Kansas Water Resources Research Institute Annual Technical Report FY 2003

Introduction

The Kansas Water Resources Institute is part of a national network of water resource institutes in every state and trust 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 though 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 Agricultural 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 between water resource 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 resource 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; scientific 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 the water resource problems of the state; Involve the many water resources stakeholders in identifying research needs and utilize their input to prioritize 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 resources 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.

Pharmaceutical Agents in Surface Waters: The Occurrence and Fate of Pharmaceuticals in Northeast Kansas Wastewater Treatment Facilities

Basic Information

Title:	Pharmaceutical Agents in Surface Waters: The Occurrence and Fate of Pharmaceuticals in Northeast Kansas Wastewater Treatment Facilities
Project Number:	2003KS30B
Start Date:	3/1/2003
End Date:	2/28/2004
Funding Source:	104B
Congressional District:	2nd District
Research Category:	Water Quality
Focus Category:	Waste Water, Agriculture, Surface Water
Descriptors:	Pharmaceuticals
Principal Investigators:	Alok Bhandari, Robert Hunter

Publication

1. 1. Close, L.; Koch, D.; Hunter, R; Bhandari, A. "Occurrence and fate of antibiotics in KS wastewater treatment facilities." Invited paper at the 21st Annual Water and the Future of Kansas Conference, Lawrence, KS, Mar 11, 2004.

PROGRESS REPORT

Pharmaceutical Agents in Surface Waters: The Occurrence and Fate of Pharmaceuticals in Northeast Kansas Wastewater Treatment Facilities

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PROJECT TITLE:	Pharmaceutical Agents in Surface Waters: The Occurrence and Fate of Pharmaceuticals in Northeast Kansas Wastewater Treatment Facilities
PROJECT NUMBER:	
START DATE:	March 1, 2003
END DATE:	February 28, 2005
INVESTIGATORS & AFFILIATIONS:	Alok Bhandari, Ph.D., P.E., Associate 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
RESEARCH CATEGORY:	Statewide Competitive Grant
FOCUS CATEGORIES:	
DESCRIPTORS:	antibiotics, pharmaceuticals, wastewater, Kansas, occurrence, fate

PROGRESS REPORT

Pharmaceutical Agents in Surface Waters: The Occurrence and Fate of Pharmaceuticals in Northeast Kansas Wastewater Treatment Facilities

Principal Investigators

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Problem and Research Objectives

Discharges from municipal wastewater treatment plants (WWTPs) are among the major sources of surface water and groundwater contamination by antibiotics and other pharmaceutical drugs. The presence of antibiotics in surface waters and groundwater is of concern because these chemicals have the potential to perturb microbial ecology, increase the proliferation of antibiotic-resistant pathogens, and pose serious threat to human health. Pharmaceutical chemicals are introduced into municipal wastewater streams from human excreta, which contain large quantities of non-metabolized or partially metabolized medicinal compounds. In order to develop solutions that control the release of antibiotics and other pharmaceutical agents into the environment, it is important to estimate the amounts of these chemicals discharged into surface waters and on land. Recent studies have detected more than 40 different pharmaceutical drugs in environmentally significant quantities in discharges from wastewater treatment facilities in Europe and across the eastern United States. Very few studies, however, have been conducted in the Midwestern United States, and these studies have not correlated the occurrence of target pharmaceuticals to community types or removal in WWTPs to treatment processes and seasonal changes.

The overall objective of proposed project is to evaluate the occurrence and fate of three widely prescribed antibiotics – azithromycin (AZI), sulfamethoxazole (SUL), and ciprofloxacin (CIP) – in raw and treated wastewater, and biosolids at four northeast Kansas wastewater treatment facilities. Information generated from this research will provide critical and timely information about the mass input of these drugs at northeast Kansas WWTPs and extent of environmental release through effluent discharges and biosolids. The proposed work will consist of measuring concentrations of target pharmaceutical drugs in raw and treated wastewater, and biosolids at four northeast Kansas WWTPs. The target antibiotics were selected because they are among the most widely used pharmaceutical drugs in the United States and are commonly detected in municipal wastewaters. The four treatment plants to be evaluated encompass a wide range in the type and size of populations served and the treatment processes employed.

The specific objectives of this research include:

(i) determining the occurrence of the target antimicrobials in the influent, effluent, and biosolids collected from the selected WWTPs;

(ii) determining fate of the antimicrobials as the water is processed in the WWTPs;

(iii) monitoring seasonal changes in antimicrobial concentrations;

(iv) correlating antimicrobial concentrations with the types of treatment processes and raw wastewater characteristics;

(v) conducting a screening evaluation of the water and biosolids samples for a wider variety of pharmaceuticals including methylxanthines (caffeine, theobromine, and theophylline), opioids (morphine, fentanyl, butorphanol, etc.), and acetaminophen;

(vi) conducting hourly and 24-hour composite samples at selected WWTPs to evaluate temporal trends in the mass input and output of pharmaceutical agents at these facilities;

Description of Methods

The four WWTPs selected for this study are located along the Kansas River. The effluent from these treatment facilities is discharged directly into the Kansas River. The four WWTPs were selected because of their proximity to Manhattan, the wide range in the size and type of communities they serve, the wide range of treatment processes employed at these facilities, and our established relationships with the personnel at these municipal plants. Raw wastewater, primary effluent, secondary effluent and sludge samples will be collected at each WWTP and transported to the environmental engineering research laboratory under ice. Sampling at each plant was performed at least once in each of the four seasons: spring (Mar-May), summer (Jun-Aug), fall (Sep-Nov), and winter (Dec-Feb). All water samples will be collected in 1-L pre-washed amber glass bottles and transported to the laboratory under ice. In the laboratory, the wastewater samples were stored at -70ºC until extraction. Sludge samples were collected from the aerators, digesters and dewatering equipment at the four WWTPs. Biosolids were separated from water by centrifugation and freeze-dried before extraction. Samples not extracted immediately were stored at -70ºC.

Extraction and analytical methods were based on the most recent literature as detailed in the original proposal. AZI was extracted by liquid-liquid extraction using MTBE and quantified using LC/MS. SUL and CIP were extracted using mix-mode solid-phase extraction cartridges, eluted with methanol and quantified using HPLC/UV/fluorescence. All samples were subjected to rigid QA/QC protocols during collection, transport, storage, preparation and analysis. Each collected sample was divided into 3 sub-samples. Appropriate surrogate and internal standards were used during extraction and HPLC or LC/MS analyses. External standards and solvent blanks were analyzed at frequent intervals to assure equipment stability. Appropriate statistical methods were used to analyze data and differentiate treatment effects.

Work Accomplished

The accomplishments thus far for this project include sampling at the four different wastewater treatment plants in the Northeast region of Kansas and method development for the analysis of and for the sample preparation of AZI, SUL and CIP in wastewater samples.

A summary of the samples collected at the four WWTPs is presented in Table 1. At least four replicate liquid samples were collected from each plant and at least two replicate solids or slurry samples were collected from clarifiers, digesters, aerators and belt filter presses.

Table 1. Description of samples collected from the WWTPs in May and August 2003.

PLANT I.D.	NUMBERS, TYPES, AND LOCATIONS OF SAMPLES		
	Solid	**Slurry**	**Liquid**
Plant 1	0	4 return line, digester	9 plant influent, plant effluent
Plant 2	2 belt filter press (BFP)	5 nitrification tank, clarifier	19 plant influent, nitrification tank, clarifier effluent, plant effluent, BFP effluent
Plant 3	2 BFP	4 primary clarifier, secondary clarifier	14 plant influent, secondary clarifier effluent, plant effluent
Plant 4	2 BFP	4 primary clarifier, secondary clarifier	17 plant influent, secondary clarifier, BFP effluent, plant effluent

Analytical method development has been completed for sulfamethoxazole, ciprofloxacin and azithromycin. A single isocratic high pressure liquid chromatography (HPLC) method was developed for sulfamethoazole and ciprofloxacin based on a binary gradient method reported by Adams *et al.* (2002). This method utilizes a HPLC with UV/VIS and fluorescence detectors positioned in series. In prior studies, sulfamethoxazole was detected by a UV/VIS detector, (Adams *et al.,* 2002), and ciprofloxacin by fluorescence detection (Golet *et al.* 2001). Solid-phase extraction methods for sulfamethoxazole and ciprofloxacin are currently being developed. These methods are based on those reported by Adams *et al*. (2002), Kolpin *et al*. (2002), and Golet *el at*. (2001) and utilize cation exchange/reverse phase cartridges, MPC (Waters®) or MCX (3M®). A method based on liquid-liquid extraction followed by LC-MS analysis has been developed to quantify azithromycin in water to concentrations as low as 50 ppb. The samples shown below were all extracted from 1 mL of water. The extraction method is as follows: to 1 mL of water, add 100 µL of 0.5 M K_2CO_3, vortex and add 10 mL of methyl-*t*-butyl ether (MTBE). Vortex for 1 minute and centrifuge at ~1,000 ×***g*** for 10 minutes. Transfer supernatant to fresh centrifuge tube and dry using N_2 at 40 °C in a H_2O bath. Reconstitute using 100 µL of mobile phase. Chromatography is performed using a Luna C18(2) (30 × 2 mm) reversed phase column. The mobile phase used is a 24:24:2:50 methanol:H_2O:tetrahydrofuran:acetonitrile with 10 mM ammonium hydroxide.

Analytical results obtained so far indicate that all four treatment plants received raw sewage containing AZI at concentrations ranging from 0.4 to 15 μg/L. No significant change in aqueous AZI concentrations was seen as the wastewater moved through the treatment plants; AZI concentrations in the effluent ranged from 0.8 to 3.8 mg/L. The data showed no discernible seasonal trend for aqueous AZI concentrations. Mass loading of AZI into the Kansas River ranged from 1.5 g/day to 81 g/day.

References

Adams, C.; Wang, Y.; Loftin, K.; Meyer, M. *Journal of Environmental Engineering*. 2002, 128, 253-260

Golet, E. M.; Alder, A. C.; Harmann, A.; Ternes, T. A.; Giger, W. *Anal Chem.* 2001, 73, 3632-3638.

Kolpin, D. W.; Furlong, E. T.; Meyer, M. T.; Thurman, E. M.; Zaugg, S. D.; Barber, L. B.; Buxton, H. T. *Environ. Sci. Technol.* 2002, 36, 1202-1211.

Publications and Presentations

1. Close, L.; Koch, D.; Hunter, R; Bhandari, A. "Occurrence and fate of antibiotics in KS wastewater treatment facilities." Invited paper at the 21st Annual Water and the Future of Kansas Conference, Lawrence, KS, Mar 11, 2004.

Information Transfer

1. “K-State Researchers Track Antibiotics in Kansas River Waters” Press release by KSU Research & Extension. Apr 5, 2004
2. “Researchers Track Antibiotics in Kansas River Waters” News article published by About.com (www.about.com), Apr 6, 2004.
3. “Antibiotics in Rivers Raise Concerns” News article published by Harris News Service, Apr 12, 2004.
4. “Water Samples Reveal Presence of Antibiotics” News article published by Topeka Capitol Journal Online, May 4, 2004.

Students Supported

1. Larry Close, MS Candidate, Department of Civil Engineering, KSU
2. Zachary Cook, MS Candidate, Department of Civil Engineering, KSU

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:	2/28/2004
Funding Source:	104B
Congressional District:	2nd District
Research Category:	Engineering
Focus Category:	Irrigation, Water Use, Groundwater
Descriptors:	Limited Irrigation
Principal Investigators:	Norman Klocke, Gary Clark, Troy Dumler, Loyd Stone

Publication

1. Klocke, N.L., J.P. Schneekloth, SR. Melvin, R.T. Clark, J.O. Payero. 2004. Field scale comparison of limited irrigation strategies. ASAE Paper No. 042280. Aug. 2004, Ottawa, Ontario, Canada. 13 pp. (Kansas Experiment Station Contribution No. 04-362-A).
2. 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. (Kansas Experiment Station Contribution No. 04-361-A).
3. 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. (Kansas Experiment Station Contribution No. 03-402-A)
4. Klocke, N.L. Soybean and grain sorghum irrigationùsummer 2002. 2003. In Report of Progress 910. Kansas State University, AES and CES, Aug. 28, 2003, Garden City, KS. pp. 11-15.

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

Principal Investigators
Dr. Norman L. Klocke, Irrigation Engineer, SW Research Extension Center
Dr. Loyd R. Stone, Soil Physicist, Dept. of Agronomy
Troy J. Dumler, Agricultural Economist, SW Research Extension Center
Dr. Gary A. Clark, Irrigation Engineer, Dept. of Biological & Agricultural Engineering, Kansas State University

Problem

Many irrigators in Kansas are facing immediate challenges with declining water yields from their wells. Estimates have been made that 30-50 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 these reductions in water use, irrigators will need to consider shifts in cropping patterns. Irrigators who have shrinking water supplies need to know what cropping combinations to select and in what proportions for best water use and profitability. Not every combination of every cropping pattern that an irrigator dreams up can be examined experimentally with research. An agronomic/economic model is needed to predict results for an individual irrigator's situation.

This project is designed to deliver a tool to irrigators for making decisions about allocating scarce water on their land and among their crops. An irrigator's questions might be:

> "I have a limited amount of water, should I put it all on one crop or on two or three crops, how much acreage in each crop, and how much water on each crop?"
>
> "I have a limited amount of water, should I use deficit irrigation on all of my cropped land or should I try to meet the full irrigation needs of my crops on less land?"

Objectives

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 our 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. Update 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.

Methods/Results

Objective 1: During the first year of this project a computerized decision tool was created based on scientifically developed crop responses to water and formalized budgeting techniques. It has been tested internally and is ready for external testing. There are two distinct resources that were used as building blocks for the water allocation model. The first component was an irrigation-yield relation relationship for each crop (figure 1) developed from a yield-evapotranspiration (ET) relationship that was based on past research in western Kansas. The yield-ET relationships were converted to yield-irrigation relationships over a range of rainfall zones with a simulation model. Similar relationships were developed for grain sorghum, wheat, sunflower, and soybean. These relationships were developed using a simulation model from are at the heart of allocating water and land to crops.

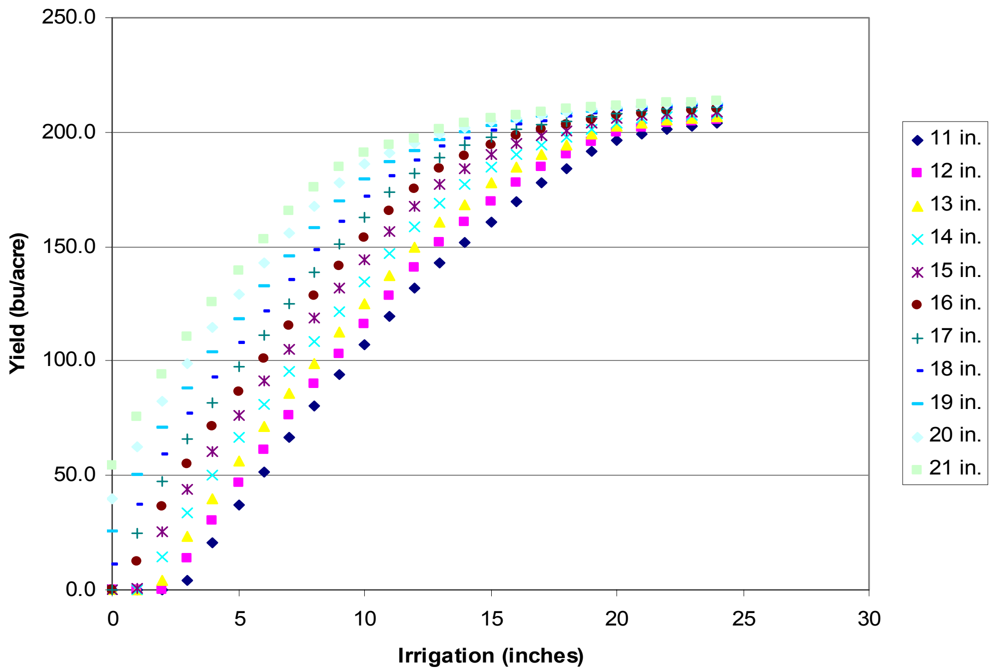


Fig.1. Corn yield in response to irrigation for annual precipitation zones in western Kansas.

The Kansas crop production budgets provide foundations for the second component of the decision model. Extensive crop production budgeting has been conducted by agricultural economists to guide producers in economic decisions concerning their operations. The economic realities of producing irrigated crops at all levels of irrigation inputs must be factored in to decisions about water allocations. The user will have the option to input crop production costs. However, the decisions become complex with multiple cropping choices.

The decision for allocating water is to divide it among one to several crops and allocate it over all the irrigated land or part of the land. We chose to take an iterative approach to the solution, and solve all of the combinations of possibilities that made senses and then rank them in order of highest net return.

