetric moisture content can be measured at biweekly intervals during the growing season. Measurements in the access tubes were recorded with a neutron probe (Model 503 DR Hydroprobe Moisture Depth Gauge; Campbell Pacific Nuclear) using a count duration of 16 s and depth increments of either 0.076 m or 0.152 m. Standard counts were recorded in the field both prior to and after access tube measurements. The mean standard count for the duration of the study was used to convert each measured count to a count ratio (CR). The soil volumetric water content ($m^3\ m^{-3}$), θ, corresponding to each measured count ratio was calculated with the calibration equation $\theta = 0.2929 \times CR - 0.0117$, which was based on laboratory calibrations and an adjustment for PVC pipe.

Vertical profiles of specific conductance and temperature within individual wells were measured approximately biweekly during the summer and monthly to quarterly during the remainder of the year in the LRS riparian-zone wells and all wells at the ARS using a YSI Model 30 meter and 50 ft cable. Specific conductance and temperature were recorded at the same time interval as pressure head in two LRS and one ARS wells using integrated multiparameter probe/datalogger units (two In-Situ MP Troll 9000 units and one YSI 600SL Sonde).

Tree inventories were performed at both the LRS and ARS in year three. At the LRS, a detailed tree inventory was performed over the full width of the riparian zone in the same area in which a tree inventory was performed in the summer of 2002. A total of 864 trees with trunk diameters larger than 0.08 m at chest height were counted, identified, and tagged in 2002. Of those trees, 810 were found again in 2005 and their health was characterized using a six category classification system based on observed foliage (fully alive, <20% dead, 20-50% dead, 50-80% dead, > 80% dead, and fully dead). At the ARS, an inventory of salt cedar and Russian olive within 45 ft (13.7 m) of wells Ash12, 21, 22, and 31 was performed using four height classes (<3 ft, 3-6 ft, 6-9 ft, >9 ft).

Weather stations (Hobo Weather Station logger and sensors, Onset Computer Corp.) were in operation at both sites during year three. The weather stations are equipped with sensors to measure precipitation, air temperature, relative humidity, global irradiance [direct and diffuse solar irradiance], wind speed and direction, and barometric pressure. The barometric pressure sensor was added to both weather stations in early summer of year three. Data are averaged (air temperature, global irradiance, barometric pressure, and wind speed and direction) or summed (precipitation) and logged at a 15-minute interval. The only exception is the relative humidity sensor, which provides a single measurement at the end of the 15-minute interval. Potential evapotranspiration was calculated from the meteorologic data using the Penman-Monteith equation. The wind speed and direction sensor failed abruptly at the LRS in November of 2005 and caused the datalogger to shut down. Data from a weather station located at a distance of approximately 10 kilometers from the site will be used to fill in the data gap caused by sensor failure and logger shutdown.

MAJOR ACTIVITIES AND PRINCIPAL FINDINGS

The principal findings of the third year of the project will be briefly discussed in the context of the six activities proposed for year three:

Activity 1: Monitoring of water levels and meteorologic parameters at both the Larned Research Site and the Ashland Research Site – Pressure-head measurements were obtained at 15-minute intervals at 19 wells at the LRS and six wells at the ARS. Meteorologic parameters were measured at 15-minute intervals at weather stations at both sites. There was no flow in the Arkansas River at the LRS at any time during year three, but there was flow in the Cimarron River at the ARS throughout the year. A paper primarily based on the LRS and ARS data was prepared and submitted to Water Resources Research in year three. A revised form of that paper is currently in review at Water Resources Research. Figure 3 is a figure from that paper in which the link between the sapflow velocity measured in a LRS cottonwood and water-table fluctuations is illustrated (fluctuations are virtually nonexistent during period of low sapflow).

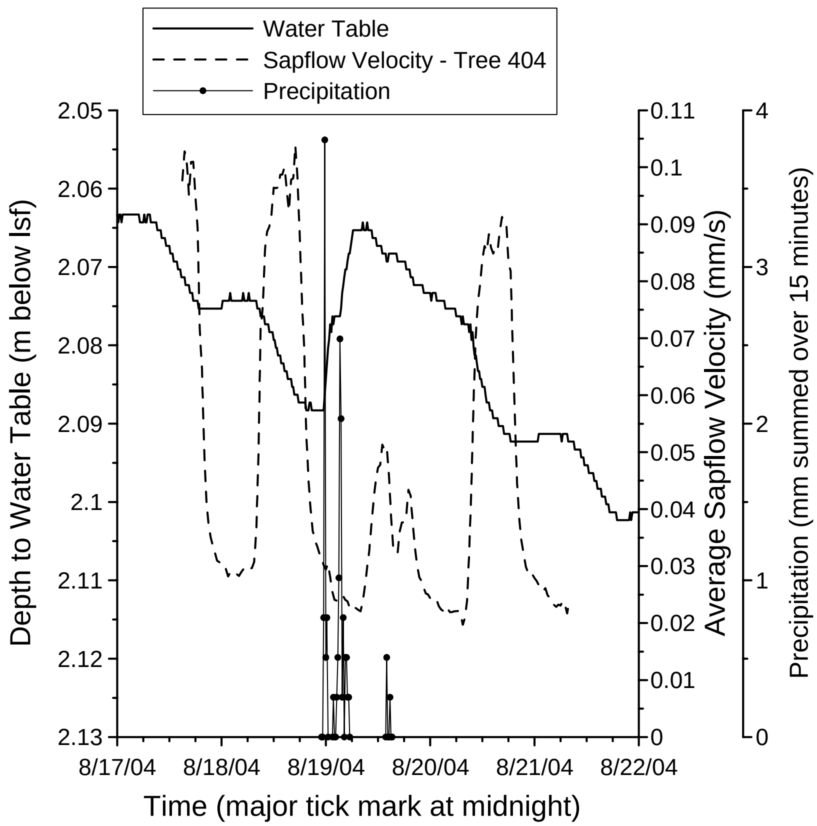


Figure 3 – Depth to water table from land surface at well LWPH2 in LRS with sapflow velocity from nearby cottonwood and precipitation from LRS weather station.

Activity 2: Monitoring of vadose-zone moisture during the growing season at both LRS and ARS – Vadose-zone moisture was monitored biweekly during the growing season at eight locations (four adjacent to monitoring wells) at the LRS and six locations (adjacent to monitoring wells) at the ARS. Figure 4 is an example of the data that were obtained. This figure displays the volumetric moisture content measured near well LWPH3 at the LRS, illustrating the wetting of the near-surface profile associated with late spring and late summer rains, and the dry down in the intervening period.

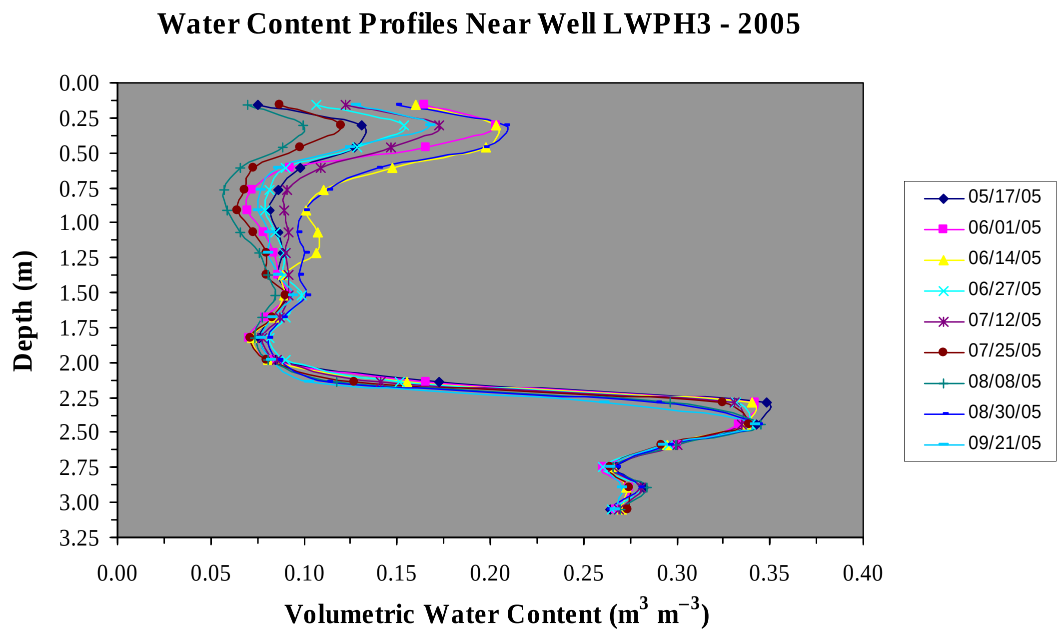


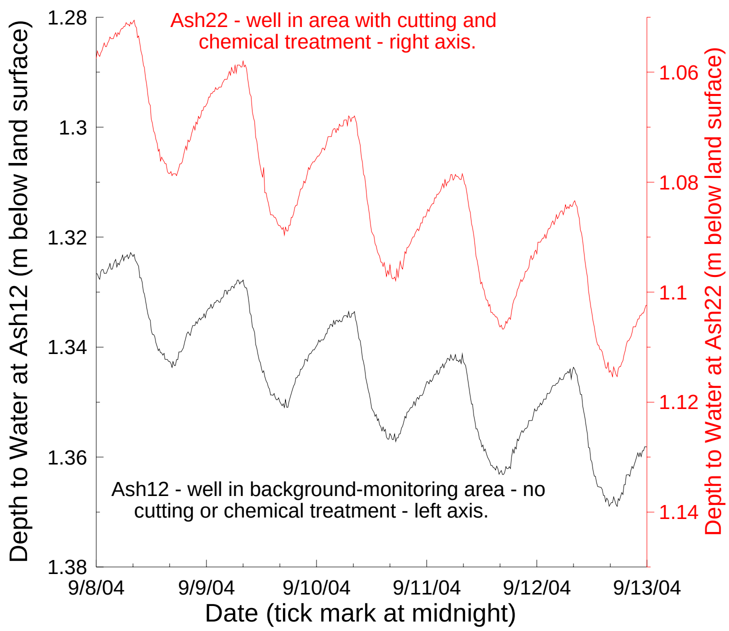
Figure 4 – Water content profiles near LWPH3 for 2005 growing season.

<u>Activity 3</u>: Determination of specific yield through use of moisture-content profiles and water-table changes (Skaggs et al., 1978) and other methods (Loheide et al., 2005) – The method of Skaggs et al. (1978) requires periods of rapid water-table change so that soil-moisture changes due to drainage/wetting will dominate over changes produced by plant water use. There were no such periods at the LRS or ARS in year three, so this method could not be used to estimate specific yield from data collected in year three. Additional data from earlier years were used to expand the LRS specific-yield database, but the ARS moisture-content data set was not amenable to such an analysis. Alternative approaches for estimation of specific yield (e.g., Loheide et al., 2005) require information on sediment texture. Samples were taken adjacent to each of the monitoring wells at the ARS to assemble a data set that could be used for that purpose. At each site, four sampling locations were identified at a distance of approximately 10 feet (3.05 m) from the well. Sampling locations were distributed as uniformly as possible around each well (ideal arrangement forming a square); however, the spatial arrangement varied from well to well due to the presence of plants and landscape features. Samples were collected (2.75-inch (0.070-m) diameter bucket auger) from all four sampling locations in 6-inch (0.152-m) depth intervals from the soil surface to the maximum depth allowable due to the presence of the water table. The samples obtained from the four sampling locations were combined (composited) by depth interval and then transported to the KSU Soil Testing and Soil Characterization Laboratories for analysis. The results of those analyses will be used in year four to aid in estimation of specific yield at the ARS.

<u>Activity 4</u>: Use water-table fluctuations to assess phreatophyte activity at LRS and ARS – This activity was a continuation of a major focus of both theoretical and field work in year two. As discussed under activity one, a paper largely based on the LRS and ARS data was prepared and submitted to Water Resources Research in year three. The primary focus of this paper was the assessment of the major controls on the water-table fluctuations and the ecohydrologic insights that can be gleaned from them. We found that spatial and temporal variations in the amplitude of the fluctuations are primarily a function of variations in 1) the meteorological

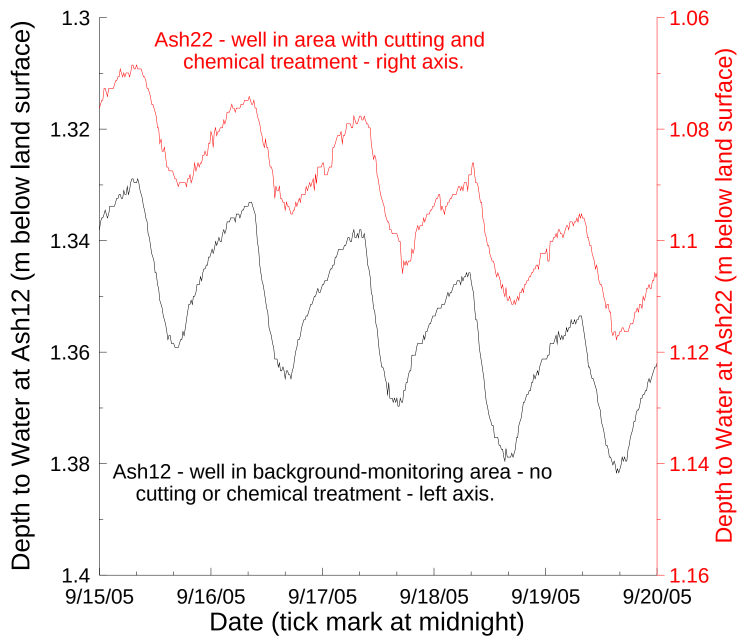
drivers of plant water use; 2) vegetation density, type, and vitality; and 3) the specific yield of sediments in the vicinity of the water table. Past hydrologic conditions experienced by the riparian-zone vegetation, either in previous years or earlier within the same growing season, are also an important control. We concluded that diurnal water-table fluctuations can be considered a diagnostic indicator of ground-water consumption by phreatophytes at most sites, so the information embedded within these fluctuations should be more widely exploited in ecohydrologic studies.

Figure 5
Comparison of Well Ash12
and Well Ash22 - Pre-Control



<u>Activity 5</u>: Characterize the initial soil-moisture and ground-water savings produced by the control activities at ARS – This activity was a major focus of year three. The ARS is subdivided into four plots of approximately four hectares each in which different salt-cedar control measures were applied. Control measures were not used in Plot 1 (plot with wells Ash11 and Ash12) so that data unaffected by those measures could be obtained throughout the project. Water-level data collected prior to any control activities clearly indicate that the magnitude of the water-table fluctuations is highly dependent on the apparent vitality of the phreatophyte community in the vicinity of each well. Salt-cedar control measures began to be implemented at the ARS in March of 2005. At that time, Plots 2-4 were clear cut except for circles ranging from 20-30 m in radius, centered at each well. The radii of those circles of vegetation were progressively reduced through repeated cuttings in the summer of 2005. Note that only the invasive phreatophytes (salt cedar and Russian olive) were cut at the site; grasses, forbs, and low-lying bushes were largely unaffected. A chemical treatment (Remedy and diesel-fuel mix) was applied to the salt-cedar regrowth in Plot 2 (plot with wells Ash21 and Ash22) following the cutting. Water levels, soil moisture, and meteorological parameters were monitored before, during, and after the control activities. Relationships were

Figure 6
Comparison of Well Ash12
and Well Ash22 - Post-Control



established between water levels in the various plots prior to cutting through a comparison of water levels from wells in Plot 1 (background-monitoring plot) with those from wells in the other plots (Figure 5). Changes in those relationships after the cutting and chemical treatment (Figure 6 – note the reversal of the relative magnitudes of the fluctuations vis-à-vis those in Figure 5 for the same depth interval) enabled initial estimation of the resulting reduction of ground-water consumption. The reductions appear to be on the order of 30-50%. Apparently, the shallow depth to water at the ARS allows substantial ground-water consumption by other mechanisms, such as transpiration by shallow-rooted vegetation and direct evaporation from the water table. Planned work for year four of this project is directed at assessing the relative importance of ground-water consumption by these other mechanisms. Unless the impact of these mechanisms is better understood, it will be difficult to reliably estimate the potential water savings to be achieved through control of invasive phreatophytes.

Activity 6: Assess phreatophyte activity in the Arkansas River riparian zone from Kinsley to Great Bend – Observations in year three along the Arkansas River riparian zone between Kinsley and Great Bend indicated that there was significant mortality of the native phreatophytes. The tree inventory at the LRS provided some insight into the rate of this mortality. Figure 7 displays the results of the tree inventory summarizing the condition of the native phreatophytes at the LRS in the summer of 2005. Virtually all of the deterioration of tree health occurred since the 2002 inventory. Comparison of the tree inventories performed in the summers of 2002 and 2005 revealed a 20-25% mortality rate over the study period, with an additional 20% of trees under severe water stress. The native phreatophytes appear to be having difficulty keeping pace with the falling water table, leading to severe stress and a high rate of mortality. At present, the canopy is still sufficiently dense to prevent encroachment by salt cedar and Russian olive. However, if the present rate of mortality continues, non-native phreatophytes may be able to exploit open areas created by tree die-off, leading to large changes in the riparian-zone community between Kinsley and Great Bend.

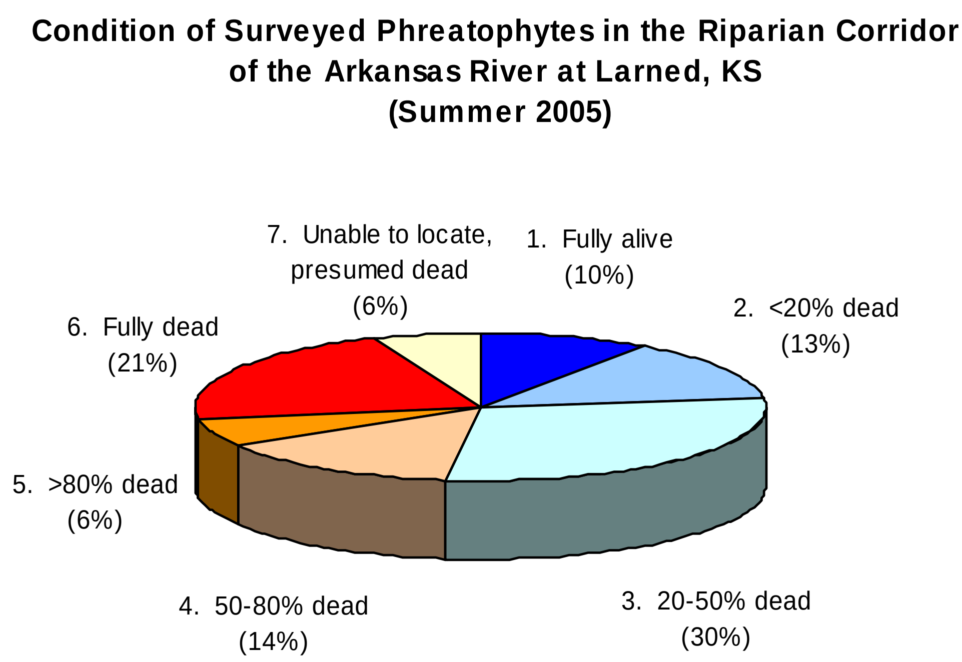


Figure 7

REFERENCES CITED

Loheide, S.P., II, Butler, J.J., Jr., and S.M. Gorelick, Estimation of groundwater consumption by phreatophytes using diurnal water table fluctuations: A saturated-unsaturated flow assessment, Water Resour. Res., v. 41, W07030, doi:10.1029/2005WR003942, 2005.

Skaggs, R.W., Wells, L.G., and S.R. Ghate, Predicted and measured drainage porosities for field soils, Trans. ASAE 22, 522-528, 1978.

PAPERS AND PRESENTATIONS

Arnold, D., and J.J. Butler, Jr., Salt-cedar control activities and water-table monitoring on the Arnold Ranch, Clark County, Kansas, an invited presentation to the CPR for Wetlands and Streams II Conference, Wichita, KS, Sept. 28, 2005.

Bauer, J., Evaluating the effectiveness of salt cedar control measures as a means of water conservation along the Cimarron River, Kansas, undergraduate honor's thesis, Department of Geological Sciences, University of Colorado at Boulder, October, 2005.

Bauer, J., Shea, J., Keller, J., Butler, J.J., Jr., Kluitenberg, G.J., and D.O. Whittemore, Diurnal water table fluctuations: An underutilized indicator of ground-water consumption by plants (abstract), Eos, v. 86, no. 52, Fall Meet. Suppl., Abstract B23A-1038, 2005.

Butler, J.J., Jr., Quantifying water consumption by phreatophytes in narrow riparian corridors, presentation to the University of Kansas Field Station & Ecological Reserves Seminar Series, March 11, 2005.

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Butler, J.J., Jr., Whittemore, D.O., and G.J. Kluitenberg, Ground water assessment in association with salt cedar control – Report on year one activities, Kansas Geological Survey Open-File Rept. 2005-19, 28 pp., 2005.

Butler, J.J., Jr., Whittemore, D.O., and G.J. Kluitenberg, Studies of ground-water consumption by phreatophytes in river valleys of Kansas (abstract), Trans. Kansas Academy Science, v. 108, no. 3/4, pp. 165-166, 2005.

Butler, J.J., Jr., Whittemore, D.O., and G.J. Kluitenberg, A field investigation of ground-water consumption by phreatophytes in river valleys of Kansas (abstract), 50th Annual Midwest Ground Water Conf., Program with Abstracts, Illinois State Geol. Survey OFS 2005-13, p. 18, 2005.

Butler, J.J., Jr., Whittemore, D.O., and G.J. Kluitenberg, A field investigation of ground-water consumption by phreatophytes, presentation at the 14th Annual Kansas Hydrology Seminar, Topeka, November 18, 2005.

Butler, J.J., Jr., Kluitenberg, G.J., Whittemore, D.O., Healey, J.M., and X. Zhan, Quantifying ground-water savings achieved by salt-cedar control measures: A demonstration project (abstract), Eos, v. 86, no. 18, Jt. Assem. Suppl., Abstract H33B-06, 2005.

Butler, J.J., Jr., Kluitenberg, G.J., Whittemore, D.O., Loheide, S.P., II, Jin, W., Billinger, M.A., and X. Zhan, A field investigation of phreatophyte-induced fluctuations in the water table, Water Resour. Res., pending revisions.

Keller, J., Shea, J., Bauer, J., Butler, J.J., Jr., Kluitenberg, G.J., and D.O. Whittemore, A field investigation of the influence of spatial variability in hydraulic properties on phreatophyte-induced fluctuations in the water table (abstract), 50th Annual Midwest Ground Water Conf., Program with Abstracts, Illinois State Geol. Survey OFS 2005-13, p. 19, 2005.

Kluitenberg, G.J., Butler, J.J., Jr., and D.O. Whittemore, A field investigation of major controls on phreatophyte-induced fluctuations in the water table (abstract), Annual Meetings Abstracts [CD-ROM], ASA, CSSA, and SSSA, Madison, WI, 2005.

Loheide, S.P., II, Butler, J.J., Jr., and S.M. Gorelick, Estimation of groundwater consumption by phreatophytes using diurnal water table fluctuations: A saturated-unsaturated flow assessment, Water Resour. Res., v. 41, W07030, doi:10.1029/2005WR003942, 2005.

Shea, J., Bauer, J., Keller, J., Butler, J.J., Jr., Kluitenberg, G.J., Whittemore, D.O., Loheide, S.P., II, and W. Jin, An assessment of the vulnerability of native phreatophytes to replacement by invasive species in a mid-continent riparian setting (abstract), Eos, v. 86, no. 52, Fall Meet. Suppl., Abstract B23A-1037, 2005.

INFORMATION TRANSFER

Thirteen presentations concerning this project were presented at various venues both within and outside of Kansas during year three. Three additional abstracts were prepared for presentations early in year four (Water and the Future of Kansas Conference - March 2006, Kansas Academy of Science Conference - April 2006). One manuscript reporting a modeling assessment of the White method for estimating groundwater consumption by phreatophytes from water-table fluctuations was published in the journal Water Resources Research in year three, and a second manuscript describing the results of the field investigation of phreatophyte-induced fluctuations in the water table was submitted to Water Resources Research and is currently undergoing revision.

STUDENT SUPPORT

Three students participating in the Applied Geohydrology Summer Research Assistantship Program of the Kansas Geological Survey were partially supported from this grant during the summer of 2005. These students contributed to the aspects of the project involving well and access-tube installation, water-level and vadose-zone monitoring, conductance measurements, and weather-station upkeep. One of the students, Jacob Bauer, used the summer program project for his undergraduate honors thesis in the Department of Geological Sciences at the University of Colorado at Boulder. His thesis was awarded the summa cum laude designation.

A Real-Time Permittivity Sensor for Simultaneous Measurement of Multiple Water-Quality Parameters

Basic Information

Title:	A Real-Time Permittivity Sensor for Simultaneous Measurement of Multiple Water-Quality Parameters
Project Number:	2005KS40B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	2
Research Category:	Water Quality
Focus Category:	Water Quality, None, None
Descriptors:	
Principal Investigators:	Naiqian Zhang, Philip Barnes, Gerard J. Kluitenberg, Andrew Ziegler

Publication

1. KSU filed a provisional patent application for Frequency-response sensors and associated signal conditioning/processing for real-time and simultaneous measurement of properties of dielectric materials in the US patent Office (Docket No. 37057-PRO) on March 8, 2006.

Annual Report

A Real-time Permittivity Sensor for Simultaneous Measurement of Multiple Water-Quality Parameters

For the period of March 1, 2005 – February 28, 2006

Naiqian Zhang, Professor
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Abstract:

The main objective of the proposed work is to develop a novel, frequency-response-based permittivity sensor to detect and measure the concentrations of several types of pollutants in surface and ground water that are crucial to water quality.

Since the beginning of the project in March 2005, we have designed and fabricated the sensor and associated signal conditioning, processing, and control circuit.

Laboratory tests were conducted to observe the frequency-responses data acquired for different types of waters, including lake, stream, tap, and distilled waters, and air. Significant differences were observed. This gives a clear indication that the sensor is capable of detecting differences in dielectric properties.

Water samples with different combinations of soil sediment and salt (KCl) concentration levels were tested using a circulation system that provided uniform sediment concentrations. The sensor accurately measured KCl concentrations at each sediment concentration level. For sediment concentration measurement, the sensor only gave accurate measurement in water without added KCl and with KCl concentration of higher than 5,000 mg/L. For simultaneously measurement, the R-square values reached 0.86 and 0.87 for KCl and sediment, respectively.

The sensor was also tested on biodiesel and desiel fuels. Distinct differences in frequency-response data clearly indicates the potential of the sensor in examining the blending ratio between biodiesel and diesel.

A hand-held probe was designed for field use of the sensor in measuring quality factors of natural waters. An RF impedance/material analyzer was acquired on loan to provide calibration data for permittivity measurement.

Annual Report

A Real-time Permittivity Sensor for Simultaneous Measurement of Multiple Water-Quality Parameters

The main objective of the research work is to develop a novel, frequency-response-based permittivity sensor to measure multiple properties of surface and ground water that are crucial to water quality. Since March 1, 2005, the sensor and associated hardware and software have been developed. A preliminary laboratory test has been conducted.

1. Hardware and software development

The sensor was designed and fabricated during summer, 2005. The signal conditioning, processing, and control circuitry was also designed and constructed during summer, 2005. This circuitry was designed for a wide frequency range and in-situ measurement environment. A program was written for a microcontroller in C language.

2. Testing apparatus

In order to generate uniform, controllable soil sediment concentrations in water samples, a circulation system in which soil-water mixture is circulated by a pump was designed and built. With this system, the actual sediment concentrations were controlled within 15% of the intended values.

3. Preliminary tests

Two preliminary tests were conducted for the sensor.

(1) Comparison of different waters

This test was intended to observe the general capability of the sensor in detecting differences in permittivity of four water types and air. Laboratory analyses have found that water in Tuttle Creek Lake contained very high nutrients such as No_3, total N, ortho P, total P, and K, whereas water in Three Miles Creek at Fort Riley contained much higher total suspended solids (TSS) and higher Ca and Mg. data acquired from these two waters showed significant differences. Differences between water samples air also are significant. This gives a clear indication that the sensor may be very useful in detecting various contaminants in water. It also is possible that the sensor may be used to detect contaminants in air.

(2) Simultaneous measurement of soil sediment concentration and salt (KCl) concentration

Samples of distilled water with 11 different KCl concentrations (0–35,000 kg/L) and 10 different soil sediment concentrations (0-3,381 mg/L) were tested in the circulation system. The soil type was sandy loam. Frequency response data (both gain and phase) were analyzed using the Partial Least Regression method (MATLAB, MathWorks). Prediction models established through this procedure successfully predicted KCl concentration at all sediment concentration levels with R-square values of above 0.95. When data of all sediment concentrations were combined, the R-square value was 0.86 (Table 1).

Table 1. R-square values achieved for predicting KCl concentration at individual and combined sediment concentration levels

Sediment concentration (mg/L)	0	148	219	323	478	707	1046	1546	2287	3381	Combined
R^2 for predicting KCl concentration	1.00	0.99	1.00	0.97	0.95	1.00	1.00	1.00	0.99	1.00	0.86

The prediction accuracy for soil sediment concentration was in general low for water samples with low KCl concentrations. However, for samples without added KCl and with KCl concentrations of above 5,000 mg/L, the prediction accuracy was very good. When data of all sediment concentrations were combined, the R-square value was 0.87 (Table 2).