The starting point for the model was to divide the land base into logical proportions of cropping base that might be farmed: 50-50, 75-25, 33-33-33, 50-25-25, and 25-25-25-25-25. The program user chooses the cropping pattern, maximum crop yields, irrigation water costs, crop production costs, and maximum water applied for the season. The program then iterates the water allocation by 10% increments over all possible combinations of crops and land allocations. For each iteration, the program calculates net return and then ranks the net returns from largest to smallest at the end of the calculations. The net return used in this program is the return to land, management, and irrigation equipment. The operating expenses are subtracted from the gross returns that make comparisons of the cropping systems possible. The program does not get to a profit or loss characterization of each system.

Five user friendly input and output screens were designed to include crop pricing and background information, irrigation cost inputs, crop production cost inputs, detailed production cost outputs, and summary net returns. Users can scroll through net returns of cropping options of the highest 15 combinations to see the possibilities and changes in net returns.

The program is in a WINDOWS based shell and will ultimately be made available by CD and a WEB site. We have demonstrated it at three professional/producer meetings to obtain feedback. This has been important during development. The most frequent comment is "when can I get a copy or where is the WEB site?" Extension agents, bankers, extension economists, irrigation specialists, producers, and consultants want to use this decision tool. Their feedback has been important to the design of this tool.

<u>Objective 2</u>: A four span linear move sprinkler irrigation system has been equipped with a segmented triple pipe manifold system for limited irrigation research. The design goals for the system included: research water management schemes to simulate center pivot management; limited irrigation experimental protocols for stage of growth or percentage of ET scheduling; random pattern of water applications; rectangular experimental plots; replicated experimental treatments; multiple crop planting patterns with access to plots; generation of crop response functions from a range of water inputs; and no-till farming practices.

The major accomplishment during 2003 was to bring the modified linear move irrigation system into full operation and to test its capabilities. There were several design and operational hurdles to overcome early in the season. The linear move on-board booster pump proved to be non-functional, which led to installation of high pressure underground water supply pipe directly from the well to the hose drag risers. The capacity of the system was also increased by increasing the size of the drag hose, risers, and nozzle orifices. The most formidable challenge during 2003, as far as the research protocol, was the revelation that a long duration residual herbicide had been applied to the experimental field during spring 2002. This affected all of the summer annual crops planned for research in 2003. We needed to uniformly apply water to the field during 2003 to remove the effects of the herbicide for the 2004 season; therefore, we could not apply differential water treatments in 2003. However, we did fully test the operational capabilities and application uniformity of the irrigation system. The experience gained from 2003 will enhance the experimental success for future years.

During 2004 we have fully implement the cropping plans for the research. During 2003 we raised corn and soybeans in the five cropping blocks. The later planted soybean and corn blocks were established with more herbicide tolerant varieties after the carryover symptoms were evident on the earlier plantings. Full irrigation was applied to all plots all season to promote as much vegetative growth as possible and leach as much chemical residue as possible. We planted winter wheat following soybean harvest during fall 2003 and will plant corn, soybean, grain sorghum, and sunflower during spring 2004.

Late planted corn results from 2003 (table 1) show that there were uniform grain yields across the plots. The non-uniformity in the early corn grain yield results were attributed to herbicide carryover. The contribution of the combination of stored soil water and rainfall reduced the need for irrigation in a year with 17 inches of annual rainfall (figure 2). Comparison of the late corn grain yield data in table 1 (199 bu/ac) with the 180 bu/ac yield response to 11 of irrigation in the 17 inch rainfall zone (figure 1) shows the potential of new corn varieties and no-till management for improving yield-irrigation relationships and ultimately irrigation water use efficiency. This is only one point on a response curve. Future years of research are needed for confirmation.

Table 1. Fully irrigated corn and soybean grain yields for 2003 at Garden City, Kansas.

Rep	Early Corn	Late Corn	Soybean
	--------	bu/ac	---------
I	191	205	54
II	200	204	43
III	145	192	44
IV	181	194	44
Avg.	179	199	46

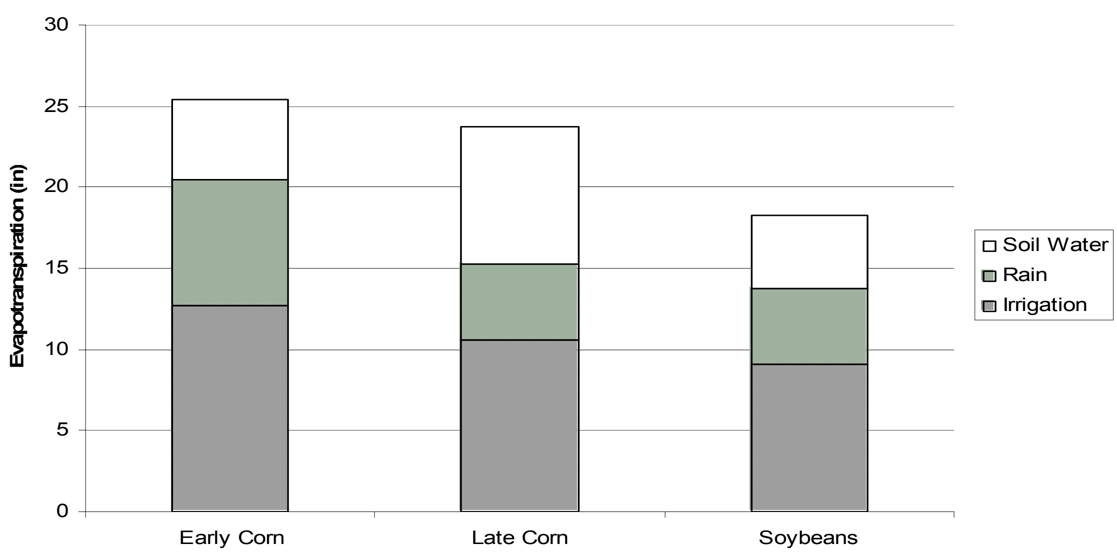


Fig. 2 Irrigation, growing season rain, and growing season stored water, used for evapotranspiration during 2003 at Garden City, Kansas.

Significance

We have a decision planning tool (water allocation model) for farmers, water resource planners, researchers, and water policy makers to examine a multitude of cropping options and limited irrigation options to maximize net economic return. This tool needs to go though final testing, be made available to the public and be supported with training assistance. The decision model is not scale dependent so that it can serve a field a farm or a watershed a river basin or an economic region.

We have an irrigation system in place to serve research for differential application of water on six levels of treatments in a random replicated pattern. The results of these experiments are to describe the yield-irrigation relationships for corn, soybean, wheat, grain sorghum, and sunflower crops which are grown in sequence in a no-till management system at the SWREC of Kansas State University at Garden City. These data will support the water allocation with new yield-irrigation relationships for no-till management. Farmers who are moving to water conserving management techniques such as no-till will need this new information. The simulation model used earlier will help extend this information into other rainfall zones.

Publications and presentations:

2003 SWREC Field Day-paper in proceedings and presentation;
2003 ASAE international meeting-paper on meeting CD on Web Library and presentation;
2004 Kansas Water Conference-published abstract and presentation;
2004 SWREC Advisory Council-meeting notes and presentation;
2004 Groundwater Management District Meeting-presentation;
2004 Finney County Soil Conservation Council-presentation;
2004 Ford County Irrigation Technology Day-presentation and demonstration of software;
2004 Central Plains Irrigation Conference-paper in proceedings and presentation
2004 ASAE international meeting-paper on meeting CD on Web Library and presentation;

Klocke, N.L., J.P. Schneekloth, SR. Melvin, R.T. Clark, J.O. Payero. 2004. Field scale comparison of limited irrigation strategies. ASAE Paper No. 042280. Aug. 2004, Ottawa, Ontario, Canada. 13 pp. (Kansas Experiment Station Contribution No. 04-362-A).

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. (Kansas Experiment Station Contribution No. 04-361-A).

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. (Kansas Experiment Station Contribution No. 03-402-A)

Klocke, N.L. Soybean and grain sorghum irrigation—summer 2002. 2003. In Report of Progress 910. Kansas State University, AES and CES, Aug. 28, 2003, Garden City, KS. pp. 11-15.

Information transfer
Radio Interview on KBUF, March 3, 2004

A Field Assessment of a Method for Estimation of Ground-Water Consumption By Phreatophytes

Basic Information

Title:	A Field Assessment of a Method for Estimation of Ground-Water Consumption By Phreatophytes
Project Number:	2003KS33B
Start Date:	3/1/2003
End Date:	2/28/2004
Funding Source:	104B
Congressional District:	2nd District
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Water Use, Methods
Descriptors:	Phreatophytes
Principal Investigators:	James J. Butler, Gerard J. Kluitenberg, Donald O. Whittemore

Publication

1. Butler, J.J., Jr., Some interesting aspects of groundwater flow in interconnected stream-aquifer systems: A report from Americans Heartland, an invited presentation to the Center for Applied Geoscience (ZAG) at the Eberhard-Karls-University of Tübingen, Germany, July 2, 2003.
2. Billinger, M., and J.J. Butler, Jr., Phreatophyte study in Solomon and Middle Arkansas River Basins, invited presentation at 2003 Annual Fall Conference of the Division of Water Resources of the Kansas Department of Agriculture, October 15, 2003.

KWRI PROGRESS REPORT – YEAR ONE

Project Title: A Field Assessment of a Method for Estimation of Groundwater Consumption by Phreatophytes – Year One
Start Date: March 1, 2003
End Date: February 28, 2004
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), Charles J. Barden, Kansas State University (Additional Cooperator), and Craig E. Martin, University of Kansas (Additional Cooperator).
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. Consumption of ground water by phreatophytes in riparian zones could also be an important factor contributing to periods of reduced streamflow. Reliable estimates of the magnitude of this consumption, however, have not yet been obtained.

In this project, we will develop a method for estimation of the amount of ground water consumed by phreatophytes. This method will be evaluated at a field site of the Kansas Geological Survey at which a great deal of previous work has been performed. The previous work, in conjunction with the additional work to be done as part of this project, will enable the methodology development and assessment to be carried out under highly controlled conditions. The end product of this research will be a technique of demonstrated effectiveness for both identifying and quantifying phreatophyte activity. Although the technique will be developed at a site with a mix of phreatophytes common in central Kansas, the approach will be equally viable in areas with different mixes of phreatophytes. The major objectives for this research project are to 1) develop a new method for quantifying the consumption of ground water by phreatophytes in hydrologic conditions common to central and western Kansas, 2) evaluate this method at a well-controlled field site, and 3) quantify ground-water consumption by phreatophytes along a portion of the middle reach of the Arkansas 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 five specific objectives for year one were as follows:

1. Establish and characterize the Larned Control Volume (LCV);

2. Commence monitoring of subsurface fluxes for water and salinity balances in the LCV;
3. Commence monitoring of phreatophyte activity;
4. Relate water-table fluctuations to phreatophyte activity during periods of negligible flux from the vadose zone;
5. Perform uncertainty analyses of water and salinity balances within the LCV.

METHODOLOGY

The ultimate objective of this project is to develop a practical approach for quantifying phreatophyte consumption of ground water. This is being done at the Larned Research Site, a field area of the Kansas Geological Survey that is located adjacent to the USGS stream-gaging station on the Arkansas River near Larned in central Kansas (Larned Research Site – Figure 1). Since the late spring of 2001, KGS personnel have done extensive work on stream-aquifer interactions at the Larned site. This previous work enables the tasks of this project to be performed in a controlled field setting.

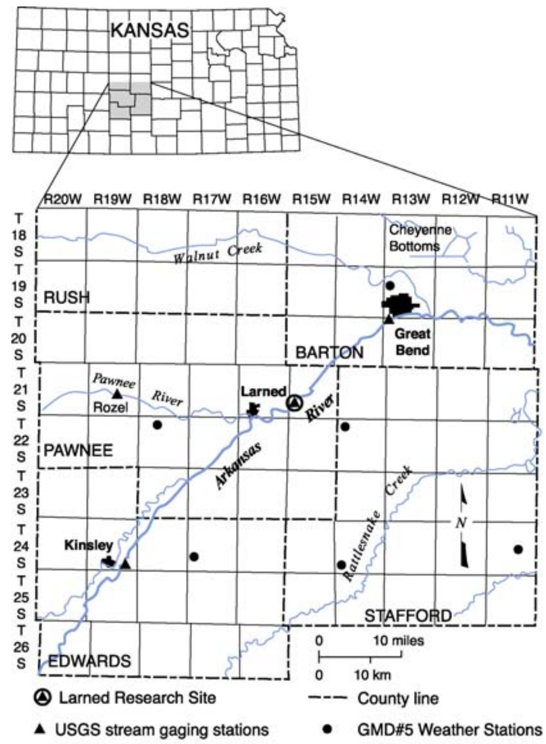


Figure 1

The methods development that is the focus of this work is being done using the control volume concept. A control volume is essentially a very large lysimeter. Water and salinity fluxes into/out of this volume are determined so that the relationship between phreatophyte activity and water-level fluctuations can be assessed (Figure 2). In the first phase of this project, the Larned Control Volume (LCV) was established in the riparian zone just west of the Arkansas River channel. Wells and vadose-zone monitoring equipment were installed within and adjacent to the LCV in May 2003. Direct-push electrical conductivity logging was used for detailed lithologic characterization at all sites prior to well installation.

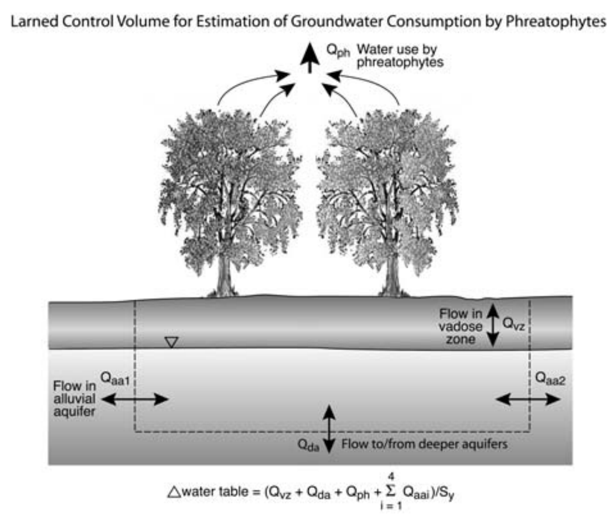


Figure 2

All wells in the LCV were equipped with integrated pressure transducer/datalogger units (In-Situ MiniTroll) that were programmed to take pressure-head readings every 15 minutes. Since the wells in the LCV could be overtopped during periods of high flow, absolute pressure transducers were used instead of the gauge-pressure sensors utilized in most hydrogeologic studies. The absolute-pressure sensors measure the pressure exerted both by the height of the overlying column of water in the well and by the atmosphere. The atmospheric pressure component is removed using data from a barometer at the site. Given the importance of the barometric pressure correction, a backup barometer was added to the monitoring network in September of 2003. Figure 3 displays records from an absolute-pressure sensor in the riparian zone prior to and after the barometric pressure correction. Manual measurements of water levels in the monitoring wells were taken on a monthly interval in order to assess the performance of the pressure sensors and, if necessary, to adjust the calibration parameters.

Vadose-zone monitoring equipment (tensiometers and neutron access tubes) was installed in the LCV in May 2003. Tensiometer readings were recorded every two to three weeks with a Tensimeter (Soil Measurement Systems). Measurements in the neutron access tubes were recorded at the same time 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 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 $\theta = 0.2992 \times CR - 0.01839$, which was based on laboratory calibrations and an adjustment for PVC pipe.

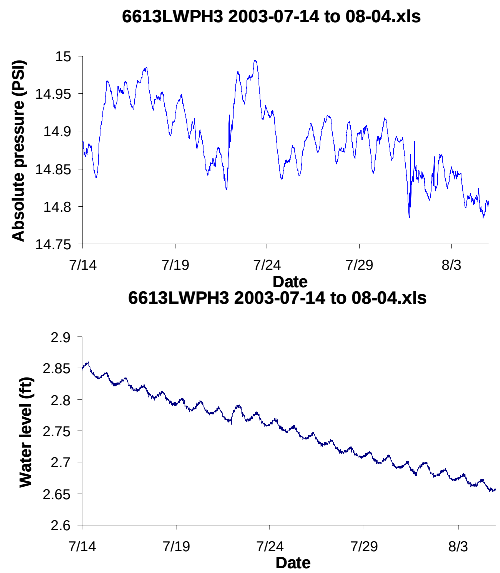


Figure 3

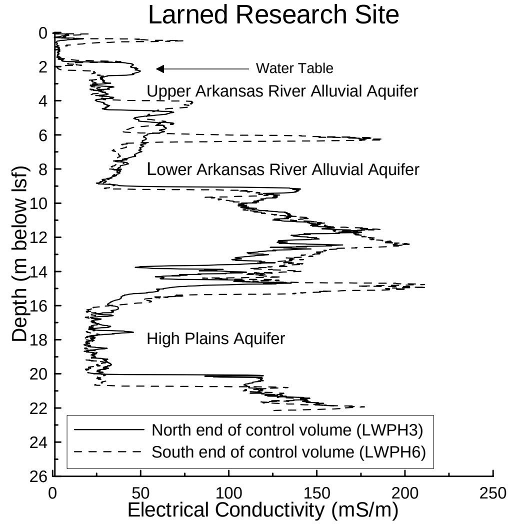
Ground-water samples were collected from all wells in the LCV and analyzed for specific conductance and major and minor constituents. A conductivity and temperature sensor with data logger (In-Situ MP Troll 9000) was installed in a well at the center of the LCV. In addition, a conductivity and temperature probe with a surface readout (YSI Model 30/50) was obtained to allow measurement of vertical profiles of these parameters in the LCV wells. Profiles have been measured in the LCV wells during 5 different months from September 2003 to February 2004.

Transpiration on the leaf scale was measured using a portable photosynthesis system (Li-Cor Li-6400). This machine consists of an infrared gas analyzer (IRGA) that measures the concentration of CO_2 and H_2O in the system air flow. There are two separate IRGA readings, one for the incoming air and one for the air in the sample chamber. A leaf is placed in the sample chamber and sealed inside. The system has its own light source and can control the concentrations of CO_2 and H_2O with the use of soda lime and Drierite, chemicals that scrub the air of CO_2 and H_2O, respectively. For all the measurements taken during this study, the concentration of CO_2 in the sample chamber was 370 PPM. Leaves from cottonwood and mulberry trees were measured under two different light levels and were maintained under conditions approximating ambient during the measurement. The light levels were 1500 μmol photons $m^{-2}\ s^{-1}$, which is typical of clear sky light in mid-morning and mid-afternoon during the summer in Kansas, and 300 μmol photons $m^{-2}\ s^{-1}$, which is typical for mostly cloudy conditions during the summer. Measurements were taken once a month from June through September 2003. Data were gathered from 7:30 AM to 4:00 PM. Leaves both near the ground and high in the canopy were measured using a cherry picker unit. Data for all of the leaves are in the form of the amount of H_2O transpired per m^2 of leaf area per second at the given light level, temperature and vapor pressure deficit. To extrapolate to the entire canopy, the m^2 leaf tissue per m^2 of ground was estimated using a leaf area index (LAI) sensor. LAI was measured on Aug. 12, 2003 between 2 PM and 4 PM. Five random points were selected within the riparian zone and LAI was measured at waist height in the four cardinal directions at each of the points. The process was repeated so that eight measurements were taken at each of the five points.

Transpiration on the tree scale was measured using sapflow sensors (Thermal Logic Model SF18). A sapflow sensor consists of two needles encased in an epoxy head. One needle has an embedded heating element, while the other has three embedded thermocouples. The installation procedure consists of removing a section of bark from the tree, emplacing the needles in the xylem, and covering the exposed xylem and probe with aluminum foil. The heater is turned on for eight seconds every 30 minutes and the temperature at three depths in the xylem above the heater is measured using the thermocouples. Three sensors are equally spaced around the circumference of the tree and remain in the tree for a period of four days. A programmable datalogger (Campbell Scientific 23X) is used to control sensor operation. The velocity of the water flow in the xylem is determined from the time it takes the heat pulse to move past the thermocouples. The volumetric rate of water movement in the trunk is determined from the thickness of the xylem and the velocity measurements. Sapflow measurements were taken every two to three weeks from June to September 2003.

A weather station (Hobo Weather Station logger and sensors, Onset Computer Corp.) was installed within 1600 m of the LCV in June of 2003 and then moved to within 800 m of the LCV in September. The weather station is equipped with sensors to measure temperature, precipitation, solar radiation, wind speed and direction, and relative humidity. Data are averaged (temperature, solar radiation, wind speed and direction, and relative humidity) or summed (precipitation) and logged at a 15-minute interval. Potential evapotranspiration is calculated from the meteorologic data using the Penman-Monteith equation.

Figure 4
Electrical Conductivity Logs
Larned Research Site



PRINCIPAL FINDINGS AND SIGNIFICANCE

The principal findings and their significance will be discussed in the context of the five objectives of the project:

Objective 1: Establish and characterize the Larned Control Volume (LCV) - five wells, four neutron-access tubes and 24 tensiometers were installed within and adjacent to the LCV. Direct-push electrical conductivity logging was used for detailed lithologic characterization at all well sites. As shown in Figure 4, three aquifer units can be identified in the shallow subsurface within the LCV. The thickness of the sandy silt zone separating the upper and lower portions of the Arkansas River Alluvial Aquifer varies across the site, so the degree of interconnection between these units also varies. The clay and silt zone separating the Arkansas River alluvial aquifer and the High Plains aquifer is consistent across the LCV. Three of the wells were screened in the upper zone of the Arkansas River alluvial aquifer (A), one in the lower zone of that aquifer (B), and one in the High Plains aquifer (C). Figure 5 provides an aerial view of the diamond-shaped LCV to the west of the river channel, and the nearby well network. Note that an additional well in the upper zone of the alluvial aquifer was installed in a pasture to the east of the riparian zone in year one to provide background information.

Objective 2: Commence monitoring of subsurface fluxes for water and salinity balances in the LCV – pressure-head measurements were obtained in all wells in the LCV and adjacent areas at 15-minute intervals beginning in the spring of 2003. These measurements clearly show that prominent diurnal fluctuations in the water table are only observed in the growing season (Figure 6) and are limited to the riparian zone (Figure 7). Gradients will be calculated from the pressure-head measurements after the vertical and horizontal locations of the wells are surveyed to a high degree of accuracy early in year two. Six tensiometers and a single neutron access tube were installed in each of four vadose-zone instrument nests in May 2003. Within each instrument nest, two tensiometers were installed at each of three depths: 0.91, 1.22, and 1.52 m. The neutron access tube was installed to a depth of 2.29 m. Figure 8 displays the water content profiles obtained over the field season from one of the nests. These profiles

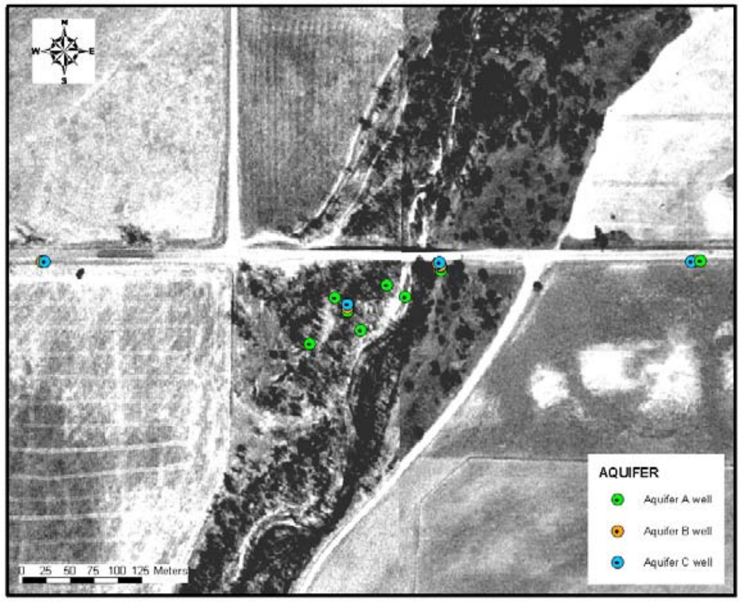


Figure 5

Figure 6
Water Table Fluctuations
Across Growing Season

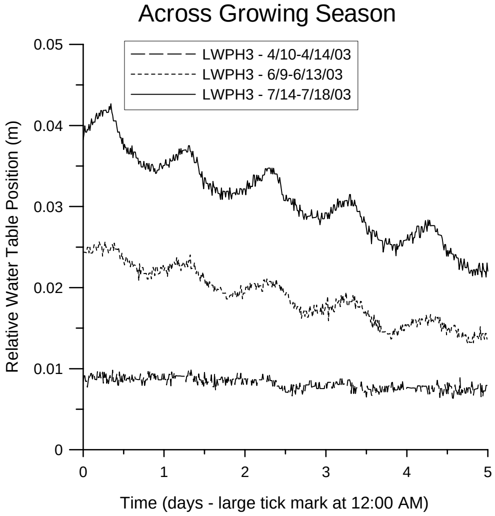
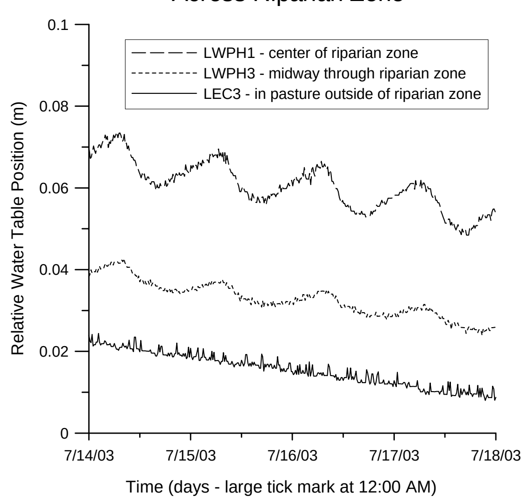
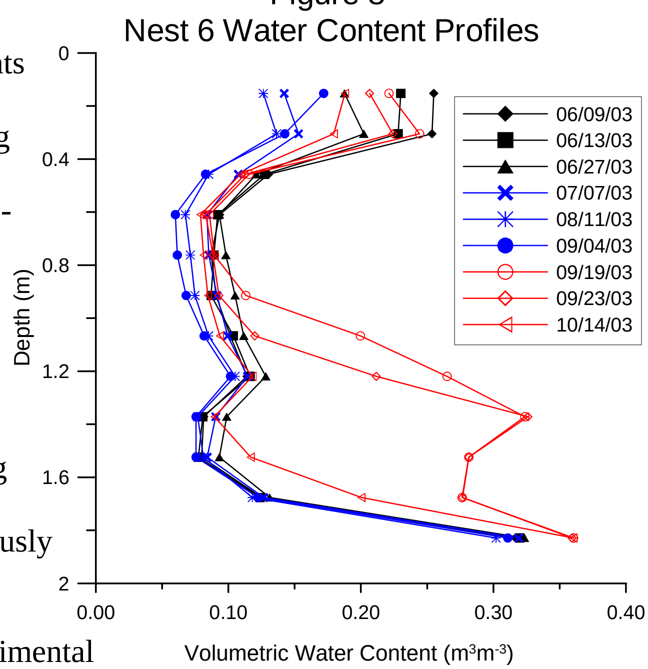


Figure 7
Water Table Fluctuations
Across Riparian Zone



indicate that very little water moved from the land surface to the water table during the monitoring period. Ground-water samples and conductivity profiles have been acquired from all wells in the LCV. These water-quality data have been useful for characterizing chemical heterogeneities in the LCV. Initial chemistry data indicate that water quality varies substantially in space and time within the LCV in response to differences in phreatophyte water consumption and recharge from precipitation and high river flow. The data collected to date suggest that phreatophyte water consumption in one summer season could be responsible for a doubling of the total-dissolved solids (TDS) concentration at one of the LCV well locations. This level of variation means that the salinity change will be valuable as an estimate of water consumption. The conductance profiles showed that the TDS concentration of the water changed with depth in some wells. Low-flow sampling at two different depths within the screened interval of the upper alluvial aquifer well at the center of the LCV also produced water with different TDS content based on chemical analysis. The spatial and temporal changes observed in conductance from well to well, and with depth in a single well, demonstrate the importance of detailed measurements at each well. Recording of specific conductance profiles is the most efficient way to obtain such detailed measurements. The specific conductance is very well correlated with the TDS concentration obtained from the sum of major dissolved constituents based on the analyses of the LCV ground waters. The sampling and conductance profile results were used to modify the procedure for salinity balance measurements for the remainder of the project.

Figure 8



Objective 3: Commence monitoring of phreatophyte activity – phreatophyte activity was monitored at the leaf- and tree-scale using a portable photosynthesis system and sapflow sensors, respectively. The analysis of the transpiration data is ongoing and will be completed in year two;

Objective 4: Relate water-table fluctuations to phreatophyte activity during periods of negligible flux from the vadose zone – a theoretical assessment of a previously developed method for estimating phreatophyte activity from water-table fluctuations has been completed. An experimental assessment of this method will be performed in year two after the high-accuracy well survey has been completed. The method will be modified for conditions at the Larned Research Site after completion of the experimental assessment;

Objective 5: Perform uncertainty analyses of water and salinity balances within the LCV – preliminary chemical data indicate that the spatial and temporal variability in chemistry at the different locations in the LCV is greater than expected. The results are being used to design an approach for more detailed monitoring of changes in the LCV wells. Another uncertainty in the salinity balance approach is the determination (based on the water chemistry) that a significant percentage of constituents dissolved in the water at the water table could be precipitated in the unsaturated zone during water consumption and slow decline in water levels. This objective will be addressed further in year two after the high-accuracy well survey has been completed.

PRESENTATIONS

Butler, J.J., Jr., Some interesting aspects of groundwater flow in interconnected stream-aquifer systems: A report from American's Heartland, an invited presentation to the Center for Applied Geoscience (ZAG) at the Eberhard-Karls-University of Tübingen, Germany, July 2, 2003.

Billinger, M., and J.J. Butler, Jr., Phreatophyte study in Solomon and Middle Arkansas River Basins, invited presentation at 2003 Annual Fall Conference of the Division of Water Resources of the Kansas Department of Agriculture, October 15, 2003.

INFORMATION TRANSFER

Two presentations concerning project methodology and the initial phase of the data collection were presented at the University of Tübingen in Germany and at the Annual Fall Meeting of the Division of Water Resources in Topeka. Two abstracts were prepared in year one for presentations early in year two (Water and the Future of Kansas Conference - March 2004, American Geophysical Union Spring Meeting - May 2004). One manuscript on the theoretical assessment of a previously developed method for estimating groundwater consumption by phreatophytes from water-table fluctuations was completed. This paper was submitted to a scientific journal early in year two.

STUDENT SUPPORT

One KSU graduate student and one KSU undergraduate were partially supported from this grant during the summer of 2003. These students contributed to the aspects of the project involving vadose-zone monitoring equipment, the sapflow sensors, and the weather station. Travel, research supplies, and cherry-picker rental were provided for a KU graduate student to perform the leaf-scale transpiration monitoring.

Development of a Framework for a Coupled Hydrologic-Economic Modeling Tool

Basic Information

Title:	Development of a Framework for a Coupled Hydrologic-Economic Modeling Tool
Project Number:	2002KS7B
Start Date:	3/1/2002
End Date:	2/28/2004
Funding Source:	104B
Congressional District:	2nd District
Research Category:	Climate and Hydrologic Processes
Focus Category:	Models, Water Quantity, Conservation
Descriptors:	economic impact, groundwater depletion
Principal Investigators:	David R. Steward, Jeffrey M. Peterson

Publication

1. Steward, D. R., Bernard, E. A., Oviatt, J. and Peterson, J. M., The hydrologic and socioeconomic impacts of groundwater management strategies addressing sustained groundwater decline in the High Plains Aquifer, 19th Annual Water and the Future of Kansas Conference, Lawence, KS, March 5, 2002, pages 39-40.
2. Peterson, J. and Steward, D. R., Modeling coupled hydrologic and economic processes in the High Plains, 20th Annual Water and the Future of Kansas Conference, Manhattan, KS, March 11, 2003, page 6.
3. Mao, D. and Steward, D. R., Modeling groundwater movement in a Sherridan County Area using ArcGIS and MLAEM, 20th Annual Water and the Future of Kansas Conference, Manhattan, KS, March 11, 2003, page 39.
4. Steward, D. R., Bernard, E. A., Bloomquist, L. E., Oviatt, C. G., Peterson, J. M. and Welch, S. M., Research on Groundwater Based Economies, 20th Annual Water and the Future of Kansas Conference, Manhattan, KS, March 11, 2003, page 41-42.
5. Steward, D. R. and Bernard, E. A., Understanding integrated processes through groundwater models and GIS technology, MODFLOW and More 2003: Understanding through Modeling, Conference Proceedings, volume 2, p. 466, Golden, CO, September 16-19, 2003.
6. Steward, D. R., Peterson, J. M. and Bernard, E. A., A coupled hydrologic-economic modeling tool to

support ground water management decisions, 21st Annual Water and the Future of Kansas Conference, Lawrence, KS, March 11, 2004, p. 17.

Development of a Framework
For A Coupled Hydrologic-Economic Modeling Tool

Final Report

For work completed March 1, 2002 to February 28, 2004

Submitted to

Kansas Water Resources Research Institute

On

June 28, 2004

Principal Investigators

David R. Steward, Kansas State University, Civil Engineering
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Project Personnel

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Joshua D. Roe, Agricultural Economics

1. Statement of Problem

This proposal addresses the critical issue of groundwater declines in the High Plains Aquifer of western Kansas. Groundwater is crucial for sustained economic vitality of this rural, agricultural region. These groundwater resources are limited and being depleted. There is a clear need for a modeling tool to help identify economically viable groundwater management strategies to sustain this important region.