Table 2 R-square values achieved for predicting sediment concentration at individual and combined KCl concentration levels

KCl concentration (mg/L)	0	1036	1533	2261	3346	4949	7322	10822	16009	23667	35000	Combined
R^2 for predicting sediment concentration	0.99	0.45	0.56	0.69	0.52	1.00	0.84	1.00	0.91	0.98	1.00	0.87

(3) Natural diesel vs. biodiesel

The sensor was also tested on non-water liquid to observe its general ability of measuring properties of various types of dielectric materials. The liquid tested was biodiesel and diesel. In the United States, biodiesel can be used as an additive to premium diesel. Adjustment of fuel injection timing and injection duration for reducing NOx emissions and increasing engine power is sensitive to the ratio of biodiesel to diesel in the blend. However, real-time monitoring of the fblending ratio has been found challenging. Thus, a sensor that is capable of measuring the composition of biodiesel in a diesel blend is necessary.

(4) Design of sensor probe for field use

A hand-held probe (Figure 1) was fabricated for testing water in river, creek, and lake. The sensor attached at the far end of the probe will be immersed into water. Signal will be transmitted to the signal conditioning/processing unit, which is connected to the near end of the probe. A series of tests were conducted to study the transmission-line effect on the data. Correction factors based on these tests will be applied to signals measured through the probe.

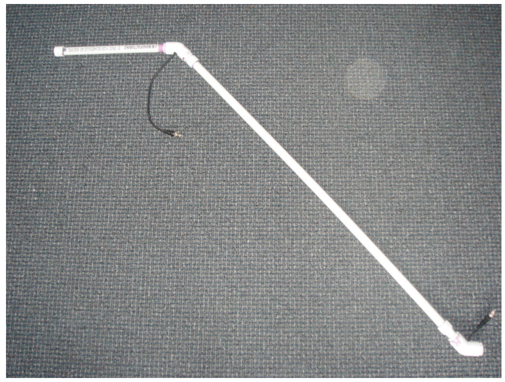

Figure 1. Sensor probe for field use

(5) Calibration of permittivity using an RF impedance meter

In February, 2006, an RF Impedance/Material Analyzer manufactured by Agilent Technology, Model E4991A, was acquired on loan. This analyzer will be used to measure real and imaginary permittivities of water samples with different types and concentrations of contaminants, as well as other liquid dielectric materials for calibration of the sensor.

Developing an Economic Tool to Predict the Value of Water Rights

Basic Information

Title:	Developing an Economic Tool to Predict the Value of Water Rights
Project Number:	2005KS44B
Start Date:	1/1/2005
End Date:	12/31/2005
Funding Source:	104B
Congressional District:	2nd
Research Category:	Not Applicable
Focus Category:	Economics, Water Use, None
Descriptors:	
Principal Investigators:	Bill Golden, Kevin Dhuyvetter, Terry Kastens, Jeff Peterson

Publication

1. 1) Golden, B., T. Kastens, K. Dhuyvetter, and J. Peterson. Developing an Economic Tool to Predict the Value of Water Rights. Research report posted to www.agmanager.info. May, 2006.
2. 2) Golden, B. The Value of Water in Western Kansas and The Voluntary Water Rights Transition Program. Presented at the Agricultural Profitability Conference. Ulysses, Kansas. February 1, 2005.
3. 3) Golden, B. Policy Solutions and Economic Impacts: Voluntary Water Retirement Programs. Presented at The Ogallala Aquifer: What Are We Doing? K-State Meeting With the Stakeholders. Manhattan, Kansas. March 17, 2006.
4. 4) Golden, B. The Economic Value of Water Rights in Kansas. Presented at the Water and the Future of Kansas Conference. Topeka, Kansas. March, 2006.
5. 5) Golden, B., and J. Peterson. Evaluation of Water Conservation From More Efficient Irrigation Systems. Presented at the State Conservation Commission spring Workshop. Hays, and Garden City, Kansas. March, 2006.
6. 6) Golden, B. The Economic Value of Water Rights in Kansas. Presented at the Kansas Water Office Conservation Reserve Enhancement Program Focus Group. Kinsley, Kansas. April, 2006
7. 7) Golden, B. Two Markets-Two Models: The Case of Irrigated and Nonirrigated Cropland.. Currently in internal review for publication. May, 2006.
8. 8) Golden, B. The Value of Water Rights in Western Kansas: A Spatial Hedonic Approach.. Currently in internal review for publication. May, 2006.

FINAL REPORT

Project Title: Developing an Economic Tool to Predict the Value of Water Rights

Project ID: 2005KS44B

Start Date: 01/01/2005

End Date: 12/31/2005

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Key Words: Ogallala, Valuation, Transition, Spatial, Appraisal

Problem and Research Objective

Governmental policy and economic research are gradually shifting toward a focus on sustainability issues and policy alternatives that achieve an absolute reduction in groundwater consumptive use. A critical water problem in the state of Kansas is developing policy alternatives that yield an absolute reduction in the consumptive use of water from the Ogallala aquifer. One such policy instrument is the voluntary Irrigation Transition Assistance Program. Through this policy, an absolute reduction in consumptive use will be achieved by purchasing and permanently retiring irrigation water rights in the Ogallala region of western Kansas. In order to implement this policy, the state of Kansas needs input from the economic community on both program structure as well as the market value of water rights. The objective of this research was to provide econometric models capable of estimating, on a parcel-specific basis, the fair market value of water rights, for all Kansas counties overlying the Ogallala aquifer. Estimates of the fair market value of water rights, at the county level, were generated. Additionally, a web-based tool was developed so that landowners and other stakeholders can estimate the fair market value of water rights on a parcel specific basis.

Methodology

Hedonic modeling techniques assume that the value of a product, in this case a parcel of land, is equal to the sum of the value of the product's component parts. One of these component parts is the value of the water right. Investigation into the value of water rights, and the role that various hydrological parameters have in determining that value, requires the development and estimation of two basic hedonic models. The first model estimated the value of nonirrigated land and was specified as

$$Y_{NI} = X_1\beta_1 + \varepsilon ,$$

where Y_{NI} is the sales price per acre of nonirrigated land, X_1 is a N x K matrix of explanatory variables associated with land characteristics, β_1 is a K x 1 vector of parameter estimates, and ε is a random disturbance term. The second model is used to estimate the value of irrigated land and was specified as

$$Y_I = X_1\beta_1 + X_2\beta_2 + \varepsilon ,$$

where Y_I is the sales price per acre of irrigated land, X_2 is a N x J matrix of explanatory variables associated with hydrological characteristics, and β_2 is a J x 1 vector of parameter estimates. The difference between the irrigated parcels' estimated sales price and its estimated nonirrigated value represents the implicit value of the water right (*VWR*) defined as

$$VWR = Y_I - Y_{NI} ,$$

where Y_I and Y_{NI} now represent their model estimated values.

Economists have long been aware that the prices of neighboring parcels of agricultural land are highly correlated. Traditionally, this correlation has been quantified by the inclusion of independent variables that are believed to cause the correlation and residual or unexplained correlation generally has been ignored. While the above mentioned hedonic models will include independent variables to explain spatial correlation, omitted variable bias might lead to residual spatial correlation. Recent advancements in geographic information systems (GIS), spatial econometric techniques, and computer algorithms allow the estimation of this residual spatial impact without specifying the actual cause of the spatial correlation. Anselin (1988) defines the spatial autoregressive moving average (SARMA) model as

$$Y = X\beta + \rho WY + \varepsilon \quad where \quad \varepsilon = \lambda W\varepsilon + u \,.$$

In this formulation W is an N x N spatial weight matrix, ρ is the coefficient on the spatially lagged dependent variable WY, which quantifies the spatial correlation in the dependent variable, λ is the coefficient on the spatially lagged disturbance term $W\varepsilon$, which quantifies the spatial correlation in the error term, and $X\beta$ represents the basic linear hedonic model for either irrigated or nonirrigated cropland.

On a county basis, both conventional hedonic models as well as spatial adjustment models were developed. Statistical measures such as Moran's I, log-likelihood ratio tests, levels of statistical significance, R^2, maximum log likelihood values, and out of sample predictive ability were used to select the most appropriate model.

Data from the Kansas Society of Farm Managers and Rural Appraisers, the Property Valuation Division of the Kansas Department of Revenue, the Kansas Division of Water Resources, the Kansas Geological Service, and the United Stated Department of Agriculture Farm Service Agency were combined, on a parcel specific basis, to create a time series data set of observed land sales transactions.

This 'quasi-appraisal' technique allowed for the unbiased estimate of the value of water rights based both on the conventional site-specific characteristics as well as the hydrological characteristics of the associated water well.

Significant Findings

1) Previous research estimated irrigated and nonirrigated values in a single model. Based on statistical tests, this research suggests that the markets for irrigated and nonirrigated land are separate and distinct and require separate model estimation.
2) This research suggests that the average annual acre-foot per acre usage (*AFU*) of irrigation water may combine the positive impact associated with well capacity and the negative impact associated with diminishing saturated thickness.
3) The literature suggests that the seniority level of the water right is a significant determinant of value. This research found no difference between the perceived value of junior and senior water rights. The lack of significance on this variable probably is due to the fact that rarely have junior water rights been restricted. If the market, based on past experience, does not see a difference between junior and senior rights, it is unlikely that seniority will be a significant determinant of the market price.
4) There is significant variation in the value of water rights within a given county, even at a constant water usage.
5) Low quality land receives a substantial discount if it is used for nonirrigated production while there is little discount associated if it used for irrigated production.
6) The distance to the nearest town is important for nonirrigated land but usually has a statistically insignificant impact on irrigated land value.

7) Contrary to previous research that suggests sales price per acre decreases with farm size for nonirrigated land, these models suggest that it actually increases for irrigated land.
8) The possible existence of market arbitrage in the irrigated land market was observed in the data. Arbitrage is the nearly simultaneous purchase and sale (pure exchange) of a good in order to profit from the price differential. The presence of arbitrage raises concerns that the number of willing buyers and sellers may be too limited for the market for irrigated land to be classified as competitive.
9) The results suggest that spatial adjustment models in the presence of unavoidable model misspecification may not lead to unbiased parameter estimates.
10) Contrary to conventional wisdom and published literature, the value of water appears to be increasing in both nominal and real terms. One possible explanation is that the rate of technological advancement in water use efficiency and crop production is increasing the value of the remaining stocks of water faster than the aquifer is being depleted.

Publications and Presentations

1) Golden, B., T. Kastens, K. Dhuyvetter, and J. Peterson. "Developing an Economic Tool to Predict the Value of Water Rights." Research report posted to www.agmanager.info. May, 2006.
2) Golden, B. "The Value of Water in Western Kansas and The Voluntary Water Rights Transition Program." Presented at the *Agricultural Profitability Conference*. Ulysses, Kansas. February 1, 2005.
3) Golden, B. "Policy Solutions and Economic Impacts: Voluntary Water Retirement Programs." Presented at *The Ogallala Aquifer: What Are We Doing? K-State Meeting With the Stakeholders*. Manhattan, Kansas. March 17, 2006.
4) Golden, B. "The Economic Value of Water Rights in Kansas." Presented at the *Water and the Future of Kansas Conference*. Topeka, Kansas. March, 2006.
5) Golden, B., and J. Peterson. "Evaluation of Water Conservation From More Efficient Irrigation Systems." Presented at the State Conservation Commission spring Workshop. Hays, and Garden City, Kansas. March, 2006.
6) Golden, B. "The Economic Value of Water Rights in Kansas." Presented at the *Kansas Water Office Conservation Reserve Enhancement Program Focus Group*. Kinsley, Kansas. April, 2006.
7) Golden, B. "Two Markets-Two Models: The Case of Irrigated and Nonirrigated Cropland.". Currently in internal review for publication. May, 2006.
8) Golden, B. "The Value of Water Rights in Western Kansas: A Spatial Hedonic Approach.". Currently in internal review for publication. May, 2006.

Information Transfer

1) The results and understanding acquired through this research were conveyed through seminars (as listed above) delivered by the investigators directly to all interested policy decision makers, irrigated producers and agribusinesses, in public meetings conducted in key irrigated areas of Kansas.
2) A final report that documented the research methods and what was learned from the study was written and delivered to the Kansas Water Resource Institute, Kansas

Division of Water Resources, Kansas Water Office, and the State Conservation Commission.

3) The final report and Excel tool were posted to a web-site that has been designed to promote learning related to groundwater management issues in Kansas (http://www.agmanager.info/).
4) The data set, methods, and results will be made available, through peer review publications, to other researchers focusing on policies needed to achieve an absolute reduction in groundwater use.

Student Support

Funding was provided to Bill Golden

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Fate of Nitrate Beneath Fields Irrigated with Treated Wastewater in Ford County, Kansas Using Field Data and Preferential Flow Modeling

Basic Information

Title:	Fate of Nitrate Beneath Fields Irrigated with Treated Wastewater in Ford County, Kansas Using Field Data and Preferential Flow Modeling
Project Number:	2005KS45B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	2nd
Research Category:	Biological Sciences
Focus Category:	Models, None, None
Descriptors:	
Principal Investigators:	Marios Sophocleous, Margaret A. Townsend, Fred Vocasek, Tom Willson, John Zupanic

Publication

1. Sophocleous, Marios, Townsend, Margaret, A., 2006. Fate of nitrate beneath fields irrigated with treated wastewater, Ford County, KS. Hydrogeology-In-Progress seminar, Department of Geology, University of Kansas, Lawrence, KS, March 8, 2006.
2. Sophocleous Marios, Townsend, M.A., Willson, T., Vocasek, F., 2006. Fate of nitrate beneath fields irrigated with treated wastewater, Ford County, KS. 23rd Annual Water and the Future of Kansas Conference, Oral Abstracts, Topeka, KS, March 16, 2006.
3. Sophocleous, Marios, 2006. Preferential flow and transport of nitrate beneath treated wastewater-irrigated fields. Kansas Geological Survey Advisory Council, Lawrence, KS, March 31, 2006.

Fate of Nitrate Beneath Fields Irrigated with Treated Wastewater in Ford County, Kansas

First-Year Progress Report
(March 1, 2005 – February 28, 2006)

Marios Sophocleous and Margaret A. Townsend, Kansas Geological Survey, University of Kansas;
Tom Willson, Kansas State University;
Fred Vocasek, Servi-Tech Agri/Environmental Consulting; and
John Zupancic, Agronomy Solutions LCC

Keywords: wastewater irrigation; dye tracer; nitrate and chloride; preferential flow; unsaturated zone; soil physical/chemical properties; water quality; Root Zone Water Quality Model; Dodge City, Kansas

Abstract

With increasingly limited groundwater resources, reuse of treated wastewater provides an alternative source of water for irrigation of crops and landscaping. A long-term irrigation project with treated wastewater south of Dodge City in Ford County, Kansas, is the focus of this study. The use of treated wastewater in that area has resulted in high nitrate concentrations (10 – 50 mg/kg) throughout the upper 50-ft profile but at varying concentrations, suggesting that preferential flow processes have occurred at the proposed study area. Evaluation of the environmental impact of such land-use strategies needs to be made in order to determine if and when this process may impact usable groundwater at depth. The goal of this project is to estimate the leaching rates and time of arrival of N- (and Cl-) contaminants using preferential flow and N-cycling numerical modeling in combination with field and laboratory measurements at the study sites. This approach also will help to identify key parameters and processes that influence N losses in agricultural soils and can facilitate evaluation of the environmental impact of different land use practices.

To achieve this goal we collected deep cores for physical and chemical properties characterization, including using the Geoprobe capabilities for electrical conductivity profiling; performed dye tracer experiments; installed neutron moisture probe access tubes and regularly collected soil moisture data; and obtained soil chemical data, crop and irrigation application rate information, climatic data, and other additional information from the ongoing study in the area, which is managed by the two consultant co-PIs on this project. This report details the data collection and analysis during the 1st year of this project. All these data are now being used in the comprehensive N-cycling model RZWQM (which also accounts for preferential flow and transport) to identify key parameters and processes that influence N losses in the study area. This second phase of this project is ongoing and will be reported in a later update of this report.

Results from this study will assist in determining leaching rates and fate of nitrogen in the High Plains aquifer from wastewater irrigation, provide additional data for enhancing the nitrogen budget for the area in question, and assist in providing information for other areas where there is an interest in using reclaimed water for landscape irrigation as a means to conserve water or for disposal purposes.

Table of contents

Fate of Nitrate Beneath Fields Irrigated with Treated Wastewater in Ford County, Kansas

Marios Sophocleous, Margaret Townsend, Tom Willson, Fred Vocasek, John Zupancic

1. Introduction

With increasingly limited groundwater resources, reuse of treated wastewater provides an alternative source of water for irrigation of crops and landscaping. In addition, utilization of the nutrients in recycled wastewater as fertilizer results in less application of fertilizer to a plant system.

A long-term irrigation project using treated municipal wastewater has been ongoing south of Dodge City in Ford County since the mid-1980s and is shown in Fig. 1. This area is underlain by the High Plains aquifer, and constitutes the study area for this project. Use of the treated wastewater, which includes inputs from both the municipality of Dodge City and -a meat-packing plant, has resulted in relatively high soil nitrate-nitrogen concentrations (10–50 mg/kg) in the soil profile at the sites irrigated with this treated wastewater effluent (Zupancic and Vocasek, 2002). Evaluation of the environmental impact of such land-use strategies needs to be made in order to determine if and when this process may impact usable groundwater at depth and what management changes may need to be made to slow down the downwards N migration.

The study area overlies the High Plains aquifer with depth to water in the range of 75 to 150 ft. The overlying soils are predominantly Harney and Ulysses silt loams (Dodge et al., 1965). Although this area has a deep water table and soils with a silty clay component, there is evidence that nitrate is migrating through the vadose zone. USGS National Water-Quality Assessment studies in the Central High Plains aquifer region indicate that nitrate from fertilizer sources and animal waste has reached the Ogallala portion of the High Plains aquifer most likely due to increased recharge from irrigation but also because of preferential flow processes (USGS, 2004). Work by the Kansas Geological Survey indicates that: (1) nitrate has reached the Ogallala aquifer in northwest Kansas (Townsend et al., 1996); (2) nitrate is migrating through the shallow vadose zone to the High Plains aquifer in south-central Kansas (Sophocleous et al., 1990a, 1990b) and (3) an overview of nitrate in Kansas groundwater (Townsend and Young, 2000) shows levels above the 2 mg/L background level (Mueller and Helsel, 1996) in several major aquifers in the state, including the High Plains.

Because of the importance of the High Plains aquifer as a source of drinking and irrigation water, the quality of the water is an important issue. Determining the rate of movement of contaminants to the groundwater is a difficult task. Field investigations in combination with modeling constitute a promising methodology for estimation of leaching rates and time of arrival of contaminants. Modeling can also better identify key parameters and processes that influence N losses in agricultural soils and can facilitate evaluation of the environmental impact of different land-use practices.

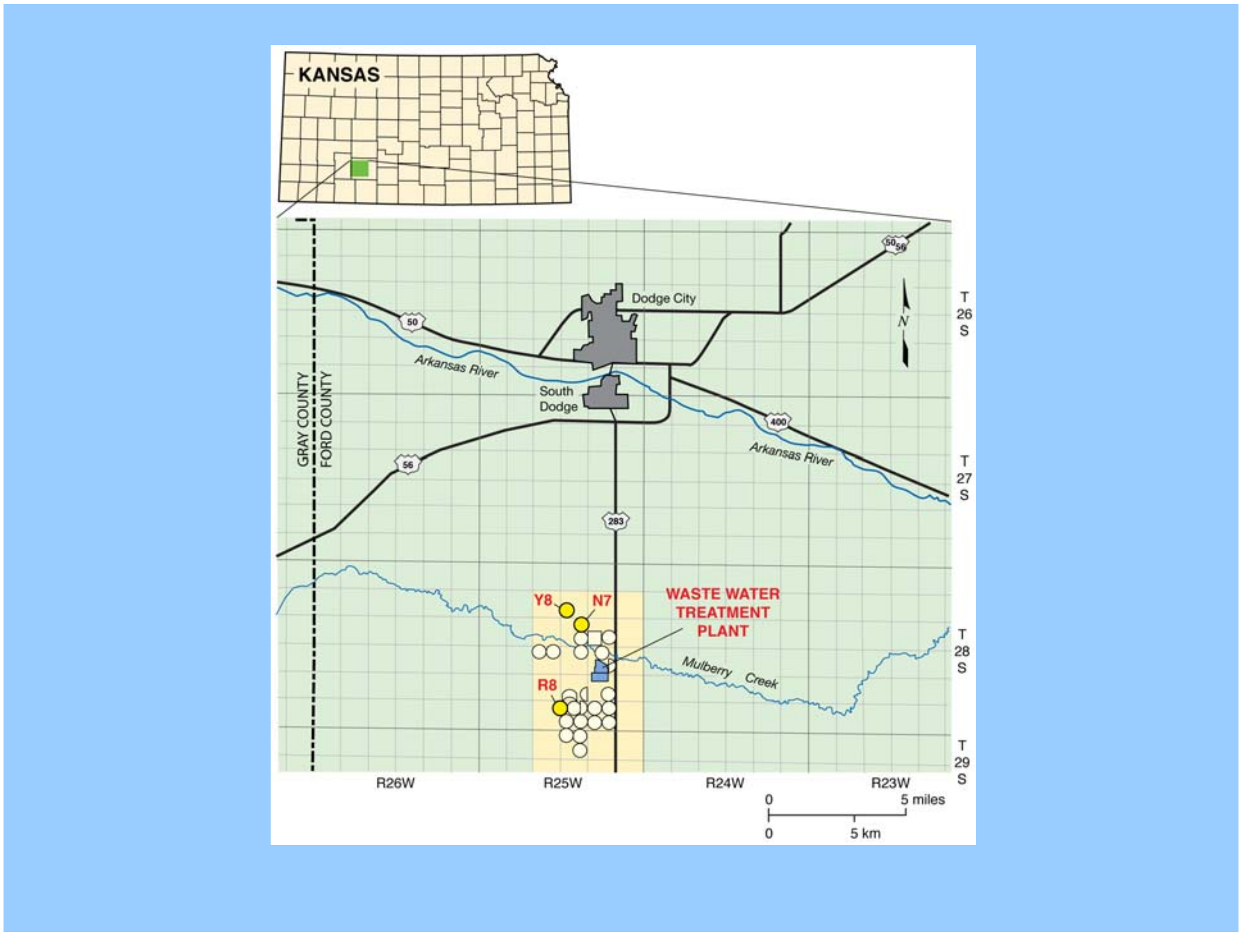

Figure 1. Location of the study area.

2. Objectives

Therefore, the objectives of this project are:

1) to conduct field sampling and other analyses to study and document the impact of treated wastewater irrigation in the area south of Dodge City; and
2) to employ sophisticated numerical modeling of N fate and transport to identify key parameters and processes that influence N losses and facilitate evaluation of the environmental impact of different land use practices.

3. Statement of the problem

The Dodge City Wastewater Treatment Plant (DCWTP) is collecting wastewater from the City and a meat packing plant into a collection station. The collected wastewater is piped about 11 miles south of the City into a wastewater treatment facility (Fig. 1). This facility consists of three covered anaerobic digesters (i.e., covered lagoons with impermeable covers that trap gas produced during decomposition of the liquid effluent) and three aeration basins. The treated water is stored in storage lagoons with a capacity of more than 2800 acre-ft. A pumping system, consisting of several electric, centrifugal pumps distributes the water to irrigate more than 2700 acres of cropland in 25 fields (Fig.1). The system is managed by Operations Management International (OMI) and the agronomic firm Servi-Tech, Inc. under contracts with the City.

Early results of soil monitoring by ServiTech company personnel showed that significant amounts of nitrate-N were passing beyond the upper 5-feet of the soil profile (Zupancic and Vocasek, 2002). Deeper coring was then undertaken, and soil nitrate-N concentrations exceeding 10 mg/kg have been detected down to depths of approximately 40 ft. Also, concentrations above the drinking water limit of 10 mg/L NO_3-N have been found in groundwater from monitoring wells in the area (Zupancic and Vocasek, 2002).

Servi-Tech personnel have also noted macropores with diameters ranging from pinpoint size to nearly 0.25 inch in the undisturbed cores collected during sampling. These macropores are most numerous in the upper soil profile, but also occur at depths down to 40 or so ft. The interior of these macropores take on a brownish color after sampling, possibly from organic carbon anoxidation, suggesting these may be historic root channels.

Thus, the occurrences of nitrate at depth and the presence of macropores suggest the possibility that preferential flow processes through macropores bypassing the attenuating effect of the soil matrix are occurring.

4. Related Research

Irrigation of secondarily treated wastewater is an acceptable, well-studied method of wastewater reuse. Land application of wastewater has been extensively studied both in the U.S.A. and abroad (Ayers and Westcott, 1989; Townsend, 1982; Hogg et al., 2003). Soil-profile monitoring at the Dodge City site began in 1987 during the second year of wastewater application. Soil-salinity impacts were the major concern in 1987, but nutrients (including nitrate) also were included in the monitoring program (Zupancic and Vocasek, 2002). The DCWTP capacity was quickly pushed beyond the design specifications and wastewater nitrogen concentrations increased about three-fold. Project-wide nitrogen budgets showed net nitrogen inputs exceeding crop nitrogen removals by 60% to 80% (Zupancic and Vocasek, 2002).

As mentioned before, the occurrences of nitrate at depth and the presence of macropores suggest the possibility that preferential flow processes have occurred. Various types of dyes have been used to stain the flow paths of water in soils to circumvent measurement difficulties of preferential flow due to tremendous spatial and temporal variability (Bouma et al., 1977; Flury et al., 1994). The results obtained from staining experiments clearly illustrate the complicated pattern of water movement with a very high spatial resolution.

The importance of macropores in preferential flow cannot be overstated. Macropores allow rapid gravitational flow of the free water available at the soil surface or above an impeding soil horizon, thus bypassing the soil matrix. Short circuiting to groundwater through macropores is of serious concern at present because of the possibilities of rapid transport of a portion of fertilizers, pesticides and other chemicals applied on the soil surface (Ahuja et al., 1993).

This concern has been exacerbated by the growing practice of minimum or no tillage, which allows chemical solutes in irrigation water applied on the soil surface to accumulate and to enter macropores at the surface. Plant residues on the surface and no tillage also enhances worm activity and allow worm holes and other macropore channels to stay open at the surface (Ahuja et al., 1993).

Preferential flow can be described using a variety of dual-porosity, dual-permeability, multi-porosity, and/or multi-permeability models (Simunek et al., 2003). The main disadvantage of such models is that, contrary to models for a single pore region, they require more input parameters to characterize both macropore and micropore systems. However, little guidance is available as to how to obtain these parameters, either by direct measurement, *a priori* estimation, or some calibration technique (Simunek et al., 2003).

Standard procedures have not yet been established for macropore input parameters. Logsdon (2002) evaluated several methods to independently measure macropore parameters using soils from the Des Moines lobe with textures ranging from sandy loam to silty clay. Rawls et al. (1996) developed empirical equations to calculate macropore size/count, areal porosity, and macropore conductivity based on three levels of available data. Jarvis et al. (1997) presented guidance on parameter estimation of macropore-system properties for input into preferential flow models based on easily measured soil physical properties. We plan to implement these suggested parameter-estimation procedures in our study and evaluate their predictive accuracy.

The effects of macropore flow on nitrogen loading are not well investigated, although several models now exist that take transport through macropores into account (Larsson and Jarvis, 1999). Under non-fertilized conditions, we should expect leaching loads to be reduced because nitrogen is inherent to the soil, so that rainwater that rapidly bypasses the soil matrix will have a smaller NO_3 concentration than the resident soil solution. With wastewater-nitrogen inputs though, the consequences of macropore flow are not very clear (Larsson and Jarvis, 1999).

Measurements of the soil hydraulic conductivity and/or soil-water retention curve are costly, time-consuming, and sometimes unreliable because of soil heterogeneity and experimental errors. Methods have been developed to estimate soil hydraulic properties from more easily measured soil properties (Wosten et al., 2001). These methods involve the use of pedotransfer functions (PTFs; see further in section 7A.2.c). A number of PTFs can be found in the literature and can be classified according to the nature of the basic input soil properties and the method adopted to generate predictions (Wosten et al., 2001). A neural network approach to estimating PTFs is available in the ROSETTA software (Schaap et al., 2001) and was shown to be reasonably good for simulating soil-moisture variations in the field (Nemes et al., 2003), and therefore we plan to employ it in our study, as well as the popular RETC code (van Genuchten et al., 1991) for quantifying the hydraulic functions of unsaturated soils (see further in section 5F.1).

Land application of treated wastewater is a proven technology that is utilized world wide (Ayers and Westcot, 1989). Reuse of wastewater is particularly common in developing countries and in arid portions of the western United States (Bouwer, 1992). Generally water quality is improved by land application of wastewater and use of the soil as a filtering system for removal of microbes, organic and inorganic forms of nitrogen and other chemicals that can be detrimental to human health (Asano, 2006; Schreffler and Galeone, 2005, Avnimelech, 1993). In most situations nitrogen is utilized by plants and mineralized in soils. However, some studies such as the study in the Lake Tahoe region in California (Hayes and deWalle, 1993), excessive application of wastewater during the winter when the ground was frozen and plants were dormant resulted in an increase of conductivity, chloride, and nitrogen in groundwater in the area. In addition, in arid areas there always exists the possibility of enrichment of anions in the irrigation water due to evapoconcentration processes (Babcock et al., 2005, Bouwer, 1992; Hayes and DeWalle, 1993). The study area near Dodge City has been in operation since 1987. Salinity and leaching nitrate are continuously under observation and methods are changed as necessary to deal with the issues (Vocasek, 2006).