This will contribute to the following objective of the State Water Plan.

3.1.6 By 2010, reduce water level decline rates within the Ogallala Aquifer and implement enhanced water management in targeted areas.

The hydrology of groundwater flow in western Kansas is fairly well understood. Much of this region is in transition from pre-development conditions, with a large volume of groundwater in storage, to depleting conditions, with less available storage. The economic transition of agriculture in western Kansas is also fairly well understood. As less water becomes available for irrigation, land use choices favor less water intensive farming practices such as dry-land wheat and grazing land.

The trends in the irrigation economy in western Kansas were reviewed by Peterson and Bernardo (2003). Although groundwater levels continue to decline throughout most of the region, irrigated acreage and total water use have remained relatively stable. During the 1990s, a rapidly increasing share of irrigated acreage was planted to water-intensive crops (corn and alfalfa). Over the same period, many irrigators invested in more efficient irrigation technology, converting from inefficient flood systems to more efficiency center pivot sprinkler systems. Groundwater withdrawals during recent decades were likely encouraged by falling real energy prices and government support programs for crop prices.

While the groundwater hydrology and economic transition of western Kansas are fairly well understood, the links between these two processes is not well understood. In particular, we do not have a scientific tool that links farm economy to physical hydrologic processes. The framework for such a tool is being developed within this report.

2. Research Objectives

The goal is to develop a framework for linking hydrologic and economic models. Specific objectives include:

- Assemble hydrologic and economic data for the GMD4 Sheridan County Special Study Area.
- Construct hydrologic and economic models of the study area.
- Use knowledge developed in creating the hydrologic and economic models to design data structures and flow of data within a fully coupled hydrologic-economic modeling tool.

The final design will enable a modeling tool to forecast the impact of groundwater management strategies on water availability and farm profits.

3. Methodology

Hydrologic and economic models are being developed for the GMD4 Sheridan County Special Study Area in western Kansas. This study area has been identified in cooperation with Groundwater Management District #4. A hydrologic model has been developed for the area including wells and regional groundwater withdrawal. An economic model has also been developed to describe irrigation decisions. Both models are being run forward in time to predict the future hydrologic and economic conditions assuming groundwater management strategies and policy do not change.

The goal of constructing this model of groundwater flow and economic decisions is to develop understanding related to coupling hydrologic and economic models. This knowledge is being used to design data structures and the flow of data within a coupled model. It is expected that the final design that is developed for this project will enable future development of a fully coupled, automated hydrologic-economic modeling tool, as part of a future project.

Methodology to develop a linked hydrologic/economic model is described in this section. First, the data used within the models are identified. Next, the individual hydrologic and economic modeling tools are described. Finally, the integrated modeling environment is described.

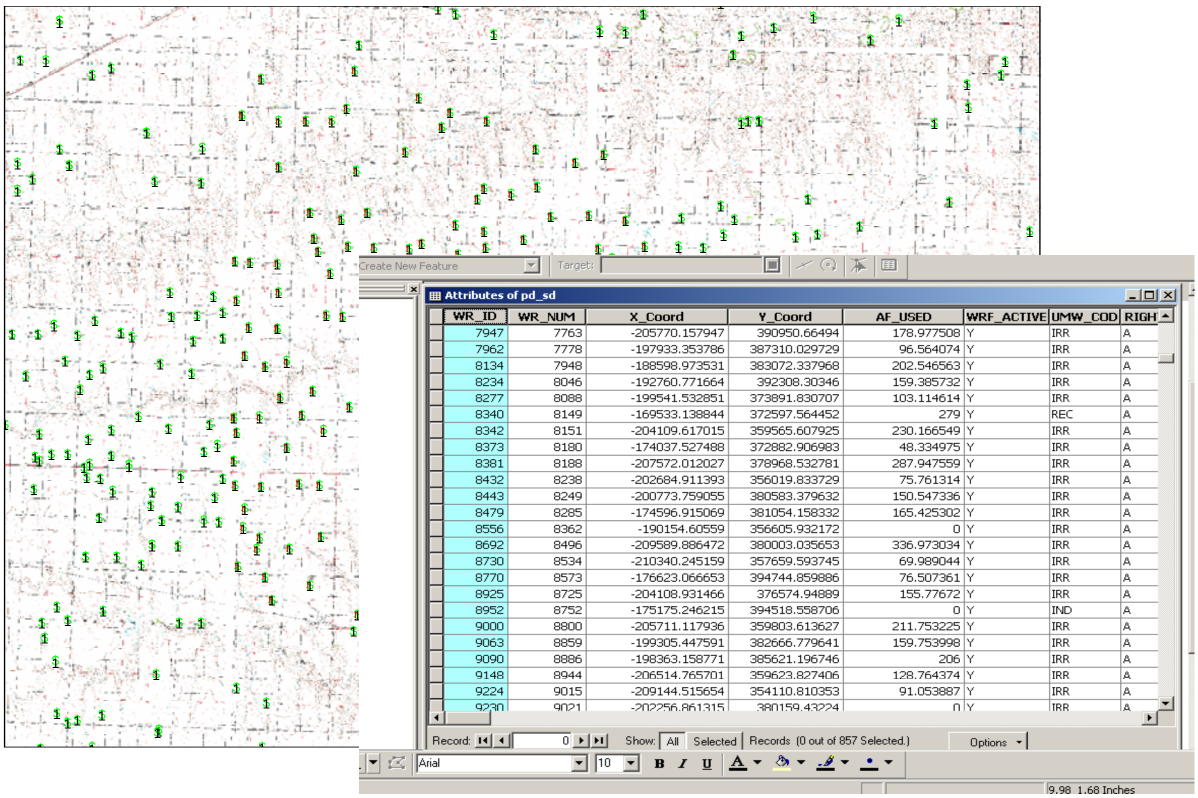
Data

Hydrologic and geologic data are required for the groundwater model. The data type and online source for this data follows:

- Recharge
  DASC (Data Access Service Center)
  http://gisdasc.kgs.ukans.edu/metadata/kats.html
- Hydraulic Conductivity
  USGS Open File Report 98-548
  http://water.usgs.gov/GIS/metadata/usgswrd/ofr98-548.html
- Specific Yield
  USGS Open File Report 98-414
  http://water.usgs.gov/GIS/metadata/usgswrd/ofr98-414.html
- Saturated Thickness
  USGS Open File Report 99-264 (pre-development)
  http://water.usgs.gov/GIS/metadata/usgswrd/ofr99-264.htm
  USGS Open File Report 00-300 (1996-1997)
  http://water.usgs.gov/GIS/metadata/usgswrd/ofr00-300_sattk9697.html
  USGS Open File Report 99-262 (1980)
  http://water.usgs.gov/GIS/metadata/usgswrd/ofr99-262.htm
- Aquifer Base (Bedrock Elevation)
  USGS Open File Report 98-393
  http://water.usgs.gov/GIS/metadata/usgswrd/ofr98-393.html
- Land Elevation
  DASC
  http://gisdasc.kgs.ukans.edu/metadata/dem_24k.html
  http://gisdasc.kgs.ukans.edu/metadata/dem_100k.html
  http://gisdasc.kgs.ukans.edu/metadata/dem_250k.html
- Wells (location and pumping rate)
  DASC
  http://gisdasc.kgs.ukans.edu/metadata/wimas.html

The data requirements for the economic model include parcel-level and time-series variables. The parcel data include the several of hydrologic variables listed above as well as water use, land use, and type of irrigation system. Hydrologic conditions (specifically, depth to water, saturated thickness, and hydraulic conductivity) affect the economics of water use because they influence pumping costs and well yields. The remaining parcel data are available from the Water Information Management & Analysis System (WIMAS) database listed in the above table. This database includes the annual report data for all irrigated parcels in the state; for our purposes only the parcels in western Kansas for the years 1990-2000 were obtained. A sample of what this database looks like is shown below.

Water Information Management & Analysis System (WIMAS)



WR_ID	WR_NUM	X_Coord	Y_Coord	AF_USED	WRF_ACTIVE	UMW_COD	RIGH
7947	7763	-205770.157947	390950.66494	178.977508	Y	IRR	A
7962	7778	-197933.353786	387310.029729	96.564074	Y	IRR	A
8134	7948	-188598.973531	383072.337968	202.546563	Y	IRR	A
8234	8046	-192760.771664	392308.30346	159.385732	Y	IRR	A
8277	8088	-199541.532851	373891.830707	103.114614	Y	IRR	A
8340	8149	-169533.138844	372597.564452	279	Y	REC	A
8342	8151	-204109.617015	359565.607925	230.166549	Y	IRR	A
8373	8180	-174037.527488	372882.906983	48.334975	Y	IRR	A
8381	8188	-207572.012027	378968.532781	287.947559	Y	IRR	A
8432	8238	-202684.911393	356019.833729	75.761314	Y	IRR	A
8443	8249	-200773.759055	380583.379632	150.547336	Y	IRR	A
8479	8285	-174596.915069	381054.158332	165.425302	Y	IRR	A
8556	8362	-190154.60559	356605.932172	0	Y	IRR	A
8692	8496	-209589.886472	380003.035653	336.973034	Y	IRR	A
8730	8534	-210340.245159	357659.593745	69.989044	Y	IRR	A
8770	8573	-176623.066653	394744.859886	76.507361	Y	IRR	A
8925	8725	-204108.931466	376574.94889	155.77672	Y	IRR	A
8952	8752	-175175.246215	394518.558706	0	Y	IND	A
9000	8800	-205711.117936	359803.613627	211.753225	Y	IRR	A
9063	8859	-199305.447591	382666.779641	159.753998	Y	IRR	A
9090	8886	-198363.158771	385621.196746	206	Y	IRR	A
9148	8944	-206514.765701	359623.827406	128.764374	Y	IRR	A
9224	9015	-209144.515654	354110.810353	91.053887	Y	IRR	A
9230	9021	-202256.861315	380159.43224	0	Y	IRR	A

(Source:http://mapster.kgs.ukans.edu/dasc/catalog/coredata.html)

The relevant time series variables include climatic variables and prices. Descriptions of these data and their sources follow:

- Expected crop prices
  Computed from time-series models of monthly NASS crop prices
  http://www.nass.usda.gov:81/ipedb/
- Energy prices
  Index constructed from BLS Kansas energy prices
  http://www.bls.gov/eag/eag.KS.htm
- Input prices
  Index of prices paid by farmers for all production items
- Evapotranspiration (ET), rainfall

K-State Research and Extension Weather Data Library
http://www.oznet.ksu.edu/wdl/

The calculations for expected crop prices and energy prices are described in Appendix A. The role of each variable in the economic model is discussed in the following section.

Modeling Tools

Hydrologic and economic models have been developed for the study area. The purpose of the groundwater model is to examine how the groundwater head in the study area declines over time. The purpose of the economic model is to examine how the economic conditions of local water users change over time as groundwater levels decline. Both models will be run in tandem on a yearly cycle to forecast the evolution of hydrologic and economic conditions.

A groundwater model has been developed for the study area that places the local hydrogeology into the regional context of flow in the High Plains Aquifer. The yearly pumping of all wells in the study area is modeled using the Theis solution. Regional flow produced by recharge and bedrock formations with changing elevation will also be included. The complete theory behind these models may be found in Strack (1989) or Haitjema (1995). Solutions are obtained in terms of a potential Φ that satisfies Darcy's Law and the Dupuit assumption of horizontal flow,

(0a) $$Q_x = - \partial \Phi/\partial x \quad ; \qquad Q_y = - \partial \Phi/\partial y$$

where Q_x and Q_y are the x- and y-components of the specific discharge vector. The potential is related to groundwater head φ for unconfined flow using

(0b) $$\Phi = 0.5\, k\, (\varphi - B)^2$$

where B is the elevation of the base of the aquifer.

The computer program MLAEM has been used for this investigation for two reasons:

1. The local detail of each well is implicitly incorporated into the model. This is important, since the economic model needs information about the head and pumping rate of each well.
2. A GIS-interface is available for this program. This is important, since the fully coupled hydrologic-economic model will eventually be linked to the state's GIS-databases.

The purpose of the economic model is to predict irrigators' water-use and land-use decisions. This decision process is modeled using the conceptual framework of Chambers and Just (1989). Each irrigator makes the two decisions in a sequential fashion by parcel; the crop selection is first made and the levels of water use and other inputs are then chosen.

These two decisions are most usefully analyzed in reverse order. Assuming z_i acres on a given parcel have been planted to crop i, the conditional expected profit from that crop is given by

(1) $$\pi_i(p_y^i, \mathbf{p}_x, p_e, \boldsymbol{\theta}, z_i) = \max_{w_i, \mathbf{x}_i} \left\{ p_y^i f_i(w_i, \mathbf{x}_i, z_i, \boldsymbol{\theta}) - \mathbf{p}_x \cdot \mathbf{x}_i - c(p_e, \boldsymbol{\theta}) w_i \right\}$$

where $\mathbf{p}_y^i$ is the expected price of crop i, $\mathbf{x}_i$ is a vector of non-water variable inputs used for crop i (e.g., fertilizer, seed), $\mathbf{p}_x$ is the corresponding input price vector, p_e is the price of energy, θ represents site-specific characteristics (hydrologic conditions, soil type, irrigation system type, etc.), $f(\cdot)$ is the production function for crop i, and $c(\cdot)$ is the marginal cost function of water delivery. Equation (1) implies crop-specific water demand function of the form

$$(2) \qquad w_i(p_y^i, \mathbf{p}_x, p_e, \boldsymbol{\theta}, z_i)$$

That is, the water use for the ith crop on a given parcel depends on the price crop i, the prices of other inputs and energy, site specific factors, and the acreage planted to crop i.

The profit-maximizing crop selection can be found from the crop specific profit functions in equation (1). That is, if a parcel contains a total of z acres and there are a total of m crop alternatives, an irrigator sets acreage levels by solving

$$(3) \qquad \max_{z_1,\ldots z_n} \left\{ \sum_{i=1}^{m} \pi_i(p_y^i, \mathbf{p}_x, p_e, \boldsymbol{\theta}, z_i) : \sum_{i=1}^{m} z_i = z \right\}$$

The solutions to this problem are the acreage allocation equations:

$$(4) \qquad z_i(\mathbf{p}_y, \mathbf{p}_x, p_e, \boldsymbol{\theta}, z),$$

where $\mathbf{p}_y = (p_y^1, \ldots, p_y^m)$ is the vector of crop prices.

Empirically estimated versions of equations (2) and (4) form the basis of the economic modeling tool. Equation (2) can be consistently estimated for each crop using ordinary least squares (OLS) regression, given data on water use on the crop in question, prices, site-specific factors, and irrigated acreage. Equation (4), however, requires the use of limited dependent variable regression techniques (Greene, 1993) because each z_i is restricted between zero and z.

To estimate the water use equations, individual datasets for each of the five major crops in western Kansas were created. Over the $T = 11$ year period of available data (1990 – 2000), the crop-i dataset contains a total of $N_i = \sum_{t=1}^{T} n_{it}$ observations, where n_{it} is the number of parcels planted to crop i in year t. The regression equation for each crop was specified as a quadratic form:

$$(5) \qquad w_j = \sum_{k=1}^{K} \beta_k r_{kj} + \frac{1}{2} \sum_{k=1}^{K} \sum_{l=1}^{K} \delta_{kl} r_{kj} r_{lj} + \varepsilon_j, \quad j = 1, \ldots, N_i$$

where j indexes observations, w_j is observed water use, r_{kj} is the kth regressor (i.e., the r_{kj}'s are the arguments of $w_i(.)$ in equation (2)), the β_k's and δ_{kl}'s are parameters to be estimated, and ε_j is a mean-zero random disturbance variable.

The datasets to estimate equation (5) were compiled from all points of diversion in the WIMAS database in western Kansas for the period 1990-2000. To account for time-series and fixed crosssectional effects, a time trend variable and county dummy variables (with Sheridan county as the base) were included as additional regressors. The summary statistics of the regression data are in table B1 (Appendix B). These statistics verify that alfalfa and corn receive substantially more water than the other crops and were grown on more parcels.

The estimation results are in tables B2 – B6 in appendix B. The overall fit of the regressions was adequate, with adjusted R-squares ranging from about 0.41 to 0.62. Most of the individual coefficients are statistically different from zero at the 95% level of confidence or higher. The magnitudes of the individual coefficients are difficult to interpret because in the quadratic form each regressor affects the dependent variable through one or more terms (equation (5)). To aid in interpretation, the elasticities of all independent variables are reported in the table below.

Estimated Elasticities

Variable	Alfalfa	Corn	Sorghum	Soybeans	Wheat
NUMYEAR	0.451	0.296	0.383	0.141	-0.010
ACRES_IRR	0.729	0.817	0.889	0.787	0.927
EXPRICE	1.094	1.045	1.479	0.056	0.122
ST	0.074	0.094	0.127	0.010	0.083
HYDRACOND	-0.0224	0.002	0.049	-0.009	-0.133
RAIN 1	-0.128	-0.059	-0.102	-0.002	-0.019
RAIN 2	-0.077	-0.022	0.010	-0.015	-0.120
RAIN 3	-0.230	-0.249	-0.259	-0.379	-0.196
TOTALET	0.256	0.365	0.508	0.287	0.067
METER	-0.055	-0.075	-0.097	-0.014	-0.108
PRICEINDEX	-4.962	-2.995	-10.192	-0.902	-0.981
HPIVOT	0.043	0.847	1.175	0.634	-0.026
LPIVOT	0.110	1.026	0.452	-0.872	1.634
OTHER	-1.078	-0.014	-2.942	-0.737	-4.709
SPRINKLER	0.323	0.067	1.218	-5.401	-1.895
DTW[a]					
FLOOD	0.060	0.249	0.174	0.093	0.131
HPIVOT	0.070	0.204	0.148	0.045	0.057
LPIVOT	0.046	0.222	0.149	0.071	0.095
OTHER	0.061	0.249	0.174	0.094	0.128
SPRINKLER	0.056	0.248	0.171	0.091	0.130
EINDEX[a]					
FLOOD	-0.821	-2.502	-2.677	0.202	0.906
HPIVOT	-0.805	-2.729	-2.949	-0.062	0.947
LPIVOT	-0.807	-2.688	-2.680	0.496	0.692
OTHER	-0.811	-2.505	-2.651	0.213	0.980
SPRINKLER	-0.825	-2.503	-2.684	0.227	0.926

[a] Because of the interaction terms in the estimated equations, the elasticites for depth to water (*DTW*) and energy index depend (*EINDEX*) on the irrigation system.

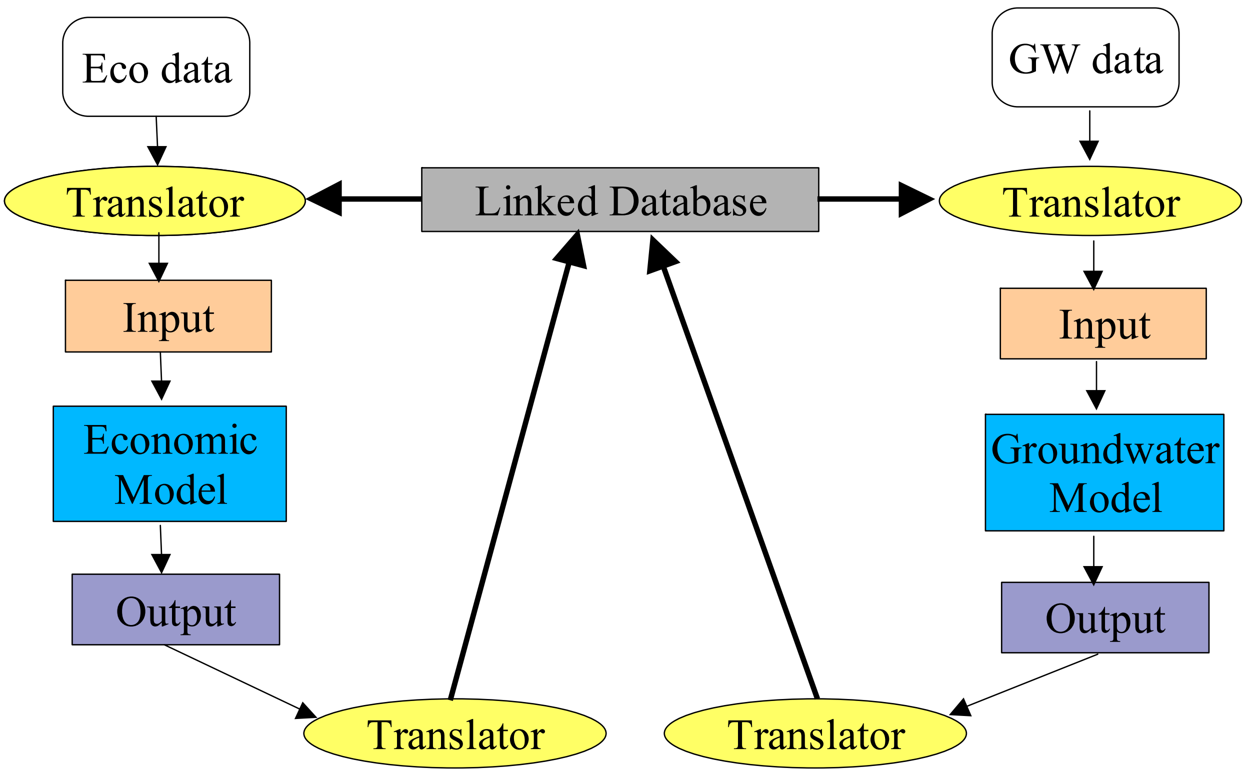
Each elasticity value is the percentage change in water use in response to a 1% change of an independent variable, holding all else constant. As expected, water use responds positively to changes in the expected output price (*EXPRICE*), although the effect is substantially stronger for alfalfa, corn, and sorghum than for soybeans and wheat. Also as expected, water use is inversely related to changes in rainfall (*RAIN_1*, *RAIN_2*, *RAIN_3*), but the rainfall elasticities are all less than one in absolute value; these estimates suggest that rainfall and irrigation water are not perfect substitutes. The negative elasticities for *METER* imply that reported water use is smaller for metered wells, or equivalently, irrigators without meters tend to over-report water consumption.

Many of the results explain recent irrigation trends in western Kansas. For example, water use has not declined significantly during the 1990s even though irrigators have rapidly adopted more efficient irrigation systems (Peterson and Bernardo, 2003). This trend is consistent with the positive estimated elasticities for efficient irrigation systems (*HPIVOT* and *LPIVOT*). Because flood irrigation is the base system type, this indicates that irrigators actually increase water use on all crops after a high-efficiency system is installed (except for soybeans with an *LPIVOT* system). The policy significance of this finding is that policies to encourage investments in high efficiency systems may not result in groundwater conservation. A trend toward increased water use is also reflected in the positive elasticities for *NUMYEAR*, indicating that the amount of groundwater pumped on a typical corn field is increasing each year throughout the time period, all else held constant.

Integrated Modeling Environment

A linked database contains information about both hydrology and economics. Information is organized using records, where each record contains information about one well. Additional data is needed for both the groundwater model (e.g., aquifer properties) and the economic model (e.g., prices). Translators have been developed to assemble data and format it into input data that is immediately accessible by the groundwater and economic models. Output results from the groundwater and economic models are then used to fill the linked database. In this way, future projections of groundwater data (e.g., pumping rates and groundwater elevations) and economic data (e.g., costs and benefits) can be assembled for individual wells.

Economic Model - Groundwater Model Coupling Diagram



The variables used in the groundwater and economic models follow.

Data Description			
Variable	Description	Units	Source
Hydrologic variables:			
DTW	Depth to groundwater	Feet	Kansas Geological Survey Section-Level Database (http://hercules.kgs.ukans.edu/geohydro/section_data/hp_step1.cfm)
ST	Aquifer saturated thickness	Feet	
HYDRACOND	Hydraulic conductivity	Feet/day	
MAXGPM	Maximum well capacity given hydrologic conditions	Gallons per minute	
B	Base elevation	Feet	
SY	Specific Yield	-	
RECHARGE	Recharge rate	Inch/year	
Technology and resource variables			
METER	Binary variable for metered well	(1=yes, 0=no)	WIMAS Database, Kansas Division of Water Resources (http://www.kgs.ukans.edu/HighPlains/WIMASmetadata.txt)
FLOOD	Binary variable for flood system	(1=yes,0=no)	
HPIVOT	Binary variable for high-pressure center pivot system	(1=yes, 0=no)	
LPIVOT	Binary variable for low-pressure center pivot system	(1=yes, 0=no)	

OTHER	Binary variable for other system type	(1=yes, 0=no)	
SPRINKLER	Binary variable for fixed sprinkler system	(1=yes, 0=no)	
ACRES_IRR	Acres irrigated	Acres	
LAGCORN	Binary variable for previous year corn	(1=yes, 0=no)	
LAT	Latitude of point of diversion	Degree	
LONG	Longitude of point of diversion	Degree	
DISCHARGE	Pumping volume of point of diversion	Acre-ft/year	
Price and policy variables			
NUMYEAR	Year (trend variable)	(1991=1, ... , 2000=10)	
EINDEX	Index of energy prices		Calculated from models described in Appendix A
EPALF	Expected alfalfa price	$/ton	
EPCORN	Expected corn price	$/bushel	
EPMILO	Expected grain sorghum price	$/bushel	
EPSOY	Expected soybean price	$/bushel	
EPWHEAT	Expected wheat price	$/bushel	
PRICEINDEX	Index of Prices Paid by producers		USDA-NASS
FAIR	Binary variable for 1996 Farm Bill policies	(1=yes, 0=no)	
Weather variables			
RAIN_1	Previous October-December rainfall	Inches	Kansas Weather Data Library (http://www.oznet.ksu.edu/wdl/
RAIN_2	January-March rainfall	Inches	
RAIN_3	May-August rainfall	Inches	
WINRAIN	Previous October-March rainfall (*RAIN_1* + *RAIN_2*)	Inches	
TOTALET	Growing season evapotranspiration	Inches	

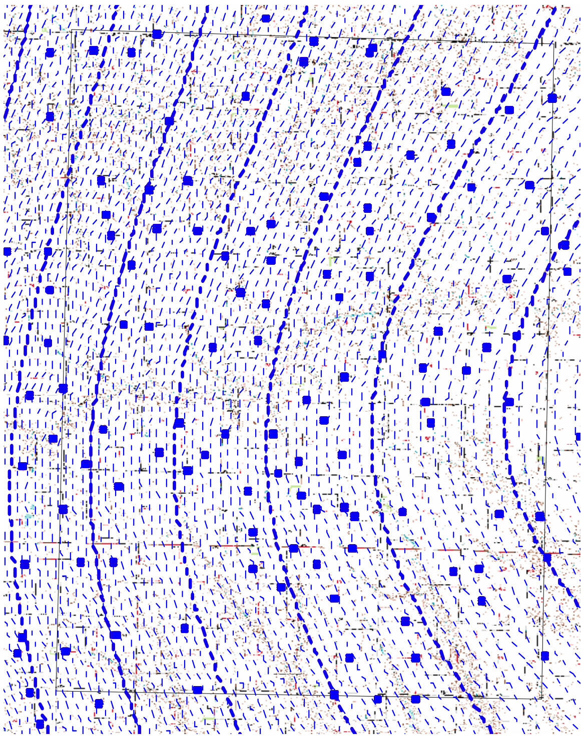
4. Results

This section shows results from running groundwater models and economic models in the study region. The following figure shows the groundwater elevation within the study region at two times; the left-hand figure is the elevation prior to pumping during the growing season and the right-hand figure is at the end of the growing season. This model was constructed using the published aquifer and recharge data from online sources listed earlier. The pumping rate for each well was obtained from the WIMAS database. This data is obtained from water use reports, which must be filed with the Department of Agriculture in Kansas for each water permit.

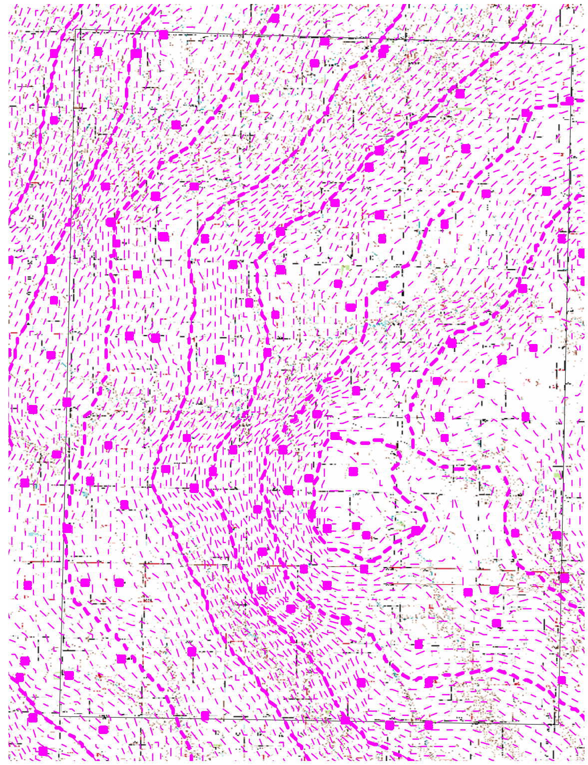
The groundwater model is being run backwards in time and compared to historical drawdowns in the region, which have averaged about 0.3m/year for the past 40 years. Predicated groundwater elevations are also being compared to observation wells in the region. Model results show that groundwater elevations are accurately reproduced by the model, with predicted elevations within 1-2m of field observations.

The groundwater model is also being run forward in time to forecast the groundwater elevation at future times.

Groundwater head at start of growing season



Groundwater head after 80 days of pumping



Crop choice equations

In the present research, we concentrate on the five most commonly irrigated crops in western Kansas: alfalfa, corn, grain sorghum, soybean and wheat. These crops account for over 97 percent of irrigated acreage. The model is actually estimated for 6 categories of crops, because we include an 'other' category that represents all other crops besides the five major ones.

The crop choice equations were estimated using a multinomial logistic regression procedure, and the results of this estimation are summarized in the table below (complete statistical results can be obtained from the authors upon request). The values in this table are the marginal effects of different variables on the probability of a given crop being planted, or the change in probability resulting from independent one-unit changes. For instance, the value –0.00018 in the upper-left cell means that a one-foot increase in depth to water will decrease the probability of planting alfalfa by 0.00018; if originally alfalfa was grown with probability 0.105 (i.e., 10.5%) then a one foot increase in depth to water will change the probability to 0.1048 (10.48%). This is of course a very small change, but a one-foot change in depth to water is a slight change as well. A 10-foot increase in depth to water would decrease the probability by about 0.2% and a 100-foot increase would reduce it by about 2%. This suggests that alfalfa is slightly more likely to be found growing in 'shallower' portions of the aquifer.

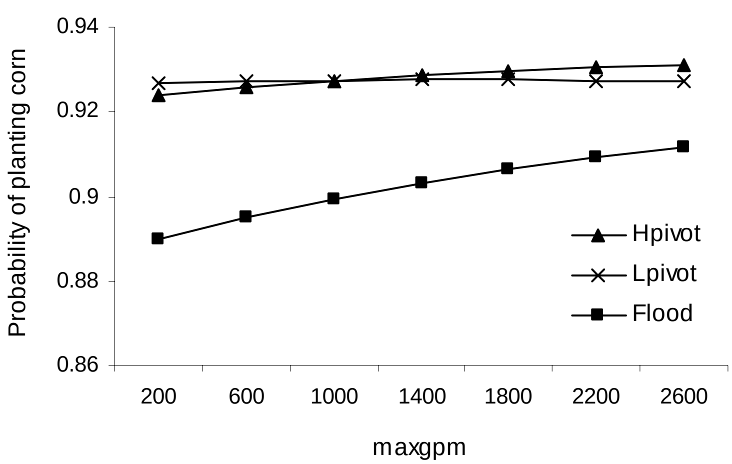
Marginal effects on crop choice probabilities

Variable	Alfalfa	Corn	Sorghum	Soybeans	Wheat	Other
DTW	-0.00018	0.00028	-0.00011	0.000038	-0.000048	0.000024
MAXGPM	-0.0000004	0.0000078	-0.0000062	0.0000029	0.0000007	-0.0000048

EPALF	-0.000013	-0.0061	0.0022	0.0047	-0.00018	-0.00055
EPCORN	0.033	0.32	-0.20	-0.13	0.025	-0.053
EPMILO	-0.023	-0.10	0.13	0.074	-0.014	-0.068
EPSOY	-0.0014	0.038	-0.0048	-0.050	0.0081	0.011
EPWHEAT	0.0099	-0.20	-0.021	0.020	-0.0055	0.20
EINDEX	-0.014	-0.35	-0.013	0.037	-0.023	0.37
PRICEINDEX	-0.000092	0.017	-0.0021	-0.0046	0.00050	-0.011
WINRAIN	-0.00076	0.0080	-0.00072	-0.0076	0.0013	-0.00014
FLOOD	-0.0084	0.12	0.016	0.0093	-0.0077	-0.12
HPIVOT	-0.0015	0.16	-0.0014	0.0099	-0.0026	-0.17
LPIVOT	-0.0075	0.16	-0.020	0.015	-0.0046	-0.143
LAG_CORN	-0.021	0.57	-0.040	0.0028	-0.020	-0.50
FAIR	0.0094	-0.19	-0.021	0.012	-0.0074	0.20

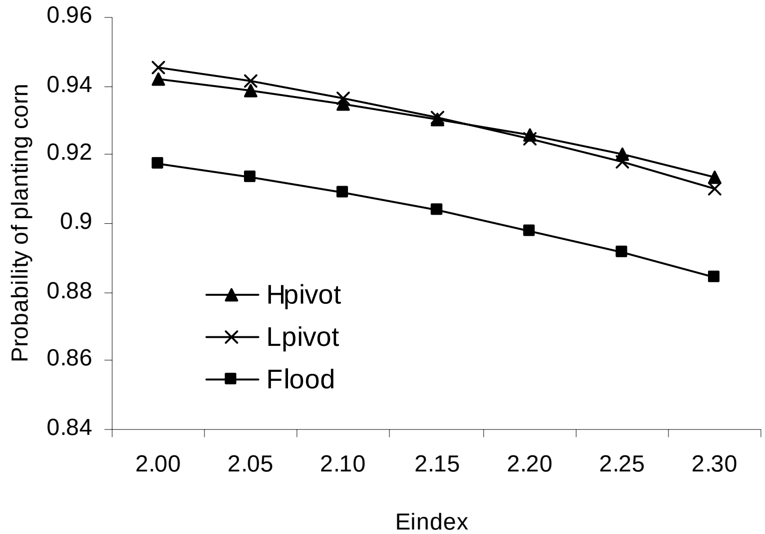
Since corn is the dominant crop in western Kansas, accounting for more than half of the data points, the change of probability of growing corn would affect the whole cropping pattern. Corn is also the most water intensive crop and therefore has the largest impact on overall water use. Therefore, we will focus the discussion on the results pertaining to corn.