5. Methodology

5A. Field monitoring sites

To analyze this nitrogen leaching problem further, we established two main monitoring sites, one in each of the two major loess-derived soil series in the project area, the Harney and the Ulysses soils (Fig.2; the Harney silt loams are the bluish and greenish colors in the slide, whereas the Ulysses silt loams are the reddish and purplish colors). One of the sites, the R8 in Harney soils, has a long-term treated wastewater irrigation history (since 1986), whereas the other site, N7 in Ulysses soils, has a short-term treated wastewater irrigation history (since 1998). In addition, a third, control site, Y8, without any wastewater irrigation record, has also been established (Fig. 2).

During the first year of this project we concentrated on establishing and instrumenting the monitoring sites and collecting the basic data for our further analyses, and this is what this report will emphasize.

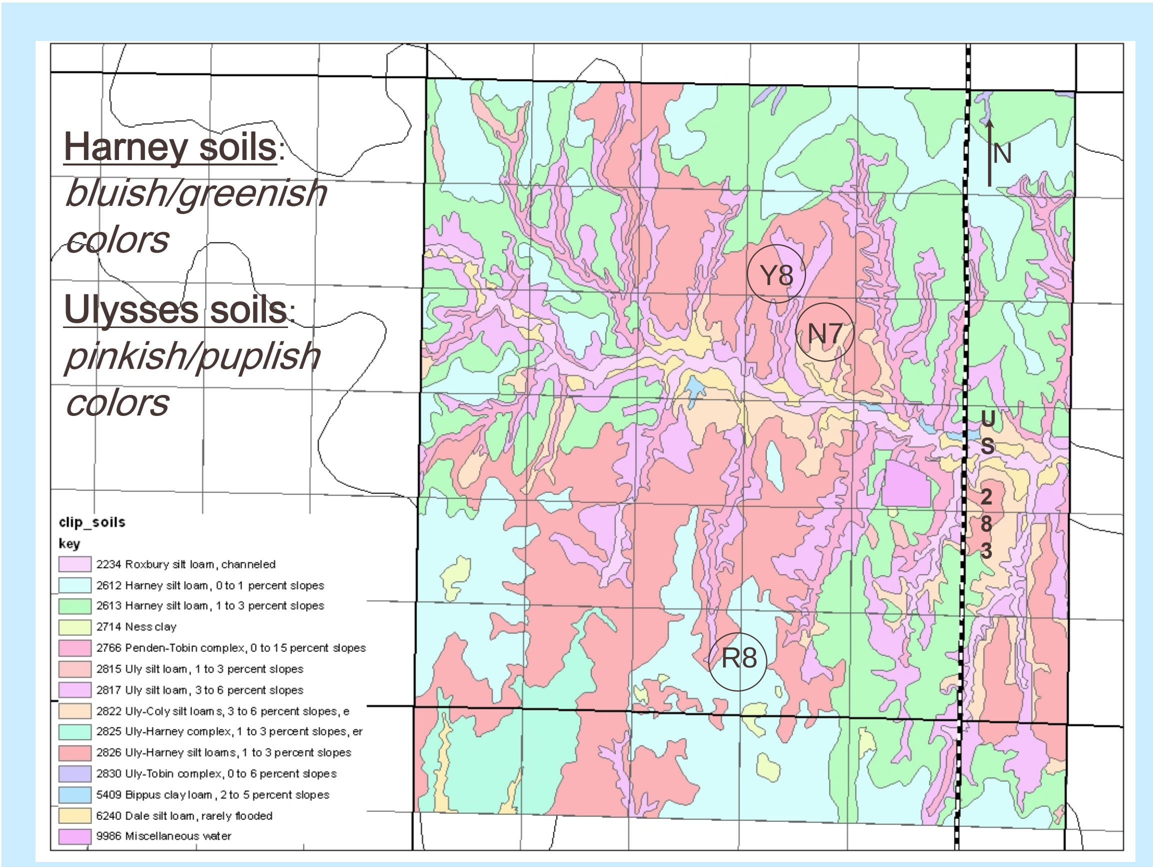

Figure 2. Map of soils in Ford County at study sites (Data downloaded from the NRCS Geospatial Data Gateway at http://soildatamart.nrcs.usda.gov).

5B. Soil sampling and analyses

We collected several deep cores, down to 50 ft, from each of the sites for a number of physical, chemical and future isotopic analyses (year 2). Analyses included: textural analysis, bulk density, percent total carbon, total Kjeldahl nitrogen, nitrate, ammonium, percent carbonate, cation exchange capacity, percent water content for various pressures, chloride, pH, electrical conductivity, sodium adsorption ratio, and others.

Soil analyses were done by the Natural Resources Conservation Services (NRCS) Lincoln Laboratory, by the Kansas State University Soil Testing Laboratory, and Servi-Tech laboratories. The NRCS Laboratory used the dry combustion method for Total Carbon (Ctot) determinations. The amount of carbonate in the soil is determined by treating the sample with HCl followed by manometrically measuring the evolved CO2. The amount of carbonate is then calculated as a CaCO3 equivalent basis. Values of total organic carbon (TOC) were determined by difference between total carbon and percent calcium carbonate (CaCO3) multiplied by 0.12, the fraction of carbon in calcium carbonate (i.e., TOC = Ctot – 0.12*CaCO3).

Cation exchange capacity (CEC) is a measure of the total quantity of negative charges per unit weight of the soil and is commonly expressed in units of milliequivalents per 100 g of soil (meq/100g) or centimoles per kilogram of soil (cmol(+)/kg). The Sodium Adsorption Ratio (SAR), i.e., the ratio of the molar concentration of the monovalent cation Na^+ to the square root of the molar concentrations of the divalent Ca^{2+} and Mg^{2+} in the soil, divided by 2, is a measure of potential hazards from high sodium levels.

The soil bulk density down to 15.2 m (50 ft) was determined from collected cores of known diameter by cutting the core in 15.2-cm (6-in) increments, weighing them in the field, and then oven-drying them in the lab. KSU Southwest Agricultural Station and the NRCS Lincoln calucated bulk density using different methods. The values calculated by the KSU Southwest Agricultural Station were used for calibration of the neutron probe.

The deep cores (of 15.2-m total length), that were collected in April, 2005, were analysed by Servi-Tech for nitrate, chloride, and electrical conductivity for each 15-cm sample according to procedures outlined in the Recommended Chemical Soil Test Procedures for the North Central Region (Univ. of Missouri Agricultural Experiment Station, 1998).

KSU soils testing laboratory performed analyses for pH, ammonium-N, nitrate-N, chloride, sediment texture, CEC, total nitrogen, total carbon, total organic carbon, and total carbonate for the upper 10 feet of cores collected at sites R8, and Y8. Total levels (inorganic and organic) of C and N were determined on a dry weight percent basis using a LECO CN 2000 combustion analyzer (LECO Corp., 1995). Calcium carbonate percentage was analyzed by pretreatment of a second LECO combustion sample with dilute (10% v/v) HCl. Carbon dioxide is released from calcium and magnesium carbonates in calcareous soils, leaving only the total organic carbon present (LECO Corp., 2000). The total organic carbon is the %C in the acid-treated sample. The total inorganic carbon is then calculated as the difference in the treated and untreated values. The percentage of carbonates is expressed as a percentage of CaCO3 by dividing the inorganic carbon by a factor of 0.12. PH is measured directly using a 1:1 slurry of 5 or 10 g of prepared soil with deionized water with an automated system. Texture was analyzed using sodium hexametaphosphate as a dispersing agent, the sand, silt, and clay fractions of the sample are estimated with the hydrometer method. Cation Exchange Capacity was measured using the displacement method with saturating ammonium acetate is used to measure the cation exchange capacity contained in a 2-g sample. Soil chloride is extracted from a 5-g sample with calcium nitrate and analyzed with the Mercury Thiocyanate colorimetric method. Methods discussed above are listed at the website:
http://www.oznet.ksu.edu/dp_agrn/SoilTesting/r_soil_testing.htm .

5C. Neutron probe calibration

A neutron probe is used to collect moisture data profiles to 50-ft depth. The probe utilizes neutron activation of water in the soil profile to record relative abundance of moisture in the soil profile. A Campbell Pacific Nuclear (CPN) 503DR Hydroprobe was jointly purchased by KSU-SWREC and KGS for use in this project.

Aluminized steel pipe of 2.05-inch OD and 1.85-inch ID was used for the neutron probe access tube. A solid steel point was welded in the lower end of the pipe, as shown in Fig. 3. The neutron probe was calibrated in the field as follows. A 2.25-inch diameter, 50-ft hole was cored with the Giddings probe, and the access tube was snuggly inserted down the hole (Fig. 4). The collected core was cut in 6-inch increments, weighted in the field, and taken to the Servi-Tech, Inc. soils lab for oven-drying and re-weighing. Following access tube installation, neutron profile readings were taken in 6-inch increments within the root zone (6-ft) and in 1-ft increments from the bottom of the root zone to 50 ft. At each site, two field corner (6-by 6-ft) plots were selected as additional calibration plots in which a 10-ft access was install in each. One plot was used for the neutron moisture calibration at the dry end-end of the moisture range, whereas the other plot was periodically wetted by applying measured amounts of water for neutron probe calibration at the wet end of the moisture range. Figure 5 shows the “wet” plot with the neutron probe being used for calibration measurements. Periodically, 8-ft long cores were collected from within the corner, calibration plots with the Giddings probe, and moisture content was calculated by oven-drying for comparison with neutron readings.

Figure 3. Aluminized steel pipe and solid steel point employed in the construction of the neutron probe access tube.

Figure 4. Field installation and welding of the neutron access tube.

Figure 5. Field corner “wet” plot for neutron probe calibration.

To convert gravimetric to volumetric moisture content, three methods were employed to estimate the soil bulk density with which the gravimetric water content was multiplied to obtain the volumetric water content: (1) the 6-inch core increments of known volume (4.0-cm in diameter) were weighted in the field and oven-dried in the lab; (2) the 4-ft Giddings probe stroke was measured for its collected core length and the weights of all the 6-inch core increments were added together to obtain the 4-ft stroke bulk density; (3) an average of three consecutive 6-inch core samples was obtained for a smother bulk density profile estimation. The last method of three-sample averaging was finally adopted as giving the most consistent results. Since both R8 and N7 sites have similar soils, all data from both the deep access tubes and the corner plots were combined to obtain the calibration curve shown in figure 6.

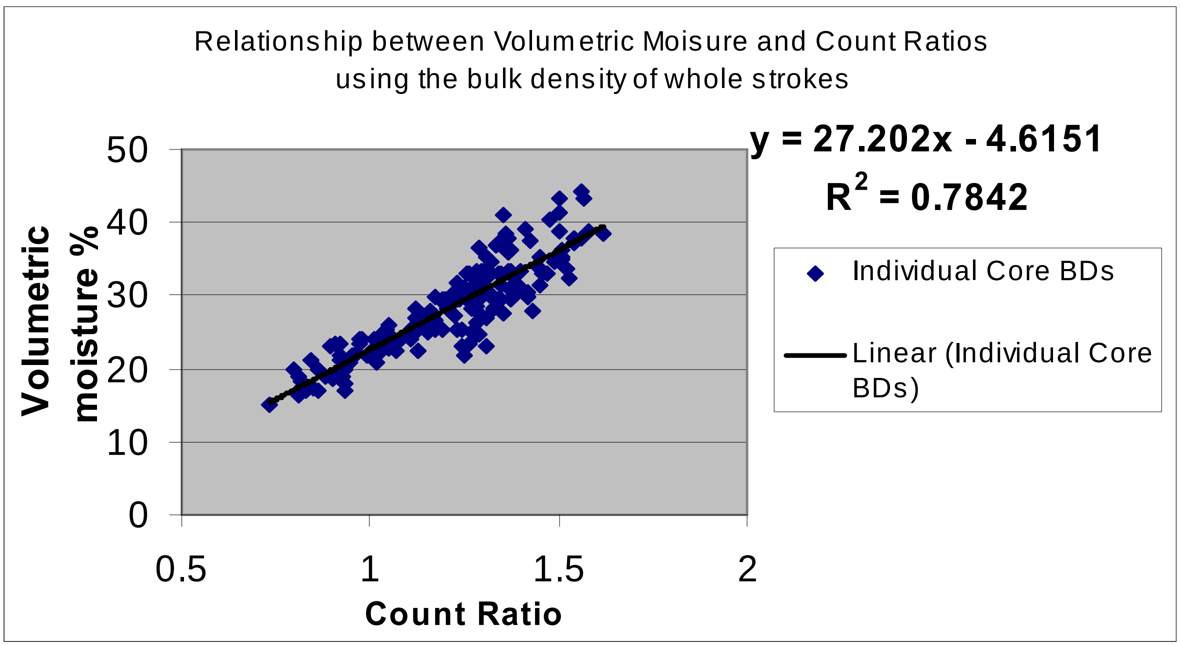

Figure 6. Neutron probe calibration curve.

5D. Water Sampling and Chemical Analysis Methods

We also sampled most of the existing wells in the area (Fig. 7) to check any impacts on the relatively deep water table, which ranges from about 70-ft close to Mulberry Creek to more than 150-ft deep as one goes away from Mulberry Creek. Water samples from monitoring, domestic, and irrigation wells and wastewater lagoons were collected by both KGS and OMI personnel.

Samples collected from domestic and irrigation wells by KGS personnel were pumped for a minimum of 10 minutes with the specific conductance and temperature being measured until both had stabilized over a sequence of three measurements. Samples were collected and kept on ice until returned to the KGS laboratory. Samples were kept in a refrigerator until analyzed. Samples for isotope analysis were kept frozen, then sent on ice to the University of Virginia laboratory for analysis and kept frozen until analyzed.

Complete inorganic water analyses were performed by the Analytical Services Section, Kansas Geological Survey (KGS). Samples for nitrate-N analysis were collected in 250-ml bottles treated with 2-ml of 10% HCl acid for preservation. Samples for all other inorganic constituents were collected in acid- rinsed 1-L polyethylene bottles, with 1-L bottles used for nitrogen-15 analyses. If needed, samples were filtered in the laboratory using a 45µ Micropore© filter prior to chemical analysis. Samples were analyzed for major cations (calcium, magnesium, sodium, potassium) and anions (chloride, bicarbonate, sulfate, nitrate, and fluoride), and other minor constituents, in addition to pH, specific conductance, temperature, and calculated total dissolved solids using standard methods described by Hathaway et al. (1975). Nitrate-N was determined using a UV method developed at the KGS (Hathaway, 1990).

Samples from the wastewater lagoons were collected by OMI personnel and analyzed by Servi-Tech labs for complete analyses (http://devteam.greensoft.com/ServitechLab/Portals/0/feeschedule.pdf).

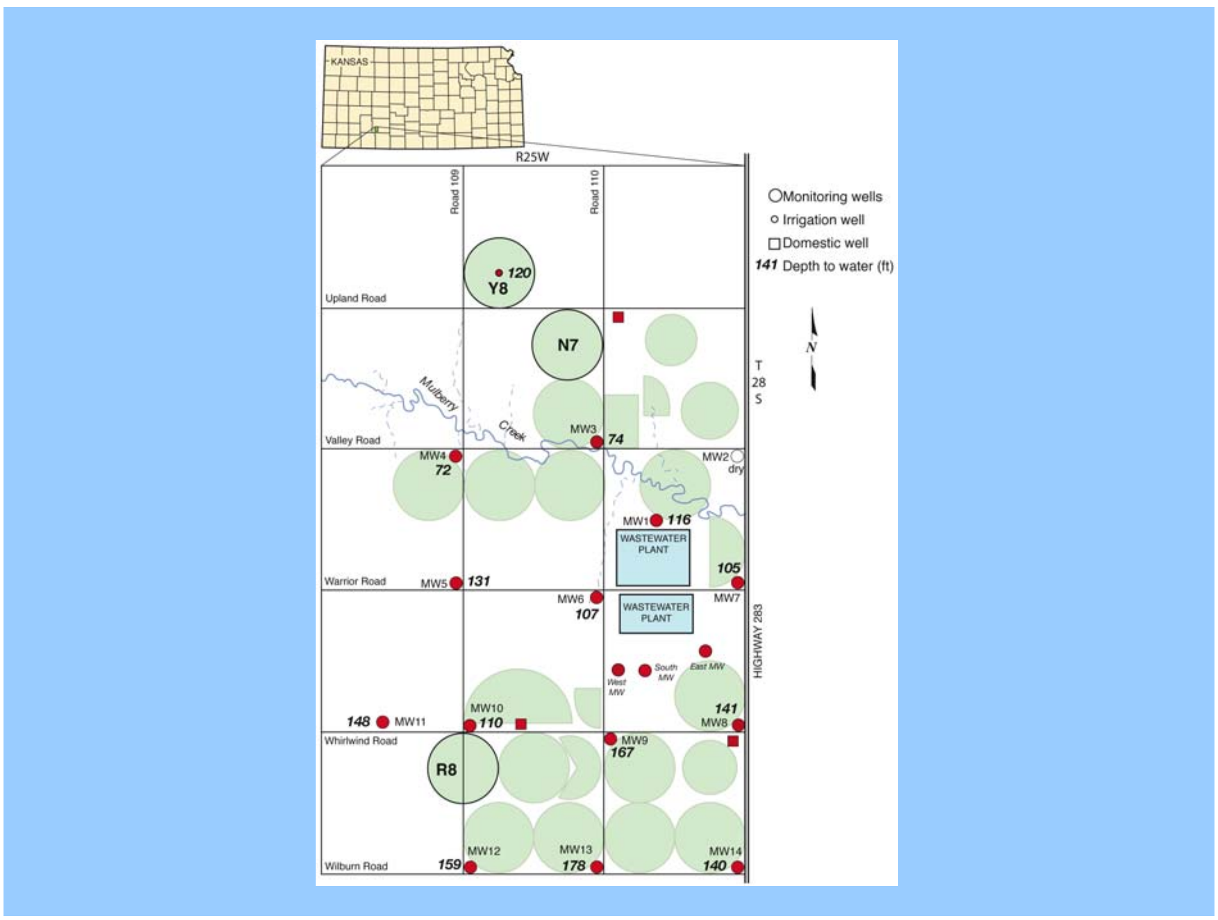

Figure 7. Depth to water measured in monitoring wells at study site in the fall of 2005.

Lysimeters

Suction lysimeters were installed at three depth levels using the Servi-Tech Giddings soil auger rig: shallow (5-6 ft), intermediate (17-26 ft), and deep (30 to 50 ft) in all sites for complete water analyses, periodic measurements of nitrate and chloride levels in pore waters, and isotopic analysis. Figure 8 shows the three depth lysimeters with PVC covers and the neutron access tube in the foreground.

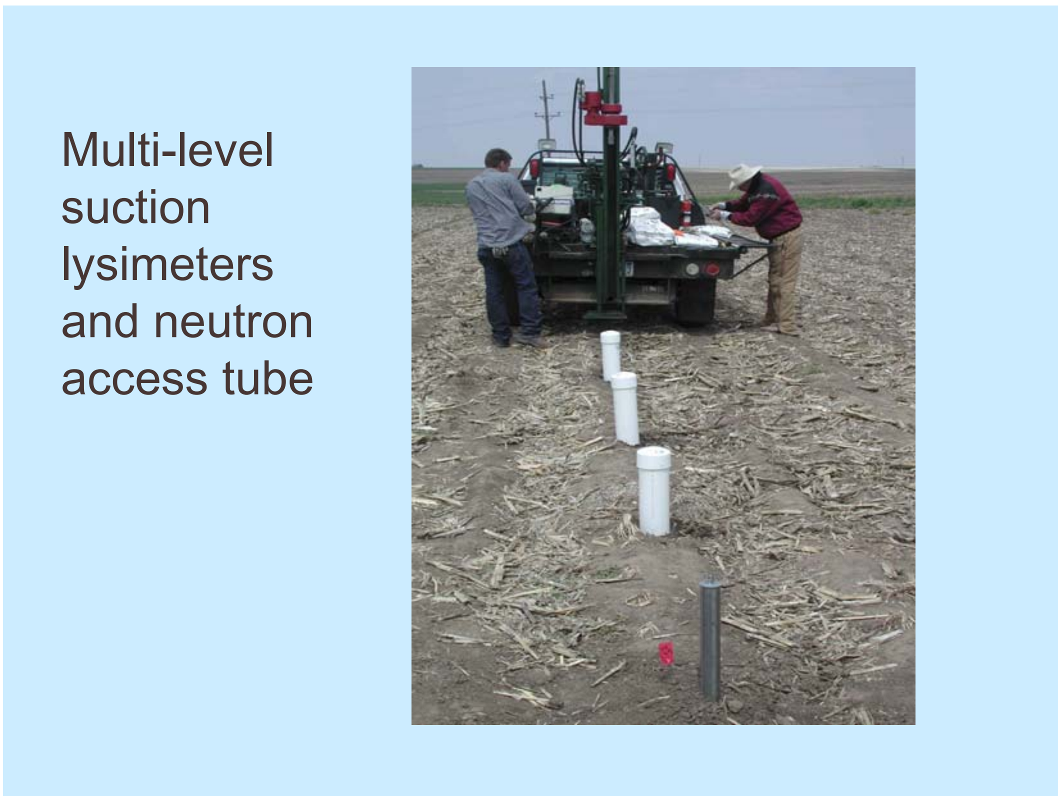

Figure 8. Multi-level suction lysimeters (covered with white PVC pipe) and neutron access tube (foreground).

5E. Dye-tracer experiments

In order to determine the preferential flow potential of each of the two major soil types in the study area in which we established our study sites (site R8 in Harney soil, and site N7 in Ulysses soil) and better explain the deep occurrences of nitrogen concentrations, we conducted two dye-tracer experiments. A literature search for a suitable dye tracer (Flury and Fluhler, 1994a,b; 1995, Petersen et al., 1997, Schwartz et al., 1999, Flury and Wai, 2003) revealed that the brilliant blue food coloring dye (FD&C Blue 1, tri-phenyl-methane dye) would be a suitable tracer because of its desirable properties of mobility and distinguishability in soils, and also non-toxicity. In June 2005 we conducted an initial pilot tracer dye solution experiment at the KGS experimental site (GEMS) in Lawrence, KS, to check on dye effectiveness in visualizing flow patterns in soils. That test proved successful and thus we decided to proceed with the brilliant blue dye tracer experiments at the study sites following the harvesting of corn that was planted at the sites. These experiments were finally conducted on November 8, 2005, following a number of postponements due to weather problems.

The steps we followed in conducting the dye-tracer tests at sites R8 and N7 are as follows: We rented a 1000-gallon water tank and filled it with 400 gallons of water. We then added a carefully pre-weighted total quantity of 6,056.7 grams of brilliant blue powder dye (3,028.4 grams per 200 gallons of water) and mixed it well to obtain a dye concentration of 4 g/L (which was also employed in the studies cited above). We prepared two 3'X5' wooden rectangular frames of 1-ft height for flooding the sites with the dye solution as shown in fig. 9.

Figure 9. Wooden rectangular frame for flooding the site with dye solution.

The amount of brilliant blue dye required to arrive at a concentration of 4 g/L was arrived as follows: The 3'X5' wooden enclosure we set up at each site would allow flooding of a 15-square foot area. Assuming an average soil porosity (based on neutron soil moisture profile readings) of 30%, the volume of solution needed to saturate the 15-ft^2 area down to a depth of approximately 5 ft would be 22.5 ft^3 or 168.3 gallons, and thus to achieve the desired dye concentration of 4 g/L, we would need to add 2,548.8 g of brilliant blue powder dye to that volume. However, because it would be rather difficult to accurately measure such an odd quantity of 168.3 gallons in a water tank, we decided to re-compute the weight of needed powder dye for a round-number volume of 200 gallons of water. Thus, to come up with the desired concentration of 4 g/L, we would need 3,028.4 g of dye in 200 gal of water.

5F. Numerical simulation

The USDA-ARS developed a Root Zone Water Quality Model (RZWQM), which includes a submodel for macropore flow and transport, as well as other modules for pesticide reactions and degradations, nutrient transformations, plant growth, and management-practice effects. One of the objectives of this study is to use the RZWQM model to study magnitudes and characteristics of macropore flow and transport as influenced by important factors in the typical soils of the area.

The Root Zone Water Quality Model (RZWQM) is a one-dimensional (vertical in the soil profile) process-based model (Ahuja et al., 2000) that simulates the growth of the plant and the movement of water, nutrients, and agro-chemicals over, within, and below the crop root zone of a unit area of an agricultural cropping system under a range of common management practices. It uses the Green-Ampt equation to simulate infiltration and Richards equation to simulate water redistribution. Rainfall or irrigation water in excess of the soil-infiltration capacity (overland flow) is routed into macropores if present. The maximum macropore flow rate and lateral water movement into macropores in the surrounding soil are computed using Poiseuilles' law and the lateral Green-Ampt equation. Macropore flow in excess of its maximum flow rate or excess infiltration is routed to runoff.

The nutrient sub-model for organic matter/nitrogen cycling of RZWQM simulates all the major pathways including mineralization-immobilization of crop residues, manure, and other organic wastes; mineralization of the soil humus fractions; inter-pool transfers of carbon and nitrogen; denitrification (production of N_2 and N_2O); gaseous loss of ammonia (NH_3); nitrification of ammonium to produce nitrate-N; production and consumption of methane gas (CH_4) and carbon dioxide (CO_2); and microbial biomass growth and death. Despite the complexity of this organic matter/N-cycling component, good estimates of initial soil carbon content and nitrogen are generally the only site-specific parameters needed. The required inputs (e.g. fast pool, slow pool) are then usually determined through an initiation wizard and calibration.

We will investigate whether significant preferential flow is occurring and determine the prediction errors made in terms of soil moisture and N-concentrations when preferential flow is ignored. Parameters for soil-hydraulic properties in the model to be employed will be measured, taken from the literature, calibrated, or estimated from soil texture, soil structure, bulk density, and organic carbon content using pedo-transfer functions.

5F.1 RETC and ROSETTA retention-curve estimation: (The information in this section was adapted from the on-line documentations of the RETC and ROSETTA programs from the Agricultural Research Service, US Department of Agriculture web site at http://www.ars.usda.gov/Services/docs.htm?docid=8910.)

Most vadose zone studies today use numerical models to simulate the movement of water and solutes in the subsurface. Knowledge about the soil hydraulic properties (i.e., the water retention curve and hydraulic conductivity) is essential for running these models. A broad array of methods currently exists to determine soil hydraulic properties in the field or in the laboratory (cf. Klute, 1986; van Genuchten et al., 1992). Most laboratory and field techniques, however, have specific ranges of applicability with respect to soil type and saturation (Klute, 1986). In addition, measurements of the soil hydraulic conductivity and/or soil water retention curve are costly, time consuming, and sometimes unreliable because of soil heterogeneity and experimental errors.

A large number of indirect methods to generate soil hydraulic properties are now available. Although these methods vary widely in terms of methodology and complexity, all use some form of surrogate data to estimate soil hydraulic properties. In broad terms, three methods can be distinguished; pore-size distribution or parametric models, inverse methods, and pedotransfer functions. We will address the first and last methods here.

Pore-size distribution models or parametric models for the soil hydraulic functions are very often used to estimate the unsaturated hydraulic conductivity from the distribution, connectivity and tortuosity of pores. The pore-size distribution can be inferred from the water retention curve, which is normally much easier to measure than the unsaturated hydraulic conductivity function. One of the most popular models was developed by Mualem (1976). The model may be simplified into closed-form expressions when the water retention is described with the functions of Brooks-Corey (1964) or van Genuchten (1980). The RETC (RETention Curve) computer program for describing the hydraulic properties of unsaturated soils may be used to fit several such analytical models to observed water retention and/or unsaturated hydraulic conductivity data.

<u>Parametric Models for the Soil Hydraulic Function</u>: Water flow in variably-saturated soils is traditionally described with the Richards equation

$$C\frac{\partial\psi}{\partial t} = \frac{\partial}{\partial z}\left(K\frac{\partial\psi}{\partial z} - K\right) \qquad (1)$$

where ψ is the soil water pressure head (with dimension L), t is time (T), z is soil depth (L), K is the hydraulic conductivity (LT^{-1}), and C is the soil water capacity (L^{-1}) approximately by the slope ($d\theta/d\psi$) of the soil water retention curve, $\theta(\psi)$, in which θ is the volumetric water content (L^3L^{-3}). The solution of the Richards equation requires knowledge of the unsaturated soil hydraulic functions $\theta(\psi)$ and $K(\psi)$ or $K(\theta)$.

One of the most popular functions for describing the $\theta(\psi)$ function has been the equation of Brooks and Corey (1964), further referred to as the BC-equation:

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \begin{cases} (\alpha\psi)^{-\lambda} & for\ (\alpha\psi > 1) \\ 1 & for\ (\alpha\psi \le 1) \end{cases} \qquad (2)$$

where S_e is the effective degree of saturation, also called the reduced water content ($0 \le S_e \le 1$), θ_r and θ_s are the residual and saturated water contents, respectively; α is an empirical parameter (L^{-1}) whose inverse is often referred to as the air entry value or bubbling pressure, and λ is a pore-size distribution parameter affecting the slope of the retention function. For notational convenience, ψ and α are taken positive for unsaturated soils (i.e., ψ denotes suction).

Several continuously differentiable (smooth) equations have been proposed to improve the description of soil water retention near saturation. A related smooth function with attractive properties is the equation of van Genuchten [1980], further referred to as the VG-equation:

$$S_e = \left[1 + (\alpha\psi)^n\right]^{-m} \tag{3}$$

where α (L^{-2}), n and m are empirical constants affecting the shape of the retention curve, and m is normally calculated as m=1−1/n.