Observing the table of marginal effects, we can find out how the probability of choosing corn changes by the changes of different variables. As well capacity (*MAXGPM*) increases by 1 unit, the probability of choosing corn increases by 0.0000078. Corn is much more likely to be grown in years when the expected corn price is high (a change of 0.32 for each $1 increase in *EPCORN*). As the price of energy (*EINDEX*) increases by $1, the probability of choosing corn decreases by 0.35. The negative response to energy prices most likely occurs because corn is water intensive and consumes more energy for pumping compared to other crops. In years of high energy prices, corn becomes less profitable relative to less water intensive alternatives. Interestingly, the 1996 Farm Act policies appeared to decrease the probability of selecting corn, all else held constant (the marginal effect of the *FAIR* variable was -0.19). This suggests that increased corn acreage in the late 1990s was due to changes in market conditions rather than policy changes *per se*.



A clearer way to examine the marginal effects for corn is to calculate the probability of choosing corn over a range of a variable. In the figure to the left, we depict how the probability of choosing corn changes by the well capacity (*MAXGPM*) under different irrigation systems. The graph shows that as the well capacity increases, the probability of choosing corn also increases. However the effects of well capacity are not the same under different irrigation technologies. Farmers using high-pressure or low-pressure center pivot systems are more likely to choose corn than those with flood systems. This illustrates the possibility that improvements in technology may not reduce water use in the long run, because they may result in irrigators switching to more water intensive crops.

The figure to the right examines the relationship between the price of energy and the probability of choosing corn under different irrigation technologies. As expected, the probability of choosing corn decreases as the price of energy increases, since corn is the water intensive crop. Again farmers using flood systems generally have the lower probability of growing corn.



Both these graphs reveal the differences and similarities among irrigation systems. Interestingly, the two types of pivot systems appear to have nearly identical impacts on corn planting decisions, while they both differ significantly from the flood systems. Switching from a high-pressure to a low-pressure system would have almost no effect on corn planting decisions, while switching from flood to either type of pivot would have a more substantial impact.

Another issue of interest about the crop selection equations is their prediction accuracy. The table below compares the actual and predicted crop choices. The rows in this table correspond to actual choices, while the columns correspond to predicted choices. For example, the first column accounts for all the data points which were predicted to be in alfalfa. There are a total of 182 such points; 40 of them were actually planted to alfalfa, 40 were in corn, 11 were in grain sorghum, 1 was in soybeans, and 84 were in other crops. The first row is an accounting of the data points which were actually planted to alfalfa. Of these 182 observations, the model predicted that 40 of them would be planted to alfalfa, 46 would be planted to corn, 13 to grain sorghum, 1 to soybeans, 6 to wheat, and 76 to other crops. The numbers on the 'diagonal' of this table reflect correct predictions. The sum of diagonal numbers is 3,742; dividing this figure by the total number of observations (6,035) reveals an overall prediction accuracy of 62%.

Cross tabulation of actual and predicted crop choices

Actual	Predicted Alfalfa	Corn	Sorghum	Soybean	Wheat	Other	Total
Alfalfa	40	46	13	1	6	76	182
Corn	40	2894	73	59	28	674	3768
Sorghum	11	74	28	2	6	106	227
Soybean	1	59	2	2	1	18	83
Wheat	6	27	6	1	3	42	84
Other	84	668	105	18	41	775	1691
Total	182	3768	227	83	85	1691	6035

Water use equations

The estimation results for the water use equations are summarized in the table on the next page. This table reports the estimated elasticities of water use with respect to different variables; an elasticity value reflects the percentage change in water use in response to a 1% change of an independent variable, holding all else constant. (So, for instance, a 1% increase in *ACRES_IRR* will increase alfalfa water use by 0.729%).

As one would expect, water use responds positively to changes in the expected output prices. A 1% increase in expected alfalfa prices, for example, increases water use on alfalfa acreage by 1.094%. Corn water use responds similarly; a 1 % increase in the expected corn price would increase corn water use by 1.045%. Water use on grain sorghum appears to be the most price sensitive among all crops, with an elasticity of 1.479; the small elasticities for soybeans and wheat indicate that water use on those crops is not very price-sensitive.

Also consistent with expectations, water use is inversely related to changes in rainfall (*RAIN_1*, *RAIN_2*, *RAIN_3*). In nearly all cases the elasticities on the rainfall variables are negative numbers, indicating that an increase in rainfall either before or during the growing season will reduce use. Evapotranspiration (*TOTALET*) has a positive elasticity in all equations, indicating that water use increases with high temperature, low humidity growing conditions. Interestingly, the rainfall elasticities are all less than one in absolute value. This suggests that rainfall and irrigation water are not perfect (i.e., one-to-one) substitutes; a 1% increase in rainfall will reduce irrigation by less than 1%, all else held constant.

Estimated elasticities of water use

Variable	Alfalfa	Corn	Sorghum	Soybeans	Wheat
NUMYEAR	0.451	0.296	0.383	0.141	-0.010
ACRES_IRR	0.729	0.817	0.889	0.787	0.927
EPALF	1.094	---	---	---	---
EPCORN	---	1.045	---	---	---
EPMILO	---	---	1.479	---	---
EPSOY	---	---	---	0.056	---

EPWHEAT	---	---	---	---	0.122
ST	0.074	0.094	0.127	0.010	0.083
HYDRACOND	-0.0224	0.002	0.049	-0.009	-0.133
RAIN 1	-0.128	-0.059	-0.102	-0.002	-0.019
RAIN 2	-0.077	-0.022	0.010	-0.015	-0.120
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TOTALET	0.256	0.365	0.508	0.287	0.067
METER	-0.055	-0.075	-0.097	-0.014	-0.108
PRICEINDEX	-4.962	-2.995	-10.192	-0.902	-0.981
HPIVOT	0.043	0.847	1.175	0.634	-0.026
LPIVOT	0.110	1.026	0.452	-0.872	1.634
OTHER	-1.078	-0.014	-2.942	-0.737	-4.709
SPRINKLER	0.323	0.067	1.218	-5.401	-1.895
DTW[a]					
FLOOD	0.060	0.249	0.174	0.093	0.131
HPIVOT	0.070	0.204	0.148	0.045	0.057
LPIVOT	0.046	0.222	0.149	0.071	0.095
OTHER	0.061	0.249	0.174	0.094	0.128
SPRINKLER	0.056	0.248	0.171	0.091	0.130
EINDEX[a]					
FLOOD	-0.821	-2.502	-2.677	0.202	0.906
HPIVOT	-0.805	-2.729	-2.949	-0.062	0.947
LPIVOT	-0.807	-2.688	-2.680	0.496	0.692
OTHER	-0.811	-2.505	-2.651	0.213	0.980
SPRINKLER	-0.825	-2.503	-2.684	0.227	0.926

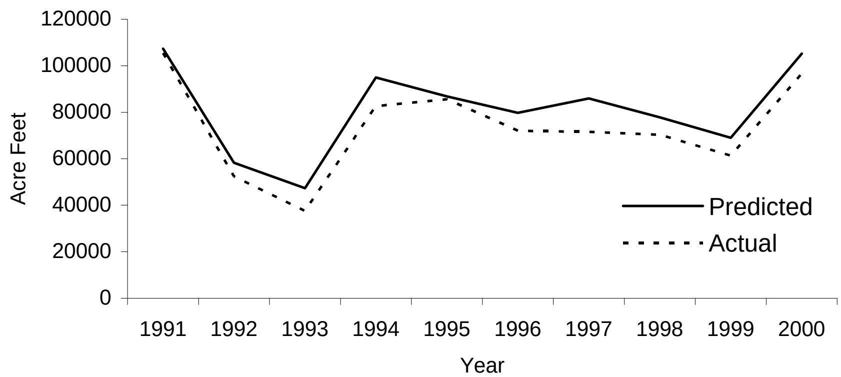
[a] Because of the ineraction terms in the estimated equations, the elasticites for depth to water (*DTW*) and energy index depend (*EINDEX*) on the irrigation system.

Another interesting result is that the elasticities for the *METER* variable are negative for all crops. All else held constant, irrigators with metered wells report less water use. Assuming that meters are accurate, this finding suggests that irrigators with unmetered wells tend to over-report their water consumption.

The elasticities for the irrigation system variables (*HPIVOT* and *LPIVOT*) are generally positive numbers. Because flood irrigation was treated as the 'base' group of data points in the estimation procedure, these results imply that irrigators with center pivot systems generally apply more water than those with flood systems. This may seem a paradoxical result given that center pivot systems are more efficient—they can deliver the same amount of water to the crop as flood systems by applying less to the field. Nevertheless, similar results have been documented elsewhere. The economic logic is that improvements in irrigation efficiency reduce the effective cost of delivering water to the crop.

Evaluating past water use trends

The equations discussed above allow us to compute predicted crop selections and crop water use for each point of diversion (POD) in the dataset. To accomplish this, the actual data on each POD was first inserted in the crop choice equations to determine which crop was most likely to be planted. After this was determined, the data was then inserted in the appropriate water use equation (e.g., the corn equation if corn was predicted to be selected), to obtain a predicted water use for that POD. Adding these predictions across PODs gives predicted total water use for Sheridan County, which can then be compared to observed total water use to assess the overall prediction accuracy of the model. Predicted versus actual total water use is shown in the graph to the right; the overall prediction error of the model is 10.4%.



Aside from 'reproducing' the observed pattern, we can also use the model to gain insights about the relative contribution of different factors to total water use. The estimation results above illustrate that a given factor may influence water use in several different ways. Changes in prices, technology, or hydrologic conditions affect which crops are grown as well as how much water is applied to those crops. Often, the net effect of a change in some variable on water use cannot be easily determined by examining the estimation results alone. For example, if the expected price of grain sorghum increases, more irrigators will be likely to plant grain sorghum instead of corn, but on the other hand, all grain sorghum growers will use more water per acre. The overall effect on water use depends on which of these effects is stronger.

To assess the net impacts of different variables, we can perform 'counter-factual' simulations. That is, we compute predictions for crop selections and crop water use, after replacing the actual values of certain variables with hypothetical values. This procedure allows us to shed light on questions of the form, "What would have happened if..."

Results for one simulation are illustrated to the left. The simulated water use in this graph represents the effect of higher commodity prices; all expected crop prices were increased from their actual values by 20%. Not surprisingly, higher commodity prices would have increased water use for all years. Over the ten year period, the price change would have led to about a 31% increase in water use. This suggests that the observed declining trend in water use over the past decade was at least partly due to the depressed commodity prices during that time period.

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Appendix A: Expected output prices and energy price index

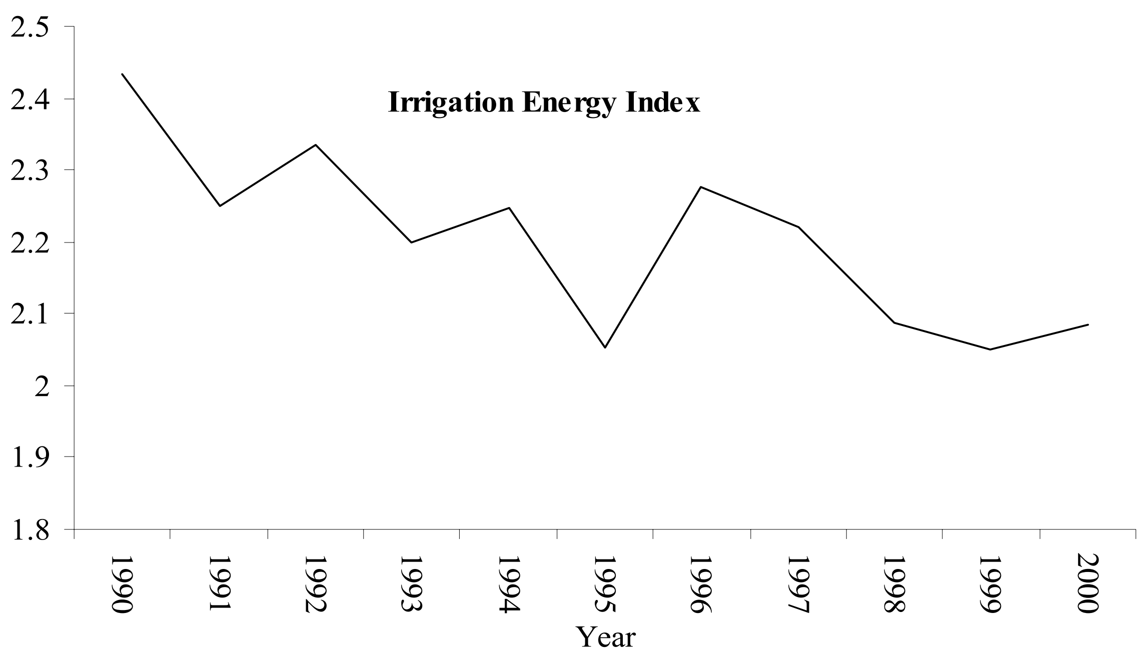
At the time water use decisions are made, an irrigator's expectation of output price is unobservable. Expected price data were constructed using the hypothesis of quasi-rational expectations: irrigators are assumed to form price expectations based on previous price trends. Time-series models of prices for the five major crops in western Kansas (alfalfa, corn, grain sorghum, soybeans, and wheat) were estimated from monthly price data obtained from the National Agricultural Statistics Service (NASS).

These time series models produce a function that predicts the expected price in month *m* as a function of prices in a fixed number of previous months: $E[P_m \mid I_{m-1}] = f(P_{m-1},\dots,P_{m-n})$, where $E[P_m \mid I_{m-1}]$ denotes the expected price in month m given information available in month $m-1$. By iterating this function over a number of months, it is possible to obtain an estimate of prices in month P_{m+x} given information at $m-1$. For all crops, expected price variables were generated as the expected price following harvest, given information available at planting.

The energy price index (*EINDEX)* was developed to reflect energy costs of irrigators in Western Kansas. It is defined as:

$$EINDEX = (\pi_{\text{electricity}} * P_{\text{electricity}}) + (\pi_{\text{gas}} * P_{\text{gas}}) + (\pi_{\text{propane}} * P_{\text{propane}}) + (\pi_{\text{diesel}} * P_{\text{diesel}}),$$

where π_x is the percent of wells powered by energy source *x* in a given year (taken from the *1997 Census of Agriculture*, NASS) and P_x is the price of energy source *x* in BTU's, expressed in 1977 dollars). As shown in the graph below, this index value reflects a general declining trend in energy prices during the study period.