The corresponding closed-form expression for the unsaturated hydraulic conductivity, K (e.g., cm/day), is (van Genuchten, 1980):

$$K(S_e) = K_o S_e^L \left\{1 - \left[1 - S_e^{n/(n-1)}\right]^{1-1/n}\right\}^2 \tag{4}$$

in which K_o is a matching point at saturation (cm/day) and similar, but not necessarily equal, to the saturated hydraulic conductivity, K_s. The parameter L (-) is an empirical pore tortuosity/connectivity parameter that is normally assumed to be 0.5 (Mualem, 1976).

Pedotranfer functions (PTFs, Bouma and van Lanen, 1987) offer another method for estimating hydraulic properties by using the fact that hydraulic properties are dependent upon soil texture and other readily available taxonomic information (e.g., the particle size distribution, bulk density and/or organic matter content). For example, fine-textured soils are known to have very different water retention characteristics and much lower saturated hydraulic conductivities than coarse-textured soils. PTFs take advantage of such information. Although considerable differences exist among PTFs in terms of the required input data (Rawls et al., 1992), all of them use at least some information about the particle-size distribution.

The computer model ROSETTA implements PTFs to predict van Genuchten (1980) water retention parameters and saturated hydraulic conductivity (Ks) by using textural class, textural distribution, bulk density and one or two water retention points as input. Although the use of more input data often leads to better predictions (Schaap and Bouten, 1996; Schaap et al., 1998) there are many cases where only limited soil information is available. ROSETTA follows a hierarchical approach to estimate water retention and Ks values using limited or more extended sets of input data (Schaap et al., 1998, Schaap and Leij, 1998a).

The hierarchical approach is reflected in the five models employed in ROSETTA. The simplest model consists of a lookup table for average hydraulic parameters for each soil textural class (sand, silty loam, clay loam, etc.). The other four models are based on neural network analysis (Schaap et al., 1998) and predict the hydraulic parameters, using additional input variables, with an increasing degree of accuracy. All five models haven been calibrated on the same data set and provide consistent predictions. The calibration data set contained 2,134 samples for water retention and 1,306 samples for saturated hydraulic conductivity, Ks (Schaap and Leij, 1998b). The samples were obtained from a large number of sources and involve agricultural and non-agricultural soils in temperate climate zones of the northern hemisphere (mainly from the USA and some from Europe). The output from the ROSETTA program provides for the θ_r, θ_s, the van Genuchten parameters α and n, and Ks values.

5G. Statistical methods

Splus 7.0 for Windows was used for statistical evaluation of water samples. The tests used were from the environmental statistics module developed by Millard (2002). The Shapiro-Wilk test was used to determine if the evaluated parameters were normally distributed. The test showed that the parameters evaluated (nitrate-N, chloride, specific conductance, and sulfate) were not normal so nonparametric tests were used for the hypothesis testing. The Kruskal-Wallis test was used for hypothesis testing for homogeneity of variances (do the values belong in the same group or are they different). The method used the Levene test for homogeneity of variance.

6. Results: Significant findings

6A. Soil Physical-Chemical properties

The soils at all sites were described from collected cores by NRCS scientists. The soils belong to the Harney-Ulysses silt loam/silty clay loam series family and are described in detail in Appendix A. Textural and other analyses of the top 5.4 m of site R8 and the top 12.2 m of site N7 as determined at the NRCS Soil Survey Lab in Lincoln, Nebraska are shown in Table 1, and the corresponding analyses of the top 0.5 m of site Y8 as determined by the KSU Soil Testing Lab are shown in Table 2.

Concentrations of total carbon (Ctot) and carbonates ($CaCO_3$) are also shown in Tables 1 and 2 for all sites. Total carbon is the sum of organic and inorganic carbon. Most of the organic carbon is associated with the organic matter fraction and the inorganic carbon is generally found with carbonate minerals.

One of the most important interactions in soils is cation exchange, in which positively charged ions are attracted to the negatively charged surfaces of clays and organic matter where they are loosely held. These cations are a major source of plant nutrients. Tables 1 and 2 contain the CEC and/or SAR for the soils at R8, N7, and Y8 sites.

The soil bulk density down to 15.2 m (50 ft) was determined from collected cores of known diameter by cutting the core in 15.2-cm (6-in) increments, weighing them in the field, and then oven-drying them in the lab. The data were smoothed by taking the average of three 15-cm samples and displayed in figure 10 for sites R8 and N7.

Sites R8 and N7 have been planted with corn in April 2005 and harvested in September 2005. Site N7 has been in corn since 1998, whereas site R8 since 2003, although it has also been planted with corn in 1996.

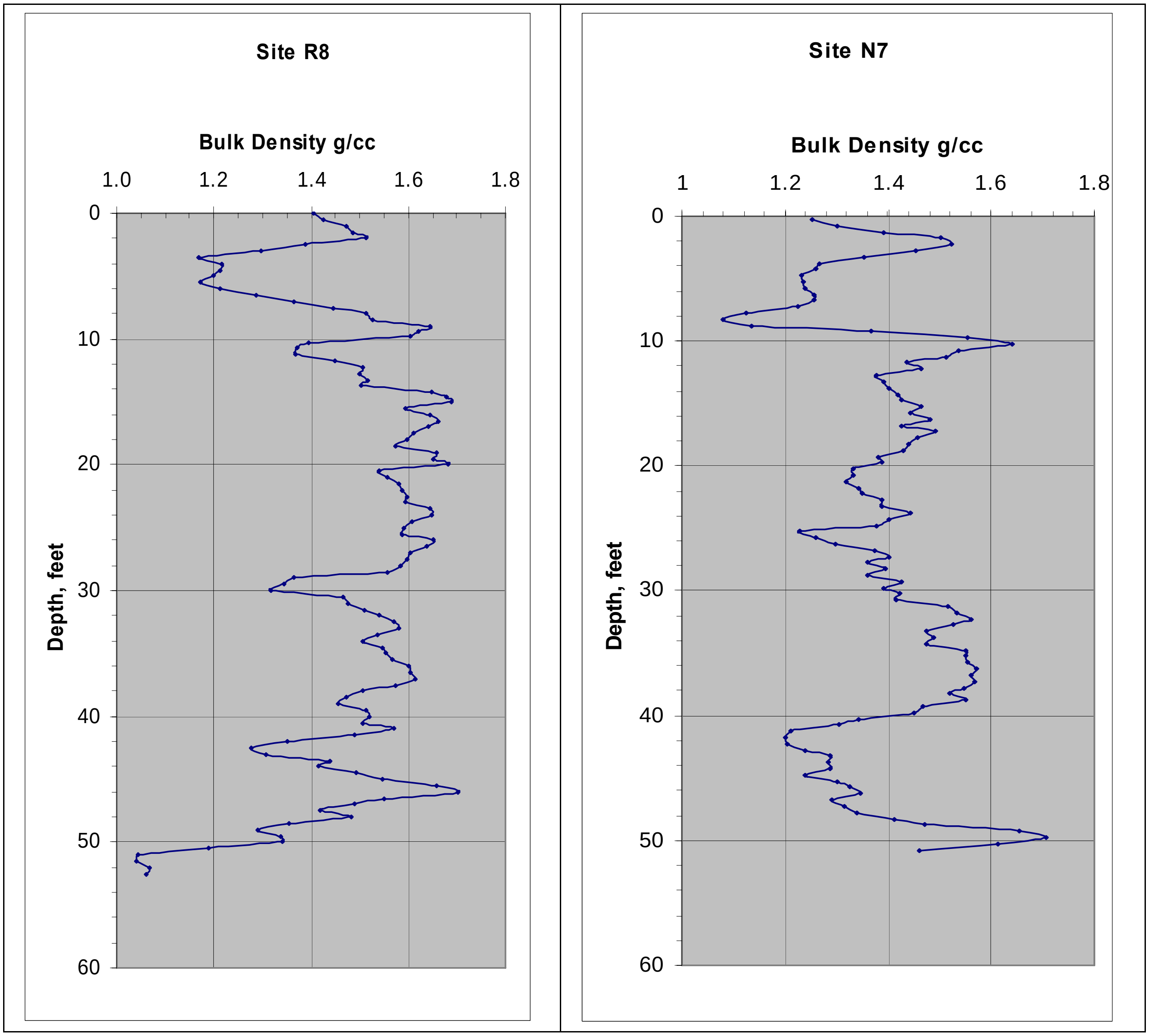

Figure 10. Soil bulk density profiles.

Table 1. Soil horizon textural and total Carbon (Ctot) and carbonate (CaCO3) analyses for sites R8 and N7 from NRCS

Site	layer_ seq	hzn_top (cm)	hzn_bot (cm)	hzn	texture	Clay (%)	Silt (%)	Sand (%)	Ctot (%)	CaCO3 (%)	CEC (cmol(+)/kg)	SAR (%)
R8	1	0	16	Ap	Silt loam	31.6	64.3	4.1	1.66	tr	23	2
R8	2	16	29	Bt1	Silty clay loam	30.5	65.9	3.6	1.03	tr	20.8	5
R8	3	29	50	Bt2	Silty clay loam	37.8	59.9	2.3	0.75	tr	25.6	6
R8	4	50	68	Bt3	Silty clay loam	43	55.3	1.7	0.56	tr	30.4	6
R8	5	68	90	Btk	Silty clay loam	38.7	59.2	2.1	0.66	2	27.5	6
R8	6	90	140	Btk2	Silty clay loam	34.3	62.7	3	1.06	6	23.8	6
R8	7	140	185	Btk3	Silty clay loam	33.3	61.5	5.2	0.63	3	22.6	6
R8	8	185	260	Btk4	Silty clay loam	34.6	50.2	15.2	2.45	19	16	4
R8	9	260	300	2Btk5	Silty clay loam	32.3	48.3	19.4		17	16.3	3
R8	10	300	410	2Btk6	Silty clay loam	28.9	49.4	21.7	1.28	11	16	3
R8	11	410	485	2Btk7	Silty clay loam	31.6	49.6	18.8	1.67	14	17.5	2
R8	12	485	540	2Bk	Silty clay loam	39.9	49.7	10.4	4.76	37	12.8	1
N7	1	0	13	Ap	Silt loam	24.2	68.3	7.5	1.53	tr	19.3	3
N7	2	13	23	A	Silt loam	27.4	68.9	3.7	1.06	tr	20.2	4
N7	3	23	43	Bt1	Silt loam	31.3	66	2.7	0.78	tr	21.5	5
N7	4	43	74	Bt2	Silty clay loam	39.1	58.2	2.7	0.53	tr	27.5	5
N7	5	74	91	Btk	Silty clay loam	38.4	59.9	1.7	0.71	3	27.4	4
N7	6	91	119	Bk1	Silty clay loam	32.9	64	3.1	1.31	9	22.8	3
N7	7	119	168	Bk2	Silt loam	31.8	63.2	5	0.62	3	22.4	1
N7	8	168	221	Bw	Loam	32.8	55.8	11.4	1.32	9	18.7	2
N7	9	221	295	BCk1	Silty clay loam	33.3	51.6	15.1	2.29	19	14.6	4
N7	10	295	363	BCk2	Silty clay loam				3.93	31	12	4
N7	11	363	399	Bkb1	Silty clay loam	32.9	59.2	7.9	2.83	23	14.3	4
N7	12	399	467	Bkb2	Silty clay loam	27.7	63.1	9.2	1.19	10	15.2	3
N7	13	467	508	C1	Loam				2.04	17	14.1	3
N7	14	508	625	C2	Silty clay loam	29.3	60.9	9.8	0.83	7	18.9	2
N7	15	625	762	C3	Silt loam	26.6	62.4	11	2.46	20	12.1	2
N7	16	762	848	C4	Silt loam	22.1	63.8	14.1	1.58	13	13.1	2
N7	17	848	889	C5	Silt loam				0.75	6	16.9	1
N7	18	889	945	C6	Loam	22	51.3	26.7	1.03	9	12.7	1
N7	19	945	1016	C7	Loam	21	40	39	1.14	10	10.6	1
N7	20	1016	1080	C8	Loam	27.2	43.1	29.7	0.88	7	15.7	1
N7	21	1080	1118	C9	Loam	26	35.9	38.1	2.42	20	10.6	1
N7	22	1118	1148	C10	Loam	23.4	44.4	32.2	0.62	5	13.5	
N7	23	1148	1219	C11	Loam	18	29	53	1.85	15	8.2	

Table 2. Soil horizon textural and total Carbon (Ctot) and carbonate (CaCO3) analyses for site Y8 from KSU.

Site	layer	depth from (cm)	depth to (cm)	clay (%)	silt (%)	sand (%)	Ctot (%)	CaCO3 (%)	CEC (meq/100g)
Y8	1	0	15.24	22	56	22	1.20	0.0	14.2
Y8	2	15.24	30.48	26	52	22	0.78	0.0	16.4
Y8	3	30.48	45.72	30	52	18	0.57	0.0	15.2
Y8	4	45.72	60.96	40	44	16	0.61	0.1	19.9
Y8	5	60.96	76.2	40	46	14	0.59	1.2	22.1
Y8	6	76.2	91.44	38	48	14	0.62	1.2	22.5
Y8	7	91.44	106.7	38	48	14	0.57	1.2	18.9
Y8	8	106.7	121.9	36	50	14	0.47	1.1	21.6
Y8	9	121.9	137.2	34	50	16	0.42	1.1	19.9
Y8	10	137.2	152.4	34	52	14	0.30	0.6	16.0
Y8	11	152.4	167.6	30	54	16	0.22	0.8	15.8
Y8	12	167.6	182.9	28	54	18	0.21	0.9	14.9
Y8	13	182.9	198.1	28	54	18	0.24	0.5	15.1
Y8	14	198.1	213.4	30	50	20	0.29	0.2	13.3
Y8	15	213.4	228.6	30	54	16	0.26	0.3	23.3
Y8	16	228.6	243.8	30	54	16	0.33	0.2	8.6
Y8	17	243.8	259.1	30	50	20	0.44	0.0	13.3
Y8	18	259.1	274.3	30	48	22	0.39	0.0	13.0
Y8	19	274.3	289.6	34	40	26	0.27	14.0	11.9
Y8	20	289.6	304.8	40	34	26	0.19	33.6	9.8

6B. Soil Hydraulic properties

6B.1 Saturated hydraulic conductivity: The saturated hydraulic conductivity was determined on collected 5.08-cm (2-in) core from sites R8 and N7 according to ASTM-D5084 Flexible wall permeameter test. The samples were classified according to the Unified Soil Classification System as fine-grained, medium to high plasticity lean clay and fat clay (CL and CH) soils. Table 3 shows the analysed core intervals, the soil Unified Classification, the measured bulk density, and the resulting saturated hydraulic conductivity.

Table 3. Saturated hydraulic conductivity from collected cores

Site	Depth (cm)	Unified Classification	Bulk Density (g/cc)	Hydraulic conductivity (cm/sec)
R8	0-16	CL	1.38	$1.4X10^{-6}$
R8	16-29	CL	1.42	$2.4X10^{-7}$
R8	29-50	CH	1.39	$4.3X10^{-7}$
R8	50-68	CH	1.49	$3.2X10^{-6}$
R8	68-90	CH	1.45	$1.4X10^{-4}$
R8	90-140	CL	---	$5.2X10^{-5}$
R8	410-485	CL	1.64	$4.2X10^{-6}$
N7	15-30	CL	1.19	$1.5X10^{-5}$
N7	30-61	CL	1.32	$2.0X10^{-5}$
N7	61-91	CH	1.26	$6.3X10^{-6}$
N7	91-122	CL	1.36	$6.8X10^{-4}$
N7	152-183	CL	1.36	$5.6X10^{-5}$
N7	183-213	CL	1.42	$4.5X10^{-6}$
N7	305-335	CL	1.52	$9.3X10^{-6}$
N7	457-488	CL	1.50	$5.2X10^{-4}$

6B.2 Retention curve data: The gravimetric water content data corresponding to seven applied pressures (0.06, 0.10, 0.33, 1, 2, 5, and 15 bar) for collected samples from sites R8 and N7 are presented in Table 4 from the NRCS Soil Survey Lab. Water retention at 0.06 to 5 bar were determined by pressure-plate extraction, whereas at 15 bar by pressure-membrane extraction.

Table 4. Water retention data (i.e., gravimetric water content {%} at different pressures {bar}) for sites R8 and N7 from NRCS lab analyses

Site	hzn_top (cm)	hzn_bot (cm)	hzn	texture	0.06 bar (%)	0.10 bar (%)	0.33 bar (%)	1 bar (%)	2 bar (%)	5 bar (%)	15 bar (%)
R8	0	16	Ap	Silt loam	47.3	43.3	35.4	23.4	18.6	16.9	15
R8	16	29	Bt1	Silty clay loam	45.3	41.9	35.3	23.4	17.9	16.3	14.2
R8	29	50	Bt2	Silty clay loam	48	43.8	38	27.5	22.4	20.3	17.8
R8	50	68	Bt3	Silty clay loam	49.8	45.1	39.5	31.1	25.9	23.8	20.1
R8	68	90	Btk	Silty clay loam	47.9	43.4	38.2	29.5	24.3	23.3	21.7
R8	90	140	Btk2	Silty clay loam	48.8	43.4	36.6	26.7	23	20.7	16.7
R8	140	185	Btk3	Silty clay loam	47	42.1	36.9	26.4	22.5	20	14.9
R8	185	260	Btk4	Silty clay loam	40.2	35.8	29.9	22.2	19.2	17.4	13.1
R8	260	300	2Btk5	Silty clay loam	36.3	34	28	21	18.2	16.8	12.6
R8	300	410	2Btk6	Silty clay loam	36.5	34	27.3	20.3	17.3	16.2	11.9
R8	410	485	2Btk7	Silty clay loam	36.5	33.7	29.2	22	19.2	17.7	12.8
R8	485	540	2Bk	Silty clay loam	35.3	30.6	26.6	20.6	19.4	17.7	12.7
N7	0	13	Ap	Silt loam				20.4	17.6	15.1	13
N7	13	23	A	Silt loam				20.6	18.3	15.8	13.1
N7	23	43	Bt1	Silt loam				22.7	20.2	18.3	15.1
N7	43	74	Bt2	Silty clay loam				28.4	25.5	23.6	18.7
N7	74	91	Btk	Silty clay loam				28.1	25.4	23.5	18.2
N7	91	119	Bk1	Silty clay loam				25.9	22.7	20.2	15.6
N7	119	168	Bk2	Silt loam				24.1	21	18.5	14.7
N7	168	221	Bw	Loam				21.4	19.1	16.9	14.1
N7	221	295	BCk1	Silty clay loam				18.8	16.6	15.3	12.1
N7	295	363	BCk2	Silty clay loam				20.8	18.2	16.5	12.2
N7	363	399	Bkb1	Silty clay loam				20.7	19	16.3	12.3
N7	399	467	Bkb2	Silty clay loam				21.2	16.4	14.8	11.3
N7	467	508	C1	Loam				20.8	16.7	15	11.3
N7	508	625	C2	Silty clay loam				22.7	17.7	15.9	12.5
N7	625	762	C3	Silt loam				21.3	16.7	14.7	11.2
N7	762	848	C4	Silt loam				18.4	14.4	12.7	10.2
N7	848	889	C5	Silt loam				22.3	17.4	15.6	12.6
N7	889	945	C6	Loam				17.3	13.7	12.3	9.6
N7	945	1016	C7	Loam				15.6	12.4	10.9	8.7
N7	1016	1080	C8	Loam				20.7	16.8	14.8	11.6
N7	1080	1118	C9	Loam				16.5	13.6	11.9	9.6
N7	1118	1148	C10	Loam				17.6	13.8	12.4	10.2
N7	1148	1219	C11	Loam				12.6	9.8	8.8	6.9
N7 core	0	30					22.6				
N7 core	30	61					23.3				
N7 core	61	91					25.4				
N7 core	91	122					27.3				
N7 core	122	152					28.3				
N7 core	152	183					27.1				
N7 core	183	213					23.9				
N7 core	305	335					20.7				
N7 core	457	488					22.8				
N7 core	609	640					23.4				

N7 core	914	945	24.8

6B.3 Water retention parameters

The RETC-estimated Brooks and Corey (BC) parameters (α and λ) and the ROSETTA-estimated Van Genuchten parameters (α and n) and Ks values for the samples displayed in Table 1 are shown in Table 5. For the RETC program, we input as θ_r the estimates predicted by ROSETTA, and as θ_s the porosity values calculated by the equation

$$\varphi = 1 - (\rho_b / \rho_s) \quad (5)$$

where φ is the soil porosity (equal to θ_s), ρ_b is the soil bulk density (taken from Fig. 5), and ρ_s is the particle density, taken as that for quartz (2.65 g/cc). We then used the RETC parameter estimation program to optimize for θ_s, α, and λ (for the BC parameters) keeping the θ_r values fixed as estimated from ROSETTA.

Please note that because some of the NRCS lab-determined moisture values corresponding to various pressures for site R8 were higher than the values of porosity determined by eq. (4) above, the lab-determined moisture values corresponding to the various pressures were scaled as follows:

$$\theta_i = (\theta_i / \theta_{i-1}) * \theta_{i-1} \quad (6)$$

where the subscript i (taking the successive values of 0.10, 0.33, 1, 2, and 15 bar) refers to the applied pressure for the corresponding moisture, and the moisture content corresponding to the initially applied pressure of 0.06 bar was taken as equal to θ_s.

Table 5. Brooks & Corey- and Rosetta-estimated Van Genuchten hydraulic parameters for soil samples from sites R8 and N7.

					RETC: Brooks and Corey				ROSETTA				
Site	hzn_top (cm)	hzn_bot (cm)	hzn	texture	Theta-R (-)	Theta-S (-)	alpha (1/cm)	lamda (-)	Theta-R (-)	Theta-S (-)	alpha (1/cm)	n (-)	Ks (cm/day)
R8	0	16	Ap	Silt loam	0.0692	0.4463	0.0105	0.3329	0.0692	0.4461	0.0034	1.6051	10.7523
R8	16	29	Bt1	Silty clay loam	0.0660	0.4216	0.0056	0.4423	0.066	0.4396	0.0033	1.6338	10.9245
R8	29	50	Bt2	Silty clay loam	0.0850	0.4928	0.0064	0.3384	0.085	0.4667	0.0019	1.6726	3.6787
R8	50	68	Bt3	Silty clay loam	0.0866	0.5182	0.0112	0.2258	0.0866	0.4745	0.0017	1.6092	2.1370
R8	68	90	Btk	Silty clay loam	0.0874	0.5002	0.0119	0.2159	0.0874	0.4897	0.0041	1.4041	6.7174
R8	90	140	Btk2	Silty clay loam	0.0650	0.4280	0.0148	0.2710	0.065	0.4746	0.0080	1.4474	20.4033
R8	140	185	Btk3	Silty clay loam	0.0648	0.4343	0.0133	0.2742	0.0648	0.4821	0.0050	1.5563	25.4097
R8	185	260	Btk4	Silty clay loam	0.0538	0.4049	0.0190	0.2607	0.0538	0.4007	0.0067	1.4415	7.7678
R8	260	300	2Btk5	Silty clay loam	0.0530	0.3806	0.0076	0.2966	0.053	0.3814	0.0049	1.4511	3.7034
R8	300	410	2Btk6	Silty clay loam	0.0565	0.4231	0.0091	0.3152	0.0565	0.4061	0.0046	1.5028	7.1236
R8	410	485	2Btk7	Silty clay loam	0.0592	0.4380	0.0153	0.2453	0.0592	0.3986	0.0031	1.5499	3.1391
R8	485	540	2Bk	Silty clay loam	0.0852	0.5897	0.0220	0.1764	0.0852	0.4074	0.0109	1.3772	2.6577
N7	0	13	Ap	Silt loam	0.069	0.4721	0.0448	0.212	0.069	0.4554	0.0239	1.3234	36.6775
N7	13	23	A	Silt loam	0.0714	0.4611	0.0313	0.196	0.0714	0.4547	0.0221	1.3195	26.5033
N7	23	43	Bt1	Silt loam	0.0865	0.4040	0.0994	0.1722	0.0865	0.4511	0.0231	1.2560	15.8234
N7	43	74	Bt2	Silty clay loam	0.0861	0.5541	0.0147	0.2033	0.0861	0.4485	0.0224	1.1639	2.9499
N7	74	91	Btk	Silty clay loam	0.081	0.459	0.0340	0.156	0.081	0.4675	0.0048	1.3687	4.5457
N7	91	119	Bk1	Silty clay loam	0.081	0.4990	0.0396	0.192	0.0817	0.4808	0.0110	1.3354	21.2129
N7	119	168	Bk2	Silt loam	0.0817	0.4987	0.008	0.217	0.0763	0.4845	0.0083	1.4028	26.5583
N7	168	221	Bw	Loam	0.0763	0.4471	0.0088	0.211	0.0808	0.4722	0.0245	1.3107	23.5885
N7	221	295	BCk1	Silty clay loam	0.0808	0.5078	0.0236	0.266	0.0832	0.4227	0.0088	1.4788	5.4375
N7	295	363	BCk2	Silty clay loam	0.0832	0.5282	0.0346	0.24					
N7	363	399	Bkb1	Silty clay loam	0.0787	0.4632	0.0156	0.202	0.0787	0.4366	0.0253	1.2939	14.3814
N7	399	467	Bkb2	Silty clay loam	0.0664	0.4483	0.0087	0.236	0.0664	0.4306	0.0073	1.3890	12.5112
N7	467	508	C1	Loam									
N7	508	625	C2	Silty clay loam	0.0548	0.3952	0.0375	0.2282	0.0548	0.3952	0.0243	1.3323	12.2096
N7	625	762	C3	Silt loam	0.0817	0.4576	0.0064	0.5641	0.0817	0.4576	0.0063	1.5926	17.1159
N7	762	848	C4	Silt loam	0.0740	0.4313	0.0056	0.6383	0.0740	0.4313	0.0056	1.6383	16.7186
N7	848	889	C5	Silt loam									
N7	889	945	C6	Loam	0.0563	0.4143	0.0249	0.3344	0.0563	0.4143	0.0249	1.3344	24.6093
N7	945	1016	C7	Loam	0.0617	0.3879	0.0102	0.4980	0.0617	0.3879	0.0102	1.4980	9.1432
N7	1016	1080	C8	Loam	0.0705	0.3878	0.0098	0.4635	0.0705	0.3878	0.0098	1.4635	4.9034
N7	1080	1118	C9	Loam	0.0662	0.3805	0.0126	0.4077	0.0662	0.3805	0.0126	1.4077	4.9682
N7	1118	1148	C10	Loam	0.0644	0.3775	0.0093	0.4880	0.0644	0.3775	0.0093	1.4880	5.8573
N7	1148	1219	C11	Loam	0.0563	0.3977	0.0166	0.4441	0.0563	0.3977	0.0166	1.4441	20.8353

6C. Soil moisture profiles

Neutron probe readings were taken twice a month during the irrigation season. Figure 11 shows neutron moisture content profiles down to 50 ft at various times during 2005 for both sites. As can be clearly seen, most of the change in soil moisture occurs in the upper 8 ft or so.

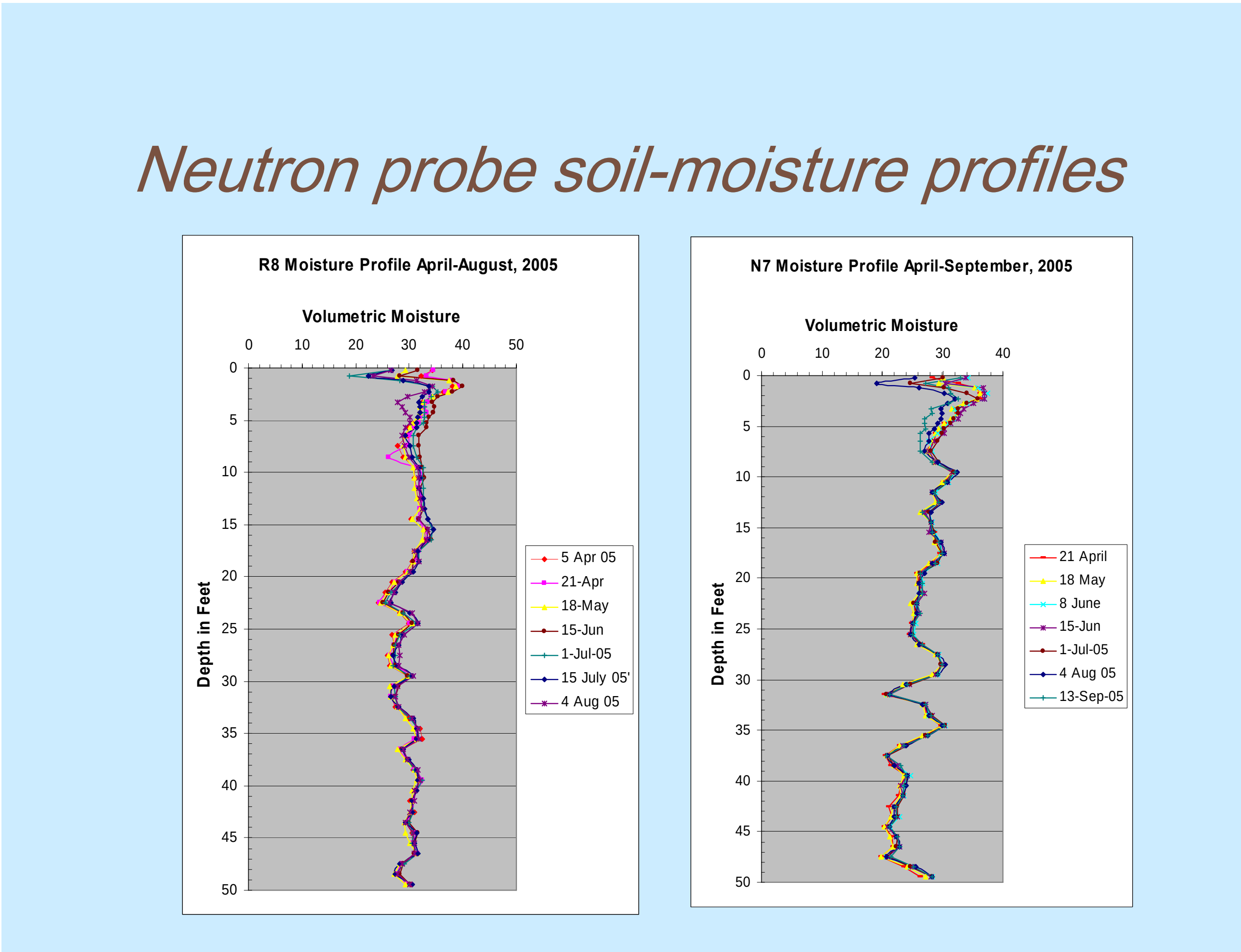

Figure 11. Soil moisture profiles at various times during 2005 measured with the neutron probe.