Appendix B: Regression Statistics

Table B1. Statistics of Water-Use Data Regression Data

		Data Means (Standard Deviation)				
Variable	Description	Alfalfa	Corn	Sorghum	Soybean	Wheat
AF_USED	Irrigation water use (acre feet)	220.93	185.47	103.23	139.47	110.61
		(114.92)	(115.51)	(95.04)	(87.45)	(99.04)
NUMYEAR	Year (1990=1, 2000=11)	5.24	5.68	3.57	5.96	4.10
		(3.15)	(3.06)	(2.79)	(3.59)	(3.12)
ACRES_IRR	Acres irrigated	131.21	133.32	102.79	121.19	131.43
		(50.86)	(65.09)	(62.42)	(59.07)	(61.78)
EXPRICE	Expected commodity price ($)	46.56	1.76	3.00	3.96	2.08
		(5.85)	(0.42)	(0.55)	(0.66)	(0.54)
DTW	Depth to groundwater (ft)	117.97	143.44	124.62	132.50	132.54
		(65.85)	(58.58	(55.08)	(57.95)	(60.45)
ST	Aquifer saturated thickness (ft)	204.78	153.29	102.95	142.71	172.74
		(96.36)	(102.84)	(88.23)	(94.73)	(106.31)
HYDRACOND	Hydraulic conductivity (ft/day)	84.13	80.61	79.36	82.93	78.81
		(23.20)	(24.27)	(25.76)	(23.83)	(25.87)
EINDEX	Index of energy prices	2.19	2.19	2.24	2.18	2.23
		(0.12)	(0.11)	(0.11)	(0.13)	(0.12)
RAIN_1	Previous October-December rainfall (in)	2.06	1.91	2.04	1.91	1.99
		(1.21)	(1.30)	(1.19)	(1.35)	(1.19)
RAIN_2	January-March rainfall (in)	7.37	6.71	6.46	6.80	7.12
		(2.64)	(2.59)	(2.84	(2.61)	(2.94)
RAIN_3	May-August rainfall (in)	9.51	10.09	8.99	8.82	8.81
		(6.97)	(6.12)	(5.27)	(4.82)	(5.82)
TOTALET	Growing season evapotranspiration (in)	36.46	39.13	32.39	35.44	48.02
		(5.46)	(5.74)	(5.02)	(5.35)	(9.94)
METER	Dummy for metered well	0.55	0.44	0.25	0.42	0.35
		(0.50)	(0.50)	(0.43	(0.49)	(0.48)
PRICEINDEX	Index of Prices Paid by producers	108.86	109.80	105.81	109.31	106.71
		(6.43)	(6.28)	(6.33)	(6.47)	(6.46)
HPIVOT	Dummy for high-pressure center pivot system	0.60	0.42	0.30	0.41	0.49
		(0.49)	(0.49)	(0.46)	(0.49)	(0.50)
LPIVOT	Dummy for low-pressure center pivot system	0.22	0.28	0.06	0.32	0.17
		(0.42)	(0.45)	(0.25)	(0.47)	(0.38)
OTHER	Dummy for other system type	0.01	0.03	0.01	0.01	0.02
		(0.10)	(0.18)	(0.11)	(0.12)	(0.13)
SPRINKLER	Dummy for fixed sprinkler system	0.03	0.01	0.01	0.01	0.01
		(0.17)	(0.07)	(0.09)	(0.06)	(0.11)
Number of observations		10,352	45,444	4,251	1,699	6,185

Table B2. Regression Results: Alfalfa Water Use

Variable	Coefficient	Standard Error	P-Value
INTERCEPT	6009.384	1241.883	<.0001
NUMYEAR	18.997	5.579	0.001
ACRES IRR	1.537	0.034	<.0001
ACRESIRR^2	-0.001	0.000059	<.0001
EXPRICE	28.266	9.873	0.004
EXPRICE^2	-0.248	0.099	0.012
DTW	0.294	0.074	<.0001
DTW2	-0.00077	0.00015	<.0001
ST	0.192	0.064	0.003
ST2	-0.00027	0.000094	0.004
HYDRACOND	1.462	0.304	<.0001
HYDRACOND^2	-0.010	0.0020	<.0001
*ST*HYDRACOND*	0.00083	0.00037	0.028
*DTW*HYDRACOND*	-0.00059	0.00058	0.314
EINDEX	-82.624	34.077	0.015
RAIN 1	-23.579	6.772	0.0005
RAIN 1^2	2.395	1.241	0.054
RAIN 2	3.595	4.913	0.464
RAIN 2^2	-0.399	0.353	0.259
RAIN 3	-10.921	1.867	<.0001
RAIN 3^2	0.294	0.050	<.0001
TOTALET	2.510	4.275	0.557
TOTALET^2	-0.013	0.053	0.805
METER	-12.542	2.513	<.0001
PRICEINDEX	-115.168	24.521	<.0001
PRICEINDEX^2	0.483	0.105	<.0001
HPIVOT	8.978	70.580	0.899
*EINDEX*HPIVOT*	2.667	32.080	0.934
*DTW*HPIVOT*	0.032	0.037	0.376
LPIVOT	23.258	81.354	0.775
*EINDEX*LPIVOT*	6.035	37.226	0.871
*DTW*LPIVOT*	-0.116	0.043	0.007
OTHER	-226.970	207.613	0.274
*EINDEX*OTHER*	102.788	94.695	0.278
*DTW*OTHER*	0.217	0.118	0.065
SPRINKLER	67.991	126.135	0.590
*EINDEX*SPRINKLER*	-15.025	57.869	0.795
*DTW*SPRINKLER*	-0.224	0.093	0.016
Adjusted R-Square	0.4892		

Table B3. Regression Results: Corn Water Use

Variable	Coefficient	Standard Error	P-Value
INTERCEPT	4684.734	293.588	<.0001
NUMYEAR	9.690	1.402	<.0001
ACRES IRR	1.384	0.016	<.0001
ACRESIRR^2	-0.00093	0.000	<.0001
EXPRICE	299.167	35.149	<.0001
EXPRICE^2	-53.641	7.757	<.0001
DTW	0.399	0.032	<.0001
DTW2	-0.00027	0.000068	<.0001
ST	0.249	0.022	<.0001
ST2	-0.00044	0.000036	<.0001
HYDRACOND	0.428	0.112	0.000
HYDRACOND^2	-0.0027	0.00073	0.000
*ST*HYDRACOND*	0.0018	0.00014	<.0001
*DTW*HYDRACOND*	-0.0018	0.00026	<.0001
EINDEX	-212.511	10.566	<.0001
RAIN 1	-4.926	1.766	0.005
RAIN 1^2	-0.221	0.331	0.505
RAIN 2	-7.220	1.030	<.0001
RAIN 2^2	0.492	0.076	<.0001
RAIN 3	-8.507	0.381	<.0001
RAIN 3^2	0.194	0.011	<.0001
TOTALET	1.915	1.124	0.088
TOTALET^2	-0.0023	0.014	0.870
METER	-14.567	0.970	<.0001
PRICEINDEX	-80.246	5.303	<.0001
PRICEINDEX^2	0.342	0.023	<.0001
HPIVOT	96.084	19.184	<.0001
*EINDEX*HPIVOT*	-45.785	8.648	<.0001
*DTW*HPIVOT*	-0.140	0.014	<.0001
LPIVOT	116.446	23.402	<.0001
*EINDEX*LPIVOT*	-56.744	10.765	<.0001
*DTW*LPIVOT*	-0.124	0.016	<.0001
OTHER	-1.630	46.658	0.972
*EINDEX*OTHER*	-4.455	21.319	0.835
*DTW*OTHER*	0.0044	0.029	0.883
SPRINKLER	7.647	117.901	0.948
*EINDEX*SPRINKLER*	2.407	52.998	0.964
*DTW*SPRINKLER*	-0.250	0.070	0.0004
Adjusted R-Square	0.6206		

Table B4. Regression Results: Grain Sorghum Water Use

Variable	Coefficient	Standard Error	P-Value
INTERCEPT	6174.383	743.753	<.0001
NUMYEAR	11.069	2.697	<.0001
ACRES IRR	0.988	0.042	<.0001
ACRESIRR^2	-0.00047	0.00011	<.0001
EXPRICE	156.414	42.122	0.0002
EXPRICE^2	-17.588	5.784	0.002
DTW	0.160	0.085	0.059
DTW2	-0.00006	0.00019	0.739
ST	0.108	0.065	0.095
ST2	0.000093	0.00012	0.423
HYDRACOND	0.327	0.308	0.288
HYDRACOND^2	-0.002	0.002	0.359
*ST*HYDRACOND*	0.00062	0.00046	0.171
*DTW*HYDRACOND*	-0.00028	0.00078	0.719
EINDEX	-123.135	22.671	<.0001
RAIN 1	4.538	5.235	0.386
RAIN 1^2	-2.377	0.975	0.015
RAIN 2	-1.874	2.473	0.449
RAIN 2^2	0.158	0.171	0.356
RAIN 3	-5.140	1.146	<.0001
RAIN 3^2	0.120	0.032	0.000
TOTALET	14.378	3.461	<.0001
TOTALET^2	-0.197	0.051	0.000
METER	-10.203	2.906	0.001
PRICEINDEX	-113.101	13.179	<.0001
PRICEINDEX^2	0.487	0.060	<.0001
HPIVOT	89.197	60.114	0.138
*EINDEX*HPIVOT*	-41.482	26.867	0.123
*DTW*HPIVOT*	-0.072	0.042	0.084
LPIVOT	34.306	92.709	0.711
*EINDEX*LPIVOT*	-2.032	42.069	0.962
*DTW*LPIVOT*	-0.324	0.077	<.0001
OTHER	-223.394	185.087	0.228
*EINDEX*OTHER*	98.944	83.399	0.236
*DTW*OTHER*	0.028	0.148	0.848
SPRINKLER	92.469	274.314	0.736
*EINDEX*SPRINKLER*	-33.828	124.319	0.786
*DTW*SPRINKLER*	-0.286	0.173	0.097
Adjusted R-Square	0.5587		

Table B5. Regression Results: Soybean Water Use

Variable	Coefficient	Standard Error	P-Value
INTERCEPT	3000.003	1512.110	0.047
NUMYEAR	3.304	6.743	0.624
ACRES IRR	1.078	0.051	<.0001
ACRESIRR^2	-0.00071	0.000058	<.0001
EXPRICE	49.573	49.926	0.321
EXPRICE^2	-6.015	6.654	0.366
DTW	0.012	0.146	0.937
DTW2	0.00032	0.00029	0.269
ST	-0.144	0.115	0.214
ST2	0.00054	0.00021	0.010
HYDRACOND	0.846	0.511	0.098
HYDRACOND^2	-0.0055	0.0036	0.124
*ST*HYDRACOND*	0.0013	0.00078	0.088
*DTW*HYDRACOND*	-0.0011	0.0014	0.409
EINDEX	12.953	49.534	0.794
RAIN 1	2.577	8.698	0.767
RAIN 1^2	-0.720	1.627	0.658
RAIN 2	-2.155	4.976	0.665
RAIN 2^2	0.135	0.364	0.710
RAIN 3	-10.133	2.146	<.0001
RAIN 3^2	0.235	0.059	<.0001
TOTALET	17.149	6.218	0.006
TOTALET^2	-0.226	0.087	0.010
METER	-1.976	4.701	0.674
PRICEINDEX	-61.353	25.799	0.018
PRICEINDEX^2	0.275	0.111	0.013
HPIVOT	93.508	94.674	0.324
*EINDEX*HPIVOT*	-41.262	42.865	0.336
*DTW*HPIVOT*	-0.123	0.068	0.072
LPIVOT	-128.652	117.852	0.275
*EINDEX*LPIVOT*	58.579	54.929	0.286
*DTW*LPIVOT*	-0.073	0.076	0.339
OTHER	-108.718	390.290	0.781
*EINDEX*OTHER*	47.087	185.723	0.800
*DTW*OTHER*	0.101	0.201	0.615
SPRINKLER	-796.636	591.938	0.179
*EINDEX*SPRINKLER*	382.780	277.360	0.168
*DTW*SPRINKLER*	-0.411	0.469	0.381
Adjusted R-Square	0.5115		

Table B6. Regression Results: Wheat Water Use

Variable	Coefficient	Standard Error	P-Value
INTERCEPT	1107.056	833.297	0.184
NUMYEAR	-0.282	2.333	0.904
ACRES IRR	0.790	0.046	<.0001
ACRESIRR^2	-0.000038	0.00010	0.711
EXPRICE	-21.397	31.405	0.496
EXPRICE^2	6.694	6.935	0.335
DTW	0.049	0.087	0.574
DTW2	0.00023	0.00018	0.197
ST	0.162	0.061	0.008
ST2	-0.00032	0.00010	0.001
HYDRACOND	2.051	0.321	<.0001
HYDRACOND^2	-0.015	0.002	<.0001
*ST*HYDRACOND*	0.0010	0.00039	0.009
*DTW*HYDRACOND*	0.00011	0.00071	0.873
EINDEX	44.955	33.401	0.178
RAIN 1	8.296	6.046	0.170
RAIN 1^2	-2.348	1.100	0.033
RAIN 2	-8.537	4.194	0.042
RAIN 2^2	0.469	0.322	0.146
RAIN 3	-4.475	1.714	0.009
RAIN 3^2	0.115	0.052	0.028
TOTALET	1.900	2.439	0.436
TOTALET^2	-0.018	0.024	0.448
METER	-12.365	2.958	<.0001
PRICEINDEX	-23.136	15.387	0.133
PRICEINDEX^2	0.104	0.070	0.139
HPIVOT	-2.445	62.993	0.969
*EINDEX*HPIVOT*	4.146	28.176	0.883
*DTW*HPIVOT*	-0.126	0.038	0.001
LPIVOT	154.531	82.597	0.061
*EINDEX*LPIVOT*	-60.946	37.758	0.107
*DTW*LPIVOT*	-0.171	0.052	0.001
OTHER	-445.289	163.335	0.006
*EINDEX*OTHER*	208.884	75.013	0.005
*DTW*OTHER*	-0.116	0.089	0.189
SPRINKLER	-179.230	230.651	0.437
*EINDEX*SPRINKLER*	89.250	104.511	0.393
*DTW*SPRINKLER*	-0.045	0.141	0.748
Adjusted R-Square	0.4051		

Appendix C. Input variables for Groundwater Model

Table C1. Aquifer.txt (input file for aquifer properties)

```
c:\text\article\gis\GIS_water_use\MLAEM\output      % working directory
361442.369273        % View region left
4356729.620249       % View region bottom
371258.655490        % View region right
4371370.048263       % View region top
2600                 % Aquifer base elevation
2861                 % Land elevation
79                   % Aquifer current saturated thickness
137                  % Aquifer pre-development saturated thickness
0.0033               % Slope of Aquifer base in x-direction
0                    % Slope of Aquifer base in y-direction
2678                 % Reference groundwater elevation
2001                 % Reference year
366350               % Reference x-location
4364050              % Reference y-location
90                   % Aquifer hydraulic conductivity
0.17                 % Aquifer specific yield
0.78                 % Aquifer recharge rate
```

Table C2. Well.txt (input file for well properties)

```
1                    % Number of years in simulation
2001                 % Year of simulation
392256.2214   4333137.9636   244     0.0000  0.0000  % x,y,id,historical pumping, 2001 pumping
395124.4284   4333352.4997   807     0.8314  0.8314  % x,y,id,historical pumping, 2001 pumping
393654.8284   4332897.5170   932     0.0000  0.0000  % x,y,id,historical pumping, 2001 pumping

…

367587.6493   4370992.4208   62881   4.3636  4.3636  % x,y,id,historical pumping, 2001 pumping
385899.2735   4368505.2354   63104   4.3636  4.3636  % x,y,id,historical pumping, 2001 pumping
393066.7475   4341848.2588   63241   0.0000  0.0000  % x,y,id,historical pumping, 2001 pumping
376154.6252   4357926.6972   63878   0.0000  0.0000  % x,y,id,historical pumping, 2001 pumping
```

Information Transfer Program

We have two major information transfer projects, an annual statewide conference entitled "Water and the Future of Kansas", and a web-based project on the High Plains Aquifer. Those are described below. Additionally, we have information transfer activities associated with each research project. Those are described in the individual research project reports.

High Plains Aquifer Information Network (HIPLAIN)

Basic Information

Title:	High Plains Aquifer Information Network (HIPLAIN)
Project Number:	2003KS32B
Start Date:	3/1/2003
End Date:	2/28/2004
Funding Source:	104B
Congressional District:	2nd District
Research Category:	Not Applicable
Focus Category:	Education, Water Quality, Groundwater
Descriptors:	Information Transfer, Website
Principal Investigators:	Margaret A. Townsend, Gary Clark, David P. Young

Publication

1. Poster session at Water and the Future of Kansas, March 2003.
2. Ogallala Aquifer Institute Annual Board Meeting, September 2003.
3. Pathfinder Applications of GIS in Science Workshop, summer, 2003.
4. Ogallala Aquifer symposium, Wray, Colorado, February, 2004 poster.

HIPLAIN – The High Plains Aquifer Information Network *www.hiplain.org*
Final Report for Year 2 (March 1, 2003 – February 28, 2004)

Principal Investigators

Margaret Townsend, Hydrogeologist, Kansas Geological Survey
Gary A. Clark, Professor, Kansas State University
David Young, Hydrologist, Kansas Geological Survey
Steven Briggeman, Computer Programmer, Kansas State University

Statement of Problem

The High Plains aquifer spans nearly 111 million acres of the Great Plains. Many communities and agricultural producers rely on the aquifer for groundwater to thrive in the semi-arid region. Uses of the aquifer include municipal, industrial, recreational, and intense agricultural production. Understanding the importance of the aquifer and ensuring its viability in the future is critical.

One key to understanding and conserving the High Plains aquifer is to have an effective method of sharing information that is practical and applicable to all users of the aquifer. Residential and agricultural users, researchers, consultants, and public policy makers need to have a common source to help them acquire the information and knowledge they need to protect and manage this vital resource.