6D. Dye-tracer experiment results

Following a number of weather-related delays, the dye-tracer experiments were finally conducted in November 2005. By the late morning of November 8, 2005 we initially applied approximately 90 gal of dye solution in each test site. By the late afternoon all that applied solution had infiltrated into the soil, and the 3'X5' wooden enclosures were again filled in with dye tracer solution. The wooden frame enclosures were covered with a reflective insulating sheet and left to seep in overnight. By the next morning of November 9, 2005 nearly all the applied dye solution infiltrated in, and the remaining dye solution in the tank was applied to each site, totaling approximately 200 gallons per site. On the next morning of November 10, 2005, a back-hoe was brought first to site R8 and then to site N7, where approximately 8-ft deep trenches along the diagonal of the flooded rectangular area were dug, and the dye-tracer patterns along the trench wall were observed, studied, and photographed. The trenches were covered with tarp and fenced until completion of our dye-patterns study.

For the site R8 in Harney soil, the dye solution penetrated down to approximately 6.5 ft and formed a more-or-less uniform "finger front" at the bottom as shown in figure 12. Figure 13 shows a closer-up view of the dye tracer movement through the blocky-structure soil layers of the Bt horizons (at approximately the 1.6 to 3.2-ft depth interval) where the tracer dye moved along the spaces in-between the blocky soil aggregates and concentrated in numerous fingers in the lower soil layer that did not exhibit the heavy blocky structure of the Bt horizons above. Figure 14 shows a closer-up view of the fingers in the lower 3.2 to 6.0-ft layer, where the dye solution under tension tries to by-pass coarser-texture lenses, as shown by the arrow in the figure.

Figure 12. Uniform finger front from Brilliant Blue dye tracer experiment at site R8.

The dye solution in the heavier, blocky-structure soil layer (0.5-1 m) moves along the spaces in-between the blocky soil aggregates …

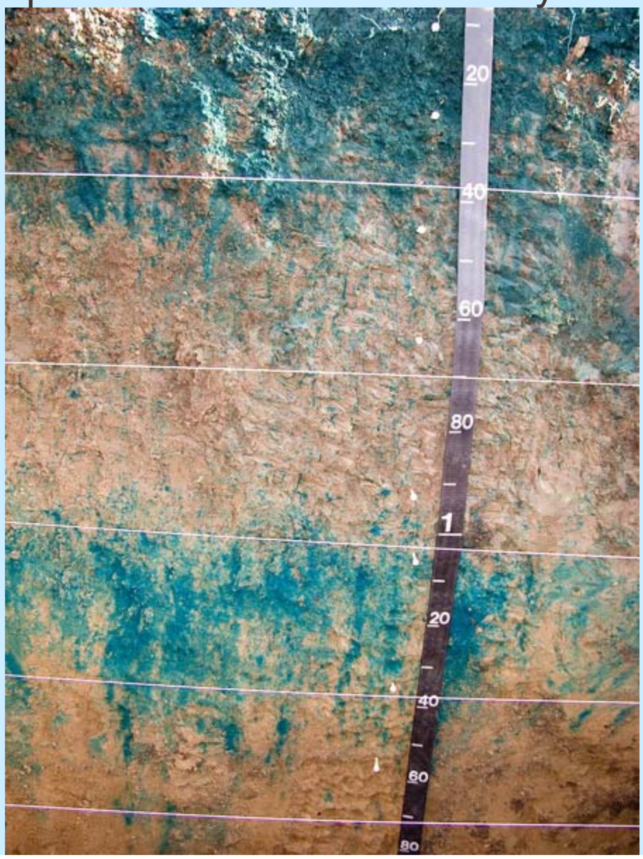

Figure 13. Brilliant Blue dye pattern detail at site R8 showing the movement of the dye through the inter soil block structure spaces of the Bt horizon and accumulating below that blocky layer into numerous fingers.

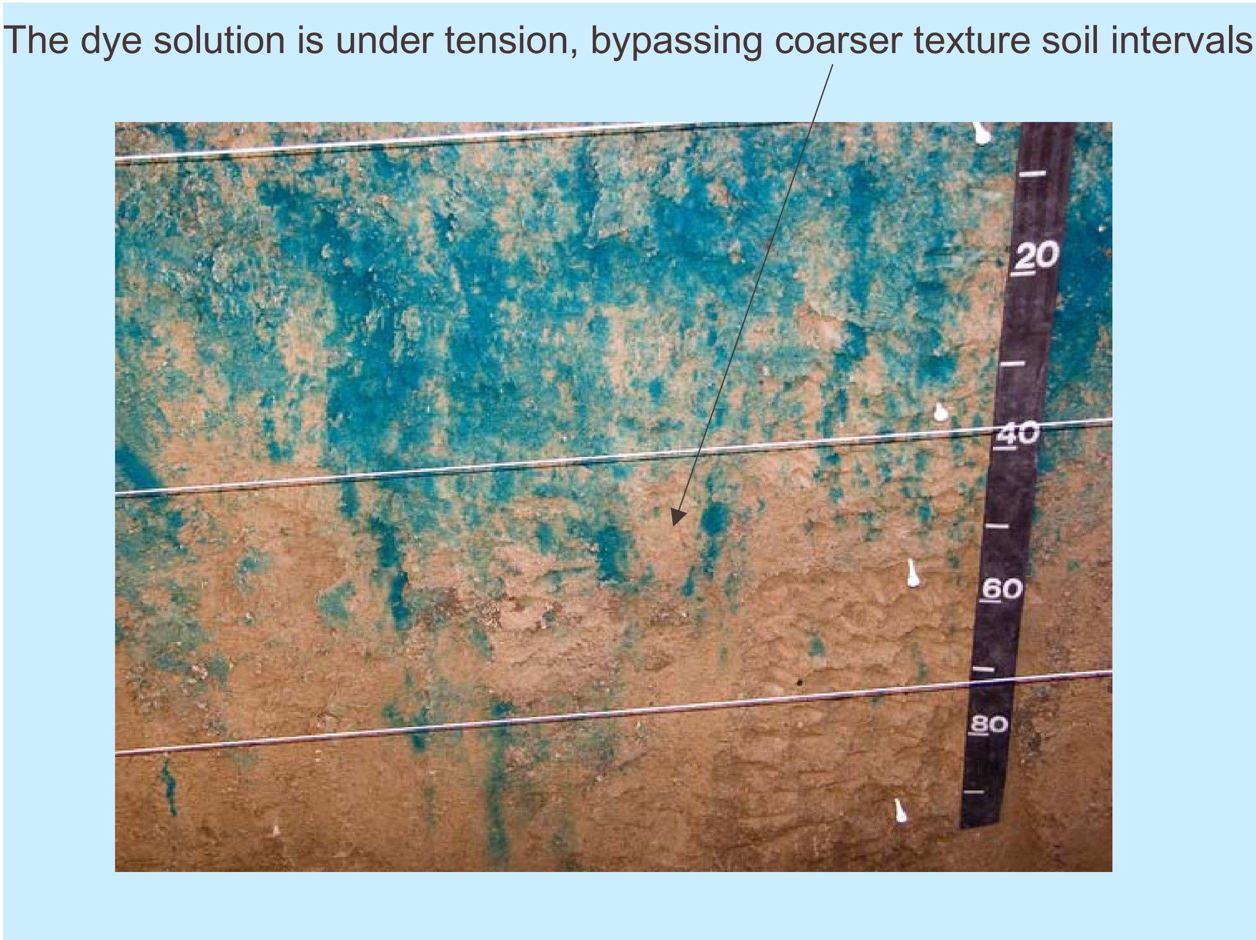

Figure 14. Site R8 Brilliant Blue dye pattern detail showing that the dye, being under tension, bypasses coarser textured soil.

For site N7 in Ulysses soil, the dye pattern was different, forming a giant funnel front ending in a big finger down to approximately 6.6 ft, as shown in figure 15. Closer examination of a side finger, indicated in figure 16, showed that the dye finger formed along a decaying root channel, as did other fingers examined in both sites.

Figure 15. Funnel front pattern from Brilliant Blue dye tracer experiment at site N7.

Figure 16. Closer up view of the funnel-front dye pattern and side finger formed along a decaying root channel.

6E. Soil nitrate, chloride, and electrical conductivity profiles

The nitrate, chloride, and electrical conductivity of collected soil cores were analyzed in 15.2-cm (6-in) increments down to 50 ft at the Servi-Tech Inc. laboratories in Dodge City, Kansas. For site R8 (with a long-term wastewater irrigation history—since 1986) we see (Fig. 17) a high nitrate peak of about 40 mg/kg around 2 ft, which decreases sharply in the depth interval of 10 to 20 ft, possibly due to alfalfa roots consuming the nitrate at those depths, as the R8 site was under alfalfa cultivation from 1997 to 2002. The nitrate picks up again reaching a secondary maximum near the depth of 30 ft, then following a decrease near that level, it progressively increases with depth down to more than 50 ft. It seems that a previous nitrate front has reached down to 30 ft, with yet older fronts making it down deeper, indicating that nitrate may had already penetrated down to those depths. The chloride and EC profiles show a peak around the depth of 10 to 12 ft, and follow a near-constant low profile below 20 ft.

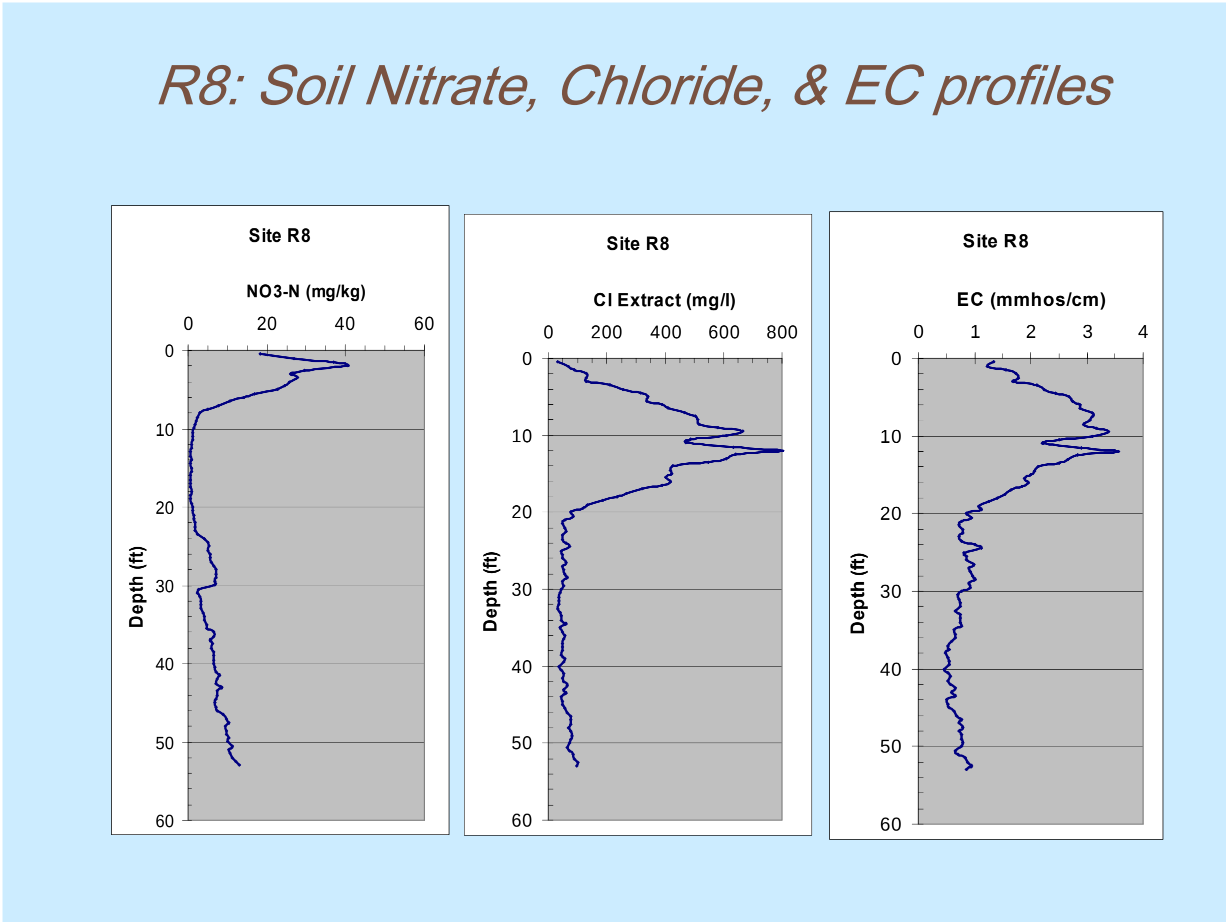

Figure 17. Soil nitrate, chloride, and electrical conductivity (EC) profiles at site R8.

For site N7 (with wastewater irrigation history since 1998) we see (Fig. 18) a deeper nitrate peak (of less than 28 mg/kg, i.e., not as high as that at site R8) around 7 to 8 ft, which coincides with corresponding Chloride and EC peaks at that level. Then, the nitrate distribution progressively decreases to a minimal, background level by the time we reach to near 30 ft, indicating that nitrate penetrated down to near 30 ft but no further. A second chloride and EC peak occurs just above that 30-ft level.

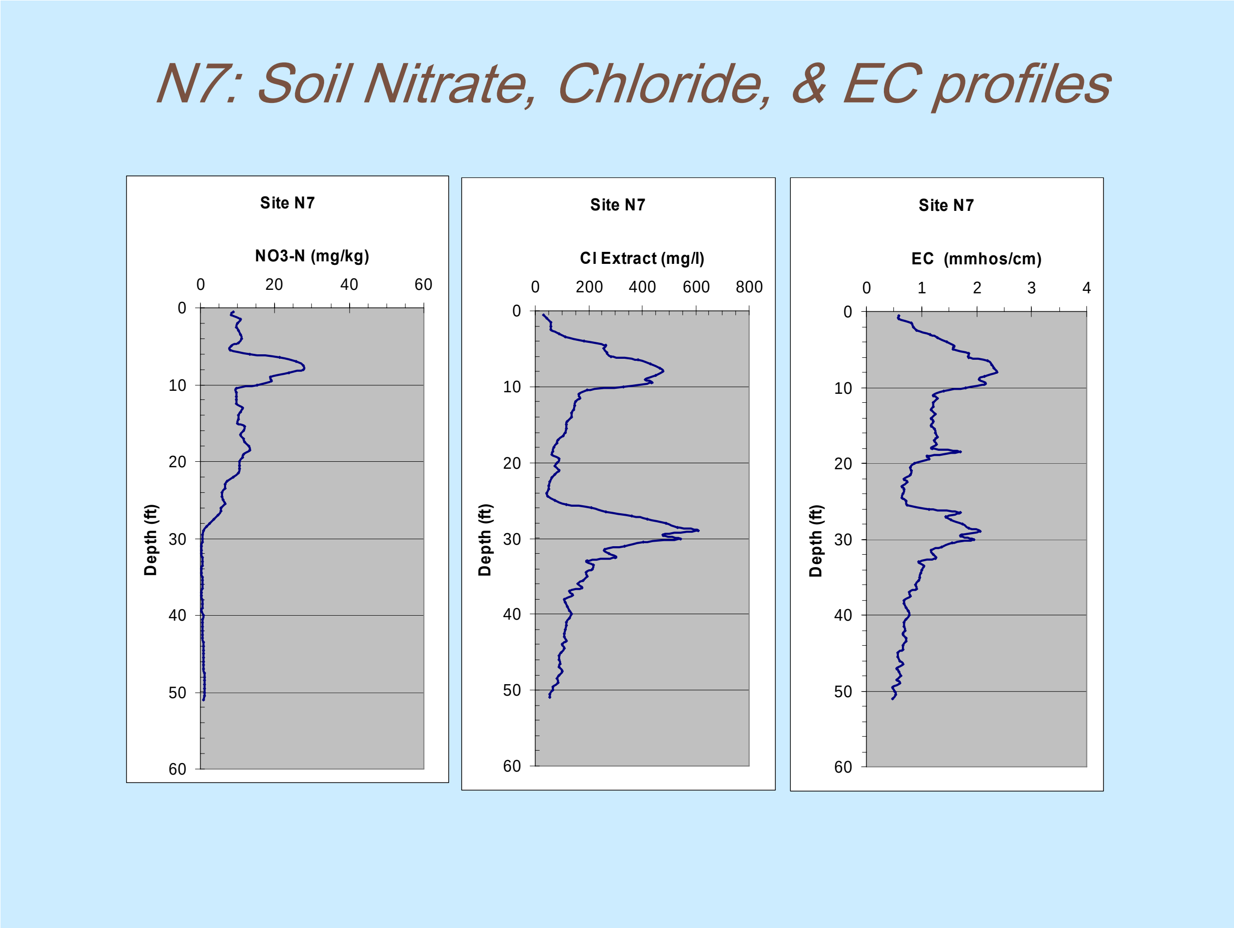

Figure 18. Soil nitrate, chloride, and electrical conductivity (EC) profiles at site N7.

Finally, for site Y8 (without any wastewater irrigation), we see (Fig. 19) a high chloride peak around the 3-ft level, but by the time we reached the 18-ft depth level, nitrate goes back to minimal, background level. However, the Chloride and EC profiles reach a peak around that depth level. Site Y8 was planted with milo during 2005.

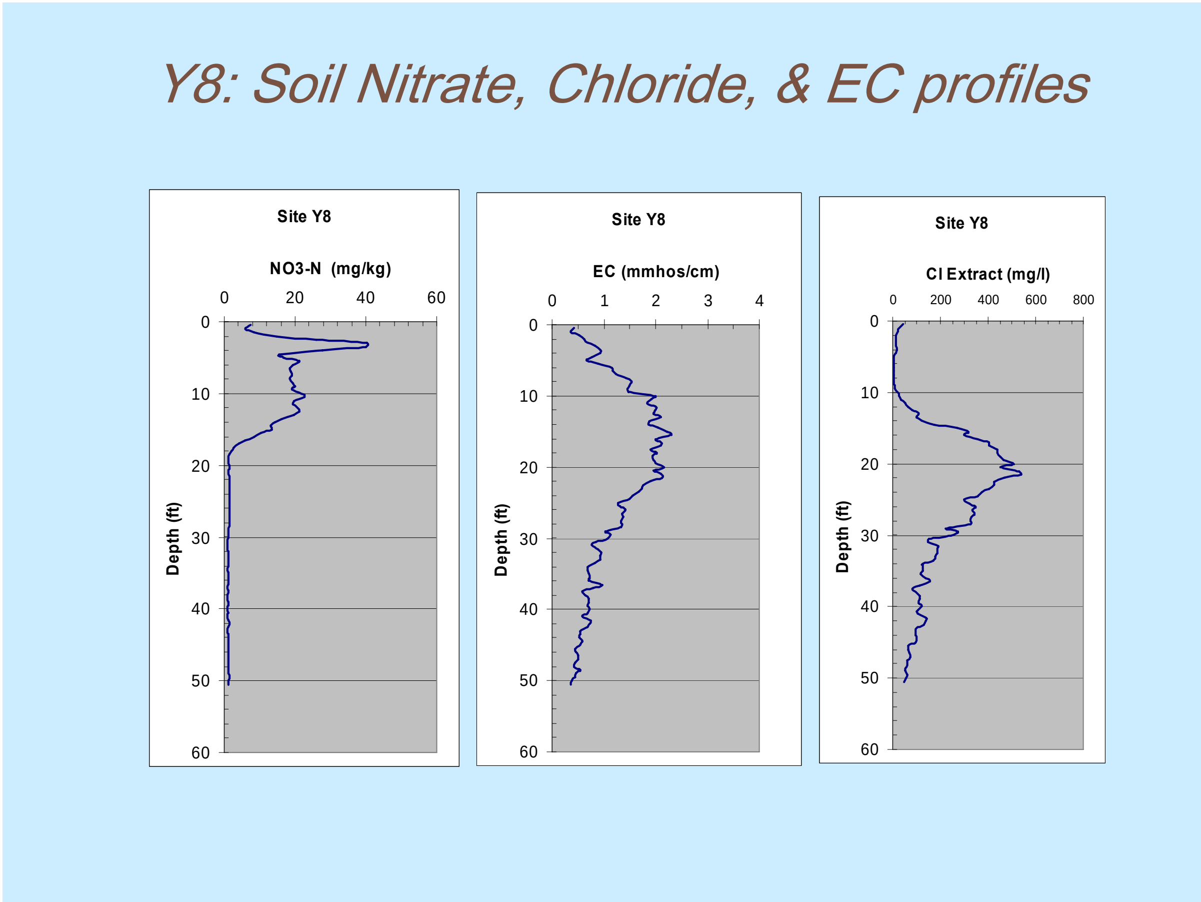

Figure 19. Soil nitrate, chloride, and electrical conductivity (EC) profiles at site Y8.

6F. Water quality

The sites were periodically irrigated from mid-May until the latter part of August 2005. The general quality of the treated wastewater effluent applied at the sites during 2005 is shown in figure 20. The chloride concentrations (in green) were around the 300 mg/L level, and the total Kjeldahl nitrogen concentrations (TKN, in blue) were around the 75 mg/L level.

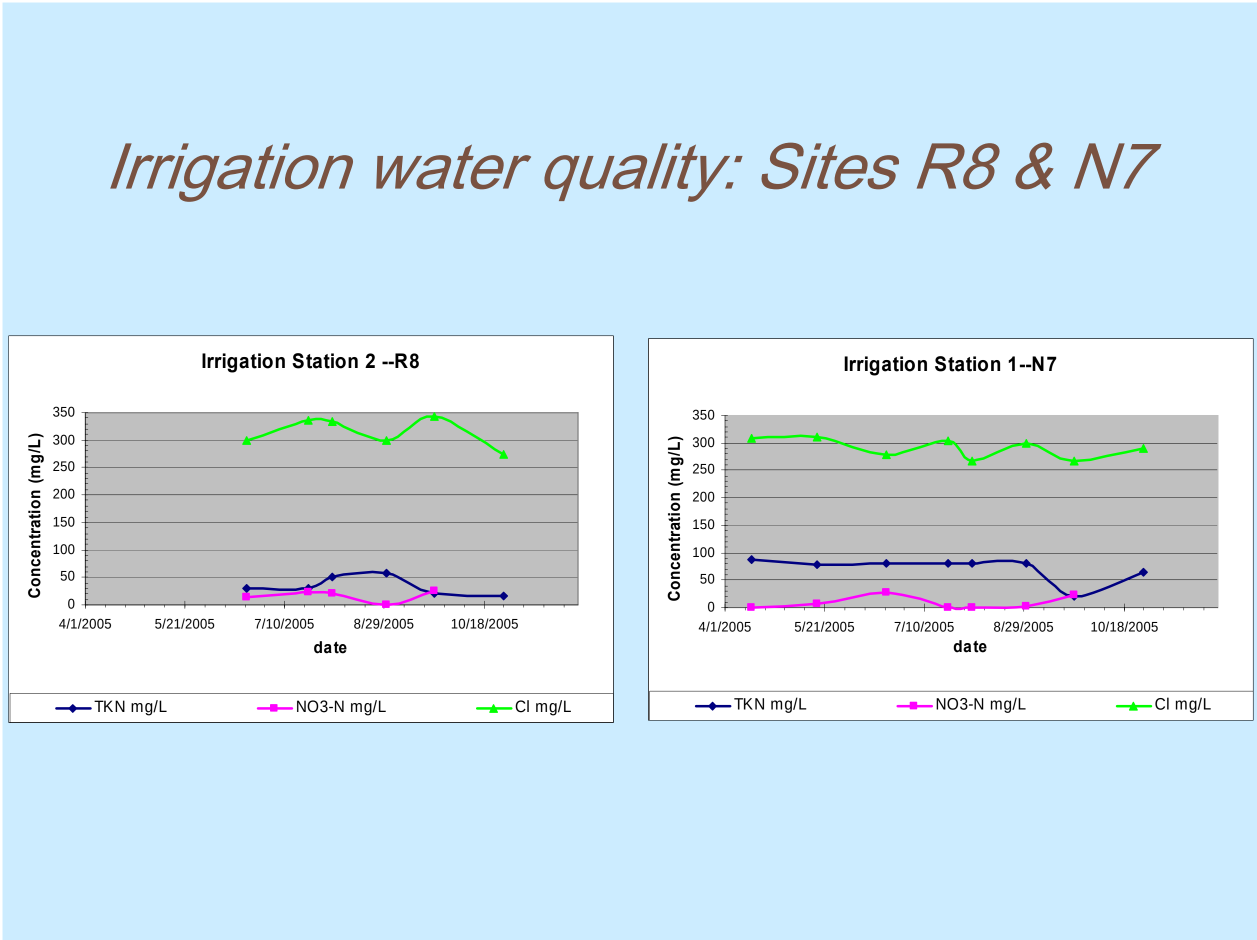

Figure 20. Treated effluent irrigation water chloride, total Kjeldahl nitrogen, and nitrate-nitrogen concentration time series applied to sites R8 and N7 during 2005.

Figure 21 shows the groundwater nitrate-N concentrations from the November, 2005 survey sampling, where wells shown in red color exceed the safe drinking water limit for nitrate-N of 10 mg/L. Notice that most of the wells have more than 2 mg/L nitrate-N in the groundwater. This indicates that anthropogenic sources have begun to impact the groundwater in the area. The 2 mg/L level is from work by the USGS on the National Water Quality Assessment program (Mueller and Helsel, 1996). Evaluation of the water chemistry in the appendices shows that the majority of the nitrogen in the lagoon wastewater used for irrigation is in the ammonium-N. The lysimeters show exceedingly high nitrate-N values and the monitoring and domestic wells have nitrate-N values generally above 2 mg/L. The change from the ammonium form in the wastewater to nitrate in the soil water is related to oxidation during the water treatment process and also to nitrification of the ammonium to nitrate by bacteria when the wastewater is applied. Nitrogen that is not utilized by the plants is available for leaching and moving to the groundwater.

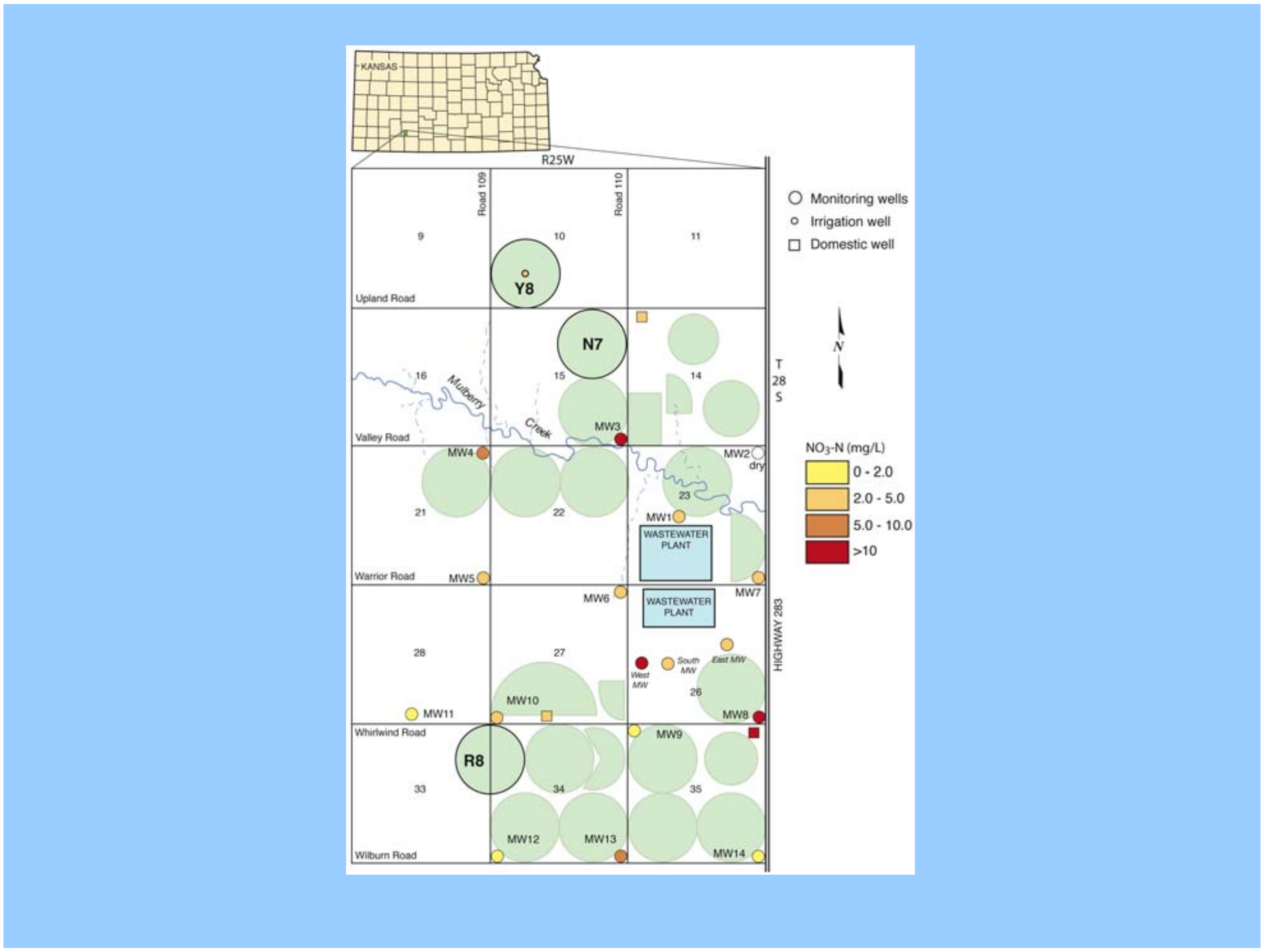

Figure 21. Groundwater nitrate-nitrogen concentrations during November 2005.

Comparison of the nitrate-N values in lysimeter water samples (Tables 6 and 7) with soil core samples shows that although there is a large amount of nitrogen stored in the soil profile, an even larger amount is moving with the soil water that is available during certain time periods most likely related to rainfall and irrigation events. Chemically the lysimeter samples show higher concentrations of constituents (such as chloride or indicated by specific conductance values, Tables 6 and 7) than either the wastewater used for irrigation or the sampled ground water (Appendices B-D). Most likely this is related to evapoconcentration of applied constituents during the growing season and possible dissolution of stored salts in the soil profile. The EC and chloride profiles in the soils indicate that high salt profiles exist throughout the unsaturated zone and this is reflected in the shallow and medium lysimeter chemistries (Tables 6 and 7).

Table 6. Site R8 comparison of soil core and lysimeter samples for nitrate-N chloride and specific conductance (SPCD). Core nitrate-N samples converted from mg/kg using bulk density and moisture measurements.

Site R8	Depth (ft)	Nitrate-N (mg/L)	Chloride (mg/L)	SPCD µS/cm
Lysimeter	5.5	148.0	793	6030
Soil Core	5.5	72.8	336	2740
Lysimeter	26.5	55.9	250	2970
Soil Core	26.5	24.2	61	980

Table 7. Site N7 comparison of soil core and lysimeter samples for nitrate-N chloride and specific conductance (SPCD). Core nitrate-N samples converted from mg/kg using bulk density and moisture measurements.

Site N7	Depth (ft)	Nitrate-N mg/L	Chloride (mg/L)	SPCD µS/cm
Soil Core	17	54.7	85	1240
Soil Core	18	60.8	82	1270
Lysimeter	17.5	117	376.7	3142

Water can be classified based on the quantity of dissolved constituents present in solution. The wastewater used for irrigation is classified generally a sodium-calcium-bicarbonate-nitrate-chloride water as compared to the water at Y8 which is a calcium-bicarbonate water (Fig. 22). The water type for the lysimeters are generally sodium-calcium-nitrate-chloride-sulfate waters. The variations in the "water-types" is indicative of the different water sources and processing that has affected the chemistry of the water. Analyses for the monitoring, domestic, and irrigation wells sampled during the study as well as for the wastewater and lysimeter samples are presented in Appendices B-D.

Figure 22 displays a trilinear diagram showing the average water quality of the irrigation water applied in both R8 and N7 sites marked as the A circle, the shallow and intermediate-depth suction lysimeter-sampled pore water from both sites marked as the B circle, and all sampled domestic, monitoring, and irrigation wells in the area left unmarked. All three sampled populations of applied wastewater, pore water from suction lysimeters, and monitoring and domestic wells form distinct groups in the trilinear diagram. The Dodge City municipal water sample from well #16 is also shown for comparison. This sample is the average of samples collected from 1990-2000 by the Kansas Department of Health and Environment (KDHE) for their annual water quality survey. The sample falls in the range of the low nitrate-N, low chloride monitoring well samples that have not been impacted by wastewater irrigation at this time.

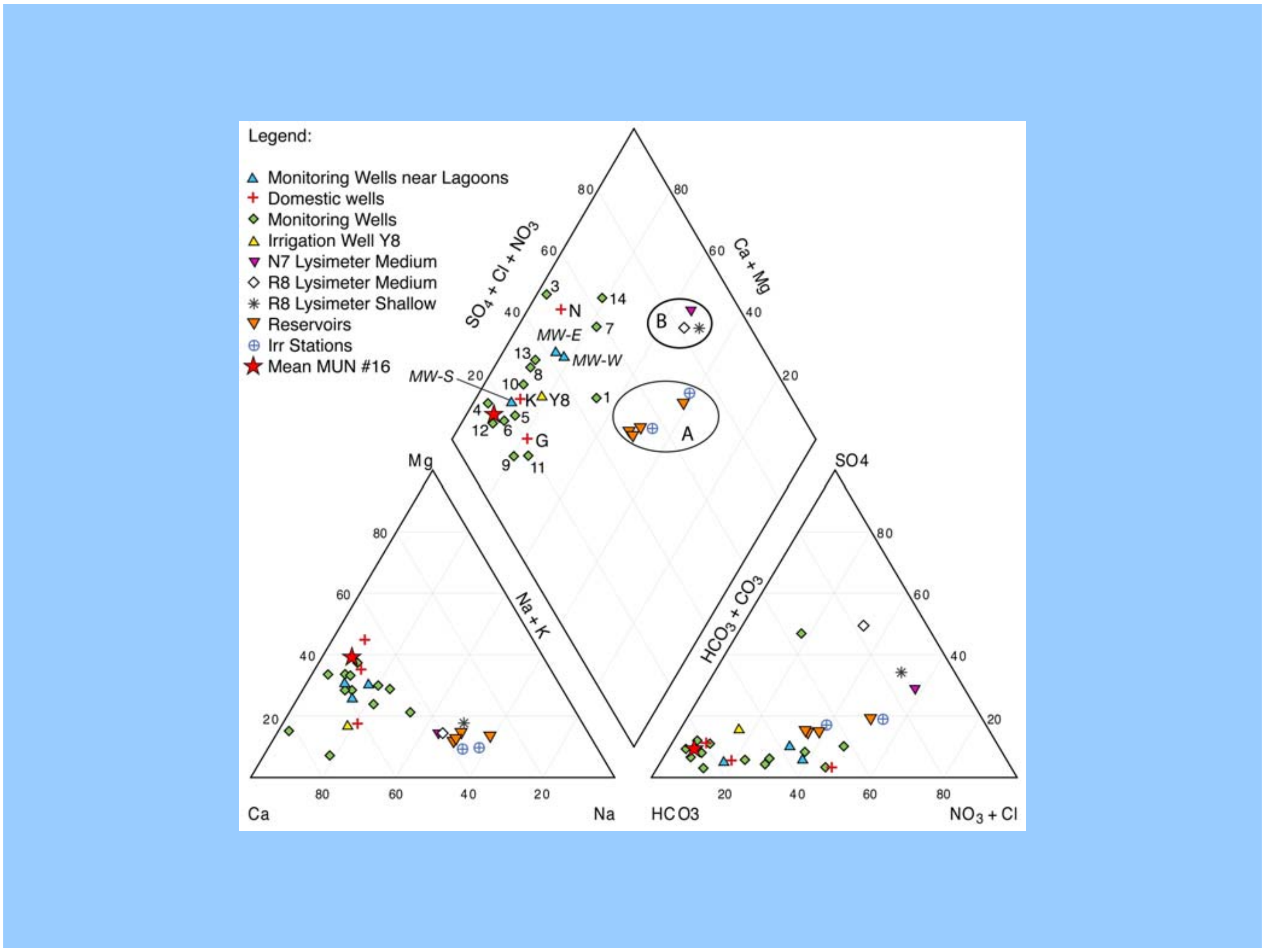

Figure 22. Trilinear diagram showing the average 2005 water quality of irrigation water applied in sites R8 and N7 (circle A), the shallow and intermediate-depth suction lysimeter- sampled pore water from sites R8 and N7 (circle B), and all sampled domestic, monitoring, and irrigation wells in the area. Included in the graph is the mean city water analysis (star) for well #16 which was used in the annual water quality survey conducted by KDHE (1990-2000).

The ground-water samples, wastewater reservoirs, and lysimeter water are statistically different based on the Kruskal-Wallis non-parametric test for group differences of nitrate-N and conductivity (Tables 8 and 9). Samples were divided into groups based on water source. The Kruskal-Wallis test is a hypothesis test that at least one of the groups is different from the others. Examination of the statistical results indicates that the groups are different for both the nitrate-N and specific conductance values.

Table 8. Kruskal-Wallis test of nitrate-N differences based on water-source within the study area.

Nitrate-N by water source mg/L	Number of Samples	Median Value Nitrate-N	Kruskal-Wallis *p* value
Reservoir	6	3.15	2.79×10^{-7}
Groundwater	21	3.5	
Lysimeters	3	117.0	

Table 9. Kruskal-Wallis test of specific conductance (SPCD) differences based on water-source within the study area.

SPCD μS/cm by well type	Number of Samples	Median Value SPCD	Kruskal-Wallis *p* value
Reservoir	6	2334	1.43×10^{-7}
Groundwater	21	484	
Lysimeters	3	3142	

6G. Land use/farming practices

Site R8 has been under treated wastewater irrigation since 1996, site N7 since 1998, and site Y8 was never irrigated with treated wastewater. The land use/cropping practices at the field sites were clarified by the farmer Mr. Chuck Nickolson who manages the farms. Sites R8 and N7 were planted in corn on April 22 and 23, 2005 and harvested in September 28 and 29, 2005, whereas site Y8 was planted in milo. The farmer planted 32,500 seeds of corn per acre in sites R8 and N7 in 30-inch ridge centers.

The land use practices followed at the sites are as follows: On the first week of April, 2005 the sites were sprayed with herbicides Roundup and 2-4D for weed control. A second spraying took place two weeks later. During the third week of June, 2005 the farmer created ridges in the field of approximately 6-inch height using appropriate tractor equipment. On the third and fourth week in June, 2005 the farmer applied 1.5 pounds active ingredient of the herbicide Atrazine per acre. Following harvesting, the farmer did stock chopping in November and December.

The LEPA irrigation sprinkler system (with drop nozzles) makes 2.5 circles per week to irrigate, and applies 0.75 inches of water per circle. The center pivots are equipped with water meters. The schedule of irrigation at the sites was obtained from Mr. Nickolson and the water meter was read each time neutron probe soil profile readings were made. He noted that the sprinkler irrigation system was running non-stop from July 21 to August 22, 2005 for both sites, except that it was shut off on August 2nd and restarted on August 3rd, 2005.

The history of cultivation of sites R8 and N7 is as follows: Site R8 was planted in corn from 2003 to the present. From 1997 to 2002 it was planted in alfalfa. From 1996 to 1997 it was planted in wheat, and in 1996 it was planted in corn. In contrast, site N7 was planted in corn from 1998 to the present. Prior to 1998, N7 was under a dryland wheat-fallow-wheat rotation.

All the information we collected from core analyses, neutron probe readings, dye tracer experiments, plus meteorologic information, and information on crop, irrigation, and other land use practices, is now being used in the RZWQM model to evaluate the environmental impacts of this treated wastewater irrigation process.

Publications and Presentations

Sophocleous, Marios, Townsend, Margaret, A., 2006. Fate of nitrate beneath fields irrigated with treated wastewater, Ford County, KS. Hydrogeology-In-Progress seminar, Department of Geology, University of Kansas, Lawrence, KS, March 8, 2006.

Sophocleous Marios, Townsend, M.A., Willson, T., Vocasek, F., 2006. Fate of nitrate beneath fields irrigated with treated wastewater, Ford County, KS. 23rd Annual Water and the Future of Kansas Conference, Oral Abstracts, Topeka, KS, March 16, 2006.

Sophocleous, Marios, 2006. Preferential flow and transport of nitrate beneath treated wastewater-irrigated fields. Kansas Geological Survey Advisory Council, Lawrence, KS, March 31, 2006.

Information Transfer

See Publications and Presentations above. In addition, Dodge City TV broadcasting news services recorded our dye-tracer experiments in November 2005 and interviewed co-PI Fred Vocasek on this project. See also Student Support below.

Student Support

A graduate student in the School of Engineering of the University of Kansas is being supported by this project. Main duties include data processing and numerical modeling. An additional hourly student from Kansas State University based in the Garden City Agricultural Experiment Station is being supported for conducting periodic neutron moisture content readings at the field sites.

Acknowledgments

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Farm operator: Chuck Nicholson
Geoprobe Systems: Wes McCall
KGS: J. Healey, B. Engard, D. Thiele, R. Ghijsen, and J. Charlton
Graduate students: VinayKumar Muralidharan (KGS current), Qinghua Zhang (KGS previous), and Amanda Feldt (KSU-Extension)

References

Ahuja, L.R., DeCoursey, D.G., Barnes, B.B., and Rojas, K.W., 1993. Characteristics of macropore transport studied with the ARS Root Zone Water Quality Model. Transactions of the ASAE, 36(2):369-380.

Ahuja, L.R., Rojas, K.W., Hanson, J.D., Shaffer, M. J., and Ma, L. (eds.), 2000. Root Zone Water Quality Model. Modeling management effects on water quality and crop production: Water Resources Publications, LLC, Highlands Ranch, CO, 372 p.

Asano, T. , 1989, Irrigation with reclaimed municipal wastewater: California experiences:

Avnimelech, Y., 1993, Irrigation with sewage effluents: the Israeli experience: Environmental Science and Technology, v. 27, no. 7, p. 1278-1280.

Ayers, R.S. and Westcot, D.W., 1989. Water Quality for Agriculture: FAO Irrigation and Drainage Paper, 29 Rev. 1, http://www.fao.org/DOCREP/003/T0234E/T0234E00.htm (Verified Nov.2004).

Babcock, M., Picchioni, G.A., Mexal, J. G., and Ruiz, A., 2005, Land application of industrial wastewater on a Chihuahuan desert ecosystem: Fourth Annual Rio Grande Basin Initiatives Conference, Alpine, TX, April 12-14, 2005, poster. http://riogrande-conference.tamu.edu/wrapup/2005/posters/Babcock.pdf

Bouchet R. (ed.) *Reuse of low quality water for irrigation* Bari: CIHEAM-IAMB, Options Méditerranéennes: Série A. Séminaires Méditerranéens; n. 1, Aswan Seminar, 1988/01/16-21, Cairo (Egypt), p. 119-132, http://ressources.ciheam.org/om/pdf/a01/CI000395.pdf.

Bouma, J., Jongerius, A., Boersma, O., Jager, A., and Schoonderbeek, D., 1977. The function of different types of macropores during saturated flow through four swelling soil horizons: Soil Sci. Soc. Am. Jour., 41: 945-950.

Bouma, J. and J.A.J. van Lanen. 1987. Transfer functions and threshold values: From soil characteristics to land qualities. p. 106-110. *In* K.J. Beek et al. (ed.). Quantified land evaluation. International Institute Aerospace Survey *Earth Sci.* ITC publ. 6. Enschede, the Netherlands.

Bouwer, H., 1992, Agricultural and municipal use of wastewater: Water Science and Technology, vol. 26, no. 7-8, p. 1583-1591.

Brooks, R.H., and A.T. Corey. 1964. Hydraulic properties of porous media. *Hydrol*. Paper 3, Colorado State Univ., Fort Collins, CO.

Dodge, D. A., Tomasu, B. I., Haberman, R. L., Roth, W. E., and Baumann, J. B., 1965. Soil Survey Ford County, Kansas: USDA Soil Conservation Service, Series 1958, no.32, 84 p.

Flury M., Fluhler, H., Jury, W.A., and Leuenberger, J., 1994. Susceptibility of soils to preferential flow of water: A field study: Water Resources Research, 30(7): 1945-1954.

Flury, Markus, Fluhler, Hannes, Jury, William A., and Jorg Leuenberger. 1994a. Susceptibility of soils to preferential flow of water: A field study. *Water Resour. Res.*, 30(7):1945-1954.

Flury, Markus and Hannes Fluhler. 1994b. Brilliant blue FCF as a dye tracer for solute transport studies-A toxicological overview. *Environ. Qual*. 23:1108-1112.

Flury, Markus and Hannes Fluhler. 1995. Tracer characteristics of brilliant blue FCF. *Soil Sci. Soc. Am. J*. 59:22-27.

Flury, Markus and Nu Nu Wai. 2003. Dyes as tracers for vadose zone hydrology. Reviews of Geophysics, 41, 1/1002.

Hathaway, L. R., Magnuson, L. M., Carr, B. L., Galle, O. K., and Waugh, T. C., 1975. Chemical quality of irrigation waters in west-central Kansas: Kansas Geological Survey Chemical Quality Series #2, 46 p.

Hathaway, L. R., 1990, Nitrate UV-spectrophotometric screening method for the Technicon Autoanalyzer II System: Kansas Geological Survey, Open-file Report no. 90-49, 4 p.

Hayes, G. J. and DeWalle, Foppe, 1993, Irrigating with municipal sewage effluent in a rural environment: Journal of Environmental Science and Health, vo. A28, no.6, p. 1229- 1247.

Hogg, T.J., Weiterman, G., and Tollefson, L.C., 2003. Effluent Irrigation: Saskatchewan Perspective: http://www.agr.gc.ca/pfra/csidc/csidpub5_e.htm (Verified Nov. 2004).

Jarvis, N.J., Hollis, J.M., Nicholls, P.H., Mayr, T., and Evans, S.P., 1997, MACRO-DB: a decision-support tool for assessing pesticide fate and mobility in soils: Environmental Modeling & Software, 12(2-3): 251-265.

Klute, A. 1986. ed. Methods of soil analysis, Part 1: Physical and mineralogical methods, second Edition. *Monogr. 9.* ASA and SSA, Madison, WI.

Larsson, M.H., and Jarvis, N.J., 1999. Evaluation of a dual porosity model to predict field-scale solute transport in a macroporous soil: Jour. Hydrology, 215: 153-171.

Logsdon, S.D., 2002. Determination of preferential flow model parameters: Soil Sci. Soc. Am. Jour., 66: 1095-1103.

Millard, S. P. 2002, EnvironmentalStats for S-PLUS, hypothesis test for k samples, Levene's Test for homogenity of variance: Version 2.0. Release 1 for Microsoft Windows.

Mualem, Y. 1976. A new model predicting the hydraulic conductivity of unsaturated porous media. *Water Resour., Res.* 12:513-522.

Mueller, D. K. and Helsel, D. R., 1996. Nutrients in the nation's waters too much of a good thing?: U. S. G. S. Circular 1136, 24 p.

Nemes, A., Schaap, M.G., and Wosten, J.H.M., 2003. Functional evaluation of pedotransfer functions derived from different scales of data collection: Soil Sci. Soc. Am. Jour., 67: 1093-1102.

Petersen, C.T., Hansen, S., and H.E. Jensen. 1997. Depth distribution of preferential flow patterns in a sandy loam soil as affected by tillage. *Hydrology and Earth System Sciences*, 4, 769-776.

Rawls, W.J., L.R. Ahuja and D.L. Brakensiek. 1992. Estimating soil hydraulic properties from soils data. P. 329-340. *In* M. Th. Van Genuchten, M.Th., F.J. Leij, and L.J. Lund (ed.). Indirect methods for estimating the hydraulic properties of unsaturated soils. Proc. Int Worksh. Riverside, CA. Oct 11-13, 1989. University of California, Riverside, CA.

Rawls, W.J., Brakensiek, D.L., and Logsdon, S.D., 1996, Estimation of macropore properties for no-till soils: Transactions of the ASAE, 39(1): 91-95.

Schaap, M.G. and W. Bouten. 1996. Modeling water retention curves of sandy soils using neural networks. *Water Resour. Res.* 32:3033-3040.

Schaap, M.G., Leij F.J. and van Genuchten M. Th. 1998a. Neural network analysis for hierarchical prediction of soil water retention and saturated hydraulic conductivity. *Soil Sci. Soc. Am. J.* 62:847-855.

Schaap, M.G., and F.J. Leij. 1998a. Using Neural Networks to predict soil water retention and soil hydraulic conductivity. Soil & Tillage Research 47:37-42.

Schaap, M.G., and F.J. Leij, 1998b. Database Related Accuracy and Uncertainty of Pedotransfer Functions, *Soil Science* 163:765-779.

Schaap, M.G., Leij, F.J., and van Genuchten, M. Th., 2001. ROSETTA: a computer program for estimating soil hydraulic parameters with hierarchical pedotransfer functions: Jour. Hydrology 251: 163-176.
Schreffler, C. L., Galeone, D. G., Veneziale, J. M., Olson, L.E., and O'Brien, D. L., 2005, Effects of spra-irrigated treated effluent on water quantity and quality, and the fate and transport of nitrogen in a small watershed, New Garden Township, Chester County, Pennsylvania: U.S.G.S. Scientific Investigations Report 2005-5043, 158 p.
Schwartz, R.C., Mcinnes, J.J., Juo, A.S.R., and C.E. Cervantes. 1999. The vertical distribution of a dye tracer in a layered soil. *Soil Science*, 164(8).
Simunek, J., Jarvis, N.J., van Genuchten, M. Th., and Gardenas, A., 2003. Review and comparison of models for describing non-equilibrium and preferential flow and transport in the vadose zone: Jour. Hydrology, 272:14-35.
Sophocleous, M.A., Townsend, M.A., and Whittemore, D.O., 1990a. Movement and fate of atrazine and bromide in central Kansas croplands: Jour. Hydrology, 115(1-4): 115-137.
Sophocleous, M.A., Townsend, M.A., Orountiotis, C., Evenson, R.A., Whittemore, D.O., Watts, C.E., and Marks, E.T., 1990b. Movement and aquifer contamination potential of atrazine and inorganic chemicals in central Kansas croplands: KS Geol. Survey Ground Water Series 12, 64 p.
Townsend, M.A., 1982. Impact of sewage irrigation on the chemistry of ground and surface waters: Proceedings Fifth Annual Madison Conference of Applied Research and Practice of Municipal and Industrial Wastes, September, 1982, Madison, WI, p. 364-379.
Townsend, M.A., Sleezer, R.O., and Macko, S.A., 1996. Effects of agricultural practices and vadose zone stratigraphy on nitrate concentration in groundwater in Kansas, USA: Water Science and Technology, 33(4-5): 219-226.
Townsend, M.A., and Young, D. P., 2000. Assessment of nitrate-nitrogen distribution in Kansas groundwater, 1990-1998: Natural Resources Research, 9(2): 125-134.
University of Missouri Extension Service, 1998. Recommended Chemical Soil Test Procedures for the North Central Region: North Central Regional Res. Pub. No. 221 (Revised), Missouri Agricultural Experiment Station SB 1001, http://muextension.missouri.edu/explorepdf/miscpubs/sb1001.pdf (Verified Nov. 2004).
USDA NRCS, 1996. Soil Survey Laboratory Methods Manual, Soil Survey Investigations Report No. 42, version 3, 716 p., ftp://ftpfc.sc.egov.usda.gov/NSSC/Lab_Methods_Manual/ssir42.pdf (Verified Nov. 2004).
U. S. Geological Survey NAWQA, 2004. Significant Findings Irrigated Agriculture Land-Use Study - central High Plains, http://webserver.cr.usgs.gov/nawqa/hpgw/sigfinds/CALFINDS.html (Verified Nov. 2004).
van Genuchten, M.Th. 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci. Am. J.* 44:892-898.
Van Genuchten, M.T., Leij, F.J., and Yates, S.R., 1991. The RETC code for quantifying the hydraulic functions of unsaturated soils. U.S. EPA Report 600/2-91/065, Washington, D.C.
van Genuchten, M.Th., and F.K. Leij. 1992. On estimating the hydraulic properties of unsaturated soils. P. 1-14. *In* M. Th. Van Genuchten, M.Th., F.J. Leij, and L.J. Lund (ed.). Indirect methods for estimating the hydraulic properties of unsaturated soils. Proc. Int Worksh. Riverside, CA. Oct 11-13, 1989. University of California, Riverside, CA.

Vacasek, F., 2006. Soil and effluent monitoring, Annual Report: Year Nineteen (2005). Report (Project Number: 05-001c) submitted to Operations Management International, Dodge City, KS, Servi-Tech, Inc., Dodge City, KS, 23 p. plus Tables and Figures.

Wosten, J.H.M., Pachepsky, Ya. A., and Rawls, W.J., 2001. Pedotransfer functions: bridging the gap between available basic soil data and missing soil hydraulics characteristics: Jour. Hydrology, 251: 123-150.

Zupancic, J. W. and Vocasek, F. F., 2002. Dealing with changes in volume and quality of effluent at the Dodge City wastewater recycling project over the last sixteen years – 1986 through 2001: 2002 Technical Conference Proceedings of the Irrigation Association, New Orleans, Louisiana.

APPENDIX A. Soil Profile Descriptions

Site R8 (core 1)

R8 SITE
DATE; 04-05-05
LEGAL: NW 34-28-25
HORIZON DESCRIPTION IN CENTIMETERS
0 to 16 Ap 10YR 3/2 silt loam; 26 percent clay; no pore; 2 percent fine roots:
16 to 29 Bt1; 10YR 3/3; silty clay loam; 30 percent clay; no pores; 5 percent fine roots:
29 to 50 Bt2; 10YR 3/3; silty clay loam; 31 percent clay; no pores; 2 percent fine roots:
50 to 68 Bt3; 10YR 4/3; silty clay loam; 36 percent clay; no pores; no roots:
68 to 90 Btk1; 10YR 5/3; silty clay loam; 30 percent clay; 4 percent very fine pores; no roots; 3 percent carbonate masses:
90 to 140 Btk2; 10YR 5/3; silt loam; 22 percent clay; 12 percent very fine pores, 5 percent fine pores; no roots; 7 percent carbonate masses:
140 to 185 Btk3; 10YR 5/4; silt loam; 20 percent clay; 12 percent very fine pores, 5 percent fine pores; no roots; 5 percent carbonate masses:
185 to 260 2Btk4; 7.5YR 5/4; silty clay loam; 32 percent clay; 5 percent very fine pores, 4 percent fine pores; no roots;3 percent carbonate masses:
260 to 300 2Btk5; 7.5YR 5/4; silty clay loam; 35 percent clay; 5 percent very fine pores, 4 percent fine pores; no roots;5 percent carbonate masses:
300 to 410 2Btk6; 7.5YR 5/4 silty clay loam; 35 percent clay; 5 percent very fine pores, 4 percent fine pores; no roots;3 percent carbonate masses
410 to 485 :2Btk7; 7.5YR 5/4 silty clay loam; 29 percent clay; 5 percent very fine pores, 4 percent fine pores; no roots;40 percent carbonate masses
485 to 510 2Bk; 10YR 7/2 silty clay loam; 29 percent clay; 5 percent very fine pores, 4 percent fine pores; no roots;40 percent carbonate masses

Site R8 (core 2)

USDA - NATURAL RESOURCES CONSERVATION SERVICE   Print Date: 01/12/2006
PEDON DESCRIPTION

Soil Name as Described/Sampled: Harney
Soil Name as Correlated:
Classification:

Description Date: 11/09/2005
Describer: Steve Graber

Site ID: 05KS057004   Pedon ID: 05KS057004

Site Note:

Pedon Type: typical pedon for series
Pedon Purpose: research site
Taxon Kind:

Location Information:
County: Ford   Quad Sheet Name:
State: Kansas
MLRA: 73 -- Rolling Plains And Breaks
Soil Survey Area:
Map Unit: --

Location Description:
Legal Description: Northeast quarter of Section 15, Township 28, Range 25

Latitude: 37 degrees 37 minutes 9.05 seconds north
Longitude: 100 degrees 2 minutes 18.96 seconds west

Datum: NAD83
UTM Zone: 14, UTM Easting: 408342 meters, UTM Northing: 4164070 meters

Geomorphic Setting: None Assigned
Upslope Shape: Cross Slope Shape:
Slope: 1.0 percent Aspect: 360 (deg)
Elevation: 2595 feet, 791.0 meters
Drainage class: well

Ap--0 to 4 inches, (0 to 10 cm); very dark grayish brown (10YR 3/2), silt loam; weak fine granular structure; noneffervescent; clear smooth boundary.

A--4 to 9 inches, (10 to 23 cm); very dark grayish brown (10YR 3/2), silt loam; moderate fine subangular blocky structure; noneffervescent; clear smooth boundary.

Bt1--9 to 20 inches, (23 to 51 cm); very dark grayish brown (10YR 3/2), silty clay loam; moderate medium prismatic parting to moderate medium subangular blocky structure; 5 percent continuous distinct clay films on all faces of peds; noneffervescent; clear smooth boundary.

Bt2--20 to 30 inches, (51 to 76 cm); dark grayish brown (10YR 4/2), silty clay loam; moderate medium subangular blocky structure; 5 percent continuous distinct clay films on all faces of peds; noneffervescent; gradual smooth boundary.

Btk--30 to 42 inches, (76 to 107 cm); brown (10YR 5/3), silty clay loam; moderate medium subangular blocky structure; common very fine moderate continuity tubular pores; 5 percent continuous distinct clay films on all faces of peds; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

Bk--42 to 55 inches, (107 to 140 cm); brown (10YR 5/3), silty clay loam; moderate medium subangular blocky structure; common very fine moderate continuity tubular pores; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; clear smooth boundary.