Research Objectives

The Internet provides a fast and convenient method for disseminating data and information. The High Plains Aquifer Information Network (HIPLAIN) establishes an informational resource site to serve all users of the High Plains aquifer. HIPLAIN focuses on providing information on many aquifer-based issues, including education, agriculture, environmental topics, technical data, and links to organizations that are associated with the aquifer.

HIPLAIN is a one-stop source for a broad group of High Plains aquifer users. By consolidating the available information into one website, individuals are able to find answers and utilize resources with a click of their mouse. HIPLAIN will provide opportunities for all potential users to increase their understanding of the region's water resources and provide information to enable better personal and public decisions on water conservation, development, and management.

Methodology

- HIPLAIN was developed in 2002/03 to be a central location for previously dispersed information on the High Plains aquifer. During the March 2003-February 2004 project period the main improvement to the website was the addition of new state pages that are being developed. The HIPLAIN States button directs users to these new pages (Fig. 1). To date, major organizations from the other 7 High Plains aquifer states have been included.
- In addition, the site is current undergoing redesign in ColdFusion language to increase efficiency and eliminate the frames format that currently exists. This will help address accessibility issues as discussed in Web Content Accessibility Guidelines for the State of Kansas Guidelines by Priority - Version 2.0 (November 20, 2001) http://da.state.ks.us/itec/WASPriorities112001.htm.

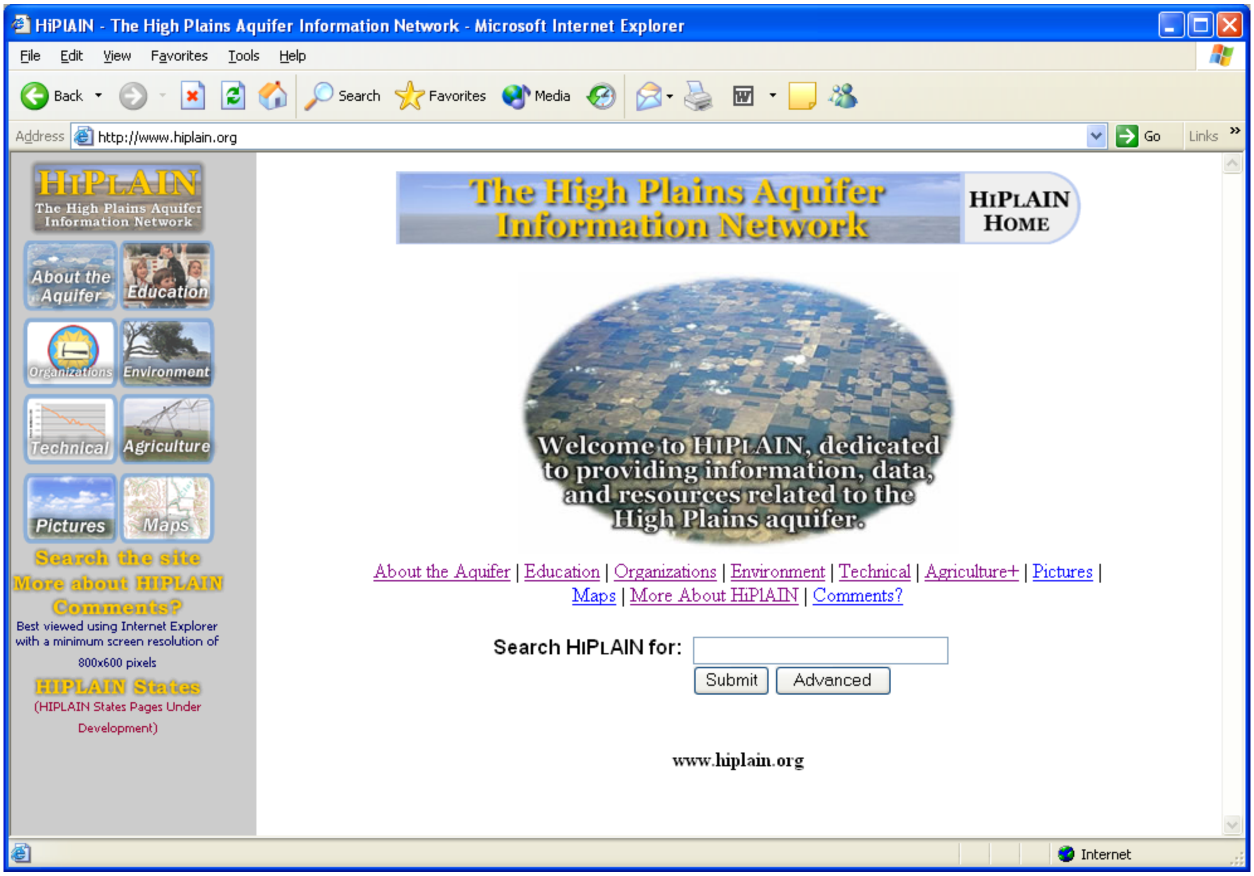


Figure 1. Home Page for **HIPLAIN** website (***www.hiplain.org***). Note addition of **HIPLAIN** States button on menu bar.

Principal Results

Year 2 objectives accomplished for HIPLAIN:

- Improved internal search engine;
- Additional hydrogeologic glossaries added;
- Additional literature search capabilities;
- Development and hosting of an Ogallala Aquifer Institute (OAI) web site;
- Acquisition of additional links to the other seven states that overlie the High Plains aquifer (in close coordination with the Ogallala Aquifer Institute);

Ongoing activities include:

- Access to the most up-to-date and newly developed database front ends and data-analysis tools from KGS and other sources;
- Continued search and posting of relevant links and maintenance;
- Procedures for future data and information dissemination through coordination with the OAI, Groundwater Management Districts (GMDs) and other educational and governmental groups;
- Legal issues concerning water rights, enforcement, and water-management programs.
- Continued acquisition of additional links to the other seven states that use the High Plains aquifer (in close coordination with the Ogallala Aquifer Institute) and to the High Plains Aquifer Coalition (HPAC);

- Redesign of the website in ColdFusion language to increase efficiency and eliminate the frames format that the current site has. This will help address accessibility issues as discussed in Web Content Accessibility Guidelines for the State of Kansas Guidelines by Priority - Version 2.0 (November 20, 2001) http://da.state.ks.us/itec/WASPriorities112001.htm.

Review of Site

In March-April 2003 the HIPLAIN website was sent to state, federal, and local agencies for review. We received a number of compliments and also comments concerning the site that we are addressing. Dr. William Carswell, Jr., USGS Regional Hydrogeologist for the Central Region (Denver), requested that the USGS District Chiefs for the High Plains states review the site and assist us in acquiring additional links for federal, state and local agencies in the those states. Also, he asked them to assist us in the acquisition of links for databases that are publicly available in their states. To date we have heard from personnel from most of the states. We have also received unsolicited positive feedback from other users.

Significance

As the project moves into its third year, several enhancements are being finalized. Keeping with the idea of increasing user-friendliness, a new layout is being designed that allows users to find their section of interest with fewer clicks of their mouse. To reduce the length of the pages, each subcategory of the main sections will have a dedicated page, with links back to the main topics or subcategories. This style of website will improve visibility of search engines and increase the overall utility of the site. The site will be run as a database with pages dynamically generated to provide ease of updating and access.

In addition to providing and improving easy access to Kansas High Plains aquifer information, third-year plans include further acquisition and development of links with all eight High Plains states concerning water policies and issues, socioeconomic issues, technical information, and access to available datasets for use by the public. HIPLAIN developers will work closely with the Ogallala Aquifer Institute (OAI) to form working relationships with the other states and to permit web access to available online data sets. The HIPLAIN and OAI groups are working together to develop an OAI web site that is hosted and maintained by KGS (http://www.hiplain.org/oai/).

Technology Transfer and Dissemination Activities

Brochures announcing the site were distributed at the Water and the Future of Kansas meeting in 2003 and 2004, an Ogallala Aquifer symposium in Colorado in February 2004, KATS Camp for teachers in April, 2004, and the 3-I Agricultural show in April, 2004.

The brochure will be sent electronically to libraries and other organizations in the early summer. We would like to send information to the school districts across the state but are only in the beginning stages of considering best how to accomplish that task.

Presentations and Publications

Poster session at Water and the Future of Kansas, March 2003.
Ogallala Aquifer Institute Annual Board Meeting, September 2003.
Pathfinder Applications of GIS in Science Workshop, summer, 2003.
Ogallala Aquifer symposium, Wray, Colorado, February, 2004 – poster.

No student support.

Water and the Future of Kansas Annual Conference

Basic Information

Title:	Water and the Future of Kansas Annual Conference
Project Number:	2003KS11B
Start Date:	1/1/2003
End Date:	2/28/2004
Funding Source:	104B
Congressional District:	
Research Category:	Not Applicable
Focus Category:	Groundwater, Surface Water, Water Quality
Descriptors:	information transfer, educational, public forum
Principal Investigators:	William Leonard Hargrove, Peter Allen MacFarlane, Margaret A. Townsend

Publication

1. Proceedings of the Annual Water and the Future of Kansas Conference. 2003. Manhattan, KS. Published by Kansas State University.

The annual Water and the Future of Kansas Conference was held on March 11, 2003. There were over 200 attendees. The theme of the conference was "The Challenge of Clean Abundant Water". The program included plenary speakers, panel discussions, a poster session, and concurrent sessions with voluntary and invited speakers. The one day conference provides a forum for water professionals in Kansas to learn about current "hot topics" and the latest research on topics of interest. The full program is below.

The Challenge of Abundant Clean Water

20th Annual

Water and the Future of Kansas Conference Program

March 11, 2003
Holiday Inn
Manhattan, Kansas

Sponsored by
Kansas Water Resources Institute (KWRI)
Kansas Center for Agricultural Resources and the Environment (K-CARE)
K-State Research and Extension
U.S. Geological Survey

Agenda

7:30-8:00 **Poster/Display Setup**

8:00-8:30 **Registration, Continental Breakfast**
View Poster Displays

8:30-10:30 **Plenary Session**

8:30-8:40 **Welcome and Opening Remarks**
Bill Hargrove, Director
Kansas Water Resources Institute

8:40-9:10 **Meeting the Challenge of TMDLs: The Case of Virginia**
Theo Dillaha, Biological and Agricultural Engineering Department, Virginia Tech University

9:10-9:40 **Nutrients in the Environment: Targeting Sources and Abatement**
Jack Meisinger, USDA-ARS, Beltsville, MD

9:40-10:10 **Prolonging the Life of Aquifers: The Flint River Drought Protection Irrigation Auction Program in Georgia**
Rob McDowell, Georgia Department of Natural Resources

10:10-10:30 Break

10:30-11:45 **Issue Forums/Panel Discussions** (Concurrent)

Surface Water Quality/TMDLs in Kansas - Dan Devlin (KSU), Moderator

Panel: Tom Stiles, KDHE
Mike Christian, K-State Research and Extension
Steve Swaffar, Kansas Farm Bureau
Charles Benjamin, KS Sierra Club

Nutrients in the Environment - Don Snethen (KDHE), Moderator
Panel: Jerry DeNoyelles, Biology Department, KU
Lisa French, Cheney Lake Watershed Project
Lyle Frees, USDA/NRCS
Tim Stroda, KS Pork Assoc.

Prolonging the Life of the Ogallala Aquifer- Tom Huntzinger KDA/DWR), Moderator
Panel: Wayne Bossert, Ground Water Management District #4
Kent Lamb, Kansas Water Authority
Bob Halloran, City Manager, Garden City, KS

Dana Woodbury, Ogallala Aquifer Institute

11:45 **Buffet Lunch**

12:30-1:30 **View Poster Papers/Displays**

CONCURRENT SESSIONS 1, 2, 3, 4

1:30-2:50 **<u>Session 1</u>**
Groundwater Management
Moderator: Earl Lewis, KWO

1:30 ***Prolonging the Life of the Ogallala Aquifer - What's Happening in the Texas High Plains***
Nolan Clark, USDA-ARS, Bushland, TX

1:50 ***A Fresh Look at Recharge Rates of the Ogallala Aquifer***
Marios Sophocleous, KGS

2:10 ***Modeling Coupled Hydrologic and Economic Processes in the High Plains***
Jeff Peterson and David Steward, KSU

2:30 ***Delineating Management Subunits in Kansas***
Susan Stover, KS Water Office

1:30-2:50 **<u>Session 2</u>**
Nutrients in the Environment
Moderator: Jim Triplett, Pittsburg State University

1:30 ***New CAFO Regulations***
Ralph Summer, USEPA

1:50 ***Implementing Nutrient Criteria for Streams and Lakes: the Oklahoma Experience***
Phillip Moershel, OK Water Resources Board

2:10 ***Establishing Nutrient Criteria for Streams and Lakes in Kansas***
Mike Tate, KDHE

2:30 ***Establishing Nutrient Criteria for Streams and Lakes on an Ecoregion Scale***
Walter Dodds, Biology Department, KSU

1:30-2:50 **<u>Session 3</u>**
The Value of Water as a Part of the Landscape
Moderator: Margaret Fast, KWO

1:30 ***A Cultural View of the Value of Water in the Landscape***
Dan Wildcat, Haskell University

1:50 ***The Value of Water Recreation***

Teri Hacker, City Commissioner from Springfield, MO

2:10 ***The Value of Recreational Fishing in Kansas***
Doug Nygren, KDWP

2:30 ***The Value of Recreational Boating/Canoeing in Kansas***
Dave Murphy, KS River Keepers

1:30-2:50 **<u>Session 4</u>**
Weather, Climate, and Water Management
Moderator: Jim Koelliker, KSU

1:30 ***Variations in Precipitation in the Great Plains: The Past 100 Years***
Jurgen Garbrecht, USDA-ARS, El Reno, OK

1:50 ***The Kansas Weather Station Network***
Mary Knapp, KSU

2:10 ***The Oklahoma Weather Mesonet***
Chris Fiebie, OK Mesonet, Norman, OK

2:30 ***Seasonal Climate Predictions and their Implication for Agricultural Management in the Central Great Plains***
Jeanne Schneider, USDA-ARS, El Reno, OK

2:50-3:10 **Break**

CONCURRENT SESSIONS 5, 6, 7, 8

3:10-4:30 **<u>Session 5</u>**
Groundwater Quality
Moderator: Gary Clark, KSU

3:10 ***An Overview of Soil and Water Contamination at Grain and Fertilizer Storage Facilities in Kansas***
Sabine Martin, Larry Erickson, and Blase Leven, Hazardous Waste Research Center, KSU

3:30 ***Potential Impacts of Past Land Use and Recharge Rates on the Ogallala Aquifer: Water Quality Issues in Kansas***
Margaret Townsend, KGS

3:50 ***Nitrate Leaching under Irrigated Corn***
John Schmidt and Loyd Stone, Agronomy Department, KSU

4:10 ***Subsurface Drip Irrigation for Corn Production in Kansas***
Freddie Lamm, KSU Northwest Research-Extension Center

3:10-4:30 **<u>Session 6</u>**

Surface Water Quality
Moderator: Morgan Powell, KSU

3:10 ***Identifying the Sources of Fecal Bacteria Contamination in Streams***
George Marchin, Biology Department, KSU

3:30 ***Fecal Bacteria: Sources, Dieoff, Transport, and Treatment***
Kyle Mankin, Biological & Agricultural Engineering Department, KSU

3:50 ***Assessing the Water Quality Status of Kansas Streams***
Chris Gnau, KDHE

4:10 ***Developing Cost and Benefit Decision Making Information for Watershed Stakeholder Groups***
Verel Benson, FAPRI, University of Missouri

3:10-4:30 **<u>Session 7</u>**

Water Educational Programs
Moderator: Hank Ernst, KWO

3:10 ***The Ogallala Aquifer Institute***
Dana Woodbury, Ogallala Aquifer Institute

3:30 ***Kansas Environmental Leadership Program (KELP)***
Judy Willingham, K-State Research and Extension

3:50 ***Stream Link***
Allison Reber, Kaw Valley Heritage Allicance

4:10 ***Educational Programs of the Kansas Association for Conservation and Environmental Education (KACEE)***
Laura Downey, KACEE

3:10-4:30 **<u>Session 8</u>**

Innovations in Water Quantity Assessment
Moderator: Walt Aucott, USGS

3:10 ***Estimates of Median Flows for Streams on the Kansas Surface Water Register***
Charles A. Perry, USGS, Lawrence, KS

3:30 ***Factors Affecting High Plains (Ogallala) Aquifer Groundwater Level Changes in GMD4 and Surrounding Areas***
Gary Hecox, KGS

3:50 ***New Internet-Based Data Access, Display, and Mapping Tools for the KGS's WIZARD Database***
Brownie Wilson, KGS

4:10 ***Real-Time Estimated Flood-Inundation Maps on the Internet for Wichita, Kansas***
Seth Sudley, USGS, Lawrence, Kansas

Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 RCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	1	0	0	0	1
Masters	3	0	0	0	3
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	4	0	0	0	4

Notable Awards and Achievements

Publications from Prior Projects