2Bk1--55 to 74 inches, (140 to 188 cm); brown (10YR 4/3), silt loam; weak medium
subangular blocky structure; common very fine moderate continuity tubular pores; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

2Bk2--74 to 96 inches, (188 to 244 cm); yellowish brown (10YR 5/4), loam; weak fine subangular blocky structure; common very fine moderate continuity tubular pores; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

2Bk3--96 to 108 inches, (244 to 274 cm); light yellowish brown (10YR 6/4), silt loam; weak fine subangular blocky structure; common very fine moderate continuity tubular pores; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

2Bk4--108 to 133 inches, (274 to 338 cm); yellowish brown (10YR 5/4), silt loam; weak fine subangular blocky structure; common very fine moderate continuity tubular pores; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; clear smooth boundary.

3Bk1--133 to 152 inches, (338 to 386 cm); yellowish brown (10YR 5/4), silt loam; moderate medium subangular blocky structure; common very fine moderate continuity tubular pores; 5 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

3Bk2--152 to 162 inches, (386 to 411 cm); light yellowish brown (10YR 6/4), silty clay loam; weak fine subangular blocky structure; common very fine moderate continuity tubular pores; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

3Bk3--162 to 181 inches, (411 to 460 cm); brown (7.5YR 5/4), silty clay loam; weak fine subangular blocky structure; common very fine moderate continuity tubular pores; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

3Btk--181 to 202 inches, (460 to 513 cm); yellowish brown (10YR 5/4), silty clay loam; weak fine subangular blocky structure; common very fine moderate continuity tubular pores; 5 percent continuous distinct clay films on all faces of peds; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

3Bt--202 to 233 inches, (513 to 592 cm); brown (7.5YR 4/4), silty clay loam; weak fine subangular blocky structure; common very fine moderate continuity tubular pores; 5 percent continuous distinct clay films on all faces of peds; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

3Bk--233 to 250 inches, (592 to 635 cm); yellowish brown (10YR 5/4), silt loam; weak fine subangular blocky structure; common very fine moderate continuity tubular pores; strong effervescence; gradual smooth boundary.

C1--250 to 283 inches, (635 to 719 cm); light yellowish brown (10YR 6/4), silt loam; structureless massive; common very fine moderate continuity tubular pores; strong effervescence; gradual smooth boundary.

C2--283 to 331 inches, (719 to 841 cm); light yellowish brown (10YR 6/4), silt loam; structureless massive; common very fine moderate continuity tubular pores; strong effervescence; gradual smooth boundary.

C3--331 to 368 inches, (841 to 935 cm); light yellowish brown (10YR 6/4), loam;
structureless massive; common very fine moderate continuity tubular pores; strong effervescence; gradual smooth boundary.

C4--368 to 409 inches, (935 to 1039 cm); light brown (7.5YR 6/4), loam; structureless massive; common very fine moderate continuity tubular pores; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

C5--409 to 480 inches, (1039 to 1219 cm); very pale brown (10YR 7/4), silty clay loam; structureless massive; common very fine moderate continuity tubular pores; 5 percent fine faint irregular carbonate masses in matrix; strong effervescence.

Site N7

N7 Site

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USDA - NATURAL RESOURCES CONSERVATION SERVICE    Print Date:  06/03/2005
PEDON DESCRIPTION

Soil Name as Described/Sampled:  Harney
Soil Name as Correlated:
Classification:  Fine, superactive, mesic Pachic Argiustolls

Description Date:  05/20/2005

Describer:  Steve Graber

Site ID:  05KS057002                   Pedon ID:  05KS057002

Site Note:

Pedon Type:   within range of series
Pedon Purpose:   research site
Taxon Kind:

Location Information:
  County:                                Quad Sheet Name:
  State:
  MLRA:
  Soil Survey Area:
  Map Unit:    --

Location Description:
  Legal Description:   Northeast 1/4 of Section 15, Township 28, Range 25

  Latitude:      degrees    minutes       seconds
  Longitude:       degrees    minutes       seconds

  Datum:
  UTM Zone:      14 UTM Easting:                 UTM Northing:

Geomorphic Setting:  None Assigned
Upslope Shape:            Cross Slope Shape:
Slope:   2.0 percent   Aspect:   280 (deg)
Elevation:       feet,       meters
Drainage class:

Primary Earth Cover:
Secondary Earth Cover:

Parent Material:
Bedrock Kind:
Bedrock Depth:    inches        ( cm)

Surface Fragments:

Particle Size Control Section:

Diagnostic Features:                                       to        in.
to       cm

Field Measured Properties:
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Pedon Notes:

Ap--0 to 5 inches, (0 to 13 cm); dark grayish brown (10YR 4/2), silt loam, very dark grayish brown (10YR 3/2), moist; weak fine granular structure; friable, hard; clear smooth boundary.

A--5 to 9 inches, (13 to 23 cm); dark grayish brown (10YR 4/2), silt loam, very dark grayish brown (10YR 3/2), moist; moderate medium granular structure; friable, slightly hard; clear smooth boundary.

Bt1--9 to 17 inches, (23 to 43 cm); dark grayish brown (10YR 4/2), silt loam, very dark grayish brown (10YR 3/2), moist; moderate medium subangular blocky structure; friable, slightly hard; 10 percent continuous distinct; gradual smooth boundary.

Bt2--17 to 29 inches, (43 to 74 cm); dark grayish brown (10YR 4/2), silty clay loam, very dark grayish brown (10YR 3/2), moist; moderate medium subangular blocky structure; firm, slightly hard; 10 percent continuous distinct; slight effervescence, by HCl, unspecified; clear smooth boundary.

Btk--29 to 36 inches, (74 to 91 cm); grayish brown (10YR 5/2), silty clay loam, dark grayish brown (10YR 4/2), moist; moderate medium subangular blocky structure; firm, hard; 10 percent fine irregular moderately cemented carbonate nodules; strong effervescence, by HCl, unspecified; gradual smooth boundary.

Bk1--36 to 47 inches, (91 to 119 cm); pale brown (10YR 6/3), silty clay loam, brown (10YR 5/3), moist; moderate medium subangular blocky structure; firm, hard; 10 percent fine threadlike carbonate masses; strong effervescence, by HCl, unspecified; gradual smooth boundary.

Bk2--47 to 66 inches, (119 to 168 cm); light yellowish brown (10YR 6/4), silt loam, yellowish brown (10YR 5/4), moist; weak fine angular blocky structure; friable, hard; 5 percent fine threadlike carbonate masses; strong effervescence, by HCl, unspecified; gradual smooth boundary.

Bw--66 to 87 inches, (168 to 221 cm); brown (10YR 5/3), loam, brown (10YR 4/3), moist; weak fine angular blocky structure; friable, hard; 2 percent fine threadlike carbonate masses; strong effervescence, by HCl, unspecified; gradual smooth boundary.

BCk1--87 to 116 inches, (221 to 295 cm); light yellowish brown (10YR 6/4), silty clay loam, yellowish brown (10YR 5/4), moist; weak fine subangular blocky structure; friable, hard; 5 percent fine irregular carbonate masses; strong effervescence, by HCl, unspecified; gradual smooth boundary.

BCk2--116 to 143 inches, (295 to 363 cm); very pale brown (10YR 7/4), silty clay loam, light
yellowish brown (10YR 6/4), moist; weak fine subangular blocky structure; friable, hard; 10 percent
fine irregular carbonate masses; strong effervescence, by HCl, unspecified; gradual smooth boundary.

Bkb1--143 to 157 inches, (363 to 399 cm); light yellowish brown (10YR 6/4), silty clay loam,
yellowish brown (10YR 5/4), moist; weak fine subangular blocky structure; friable, hard; 5 percent
fine irregular carbonate masses; strong effervescence, by HCl, unspecified; gradual smooth boundary.

Bkb2--157 to 184 inches, (399 to 467 cm); light brown (7.5YR 6/4), silty clay loam, brown (7.5YR
5/4), moist; weak fine subangular blocky structure; friable, hard; 10 percent fine irregular
carbonate masses; strong effervescence, by HCl, unspecified; gradual smooth boundary.

C1--184 to 200 inches, (467 to 508 cm); very pale brown (10YR 7/4), loam, light yellowish brown
(10YR 6/4), moist; structureless massive; friable, hard; 5 percent fine irregular carbonate masses;
strong effervescence, by HCl, unspecified; gradual smooth boundary.

C2--200 to 246 inches, (508 to 625 cm); light brown (7.5YR 6/4), silty clay loam, brown (7.5YR 5/4),
moist; structureless massive; friable, hard; 5 percent fine threadlike carbonate masses; strong
effervescence, by HCl, unspecified; gradual smooth boundary.

C3--246 to 300 inches, (625 to 762 cm); light yellowish brown (10YR 6/4), silt loam, yellowish brown
(10YR 5/4), moist; structureless massive; friable, hard; 5 percent fine irregular carbonate masses;
strong effervescence, by HCl, unspecified; gradual smooth boundary.

C4--300 to 334 inches, (762 to 848 cm); very pale brown (10YR 7/4), silt loam, light yellowish brown
(10YR 6/4), moist; structureless massive; friable, hard; 2 percent fine irregular carbonate masses;
strong effervescence, by HCl, unspecified; gradual smooth boundary.

C5--334 to 350 inches, (848 to 889 cm); light yellowish brown (10YR 6/4), silt loam, yellowish brown
(10YR 5/4), moist; structureless massive; friable, hard; 2 percent fine irregular carbonate masses;
strong effervescence, by HCl, unspecified; gradual smooth boundary.

C6--350 to 372 inches, (889 to 945 cm); very pale brown (10YR 7/4), loam, light yellowish brown
(10YR 6/4), moist; structureless massive; friable, hard; 2 percent fine irregular carbonate masses;
strong effervescence, by HCl, unspecified; gradual smooth boundary.

C7--372 to 400 inches, (945 to 1016 cm); very pale brown (10YR 7/4), loam, light yellowish brown
(10YR 6/4), moist; structureless massive; friable, hard; 2 percent fine irregular carbonate masses;
strong effervescence, by HCl, unspecified; gradual smooth boundary.

C8--400 to 425 inches, (1016 to 1080 cm); light brown (7.5YR 6/4), loam, brown (7.5YR 5/4), moist;
structureless massive; friable, hard; 5 percent fine irregular carbonate masses; strong
effervescence, by HCl, unspecified; gradual smooth boundary.

C9--425 to 440 inches, (1080 to 1118 cm); very pale brown (10YR 7/4), loam, light yellowish brown
(10YR 6/4), moist; structureless massive; friable, hard; 15 percent fine irregular carbonate masses;
violent effervescence, by HCl, unspecified; gradual smooth boundary.

C10--440 to 452 inches, (1118 to 1148 cm); brownish yellow (10YR 6/6), loam, yellowish brown (10YR
5/6), moist; structureless massive; friable, hard; 2 percent fine irregular carbonate masses;
violent effervescence, by HCl, unspecified; gradual smooth boundary.

C11--452 to 480 inches, (1148 to 1219 cm); very pale brown (10YR 7/4), loam, light yellowish brown
(10YR 6/4), moist; structureless massive; friable, hard; 10 percent fine irregular carbonate masses;
violent effervescence, by HCl, unspecified smooth boundary.

Site Y8

USDA - NATURAL RESOURCES CONSERVATION SERVICE   Print Date: 04/03/2006
PEDON DESCRIPTION

Soil Name as Described/Sampled: Harney
Soil Name as Correlated:
Classification:

Description Date: 11/09/2005
Describer: Steve Graber

Site ID: **Y8**   Pedon ID: 05KS057004

Site Note:

Pedon Type: typical pedon for series
Pedon Purpose: research site
Taxon Kind:

Location Information:
County: Ford   Quad Sheet Name:
State: Kansas
MLRA: 73 -- Rolling Plains And Breaks
Soil Survey Area:
Map Unit: --

Location Description:
Legal Description:

Latitude: 37 degrees 37 minutes 9.05 seconds north
Longitude: 100 degrees 2 minutes 18.96 seconds west

Datum: NAD83
UTM Zone: 14, UTM Easting: 408342 meters, UTM Northing: 4164070 meters

Geomorphic Setting: None Assigned
Upslope Shape: Cross Slope Shape:
Slope: 1.0 percent Aspect: 360 (deg)
Elevation: 2595 feet, 791.0 meters
Drainage class: well

Ap--0 to 4 inches, (0 to 10 cm); very dark grayish brown (10YR 3/2), silt loam; weak fine granular structure; noneffervescent; clear smooth boundary.

A--4 to 9 inches, (10 to 23 cm); very dark grayish brown (10YR 3/2), silt loam; moderate fine subangular blocky structure; noneffervescent; clear smooth boundary.

Bt1--9 to 20 inches, (23 to 51 cm); very dark grayish brown (10YR 3/2), silty clay loam; moderate medium prismatic parting to moderate medium subangular blocky structure; 5 percent continuous distinct clay films on all faces of peds; noneffervescent; clear smooth boundary.

Bt2--20 to 30 inches, (51 to 76 cm); dark grayish brown (10YR 4/2), silty clay loam; moderate medium subangular blocky structure; 5 percent continuous distinct clay films on all faces of peds; noneffervescent; gradual smooth boundary.

Btk--30 to 42 inches, (76 to 107 cm); brown (10YR 5/3), silty clay loam; moderate medium subangular blocky structure; common very fine moderate continuity tubular pores; 5 percent continuous distinct clay films on all faces of peds; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

Bk--42 to 55 inches, (107 to 140 cm); brown (10YR 5/3), silty clay loam; moderate medium subangular blocky structure; common very fine moderate continuity tubular pores; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; clear smooth boundary.

2Bk1--55 to 74 inches, (140 to 188 cm); brown (10YR 4/3), silt loam; weak medium
subangular blocky structure; common very fine moderate continuity tubular pores; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

2Bk2--74 to 96 inches, (188 to 244 cm); yellowish brown (10YR 5/4), loam; weak fine subangular blocky structure; common very fine moderate continuity tubular pores; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

2Bk3--96 to 108 inches, (244 to 274 cm); light yellowish brown (10YR 6/4), silt loam; weak fine subangular blocky structure; common very fine moderate continuity tubular pores; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

2Bk4--108 to 133 inches, (274 to 338 cm); yellowish brown (10YR 5/4), silt loam; weak fine subangular blocky structure; common very fine moderate continuity tubular pores; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; clear smooth boundary.

3Bk1--133 to 152 inches, (338 to 386 cm); yellowish brown (10YR 5/4), silt loam; moderate medium subangular blocky structure; common very fine moderate continuity tubular pores; 5 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

3Bk2--152 to 162 inches, (386 to 411 cm); light yellowish brown (10YR 6/4), silty clay loam; weak fine subangular blocky structure; common very fine moderate continuity tubular pores; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

3Bk3--162 to 181 inches, (411 to 460 cm); brown (7.5YR 5/4), silty clay loam; weak fine subangular blocky structure; common very fine moderate continuity tubular pores; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

3Btk--181 to 202 inches, (460 to 513 cm); yellowish brown (10YR 5/4), silty clay loam; weak fine subangular blocky structure; common very fine moderate continuity tubular pores; 5 percent continuous distinct clay films on all faces of peds; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

3Bt--202 to 233 inches, (513 to 592 cm); brown (7.5YR 4/4), silty clay loam; weak fine subangular blocky structure; common very fine moderate continuity tubular pores; 5 percent continuous distinct clay films on all faces of peds; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

3Bk--233 to 250 inches, (592 to 635 cm); yellowish brown (10YR 5/4), silt loam; weak fine subangular blocky structure; common very fine moderate continuity tubular pores; strong effervescence; gradual smooth boundary.

C1--250 to 283 inches, (635 to 719 cm); light yellowish brown (10YR 6/4), silt loam; structureless massive; common very fine moderate continuity tubular pores; strong effervescence; gradual smooth boundary.

C2--283 to 331 inches, (719 to 841 cm); light yellowish brown (10YR 6/4), silt loam; structureless massive; common very fine moderate continuity tubular pores; strong effervescence; gradual smooth boundary.

C3--331 to 368 inches, (841 to 935 cm); light yellowish brown (10YR 6/4), loam;
structureless massive; common very fine moderate continuity tubular pores; strong effervescence; gradual smooth boundary.

C4--368 to 409 inches, (935 to 1039 cm); light brown (7.5YR 6/4), loam; structureless massive; common very fine moderate continuity tubular pores; 2 percent fine faint irregular carbonate masses in matrix; strong effervescence; gradual smooth boundary.

C5--409 to 480 inches, (1039 to 1219 cm); very pale brown (10YR 7/4), silty clay loam; structureless massive; common very fine moderate continuity tubular pores; 5 percent fine faint irregular carbonate masses in matrix; strong effervescence.

APPENDIX B. Water chemistry for monitoring, domestic, and irrigation wells near study areas, Dodge City, Kansas, Spring 2005

SAMPLE ID	Location	Depth ft.	Specific Cond. µS/cm	TDS mg/L	pH	SiO2 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Sr mg/L	B µg/L	Fe µg/L	Mn µg/L	CO3 mg/L	HCO3 mg/L	SO4 mg/L	Cl mg/L	F mg/L	NO3 mg/L	NO3-N mg/L	I- µg/L	Br mg/L
East MW	T28S R25W Sec 26 NE SW SW	185	1022	613	8.00	35.4	128.0	33.6	37.5	5.6	2.06	88	40	9		380	53.7	118.0	0.307	16.5	3.7	0.3794	593.9
Gepford Dom (N7)	T28S R25W Sec 14 NW NW NW	245	304	182	8.00	14.4	38.8	6.6	15.0	2.8	0.35	33	<26	<4		154	17.4	4.0	0.414	11.8	2.7	0.0559	0.4
Kolbeck Dom (R8)	T28S R25W Sec 27 SW SE SE	200	322	193	7.90	18.1	34.1	14	9.3	3.2	0.81	49	<26	<4		154	9.8	13.9	0.674	15.3	3.5	0.0847	0.3
MW #1	T28S R25W Sec 23 NW SE SE	420	1501	901	7.80	33.1	140.0	40.0	117.0	6.0	2.14	147	<33	<4		530	64.9	210.2	0.443	10.8	2.4	0.0342	71.9
MW #3	T28S R25W Sec 15 SE SE SW	220	522	313	7.50	16.8	81	9.2	3.2	3.1	0.41	80	<26	<4		169	9.3	44.5	< 0.1	79.7	18.0	0.1308	1.6
MW #4	T28S R25W Sec 21 NE NE NE	180	774	464	7.95	30.6	65.0	21.6	5.3	3.5	1.21	45	<26	<4		295	9.4	5.0	0.426	36.0	8.1	0.0704	4.8
MW #5	T28S R25W Sec 21 SE SE SE	240	415	249	8.25	30.8	52.6	15.7	14.3	4.1	0.95	47	<26	<4		207	23.3	10.5	0.609	8.7	2.0	0.0887	1.2
MW #6	T28S R25W Sec 27 NE NE NE	270	484	290	8.10	31.2	59.9	17.8	13.6	4.3	1.06	49	<26	<4		260	20.2	10.4	0.525	12.1	2.7	0.0929	1.9
MW #7	T28S R25W Sec 23 SE SE SE	380	771	463	8.05	17.5	80	21.8	36.7	3.9	1.14	223	<26	15		201	39.5	122.6	0.114	15.4	3.5	0.3389	706.4
MW #8	T28S R25W Sec 26 SE SE SE	360	595	357	8.00	38.1	66.8	23.9	13.8	4.0	1.41	73	<26	<4		248	13.0	35.3	0.702	47.1	10.6	0.1678	1.8
MW #9	T28S R25W Sec 35 NW NW NW	220	474	284	8.15	58.0	48.4	17.5	22.1	4.1	1.01	115	476	85		262	23.2	5.0	0.107	6.1	1.4	0.0640	4.6
MW #10	T28S R25W Sec 27 SW SW SW	220	238	143	7.95	11.9	26.2	9.4	5.7	2.3	0.60	29	<26	<4		111	7.2	11.3	0.506	16.3	3.7	0.0583	1.8
MW #11	T28S R25W Sec 28 SW SE SE SE	225	398	239	8.25	65.8	43.4	16.0	25.3	4.6	1.05	109	<26	<4		210	24.8	6.2	1.490	5.7	1.3	0.0688	0.8
MW #12	T28S R25W Sec 34 SW SW SW	265	414	248	8.05	42.4	52.0	18.3	9.5	3.7	1.10	46	<26	<4	10.1	232	14.3	7.4	0.864	7.6	1.7	0.0626	0.1

APPENDIX B. continued

SAMPLE ID	Location	Depth ft.	Specific Cond. µS/cm	TDS mg/L	pH	SiO2 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Sr mg/L	B µg/L	Fe µg/L	Mn µg/L	CO3 mg/L	HCO3 mg/L	SO4 mg/L	Cl mg/L	F mg/L	NO3 mg/L	NO3-N mg/L	I- µg/L	Br mg/L
MW #13	T28S R25W Sec 34 SE SE SE	240	587	352	8.25	44.8	139.0	28.1	12.9	5.2	1.61	64	734	136		238	18.2	48.6	0.926	23.5	5.3	0.2331	2.6
MW #14	T28S R25W Sec 35 SE SE SE	260	233	140	9.60	24.4	32.1	1.9	9.0	3.1	0.54	60	<26	<4		42	43.2	7.1	0.647	8.3	1.9	0.0439	3.2
MW-West	T28S R25W Sec 26 SW NW NW	185	989	593	8.05	35.1	110.0	38.3	42.2	6.6	2.07	142	56	37		355	28.0	112.1	0.782	50.4	11.4	0.2690	17.2
Nicholson	T28S R25W Sec 35 NE NE NW	190	641	385	7.85	22.3	58.4	34.6	12.7	5.1	1.50	60	<26	<4		187	10.0	62.1	0.471	77.4	17.5	0.2006	2.6
South MW	T28S R25W Sec 26 SW NE NE	180	589	353	8.05	34.5	72.2	23.1	15.1	4.7	1.45	69	<26	<4		297	15.1	28.5	0.595	17.8	4.0	-0.0138	214.4
Y8 Irr	T28S R25W Sec 10 SW C	180	421	253	7.95	25.6	58.0	9.2	18.7	3.5	0.49	62	69	4		173	31.6	14.5	0.338	15.1	3.4	0.1263	0.8
Mun Well #16	T26S R24W Sec 20 SW SW SW	250	478	358	7.6	56.1	48.3	21.5	9.3	3.7		125	62.5	66		195	16.7	5.7	2.4	1.2			

APPENDIX C. Water chemistry analyses for Reservoirs and Irrigation well discharge points at OMI wastewater treatment plant, Dodge City, Kansas 2004-2005.

Site	Sample Date	Spec. Cond. µmhos/cm	TDS mg/L	pH	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	B mg/L	CO3 mg/L	HCO3 mg/L	SO4 mg/L	Cl mg/L	NO3-UV mg/L	NO3-N mg/L	NH3-N mg/L	NH4 mg/L
#1 Reservoir (North)	3/31/2004		1344	7.9	196	29	250	36	0.300	0.0	804.0		344.0	0.1	0.1	99.6	128.1
#1 Reservoir (North)	4/28/2004	2120	1357	8.0	181	41	250	36	0.300	0.0	820.0		320.0	0.1	0.1	101.0	129.9
#1 Reservoir (North)	6/24/2004	2820	1805	7.6	173	39	260	36	0.320	0.0	798.0		317.0	11.1	2.5	78.7	101.2
#1 Reservoir (North)	10/26/2004	2510	1606	7.8	170	28	260	40	0.320	0.0	730.0		252.0			96.0	123.4
#1 Reservoir (North)	3/25/2005	2210	1510	8.4			230	37	0.350		628.0		314.0	2.2	0.5	90.5	116.4
#2 Reservoir (Middle)	3/31/2004	2150	1376	7.9	194	29	260	37	0.300	0.0	806.0		329.0	0.1	0.1	104.0	133.7
#2 Reservoir (Middle)	4/28/2004	2210	1413	7.8	183	38	250	36	0.260	0.0	830.0		315.0	0.1	0.1	108.0	138.9
#2 Reservoir (Middle)	6/24/2004	2930	1875	7.4	183	39	270	37	0.320	0.0	882.0		342.0	9.7	2.2	88.7	114.0
#2 Reservoir (Middle)	10/26/2004	2630	1683	7.8	194	23	240	40	0.000	0.0	784.0		221.0		0.1	108.0	138.9
#2 Reservoir (Middle)	5/25/2005	2430	1510	8.0			230	37	0.420		616.0		346.0	2.2	0.5	98.1	126.1
#2 Reservoir (Middle)	8/3/2005	2500	1587	8.1	120	36	220	34	<1	<1	757.0	175.0	269.0	0.1	0.1	80.0	102.9
#2 Reservoir (Middle)	11/17/2005		1286	8.0	115	27	190	36	0.810	0.0	496.0					75.1	96.6
#3 Reservoir (South)	4/28/2004	2210	1357	7.9	168	42	260	37	0.290	0.0	596.0		331.0	0.1	0.1	85.3	109.7
#3 Reservoir (South)	5/26/2004	2680	1715	8.2	163	43	260	37	0.270	0.0	642.0		341.0	15.9	3.6	83.1	106.8
#3 Reservoir (South)	6/24/2004	2600	1664	7.8	157	44	270	37	0.340	0.0	644.0		340.0	9.3	2.1	73.6	94.6
#3 Reservoir (South)	9/16/2004			8.3	167	43				0.0	756.0		303.0	0.1	0.1	64.1	82.4
#3 Reservoir (South)	9/16/2004			8.3	167	43				0.0	756.0		303.0			64.1	82.4
#3 Reservoir (South)	10/27/2004						270	42					324.0			29.8	38.3
#3 Reservoir (South)	8/3/2005	2400	1530	8.1	120	36	220	34	<1	<1	720.0	175.0	312.0	0.1	0.1	70.0	90.0
#4 Reservoir (Final)	7/29/2004	2510	1606	8.2	159	42	270	37	0.300	0.0	598.0		359.0	15.9	3.6	17.4	22.4
#4 Reservoir (Final)	8/19/2004	2400	1536	8.2	165	37	300	38	0.370	0.0	462.0		378.0	13.7	3.1	16.0	20.6
#4 Reservoir (Final)	9/16/2004	2350	1504	9.3	99	43	350	39	0.370	10.0	250.0		432.0	4.4	1.0	0.1	0.1
#4 Reservoir (Final)	9/16/2004	2350	1504	9.3	99	43	350	39	0.370	0.0	260.0		432.0			0.1	0.1
#4 Reservoir (Final)	10/26/2004	2290	1466	9.3	80	49	390	37	0.380	10.0	13.0		363.0	0.1	0.1	0.3	0.4
#4 Reservoir (Final)	3/25/2005	2210	1414	8.5			230	35	0.270		512.0		321.0	6.6	1.5	62.8	80.7
#4 Reservoir (Final)	4/14/2005	2230	1427	8.3			230	36	0.300				304.0	9.7	2.2	54.0	69.4
#4 Reservoir (Final)	5/17/2005	1990	1274	8.40	133	15	230	36	0.330	10.0	508.0		336.5	74.9	16.9	27.6	35.5
#4 Reservoir (Final)	11/17/2005		0	8.4	117	30	249	0	0.000	0.0	238.0		0.0	57.6	13.0	2.7	3.5
Irrigation Station #1	5/26/2004	2740	1754	8.1	191	27	250	36	0.280	0.0	836.0		315.0	6.2	1.4	94.8	121.9

APPENDIX C. continued

Site	Sample Date	Spec. Cond. µmhos/cm	TDS mg/L	pH	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	B mg/L	CO3 mg/L	HCO3 mg/L	SO4 mg/L	Cl mg/L	NO3-UV mg/L	NO3-N mg/L	NH3-N mg/L	NH4 mg/L
Irrigation Station #1	7/29/2004	2720	1741	7.8	167	36	260	37	0.300	0.0	804.0		350.0	23.9	5.4	28.9	37.2
Irrigation Station #1	8/19/2004	2740	1754	7.7	163	32	270	38	0.310	0.0	776.0		354.0	1.3	0.3	77.9	100.2
Irrigation Station #1	9/16/2004	2590	1658	7.7	159	36	260	41	0.300	0.0	750.0		318.0			82.8	106.5
Irrigation Station #1	4/14/2005	2230	1581	8.3			230	36	0.500				309.0	3.1	0.7	85.0	109.3
Irrigation Station #1	5/17/2005	2200	1408	7.9	136	9	220	36	0.390	0.0	524.0		312.0	32.3	7.3	57.9	74.4
Irrigation Station #1	6/21/2005	2170	1523	7.6	136	11	240	38	0.400	0.0	582.0		278.0	119.6	27.0	64.0	82.3
Irrigation Station #1	7/22/2005	2130	1504	7.8	149		230	38	0.350	0.0	526.0		305.0			76.9	98.9
Irrigation Station #1	8/3/2005	2200	1376	8.2	120	36	230	34	1.000	<1	766.0	200.0	291.0	0.1	0.1	70.0	90.0
Irrigation Station #1	8/30/2005	2120	1504	7.8	138	-2	260	45	0.430	0.0	530.0		267.0	7.5	1.7	65.3	84.0
Irrigation Station #1	9/23/2005	1930	1331	7.4	138	27	240	41	0.450	0.0	286.0		300.0	103.7	23.4	4.5	5.8
Irrigation Station #1	10/28/2005	2010	1331	7.4	131	18	196	35	0.704	0.0	480.0		266.0			55.2	71.0
Irrigation Station #2	6/21/2005	2170	1389	7.40	136	14	240	38	0.370	0.0	344.0		299.0	61.1	13.8	18.8	24.2
Irrigation Station #2	7/22/2005	2130	1363	8.01	152		280	46	0.420	0.0	308.0		337.0	101.0	22.8	26.2	33.7
Irrigation Station #2	8/3/2005	1800	1139	8.2	120	36	220	34	<1		406.0	175.0	275.0	88.6	20.0	20.0	25.7
Irrigation Station #2	8/30/2005	2120	1357	8.2	125	3	300	51	0.440	0.0	394.0		334.0	3.5	0.8	33.3	42.8
Irrigation Station #2	9/23/2005	1930	1235	8.4	109	32	230	41	0.960	0.0	206.0		300.0	109.9	24.8	0.3	0.4
Irrigation Station #2	10/28/2005	2010	1286	8.6	115	29	253	42	0.717	0.0	228.0		344.0			0.4	0.5
Average values																	
#1 Reservoir (North)		2352	1524	7.94	180	34	250	37	0.32	0.00	756.00	181.3	309.4	3.4	0.66	93.2	119.8
#2 Reservoir (Middle)		2475	1533	7.86	165	32	237	37	0.35	0.00	738.71	175.0	303.7	2.5	0.52	94.6	121.6
#3 Reservoir (South)		2473	1567	8.10	157	42	256	37	0.30	0.00	685.67	175.0	322.0	5.1	0.86	67.1	86.3
#4 Reservoir (Final)		2291	1303	8.66	122	37	289	33	0.30	4.29	355.13	181.3	325.1	22.9	4.60	20.1	25.9
Irrigation Station #1		2315	1539	7.8	148	23	241	38	0.5	0.0	623.6	200.0	305.4	33.1	6.1	63.6	81.8
Irrigation Station #2		2027	1295	8.14	126	23	254	42	0.58	0.00	314.33	175.0	314.8	72.8	16.44	16.5	21.2

APPENDIX D. Lysimeter water chemistry for sites N7 and R8, summer 2005

Sample ID	Date	Depth ft.	Spec. Cond. µS/cm	TDS mg/L	pH	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	B mg/L	Fe µg/L	Mn µg/L	CO3 mg/L	HCO3 mg/L	SO4 mg/L	Cl mg/L	F mg/L	NO3 mg/L	NO3-N mg/L	Total Al mg/L	Total Cu mg/L	Total Mo mg/L	Total Zn mg/L
N7 MEDIUM	7/19/05		2980	1910	7.7	240	56	320	14	0.32	< 0.05	< 0.005	< 10	220	420	380	< 1	518.3	117	< 0.05	< 0.01	< 0.01	0.06
N7 MEDIUM	7/19/05	17.5	3080	1970	7.5	260	55	320	14	0.32	< 0.05	< 0.005	< 10	260	420	390	< 1	540.5	122	< 0.05	< 0.01	< 0.01	0.05
N7 MEDIUM	7/19/05	17.5	3240	2070	7.8	270	55	330	14	0.33	< 0.05	< 0.005	< 10	370	480	390	< 1	549.3	124	< 0.05	< 0.01	< 0.01	0.06
N7-Medium	9/20/05	17.5	3100	1980	7.6	310	66	390	17	0.4	< 0.05	< 0.005	< 1	250	480	370	< 10	518.3	117				
N7-Medium	9/20/05	17.5	3180	2040	7.5	340	71	410	18	0.51	< 0.05	< 0.005	< 1	270	480	370	< 10	496.2	112				
N7 Medium	9/20/05	17.5	3270	2090	7.6	340	72	420	18	0.46	< 0.05	< 0.005	< 1	300	510	360	< 10	487.3	110				
R8 MEDIUM	7/19/05	26.5	2980	1910	7.6	280	62	350	8	0.21	< 0.05	0.078	< 10	320	780	300	< 1	243.7	55	< 0.05	0.02	< 0.01	0.07
R8 MEDIUM	7/19/05	26.5	3100	1980	7.9	280	58	350	8	0.17	< 0.05	0.035	< 10	490	810	250	< 1	248.1	56	< 0.05	0.01	< 0.01	0.08
R8 Medium	9/20/05	26.5	2900	1860	7.6	300	63	390	8	0.18	< 0.05	0.022	< 1	350	810	240	1.3	250.7	56.6				
R8 MEdium	9/20/05	26.5	2930	1880	7.5	290	63	400	8	0.17	< 0.05	0.016	< 1	370	870	230	1.2	248.1	56				
R8 Medium	9/20/05	26.5	2940	1880	7.5	330	70	440	8	0.19	< 0.05	0.009	< 1	380	870	230	1.3	246.8	55.7				
R8 SHALLOW	7/19/05	5.5	6540	4190	7.5	440	160	790	29	0.38	< 0.05	0.019	< 10	460	1050	1000	1.4	695.5	157	< 0.05	0.02	< 0.01	0.05
R8 SHALLOW	7/19/05	5.5	5930	3800	7.3	400	140	730	27	0.39	< 0.05	0.013	< 10	460	1020	790	1.3	691.1	156	< 0.05	0.02	< 0.01	0.06
R8 SHALLOW	7/19/05	5.5	5620	3600	7.8	430	120	690	26	0.42	< 0.05	0.009	< 10	800	1140	590	1.3	580.3	131	< 0.05	0.02	< 0.01	0.07
Average Values																							
N7 Medium			3142	2010		293	63	365	16	0.4				278	465	377		518.3	117.0				
R8 MEDIUM			2970	1902		296	63	386	8	0.2				382	828	250		247.5	55.9				
R8 SHALLOW			6030	3863		423	140	737	27	0.4				573	1070	793		655.6	148.0				

Water Quality in Surface Water: Pharmaceuticals in Municipal Wastewater

Basic Information

Title:	Water Quality in Surface Water: Pharmaceuticals in Municipal Wastewater
Project Number:	2005KS57B
Start Date:	3/1/2004
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	
Research Category:	Water Quality
Focus Category:	Waste Water, Treatment, Toxic Substances
Descriptors:	antibiotics, solid-phase extraction, ciprofloxacin, sulfamethoxazole
Principal Investigators:	Alok Bhandari, Robert Hunter

Publication

1. Bhandari, A.; Kim, W.; Xia, K. Pharmaceuticals and hormones in the water environment. Invited talk at the South Dakota Department of Environmental & Groundwater Quality Conference, Pierre, SD. March 15-16, 2006.
2. Kim, W.; Bhandari, A.; Close, L.; Koch, D.; Hunter, R.P. Occurrence and fate of antimicrobials in Northeast Kansas wastewater treatment facilities. Poster to be presented at the 61st Annual Kansas Water Environment Association Conference, Topeka, KS, April 10- 13, 2006.
3. Bhandari, A.; Kim, W.; Xia, K.; Hunter, R.P. Occurrence and fate of antimicrobials and endocrine disrupting chemicals in municipal wastewater treatment facilities. To be presented at the 2006 International Conference of Environmental & Water Resources Institute, American Society of Civil Engineers, December 18-20, 2006, New Delhi, India.

PROJECT REPORT

Water Quality in Surface Water: Pharmaceuticals in Municipal Wastewater

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PROJECT TITLE:

Water Quality in Surface Water: Pharmaceuticals in Municipal Wastewater

PRINCIPAL INVESTIGATORS:

Alok Bhandari, Ph.D., P.E., Assistant Professor of Environmental Engineering, Department of Civil Engineering, Kansas State University

Robert Hunter, M.S., Ph.D., Assistant Professor of Veterinary Pharmacology, Department of Anatomy and Physiology, Kansas State University

PROJECT CATEGORY: Research

PROJECT DURATION: March 1, 2004 – February 28, 2006

DATE OF SUBMISSION: April 25, 2006

KEY WORDS: antibiotics, wastewater, ciprofloxacin, sulfamethoxazole, solid-phase extraction

PROBLEM AND RESEARCH OBJECTIVES

The State Water Plan of Kansas aims at ensuring that all public water suppliers have adequate water treatment by the year 2010. The Plan also envisages a significant increase in recreational opportunities at public lakes and streams in Kansas by the year 2010. These goals, however, stand to be directly impacted by the water quality in surface water bodies designated for recreation and water supply. The detection of pharmaceutical chemicals in rivers downstream of municipal wastewater treatment plants (WWTPs) across the United States and Europe has raised serious human health concerns. Most operating WWTPs and water treatment plants (WTPs) currently were not designed to remove these agents from wastewater or drinking water. Furthermore, regulatory agencies do not currently mandate publicly owned treatment works to monitor these contaminants in water or wastewater.

Pharmaceutical agents, including antibiotics, are introduced into municipal wastewater streams through direct disposal of medicines or from human excreta, which contains large quantities of non-metabolized or partially metabolized pharmaceutical compounds. Uncontrolled environmental release of such chemicals in the water environment can result in the development of antibiotic-resistant organisms, including resistant pathogens. Exposure to these contaminants through soil, water, or food can also result in hormonal imbalances in sensitive populations and children, and diminished resistance to diseases. The discharge of pharmaceutical agents in municipal sewers is also worrisome because these chemicals can partition and accumulate in biosolids, which are often used as agricultural soil amendments in Kansas and the mid-western United States.

The lack of information about the occurrence and fate of pharmaceutical agents in WWTPs in the State of Kansas makes it difficult to assess the potential impacts of wastewater effluents on surface water and groundwater quality. In order to develop solutions that control the release of pharmaceutical agents into the environment, it is important to first estimate their input into surface waters and land. Through this project, we have furthered our understanding of the occurrence and fate of antibiotics in municipal wastewater through week-long composite sampling at one WWTP during two seasons.

The specific tasks of this study included:

i) week-long composite sampling at a WWTP to evaluate daily fluctuations in the throughput of target pharmaceutical agents (ciprofloxacin and sulfamethoxazole) at this facility;

ii) comparison of target chemical concentrations and loading in to seasons of the year;

iii) estimating the extent of removal of the target chemicals during wastewater treatment.

The treatment plant evaluated was a 5 MGD facility owned and operated by the City of Manhattan, KS. This project originally included a screening evaluation of water samples for a wider variety of pharmaceuticals including methylxanthines, opioids and acetaminophen. However, the scope was narrowed significantly due to the departure of the co-PI (Dr. Robert Hunter) who accepted a position in industry in Fall 2004.

METHODOLOGY

Influent and effluent samples were obtained from automated samplers installed at the WWTP. The samples were 24-hour composites of influent and effluent wastewater collected between 8 and 10 am over a week. Samples were not collected on Sundays because of access restrictions. Samples were transferred from autosamplers into 250-mL pre-washed amber glass bottles and transported to the laboratory under ice. In the laboratory, the wastewater samples were stored at -4ºC until extraction.

Extraction and analytical methods were based on recent literature reports. For ciprofloxacin, a modified, validated variation of two reverse-phase HPLC methods was used.[1,2] The mobile phase consisted of 30:70 (v/v) acetonitrile:ammonium formate with a flow rate of 0.3 mL/min. Antibiotics were extracted from 50 mL wastewater samples using solid-phase extraction (SPE). Oasis HLB (hydrophobic-lipophilic balance) SPE cartridges (6 cc, 200 mg, 20 μm, WAT106202) by Waters Corporation, Millford, MA were used. HLB is a water-wettable reversed-phase sorbent that is resistant to pH extremes and shows no adverse effect of drying on solute recovery. Raw influent was spiked with the surrogates enrofloxacin and sulfamethazine to achieve aqueous concentrations of 5 ppm and 50 ppb, respectively. Samples were filtered sequentially through a Whatman 41 ashless filter, a Millipore 1.6 μm glass fiber filter and a 0.4 μm membrane filter and acidified to pH 3 with formic acid. SPE cartridges wre conditioned by passing methanol and HPLC water. Sample was loaded on the cartridges a filtered at 1 mL/min. Cartridges were washed wit 5% methanol and the antibiotics were eluted using 4 mL of methanol. The extract was evaporated nearly till dryness and then reconstituted in 1 mL of the HPLC mobile phase. Samples were analyzed using a Phenomenex Synergi 4 μ hydro RP 80 A (150 x 4.6 mm, 4 μm) reverse phase column.

SIGNIFICANT FINDINGS

Figures 1 to 3 illustrate the mean concentrations (and standard deviations) of ciprofloxacin (CIP) and sulfamethoxazole (SMX) entering and exiting the wastewater treatment plant during early August (summer) and early December (winter). Means and standard deviations represent three replicate extractions of the composite sample collected on a particular day. The last data points indicate the mean and standard deviations of CIP and SMX during the entire week of sampling.

[1] Golet *et al*., (2001) Trace determination of fluoroquinolone antibacterial agents in urban wastewater by solid-phase extraction and liquid chromatography with fluorescence detection. *Anal. Chem.*, **73**, 3632-3638.
[2] Golet *et al*., (2002) Determination of fluoroquinolone antibacterial agents in sewage sludge and sludge-treated soil using accelerated solvent extraction followed by solid-phase extraction. *Anal. Chem.*, **74**, 5455-5462.

Figure 1 illustrates the influent CIP and SMX concentrations for samples collected during a week in early August 2005. The operating conditions in the activated sludge system during the sampling period are summarized in Table 1.

Table 1. Wastewater Treatment System Characteristics in Early August 2005

Total suspended solids	1721 mg/L
Volatile suspended solids	1318 mg/L
Influent BOD	162 mg/L
Effluent BOD	5 mg/L
Effluent Temperature	24 C
Flow	4.84 MGD
Waste Sludge Flow	0.08 MGD
Sludge Age	4.2 days

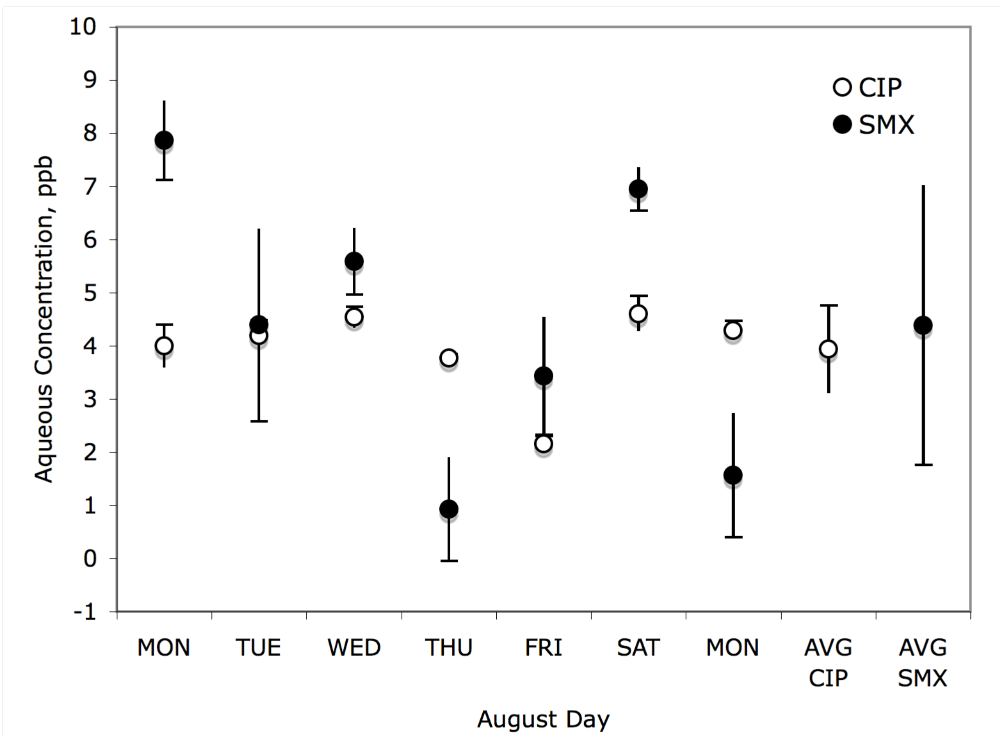

Figure 1. Influent CIP and SMX concentrations in composite samples collected in early August.

Several inferences can be drawn from the data illustrated in Figure 1:

(1) In early August, the influent CIP concentrations were consistent (4 ± 1 ppb), while the influent SMX concentrations were more variable ranging from 1 to 8 ppb with a mean of 5 ± 3 ppb.

(2) Influent CIP concentrations were consistent in replicate extracts (small error bars for each data point) indicating that the extraction procedure was repeatable. Influent SMX concentrations appeared to be less consistent (larger error bars). SMX extraction,

although not as consistent as CIP, gave reasonably repeatable results for replicate extracts on most days.

(3) CIP and SMX concentrations in the raw wastewater were of the same order of magnitude.

(4) The daily mass loadings of CIP and SMX into the wastewater treatment facility were approximately 73 g/day and 92 g/day, respectively.

Figure 2 illustrates the effluent CIP and SMX concentrations for samples collected during the same week in early August 2005.

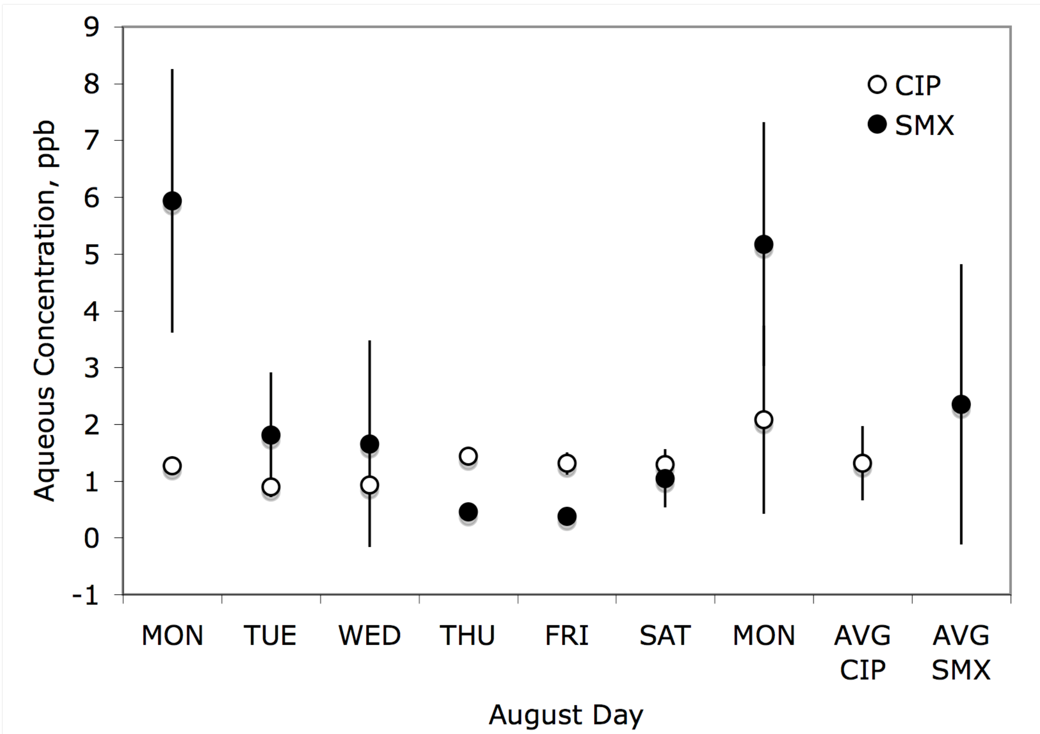

Figure 2. Effluent CIP and SMX concentrations in composite samples collected in early August.

The following inferences can be drawn from the data illustrated in Figure 2:

(1) In early August, the effluent CIP concentrations were consistent (1.5 ± 0.5 ppb), while the effluent SMX concentrations were more variable ranging from nearly zero to 6 ppb with a mean of 2.5 ± 2.5 ppb.

(2) CIP concentrations were consistent in replicate extracts (small error bars for each data point) indicating that the extraction procedure was repeatable. SMX concentrations were less consistent (larger error bars). SMX extraction, although not as consistent as CIP, gave reasonably repeatable results for replicate extracts on most days.

(3) CIP and SMX concentrations in the treated wastewater were of the same order of magnitude.

(4) The daily mass loadings of CIP and SMX into the receiving stream were approximately 27 g/day and 46 g/day, respectively.

(5) Removal efficiencies for CIP and SMX over the sampling period were 62.5% and 50%, respectively.

Figure 3 illustrates the influent CIP and SMX concentrations for samples collected during a week in early August 2005. The operating conditions in the activated sludge system during the sampling period are summarized in Table 1.

Table 2. Wastewater Treatment System Characteristics in Early December 2005

Total suspended solids	1925 mg/L
Volatile suspended solids	1542 mg/L
Influent BOD	183 mg/L
Effluent BOD	6 mg/L
Effluent Temperature	18 C
Flow	4.25 MGD
Waste Sludge Flow	0.02 MGD
Sludge Age	7.5 d

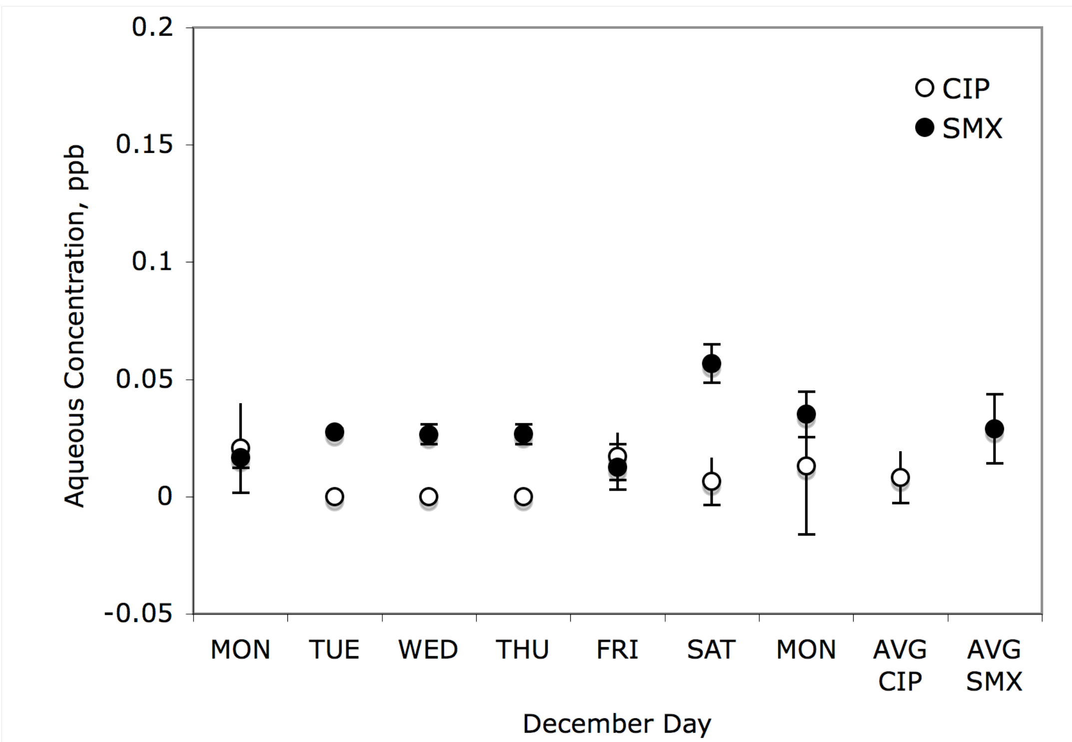

Figure 3. Influent CIP and SMX concentrations in composite samples collected in early December.

The following inferences can be drawn from the data illustrated in Figure 3:

(1) In early December, the influent CIP concentrations were consistent (0.008 ± 0.01 ppb), while the influent SMX concentrations were 0.03 ± 0.01 ppb.

(2) CIP and SMX concentrations were consistent in replicate extracts (small error bars for each data point) indicating that the extraction procedure was repeatable for both antimicrobials.

(3) CIP and SMX concentrations in the treated wastewater were about the same order of magnitude.
(4) The daily mass loadings of CIP and SMX into the receiving stream in December were approximately 0.13 g/day and 0.48 g/day, respectively.
(5) CIP and SMX concentrations were nearly two orders of magnitude lower in the first week of December than in the first week of August.

PUBLICATIONS, PRESENTATIONS AND INFORMATION TRANSFER

This work resulted in the following technical presentations:

- Bhandari, A.; Kim, W.; Xia, K. "Pharmaceuticals and hormones in the water environment." Invited talk at the South Dakota Department of Environmental & Groundwater Quality Conference, Pierre, SD. March 15-16, 2006.
- Kim, W.; Bhandari, A.; Close, L.; Koch, D.; Hunter, R.P. "Occurrence and fate of antimicrobials in Northeast Kansas wastewater treatment facilities." Poster to be presented at the 61st Annual Kansas Water Environment Association Conference, Topeka, KS, April 10-13, 2006.
- Bhandari, A.; Kim, W.; Xia, K.; Hunter, R.P. "Occurrence and fate of antimicrobials and endocrine disrupting chemicals in municipal wastewater treatment facilities." To be presented at the 2006 International Conference of Environmental & Water Resources Institute, American Society of Civil Engineers, December 18-20, 2006, New Delhi, India.

In addition a manuscript is in preparation and will be submitted to the *Journal of Environmental Engineering*.

A talk titled "Pharmaceuticals and hormones in the water environment" was also delivered as part of the Graduate Seminar in Civil Engineering at Kansas State University (March, 2006).

STUDENT SUPPORT

1. Wongee Kim, Ph.D. student, Department of Civil Engineering, KSU

Information Transfer Program

In addition to the project listed below, several of the research projects included information transfer activities as listed below by project.

Project 2003KS33B - Thirteen presentations concerning this project were presented at various venues both within and outside of Kansas during year three. Three additional abstracts were prepared for presentations early in year four (Water and the Future of Kansas Conference -March 2006, Kansas Academy of Science Conference - April 2006). One manuscript reporting a modeling assessment of the White method for estimating groundwater consumption by phreatophytes from water-table fluctuations was published in the journal Water Resources Research in year three, and a second manuscript describing the results of the field investigation of phreatophyte-induced fluctuations in the water table was submitted to Water Resources Research and is currently undergoing revision.

Project 2005KS57B - Dodge City Television station recorded dye experiments and interviewed co-PI Fred Vocasek about leaching of nitrates in the field.

Project2005KS40B - 1) The results and understanding acquired through this research were conveyed through seminars delivered by the investigators directly to all interested policy decision makers, irrigated producers and agribusinesses, in public meetings conducted in key irrigated areas of Kansas. 2) A final report that documented the research methods and what was learned from the study was written and delivered to the Kansas Water Resource Institute, Kansas Division of Water Resources, Kansas Water Office, and the State Conservation Commission. 3) The final report and Excel tool were posted to a web-site that has been designed to promote learning related to groundwater management issues in Kansas (http://www.agmanager.info/). 4) The data set, methods, and results will be made available, through peer review publications, to other researchers focusing on policies needed to achieve an absolute reduction in groundwater use.

Project 2003KS31B - KBUF radio presentations for live interviews on five occasions

KSU news release used by High Plains Journal, Kansas Farmer

Klocke, N.L., Clark, G. A., Stone, L.R., Dumler, T.J., and Briggeman, S. 2004. Crop Water Allocator (CWA). [World Wide Web]. Version 1.5. www.oznet.ksu.edu/mil. Kansas State University, AES.

Activity for CWA on the Internet: 1,100 hits in 330 downloads during 2005.

Water and the Future of Kansas Annual Conference

Basic Information

Title:	Water and the Future of Kansas Annual Conference
Project Number:	2004KS38B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	2nd
Research Category:	Not Applicable
Focus Category:	Agriculture, None, None
Descriptors:	
Principal Investigators:	William Hargrove, Peter Allen MacFarlane

Publication

Annual Conference and Other Meetings

The annual Water and the Future of Kansas Conference is an event sponsored by KWRI. The conference: 1) is an important venue for disseminating results of research sponsored by KWRI; 2) serves as a "Water Resources Town Meeting" to discuss general research needs, specific agency needs, and technology transfer needs in the area of water resources; and 3) provides a forum for stakeholders to make input that would serve as a basis for the competitive grants program "Call for Proposals". This annual conference is usually held in March.

KWRI 2005 Program Management and Annual Conference Budget

March 1, 2005 to February 28, 2006			Total Project Costs
Salaries	Federal Funds	Non-Federal	
William Hargrove -- 3% Project Year	$ -	$ 3,811	$ 3,811
Total Salaries	$ -	$ 3,811	$ 3,811
Fringe Benefits -- 32.5% -- Unclassified Staff	$ -	$ 1,239	$ 1,239
Total Fringe Benefits	$ -	$ 1,239	$ 1,239
Total Salaries, Wages & Fringe Benefits	$ -	$ 5,050	$ 5,050
Other Direct Costs			
Workshop Costs -- "Water and the Future of Kansas"	$ 2,700	$ -	$ 2,700
Travel			
Travel	$ 1,500	$ -	$ 1,500
Materials and Supplies			
Workshop Supplies	$ 500	$ -	$ 500
Subtotal -- Direct Costs	$ 4,700	$ 5,050	$ 9,750
Facilities and Administrative Costs			
Unrecovered KSU IDC -- 46% of Federal Funds		$ 2,162	$ 2,162
Waived KSU IDC -- 46% of KSU Matching		$ 2,323	$ 2,323
	$ -	$ 4,485	$ 4,485
Total Contract Costs	$ 4,700	$ 9,535	$ 14,235

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	9	0	0	0	9
Masters	1	0	0	0	1
Ph.D.	1	0	0	0	1
Post-Doc.	1	0	0	0	1
Total	12	0	0	0	12

Notable Awards and Achievements

An undergraduate student, Jacob Bauer, used the summer program project in Project 2003KS33B for his undergraduate honors thesis in the Department of Geological Sciences at the University of Colorado at Boulder. His thesis was awarded the summa cum laude designation.

Publications from Prior Projects

None